

High-angle Fracture Prediction Method, Computer Device and Computer-readable Storage Medium

Cross Reference to Related Applications

- 5 This application claims priority from Chinese Application Number 201910001147.5, entitled "Method and Apparatus for Predicting High-angle Fracture", filed on January 02, 2019, the subject matter of which is incorporated herein by reference.

Technical Field

- 10 The invention relates to the technical field of oil and gas exploration, in particular to a high-angle fracture prediction method, a computer device and a computer-readable storage medium.

Background

- 15 At present, sweet spot parameters such as fracture distribution density, fracture direction and the like which are very important for shale gas exploration and development are still not available. Only a point estimation can be performed based on drilling information, and it is impossible to perform a quantitative fracture prediction in the whole region. With the application of wide azimuth seismic data, the study on seismic anisotropy is forwarded, which
20 can effectively solve the problem of quantitative prediction of HTI (Horizontal Transverse Isotropy, which is an anisotropic medium model for describing a set of parallel oriented vertical cracks distributed in isotropic media. It belongs to azimuthal anisotropy, and theseismic wave propagates in this kind of medium with characteristics of velocity changing with directionnot only shown as being changed with a phase angle, but also being changed with an observation
25 azimuth. It is generally believed that azimuthal anisotropy is caused by stress and oriented vertical fractures) medium fractures and plays an important role in the specific exploration and development of shale gas.

- At the present stage, there are many methods for predicting fractures by using wide azimuth seismic data, and the result of prediction of azimuth amplitude variation with offset
30 (AVAz) is used to reflect interface information, but not suitable for prediction of reservoir internal fracture information. P-wave fast and slow velocity anisotropy analysis (VVAz) is based on velocity difference information of wide azimuth seismic processing, belongs to stratum horizon data information, produces a too low resolution, and can only well control the

distribution law of fractures. The method suitable for prediction of reservoir internal fractures is an anisotropic inversion, and the result of fractures prediction in this method reflects the information of fractures within the intervals of reservoir. This method is applicable to the quantitative study of fractures in the intervals of reservoir, but in this method, it is not reasonable to use an isotropic low-frequency model in the process of azimuthal anisotropy inversion fracture prediction, and the source of low-frequency information is limited. It is easy to cause the regularity of the result of fracture prediction to be weak, so that the anisotropic information of azimuth seismic data is suppressed.

10 Summary of the Invention

Embodiments of the present invention provide therein a high-angle fracture prediction method, a computer device and a computer-readable storage medium, in which the information of the anisotropic difference of the fast velocity and slow velocity of P-wave is fused into a low-frequency model to acquire anisotropic information of a formation, so as to predict the required fracture information, and solve the technical problem of the prior art that it is impossible to provide a reasonable low-frequency model in the process of azimuthal anisotropy inversion fracture prediction.

An embodiment of the present invention provides a high-angle fracture prediction method, comprising the following steps of:

20 performing a first azimuthal anisotropy inversion on wide azimuth seismic data of a target region based on a constructed isotropic low-frequency model, to acquire a first anisotropy intensity;

performing P-wave fast and slow velocity anisotropy analysis on the wide azimuth seismic data of the target region, to acquire anisotropy of P-wave fast and slow velocity difference and a fast P-wave velocity direction;

25 fitting the first anisotropy intensity and the anisotropy of P-wave fast and slow velocity difference, to acquire a P-wave fast and slow velocity difference-based anisotropy intensity;

establishing an azimuthal P-wave anisotropic low-frequency model according to the P-wave fast and slow velocity difference-based anisotropy intensity and the fast P-wave velocity direction;

30 performing a second azimuthal anisotropy inversion on the wide azimuth seismic data of the target region based on the azimuthal P-wave anisotropic low-frequency model, to acquire a second anisotropy intensity and a second anisotropy direction; and

analyzing the second anisotropy intensity and the second anisotropy direction, to acquire a

fracture prediction result.

An embodiment of the invention further provides a computer device comprising a memory, a processor and a computer program stored on the memory and executable by the processor, wherein when executing the computer program, the processor implements the

5 following steps of:

performing a first azimuthal anisotropy inversion on the wide azimuth seismic data of a target region based on a constructed isotropic low-frequency model, to acquire a first anisotropy intensity;

10 performing P-wave fast and slow velocity anisotropy analysis on the wide azimuth seismic data of the target region, to acquire anisotropy of P-wave fast and slow velocity difference and a fast P-wave velocity direction;

fitting the first anisotropy intensity and the anisotropy of P-wave fast and slow velocity difference, to acquire a P-wave fast and slow velocity difference-based anisotropy intensity;

15 establishing an azimuthal P-wave anisotropic low-frequency model according to the P-wave fast and slow velocity difference-based anisotropy intensity and the fast P-wave velocity direction;

performing a second azimuthal anisotropy inversion on the wide azimuth seismic data of the target region based on the azimuthal P-wave anisotropic low-frequency model, to acquire a second anisotropy intensity and a second anisotropy direction; and

20 analyzing the second anisotropy intensity and the second anisotropy direction, to acquire a fracture prediction result.

An embodiment of the present invention further provides a computer-readable storage medium which stores a computer program for implementing the following steps of:

25 performing a first azimuthal anisotropy inversion on wide azimuth seismic data of a target region based on a constructed isotropic low-frequency model, to acquire a first anisotropy intensity;

performing P-wave fast and slow velocity anisotropy analysis on the wide azimuth seismic data of the target region, to acquire anisotropy of P-wave fast and slow velocity difference and a fast P-wave velocity direction;

30 fitting the first anisotropy intensity and the anisotropy of P-wave fast and slow velocity difference, to acquire a P-wave fast and slow velocity difference-based anisotropy intensity;

establishing an azimuthal P-wave anisotropic low-frequency model according to the P-wave fast and slow velocity difference-based anisotropy intensity and the fast P-wave velocity direction;

performing a second azimuthal anisotropy inversion on the wide azimuth seismic data of the target region based on the azimuthal P-wave anisotropic low-frequency model, to acquire a second anisotropy intensity and a second anisotropy direction; and

analyzing the second anisotropy intensity and the second anisotropy direction, to acquire a fracture prediction result.

In the embodiments of the present invention, a first azimuthal anisotropy inversion is performed on wide azimuth seismic data of a target region based on a constructed isotropic low-frequency model, to acquire a first anisotropy intensity; then P-wave fast and slow velocity anisotropy analysis is performed on the wide azimuth seismic data of the target region, to acquire anisotropy of P-wave fast and slow velocity difference and a fast P-wave velocity direction, the first anisotropy intensity is fitted with the anisotropy of P-wave fast and slow velocity difference, to acquire a P-wave fast and slow velocity difference-based anisotropy intensity; an azimuthal P-wave anisotropic low-frequency model is established according to the P-wave fast and slow velocity difference-based anisotropy intensity and the fast P-wave velocity direction, to achieve that results of anisotropy analysis of P-wave velocity difference can be fused into the establishment process of the azimuth anisotropy low-frequency, thereby solving the technical problem of the prior art that it is impossible to provide a reasonable low-frequency model in the process of azimuthal anisotropy inversion fracture prediction. Then a second azimuthal anisotropy inversion is performed on the wide azimuth seismic data of the target region based on the azimuthal P-wave anisotropic low-frequency model, to acquire a second anisotropy intensity and a second anisotropy direction; and the second anisotropy intensity and the second anisotropy direction are analyzed, to acquire a fracture prediction result and realize the quantitative prediction of the fractures, which not only has the overall rationality of fracture distribution, but also ensures the accuracy of the fracture prediction.

Brief Description of the Drawings

In order to more clearly explain the embodiments of the invention or the technical solution in the prior art, drawings that need to be used in the description of embodiments or the prior art will be simply introduced below, obviously the drawings in the following description are merely some examples of the invention, for persons ordinarily skilled in the art, it is also possible to acquire other drawings according to these drawings without making creative efforts.

FIG. 1 is a flowchart of a high-angle fracture prediction method according to an embodiment of the present invention.

FIG. 2 is a process flowchart of a specific high-angle fracture prediction method according

to an embodiment of the present invention.

FIG. 3 is a schematic diagram of an optimized logging interpretation result according to an embodiment of the present invention.

FIG. 4 is a schematic diagram of a seismic petrophysical interpretation template for a fracture-type reservoir according to an embodiment of the present invention.

FIG. 5 is a schematic diagram of an isotropic low-frequency model profile according to an embodiment of the present invention.

FIG. 6 is a schematic diagram of a fast P-wave velocity profile (indicated by a) and a slow P-wave velocity profile (indicated by b) according to an embodiment of the present invention.

FIG. 7 is a schematic diagram of a fracture azimuthal angle from a fracture azimuthal angle statistical analysis acquired by fast and slow P-wave velocity analysis according to an embodiment of the present invention, which is considered to be perpendicular to an anisotropic direction.

FIG. 8 is a schematic diagram showing a fitting relationship between anisotropy of the P-wave fast and slow velocity difference and a first anisotropy intensity according to an embodiment of the present invention.

FIG. 9 is a schematic diagram of an anisotropy intensity contrast profile according to an embodiment of the present invention (the upper graph a is: an anisotropy (J) profile acquired by fast and slow P-wave velocity analysis; b is an anisotropy intensity (b_{1v}) profile based on the P-wave fast and slow velocity difference, that is acquired after fitting J to the first anisotropy intensity (b_1) and after correction).

FIG. 10 is a schematic diagram of an azimuthal anisotropic low-frequency model according to an embodiment of the present invention.

FIG. 11 is an anisotropy intensity profile according to an embodiment of the present invention (the upper graph is: the first anisotropy intensity (b_1) acquired by the first azimuthal anisotropy inversion; the middle graph is: the anisotropy intensity (b_{1v}) after the fast and slow P-wave velocity analysis and correction; the lower graph is: the second anisotropy intensity (b_{12}) acquired by the second anisotropy inversion).

FIG. 12 is a plan view of a fracture comprehensive analysis according to an embodiment of the present invention (a: the fracture density and direction acquired by the first anisotropy inversion; b: the fracture density and direction acquired after the fast and slow P-wave velocity analysis and correction; c: the fracture density and direction acquired by the second anisotropy inversion).

FIG. 13 is a schematic diagram of fracture azimuthal angle statistical analysis according to an embodiment of the present invention (a: a histogram of fracture azimuthal angle statistical analysis acquired by the first anisotropy inversion; b: a histogram of fracture azimuthal angle statistical analysis acquired by fast and slow P-wave velocity analysis; c: a histogram of fracture azimuthal angle statistical analysis acquired by the second anisotropy inversion).

FIG. 14 is a schematic block diagram of a system configuration of a computer device according to an embodiment of the present invention.

Detailed Description of the Preferred Embodiment

Hereinafter the technical solution in the embodiments of the present invention will be described clearly and integrally in combination with the accompanying drawings in the embodiments of the present invention, and obviously the described embodiments are merely part of the embodiments, rather than all of the embodiments. Based on the embodiments of the present invention, all other embodiments that are acquired by persons skilled in the art without making creative efforts fall within the protection scope of the present invention.

In an embodiment of the present invention, a high-angle fracture prediction method is provided, as shown in FIG. 1, the method comprising:

step 101: performing a first azimuthal anisotropy inversion on wide azimuth seismic data of a target region based on a constructed isotropic low-frequency model, to acquire a first anisotropy intensity;

step 102: performing P-wave fast and slow velocity anisotropy analysis on the wide azimuth seismic data of the target region, to acquire anisotropy of P-wave fast and slow velocity difference and a fast P-wave velocity direction;

step 103: fitting the first anisotropy intensity and the anisotropy of P-wave fast and slow velocity difference, to acquire a P-wave fast and slow velocity difference-based anisotropy intensity;

step 104: establishing an azimuthal P-wave anisotropic low-frequency model according to the P-wave fast and slow velocity difference-based anisotropy intensity and the fast P-wave velocity direction;

step 105: performing a second azimuthal anisotropy inversion on the wide azimuth seismic data of the target region based on the azimuthal P-wave anisotropic low-frequency model, to acquire a second anisotropy intensity and a second anisotropy direction;

step 106: analyzing the second anisotropy intensity and the second anisotropy direction, to acquire a fracture prediction result.

In an embodiment of the present invention, as shown in FIG. 2, the step 101 is implemented specifically as follows:

(1) Acquiring logging data of a target region, including logging P-wave and S-wave curves, a density curve, P-wave and S-wave impedances, a P-wave and S-wave velocity ratio and a rock mineral composition curve, a porosity curve, a water saturation curve and drilling stratification data, as shown in the FIG. 3. Logging evaluation and analysis of a fracture-type reservoir are completed according to the logging data, there servoir fracture will lead to the anisotropy of the formation, so that it is necessary to establish a petrophysical model based on the fracture, and determine the sensitive elastic parameters of the anisotropic reservoir caused by the fracture. This process selects a P-wave and S-wave velocity ratio as the sensitive elastic parameter of this type of reservoir fracture. As shown in FIG.4, with a slight change in fracture porosity, the P-wave and S-wave velocity ratio of the formation features a greater change, wherein, Φ_{frac} denotes a porosity of the fracture, Sw_t denotes a saturation of water, and Φ_t denotes a stratum total porosity.

(2) Acquiring seismic horizon data of the target region, establishing a structural frame model by using the structural interpretation results (mainly the seismic horizon data), and establishing an isotropic low-frequency model based on the logging data, as shown in FIG. 5.

(3) Acquiring wide azimuth seismic data of the target region, and quality of the wide azimuth seismic data is directly related to the subsequent inversion effect, so that it is necessary to evaluate the quality of the wide azimuth seismic data, with the focus on the distribution characteristics of azimuth and offset of the wide azimuth seismic data and the formulation of the most favorable principles of azimuth and offset division. Specifically, the wide azimuth seismic data of the target region is divided and stacked in a manner of dividing the azimuthal angle at first and then dividing the offset, to form multiple partial angle stacked seismic data with different azimuths.

(4) Performing a multi-azimuth pre-stack anisotropy inversion on the multiple partial angle stacked seismic data of different azimuths based on the constructed isotropic low-frequency model, and performing a pre-stack inversion on each azimuth, to acquire the sensitive elastic parameter data (P-wave and S-wave velocity ratio data) of the divided azimuth fracture.

(5) Determining a first anisotropy intensity according to the divided azimuthal P-wave and S-wave velocity ratio.

Herein, the first anisotropy intensity is determined according to the following formula:

$$\log \left(\frac{V_p}{V_s} \right)_1 = b_0 + b_1 \cdot \cos[2(\omega - \phi)] + b_2 \cdot \cos[4(\omega - \phi)];$$

wherein, V_p denotes a P-wave velocity, V_s denotes an S-wave velocity, b_1 denotes a first anisotropy intensity, ω denotes an azimuthal angle of the seismic data, i.e., an azimuthal angle of a work area survey network, ϕ denotes a first anisotropy direction, namely an azimuthal angle of the seismic data, b_0 denotes an isotropic background, b_2 denotes anisotropy of the influence of high-order noise in the first azimuthal anisotropy inversion ,

$\left(\frac{V_p}{V_s} \right)_1$ denotes an P-wave and S-wave velocity ratio acquired after the first azimuthal anisotropy inversion based on isotropic low-frequency models.

In an embodiment of the present invention, as shown in FIG. 2, the step 102 is implemented specifically as follows:

(1) Processing the wide azimuth seismic data of the target region to acquire a fast P-wave velocity, a slow P-wave velocity and a fast P-wave velocity direction, which are P-wave fast and slow velocity profiles as shown by a and b in FIG. 6.

(2) Performing a P-wave anisotropy analysis to acquire anisotropy of P-wave fast and slow velocity difference and the direction of fast P-wave velocity. In terms of fast and slow P-waves, the fast P-wave propagates along the isotropic direction of the formation, and it is generally considered that the direction of fast P-wave propagation corresponds to the direction of fracture growth, and the direction of anisotropy may be perpendicular to the direction of fracture. FIG. 7 is a statistical analysis diagram of the fracture azimuthal angle acquired from fast P-wave velocity direction analysis.

Herein, the anisotropy of the P-wave fast and slow velocity difference is determined according to the following formula:

$$J = \frac{Vp^{NMO}_{fast} - Vp^{NMO}_{slow}}{Vp^{NMO}_{fast}} ;$$

wherein, J denotes anisotropy of the P-wave fast and slow velocity difference, Vp^{NMO}_{fast} denotes a fast P-wave velocity, Vp^{NMO}_{slow} denotes a slow P-wave velocity. It is considered here that the direction of fast P-wave propagation corresponds to the direction of

fracture growth.

(3) Analyzing the anisotropy parameters acquired from the P-wave velocity anisotropy analysis, and analyzing the histogram of fast P-wave velocity in the horizon data, the main azimuthal angle in which anisotropy occurs in the horizon data can be acquired, as shown in FIG. 7, and the determined azimuth is used as an input to establish an anisotropic low-frequency model.

In an embodiment of the present invention, as shown in FIG. 2, the step 103 is implemented specifically as follows.

The result of the first azimuthal anisotropy inversion in the step 101 is compared with the result of the P-wave fast and slow velocity difference anisotropy analysis in the step 102. Firstly, analysis is performed on the result of the first anisotropy inversion and the result of the P-wave fast and slow velocity difference anisotropy analysis that represents fracture intensity. Since the two results are different in the range of values reflecting the fracture intensity, it is necessary to correct the range of the anisotropy (J) of the P-wave fast and slow velocity difference in the result of the P-wave fast and slow velocity difference anisotropy analysis to have the same range of the first anisotropy intensity (b_1) acquired from the first azimuthal anisotropy inversion, and a relationship between the two is acquired by fitting the two using the intersection analysis method, in which the anisotropy (J) of the P-wave fast and slow velocity difference is converted into an anisotropy intensity (b_{1v}) based on the P-wave fast and slow velocity difference having the same range as the first anisotropy intensity (b_1), as shown in FIG. 8. "a" in FIG. 9 shows the anisotropy (J) caused by the fast and slow P-wave velocity difference, and "b" in FIG. 9 is a schematic diagram showing comparison and analysis of the anisotropy intensity (b_{1v}) based on the P-wave fast and slow velocity difference that is formed after the anisotropy caused by the fast and slow P-wave velocity difference is corrected to be within the range of the first anisotropy intensity (b_1).

The fitting formula is as follows:

$$b_{1v} = -0.23 \times J - 0.005.$$

In an embodiment of the present invention, as shown in FIG. 2, the step 104 is implemented specifically as follows:

fusing the anisotropy intensity (b_{1v}) based on the P-wave fast and slow velocity difference and the fast P-wave velocity direction into the constructed isotropic low-frequency models. An azimuthal P-wave anisotropic low-frequency model is established by fitting an approximate

relationship (the following formula) of the anisotropic P-wave and S-wave velocity ratio, as shown in FIG. 10.

Herein, the approximate relationship of the anisotropic low-frequency model of the azimuthal P-wave is shown as follows:

$$\left(\frac{V_p}{V_s}\right)_{01} \approx e^{2b_{1v} \cdot \cos^2(\omega - \phi_v)} \cdot \left(\frac{V_p}{V_s}\right)_0;$$

Wherein, V_p denotes a P-wave velocity, V_s denotes an S-wave velocity, b_{1v} denotes P-wave fast and slow velocity difference-based anisotropy intensity, ω denotes an azimuthal angle of the seismic data, ϕ_v denotes a direction perpendicular to the fast P-wave velocity,

$\left(\frac{V_p}{V_s}\right)_{01}$ denotes the anisotropic low-frequency model of the azimuthal P-wave, and

$\left(\frac{V_p}{V_s}\right)_0$ denotes an isotropic low-frequency model.

In an embodiment of the present invention, the step 105 is implemented specifically as follows:

performing a second azimuthal anisotropy inversion on the wide azimuth seismic data of the target region in accordance with the following formula, based on the azimuthal P-wave anisotropic low-frequency model, to acquire a second anisotropy intensity and a second anisotropy direction:

$$\log\left(\frac{V_p}{V_s}\right)_2 = b_0 + b_{12} \cdot \cos[2(\omega - \phi_2)] + b_{22} \cdot \cos[4(\omega - \phi_2)];$$

wherein, V_p denotes a P-wave velocity, V_s denotes an S-wave velocity, b_0 denotes an isotropic background, b_{12} denotes a second anisotropy intensity, ω denotes an azimuthal angle of the seismic data, ϕ_2 denotes a second anisotropy direction, b_{22} denotes anisotropy

of the influence of high-order noise in the second azimuthal anisotropy inversion; $\left(\frac{V_p}{V_s}\right)_2$ denotes an P-wave and S-wave velocity ratio acquired after the second azimuthal anisotropy

inversion.

In an embodiment of the present invention, the step 106 is implemented specifically as follows:

analyzing the second anisotropy intensity and the second anisotropy direction to acquire a fracture prediction result, wherein the anisotropy intensity reflects the density of the fractures to some extent, and the anisotropy direction is approximately perpendicular to the direction of the fracture in azimuth, so that the fracture density and the fracture direction are acquired.

Hereinafter, the advantage of the method of the present invention will be explained by comparing the data acquired by the first anisotropy inversion with the data acquired by the second anisotropy inversion.

FIG. 11 is an anisotropy intensity profile according to an embodiment of the present invention (the above graph is: the first anisotropy intensity (b_1) acquired by the first azimuthal anisotropy inversion; the middle graph is: the anisotropy intensity (b_{1v}) after the fast and slow P-wave velocity analysis and correction; the lower graph is: the second anisotropy intensity (b_{12}) acquired by the second anisotropy inversion).

FIG. 12 is a plan view of a fracture comprehensive analysis according to an embodiment of the present invention (a: the fracture density and direction acquired by the first anisotropy inversion; b: the fracture density and direction acquired after the fast and slow P-wave velocity analysis and correction; c: the fracture density and direction acquired by the second anisotropy inversion). From FIG. 12, the fracture direction acquired by the first anisotropy inversion is relatively scattered, and the regularity of predicting fracture is not strong; after the anisotropy correction based on the P-wave fast and slow velocity, the acquired fracture direction only reflects the general regularity, but the resolution is low, and the fracture azimuth regularity acquired after the second anisotropy inversion is strong, and the resolution for predicting fractures is improved.

FIG. 13 is a schematic diagram of fracture azimuthal angle statistical analysis according to an embodiment of the present invention (a: a histogram of fracture azimuthal angle statistical analysis acquired by the first anisotropy inversion; b: a histogram of fracture azimuthal angle statistical analysis acquired by fast and slow P-wave velocity analysis; c: a histogram of fracture azimuthal angle statistical analysis acquired by the second anisotropy inversion). From FIG. 13, the fracture direction acquired by the first anisotropy inversion is relatively scattered, after the anisotropy correction based on the P-wave fast and slow velocity, the acquired fracture direction only reflects the general regularity; and the fracture azimuth regularity acquired after

the second anisotropy inversion is strong.

The present invention further provides a computer device, which may be a desktop computer, a tablet computer and a mobile terminal, and etc., and the present embodiment is not limited thereto. In the embodiment, the computer device may complete the implementation of the high-angle fracture prediction method.

FIG. 14 is a schematic block diagram of a system composition of a computer device 500 according to an embodiment of the present invention. As shown in FIG. 14, the computer device 500 may include a processor 100 and a memory 140, wherein the memory 140 is coupled to the processor 100. It is worth noting that this figure is exemplary; other types of structures may also be used in addition to or instead of the structure to implement telecommunications functions or other functions.

In an embodiment, a computer program implementing a high-angle fracture prediction function may be integrated into the processor 100. Wherein the processor 100 may be configured to perform the following controls:

performing a first azimuthal anisotropy inversion on wide azimuth seismic data of a target region based on a constructed isotropic low-frequency model, to acquire a first anisotropy intensity;

performing P-wave fast and slow velocity anisotropy analysis on the wide azimuth seismic data of the target region, to acquire anisotropy of P-wave fast and slow velocity difference and a fast P-wave velocity direction;

fitting the first anisotropy intensity and the anisotropy of P-wave fast and slow velocity difference, to acquire a P-wave fast and slow velocity difference-based anisotropy intensity;

establishing an azimuthal P-wave anisotropic low-frequency model according to the P-wave fast and slow velocity difference-based anisotropy intensity and the fast P-wave velocity direction;

performing a second azimuthal anisotropy inversion on the wide azimuth seismic data of the target region based on the azimuthal P-wave anisotropic low-frequency model, to acquire a second anisotropy intensity and a second anisotropy direction; and

analyzing the second anisotropy intensity and the second anisotropy direction, to acquire a fracture prediction result.

In an embodiment of the present invention, when executing the computer program, the processor implements:

the wide azimuth seismic data of the target region is divided and stacked in a manner of dividing the azimuthal angle at first and then dividing an offset, to form multiple partial angle

stacked seismic data with different azimuths;

performing an azimuth anisotropy inversion on the multiple partial angle stacked seismic data of different azimuths based on the constructed isotropic low-frequency model, to acquire a divided azimuthal P-wave and S-wave velocity ratio; and

- 5 determining the first anisotropy intensity from the divided azimuthal P-wave and S-wave velocity ratio.

In an embodiment of the present invention, when executing the computer program, the processor implements:

- 10 processing the wide azimuth seismic data of the target region, to acquire a fast P-wave velocity, a slow P-wave velocity and a fast P-wave velocity direction; and

determining anisotropy of the P-wave fast and slow velocity difference based on the fast P-wave velocity and the slow P-wave velocity.

In an embodiment of the present invention, when executing the computer program, the processor implements:

- 15 fitting the first anisotropy intensity and the anisotropy of P-wave fast and slow velocity difference in accordance with the following formula, to acquire the P-wave fast and slow velocity difference-based anisotropy intensity:

$$b_{1v} = -0.23 \times J - 0.005;$$

- 20 wherein, b_{1v} denotes P-wave fast and slow velocity difference-based anisotropy intensity; and J denotes anisotropy of the P-wave fast and slow velocity difference.

In an embodiment of the present invention, when executing the computer program, the processor implements:

- 25 establishing the azimuthal P-wave anisotropic low-frequency model in accordance with the following formula, according to the P-wave fast and slow velocity difference-based anisotropy intensity and the fast P-wave velocity direction:

$$\left(\frac{V_p}{V_s} \right)_{01} \approx e^{2b_{1v} \cdot \cos^2(\omega - \phi_v)} \cdot \left(\frac{V_p}{V_s} \right)_0;$$

wherein, V_p denotes a P-wave velocity, V_s denotes an S-wave velocity, b_{1v} denotes P-wave fast and slow velocity difference-based anisotropy intensity, ω denotes an azimuthal angle of the seismic data, ϕ_v denotes a direction perpendicular to the fast P-wave velocity,

$\left(\frac{V_p}{V_s}\right)_{01}$ denotes the anisotropic low-frequency model of the azimuthal P-wave, and

$\left(\frac{V_p}{V_s}\right)_0$ denotes an isotropic low-frequency model.

In another embodiment, the high-angle fracture prediction function may be configured separately from the processor 100, for example, the high-angle fracture prediction function may be configured on a chip connected to the processor 100, and the high-angle fracture prediction function is realized by the control of the processor.

As shown in FIG. 14, the computer device 500 may further comprise an input unit 120, a display 160, and a power supply 170. It is worth noting that the computer device 500 does not either necessarily comprise all of the components shown in FIG. 14; in addition, the computer device 500 may also comprise components not shown in FIG. 14, with reference to the prior art.

Among other things, the processor 100, sometimes referred to as a controller or an operational control, may comprise a microprocessor or other processor apparatuses and/or logic apparatuses, the processor 100 receives inputs and controls operation of the components of the computer device 500.

The input unit 120 provides an input to the processor 100. The input unit 120 is, for example, a key or a touch input apparatus.

The memory 140 may be, for example, one or more of a buffer, a flash memory, a hard drive, a removable medium, a volatile memory, a non-volatile memory, or other suitable apparatuses. A program executing related information may be stored, and the processor 100 may execute the program stored in the memory 140 to implement information storage or processing and the like.

The memory 140 may be a solid state memory such as read only memory (ROM), random access memory (RAM), SIM card, or the like. The memory may also be such a memory that it saves information even when power is off, on which data can be selectively erased and more data is set, and an example of which is sometimes referred to as an EPROM or the like. The memory 140 may also be some other types of apparatuses. The memory 140 includes a buffer memory 141 (sometimes referred to as a buffer). The memory 140 may include an application/function storage unit 142 for storing application programs and function programs or a flow for performing operation of an electronic device by the processor 100.

The memory 140 may also include a data storage unit 143 for storing data, such as contacts, digital data, pictures, sounds, and / or any other data used by the electronic device. A drive program storage unit 144 of the memory 140 may include various drive programs of the electronic device for communication functions and/or for executing other functions of the electronic device, such as a messaging application, an address book application, and the like.

The display 160 is used for displaying objects to be displayed, such as images and text, and the like. The display may be, for example, an LCD display, but is not limited thereto.

The power supply 170 is used to provide power to the computer device 500.

The embodiment of the present invention also provides a computer-readable storage medium which stores a computer program for implementing the any of the high Angle fracture prediction methods.

The computer-readable storage medium may include physical means for storing information which may be digitized and then stored in a medium using electrical, magnetic or optical means. The computer-readable storage medium according to the present embodiment may include an apparatus for storing information in an electric energy manner, e.g., various types of memories such as RAM, ROM, and the like; an apparatus for storing information in an magnetic energy manner, such as a hard disk, a floppy disk, a magnetic tape, a magnetic core memory, a bubble memory, a U disk; an apparatus for storing information in an optical manner, such as a CD or a DVD. Of course, there are other kinds of readable storage media, such as a quantum memory, a graphene memory, and the like.

In summary, the high-angle fracture prediction method, the computer device and the computer-readable storage medium provided in the present invention have the following beneficial effects:

a first azimuthal anisotropy inversion is performed on wide azimuth seismic data of a target region based on a constructed isotropic low-frequency model, to acquire a first anisotropy intensity and a first anisotropy direction; then P-wave fast and slow velocity anisotropy analysis is performed on the wide azimuth seismic data of the target region, to acquire anisotropy of P-wave fast and slow velocity difference and a fast P-wave velocity direction, the first anisotropy intensity is fitted with the anisotropy of P-wave fast and slow velocity difference, to acquire a P-wave fast and slow velocity difference-based anisotropy intensity; an azimuthal P-wave anisotropic low-frequency model is established according to the P-wave fast and slow velocity difference-based anisotropy intensity and the fast P-wave velocity direction, to achieve that results of anisotropy analysis of P-wave velocity difference can be fused into the establishment process of the azimuth anisotropy low-frequency, thereby solving the technical

problem of the prior art that it is impossible to provide a reasonable low-frequency model in the process of azimuthal anisotropy inversion fracture prediction. Then a second azimuthal anisotropy inversion is performed on the wide azimuth seismic data of the target region based on the azimuthal P-wave anisotropic low-frequency model, to acquire a second anisotropy intensity and a second anisotropy direction; and the second anisotropy intensity and the second anisotropy direction are analyzed, to acquire a fracture prediction result and realize the quantitative prediction of the fractures, which not only has the overall rationality of fracture distribution, but also ensures the accuracy of the fracture prediction.

The foregoing is merely preferred embodiments of the present invention and is not intended to limit the present invention, and various modifications and variations can be made to the embodiments of the present invention by those skilled in the art. Any modifications, equivalents, improvements, etc. made within the spirit and principle of the present invention are intended to be included within the protection scope of the present invention.

Claims

1. A high-angle fracture prediction method applied in oil and gas exploration and implemented by a computer device comprising an input unit, a processor and a memory, the method comprising the following steps of:

performing, by the processor, a first azimuthal anisotropy inversion on wide azimuth seismic data of a target region based on a constructed isotropic low-frequency model, to acquire a first anisotropy intensity;

performing, by the processor, P-wave fast and slow velocity anisotropy analysis on the wide azimuth seismic data of the target region, to acquire anisotropy of P-wave fast and slow velocity difference and a fast P-wave velocity direction;

fitting, by the processor, the first anisotropy intensity and the anisotropy of P-wave fast and slow velocity difference, to acquire a P-wave fast and slow velocity difference-based anisotropy intensity;

establishing, by the processor, an azimuthal P-wave anisotropic low-frequency model according to the P-wave fast and slow velocity difference-based anisotropy intensity and the fast P-wave velocity direction;

performing, by the processor, a second azimuthal anisotropy inversion on the wide azimuth seismic data of the target region based on the azimuthal P-wave anisotropic low-frequency model, to acquire a second anisotropy intensity and a second anisotropy direction; and

analyzing, by the processor, the second anisotropy intensity and the second anisotropy direction, to acquire a fracture prediction result;

wherein fitting, by the processor, the first anisotropy intensity and the anisotropy of P-wave fast and slow velocity difference in accordance with the following formula, to acquire the P-wave fast and slow velocity difference-based anisotropy intensity:

$$b_{1v} = -0.23 \times J - 0.005;$$

wherein, b_{1v} denotes P-wave fast and slow velocity difference-based anisotropy intensity; and J denotes anisotropy of the P-wave fast and slow velocity difference;

wherein establishing, by the processor, the azimuthal P-wave anisotropic low-frequency model in accordance with the following formula, according to the P-wave fast and slow velocity difference-based anisotropy intensity and the fast P-wave velocity direction:

$$\left(\frac{V_p}{V_s} \right)_{01} \approx e^{2b_{1v} \cdot \cos^2(\omega - \phi_v)} \cdot \left(\frac{V_p}{V_s} \right)_0;$$

wherein, V_p denotes a P-wave velocity, V_s denotes an S-wave velocity, b_{lv} denotes P-wave fast and slow velocity difference-based anisotropy intensity, ω denotes an azimuthal angle of the seismic data, ϕ_v denotes a direction perpendicular to the fast P-wave velocity,

$$\left(\frac{V_p}{V_s} \right)_{01}$$

denotes the anisotropic low-frequency model of the azimuthal P-wave, and

$$\left(\frac{V_p}{V_s} \right)_0$$

5 denotes an isotropic low-frequency model.

2. The high-angle fracture prediction method according to claim 1, wherein performing, by the processor, a first azimuthal anisotropy inversion on wide azimuth seismic data of a target region based on a constructed isotropic low-frequency model, to acquire a first anisotropy intensity comprises the following steps of:

10 the wide azimuth seismic data of the target region is divided and stacked in a manner of dividing the azimuthal angle at first and then dividing an offset, to form multiple partial angle stacked seismic data with different azimuths;

performing an azimuth anisotropy inversion on the multiple partial angle stacked seismic data of different azimuths based on the constructed isotropic low-frequency model, to acquire a
15 divided azimuthal P-wave and S-wave velocity ratio; and

determining the first anisotropy intensity according to the divided azimuthal P-wave and S-wave velocity ratio.

3. The high-angle fracture prediction method according to claim 1, wherein performing, by the processor, P-wave fast and slow velocity anisotropy analysis on the wide azimuth seismic
20 data of the target region, to acquire anisotropy of P-wave fast and slow velocity difference and a fast P-wave velocity direction comprises the following steps of:

processing the wide azimuth seismic data of the target region, to acquire a fast P-wave velocity, a slow P-wave velocity and a fast P-wave velocity direction; and

determining anisotropy of the P-wave fast and slow velocity difference based on the fast P-
25 wave velocity and the slow P-wave velocity.

4. A computer device applied in oil and gas exploration, comprising a memory, a processor, an input unit, and a computer program stored on the memory and executable by the processor, wherein when executing the computer program, the processor implements the following steps of:

performing a first azimuthal anisotropy inversion on the wide azimuth seismic data of a

target region based on a constructed isotropic low-frequency model, to acquire a first anisotropy intensity;

performing P-wave fast and slow velocity anisotropy analysis on the wide azimuth seismic data of the target region, to acquire anisotropy of P-wave fast and slow velocity difference and a fast P-wave velocity direction;

fitting the first anisotropy intensity and the anisotropy of P-wave fast and slow velocity difference, to acquire a P-wave fast and slow velocity difference-based anisotropy intensity;

establishing an azimuthal P-wave anisotropic low-frequency model according to the P-wave fast and slow velocity difference-based anisotropy intensity and the fast P-wave velocity direction;

performing a second azimuthal anisotropy inversion on the wide azimuth seismic data of the target region based on the azimuthal P-wave anisotropic low-frequency model, to acquire a second anisotropy intensity and a second anisotropy direction; and

analyzing the second anisotropy intensity and the second anisotropy direction, to acquire a fracture prediction result;

wherein fitting, by the processor, the first anisotropy intensity and the anisotropy of P-wave fast and slow velocity difference in accordance with the following formula, to acquire the P-wave fast and slow velocity difference-based anisotropy intensity:

$$b_{1v} = -0.23 \times J - 0.005;$$

wherein, b_{1v} denotes P-wave fast and slow velocity difference-based anisotropy intensity; and J denotes anisotropy of the P-wave fast and slow velocity difference; and

wherein establishing, by the processor the azimuthal P-wave anisotropic low-frequency model in accordance with the following formula, according to the P-wave fast and slow velocity difference-based anisotropy intensity and the fast P-wave velocity direction:

$$\left(\frac{V_p}{V_s} \right)_{01} \approx e^{2b_{1v} \cdot \cos^2(\omega - \phi_v)} \cdot \left(\frac{V_p}{V_s} \right)_0;$$

wherein, V_p denotes a P-wave velocity, V_s denotes an S-wave velocity, b_{1v} denotes P-wave fast and slow velocity difference-based anisotropy intensity, ω denotes an azimuthal angle of the seismic data, ϕ_v denotes a direction perpendicular to the fast P-wave velocity,

$$\left(\frac{V_p}{V_s} \right)_{01}$$

denotes the anisotropic low-frequency model of the azimuthal P-wave, and

$$\left(\frac{V_p}{V_s} \right)_0$$

denotes an isotropic low-frequency model.

5. The computer device according to claim 4, wherein when executing the computer program, the processor implements the following steps of:

5 the wide azimuth seismic data of the target region is divided and stacked in a manner of dividing the azimuthal angle at first and then dividing an offset, to form multiple partial angle stacked seismic data with different azimuths;

performing an azimuth anisotropy inversion on the multiple partial angle stacked seismic data of different azimuths based on the constructed isotropic low-frequency model, to acquire a divided azimuthal P-wave and S-wave velocity ratio; and

10 determining the first anisotropy intensity from the divided azimuthal P-wave and S-wave velocity ratio.

6. The computer device according to claim 4, wherein when executing the computer program, the processor implements the following steps of:

15 processing the wide azimuth seismic data of the target region, to acquire a fast P-wave velocity, a slow P-wave velocity and a fast P-wave velocity direction; and

determining anisotropy of the P-wave fast and slow velocity difference based on the fast P-wave velocity and the slow P-wave velocity.

7. A computer-readable storage medium applied in oil and gas exploration, wherein the computer-readable storage medium, a processor and an input unit are comprised in a computer device, the computer-readable storage medium stores a computer program for implementing the following steps of:

20 performing, by the processor, a first azimuthal anisotropy inversion on wide azimuth seismic data of a target region based on a constructed isotropic low-frequency model, to acquire a first anisotropy intensity and;

25 performing, by the processor, P-wave fast and slow velocity anisotropy analysis on the wide azimuth seismic data of the target region, to acquire anisotropy of P-wave fast and slow velocity difference and a fast P-wave velocity direction;

30 fitting, by the processor, the first anisotropy intensity and the anisotropy of P-wave fast and slow velocity difference, to acquire a P-wave fast and slow velocity difference-based anisotropy

intensity;

establishing, by the processor, an azimuthal P-wave anisotropic low-frequency model according to the P-wave fast and slow velocity difference-based anisotropy intensity and the fast P-wave velocity direction;

5 performing, by the processor, a second azimuthal anisotropy inversion on the wide azimuth seismic data of the target region based on the azimuthal P-wave anisotropic low-frequency model, to acquire a second anisotropy intensity and a second anisotropy direction; and

analyzing, by the processor, the second anisotropy intensity and the second anisotropy direction, to acquire a fracture prediction result;

10 wherein fitting, by the processor, the first anisotropy intensity and the anisotropy of P-wave fast and slow velocity difference in accordance with the following formula, to acquire the P-wave fast and slow velocity difference-based anisotropy intensity:

$$b_{1v} = -0.23 \times J - 0.005;$$

wherein, b_{1v} denotes P-wave fast and slow velocity difference-based anisotropy intensity;

15 and J denotes anisotropy of the P-wave fast and slow velocity difference; and

wherein establishing, by the processor, the azimuthal P-wave anisotropic low-frequency model in accordance with the following formula, according to the P-wave fast and slow velocity difference-based anisotropy intensity and the fast P-wave velocity direction:

$$\left(\frac{V_p}{V_s} \right)_{01} \approx e^{2b_{1v} \cdot \cos^2(\omega - \phi_v)} \cdot \left(\frac{V_p}{V_s} \right)_0;$$

20 wherein, V_p denotes a P-wave velocity, V_s denotes an S-wave velocity, b_{1v} denotes P-wave fast and slow velocity difference-based anisotropy intensity, ω denotes an azimuthal angle of the seismic data, ϕ_v denotes a direction perpendicular to the fast P-wave velocity,

$$\left(\frac{V_p}{V_s} \right)_{01}$$

denotes the anisotropic low-frequency model of the azimuthal P-wave, and

$$\left(\frac{V_p}{V_s} \right)_0$$

denotes an isotropic low-frequency model.

25 8. The computer-readable storage medium according to claim 7, wherein the computer program for implementing the following steps of:

the wide azimuth seismic data of the target region is divided and stacked in a manner of dividing the azimuthal angle at first and then dividing an offset, to form multiple partial angle stacked seismic data with different azimuths;

5 performing an azimuth anisotropy inversion on the multiple partial angle stacked seismic data of different azimuths based on the constructed isotropic low-frequency model, to acquire a divided azimuthal P-wave and S-wave velocity ratio; and

determining the first anisotropy intensity according to the divided azimuthal P-wave and S-wave velocity ratio.

10 9. The computer-readable storage medium according to claim 7, wherein the computer program for implementing the following steps of:

processing the wide azimuth seismic data of the target region, to acquire a fast P-wave velocity, a slow P-wave velocity and a fast P-wave velocity direction; and

determining anisotropy of the P-wave fast and slow velocity difference based on the fast P-wave velocity and the slow P-wave velocity.