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基于单程波真振幅分步傅里叶叠前深度偏移方法

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摘 要: 这里将单程波真振幅方程与分步傅里叶算子 (SSF) 相结合, 同时还结合了保幅算法和分步傅里叶算法的优点, 因此该方法具有计算量小, 占内存少, 能处理横向变化的速度等优点。并且克服了傅里叶有限差分方法偏移后的振幅都有很大的偏差的不足。与目前广泛应用的常规的分步有限差分叠前深度偏移相比, 具有成像精度高, 保持地震波动力学特征等优点。在 Mam-ousi 模型上成功地进行了真振幅分步傅里叠前深度偏移处理, 取得了理想的成像效果。

关键词: 单程波动方程; 真振幅; 分步傅里叶算子; 叠前深度偏移
中图分类号: P 631.4 文献标识码: A

0 前言

为了得到较好的成像效果, 人们致力于研究基于波场延拓理论的波动方程叠前深度偏移算法。根据采用的波场延拓算子的不同, 近年来研制出的波动方程叠前深度偏移算法有多种: 运用波数 ~ 频率域的相移法; 相移加插值 PSPF^[1]算法; 分步傅氏 SSF 算法^[2]; 频率 ~ 空间域的有限差分 FD 算法等^[3]。在成像过程中, 相移法和有限差分算法各有优缺点。分步傅立叶偏移方法在处理速度横向变化的能力与计算效率等方面, 较之“相移加插值”方法明显存在优势。该方法的地震成像没有倾角限制, 但对复杂地质体 (如超覆、逆掩断层、盐丘等) 成像, 其内部速度场横向变化非常剧烈, 成像的误差非常大。严格地说, 相移法只适用于垂向速度变化, 不允许速度的横向变化。由于分步傅立叶方法没有考虑速度场二阶以上的扰动, 因此, 它很难使复杂地质体正确成像。有限差分算法能够保持地震波的动力学特征, 允许速度的任意变化, 但存在偏移角度的限制。那么, 如何才能有一种高计算效率, 且成像精度高的偏移算法呢?

最近几年来, 人们都是在原有方法的基础上, 在提高计算效率和保幅方面做进一步研究。作者

在本文依赖传统的 SSF 偏移算子高计算效率的优势, 提出了基于单程波方程的真振幅分步傅里叶偏移算法, 这样既提高了计算效率, 又解决了 SSF 算子在强横向介质中不适应的问题, 并通过 Mam-ousi 模型试算来验证了此算法。

1 真振幅分步傅里叶偏移原理

1.1 单程波方程

张关泉^[4]证明了光滑不均匀介质中, 全声波方程近似为

$$[(\Lambda + \frac{\partial}{\partial z})(\Lambda - \frac{\partial}{\partial z}) + \frac{v'}{v}(I + H)\Lambda] \cdot P(t, x, y, z) = 0 \tag{1}$$

其中 $P(t, x, y, z)$ 为波场值; v 为介质速度; $v' = \frac{\partial v}{\partial z}$; I 是单位算子, $\Lambda = (\frac{1}{c} \frac{\partial^2}{\partial t^2} - \frac{\partial^2}{\partial x^2} - \frac{\partial^2}{\partial y^2})^{\frac{1}{2}}$, 称为拟微分算子; H 也是拟微分算子, 满足方程 $[\frac{\partial}{\partial t^2} - (v \frac{\partial}{\partial x})^2]H = (v \frac{\partial}{\partial x})^2 + (v \frac{\partial}{\partial y})^2$ 。

并由此提出了下面的单程波分解方程:

$$\begin{cases} (\frac{\partial}{\partial z} + \Lambda)D(t, x, y, z) + \frac{v'}{2v}(I + H)D = 0 \\ (\frac{\partial}{\partial z} - \Lambda)U(t, x, y, z) + \frac{v'}{2v}(I + H)U = 0 \end{cases} \tag{2}$$

式(2)中 $U = \frac{1}{2}(\frac{\partial}{\partial z} + \Lambda)P(t, x, y, z)$ 和 $D = \frac{1}{2}(\frac{\partial}{\partial z} - \Lambda)P(t, x, y, z)$, 分别代表上行波场和下行波场。

为了实现真振幅共炮偏移, 张宇^[5]提出了单程波方程和边界条件

$$\begin{cases} (\frac{\partial}{\partial z} + \Lambda - \Gamma)P_D(x, y, z; \omega) = 0 \\ P_D(x, y, z = 0; \omega) = \frac{1}{2i}\Lambda^{-1}\delta(x - x_s) \end{cases} \quad (3)$$

和

$$\begin{cases} (\frac{\partial}{\partial z} - \Lambda - \Gamma)P_U(x, y, z; \omega) = 0 \\ P_U(x, y, z = 0; \omega) = Q(x, y; \omega) \end{cases} \quad (4)$$

式中 $P_U = (i\Lambda)^{-1}U$, $P_D = (i\Lambda)^{-1}D$ 分别代表上行波和下行波的声压波场; $\delta(x - x_s)$ 为震源函数; $Q(x, y; \omega)$ 为地表接收的地震记录, $\Gamma = -\frac{1}{2} \cdot$

$(\frac{\partial \Lambda}{\partial z})\Lambda^{-1}$ 为拟微分算子。

1.2 真振幅偏移算子

以上行波方程(3)为例:

$$(\frac{\partial}{\partial z} - \Lambda - \Gamma)P_U(x, y, z; \omega) = 0 \quad (5)$$

(1)以参考速度做相移法。在空间频率域中方程(5)分二步实现:

$$\frac{\partial}{\partial z} \bar{U}(\omega, k_x, k_y, z) = \lambda_0(z) \times \bar{U}(\omega, k_x, k_y, z) \quad (6)$$

$$\frac{\partial}{\partial z} \bar{U}(\omega, k_x, k_y, z) = v_0(z) \bar{U} \times (\omega, k_x, k_y, z) \quad (7)$$

其中 k_x 、 k_y 分别为 x 、 y 方向的空间波数; $v_0(z)$

为随深度变化的参考速度。

$$\lambda_0(z) = i \frac{\omega}{v_0(z)} \left[1 - \frac{v_0^2(z)(k_x^2 + k_y^2)}{\omega^2} \right]^{\frac{1}{2}}$$

$$v_0(z) = -\frac{1}{2} \frac{\partial}{\partial z} \lambda_0(z)$$

方程(6)的求解可以写成:

$$\frac{\partial}{\partial z} \bar{U}(\omega, k_x, k_y, z) = \left[-\frac{1}{2} \frac{\partial}{\partial z} \ln \lambda_0(z) \right] \times \bar{U}(\omega, k_x, k_y, z) \quad (8)$$

$$\frac{\partial}{\partial z} \bar{U}(\omega, x, y, z) = \left[-\frac{1}{2} \frac{\partial}{\partial z} \ln \frac{v_0(z)}{v(x, y, z)} \right] \times \bar{U}(\omega, x, y, z) \quad (9)$$

式(8)为变量 z 的常微分方程, 经求解可得:

$$\bar{U}(\omega, k_x, k_y, z + \Delta z) = \left[\frac{v_0(z + \Delta z) \sqrt{1 - \frac{v_0^2(z)}{\omega^2}(k_x^2 + k_y^2)}}{v_0(z) \sqrt{1 - \frac{v_0^2(z)}{\omega^2}(k_x^2 + k_y^2)}} \right]^{\frac{1}{2}} \bar{U}(\omega, k_x, k_y, z) \quad (10)$$

(2)薄镜校正项。求解该常微分方程(9)得到:

$$\bar{U}(\omega, k_x, k_y, z + \Delta z) = \left[\frac{v(x, y, z + \Delta z) v_0(z)}{v(x, y, z) v_0(z + \Delta z)} \right]^{\frac{1}{2}} \bar{U}(\omega, k_x, k_y, z) \quad (11)$$

为了得到正确的偏移振幅, 在偏移之前必须进行球面扩散校正。式(10)和式(11)就是在 SSF 的基础上, 针对散射项所做的偏移算子, 能够正确地显示出振幅的信息。

2 模型试算

为了验证本文中方法的保幅性, 首先我们设计了一个简单的 2D 凹槽模型。图 1 是用传统 SSF

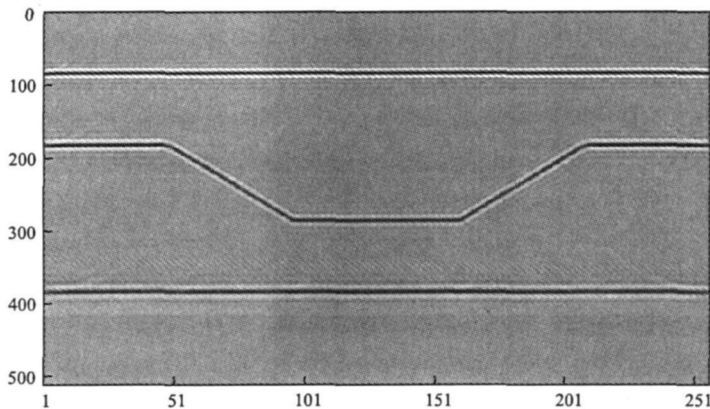


图 1 传统 SSF 偏移成像

Fig 1 Traditional SSF migration imaging

偏移成像剖面, 可见能够给出正确的成像位置, 但是该方法对构造成像而言精度比较低。

图 2 为真振幅 SSF 偏移成像剖面, 它不但给出了正确的成像位置, 而且整张剖面的成像振幅比较均衡。该方法对于倾斜界面和最下面的平层的成像, 比传统 SSF 方法的成像效果好, 精度更高, 而且对构造成像更加清晰, 这说明该方法能有效处理强间断速度变化。

作者在文中用 Mamousi 模型验证该方法, 能够有效地解决复杂地质模型。Mamousi 模型构造复杂, 存在剧烈的横向变速, 因此 Mamousi 模型是国际公认的检验叠前深度偏移方法的理想模型。图 3 是 Mamousi 模型速度场, 这里所采用的数据集的参数为: 共有 240 个炮集, 每炮 96 道, 炮间距 25 m, 道间距 25 m, 采样率 4 ms。下页图 4 是在准确的速度模型下, 用传统的 SSF 叠前深度偏移成像的结果。下页图 5 是在准确的速度模型下, 得到的真振幅 SSF 叠前深度偏移成像的结果。从二者的对比中可以更加明显地看出, 真振幅 SSF 偏移成像

的结果中模型浅层的三个大的断层, 以及中深层的背斜和低速体等构造形态, 都能够得到更好的体现, 刻画出了波场随速度场变化的细节, 整个偏移剖面具有质量很高的成像效果。通过以上针对 Mamousi 模型的偏移成像结果的对比, 可以看出与传统 SSF 偏移算子相比, 真振幅 SSF 偏移算子的优势所在。

3 结论

真振幅 SSF 偏移是基于传统的 SSF 的一种偏移方法, 通过对凹槽模型和 Mamousi 模型的多个炮点的偏移成像结果对比, 真振幅 SSF 叠前深度偏移方法是实现较复杂地质构造成像的一种快速有效的方法, 它解决了传统 SSF 方法不能保证实现保幅偏移成像的缺点, 在提高计算效率的同时, 也加强了速度场横向变化的适应性。在降低计算量和提高成像质量方面将会有很大的优越性。

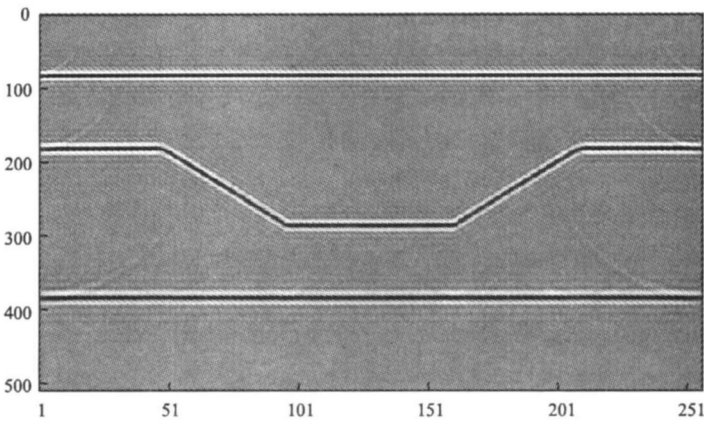


图 2 真振幅 SSF 偏移成像

Fig 2 True amplitude SSF migration imaging

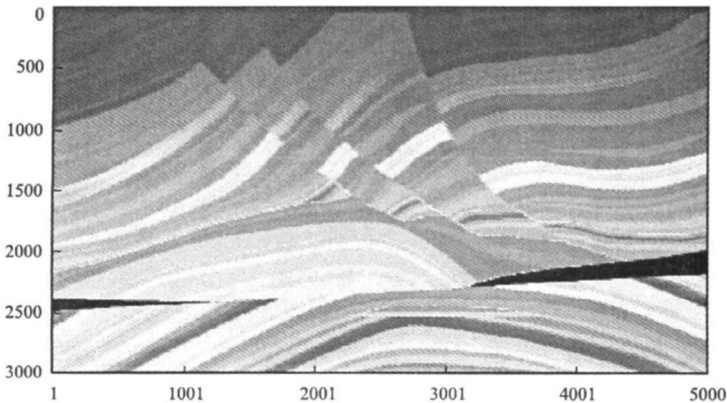


图 3 Mamousi 模型速度场

Fig 3 Velocity field of Mamousi model

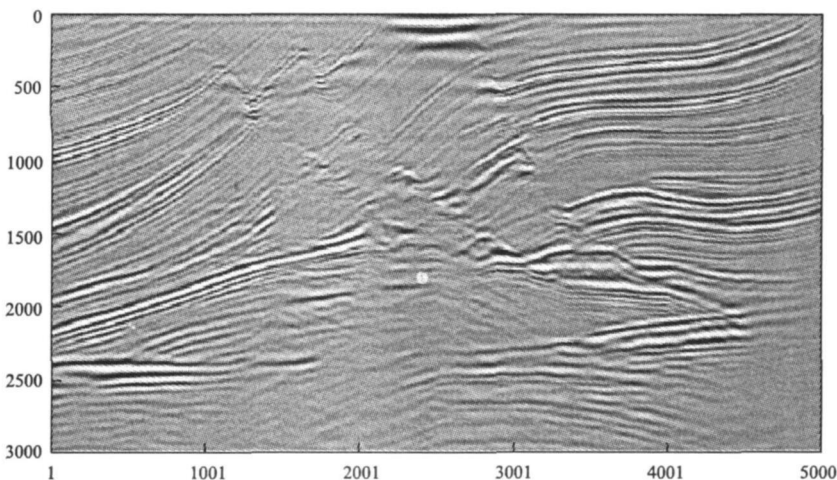


图4 Mamousi模型传统的SSF偏移成像结果

Fig 4 Traditional SSF migration imaging of Mamousi model

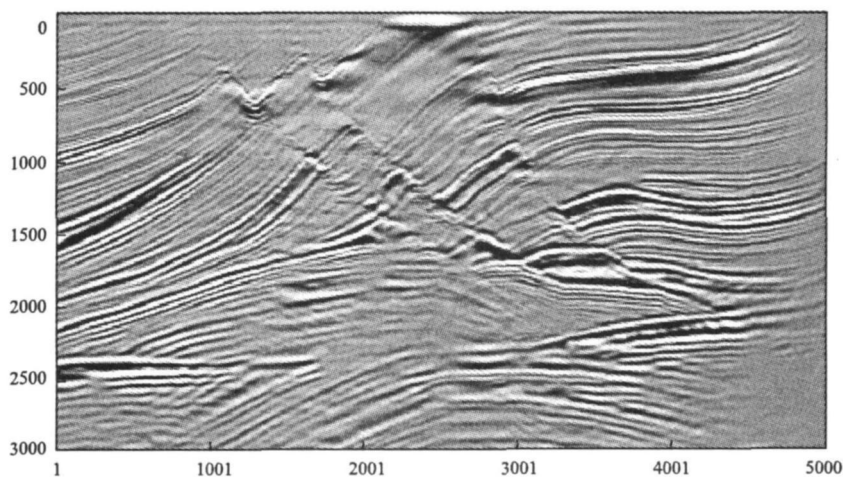


图5 Mamousi模型真振幅SSF偏移成像结果

Fig 5 True amplitude SSF migration imaging of Mamousi model

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As carbonate rock reservoir is an important target of the oil-gas exploration fields, its change of wave fields characteristics are specially complex. In order to improve the recognition degree of the reservoir multi-wave seismic data, high-precision numerical simulation is one of the effective ways. Based on the isotropic elastic wave equation, this paper derived the P-S wave separation equation, adopted the high-order staggered-grid finite-difference technology to simulate seismic wave propagation in the carbonate rock reservoir media, acquired the total elastic wave fields of the reservoir model, separated the P wave and S wave information, and preserved the P-S wave energy information. This paper also combined with AVO technology to analyze the elastic wave AVO response characteristics in this type of carbonate rock reservoir, examined the simulation result based the reservoir model, and analyzed and researched the wave fields response characteristic and the propagation law, which provided the reference for the carbonate rock reservoir identification and prediction, and better met the practical needs of complicated oilfield exploration and development.

Key words carbonate rock; wave field characteristics; AVO technique; perfectly matched layer; forward modeling

SEISMIC WAVEFORM SHAPE DESCRIPTION TECHNIQUE AND ITS APPLICATION IN SEISMIC FACIES ANALYSIS

YAO Shuang¹, YAN Jian-guo^{1,2}, LI Xue-feng¹, et al (1 The College of Information Engineering Chengdu University of Technology, Chengdu 610059, China; 2 The Key Lab of Earth Exploration and Information Technology, Ministry of Education, Chengdu University of Technology, Chengdu 610059, China). *COMPUTING TECHNIQUES FOR GEOPHYSICAL AND GEOCHEMICAL EXPLORATION*, 2011, 33(1): 24

In seismic attributes, the general variation of waveform and its distributed rule is most important seismic parameter. Picking and identifying the waveform information is of benefits to reservoir prediction, reservoir description and improving drilling successful rate. Using waveform to create seismic facies is to use neural network technique to quantitatively describe the general variation of seismic signal. The core of this technologies is the wave shape description and characterization techniques. Taking Stratigraphic for

example, by the detailed analysis and comparison with the influence over waveform shape changes caused by the main parameters (amplitude, phase and frequency) which make up of the waveform shape, this paper summarizes waveform shape variation and waveform shape description method which can be used and discusses the effect and significance wave shape classification in Seismic facies analysis.

Key words seismic facies; waveform classification; model trace; seed file

GROUND ROLL ATTENUATION IN TIME-FREQUENCY AND ITS APPLICATION

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Ground roll is a kind of strong noises in seismic data. Some methods are applied to attenuate ground roll such as frequency filter, F-K filtering, velocity filtering and so on, which have limitations because of the frequency dispersion of ground roll. A new method is proposed based on the ground rolls features that change with offsets, which includes (1) understanding the characteristics of ground roll with offsets by decomposing the zone data contained ground roll using Fourier or time-frequency analysis; (2) designing filters with different offsets and apply them to data; (3) Analyzing the removed noises by subtract them from raw data and research the filter parameters; (4) determining the optimal parameters in time-frequency and offset domain to ensure that we attenuate noise and preserve the low frequency signals. Good results are obtained when applying the method to high density seismic data.

Key words ground roll attenuation; time-frequency and offset domain; high density; single point receiver; filter

A TRUE AMPLITUDE SPLIT-STEP FOURIER PRE-STACK DEPTH MIGRATION BASED ON ONE-WAY WAVE EQUATION

XIE Jian-jian, WANG Xu-ben (Chengdu University of Technology, Key Lab of Earth Exploration and Information Technology of Ministry of Education, Chengdu 610059, China). *COMPUTING TECHNIQUES FOR GEOPHYSICAL AND GEOCHEMICAL EXPLORATION*, 2011, 33(1): 36

In this paper, we take the combination of the true amplitude one-way wave equation with split-step Fourier operator (SSF) operator, which includes the advantages of the amplitude preservation method and sub-step Fourier method. Therefore it has the advantages of calculation, accounting for less memory, the significant amplitude deviation after the Fourier finite difference migration method. It has the advantage of high precision imaging with dynamic characteristics of seismic waves compared with the widely used split-step finite difference pre-stack depth migration we successfully carried out the true amplitude split-step Fourier pre-stack depth migration based on the Mannousi model and achieve a good imaging result.

Key words one-way wave equation; true amplitude; split-step Fourier operator; pre-stack depth migration

APPLICATION OF TIME-WINDOW AND MULTIWAVELET METHOD IN PRODUCING THE HIGH PRECISION SYNTHETIC SEISMOGRAM

LI Jin-lei; QU Da-peng; CHEN Zu-qing (Research Institute of Exploration Southern Division Company SINOPEC, Chengdu Sichuan 610041, China). *COMPUTING TECHNIQUES FOR GEOPHYSICAL AND GEOCHEMICAL EXPLORATION*, 2011, 33(1): 40

Synthetic seismogram plays an important role in the seismic interpretation and reservoir prediction. Through analyzing the characteristics of the seismic wavelet which is time-varying and spatially variable, the paper explains the need for dividing the time window, then by combining the synthetic seismogram Principles with the methods, it is proposed that a general method using the divided time window to produce a high-precision synthetic seismogram, which utilizes the ricker wavelet and the extracted wavelet from the closest well seismic. Finally, this method is used on the actual well, the synthetic seismogram which is coincided not only with the seismic but also the higher resolution.

Key words seismic wavelet; time window; synthetic seismogram; high precision; resolution

A STUDY OF APPLICATION OF GRAVITY AND MAGNETIC INFORMATION FOR THE WEST FOOT OF MOON MOUNTAIN TO ORE EXPLORATION PROSPECT FORECAST IN NINGXIA PROVINCE

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The gravity and magnetic information of the west foot of Moon mountain had been processed and interpreted. The magnetic anomaly, gravity anomaly and geochemical composite abnormal characteristics have been researched comprehensively. By analyzing mineralization geological background it could be indicated that the magnetic anomaly in researching area might probably result from the insidious medium-basic cryptovolcanic rock or the polymetal Iron-Copper ore associated to the rocks. Then the south of Chelwan, Zhaojialao, Quanewan and the north of Wamm in magnetic anomaly areas were forecasted to be the important exploration target areas of deposit.

Key words gravity and magnetic information; ore exploration prospect forecast; west foot of Moon mountain

GEODETIC COORDINATE SYSTEM AND PROJECTIVE COORDINATE SYSTEM

GAO De-zhang (Institute of Shanghai Offshore Petroleum Branch, SINOPEC, Shanghai 200120, China). *COMPUTING TECHNIQUES FOR GEOPHYSICAL AND GEOCHEMICAL EXPLORATION*, 2011, 33(1): 51

Geophysical and geochemical exploration work, all measuring points has its only location on land, in sea and air space. According to the design requirements of work, the measuring points were marked by different ways in different stages. In the field observations, the measured points positioning by GPS (global positioning system) or DGPS (difference global positioning system) were marked by geodetic coordinate in geodetic coordinate system. In showing work, the measuring points were marked by plane rectangular coordinate in projective coordinate system. In this article, establishment and characteristics of geodetic coordinate system and common projective coordinate system, selection and application of projective coordinate system were described, but specific formulas were not involved.

Key words geodetic coordinate; projective coordinate; plane rectangular coordinate; isometric projection

THE ANALYSIS OF AEROMAGNETIC ANOMALIES ABOUT MULTIMETAL ORE-FORMING IN THE MIDDLE-SOUTH SECTION OF DAXING'ANLING MOUNTAIN

CUI Zhì-qiang; MENG Qín-mín; XU Zhì-lì et al (Institute of Geophysical and Geochemical Exploration, CAGS, Langfang 065000, China). *COMPUTING TECHNIQUES FOR GEOPHYSICAL AND GEOCHEMICAL EXPLORATION*, 2011, 33(1): 56

As the northern orogenic belt based on Paleo-A-