A Velocity Model Building Method in the Igneous Rock Based on Facies-controlled Inversion

Introduction

With the deepening of oil and gas exploration and development, the geological objectives are often more complex, and the lateral seismic velocity changes dramatically. Although there are many velocity analysis methods at present, they are difficult to adapt to the velocity modelling of complex structures due to the limitation of assumptions, which affects the imaging accuracy. Especially in the regions with igneous rocks, the drastic laterally changes of lithology and velocity lead to the complex and changeable seismic wave field and the distortion of time-domain structure imaging, which makes the velocity modelling and imaging extremely difficult. In addition, due to the characteristics of high velocity and strong heterogeneity of igneous rocks, the absorption and shielding effect to seismic waves are obvious, which makes the waveform quality of the strata between igneous rocks or the underlying strata poor, seriously affects the sedimentary facies research and structural description, and restricts the understanding of the underlying oil and gas reservoirs.

This paper takes H survey in western China as an example. The study survey is rich in oil and gas, and the Ordovician karst fractures and cavities are good reservoir space. Fine imaging of small fractures and cavities inside the Ordovician System has been studied for many years. Permian igneous rocks are widely developed in its overlying strata, and their lithofacies, thickness and velocity vary greatly in space, resulting in high-frequency torsion of underlying strata in structural characteristics, which brings difficulties to the identification and fine interpretation of fractures and cavities inside the Ordovician System. Therefore, in view of some problems in the current modelling, combined with the special geological conditions of igneous rocks in the study area, this paper proposes a method of igneous rock velocity modelling based on facies-controlled inversion.

Method

The velocity model building of facies-controlled inversion of igneous rocks must be based on the geological laws, with inversion velocity as the main part, superimposed velocity spectrum as the reference, well logging data and horizon data as constraints, and combined with the results of petrophysical experiments, forward modelling and seismic facies analysis to comprehensively study the velocity field characteristics of the target area.

1. Seismic facies identification of igneous rocks

The volcanic rock types are classified by thin section identification and chemical analysis of the volcanic rocks. The periods of volcanic rocks are divided by dating data. The genetic model of volcanic rocks is studied, and three models of volcanic rock formation are clarified. Then, the distribution of igneous rocks is determined and the range of seismic facies is described by combining seismic facies and seismic attributes. However, there are many seismic attributes, some of which are relatively sensitive to specific research objects. In the study of igneous rocks, it is necessary to select sensitive attributes for analysis and extraction. Its theoretical basis is: the attributes derived from time is helpful to explain the details of the structures; the attributes derived from amplitude and frequency are used to solve the formation and reservoir characteristics; generally speaking, amplitude is the most stable and valuable attribute; frequency is more conducive to reveal the formation details; the mixed
attributes include the factors of amplitude and frequency, so they are more conducive to the measurement and analysis of seismic characteristics of igneous rocks. Based on the above analysis, the volcanic activity characteristics of "four kinds of lithologies, three facies belts and three periods" are defined in the area (Figure 1).

Figure 1(a) four kinds of lithologies: tuff, basalt, andesite and dacite 1(b) three facies zones: A: Blank facies zone: Dacite zone; B: Chaotic facies zone: Tuff—basalt—andesite—dacite zone; C: Parallel facies zone: Tuff—basalt—dacite zone. 1(c) three periods: 1st explosive facies: vitric tuff is mainly sandwiched in the clastic rocks; 2nd overflow facies: basalt and andesite; 3rd overflow facies and pyroclastic flow facies: dacite, welded tuff and tuff

2. Multi-parameter inversion

Multi-parameter inversion based on well logging constraints not only relies on acoustic and density curves for acoustic impedance inversion, but also integrates resistivity, gamma ray, spontaneous potential and neutron logging data etc(Yang et al,2011). The inversion method can make full use of well logging data and complement with seismic data. Firstly, the initial model is used to construct the seismic traces which are most similar to the original seismic traces to conduct inversion. By iteratively adjusting and optimizing the parameters, the residual error is minimized, and the data volume with optimal spatial weight distribution is obtained. Then, the data volume is applied to the well logging data with different attributes to obtain the corresponding well logging attribute data volumes. Compared with sedimentary rocks, igneous rocks are usually characterized by high wave velocity, high density and high resistivity.

It is found by analysis of well logging data that dacite corresponds to low interval transit time, high gamma ray, low density and relatively low resistivity; basalt corresponds to low interval transit time, low gamma ray, high density and high resistivity; tuff corresponds to high interval transit time, high resistivity and a wide range of gamma ray value. From the well logging characteristics, it can be seen that using one well logging attribute alone cannot distinguish these three kinds of lithologies well, and it is difficult to meet the description requirements of complex igneous rock morphological characteristics, so multi-parameter inversion is an effective method (Figure 2).
Figure 2 Well1 is located in chaotic facies zone with thick tuff, low VSP and DT velocity, and different from dacite zone on the right side. Two sets of rock strata can be seen at WELL4 and WELL8, the upper layer is high-speed and the lower layer is low, which corresponds that the dacite tuff with high GR value and clastic tuff with low GR value.

3. Forward modelling verification of the model

In order to verify the accuracy of the model, the igneous rock model of the target area is used for forward modelling based on well logging curves. The velocity curve obtained from well logging data is used to provide the velocity information of the strata, and as a constraint to establish the velocity model of the target layers. Well logging curves have very high vertical resolution. The velocity provided by well logging curves not only reflect the velocity of underground strata, but also have fine vertical stratification, which is closest to the real situation of strata. In order to further test the authenticity of blank facies zones, chaotic facies zones and parallel facies zones on seismic section, we select four wells located in the characteristic area to establish forward model. The forward model further verifies the authenticity of blank facies zone, chaotic facies zone and parallel facies zone on seismic section of igneous rocks, as well as the consistency and reliability of seismic and well logging data(Figure 3).

Figure 3 Selected four wells and forward model

Examples

Through the high-precision velocity model obtained by this method, combined with the pre-stack depth migration imaging technology, the distortion of the underlying structures of igneous rocks is eliminated, the real structure shapes are restored, the pseudo fault
phenomenon is eliminated, and the deep carbonate fracture-vuggy reservoirs are accurately imaged, which lay a good data foundation for further reservoir research.

Figure 4 shows the comparison of pre-stack depth migration sections before and after the application of this method. After the application of this technique the pseudo faults disappear, the stratigraphic continuity is improved significantly, and the imaging accuracy of Ordovician carbonate fracture-vuggy reservoirs is improved significantly.

**Figure 4** the comparison of pre-stack depth migration sections before (legacy data) and after (new data) the application of this method.

**Conclusions**

The velocity field based on the facies-controlled inversion method has high precision and high density, which provides a favorable guarantee for the implementation of high-precision imaging. The inversion for establishing velocity field is different from reservoir inversion in that the former pays more attention to the rationality of velocity field and their parameter optimization processes are also different. Additionally, the inversion between wells should be based on seismic data and constrained by geological laws such as horizon, seismic facies, geological facies and electrofacies, so as to establish high-precision velocity model conforming to geological laws.

**References**