

裂缝性储层的地震响应特征

——以川中地区致密砂岩储层为例

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摘要:

为了提取裂缝性储层在不同地震剖面上的地震响应特征,利用相干分析方法得到了裂缝性储层发育区的裂缝识别标志。首先用模型正演方法设计符合研究区地质实际的裂缝性储层地质模型,以此建立研究区主频条件下的地震模型,总结裂缝发育区常规剖面上的地震响应特征;而后对地震模型进行相干性分析,得到了相干剖面上裂缝发育区的识别标志,对比发现相干分析的识别标志和常规剖面的地震响应特征是相吻合的,而且特征更明显、响应更清晰;最后通过钻井证实该区域裂缝发育带的存在,有效证明了相干分析方法在识别、预测裂缝发育带上是可靠的、科学的。

关键词:

裂缝;模型正演;地质模型;地震模型;地震响应;相干分析

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0 引言

裂缝油气藏勘探在油气勘探中占有重要位置,中国目前所发现的低渗透储层的地质储量约占全部探明地质储量的 25 %^[1],而裂缝性储层作为低渗透储层的主要代表,在全球有广泛的分布,其主要的储集空间与运移通道是由于构造变形作用或物理化学成岩作用,在岩石中形成的宏观面状不连续,及在应力作用下岩石未发生明显位移的破裂的裂缝^[2];由于裂缝的成因复杂,其发育程度受多种因素控制,地震资料中虽包含有裂缝信息,单因裂缝因素引起的地震响应要远远小于其他地质因素引起的响应,因此利用地震

资料识别裂缝存在比较困难^[3],所以裂缝发育带的准确识别对致密储层的勘探开发具有重要意义^[4-5]。

世界能源组织的最新报告指出,世界将在石油时代之后迎来天然气时代^[6],川中 AY 地区须家河组是致密砂岩储层,目前已发现多个气藏,勘探开发前景十分广阔,但由于储层受裂缝控制,勘探难度大。前人虽然对 AY 地区进行过大量研究,但是到目前裂缝的分布规律尚不清楚,文章通过建立该区裂缝的地质模型来模拟裂缝的地震响应,再根据该地震响应来预测研究区可能的裂缝发育带,最后用实例来验证正演模型的正确性,从而找到在 AY 地区地震剖面上识别裂

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缝的有效方法。

1 裂缝型储层模型正演

1.1 模型正演原理

正演模拟是指用物理模型和数学模型代替地下真实介质,用物理实验和数学计算模拟地震记录的形成过程,以得到理论地震记录的各种方法和技术^[7]。

1.2 裂缝的地质模型及地震模型

原理上,从地质模型计算合成地震记录是不困难的,但这样的计算已包含了如下简化:a)认为地层在纵向上是由大量具有不同弹性特点的薄层构成,而在横向上是均匀的;b)未考虑所有波的转换(如纵、横波之间的转换)、吸收以及绕射等能量的损失;c)地震子波以平面波的形式垂直向下入射到地层界面,各薄层的反射子波都与地震子波形状相同,只是振幅及极性不同^[8]。

AY地区储层中常见的裂缝类型有层间缝和穿层缝,据工区储层的特点,笔者设计与本区储层地质、物理特性类似的二种裂缝的地质模型(图1a,b),模型

中砂岩(图1中橙黄色表示)速度为4500 m/s、泥岩(图1中灰白色表示)速度为3000 m/s,裂缝中天然气及填隙物(图1中黑色表示)的速度为510 m/s,按上述计算原理分别得到了在无噪和有10%噪音下,主频为50、60、70、80、85、90和100 Hz的层间缝、穿层缝的多个地震模型通过对比发现,主频为50 Hz时的地震模型对裂缝响应比较敏感,因而选取主频50 Hz的地震响应剖面加以分析(图2a,b,c,d)。

1.2.1 层内缝

这种缝仅存在于储集体内。其地质模型(图1a)顶层泥岩厚为20 m,底层泥岩厚为60 m,砂岩厚度120 m,裂缝宽0~3 cm不等(图1a中黑色部分表示),裂缝密度为0.1~3条/m,裂缝纵向延伸40 m左右。该模型中设计了两个裂缝发育区,左边为高角度裂缝,范围较大,横向延伸约100 m;右边为低角度裂缝,范围较小,横向延伸约80 m。从其地震模型(图2)来看,在无噪音地震剖面上(图2a)两个裂缝发育带均有反映,均为杂乱反射,但右边的低角度裂缝发育区更为明显;在10%噪音地震剖面上(图2b),高角度裂缝发育区变得模糊,而低角度裂缝发育区仍可识别,但均为局部杂乱的反射特征。

1.2.2 穿层缝

这种缝常穿越多个地层,因此称为穿层缝。其地质模型(图1b)为砂泥岩互层,共设计三层,各层厚36 m,裂缝宽0~10 cm不等;裂缝密度为0.2~4条/m。裂缝纵向延伸100 m左右,跨越三个层,横向范围左边的裂缝发育带约70 m,右边的裂缝发育带约80 m。从其地震模型(图2)来看,在无噪音地震剖面上(图2c)两个裂缝发育带均有反映,均为杂乱反射,并使正常的地层界面反射发生变形,但右边的较大范围的裂缝发育区变形更为明显;在10%噪音地震剖面上(图2d),左边的裂缝发育区变得模糊,右边的裂缝发育区仍可识别,表现为局部杂乱的反射特征。

由于工区储层中存在少量的泥岩夹层,为了了解泥岩夹层在地震剖面上的反射特征,特设计了其地质模型(图1c),该模型中泥岩薄层规模为左边5 m×30 m~5 m×15 m不等,右边为2 m×10 m~2 m×20 m不等,其地震模型见图2。不同规模的泥岩夹层在地震剖面上表现为同相轴的弯曲(图2e,f),与裂缝形成的杂乱反射明显不同。

2 相干分析

地震相干分析技术着眼于地震反射波形的相似性,目的是要确定地下储层的横向岩性变化,其假设

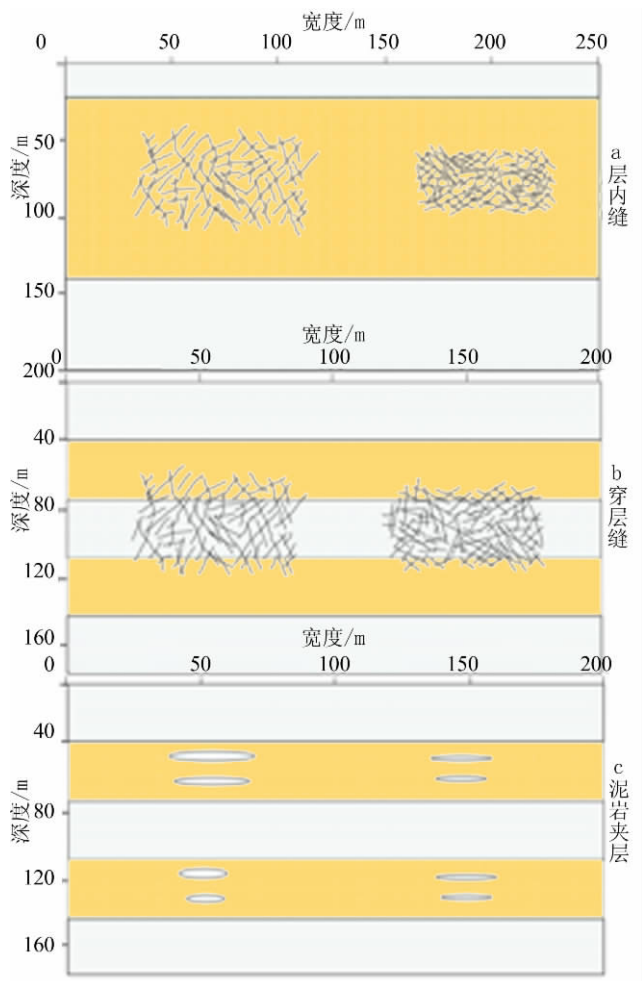


图1 地质模型示意图

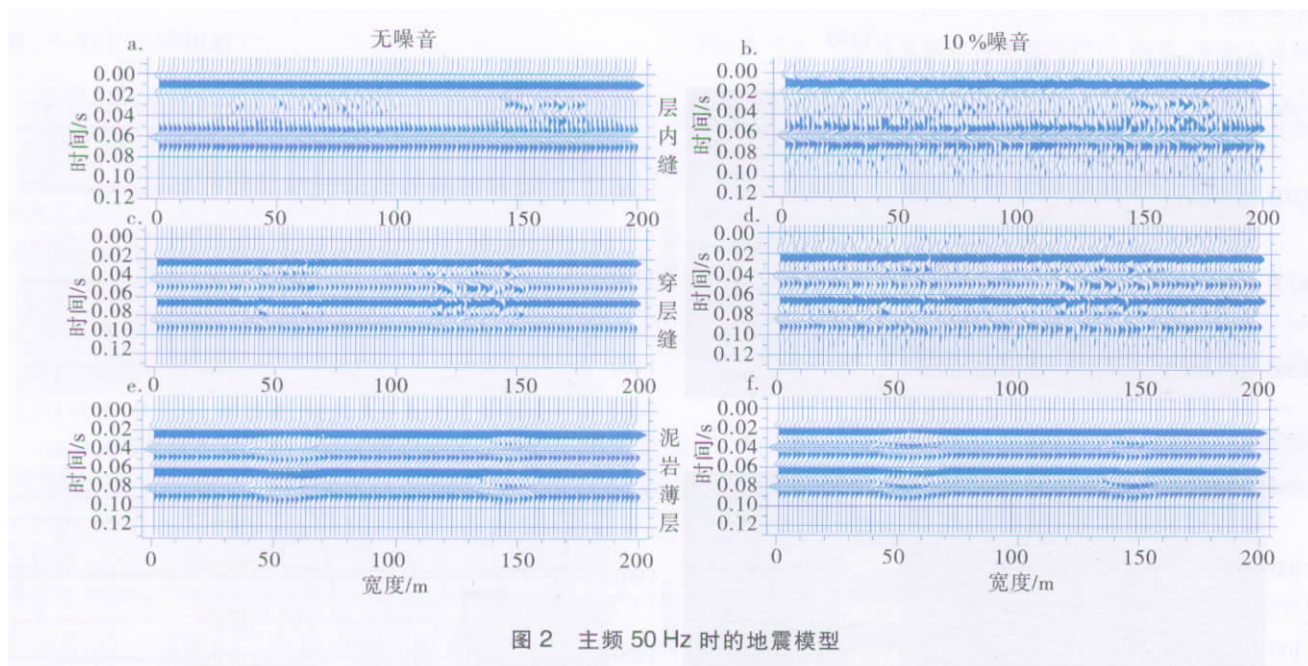


图 2 主频 50 Hz 时的地震模型

条件是在地层连续,横向上地质、地球物理参数变化不大的情况下,道与道之间的波形应该相似^[9],也称作相干。

对图 2 上的地震剖面进行相干分析可得到图 3 上的 6 张剖面图。由图 3 知,对于层内缝来讲,在无噪音与 10 %噪音的剖面上,两个裂缝发育区表现为明显的不相干,但无法判定裂缝的角度,不相干的区域与裂缝的规模有关。对于穿层缝来讲,在无噪音与 10 %噪音的相干剖面上,两个裂缝发育区也表现为

明显的不相干,只不过右边的裂缝发育区反映更明显,这可能与裂缝发育区中裂缝的倾角、规模、密度有关。局部泥岩夹层在相干剖面上也有反映,其特征与穿层缝类似,但可借助于常规剖面上同相轴的弯曲(而非裂缝造成的杂乱)与裂缝的不相干加以区分。

3 应用

本次研究以川中 AY 地区为例,该地区处于川

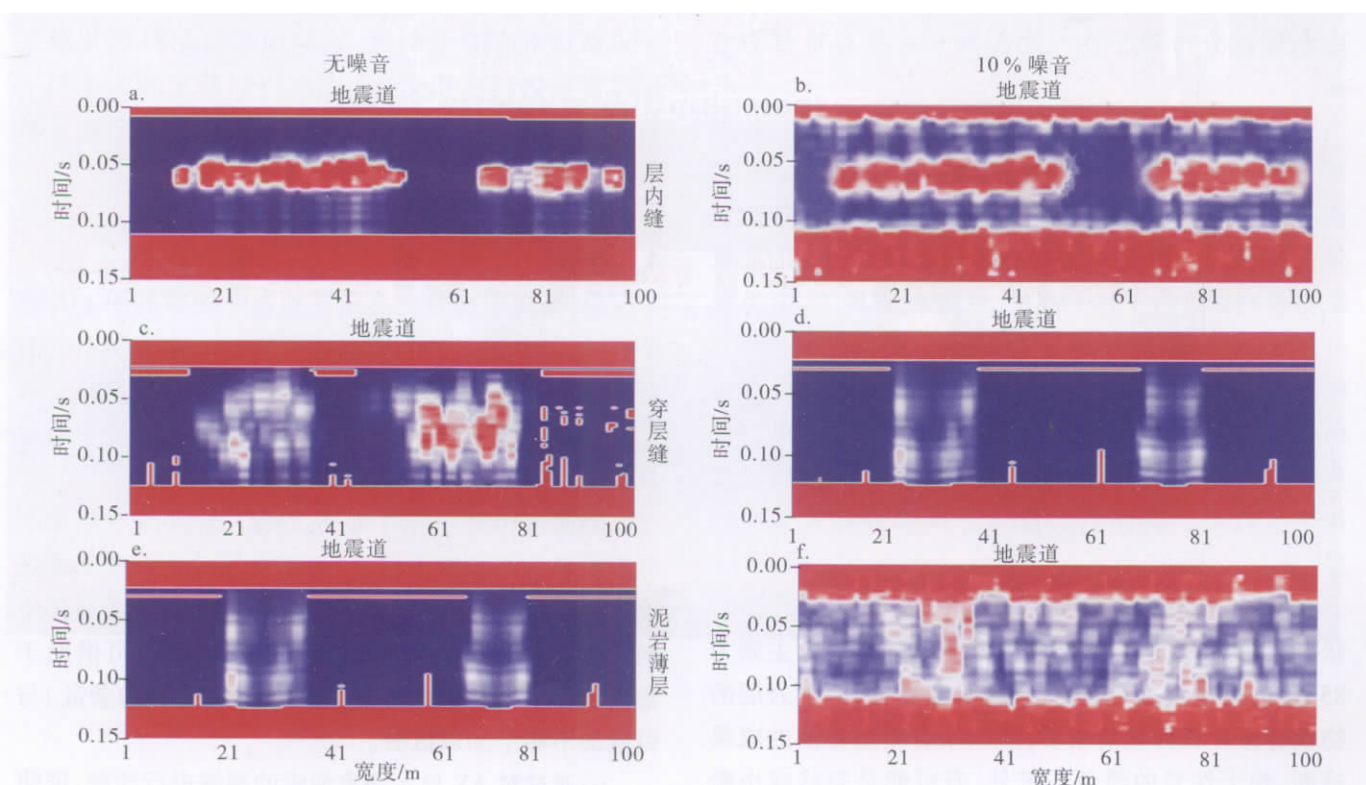


图 3 主频 50 Hz 时地震模型的相干剖面

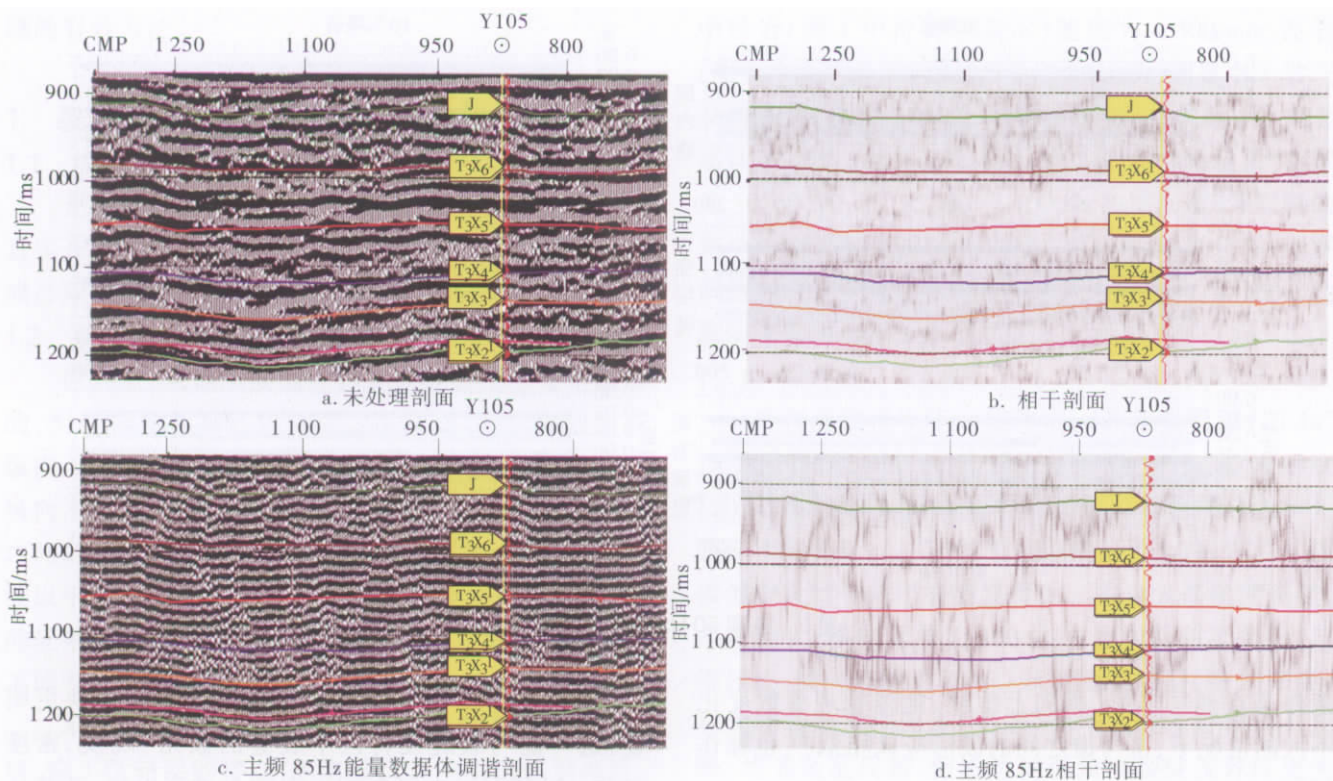


图4 2006ww36测线相干分析图

中古隆平缓区向川东南中隆高陡构造区的过渡地带,基底稳定,起伏不大,断裂不发育,仅发育裂缝及小断层,构造应力主要来自川东,以压应力为主,主要形成低缓构造,地层较为平缓,但对于川中须家河组的致密砂岩来讲,储层受裂缝控制,预测该区裂缝的分布对于油气勘探和开采具有重要的意义。

对工区的地震剖面首先进行频谱分解处理,处理后可得到主频为50,60,70,80,85,90和100 Hz等的能量数据体,通过对比,主频为85 Hz的能量数据体分辨率高,因此分别对原始剖面与85 Hz的能量数据体剖面进行了相干分析,见图4。在图4b中为置处2006ww36测线的相干剖面图,图4d为主频为85 Hz的能量数据体剖面,在图4b,d上分布有许多的黑色异常,这些异常表明在2006ww36测线剖面 and 主频为85 Hz的调谐剖面上的相应位的地震道数据相干性差,其颜色的深浅分别代表着相干性的差、好。

但在图4b中黑色异常区没有图4d中黑色条带状特征明显,这是因为经过频谱分解处理后的主频为85 Hz的调谐剖面(图4c)分辨率提高了,地下岩层的物理特性显现得更清晰了,所以结合模型正演的成果推断,相干性差的黑色条带处,有可能是裂缝或小断裂的响应特征。

通过测井资料证实,图4d上通过Y105井的干涉黑色条纹处,声波产生周波跳跃或者忽大忽小等幅度异常变化的现象、该深度孔隙度也相对较高、补偿密度测井出现尖锐低值,深浅双侧向电阻率表现为高值(裂缝内充气所致)且出现正差异,这些特征说明该处存在着裂缝,这与须家河组取芯井段裂缝发育段的特点相吻合。由此可以断定这些不相干特征是证实裂缝真实存在的依据,因而结论是正确的。

4 结论

a) 低角度裂缝比高角度裂缝在地震剖面上有更明显的反映,层内缝和穿层缝多表现为地震剖面上的杂乱反射,但并不改变来自界面的正常反射特征,只是穿层缝使正常界面反射变形较大;泥岩夹层在地震剖面上主要表现为同相轴的微弯曲。

b) 通过相干分析可知,层内缝与穿层缝在地震剖面上表现为明显的不相干,裂缝发育区大小决定了在地震剖面上能否对其进行识别;局部泥岩夹层在相干剖面上也有反映,其特征与穿层缝类似,但可借助于常规剖面上同相轴的弯曲(而非裂缝造成的杂乱)与裂缝的不相干加以区分。

c) 通过对AY地区须家河组的裂缝进行预测,证明了相干分析预测裂缝的方法是可行的。储层裂缝越发

育,不相干区域就越大。

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Application of Structural Equation Model of Optimization Factor in Shale Gas Development Target Area

Li Wuguang, Yang Shenglai, Lou Yi, Sun Xiaoxu (MOE Key Laboratory of Petroleum Engineering, China University of Petroleum, Beijing, 102249, China) **NGO, 2011, 29 (3):42–44**

ABSTRACT: Industrial mining of shale gas has its own unique development mode and shale gas development zone shall be determined in its initial development phase. In China, shale gas development zone selection system is still in experimental stage and it is necessary to further develop and complete the system. Analyzed are the current shale gas development evaluation theories and introduced are experience and reasonable methods for using foreign shale gas development evaluation systems for reference. Considering shale gas development characteristics in China, established is a structural equation model of shale gas development zone selection factors affecting the evaluation system, adopted is principal component analysis method to verify the rationality of the selected affecting index, applied is the structural equation modeling method to design the relational model of comprehensive evaluation effect factors for the shale gas development zone, objectively and comprehensively identify the effect factors for shale gas development zone selection and calculate objectively weights of each effect factor in order to make a correct decision.

KEYWORDS: Shale gas; Development zone; Selection; Influence factor; Structural equation; Model

Prediction for Coal Bed Gas Output Based On Fractal and ARIMA

Wang Yu, Li Zhiping, Liu Chao (China University of Petroleum, Beijing, 100083, China) **NGO, 2011, 29 (3): 45–48**

ABSTRACT: Coal bed gas production capacity may be affected by many complex factors, these factors are difficult to control, its simulation process is complicated, relative information is difficult to obtain and it is necessary to analyze accurately coal bed gas potential production capacity by adopting other mathematics methods in case of incomplete information. Adopted is fractal theory of R/S (Heavy Standard Differential Method) analysis method to analyze variation trend of coal bed gas production capacity, adopted is the modeling method ARIMA, which is based on the mathematical statistics theory, to predict coal bed gas output in order to use the parameter estimation in the R/S analysis method to reflect adaptability of the ARIMA model and increase prediction accuracy. Applied is the fractal-ARIMA prediction method to predict production output of one coal bed gas well in Qinshui, Shanxi Province in China and verification results show that such prediction results are accurate and are consistent with coal bed gas production output variation of this gas well. The fractal-ARIMA prediction method can make full use of information obtained already to realize dynamic extrapolation prediction in case of lack of information necessary in dynamic prediction method of coal bed gas production output based on fractal analysis and ARIMA model.

KEYWORDS: Coal bed gas output prediction; Fractal analysis; Autoregressive integrated moving average model; Heavy standard differential R/S; Time series

Seismic Response of Fractured Reservoirs

—Taking the Tight Sandstone Reservoirs in the Central Region of Sichuan for Example

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Luo Fang (CNPC Chuanqing Drilling Engineering Co., Ltd. Geological Exploration and Development Research Institute, Chengdu, Sichuan, 610500, China)

Li Yang (CNPC Qinghai Oil Field Company Golmud Refinery, Golmud, Qinghai, 816000, China) **NGO, 2011, 29 (3):49–53**

ABSTRACT: Coherent analysis method is adopted to obtain fracture identification marks in fractured reservoir development areas in order to obtain seismic response characteristics of fractured reservoirs on different seismic profiles. Adopted is the forward modeling firstly in this method to design the geological model of the fractured reservoirs consistent with actual conditions in the researched area, establish the seismic model under main frequency conditions in the area accordingly and summarize seismic response characteristics of fracture development areas on the conventional profiles. Conducted is coherent analysis on the seismic model and obtained are fracture identification marks in fracture development areas on relative profiles and it is found through comparison that the identification marks resulting from coherent analysis is consistent with the seismic response characteristics on the conventional

profiles and the characteristics are more obvious and the response is more clear. Finally, it is confirmed through drilling that fracture development zones are real in the areas, which shows that the coherence analysis is an effective, reliable and scientific method for identifying and predicting fracture development zones.

KEYWORDS: Crack; Forward modeling; Geological model; Seismic model; Seismic Response; Coherence analysis

Study on Shale Gas and its Aggregation Mechanism

Bai Zhaohua, Shi Baohong, Zuo Xuemin (Xi'an Petroleum University Oil and Gas Resources Institute, Xi'an, Shaanxi, 710065, China) **NGO, 2011, 29 (3):54-57**

ABSTRACT: Shale gas exploration and development is very important in the unconventional natural gas exploration and development field and to know well its geological theory is an important foundation for its exploration and development. Researchers in China have carried out comparative studies on the similarity of shale gas gathering mechanism conditions and geological conditions in China and America and summarized foreign shale gas geology theories. They point out that good geology conditions for shale gas gathering exist in China and such initial common view on shale gas generation, migration and accumulation conditions has been formed as that shale gas generation and accumulation reflects very complicated multiple-mechanism alternation characteristics and has features of self-generation and self-accumulation. Main factors for controlling shale gas accumulation includes total organic carbon content, organic matter maturity, rock mineral composition, formation pressure and temperature, high quality clay shale thickness and distribution area, etc. Analytical investigation on shale gas accumulation features, generation and accumulation mechanism and enrichment regularity is conducive to better evaluate and develop shale gas resources in China.

KEYWORDS: Shale gas; Geologic feature; Accumulation mechanism; Reservoir state

CORROSION AND CORROSION PROTECTION

Application of Duplex Stainless Steel in Oil and Gas Industry

Jiang Fang, Cao Xiaoyan, Shi Daiyan (China Petroleum Engineering Co., Ltd. Southwest Company, Chengdu, 610017, China)

Yang Guang, Chen Caohui (PetroChina Tarim Oil Field Company, Kurla, Xinjiang, 841000, China) **NGO, 2011, 29 (3):58-60**

ABSTRACT: KL2 Gas Field is a large CO₂ condensate gas field with high output and its gas gathering and transportation pipelines suffer severe CO₂ corrosion. Duplex stainless steel is used in the gas field development, since this kind of material is used largely for the first time in China's condensate gas field development, its technical requirements are very important for safe application. Based on relative requirements in codes, standards and specifications followed in the gas field surface engineering design and combined with technical features of this project, additional technical requirements are put forward for steel pipes, fittings and clad steel plates made of duplex stainless steel. Special examination requirement in these additional technical requirements includes stress corrosion test being able to bear or endure environment conditions at site and detrimental intermetallic phase test being able to control fabrication quality, in which method B and C in ASTM A 923 is adopted respectively for impact toughness test and ferric chloride solution pitting corrosion test. The gas field has been developed for 6 years successfully, which has proved that these special technical requirements for duplex stainless steel have good effects for the project and are suitable to similar projects.

KEYWORDS: Duplex stainless steel; Test; Intermetallic phase

Moulding Process for Pipe-in-Pipe of Polyurethane Insulation Pipe and its Quality Control

Jiang Linlin, Han Wenli, Zhang Honglei, Wang Wei (CNPC Engineering Institute of Technology, Tanggu, Tianjin, 300451, China) **NGO, 2011, 29 (3):61-63**

ABSTRACT: Directly berried insulated pipelines with large diameter are of underground facilities. After these pipelines are put into operation, their inspection and maintenance are very difficult and the costs for inspection and maintenance are also very high, so quality of the pipelines is one of the key factors affecting overall construction