Prediction on 3D Distribution of Natural Gas Reservoir by Stochastic Simulation of Seismic-Petroleum Accumulation Unit

-Taking Northern Slope in Sanhu Region of Qaidam Basin as Example.

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Fund Project: Funded by national science and technology major projects of CNPC, entitled "research and application on geophysics technology of complex natural gas reservoir predicting and hydrocarbon indicator" (2011ZX05007-006).

Background

Natural gas exploration in Qaidam basin of China mainly involves the Quaternary bio-gas prospecting in Sanhu area, the Tertiary oil-type gas prospecting in western Qaidam basin and the Jurassic coal-type gas prospecting in northern Qaidam basin. This paper focused on the Quaternary bio-gas and the upper Tertiary oil-type gas prospecting in Sanhu area.

Biogenic methane is methane bacteria under anaerobic conditions the substrate consumption of simple nutrition Organic matter generated metabolites. When the accumulation conditions is suitable and reasonable, biogenic methane could gather into a clean, efficient energy. The Quaternary bio-gas area in the northern slope of Sanhu area is the largest bio-gas area in China and one of four the most potential onshore gas fields in China[1]. Sanhu area makes up of three secondary structural units: the southern slope, central depression and the northern slope in which the Quaternary bio-gas area lies[6,7] (Fig. 1). The Quaternary strata are composed by thin interbed of loose shale and sand, in which is the potential area for gas exploration. The special depositional environment of thin interbed of loose sand and shale in Sanhu area has been forming dynamic gas reservoir accumulation pattern: consistent "generation, accumulation, and dissipation", making the biogas reservoir in this area is dispersion-type lithologic gas reservoir.

Natural gas exploration in Sanhu area now is divided into two levels: one is the Quaternary bio-gas prospecting. From 2007 to now lithologic trap and gas anomaly prospecting are done increasingly at the slope zone situated at structural nose uplift settings but structural trap prospecting before 2007. Another is structural trap prospecting of the upper Tertiary oil-type gas[6,7].

Since 2007, the gas-bearing abnormity prediction in the northern slope of Sanhu region has been mainly characterized by 2D seismic, post-stack, P-wave, single parameter and qualitative prediction in order to forecast the horizontal and vertical distribution of the lithologic gas reservoir[2,3]. However, current prediction method has not met the development demands of exploration. With the improving research on reservoir-forming units of gas reservoir and controlling factors of traps, in order to make integrated recognition on continuous distribution of biogas reservoir, utilizing of multi-disciplinary data to quantitatively predict gas-bearing abnormity is increasingly required. There is almost all 2D seismic data whose dominant frequency is 15-25Hz in Sanhu region and there are all thin alternate layers (thickness: 1-3m) of loose sandstone and mudstone. So it is very difficult to carry on post-stack acoustic impedance inversion and pre-stack AVO inversion in the exploration area of lithologic gas reservoir in the northern slopes, Sanhu region[6,7].

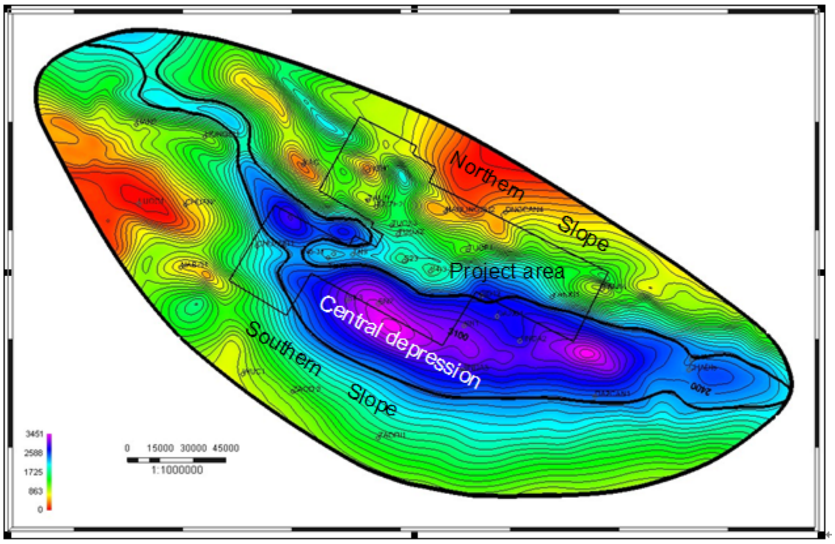

Figure 1 project area of Sanhu area in Qaidam basin

In order to find directly gas reservoir with seismic data[4], and further identify true and false anomalies, and effectively amplify anomaly caused by gas-bearing factors, under the premise of obtaining reliable seismic data from seismic static correction processing and relative fidelity processing[2], putting the seismic data into the geostatistic model[5], 3D petrophysics modeling based on S-wave data in multiscale viscoelastic media is conducted by utilizing synthetically multi-disciplinary information including seismic data, logging data, geological data and production dynamics data so as to realize quantitative prediction of fluid distribution and 3D quantitative distribution characteristics of bio-gas reservoir[6,7]. It can significantly reduce the multi-solution and drilling risk. It is very useful for searching new lithologic gas reservoir.

Recently, thread in gas reservoir prediction in Sanhu area includes two aspects: the first one is “finding traps”, which focuses on reservoir prediction; the second one is “finding anomaly”, which focuses on gas-containing detection. Commonly, difficulties in gas exploration mainly lie in following constraints: tectonic amplitude, lithologic thinning out plugging, gradient of porosity and permeability, grade of gas-containing anomaly, gas-containing saturation, and gas-containing abundance, et al. Depending on the quality of these constraints, thinking of gas prediction is divided into “finding traps” and “finding anomaly”. Finding traps is the way that locking on beneficial reservoir by reservoir prediction firstly and then searching gas accumulation distribution by gas containing detection in it, which is feasible when the control factors for gas accumulation formation are in favorable situation. Contrarily, finding anomaly is the way that searching gas accumulation distribution by seismic-based gas-containing detection directly, which is feasible when the control factors for gas accumulation formation are in bad situation.

Aims

The fact is that no matter the constraints for gas prediction are feasible or not, gas reservoir does exist in strata with specific characters, which have corresponding features in geophysics data such as seismic and logging, at all times. Therefore, in exploration areas which are dominated by seismic data, integration and correlation of seismic anomaly unit of gas reservoir in the 3rd-order sequence unit with gas-containing anomaly unit will help us to construct seismic gas-containing anomaly unit, which constitute seismic-petroleum accumulation unit in terms of geological interpretation of hydrocarbon accumulation. Further by three-dimension stochastic modeling with seismic-petroleum accumulation unit (SPAU), the three-dimensional distribution characterizations can be quantitatively predicted.

SPAU seismic stochastic simulation is to convert the geological problem of “finding traps” to the technical problem of “finding anomaly”. Hence, the most important aim of the paper is possible to find gas reservoir by SPAU modeling when traps are nearly impossible to be found. By utilizing synthetically multi-disciplinary information including seismic data, logging data, geological data and production dynamics data, fluid distribution and 3D distribution characteristics of natural gas reservoir can be predicted quantitatively.

Methods

According to distribution character of lithological gas reservoir in the plane and profile, we predicted the bio-gas contain anomaly in the north slope of Sanhu area. This process gradually require integration of refined and quantified data over multi-disciplines to facilitate an generation of more reasonable and comprehensive prediction on gas contain anomaly promoted by significant research advances on gas reservoir accumulation unit and key control factors on gas trap. Further we could obtain a knowledge on the continuous distribution characteristics of local bio-gas reservoir. As refinement and quantification has been the total develop tendency in exploration and development of hydrocarbon, techniques and methods for this purpose need to be overlap and extend mutually. The exploration of natural gas in Sanhu area has come to post stage, hence the application of high precise seismic data, vector seismic data and S-wave logging data increasingly became popular, which provide and solid background on data for fluid prediction and petrophysics modeling.

The SPAU is defined as the geological interpretation of hydrocarbon accumulation on seismic gas-containing abnormal unit. The level hierarchies of SPAU depend on the hierarchy of gas accumulation units and sequence stratigraphical units, and at the same time depend on research precision of reservoir units. The SPAU can quantitatively characterize the level hierarchy and geological significance of gas accumulation unit, and quantitatively correlation gas-containing anomaly in logging and seismic data.

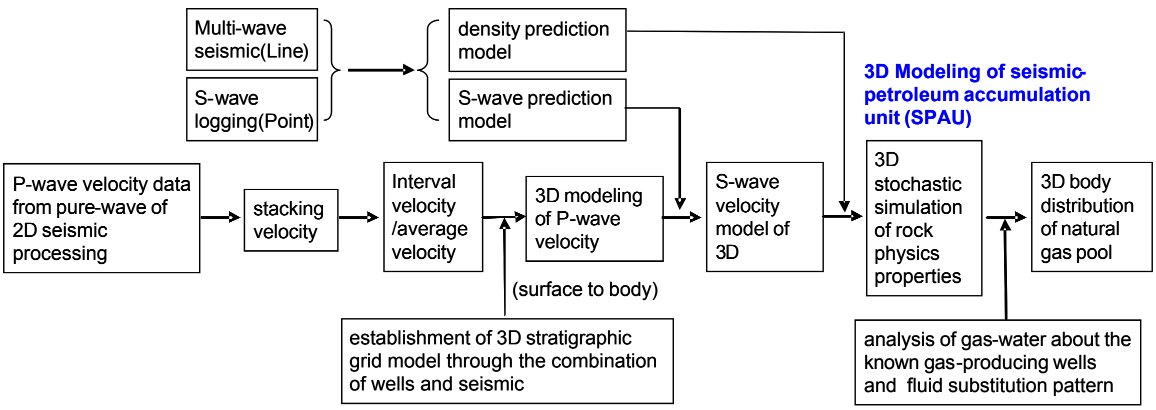

Figure 2 principle of SPAU stochastic simulation of sensitive petrophysical properties based on S-wave model

The principle of SPAU is using S-wave logging data or multi-wave seismic exploration data to construct S-wave prediction model and density prediction model, integrating 2D (or 3D) post-stack P-wave seismic data to geostatistical 3D model, and scale matching and gridding for strata unit after seismic trace discretizing (Fig. 2). Firstly, we should up-scaling geological grid unit according to local geological quality requirements. This is because demand of scales for the geological grid units in the stage of trap pre-exploration is not as fine as in the stage of development. With regard to 2D seismic research area in this paper, size of the strata grid unit should less than the distance between seismic survey lines in horizontal scale and lager enough to recognize the thinnest layer in vertical scale. Secondly, we should resampling seismic trace in the way of geological grid unit, based on vertical resolution capability and horizontal variability of seismic trace wavelet. Finally, according to Cloud transform, Gauss transform and variogram-fitting analysis and constrained by VSP logging data, S-wave data and regular logging data, we can obtain 3D stochastic model of pre-stack petrophysical attribution distribution based on S-wave prediction model by sequential indicator simulation. Thus, seismic anomaly is implemented on strata grid unit by seismic trace gridding. Combined with petrophysical analysis which transform seismic anomaly to gas-containing anomaly, we can make comprehensive quantitative prediction on spatial distribution features of seismic gas-containing anomaly in the sequence of “point-line-surface-body”. The fluid substitution model constructed from typical gas producing well data could be applied to transform the seismic gas-containing anomaly unit in strata grid unit to gas-water anomaly unit, which realize quantitative prediction for SPAU (or trap unit). The hierarchies of gas accumulation unit are corresponding well with gas-containing anomaly unit. The hierarchy of gas accumulation unit is divided to four levels: combination of gas reservoir accumulation systems, systems of gas reservoir accumulation, combination of gas reservoir accumulation, and gas reservoir. In this paper, our research focuses on the 3rd level accumulation unit in the stage of trap pre-exploring, that is “combination of gas reservoir accumulation”, which corresponding to “gas zones” unit in gas field development department.

The technique frame of SPAU (Fig. 3) is specified as following. Firstly, comprehensive interpretation of log and seismic and gas-containing anomaly analysis of rock physics of log and seismic must be done. Taking stratigraphic grid units as standard and correcting by logging data, we can gridding and discretize seismic trace. Constrained by testing dynamic data, sensitive properties of rock physics can be simulated stochastically, which are interpreted by hydrocarbon accumulation and realized by fluid substitution. Ultimately, we obtain 3D distribution model of SPAU and submit drilling goals and wells. Two points must be strengthened: One is the analysis and apply of transverse wave logging data such as DSI and multi-wave and multi-component seismic data; another is fluid substitution.

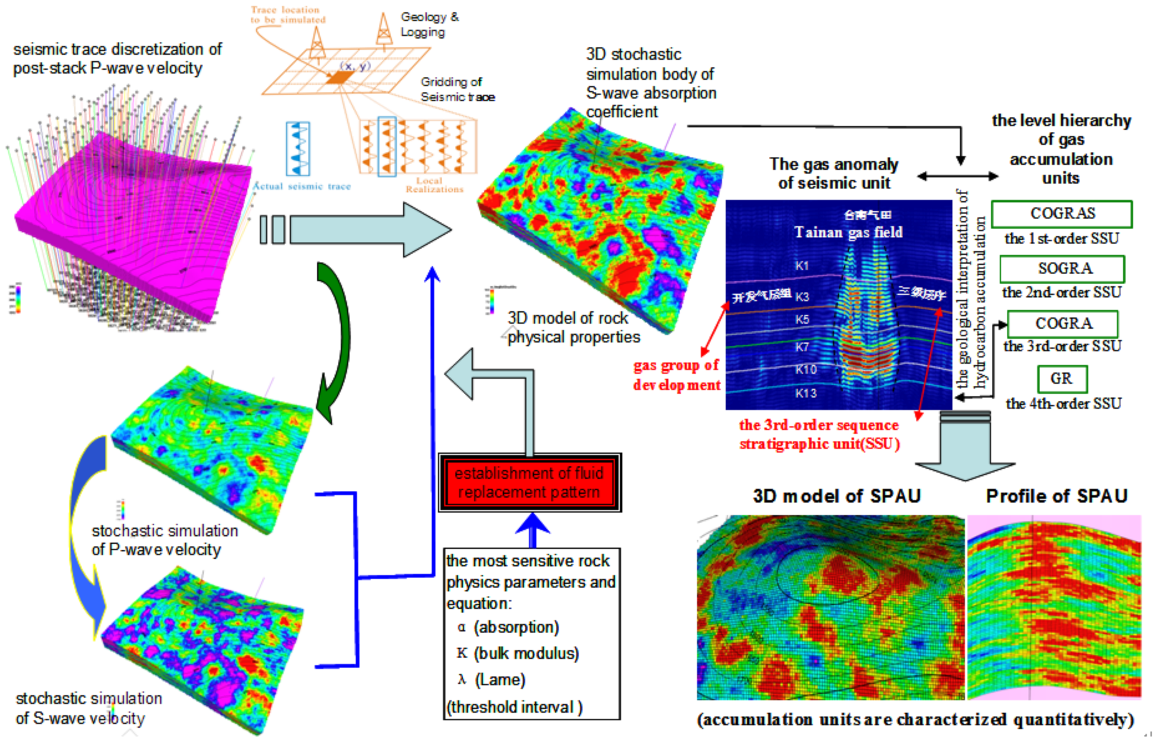

Figure 3 technique frame of SPAU modeling

The workflow of SPAU include four steps. The 1st step is to identify seismic anomaly units. The 2nd step is to detect gas anomaly units. The 3rd step is to simulate the seismic gas-containing anomaly unit stochastically and make hydrocarbon accumulation interpretation, further building SPAU. The 4th step is to conduct SPAU prediction and comprehensive evaluation.

Results

SPAU was firstly applied in gas prediction in Sanhu area of Qaidam basin. It is from the geology, well logging, seismic, production and dynamic data to start and based on P-wave seismic reflection and propagation in special multi-scale viscoelastic media that is thin and alternate beds of unconsolidated sandstone and clay stone with under compacted and weak digenesis of the quaternary strata. With the method underground bodies of petrophysical properties more sensitive to the gas-bearing abnormalities can be obtained. And threshold interval of response about gas and water abnormalities, which is about the most sensitive rock physics property, is analyzed quantitatively to establish gas-water recognition pattern, by which fluid substitution is done for three-dimensional quantitative model on properties of rock physics. So the most probable, three-dimensional and spatial distribution characteristics about the bio-gas reservoir are found. It has realized transformations from 2D to 3D, from post-stack to prestack, from qualitative to quantitative, from P-wave to S-wave and from lithologic to fluid so on.

The Quaternary bio-gas area in the northern slope is the largest bio-gas area in Sanhu area of Qaidam Basin. Aimed at the quaternary bio-gas of thin interbed of loose sand and shale in Sanhu area, this paper analyzed the conflict focus of the quaternary bio-gas exploration from the seismic-petroleum accumulation science. The conflict focus is “for reservoir, which controlled accumulation”, pointed out how to find low saturation gas lithologic reservoir in the eight lithologic gas reservoir slope, and the key is to figure out gas reservoir unit and the heterogeneity of controlling factors. This paper using seismic data, logging, geology, testing and so on, using seismic data as the core and taking logging, geology and testing data as the constraints in order to the two-dimensional seismic data gridding, Through variogram analysis and the sequential indicator simulation method to build the 3D petrophysical stochastic model, the petrophysical properties body was obtained which is more sensitive to gas abnormal. The gas and water identification mode was built by analyze the most sensitive gas threshold range of petrophysical properties, and the fluid substitution is made for the 3D model of petrophysical properties, The grid cell distribution of model and seismic reservoir unit were found, at the end, the possible 3D spatial distribution characteristics of bio-gas reservoir can be acquired. The drilling effectiveness shown that the S-wave petrophysical simulation method can predict the distribution of 3D gas reservoir, the application effects are obvious, the applicability is strongly, and it is worth promoting.

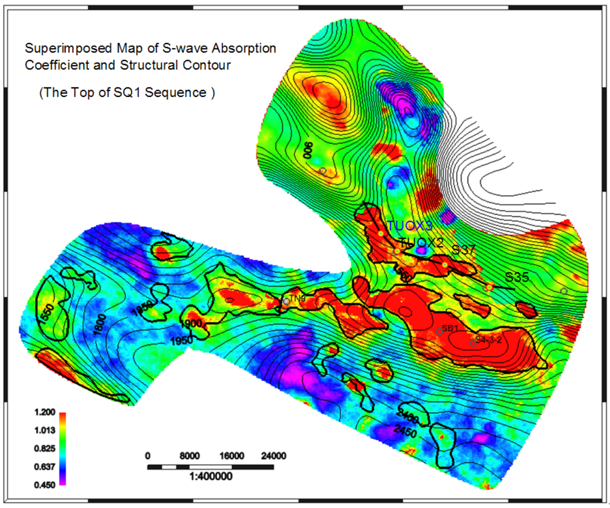

Figure 4: the distribution characteristics of S-wave absorption coefficient from SPAU modeling

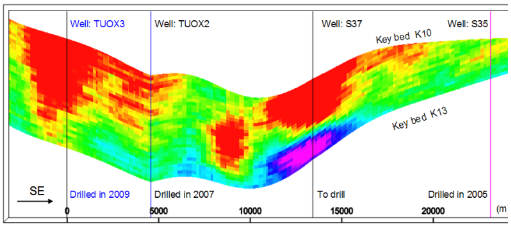

Figure 5: the profile of S-wave absorption coefficient from SPAU modeling

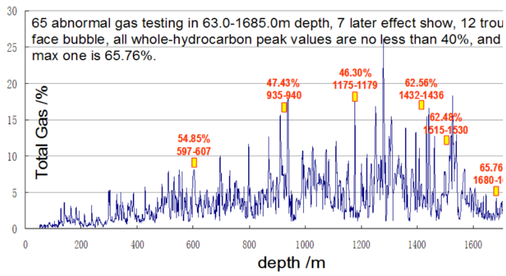

Figure 6: all whole-hydrocarbon peak value curve of TUOX3

Based on stochastic simulation of SPAU, we predicted 3D distribution of gas reservoir in Sanhu North Slope, from which 5 exploratory wells and 1 risk well were submitted and adopted.

One of the examples is well TUOX3 drilled recently in 2009, the features of probable gas-bearing anomalies have been found in the SQ1 sequence (between key bed K10 and K13) of the Tuo-xi Slope, which shows that the S-wave absorption coefficient in the red color rises (Fig. 4). The S-wave absorption coefficient in the SQ1 sequence and structural contour of key bed K10 that is the top surface of the SQ1 sequence are superimposed together in time domain.

According to the figure 5, the abnormal features of multi-well profile from well TUOX3 to TUOX2 and to S37 and to S35 about S-wave absorption coefficient at the southwestward structural nose uplift of Tai Ji Nai Er anticline are shown in the figure 4. The abnormal response is predicted comprehensively as the characteristics of gas-bearing. There have been good hydrocarbon indicator results in the logging information of drilled three wells. And dozens gas-related layers have already been interpreted. Forecasting methods discussed in

Adopted wells	Show of gas and gas-testing	Well type
TUOX3	Total Gas Peak Values are no less than 40%; the max one is 65.76%; ready for gas testing.	Exploratory
YANX1	The max Total Gas Peak Value is up to 62.68%; interpreted 44 gas-related layers are ready for gas testing.	Exploratory
TN13	The max Total Gas Peak Value is up to 76.63%; interpreted 25 gas-related layers are ready for gas testing.	Exploratory
TUOX4	2011 deployment	Exploratory
TN14	2011 deployment	Exploratory
TNSH1	Found oil type gas in Tertiary	Risk

Figure 7 Show of gas and gas -testing

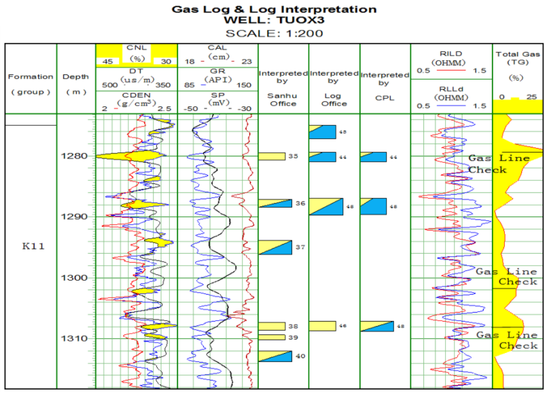

Figure 8 well log interpretation of TUOX3

this article have initially been authenticated to be correct and reliable. The response of gas-bearing anomalies at about 1280 meters is corresponding to that at about 1425 milliseconds 5 exploratory wells were adopted and 3 of them with good SG&O (Fig. 6,7,8). The max total-hydrocarbon peak value are 65.76%, 62.68% and 76.63% respectively in well TUOX3, YANX1 and TN13. It is expected to be 26.856 billion cubic meters reservoir scale (Fig. 6).

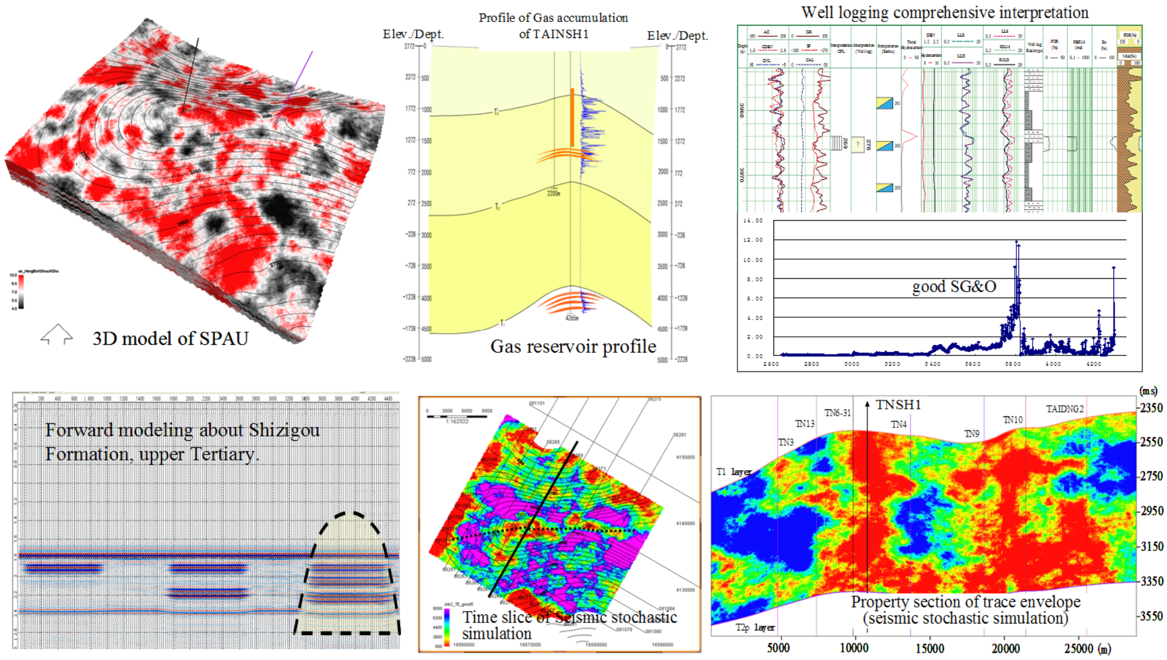

Figure 9 3D distribution prediction of gas reservoir from SPAU modeling about the risk well TNSH1

Based on stochastic simulation of SPAU, risk well position can be confirmed and drilled. The abnormal response characteristics of gas-bearing is decided by the forwarding modeling. Finally, oil type gas was shown in the risk well TNSH1. Good SG&O show and well log interpretation confirmed gas-bearing (Fig. 9). Now gas testing is in progress.

Conclusions

Combining with drilling and logging data, geological and dynamic production data, 2D post-stack P-wave seismic data can be integrated into the geostatistial model for 3D body prediction about pre-stack S-wave rock physics properties by utilizing geostatistial stochastic simulation method in multiscale viscoelastic media. In this way, the abnormity caused by gas-bearing factors can be amplified further. It has provided technical support for gas exploration and reduced significantly the solution ambiguity and uncertainty.

Four aspects the summaries are available as following:

1.SPAU implements architecture of seismic-petroleum accumulation discipline. And it can significantly guide quantitative exploration of oil and gas;

2.The method can solve the problem about scale matching of different geological object.

3.It can predict not only boundary of gas reservoir, but also continuous distribution of inner characteristics.

4.It can quantitatively predict Sg distribution in 3D space.

It has already been proven to be effective by exploration drilling. But it also needs to be improved further.

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