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Application of seismic inversion technology to volcano rock reservoir prediction in Yingshan area

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Abstract: The volcano rock is usually located in the area which has experienced intense tectonic movement, led to complex lithology, diversification of lithofacies, reservoir heterogeneity seriously and so on.Due to above reasons, volcanic reservoir distribution is easy to be affected and is difficult to predict. This article argues that wave impedance and density are the sensitive parameters of volcanic rock favorable reservoir in Yingcheng formation by analyzing volcano rock reservoir sensitivity in Yingshan area. Using logging constrained sparse pulse inversion method for wave impedance inversion, and then using simulative sound wave curve obtained by the correlation of acoustic and density for inversion again, the wave impedance and density data volume are respectively obtained for reservoir prediction. The favorable reservoir distribution division is concluded by the inversion results. The favorable reservoir zone map is got with considering secondary fracture mechanism, volcano facies belt and other factors. The inversion predicted results are compared with existing drilling to test the effectiveness of inversion. Results indicate that the prediction of volcanic reservoir could be accurate through this seismic inversion technology, which provide the reliable basis for reservoir evaluation and well drilling plan. The application effect is good.

Keywords: *Yingshan area; Sensitive parameter analysis; logging constrained inversion; volcanic rock reservoir*

I. INTRODUCE

Volcanic geological genetic background and reservoir forming mechanism are greatly different from sedimentary rock. Volcano has characteristics of complicated structure, quick change of lateral lithology and poor layered property, and the distribution is difficult to predict[1-2]. Most of volcanic rocks developed in the early period the basin formation and buried deeply. Geophysical characteristics show the physical interface is not obvious and wave field is complex[3]. Therefore, volcanic building basin formation distribution is complex and difficult the exploration target is difficult to recognise. To the complex structure region, simply using seismic attributes is difficult to predict the volcanic reservoir[4]. Many scholars carried out many trials in the using inversion method to identify the volcanic reservoir[5].

With the continuous development of inversion method, seismic inversion technology plays an important role in the volcanic rock reservoir prediction. The seismic inversion based on the model is an effective technical method, which overcome the problem of the inversion precision and low resolution[6]. Logging constrained seismic inversion method bases on geological model, by the organic combination of logging and 3D seismic data and model optimizing iterative perturbation algorithm, with seismic interpretation the horizon or sequence as control, starting from the well point interpolation and extrapolation, the initial wave impedance model forms. And then through continuous model modification making modeling seismic synthetic data accurately match the real seismic data, the final model data is inversion result. The inversion result is obtained by forward modeling, avoiding the

problems of the direct seismic data inversion, so high resolution stratigraphic wave impedance data can be obtained, providing favorable conditions for the thin layer reservoir fine description[7].

Yingshan area is a construction deep sag area, of which the scale is larger, controlled by shear fracture. Yingshan area is the main replacement regions of deep natural gas exploration after Xujiaweizi area[8]. At present, there are five deep exploration wells in the research area. There are 17 species lithology in Yingcheng formation such as rhyolite, dacite and andesite and so on. The previous have done many researchs for fracture formation mechanism, oil and gas resource potential and rock physical characteristics in the research area, thinking that the study area has good reservoir-cap conditions and oil and gas favorable area[9-10]. Therefore, the study of volcanic rock reservoir prediction has direct significance to the oil and gas exploration in Yingshan area. This paper carries out the volcanic rock reservoir identification and prediction by using logging constrained inversion in Yingshan area, and achieves good application effect.

II. GEOLOGICAL CONDITION

Yingshan area locates in the eastern part of songliao basin, of which tendency is near south-north, and is in the southeast uplift area. Yingshan area is adjacent to Chaoyanggou terrace and the transition deep concave area the southeast uplift to central depression. The tectonic deformation is relatively strong, especially at fracture and structure, strongly controlled by deep. The Yingcheng formation volcanic rocks in the study area are derived mainly through rift tectonic and depression tectonic development stages. The volcanic rock was accompanied with periods of volcanic activities, divided into three cycles and six issues from bottom to top(Fig1). Rhyolitic developed extensively in the whole work area with large thickness; Andesite primarily developed in the middle-east and southeast corner of the area; Dacite mainly developed in east and southeast parts of the area. Each cycle of volcanic eruption has the characteristics of migration, superimposing, multiple thickness center and activity intensity migrating from the southeast to the northwest. And sedimentary rock has a regional development. The volcanic rock purpose layer depth is 2500-5000m. Thickness changes abviously, ranging from 0m to 1500 m, and has a wide range of distribution, almost covering the entire area, but in the local volcanic rock is not developed. Purpose layer reflection characteristics mainly show clutter and moundy reflection, and internal continuity and layer are poor. Multiphase eruption and the late alteration filling led to relative density reservoir and multiple reservoir development. Volcanic rock reservoir is controlled by volcanic institutions, volcanic rock lithology and unconformity surface.

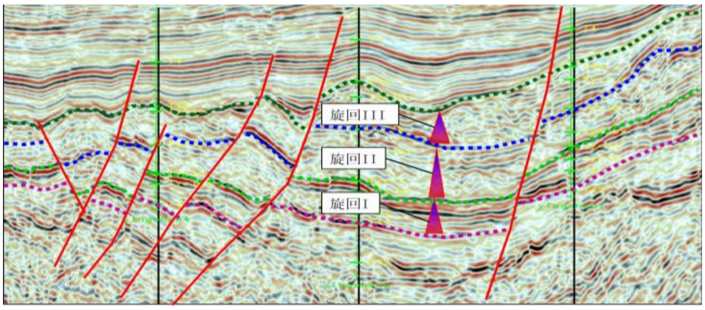

Fig 1 Seismic profile in wells

III. KEY TECHNOLOGY

3.1 Curve pretreatment

In reservoir prediction, the validity of the logging data is very important. In earthquake geological calibration, stratigraphic correlation and constrained seismic inversion, the accuracy of the logging data determines the success or failure of the whole work. However, the time of well logging, well logging series and the environment are different, there is each different measurement range in wells in research area. At the same time, the inspection it is found that random noise exists in well logging curve in work area by inspection. According to these problems, this paper carries out depth curve matching, curve singular value editing, random noise interfering signal elimination and environmental correction, processing standardized curve for each well.

3.1.1 Logging curve singular value removing

Curve edit mainly includes three parts: the depth of the curve match, singular value edit and random noise elimination. Depth curve match aim to make different time measured curve of the same well aligned, and the intersection analysis results are more reliable. Correction method is to change the depth of unaligned curves based on the characteristic curve of interface information. The purpose singular value edit is elimination of no lithologic factors and correction methods mainly is through manual editi to invalid data. Random noise elimination is mainly used to eliminate the burr interference of curve, which has nothing to do with formation property. Correction method is mainly through smooth filtering.

3.1.2 Curve standardization

Standardization is an important part of logging data preprocessing, usually selecting a regionally developed mudstone as the symbol layer. From statistical analysis of the lithology for Yingcheng formation in this area, we learn that Yingcheng formation does not almost contain a stabilized mudstone, so mudstone is not suitable for a symbol of layer. Most of the wells contain rhyolite and tuff in the study area, so using rhyolite and tuff as a symbol of layer carry out normalized curve processing, the density and longitudinal wave curves, etc. According to the above principle the normalized processing for density, sonic and GR curves, etc of volcanic period is completed(Fig2 to Fig7). The completion of normalization for curve lays good data foundation for the subsequent reservoir prediction.

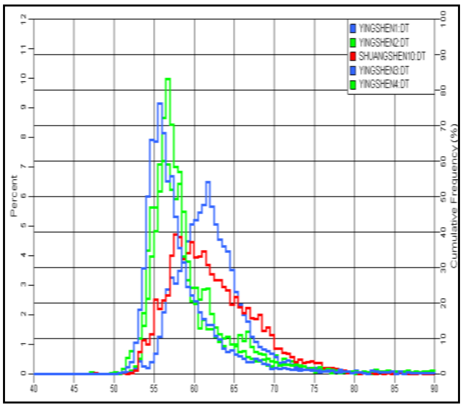

Fig 2 DT curve before normalization

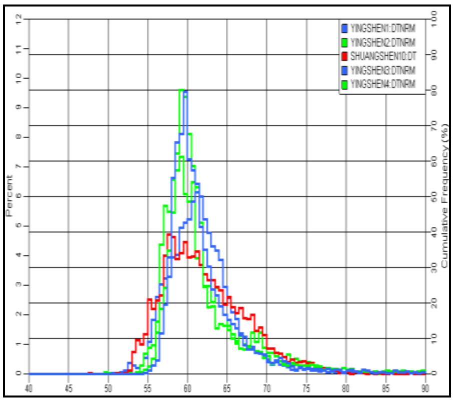

Fig 3 DT after normalization

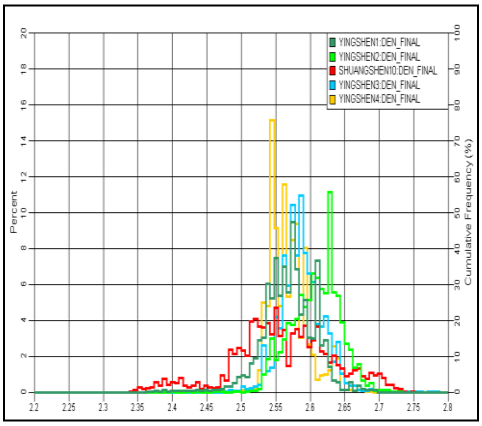

Fig 4 DEN curve before normalization

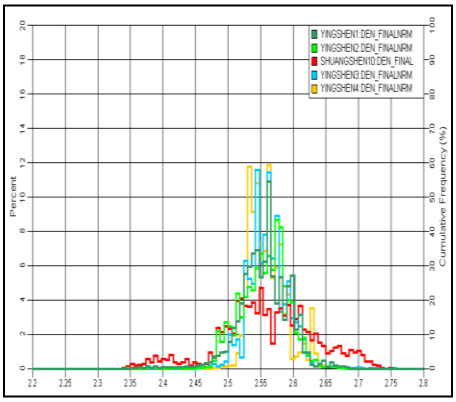

Fig 5 DEN curve after normalization

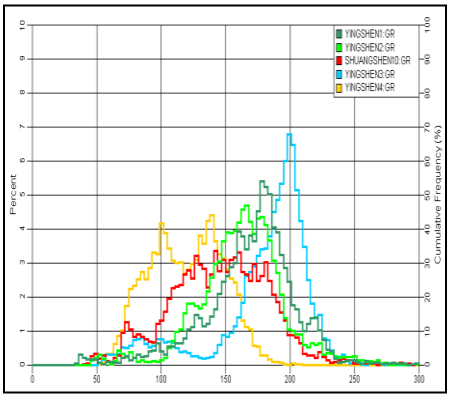

Fig 6 GR curve before normalization

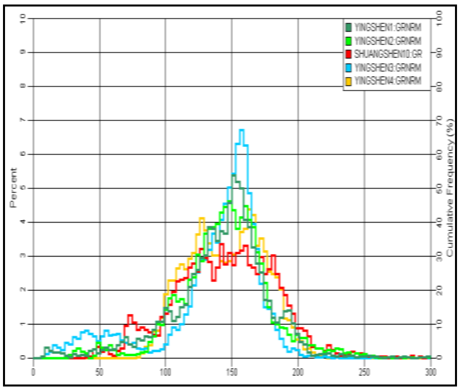

Fig 7 GR curve after normalization

3.2 Volcanic rock reservoir sensitive parameter analysis

3.2.1 Volcanic lithology sensitive parameter analysis

There are many different kinds of volcanic rock and volcano lithologic is extremely complex, which is a big difficulty for volcanic rock reservoir prediction. First of all, according to the ph of volcanic lava, pyroclastic granularity and the characteristics of the retain reservoir, the volcanic stratigraphic lithology can be divided into rhyolite, dacite, andesite, volcanic breccia and tuff and sedimentary rock six kinds in Yingcheng formation in this area. Try to distinguish the lithology through all sorts of elastic parameters intersection, but analysis shows no regularity between each lithology in the study, and six kinds of lithologic are indistinguishable. So we need to find out the common ground in six kinds of lithology and reclassify to achieve the purpose to distinguish lithology. According to the ph value of volcano and their development of reservoir, the volcano is divided into rhyolite, dacite, andesite and sedimentary rocks. In the process of division, the neutral rock is distinguished in tuff and volcanic breccia rocks by GR value on the basis of the previous rhyolite, dacite, andesite, and sedimentary rock. Tuff and high GR value breccia are classified as rhyolite and low GR value breccia is classified as andesite. The rock physic analysis can reduce the overlap region, thus effectively distinguishing the lithology. Sedimentary rock shows as low density and low wave impedance characteristics, and andesite in volcanic rock shows as the high wave impedance characteristics, therefore volcanic rock and sedimentary rock can be separated by density. And then the andesite can be divided from volcanic rocks by wave impedance.

3.2.2 Volcanic reservoir sensitive parameter analysis

On the basis of distinguishing lithology, try to distinguish reservior of different lithology. According to the experience value of reservoir in Xujiaweizi area reservoir (acid rock density is less than 2.53, neutral rock is less than 2.65), combining the DT curve detail reservoir on the basis of the previous logging comprehensive interpretation. The rhyolite reservoir density threshold value is 2.53 g/cc and the andesite reservoir density threshold value is 2.65 g/cc. Applicating the latest standard of reservoir obtains interpretation result and calibrates for a variety of elastic parameters histogram and crossplot(Fig8 to Fig11). From fig8, in the case of not to distinguish the lithology, reservoir and the reservoir zone superpose seriously, so they can not be distinguished well. The reservoir needs to be devided by different lithologic threshold value. (rhyolite reservoir density threshold value is 2.53 g/cc, andesite reservoir density threshold value is 2.65 g/cc).

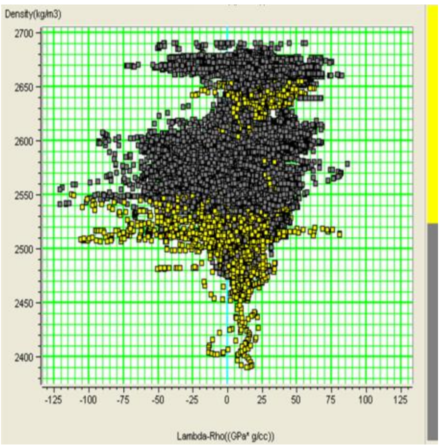

Fig 8 Volcanic rock reservoir parameter crossplot

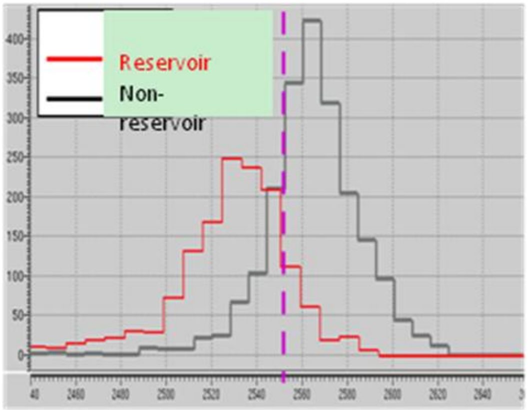

Fig 9 Volcanic reservoir and the reservoir density histogram

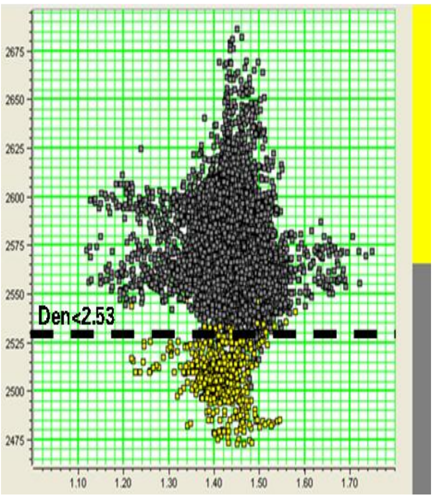

Fig 10 Rhyolite reservoir parameter crossplot

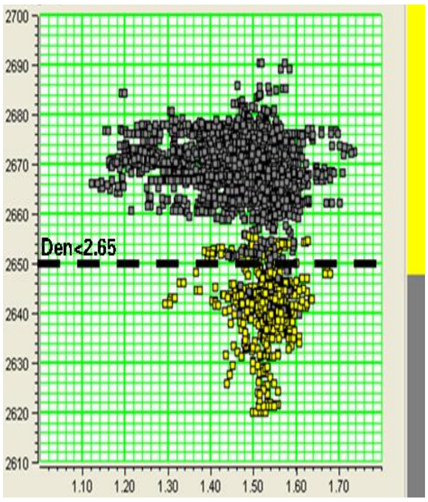

Fig 11 Andesite reservoir parameter crossplot

3.3 Seismic inversion technology base

According to the result of the favorable reservoir sensitivity analysis, wave impedance and density are the sensitive parameters of favorable volcanic rock reservoir in Yingcheng formation. This inversion is earthquake - logging joint inversion. The low frequency and high frequency information of the result are derived from logging data and the middle frequency information depends on the seismic data. Useing the model of optimizing iterative perturbation algorithm, through constantly changing of initial geological model, makes forward seismic data of the modified model most similar to the original seismic data, thus overcoming the limit of seismic resolution, best approximating logging resolution and while maintaining a good lateral continuity. The seismic inversion technique basing on model abundant high-frequency information and completed low-frequency components in logging data to make up for the limited bandwidth of seismic and can obtain reasonable wave impedance data.

Due to being unable to introduce constraint in the process of inversion, the actual noise in seismic records will seriously affect the inversion result, so conjugate gradient method is used. The main advantages of which using conjugate gradient method solves the formation wave impedance are: (1) algorithm is accurate and stable; (2) the matrix inversion is not made, so the problem in the processing of matrix is avoided; (3) the good antinoise ability; (4) it is easy to perform the constraint in the process of solving. Therefore, instead of directly solving, logging constrained inversion uses conjugate gradient method to successively approximatly calculate the formation wave impedance information through iteratively modifying formation model.

The difficulties of reservoir prediction in this area are less well data, complex lithology and dense reservoir. According to the different lithologic reservoir physical property down limit, reservoir thickness is finally predicted in this area. After the extensive experiments, reservoir prediction scheme that wave impedance inversion and density inversion are conbined to identify reservoir ultimately are determined. First using logging constrained sparse pulse inversion method conduct wave impedance inversion, obtaining wave impedance data volume(Fig12). And then on the basis of density curve, using the correlation of acoustic and density forms a new simulativesound wave curve. Using the simulative sound wave curve to make sparse pulse inversion again forms new wave impedance data volume. Transforming the data volume into density dimension gets the density inversion data volume(Fig13). According to the result of sensitive parameter analysis, the time thickness of the sensitive parameters for each period is extracted. And then the time thickness is turned into real reservoir thickness by well data calibration, accomplishing reservoir prediction.

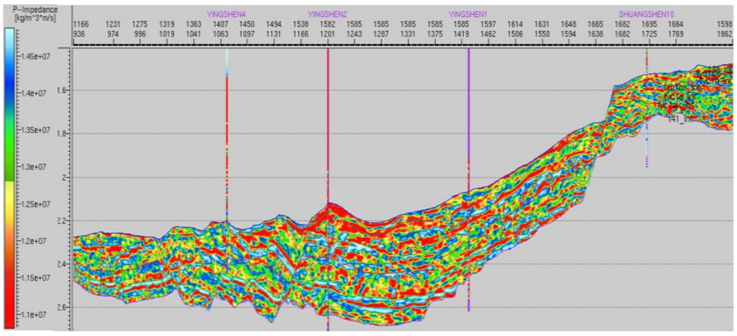

Fig 12 Wave impedance inversion profile in wells

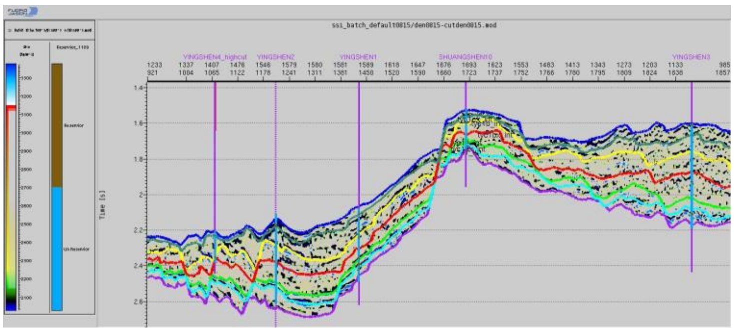

Fig 13 Reservoir prediction thickness profile in wells

IV. INVERSION PREDICTION EFFECT ANALYSIS

4.1 Inversion prediction effect

Yingcheng formation volcanic rock in the study area is divided into three phases of cycle and six times by the seismic comprehensive interpretation. There is thin-interbed development in the upper part of each cycle. Through the statistics of predicted values and the real value in well for each period, reservoir prediction error is calculated. The result shows that the alignment in well is better. The maximum absolute error is 7.4 m. The average absolute error is 2.9 m. The average relative error is about 16.9%. There are two sampling points of which relative error is greater than 25%, because the low density of sedimentary rock exists at the top and the whole reservoir thickness is smaller, leading to the big reservoir prediction thickness in well in issue 6. The relative error is 55.38%, but the absolute error is only 4 m. Affected by the seismic resolution at the same time, the thickness of one sample in well is more than 4m, leading to the big calculation error in issue 3. The relative error is 120%, but the absolute error is 2.4m. In period 2, due to the effect of low density deposition layer, small thickness value is estimated.

4.2 Characteristics of volcanic rock reservoir distribution

From the inversion prediction result, the volcanic reservoir mainly developed at the bottom of the cycle2 and cycle3 (issue3 and issue5) in Yingcheng formation. The previous think that volcanic reservoir is mainly located near volcanic crater and the proximal place and is controlled by secondary faults, volcanic mechanism and volcanic facies belt (zi-hui feng, etc., 2008). Combining with regional tectonic background and inversion result, considering the influence of the volcanic facies belt to the physical properties distribution of reservoir and using different corresponding threshold value to different lithology reservoir, the volcanic reservoir distribution range is got in Yingshan formation. On the whole, there is a big difference in reservoir distribution range and thickness of three cycles. From cycle I to cycle III, reservoir distribution range thickness increase gradually. The rhyolite and andesite reservoir is developed in issue1 of cycle1. The rhyolite reservoir mainly distributes in the southeast, and the andesite reservoir distributes in the southwest. The reservoir distribution is obviously controlled by fracture and volcanic institutions. The volcanic reservoir is mainly distributed in central region of cycle2 in the study area, shows as two distinct bands. On the whole, the reservoir distribution is controlled by fracture and volcanic institutions. The reservoir development is good in cycle3, widely distributing in the whole area.The reservior thickness of central and southern region in study area is the largest. The reservior presents Superimposition characteristic on the longitudinal characteristics, and overall reservoir characteristic show that the central strip is the most developed in the research area.

V. CONCLUSION

5.1 Using crossplot carries out volcanic rock reservoir sensitive parameter analysis. It is learned wave impedance and density are the sensitive parameters of reservoir in this area. Using different density threshold for volcanic reservoir division can well predict the favorable reservoir in research area.

5.2 The volcanic lithology is complex, and the volcanic rock belongs to low porosity and permeability reservoir. the, using logging constrained seismic inversion technology for comprehensive reservior evaluation predicts that favorable reservoir superimposed each other and mainly locates in the central strip of the study area. The result has high consistency with the actual drilling result of known well, showing that this method has higher accuracy. The inversion results can be verified through the subsequent exploration and development.

5.3 If the seismic inversion can be combined with sequence stratigraphy and sedimentology, the accuracy of seismic inversion for reservoir prediction can be further improved.

VI. ACKNOWLEDGEMENTS

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