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# 海南特殊地理环境下的地震资料处理技术研究

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**摘要**:海南福山凹陷地理环境特殊,属于陆地与浅海过渡区域,其地表条件及地质条件复杂多样,由此导致了地震资料品质差、分辨率低。通过开展地震资料处理技术研究与应用,处理后的资料效果令人满意。关键的处理技术包括微测井积分法静校正技术、匹配滤波法子波整形技术以及交互减去法压制多次波技术。针对海南特殊地理地表条件,在大炮初至、折射法静校正和层析法静校正等常规静校正技术无法发挥作用的情况下,开发研制的微测井积分法静校正技术较好地解决了静校正问题,使得有效反射的连续性得到明显的改善。在对主要的地震资料一致性处理方法优缺点对比的基础上,采用匹配滤波法子波整形技术消除了不同接收条件下的地震信号的不一致性。研究区内浅表层火成岩的存在,导致了多次波异常发育,采用交互减去法压制多次波技术后,消除了多次波干扰,有效地保护了一次有效反射信号。

**关键词**: 静校正;子波整形;多次波压制;信噪比;资料品质
**中图分类号**:P631.445 **文献标识码**:A

海南福山凹陷位于海南岛北部的琼北丘陵和琼州海峡之中,属于北部湾盆地的一部分,凹陷总面积为 2 920 $km^2$,其中陆地面积 1 900 $km^2$,滩海面积 140 $km^2$(水深 0～5 m),琼州海峡海域面积 880 $km^2$(水深大于 5 m)。海南福山凹陷三维地震勘探区的地理环境特殊,既有陆上的丘陵地带,又有海陆过渡带和浅海分布区,陆上植被发育,有密集的灌木丛、香蕉林等,部分地区火成岩出露地表。

自 1993 年以来,在海南福山凹陷开展了大规模持续不断的地震勘探技术攻关研究,地震资料品质得到了明显改善,但是,由于其特殊的地理环境、复杂的地表地质条件等因素,严重地影响了地震资料的品质,制约了该区油气勘探的步伐。因此,需要开展新的地震处理技术研究以进一步提高地震资料的品质。

## 1 微测井积分法静校正技术

位于海南岛北部的琼北丘陵与港湾区的三维地震勘探工区,其地表起伏变化较大,相对高差 30～50 m,最大高差为 130 m。

表层岩性为红土、凝灰岩、玄武岩等,地表结构复杂,地层速度变化剧烈、无规律性。地表 0～5 m 的平均速度由 500 m/s 快速变化到 2 000 m/s,岩性由浮土突变为火成岩,而且地表下的火成岩呈薄层片状不均匀叠置分布。

表层火成岩是导致该区静校正问题严重的主要因素。由于表层火成岩大量发育,使得浅、表层初至波传播路径复杂,初至波特征不明显(图 1),无法拾取初至,导致大炮初至、折射法静校正和层析法静校正等常规处理手段无法发挥其应有的作用。

由于静校正问题严重,极大地影响了地震资料的品质,因此,如何解决好静校正问题成为本区地震资料处理的关键之一[1,2]。

### 1.1 微测井积分法静校正

近年来通过对福山凹陷资料的处理,我们积累了一些针对本区资料处理的经验,形成了一些特色技术,微测井积分法静校正就是其中之一。利用该方法求取全区静校正量,确保静校正低频分量的准确性,避免产生虚假地质现象。

微测井积分法静校正的原理是:首先利用微测井初至拾取的结果,求取每口井的微测井速度曲线,用地表和解释的低降速带作为控制层,采用克里金内插技术建立微测井速度数据体(图 2),拾取相对稳定、平缓的高速层顶面,然后利用积分法求取静校正量(图 3)。在本区 205 $km^2$ 范围内,微测井总量达到 252 口。

通过微测井积分法得到静校正量,最终将地震数据校正到统一基准面上。在实际处理中,将静校正量分解为高频分量和低频分量,高频分量可用于

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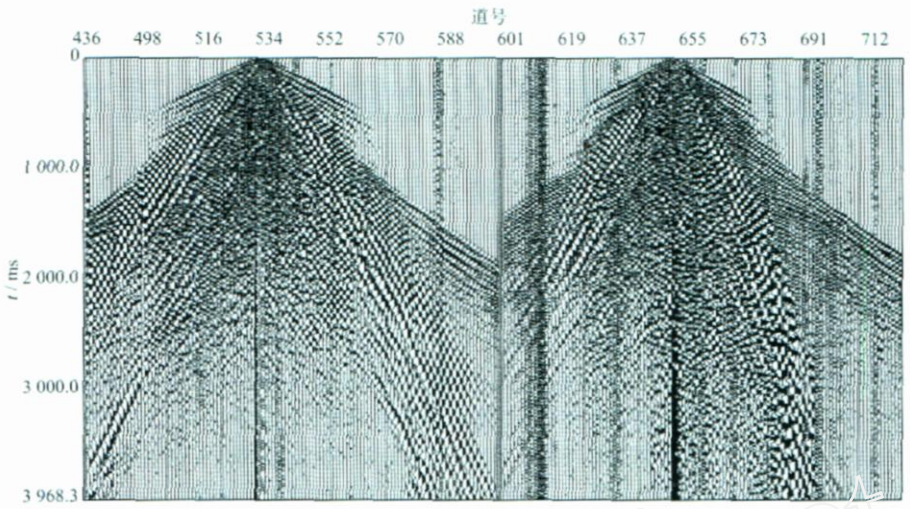


图 1 海南福山凹陷三维地震原始单炮记录

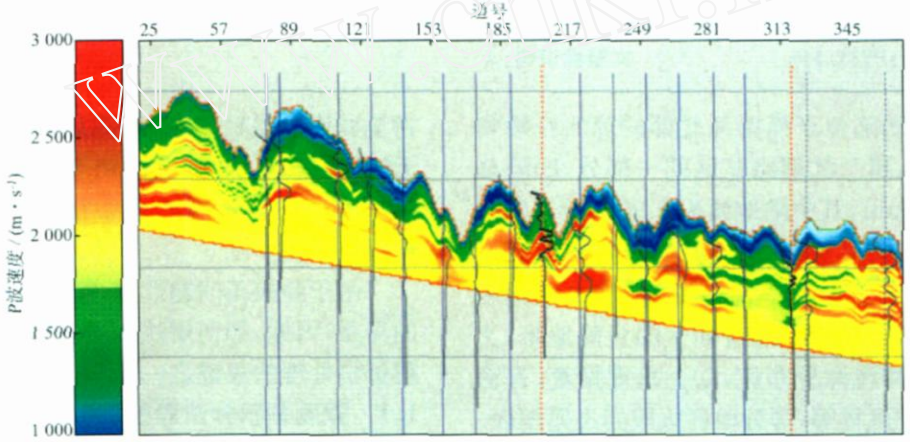


图 2 微测井积分法静校正的表层速度模型

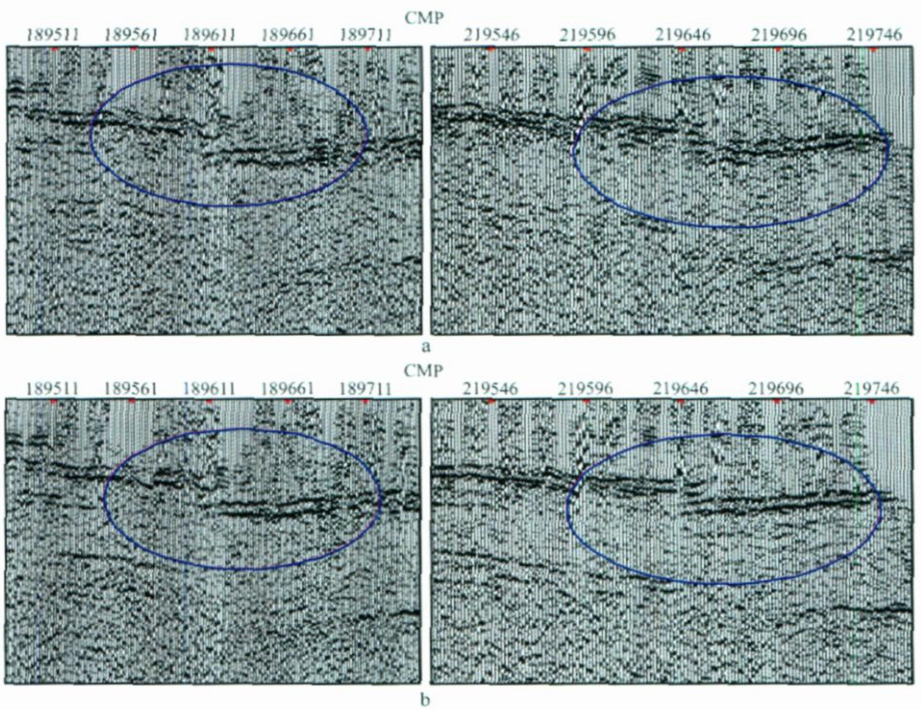


图 3 微测井积分法静校正前(a)、后(b)叠加剖面对比

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解决地震波成像问题,低频分量可以理解为浮动基准面,其物理含义为近地表光滑面,在这个基准面上进行叠加成像。

### 1.2　剩余静校正

采用速度分析与地表一致性反射波剩余静校正多次迭代的方法解决剩余静校正问题。通过反复试验和分析,选用时、空变剩余静校正参数,最后通过速度分析与地表一致性反射波剩余静校正的多次迭代,使剩余静校正问题得到较好的解决。

海南福山凹陷解决静校正问题的核心为:①由微测井资料求取瞬时层速度曲线,进行合理的异常值修正;②三维空间建模;③以火成岩厚度、相同地理环境和相近空间位置为依据,增加"虚拟"微测井控制点;④可视化环境下的标志控制层对比;⑤保证实际炮点、检波点的空间位置呈最佳倾斜平面;⑥用积分法逐点求取地震波浅层旅行时,计算精确的静校正量。

## 2　地震子波整形技术

海南福山凹陷既有陆上勘探,又有海上勘探,在进行野外地震资料采集时,接收检波器分别采用了陆地检波器、井下检波器和压电检波器 3 种。

陆上所用的陆地检波器为动圈式速度检波器,海上采用的压电检波器为压电型加速度检波器,两种检波器在感应机理、特性等方面存在差异,使得接收到的地震信号在频率、相位和能量等方面有较大区别。陆地检波器为机电转换,感应物理量为振动速度,具有频率低、频带窄的频率响应特征,其灵敏度低,灵敏度与频率无关。压电检波器为压电转换,感应物理量为振动加速度,具有频率高、频带宽的频率响应特征,其灵敏度高,灵敏度随频率的增大而增高。

实际生产中,检波器类型不同导致了资料不一致性问题,解决问题的主要方法有:时移法、调整反褶积参数法和匹配滤波法。时移法的实现过程简单,只能部分改善两组地震资料的一致性,难以兼顾浅、中、深层的差异变化,应用效果差。调整反褶积参数法可以较好地消除不同数据间的频率差异,并能提高资料的信噪比,但准确选择反褶积参数有一定的难度。匹配滤波法的实现过程虽简单,但能较好地解决不同资料的拼接或一致性问题。

匹配滤波法的基本原理为:对于两个存在差异的地震记录,先用一个匹配滤波算子对其中一个地震记录进行滤波,把另一个地震记录作为期望输出,使滤波后的地震记录逼近另一个地震记录,然后利用最小二乘法求取匹配滤波算子,再将滤波算子作为第一个地震记录,即可实现匹配滤波[3~5]。

在应用匹配滤波法进行子波整形处理过程中,以陆地检波器接收的地震记录为期望输出,对压电检波器的地震记录进行滤波处理,使其结果逼近陆地检波器接收的地震记录,最终消除陆地检波器记录与压电检波器记录间的子波差异。子波整形的最终处理效果以地震反射同相轴是否连续、光滑及协调一致为判别依据。

图 4 是子波整形前后陆地检波器与压电检波

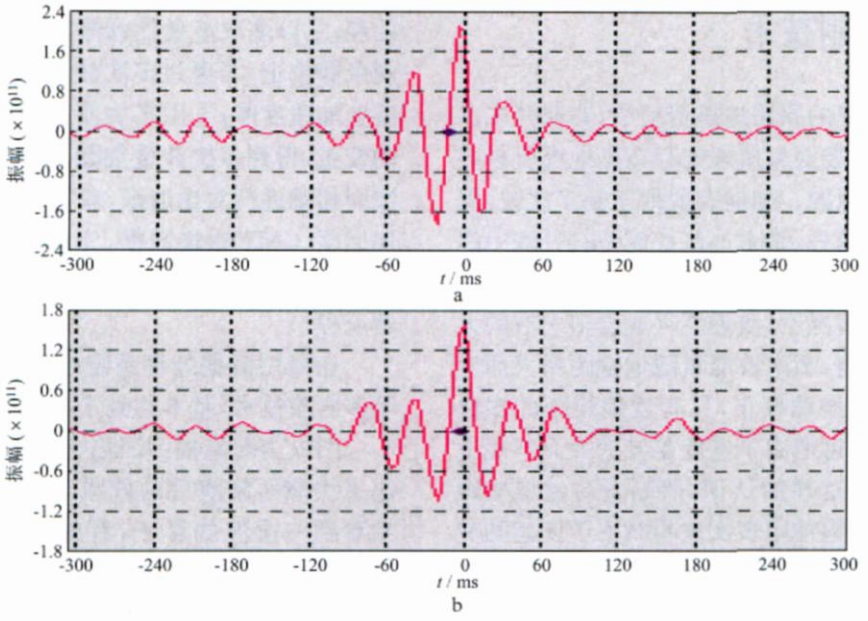


图 4　子波整形前(a)、后(b)陆地检波器与压电检波器的相关函数

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器间的相关函数,子波整形前,陆地检波器与压电检波器相邻地震道的互相关函数的最大振幅值不在零点处,有时间差,相差 10 ms 左右,即两者相似性差;经过子波整形处理后,陆地检波器与压电检波器相邻地震道的互相关函数的最大振幅值已位于零点处,表明两者相似性较好。

图 5a 是子波整形前的叠加剖面,在不同检波器接收资料的拼接处,地震反射同相轴存在明显的断开现象,即时间、频率和振幅等方面存在差别,这种差别在浅层和深层资料中都存在。图 5b 是子波整形处理后的叠加剖面,消除了不同类型检波器接收资料之间的子波差异,在不同检波器接收资料的拼接处,地震反射同相轴变得光滑、连续和协调一致。

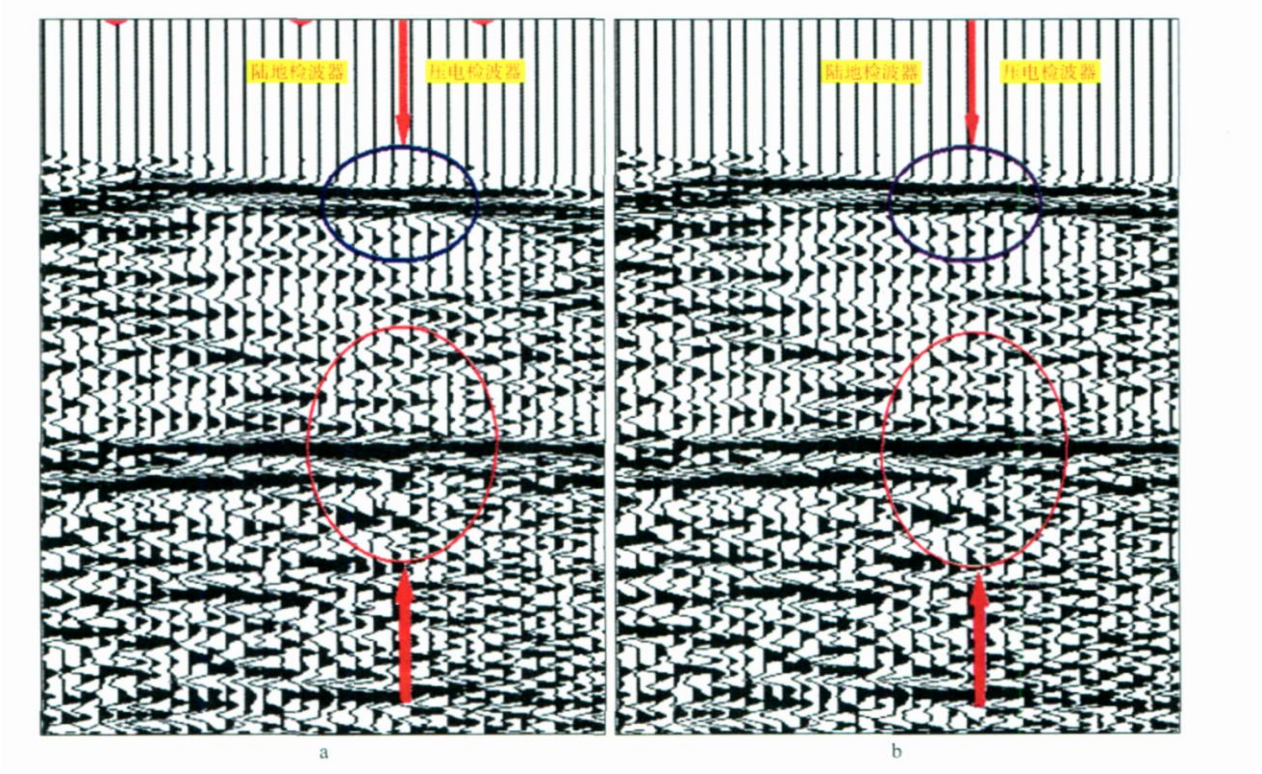


图 5 子波整形前(a)、后(b)共检波点叠加剖面对比

## 3 多次波压制技术

海南福山凹陷的原始地震资料中,普遍存在多次波干扰现象,浅表层火成岩的存在是地震资料多次波发育的主要原因。如何有效地压制多次波,保护一次有效反射信号,是本地区地震资料处理中的又一关键环节[6~9]。

在起伏地表情况下,浅表层火成岩多次波的大炮检距同相性变差,多次波能量随炮检距增大而变小,用一次波速度作动校正,只有近炮检距的多次波能够同相叠加,远道由于速度差异变大而不能进行同相叠加,基于这样的认识,研制了对近炮检距多次波压制、对远炮检距多次波暂时不予压制的交互减去法压制多次波技术,远炮检距多次波在多次叠加时再予以压制。

交互减去法压制多次波的实现过程为:①对 CMP 道集进行地表一致性振幅补偿和波形一致性处理;②以多次波最佳成像为目标进行地表一致性剩余静校正;③通过多次波速度谱解释,得到多次波叠加速度体;④用多次波速度对 CMP 道集进行动校正,得到多次波叠加数据体;⑤对较强的多次波同相轴进行对比追踪,获得多次波等 $t_0$ 时间、叠加速度、CMP 道集数据,完成局部多次波压制;⑥输出减去多次波后的 CMP 道集,进入其他常规处理流程。

在商用数据处理系统中研发的交互减去法压制多次波技术,基本达到了压制多次波的目的。

图 6 为海南福山凹陷三维地震资料交互减去法多次波压制前后的效果对比。处理前,几乎很难看到一次波的影子,有效波成像效果差,采用交互减去法压制多次波后,多次波背景下的一次有效信号得以成像,断面波及地震反射层成像清晰。

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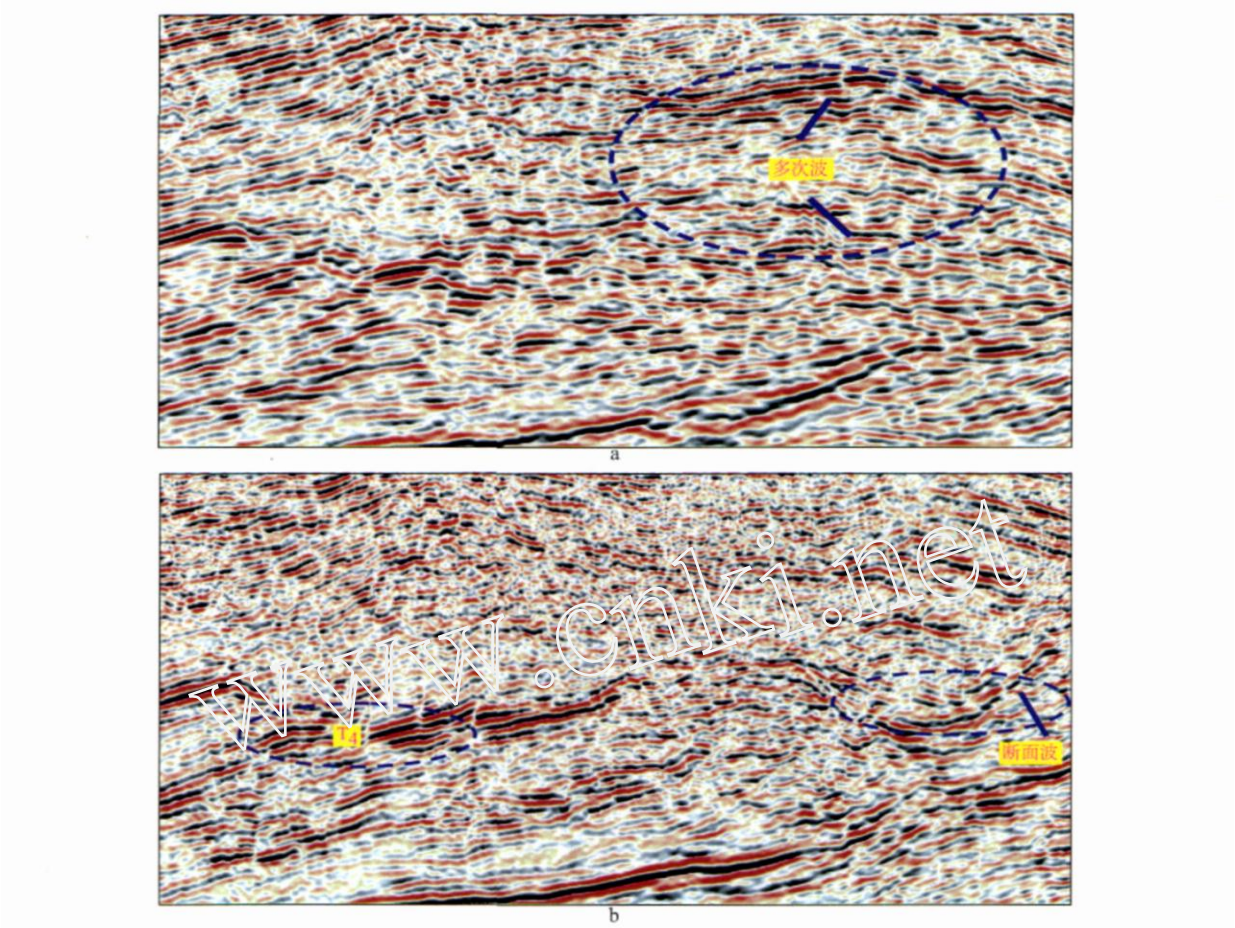


图 6　交互减去法压制多次波前(a)、后(b)的效果对比

## 4　结束语

海南福山凹陷特殊地理环境下的三维地震资料处理技术研究,取得了令人满意的效果,主要有以下几方面认识。

1) 微测井积分法静校正技术的应用,较好地解决了海南特殊地理环境情况下的静校正问题,地震反射同相轴的连续性得到明显改善,同相轴的形态真实可靠。

2) 交互减去法压制多次波技术的具体应用,以及叠前、叠后多次波压制技术的综合应用,使得海南火成岩发育区的多次波干扰得到了一定程度的压制。

3) 应用新的地震资料处理技术后,地震资料的整体波组特征变好,浅层、深层的地震资料信噪比和分辨率都有明显提高。

4) 海南福山凹陷火成岩复杂分布区表层结构建模研究的开展,提高了静校正精度,该技术可以用以指导表层火成岩覆盖区的激发条件选择,实现野外三维采集的炮点逐点设计,提高野外采集的激发效果和采集质量。

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**Identification of environmental influential factors affecting LWD resistivity. Liu Zhidi, Lin Hong, Wang Ying.** PEG, **2008, 31(3): 197～200**

Distinguishing the primary factors from environmental influential factors affecting logging-while-drilling resistivity is a perquisite to environmental correction. In this paper, the author summarized the environmental factors affecting LWD resistivity, and proposed to distinguish the factors by the separation between phase and amplitude resistivity curves. A workflow for identifying factors affecting LWD resistivity has been established by assimilating previous studies, and it has been verified with real data.

**Keywords:** logging-while-drilling resistivity; environmental impact; identification

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**Processing of seismic data from Hainan Island. Zhao Jianzhang, Zhang Jinduo, Lai Jiangde, Cai Dongdi, Yang Guangqin.** PEG, **2008, 31(3): 201～205**

Fushan sag, Hainan Island is special in geography. It is located in the transition area of land and shallow sea, featuring complex surface and subsurface conditions. The data acquired from the sag are poor in quality and low in resolution. Object-oriented data processing study has been carried out, and a suite of techniques has been developed. The techniques mainly include uphole integral static correction, matched filtering wavelet shaping, and interactive multiple removal. The uphole integral static correction was developed to replace commonly used static correction methods such as shooting first break, refraction statics, and tomographic statics to improve the continuity of reflections. The matched filtering wavelet shaping is used to remove the disagreement of seismic signatures acquired in different receiving conditions. Multiples are well developed due to the presence of igneous rocks in shallow formation. Interactive multiple removal is effective in protecting primaries in seismic data.

**Keywords:** static correction; wavelet shaping; multiple removal; signal-to-noise ratio; data quality

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**Controlling factors of the forming of oil reservoir of Yanan Formation in Hsd working area. Zhang Weihua, Zhang Xiurong, Cai Yuhua.** PEG, **2008, 31(3): 206～211**

Analysis of source-reservoir-cap rock and drilling data reveals that structure controls the forming of hydrocarbon reservoirs of Yanan Formation in Hsd working area. From the characteristics analysis of both regional and local structure of Yanan Formation, we divided the working area into 3 secondary structural units: fracture development area in the north, anticlinal and nose-like structural area in the east, and stable area in the west, and analyzed the types of structure each area belongs to. Considering the productivity of wells, it is concluded that faulted anticlines are the most favourable structure, the fracture development area in the north is the most favourable prospect, and the anticlinal and nose-like structural area in the east is the relatively favourable prospect. Depicting of interfomation fractures should be the focus in further work.

**Keywords:** Hsd working area; factoring controlling the forming of reservoir; structure; Yangan Formation

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**Seismic prediction of nearshore subaqueous fan in Shaobo, Gaoyou Depression. Xia Lianjun, Wu Xiangyang, Mao Shuli, Zhang Shaofeng.** PEG, **2008, 31(3): 212～218**

Many terrestrial rifted lake basins in east China were in its development stage in the Mesozoic or Cenozoic era, and nearshore subaqueous fans were well developed in the downthrown block of the faults. Most of the fans are developed in the steep slope of the rifted lake basin. Sands in the fan form structural-lithologic composite hydrocarbon reservoir because of fault sealing. Zhenwu and Fumin oilfield found according to the pattern of structural trap at the early stage are located in the south steep slope of Gaoyou depression, and they have been proved to be structural-lithologic composite oil reservoir in the later development. Therefore delineating subaqueous fan and the distribution of sand in the fan are vital for the further exploration in the south steep slope of Gaoyou depression. This paper discussed the prediction of nearshore subaqueous fans in the south steep slope of Gaoyou depression by seismic methods. The predicted results were confirmed by drilling.

**Keywords:** Gaoyou depression; steep slope; nearshore subaqueous fan; composite hydrocarbon reservoir; seismic prediction

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**Time-frequency analysis and its application in reservoir prediction. Liu Baihong, Zheng Silian, Ren Peng.** PEG, **2008, 31(3): 219～224**

This paper proposed to predict lithologic reservoirs with wavelet transform based time-frequency analysis. We discussed the procedure of time-frequency analysis based on wavelet transform, and the key steps of reservoir prediction with spectral decomposition. The proposed methods were demonstrated with data from Daniudi gas field, Ordos Basin.

**Keywords:** time-frequency analysis; spectral decomposition; spectral imaging; reservoir prediction; frequency division

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**Analysis of real-time performance bottleneck in geoscientific visualization software in network environment. Duan Wenchao.** PEG, **2008, 31(3): 225～230**

This paper discussed in detail the real-time problem related to geophysical 3-D visualization software in network environment. By analyzing the flow and flux of protocol stream, the author concludes that network band is the controlling factor that limits real-time response of geophysical 3-D visualization software over network. The conclusion was demonstrated by a real instance. Several possible solutions were put forward to improve real-time response. Their applicability in geophysical software environment was investigated. It is concluded that remote hardware acceleration is the best solution to 3-D visualization applications in petroleum geophysical exploration industry.

**Keywords:** network environment; real-time performance bottleneck; remote hardware acceleration; parallel rendering; OpenGL instruction flow

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**Application of GDI+ graphics printout in geological data management. Song Fuying.** PEG, **2008, 31(3): 231～234**

This paper discussed the printout of cards in the SINOPEC geological data management system. Based on a review of the principles of GDI+ graphics printout under .net environment, we described in detail the pagination of GDI+ graphics and the printout of the paged GDI+ graphics in sequence or by selected pages. Based on this technology, the printout of geological data cards was realized.

**Keywords:** geological data management; .NET environment; GDI+ graphics printout; paging printout; printout of selected page

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