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Application and Development of Full Waveform Inversion of Seismic Exploration

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Abstract: Firstly, for the 1980s developed full waveform inversion and its application in the development of exploration geophysics are analyzed; secondly, the face of quantitative and refinement requirements of seismic exploration, seismic exploration proposed full waveform trans research ideas to play with other aspects of data processing or process technology combined, and the prospect of the development trend of full waveform inversion; finally, discusses the numerical simulation of full waveform inversion of seismic wave field inversion initial velocity model to obtain the objective function Select the form, the key issues to enable optimization algorithm and anisotropic media applications, and summarized by full waveform inversion Laplace domain inversion to obtain initial velocity model, combined with ray tracing and full parallel computing is to the wave equation method to simulate the great advantage of the seismic wave field, and the flexibility to choose the form of the inversion objective function and optimization algorithm to update the velocity model parameters to speed up the process of practical full waveform inversion method.
Keywords: Full waveform inversion; numerical simulation; initial velocity model; inversion objective function; anisotropy.

INTRODUCTION

Mr. Zhao nine chapters' famous geophysicist geophysics has described as "the poor blue sky under their lives, two vast are not seen." Geophysical inverse problem is the abnormal distribution of the Earth's interior to determine the mode of occurrence of geological bodies (shape, occurrence, spatial position) and physical parameters (flexibility, speed, density, magnetism, electricity, etc.) by observing geophysical process. Over the past decades, the inversion technique in the field of physics of Earth has been widely used. Today, geophysical inversion, seismic inversion has become especially oilfield exploration and development of conventional techniques is becoming Oilfield refinement, quantitative explanation of the core technology [1].

With the continuous development of seismic exploration, geological conditions they face more complex. The surface often encounter the desert, Gobi, mountains and other landforms, shallow absorption decay desert area is very serious, in addition to the serious subject exploration of deep and shallow surface conditions outside, but also faced with seismic resolution and low angle insufficient information problem. In view of this, to improve the inversion accuracy and stability, achieve the quantitative description of elastic parameters become an urgent requirement to carry out geophysical work.

In recent years, the use of full waveform inversion kinematic and dynamic properties of seismic waves, and taps its potential in determining the mode of occurrence and quantitative description of underground subsurface physical parameters area. In addition, since the flexibility to implement full waveform inversion domain selection, make it in the numerical simulation of seismic wave field inversion initial velocity model to obtain objective functional form selection; optimization algorithm is enabled, as well as aspects of the application of anisotropic media we have made considerable progress. With the development of computer information technology, full waveform inversion technique in the exploration process, especially having good effect in the marine data, combined with the discovery of combustible ice, providing a wider application of full waveform inversion Space [2-4].

FULL WAVEFORM INVERSION OF SEISMIC EXPLORATION APPLICATION

Application of full waveform inversion

Under ideal observing system, using seismic wave field of information retrieval directly strike the Earth media elasticity parameters, its retrieval accuracy can be achieved Fresnel magnitude; and full waveform inversion (Full Waveform Inversion) the direct use of amplitude of travel time and phase seismic wave field sports Science and kinetic parameters, the retrieval accuracy can be achieved wavelength order to obtain a high accuracy and resolution of the velocity model is to

improve the seismic velocity model, offset advanced means of imaging precision.

Tarantola, who in the 1980s proposed the theory of generalized least squares time domain full waveform inversion method, a profound impact on the development of multi-dimensional seismic inversion theory. The late 1980s and early 1990s Pratt, who will be full waveform inversion theory is extended to the frequency domain, forming a frequency domain full waveform inversion (i. e waveform tomography), which greatly improved the inversion computational efficiency, while also facing the initial velocity model inversion due to lack of precision or limited bandwidth of seismic data inversion caused local minimum challenge.

In the 21st century, Shin *et al.*, use of damped wave field inversion low-frequency component of the zero model as an initial model frequency domain waveform inversion (i. e Laplace domain full waveform inversion method); Pratt will be entirely different domain inversion waveform inversion combine theoretical and applied research in the 21st century full waveform inversion to open a new chapter. Application of full waveform inversion Most marine seismic data: for example Pecher I A non-linear full waveform inversion technique should Peru for offshore a bottom simulating reflector (BSR); Song Haibin successfully used in Japan and other East Nankai Trough double bottom simulating reflector velocity structure inversion. Huo Yuanyuan full waveform inversion methods such as the use of genetic algorithms, inversion layer of high-resolution seafloor reflection rate structure, clearly identified the speed reversal characteristics of the seabed of the reflective layer, and explain the seabed beneath the reflective layer containing free gas sheet. In addition to the seafloor reflection layer, full waveform inversion is another hotspot Application of Norwegian North Sea Valhall field. In the Valhall field, there is a cloud of gas and multiples of such imaging precision drop, but the application of full waveform inversion can provide high-resolution velocity model, thus contributing to a more effective and safe drilling operations and the corresponding seismic data Explanation. Ma and other data to 2D streamer seabed (OBC) performed an imaging-oriented full waveform inversion (IGFWI), in the absence of added data structure constraints, the first low-frequency component of the refractive update the model data, then use the reflection data inversion high frequency detail, get a good inversion effect [5].

Full waveform inversion and full-wave shift of the method of combining

Previous application shows full waveform inversion theory also has drawbacks: the inversion process in the presence of a large number of local minima easily lead to the inversion results cannot converge to the global minimum. In view of this, the future should be considered: (1) obtain a better initial velocity inversion model; (2) in the initial velocity model only poor case, the combined effect of the source or detector like it. His method of reducing the number of local extrema; (3) The poor in the initial velocity, reducing the number of local minima under limited circumstances, to enable genetic algorithms, simulated annealing and other intelligent inversion methods or develop new intelligent inversion algorithm .

In practical theory full waveform inversion process, it can be found in full waveform inversion of the data, especially as a number of special noise-sensitive waves, surface waves and other noise rule. Therefore, the data for the FWI's stack during pretreatment is necessary to maximize the suppression of random noise, without destroying the valid signal. Marine seismic data also need multiple suppression of the free surface, land seismic data is spread surface facing surface statics problem. For example, data processing aspects of the source can be superimposed multiple attenuation, crosstalk and noise caused by a combination of illusion, the full waveform inversion, and the generated super gun, reduce the cost of computing. Therefore, the future is likely to be full waveform inversion and prestack denoising, multiple suppression, statics, etc. pretreatment process of combining.

The end result of seismic data inversion for lithology, physical property and oil explanation, such as subsurface imaging result can be obtained reflection coefficient, provide conditions for lithology, physical property, oil resistance and good interpretation of the reservoir. Obviously, the core of full waveform inversion of seismic wave propagation process, the use of discrete grid points after the incident field estimated total underground velocity structure. Accordingly, the core of the wave field migration of underground reflection coefficient, reflection coefficient is calculated utilizing underground grid points than the incident field uplink and downlink of the incident wave field. Therefore, from the point of view of seismic data interpretation, full waveform inversion combined with full-wave shift would be the best solution, but also the future even full waveform inversion is the development trend of seismic imaging.

RESEARCH AND DEVELOPMENT OF FULL WAVEFORM INVERSION ANALYSIS

Seismic wave field numerical simulation

At present, the numerical simulation of seismic wave field into a geometric ray method and wave equation. Among them, the geometric ray method (i. e, the ray tracing method) is from the point of view of seismic wave field kinematic considerations, kinetic information of seismic wave field is not considered, therefore, the calculation speed is faster than the wave equation. But in the practical application of seismic exploration, wave equation but it has always played a more important role.

Wave equation including the finite element method, finite difference method, finite volume method, pseudo-spectral method and the spectral element method, these methods has advantages and disadvantages. FEM realistic simulation for complex formation form, but its memory footprint and a large amount of computation, ocean exploration is not suitable for a high degree, often set different boundary conditions. Today the most commonly used finite difference method although there are advantages in computing speed and memory footprint, but also due to the discrete produce undesirable frequency grid

Scattered, thereby reducing the numerical simulation of the resolution, but cannot borrow indefinitely to improve the accuracy of finite difference scheme to eliminate grid dispersion, for which Yang and other top-hui put forward after the finite difference calculation in 1997 for solving wave equation and smoothing treatment and anti-diffusion treatment to suppress grid dispersion. Perspective on the discrete method, finite volume method is intermediate finite element method and finite difference method, both seeking value grid points, and assumed value distribution between grid points. Spectral element within discrete grid rule is the use of pseudo-spectral method, while the overall use of finite element method, can be viewed as a special kind of Finite Element Method.

Get initial velocity inversion model

No matter which domain inversion, inversion are in the residual wave field observations and theoretical wave field minimization purposes, which observed wave field information can be obtained by the detector, updated theory of wave field is required persons to initialization. With the refinement of seismic exploration, how to get good initial velocity model increasingly underground velocity structure inversion is more important. Current methods given initial velocity model number, Chen Jin and other summary there are three categories: (1) artificially given a uniform background velocity field as the initial velocity model full waveform inversion; (2) in accordance with the existing gravity and magnetic exploration area electric shock and acoustic logging data speed information obtained through interpolation an initial velocity model; (3) the use of other methods of seismic and geological data analysis to obtain the initial velocity model, but the seismic data acquisition for the low-frequency long-wavelength structure reconstruction short weight.

Laplace domain full waveform inversion sensitivity to low-frequency component seismic data deletion lower than the frequency domain, so even given a simple initial velocity model, Laplace domain full waveform inversion can be obtained long-wavelength part of the model, preferably It addresses the class 3 methods to obtain initial velocity model deficiencies. Chung et Laplace domain inversion will be extended to an elastic medium, the use of the Laplace exponent exponential decay constant of the shot records to be modified in order to achieve zero-frequency domain Laplace updated components to take advantage of observations wave field data to obtain a long wavelength velocity model.

The objective function in the form of choice

Actual seismic data for seismic inversion always contains noise, since Tarantola made full waveform inversion method for a long time, these are assumed to be Gaussian noise, and therefore the choice of the objective function, and essentially they are the wave field observations and theoretical wave field residual L2 norm. However, the noise data is not necessarily Gaussian distribution, the study found, the inversion data is not subject to Gaussian distribution, even in the presence of outliers, L1 norm form inversion results are also more stable, the data is also less sensitive to noise, if using frequency-domain L2 Functional still want to get a stable and reliable inversion results, increase the frequency of the sampling interval in order to increase data redundancy, to pay the cost of inverse calculation efficiency is a necessary condition. Functional stronger than the anti-L1 L2 functionals noise, but the presence of the wave field is close to zero residual instability, and therefore,

Functional use between L1 and L2 Functional can be mixed automatically switch the L1 / L2 norm regarded as a more flexible option, only enhanced noise resistance and avoid the L1 wave field residues the difference is close to zero instability. However, we first need to determine the residual wave field determination threshold for automatic switching between L1 and L2, and this requires complicated process of trial and error. In addition based on various forms Norm select the target function, but also based on different types of functions to select the target function, as can the waveform amplitude and phase separation of the objective function of the natural logarithm, exponential objective function, integral objective functions. Therefore, the objective function in the form of selection will be the future full waveform inversion is an important issue.

Optimization algorithm enabled

Optimization process of the objective function for the velocity model iterative update process optimization algorithm selection and model iterative updating efficiency is closely related to the routine use is to determine the search, gradient optimization of the steepest descent method directly use the objective function gradient update the model parameters, it is not sensitive to the initial model, but with the increase in the number of iterations, the convergence is slow. Suitable for solving the problem of small scale Newton's method to update the model parameters by calculating the Hessian matrix, but a large amount of

calculation, in order to save computing time Hessian matrix can be used BFGS method or DFP approximate Hessian matrix, that is quasi-Newton method. With the fine, the massive amount of data exploration inversion is inevitable, resolve computing and data storage problem is particularly urgent, improved BFGS projection method to update the Hessian matrix can reduce the amount of computation and memory usage, speed up the convergence, but its single iteration costs are still relatively high. If you avoid the use of conjugate gradient repeat the search method to calculate Hessian matrix, which can improve the convergence speed. But for large-scale problems in the nearly empty high-dimensional space, the formula to determine the optimization search very difficult, intelligent heuristic optimization algorithms such as simulated annealing Algorithm, genetic algorithms and other large-scale high-dimensional search possible. At the same time, intelligent heuristic search has brought massive computing, parallel computing (GPU) can accomplish a great deal, a new super-intelligent algorithm design will be one of the future research directions.

Application of anisotropic media

Full waveform inversion is extremely suitable for wide-azimuth geometry, its imaging resolution and accuracy for speed in anisotropic media on the horizontal and vertical directions are extremely sensitive to differences. Whether acoustic or anisotropic media elastic anisotropy medium, due to the coupling between the parameters, the resolution of full waveform inversion parameter lower than the isotropic medium. Shale is a typical anisotropic media, oil and gas reservoir cap good, if not considered in the oil and gas exploration in its anisotropy Sex, the consequences would be disastrous. In addition, the anisotropy is reliable quantitative AVO analysis of key factors. Therefore, the application of full waveform inversion in anisotropic media dilemma is mainly from the anisotropic parameters.

In fact, for the parameters of anisotropic media, Alkhalifah *et al* have confirmed transverse anisotropic (VTI) media P wave reflection time difference can be used normal moveout velocity and anisotropy parameters parameterized expression. In addition, Gholami put forward a hierarchical screening strategy parameters inversion VTI media. Plessix, also discussed lateral full waveform inversion in anisotropic media parametric confirmed normal moveout velocity and anisotropy parameters is the most critical parameter back, and narrow-azimuth streamer data from the North Sea through the whole waveform inversion results show that elliptical full waveform inversion and the isotropic medium model stretched full waveform inversion difference is very small, although trade-off between speed inhomogeneity and anisotropy, but the initial velocity inversion model consider shear wave velocity ratio increases full waveform inversion effect.

In addition to focus on the anisotropy parameters of, Lee put forward the use of the elastic coupling method and frequency-domain waveform inversion method based on finite difference method unit in VTI media Jeong, etc. The back-propagation algorithm is applied to the anti-technology anisotropic overthrust model synthetic seismic data, well inversion effect. Anisotropic inversion cannot be separated from the data using the large offsets, and for large shift away from full waveform inversion of data, many low-value spectrum data, the objective function converge to the global minimum solution is very difficult, Kim put forward to reduce the number of local minima and improve the convergence of the inversion to remove the minimum value of these spectrum through filtering techniques [6].

Seismic wave propagation in anisotropic media will bring internal absorption and multiple scattering, ie attenuation effect. Therefore, the practical study full waveform inversion of anisotropic media, but also cannot avoid formation of absorbing and multiple attenuation. Suppose attenuation and multiple attenuation is additive, Q factor can be divided into Q (s multiple attenuation) and Qd (attenuation), the Q-factor model to estimate anisotropic medium becomes full waveform inversion key technology. Yang put forward on the ground vertically incident seismic data and zero-offset vertical seismic profile (VSP) data from 1D viscoelastic waveform inversion at the same time to give Q-factor model, and they used this method a practical Nanyang Oilfield seismic lines and zero-offset seismic data inversion and achieved good results. At low SNR, no vertical seismic profile data and other conditions, based on matched filtering Q estimation methods, and depending on the center frequency of the common image gather to estimate the changes associated with the frequency domain Q tomography inversion method of attenuation frequency, provides the possibility to estimate the Q-factor model. In short, will expand to full waveform inversion in anisotropic media have great significance, therefore, full waveform inversion for acoustic anisotropic media, anisotropic elastic media, and even the viscoelastic anisotropic media will be the next must face [7].

EPILOGUE

In this paper, application and development of full waveform inversion conduct a summary review of analysis and proposed future development envisaged; discusses the full waveform inversion several key issues, and research on these key issues will greatly facilitate the full promotion and application of waveform inversion, seismic exploration "blind attack deep to find" provides more effective theory and tools [8-9].

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