Seismic Dispersion and Attenuation in Shale Oil Reservoir: Laboratory Experiments and Theoretical Analysis

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Abstract

Different lithofacies of shale oil reservoir invole different lithology(mineral composition), structure(laminated and interbedded crack), pore type and permeability. One of our objectives is to explore the frequency dependent elastic properties and attenuation of the rocks with different lithofacies characteristics for shale oil reservoir. For another significant purpose, we attempt to explain the possible dispersion and attenuation mechanisms in shale using existing theoretical models. We first executed two sets of stress–strain oscillation experiments on partially white-oil saturated samples with different lithofacies, which comes from Inter-Salt shale oil in QianJiang Sag, to investigate the dispersion of elastic moduli, elastic and anelastic parameters, anisotropy and attenuation from seismic to ultrasonic frequencies. Assuming that the formation conforms to the characteristics of VTI medium, the experiments were carried out at a confining pressure range between 5 and 30MPa in the frequency range 1 to 1000Hz using two samples drilled in vertical and parallel directions to the formation bedding. And then we not only evaluate the applicability of the anisotropic Gassmann theory to the Inter-Salt shale, but also discuss the experimental phenomenon at mesoscopic and microscopic scales. The results of our broad-frequency experiment study illustrated that the dispersion and attenuation for compression/extension vertical to bedding is larger than that parallel to bedding in partial fluid saturation, and exhibiting different attenuation characteristic peaks. The increase of shear stiffness tensor with frequency seems to indicate the inapplicability of anisotropic Gassmann theory. The interpretation of the attenuation measurements in terms of well-established theoretical models which depict the wave-induced flow of pore fluid at the mesoscopic scale was discussed in terms of the Lithofacies characteristics, include intergranular pores and horizontal interlayer fractures,et al.

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— Laboratory Experiments and Theoretical analysis

Reporter: Zengjia Xiao

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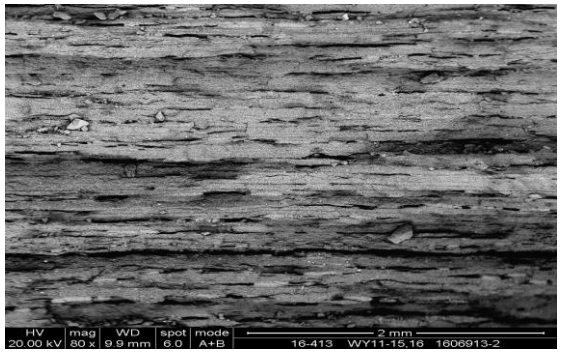
Introduction

Motivation

- shales are anisotropic materials with a transversely isotropic(TI) symmetry. however, the seismic dispersion and attenuation could also be anisotropic in shale oil reservoir?

- Main controlling factors of seismic velocity dispersion and attenuation in shale oil reservoirs: mineral, structure, pore or horizontal micro-cracks and fluid? How to explain it?



Outline of The Report

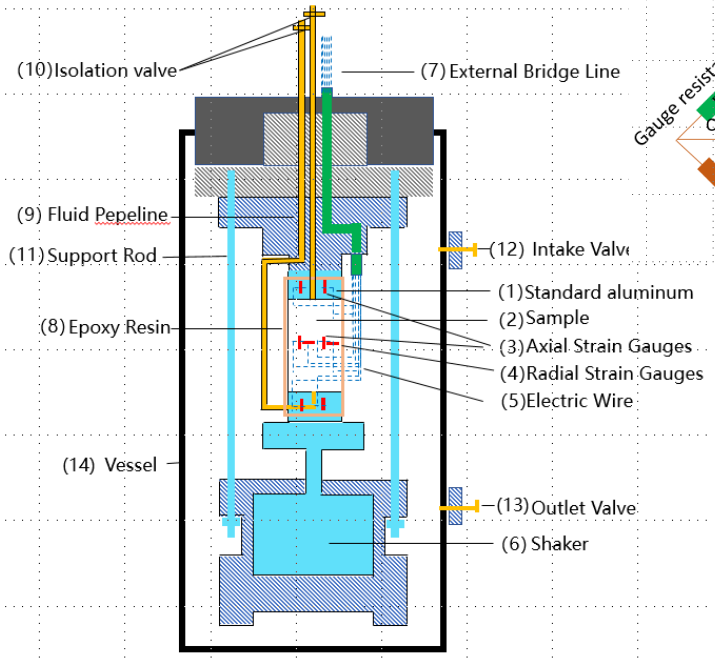
Part Ⅰ: Description of Experiment Details

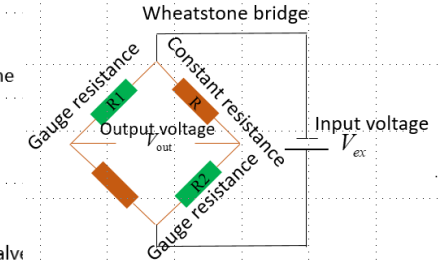
Part Ⅱ: Experimental Results and Discussion

Part Ⅰ:Description of Experiment Details

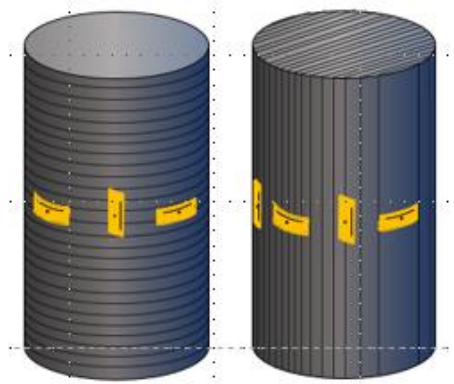
Experimental apparatus and test method

How to get the TI's medium Young's modulus and Poisson's ratio?





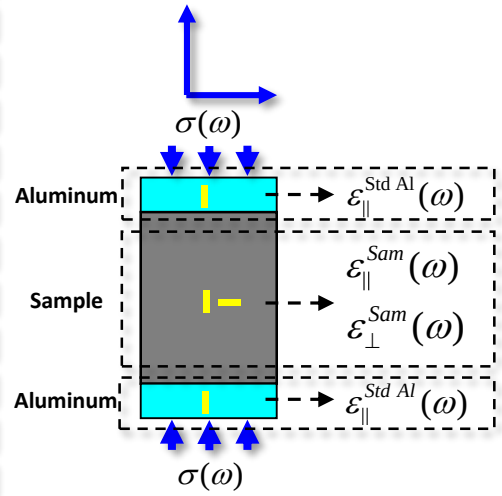
$$\varepsilon = \frac{2V_{out}}{k_{GS} * k_{GF} * V_{ex}}$$



Schematic drawings of the experimental setup (Batzle,2006)

Vertical Sample

Horizontal Sample



Standard Aluminum:

$$E^{Std\ Al} = \frac{\sigma^{Std\ Al}(\omega)}{\varepsilon_{\perp}^{Std\ Al}(\omega)}$$

Shale Sample:

$$E_{H,V}(\omega) = \frac{\sigma^{Sam}(\omega)}{\varepsilon_{\parallel}^{Sam}(\omega)} = \frac{\sigma^{Std\ Al}(\omega)}{\varepsilon_{\parallel}^{Sam}(\omega)}$$

$$= E^{Sam} \bullet \frac{\varepsilon_{\parallel}^{Std\ Al}(\omega)}{\varepsilon_{\parallel}^{Sam}(\omega)}$$

$$\nu_{HH,HV,VH}(\omega) = \frac{\varepsilon_{\perp}^{Sam}(\omega)}{\varepsilon_{\parallel}^{Sam}(\omega)}$$

$$Q_E^{-1}(\omega) = \tan(\theta_{\parallel}^{Std\ Al}(\omega) - \theta_{\parallel}^{Sam}(\omega))$$

E_V, ν_{VH} E_H, ν_{HH}, ν_{HV}

Part Ⅰ:Description of Experiment Details

Description of Samples and Experimental Procedure

The characteristics of the shale and the experimental conditions

The vertical and horizontal samples of the shale oil

V-Sample H- Sample

Table1 Sample information

	V-Sample	H-Sample
Depth	2819.13m	2819.13m
Diameter	38.14mm	38.26mm
Length	56.53mm	55.98mm
density	2.35g/cm^3	2.37g/cm^3
porosity	12.09%	11.95%

Table2 Mineral content

Mineral	%
Quartz	10.6
Clay	17.9
Carbonate	34.3
Glauberite	30.7
Others	6.5

Table3 Fluid properties

Fluid	
Name	White oil
Density	0.82g/cm^3
viscosity	6.56mPas
Saturation	92%

Table4 Experiment conditions

Frequency range		Confining pressure	Saturability	Temperature
1-2000Hz	1MHz	5-30MPa	92%	25℃

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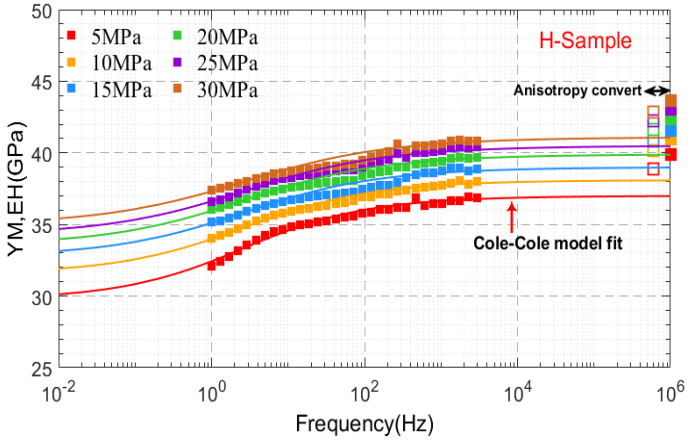
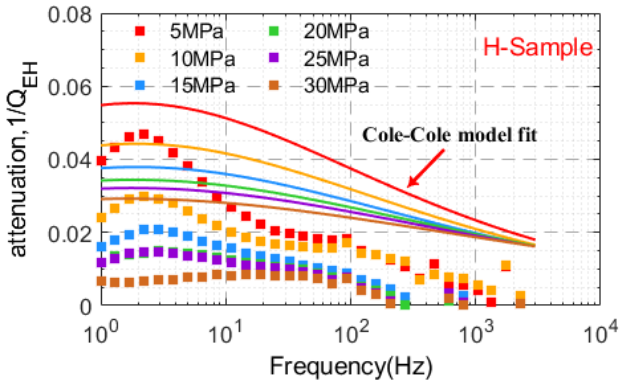
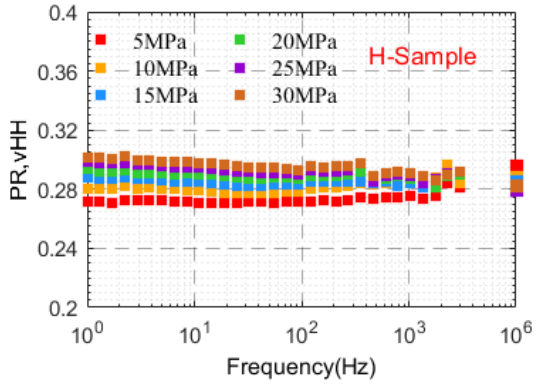
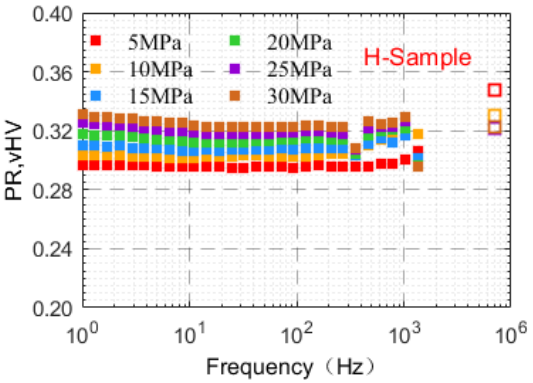
TI's Young's Modulus and Poisson's Ratio and attenuation

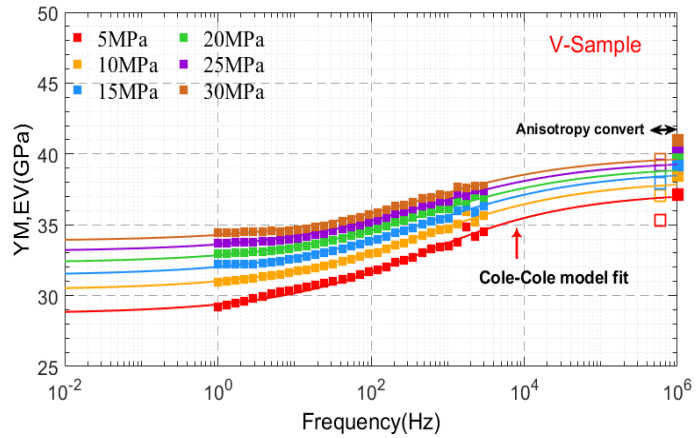
The Young's modulus dispersion and extensional attenuation are anisotropic

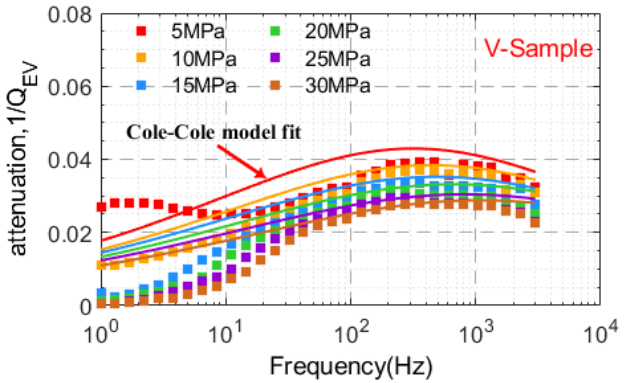


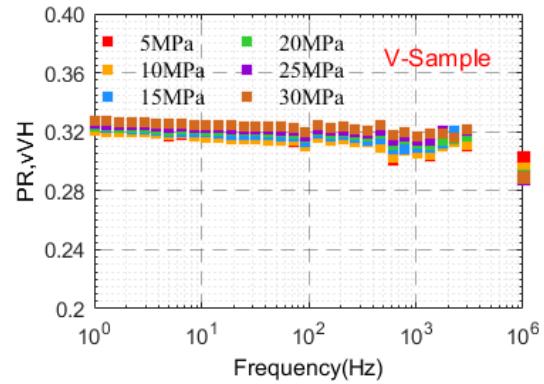


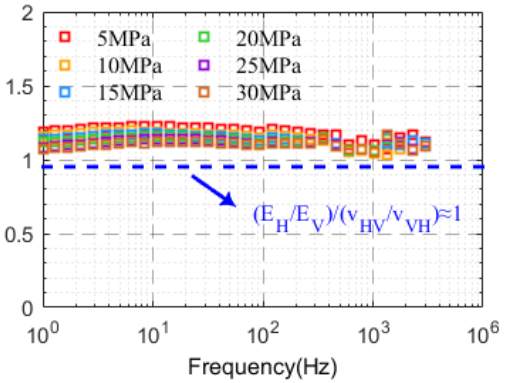








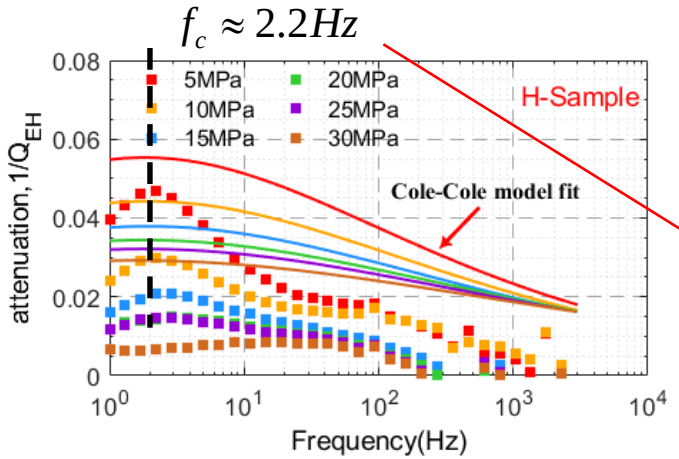


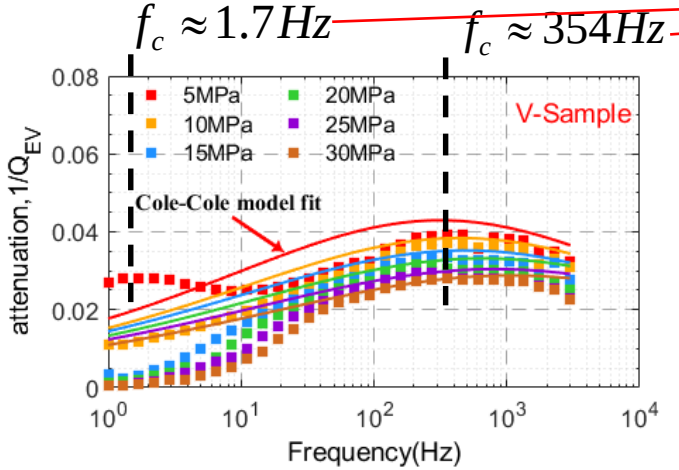


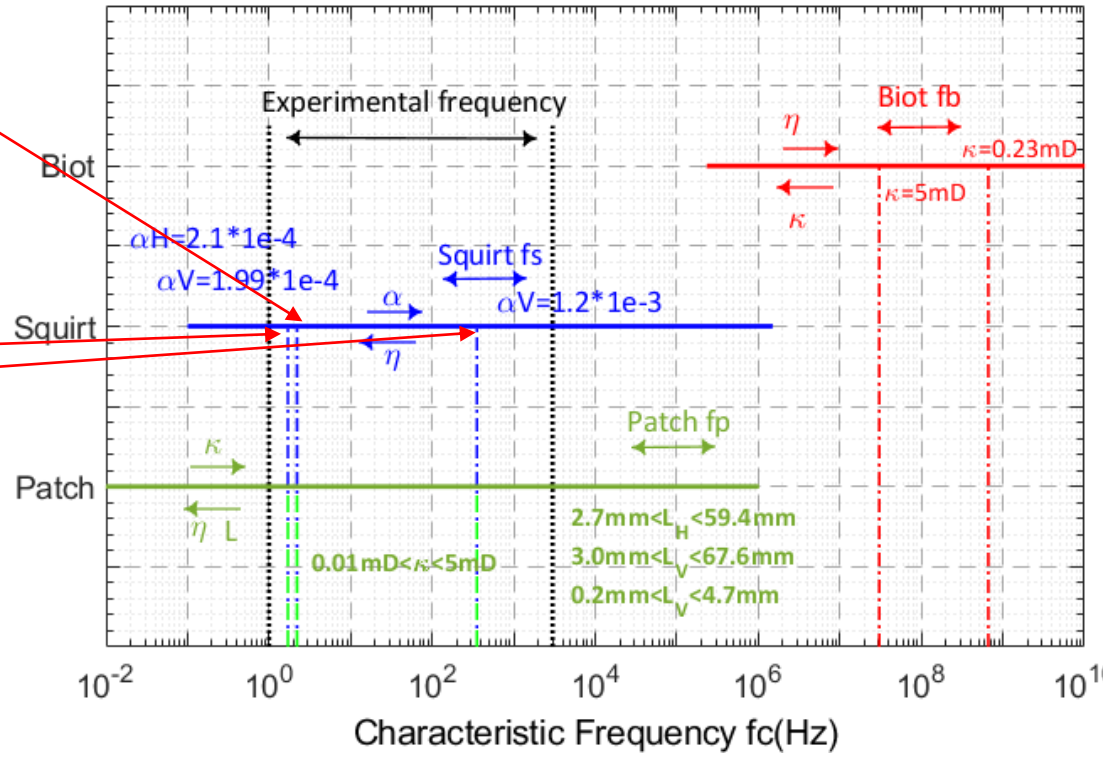
Part Ⅱ:Experimental Results and Discussion

Discussion of dispersion and attenuation

Compare different attenuation mechanisms based on characteristic frequencies







macroscopic scale:

$$f_{biot} \approx \phi\eta / 2\pi\rho_{fl}\kappa \quad ①$$

microscopic scale:

$$f_{squirt} \approx K_0\alpha^3 / \eta \quad ②$$

Mesoscopic scale:

$$f_{patchy} \approx \kappa K_s / \pi L^2 \eta \quad ③$$

Mavko et al. 2009

Conclusions

- Our measurements demonstrate the seismic dispersion and attenuation are anisotropic and pressure-sensitive in shale oil reservoir.

- Shale seismic dispersion and attenuation factors are complex and may include one or more of the existing theoretical mechanisms, mesoscale fluid patchy saturation and microscale squirt-flow.

And further research will be conducted.

Acknowledgement

Thank you for listening!