地球物理学报 » 2012, Vol. » Issue (6) :2129-2140 doi:10.6038/j.issn.0001-5733.2012.06.035
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引用本文(Citation):
陈雪莲, 唐晓明.孔、裂隙并存地层中的声波测井理论及多极子声场特征. 地球物理学报, 2012,(6): 2129-2140,doi: 10.6038/j.issn.0001-5733.2012.06.035

CHEN Xue-Lian, TANG Xiao-Ming.Numerical study on the characteristics of acoustic logging response in the fluid-filled borehole embedded in crack-porous medium.Chinese J.Geophys. (in Chinese),2012,(6): 2129-2140,doi: 10.6038/j.issn.0001-5733.2012.06.035

孔、裂隙并存地层中的声波测井理论及多极子声场特征

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Numerical study on the characteristics of acoustic logging response in the fluid-filled borehole embedded in crack-porous medium

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摘要 在油、气储层的勘探和开发中观察到的一个现象是储层岩石中普遍存在孔隙和裂隙.随着近年来孔、裂隙介质弹性波动理论的进展,我们可以将此理论应用于测井技术,以此来指导从声波测井中测量孔、裂隙地层的声学参数.本文计算了孔、裂隙地层里充流体井眼中的多极子声场,分析了声场随裂隙介质的两个主要参数(即裂隙密度和裂隙纵横比)的变化特征.井孔声场的数值计算表明裂隙密度可以大幅度地降低井中声波纵、横波的波速和振幅.随着裂隙密度的增加,在测井频段内也可以看到纵、横波速的频散现象(这种频散在孔隙地层中一般是观察不到的).本文还研究了多极子模式波 (即单极的Stoneley波、伪瑞利波以及偶极的弯曲波)随裂隙参数的变化特征.结果表明,这些模式波的振幅激发和速度频散都受裂隙密度的影响.裂隙密度越高影响越大.此外,裂隙还对模式波的传播造成较大的衰减.相对裂隙密度而言,裂隙纵横比是一个频率控制参数,它控制裂隙对声场影响的频率区间.本文的分析结果对裂缝、孔隙型地层的声波测井具有指导意义.

关键词 裂隙, 孔隙地层, 声波测井, 裂隙密度, 频散

Abstract: In the exploration and development of hydrocarbon reservoirs, a common observation is the universal presence of cracks and pores in formation rocks. With the recent development of elastic wave theory for the cracked porous rock, it is now possible to utilize the theory as a foundation for measuring elastic properties of such rocks using acoustic logging. We have implemented the theory to calculate the multipole acoustic propagation in the fluid-filled borehole. The acoustic wave characteristics are studied for two controlling parameters of the cracked rock, namely crack density and crack aspect ratio. The calculated full waveforms show that cracks significantly reduce the velocity and amplitude of compressional and shear waves. With the increase of crack density, the dispersion of compressional and shear waves, which is insignificant for a poroelastic formation, can even be observed in the logging frequency range. The borehole guided waves, i.e., the monopole Stoneley wave, pseudo-Rayleigh wave, and the dipole flexural wave are analyzed in connection with the crack parameters. The results show that both the velocity dispersion and wave amplitude excitation characteristics of these guided modes are significantly affected by the presence of cracks. The cracks also induce significant attenuation of the waves along the borehole. The effects become pronounced with the increase of cracks density. In comparison, the crack aspect ratio parameter controls mainly the frequency band where these effects occur. The analysis results can be used to provide a guideline for acoustic logging in cracked/fractured formations.

Keywords Crack, Porous medium, Acoustic logging, Crack density, Dispersion

Received 2011-10-05;

Fund:

国家自然科学基金(41174088)和国家青年自然科学基金(40804020)项目, 中央高校基本科研业务费专项资金(10CX04007A)资助.

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http://118.145.16.227/geophy/CN/10.6038/j.issn.0001-5733.2012.06.035 或 http://118.145.16.227/geophy/CN/Y2012/V/I6/2129
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