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·勘探技术·

基于盲信号处理技术的地震弱信号分离方法

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摘要:盲信号处理技术作为现代信号处理领域的研究热点之一,面临着在源信号和传输通道参数未知或知之甚少的情况下,由一个传感器或者转换器的输出信号中分离出的源信号难以有效测控的问题。通过研究盲信号处理技术在地震弱信号分离中的应用,在分析隐蔽油气藏地震反射信息特征与盲信号处理理论之间关系的基础上,建立适合储层目标弱信号分离的地震盲源信号混叠模型,提出了分离2种弱信号的新方法,并利用围岩反射在各地震道的相似性和目标储层弱信号的差异性设计迭代法加以实现。模型仿真实验和实际地震资料的处理结果表明,该算法能够有效地分离地震弱信号,达到提高地震资料分辨率的目的。

关键词:盲信号处理 地震弱信号 分辨率 盲源分离 隐蔽油气藏
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胜利油区的勘探目标已经由构造油气藏逐步向小砂体、薄互层、微裂缝等隐蔽型油气藏转移,勘探目的层位的深度也越来越大[1]。由于这些非常规地质体埋藏深、规模小,地表震源激发的地震波在介质中经过较长时间的传播与散射以及介质非弹性效应造成的地震反射信号的衰减,使地表检波器接收到的目的层的反射信号能量相对较弱,经常被淹没在背景噪声中,同时波形也会发生畸变[2],由于受分辨率的限制,其追踪描述以及含油气性判别成为制约勘探成效的主要难题,在地震资料上难以准确识别这类隐蔽型油气藏[3-4]。

在应用地震资料解释储层时需要追踪强振幅反射,但受分辨率的限制,目前的地震解释技术对弱信号或空间弱变化信号难以有效检测,造成弱信号拾取解释难度大,难以准确确定小地质体的边界。因此,如何从地面接收的地震信号中检测、提取并重建淹没在背景噪声中的有效弱信号是目前地震信号处理所面临的一个较为复杂的难题。针对弱信号的提取与分离问题,目前主要应用独立分量分析法[5]、二阶统计量法[6]、高阶统计量法[7]和自回归模型[8]等方法。笔者基于盲信号处理理论[9-11],将不同的地质目标看成源信号,则观测到的信号可认为是由多个信号混叠而成的,通过算法设计,实现了弱信号的提取与分离,并取得了较好的应用效果。

1 方法原理

1.1 混叠模型的建立

依据地震信号中储层目标弱反射和围岩反射的关系,将地下反射界面看成是地震反射波的信号源,地震数据是不同反射源信号的叠加,信号源的尺度与其在地震记录上的分布范围相对应。强信号是能量强、连续性好的信号,弱信号是地震剖面上稳定反射中能量弱、连续性差的信号,进而建立起反映隐蔽地质体的弱信号地球物理模型(图1a)。模型由4套连续性地层和多个豆荚状的砂体组成,其中,连续性地层的层速度由浅到深依次为3 000,3 100,2 500和4 500 m/s。砂体可以分为2类:一类厚度约为12 m,延展长度约为250 m;另一类厚度约为6 m,延展长度约为100 m,层速度为3 500 m/s。其对应的正演模拟(图1b)记录为26 Hz雷克子波的合成地震记录。图1的对比结果表明,尽管地质模型中的砂体分布非常明显,但合成地震记录上却没有显示与之对应的同相轴。这是由于相对于构造引起的地震反射波,砂体储层的反射非常弱,仅能使反射波同相轴发生微小的变化,导致其反射特征在记录中无法显示出来。

由于地质体的界面均能产生反射波,因此均可将其看作是地下地震的信号源。将盲信号处理理

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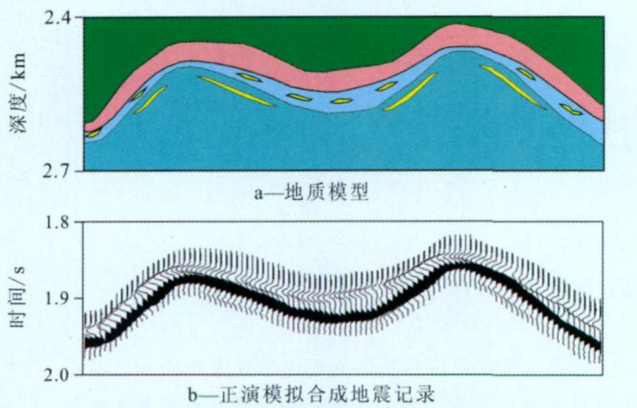

图1　隐蔽地质体地质模型与正演模拟合成地震记录

论与地球物理模型结合，可将地震记录看作是由不同信号源产生的围岩信号和砂体储层弱信号组成的。其中，围岩信号尽管在各道上的时间、振幅有差异，但其具有相同的波形，因此空间分布相对稳定连续，可以用统一的函数来表示；而弱信号的分布范围较小，空间变化明显。由此，地震盲源信号混叠模型的数学表达式为

$$x(i,t)=\sum_{k=1}^{n}A_{ik}F_k\left(t-t_{ik}\right)+s_i(t)\qquad i=1,2,\cdots,m \tag{1}$$

式中：x 为地震数据；i 为地震道个数；t 为地震双程旅行时间，s；n 为信号源个数；A_{ik} 为围岩信号的振幅；F_k 为第 k 个围岩信号源；t_{ik} 为时间延迟，s；$s_i(t)$ 为第 i 道中的弱信号；m 为相邻地震道的个数，一般取偶数。

1.2　分离方式

理论上对地震记录进行盲信号分离处理可以在信号源及传播介质参数未知的情况下，将地震信号分解为多个信号分量，进而进行弱反射信号的重构。忽略围岩反射在各个地震道上的能量差异，式（1）中地震数据可简化为

$$y(i,t)=\sum_{k=1}^{n}F_k\left(t-t_{ik}\right)+s_i(t) \tag{2}$$

式中：$y(i,t)$ 为围岩信号。

在研究隐蔽圈闭地震反射信号特征的基础上，根据隐蔽圈闭反射信号能量弱且与围岩反射在能量、频率、传播方向等方面的差异，基于盲信号处理理论提出了2种分离地震弱信号的方法。

方法1　采用盲信号分离技术从 m 个地震道中分解出 n 个源信号来计算围岩信号，其数学表达式为

$$y(i,t)=\sum_{k=1}^{n}F_k\left(t-t_{ik}\right)\qquad i=1,2,\cdots,m \tag{3}$$

则弱信号表示如下

$$s_i(t)=x(i,t)-y(i,t) \tag{4}$$

方法2　不再求取每个围岩源信号的单分量，而是采用由 m 个地震道直接构建整体围岩信号，然后由式（4）得到弱信号。

对比分析结果表明，方法1具有明确的物理意义，但是由于源信号数目和时间延迟是不可知的，导致现有的盲信号分离算法并不能获取准确、稳定的解甚至无解。而方法2则可以针对围岩信号在 m 个地震道上的相似性和弱信号在各道上的差异性，设计迭代法加以实现，具有较好的可行性。笔者采用方法2设计迭代法来实现地震弱信号的分离。

1.3　迭代法实现地震弱信号分离

根据地震弱信号盲源信号混叠模型，以中间地震道为研究目标，地震弱信号分离的数学表达式为

$$y^{*}(t)=y\left(\frac{m}{2}+1,t\right)=\sum_{k=1}^{n}A_kF_k\left(t-t_{ik}\right) \tag{5}$$

式中：$y^{*}(t)$ 为未知的围岩信号。

迭代法求取围岩反射的基本思路是将地震道看成是 n 个源信号的混叠，利用相邻地震道中围岩信号的相似性来提取目标地震道中围岩反射信息。如果围岩反射的基本信号已知，那么围岩反射可利用投影原始地震数据快速求取。然而实际情况下，围岩信号是未知的，这就需要通过迭代法从多个相邻的地震道中提取围岩信号。具体步骤如图2所示。

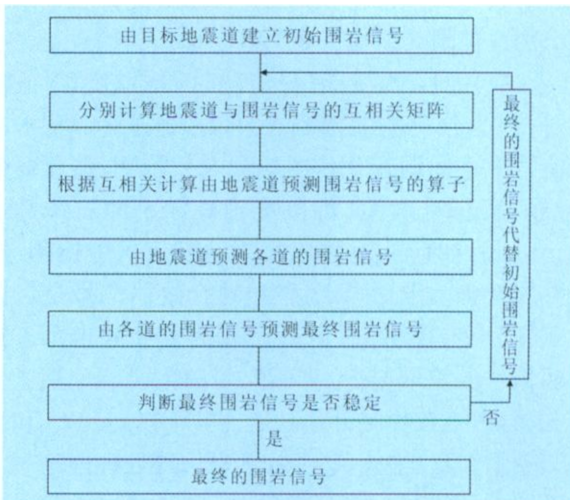

图2　盲信号分离处理技术实现流程

2　模型验证

采用上述技术对图1的地质模型进行地震弱信号分离处理。经过地震弱信号分离处理后，再对该

分离结果进行低频校正进而得到处理结果（图3）。通过弱信号分离处理结果与地质模型叠置对比可看出，剖面上同相轴与地层吻合程度较好，在原始地震剖面上无法识别的小砂体反射显现清楚，验证了该算法对提取地震目标储层弱信号的有效性，进而达到提高地震资料分辨率的目的。

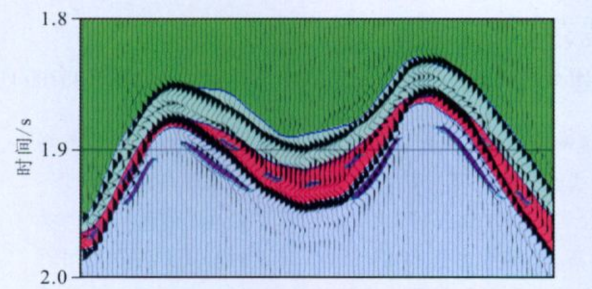

图3　合成记录道地震资料处理结果

3　应用实例

对胜利油区某区块常规地震资料无法识别的砂砾岩体采用基于盲信号处理技术的地震弱信号分离算法进行处理。处理后地震资料对比结果（图4）显示，原始地震剖面上能量较弱的砂砾岩体反射经过弱信号分离处理后得到了加强，处理结果再进行一次弱信号分离处理，即2次处理，剖面中部被围岩反射掩盖的砂砾岩体的反射显现出来，且反射特征非常清晰。

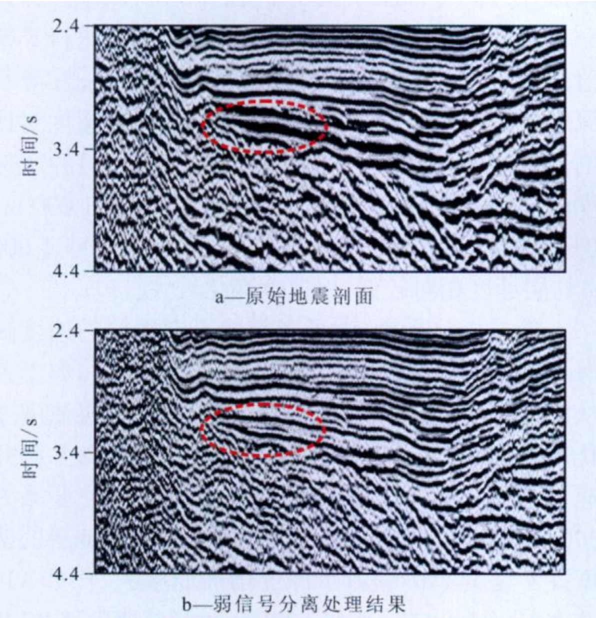

图4　弱信号分离处理结果与原始地震剖面对比

4　结束语

提出了一种基于盲信号处理的地震弱信号分离方法，根据围岩反射与储层弱信号特征，建立了地震盲源信号混叠模型，较准确地反映了地震信号中这2类信号间的关系，由此实现了目标储层弱信号的提取。在此基础上提出的2种弱信号分离方法，方法1的物理意义明确，但难以实现；方法2则利用相邻地震道中同一源信号的相似性，可通过设计迭代法加以实现。模型实验仿真及实际地震资料处理结果验证了该方法用于地震弱信号提取的合理性及有效性。

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depression, red mudstone's vertical structure and the relationship with sequence boundary are discussed herein. The mudstone in Es_4 of Yong 82 well mainly includes 4 types: red loose mudstone, red compact massive mudstone, dark grey banding mudstone and grey or grayish purple gypsum mudstone. The red loose mudstone has strong striated rock surface, and its chemical element combinations are close to paleosol. The mudstone's chemical index of alteration analysis indicates that the red loose mudstone has suffered low chemical paleo-weathering, its CIA tends to be lower from top to bottom, indicating rocks' chemical paleo-weathering tends to be lower when the depth increases. The top of the red loose mudstone is relative to the sequence boundary in Es_4. However, the grey sandstone with red mudstone in the top of early Es_4 should be attributed to upper sequence's low stand system.
Key words: Shahejie Formation; mudstone; geochemistry characteristics; sequence bounday; paleosol; Dongying depression
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Mu Xing. Seismic weak signal separation based on blind signal processing. *PGRE*, 2012, 19(5): 47-49.

Abstract: Blind signal processing technique is one of the hot topics in the field of modern signal processing, aiming at solving problems such as how to separate or estimate the waveforms of the original source from an array of sensors or transducers without or with little knowledge of original waveforms and the characteristics of transmission channels. This paper presents the application of blind signal processing technology to the extraction of seismic weak signals. Based on the investigation and analysis of the relationship between blind signal processing theory and seismic reflection features of subtle pool, an aliasing model of seismic blind-source signals is established in order to extract weak signals from seismic data of target reservoirs. At same time, two new strategies for weak signal extraction are proposed. Using reflection similarity among seismic traces of surrounding rocks and reflection differences of weak signals from target reservoirs, we developed an iterative algorithm for weak signals extraction. The results of simulation and seismic data processing show that the method can extract seismic weak signals successfully and thus improves the resolution of seismic data.
Key words: blind signal processing; seismic weak signal; resolution; blind source separation; subtle reservoir
Mu Xing, Geoscience Research Institute of Shengli Oilfield Company, SINOPEC, Dongying City, Shandong Province, 257015, China

Pang Jiandong, Li Sanfu, Jia Cunfu et al. Speed laws and velocity field establishing in ocean deep water area-case of Baiyun sag. *PGRE*, 2012, 19(5): 50-53.

Abstract: he complexity of velocity structure in deepwater area leads to distortion of the sedimentary layer structure and the difficulty of depth forecast, and seriously hampered oil and gas exploration of the deepwater area. We analyze characteristics and influencing factors of velocity structure in the Baiyun sag, using AL velocity, VSP velocity, and recognize that there is no necessary relationship between formation velocity and the water depth, and the sedimentary environment essential difference between continental shelf, continental slope deep water area is the fundamental cause of the abnormal rate. Then, we buildup the depth conversion method suitable for the deepwater area of Baiyun sag, by use of the mutual restraint of drilling speed, velocity of coherent inversion and seismic stacking speed. This method resolves tectonic distortion due to rough subsea preferably, and improves depth-prediction accuracy considerably.
Key words: slope waters; velocity structure; coherent velocity inversion of pre-stack seismic; time-depth conversion velocity field; Baiyun sag
Pang Jiandong, Drilling Engineering Research Institute, CNOOC Energy Technology & Services Limited, Zhanjiang City, Guangdong Province, 524057, China

Feng Hongxia, Lü Zengwei, Li Shaoxia et al. Influential factor of SP curve in upper Sha4 member, Chunhua oilfield. *PGRE*, 2012, 19(5): 54-56.

Abstract: The abnormal phenomena of the data of SP log appeared in the upper Sha4 member in Chunhua oilfield. Some reservoirs have been missed easily and the thickness of some reservoir is inaccurate during the process of identifying reservoir. Based on the theory of SP curve occur, some reasons are analyzed such as formation thickness, formation water salinity and lithological change. The result shows that the abnormal pressure, reservoir thickness, lithology and fluid property caused salt concentration unequal of drilling fluid when the formation was drilled, and this resulted in the anomaly drop of SP curve. In some reservoir, the mud filtrate salinity is more than formation water salinity, this caused SP curve anomaly positive. High carbonate content and microfracture caused by abnormal pressure are the main reasons resulted in SP curve anomaly negative in mudstone. The research obtained good effect in the process of production and improved the accuracy of the logging data interpretation.
Key words: upper Sha4 member; reservoir; mudstone; self-potential; diffusion-adsorption electrodynamic potential
Feng Hongxia, Shengli Well Logging Company, Dongying City, Shandong Province, 257000, China

Wang Zhengbo, Ye Yinzhu, Wang Qiang et al. Forecast of remaining oil distribution after polymer flooding by area-split and superposition method. *PGRE*, 2012, 19(5): 57-60.

Abstract: Until the end of 2011, oil recovery after polymer flooding is about 53% in China. Residual oil reserves after polymer flooding own pretty high exploitation potential. In order to extract the amount of remaining oil efficiently, it's necessary to study residual oil law and its potential distribution after polymer flooding. For that reason, area-split and superposition method has been put forward specifically, which can be utilized in forecast and studying on residual oil potential distribution of single well and whole reservoir after polymer flooding. Then, the key reservoir in the north of Daqing placanticline is selected as a typical object. After that, the residual oil distribution law of 37 wells after polymer flooding is studied respectively. Finally, based on the changes of recovery