International Journal of Mining Science and Technology 23 (2013) 167–172

Contents lists available at SciVerse ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

Integrative method in lithofacies characteristics and 3D velocity volume of the Permian igneous rocks in H area, Tarim Basin

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ARTICLE INFO

Article history:
Received 9 July 2012
Received in revised form 14 August 2012
Accepted 12 September 2012
Available online 25 May 2013

Keywords:
Characteristics of igneous rocks
Fitting of logging curves
Seismic inversion
Velocity volume
Seismic facies

ABSTRACT

This paper introduces horizon control, seismic control, logging control and facies control methods through the application of the least squares fitting of logging curves, seismic inversion and facies-controlled techniques. Based on the microgeology and thin section analyses, the lithology, lithofacies and periods of the Permian igneous rocks are described in detail. The seismic inversion and facies-controlled techniques were used to find the distribution characteristics of the igneous rocks and the 3D velocity volume. The least squares fitting of the logging curves overcome the problem that the work area is short of density logging data. Through analysis of thin sections, the lithofacies can be classified into eruption airfall subfacies, eruption pyroclastic flow subfacies and eruption facies.

1. Introduction

The H area is a 3D working area in the Tarim Basin. The precision of the velocity field is influenced by Permian igneous rocks, and it is hard to ascertain structures with low amplitudes. Studying the characteristics of the igneous rocks and the law of velocity variance can improve the precision of mapping structures with low amplitudes. There are two problems. (1) The lithology of igneous rocks varies and the genetic model is unclear. (2) The igneous rocks have a large distribution, uneven thickness and velocity in both vertical and horizontal directions. It is hard to ascertain the clasolite and lithologic traps with low amplitudes from the Carboniferous and the Silurian. Studying the lithofacies characteristics and the genetic model plays an important role in improving the precision of attaining the velocity field.

The lithology of igneous rocks can be identified by drilling and logging data. The igneous rock characteristics of velocity and distribution in 2D or 3D can be found from the seismic attributes and seismic inversion. The impedance seismic inversion was used to predict the thickness of the igneous rocks [22]. [23] applied a multi-parameter inversion to predict the igneous rock characteristics of the 2D or 3D distribution. [24] used seismic inversion and seismic attribute clustering analysis to predict the igneous intrusion periods and the 2D distribution.

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2. Research idea and method

The integrative methods of horizon control, seismic control, logging control and facies control were applied in this study area. These methods are presented in Fig. 1.

Fig. 1 shows the interpretations of seismic and inversion horizons of the horizon control. The volumes of seismic data and inversion data are seismic control, whereas the logging data and the VSP are logging control. The identification of seismic facies and classification of electrofacies are facies control. The method takes full advantages of seismic, logging and drilling to analyze the igneous rocks.

Based on this idea, the entire process and material technical route to study the characteristics of igneous rocks and the law of the velocity variance are shown as Fig. 2.

2.1. Least square fitting method for the velocity and density of igneous rocks

Fourteen drillings were rectified in this area including H1, H4 and H6. But only four wells had density logging. It was a bottleneck for further seismic inversion. The velocity can be converted into density by Gardner's rule, although Gardner's rule was aimed at a specific stratum and geological background. The existing logging data were used to match the Gardner's rule and thus the density representing the target stratum was found.

In 1974 Gardner and his co-workers found the relationship between velocity and density through a great quantity of

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http://dx.doi.org/10.1016/j.ijmst.2013.04.025

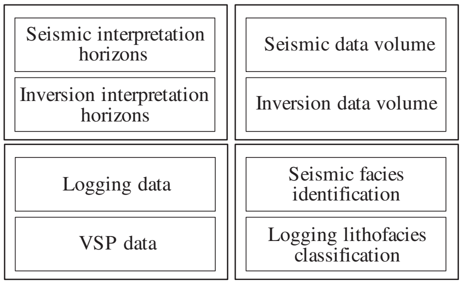

Fig. 1. Methods of horizon control, seismic control, logging control and facies control.

experimental data. This relationship is called Gardner's rule and is described as [1]:

$$D = 0.31V^{0.25} \quad (1)$$

where D is density, g/cm^3; and V is velocity, m/s. The scale factor is 0.31 whereas the index is 0.25. The relationship between velocity and density is found by laboratory observation for the saturated saltwater rock and outdoor statistics. The relation is usually quoted in seismic data digital processing and theoretical research [2–5].

In practice, rock characteristics vary with the rock surroundings and in many trials Gardner's rule has been found to be inapplicable to different lithologies and surroundings. In order to solve this problem, the relation is given as follows.

$$D = aV^b \quad (2)$$

where a is the scale factor and b the index. Different areas have different relationships between density and velocity and different relationships have different a and b values.

"a" and "b" can be obtained by the least squares fitting method. The fundamental principle of the method is to find a fitting function that makes the function $\varphi = \sum(D_i - aV_i^b)^2$ minimal for all the samples (V_i, D_i). That is to say $\frac{\partial\varphi}{\partial a} = 0$ and $\frac{\partial\varphi}{\partial b} = 0$. $D = aV^b$ is converted into $\ln D = \ln a + b\ln V$, and the problem is minimal if the function $\varphi = \sum(\ln D_i - \ln a - b\ln V_i)^2$. The partial derivatives of a and b respectively are calculated.

$$\frac{\partial\varphi}{\partial a} = -2\sum(\ln D_i - \ln a - b\ln v)\frac{1}{a} \quad (3)$$

$$\frac{\partial\varphi}{\partial b} = -2\sum(\ln D_i - \ln a - b\ln v)\ln v \quad (4)$$

If $\frac{\partial\varphi}{\partial a} = 0$ and $\frac{\partial\varphi}{\partial b} = 0$,

$$b = \left(\sum \ln D_i \ln V_i - \frac{\sum \ln D_i \sum \ln V_i}{m}\right) \Big/ \left(\sum(\ln V_i)^2 - \frac{(\sum \ln V_i)^2}{m}\right) \quad (5)$$

$$\ln a = \frac{\sum \ln D_i - b\sum \ln V_i}{m} \quad (6)$$

where m is the number of samples; D the density, g/cm^3 and V the velocity, m/s. "a" and "b" can be obtained from it, as well as the fitting relation of the igneous rocks in the work area.

2.2. Facies control technique and its realization

The facies control technique is a method used to study the objective law between the lithofacies and the geophysics parameters by mathematical relationships or models. The parameters include velocity, density, impedance and the seismic attribute parameters. The seismic wave attributed section or the inversion section are automatically converted into a lithofacies section by computer [6–10]. It is difficult to extrapolate conventional facies analysis at the well points and it is difficult to obtain an accurate lithofacies distribution [11,12]. Compared with conventional facies analysis, the facies control technique can provide a quantitative analysis, as well as solving the problems of ambiguity and uncertainty. The method has great application value [13–15].

The realization process of facies control can be divided into three parts: (1) Single well microfacies classification, attribute parameters fitting of dual well microfacies, and analysis of the geophysical parameters law which varies with depth in every microfacies; (2) Microfacies initial model building and the preponderant microfacies which is reserved by the filter of the attributed parameters section; (3) The electrofacies which is inserted into the section to calibrate the microfacies, and the microfacies are selected at different grades.

3. Igneous lithology and lithofacies characteristics

3.1. Thin section analysis and rock type classification

Through analyses of thin sections and rock cuttings, the lithology is classified into sixteen types: (1) The lavatic basite including trachybasalt, tholeiite, vesicular basalt and vitrobasalt. (2) The lavatic mesite including andesite. (3) The lavatic acitite including tuffaceous dacite and tuffaceous rhyolite. (4) The efflata including vitric tuff, crystal tuff, crystal-vitric tuff, crystal-lithic tuff, dust tuff, tuffite, tuffaceous sedimentary rock, flow vitric welded tuff and welded tuff. Fig. 3 shows the classical pictures of the different lithology thin section under the scanning electron microscope.

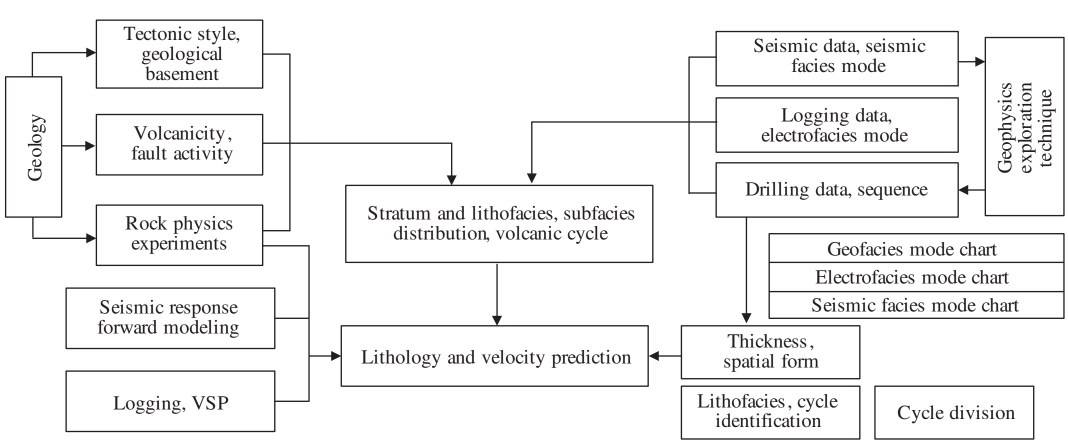

Fig. 2. Technical route to study the characteristics of igneous rocks and the law of the velocity variance.