PS Simultaneous Measurement of Acoustic and Electrical Anisotropy of Shales under Elevated Pressure: A Preliminary Study*

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Abstract

Low-porosity shales are generally considered transverse isotropic (TI) materials, both elastically and electrically. This paper explores the correlation of elastic and electrical anisotropy of shales to mineralogy and organic richness. Both elastic and electrical anisotropies in rocks are known to be functions of clay and kerogen contents. The elastic anisotropy in clay- and organic-rich shales is related to their laminated and lenticular texture that is enhanced with compaction and diagenesis leading. The correlation of complex resistivity and anisotropy in shales with clay content has been theoretically modeled using the cation exchange capacity of the clay minerals. Although it appears likely that elastic and electrical anisotropy might be controlled by similar petrophysical properties, very little research exists that explores the relationship between these two anisotropies and how petrophysical properties might influence them. This paper presents experimental data of elastic and electrical anisotropy in shales acquired with a new system that allows simultaneous measurements of acoustic velocities and complex resistivities under hydrostatic pressure in three directions: parallel, 45°, and perpendicular to any orientation, such as bedding planes. The results of five shale samples show the following: -Elastic and electrical anisotropy are inversely related to pressure. -Electrical anisotropy is generally higher than elastic anisotropy. -Electrical anisotropy is more sensitive to pressure change. -Complex resistivity anisotropy for in-phase and phase resistivity is highly dependent on frequency. Future plans are to measure shale samples with varying clay and organic contents and correlate anisotropy to petrophysical properties.

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Revil, A., W.F. Woodruff, C. Torres-Verdín, and M. Prasad, 2013, Complex conductivity tensor of anisotropic hydrocarbon-bearing shales and mudrocks: Geophysics, v. 78/6, p. D403-D418.

Sone, H., 2012, Mechanical properties of shale gas reservoir rocks and its relation to the in-situ stress variation observed in shale gas reservoirs: Doctoral dissertation, Stanford University, Stanford, California.

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Woodruff, W.F., A. Revil, and C. Torres-Verdín, 2014, Laboratory determination of the complex conductivity tensor of unconventional anisotropic shales: Geophysics, v. 79/5, p. E183-E200.

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I. ABSTRACT

This study explores the correlation of acoustic and electrical anisotropy of shales to mineralogy and organic richness. It provides experimental data of acoustic and electrical anisotropy in shales acquired with a new system that enables the simultaneous measurements of acoustic velocities and complex conductivities under hydrostatic pressure in three directions: parallel, 45°, and perpendicular to any orientation, such as bedding planes. Three anisotropic parameters are discussed:

- Acoustic velocity anisotropy
- Acoustic wave attenuation anisotropy
- Complex conductivity anisotropy

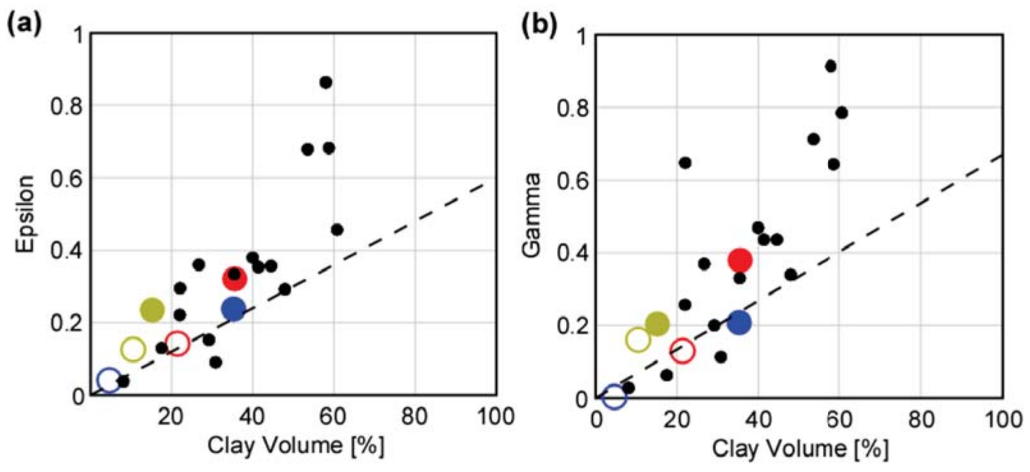
The results of the shale samples show an inverse correlation between acoustic and electrical anisotropy and confining pressure. Acoustic attenuation and resistivity anisotropy exist in samples with limited velocity anisotropy and are more sensitive to pressure variation.

II. INTRODUCTION

Both elastic and electrical anisotropies in rocks are known to be functions of clay and kerogen contents.

Acoustic Anisotropy

The elastic anisotropy in clay- and organic-rich shales is related to their laminated and lenticular texture that is enhanced with compaction and diagenesis leading. Various studies show that velocity anisotropic parameters of shale samples are strongly correlated to the clay and kerogen content of the rock (Vernik and Liu 1997; Sone 2012).



(Sone, 2012)

The study of the relationship between attenuation anisotropy and clay/organic content on organic-rich shales is highly limited. This study may shed light on controlling factors of wave propagation in shales, especially for the formations with limited velocity anisotropy, and provide a new method to interpret the organic contents and textures of shales.

Electrical Anisotropy

Revil et al. (2013) developed theoretical model to describe and predict anisotropic complex conductivity of porous media using saturation, salinity, tortuosity, formation factor, counterion mobility, and cation exchange capacity.

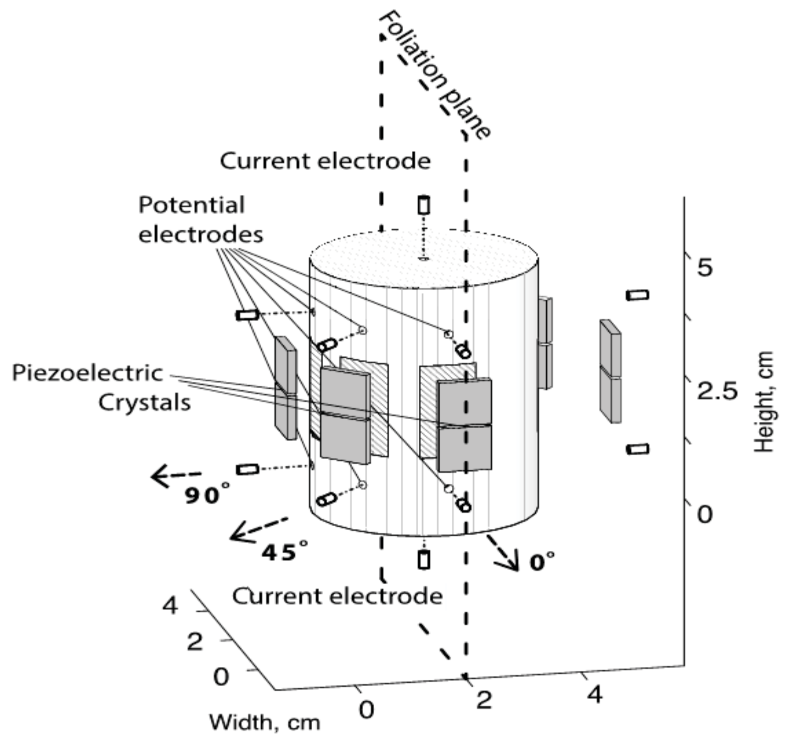
$$\sigma_{ij}' \approx F_{ij}\left(S_w{}^n \sigma_w\right) + T_{ij} S_w{}^p \rho_S \left[\beta_{(+)}(1-f) + \beta_{(+)}^S f\right] \mathrm{CEC}$$

$$\sigma_{ij}'' = T_{ij} S_w{}^p \rho_S \beta_{(+)}^S f_M \,\mathrm{CEC}$$

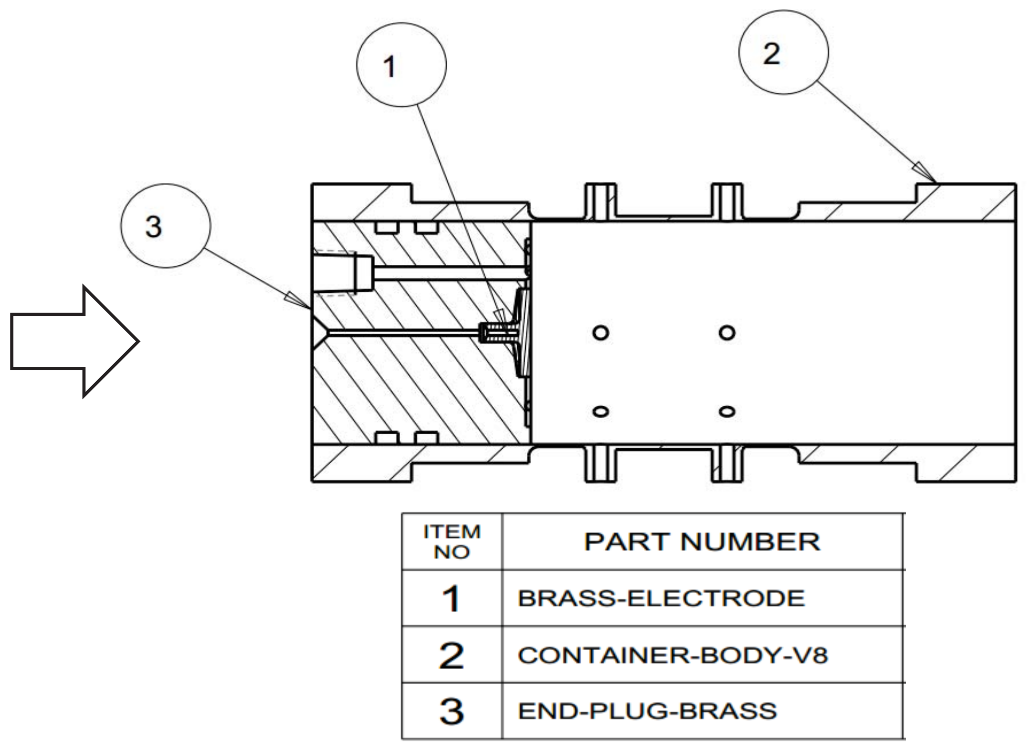
III. METHODOLOGY AND SAMPLES

Methodology

Woodruff et al. (2014) presented method to measure elastic and complex conductivity tensor for same sample simultaneously.

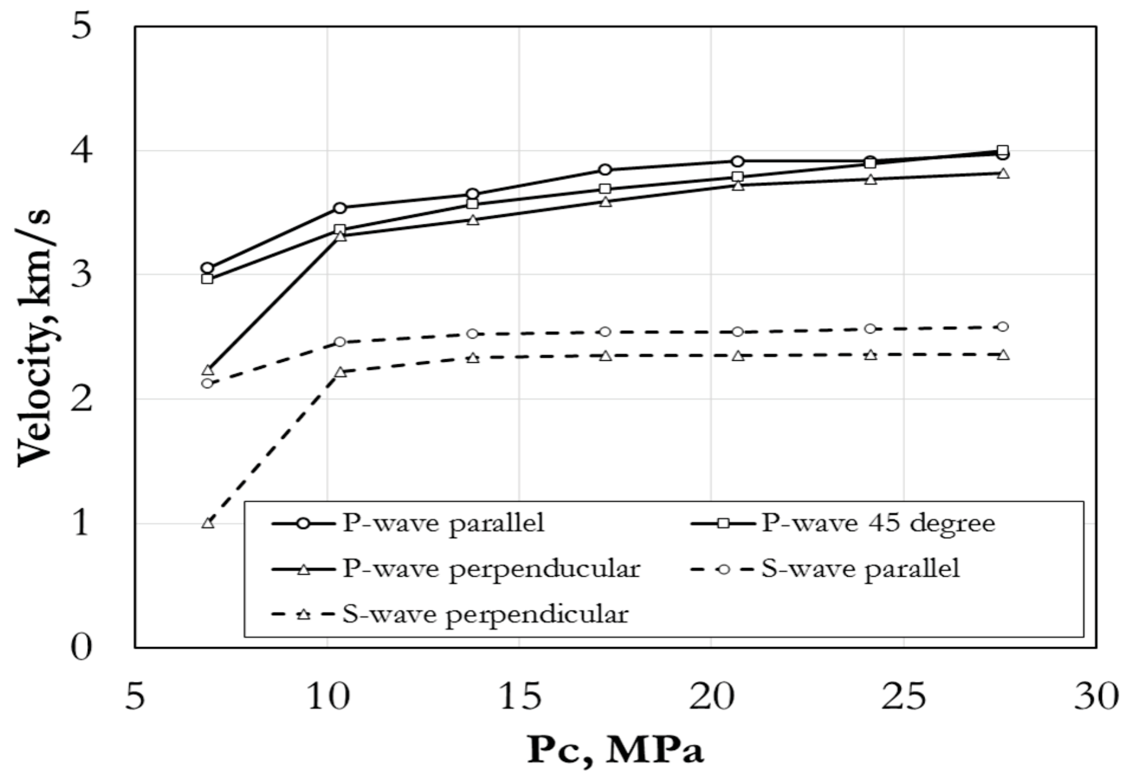


(Woodruff et al. 2014)



ITEM NO	PART NUMBER
1	BRASS-ELECTRODE
2	CONTAINER-BODY-V8
3	END-PLUG-BRASS

Sample jacket designed based on Woodruff's setup (Modified on Andre Panfiloff's design)



The jacket was validated by measuring velocities at three directions to the bedding of one layered sandstone sample under elevated pressures.

Acoustic test: pulse transmission technique (1MHz)
Electrical test: spectral induced polarization (1mHz-45KHz)

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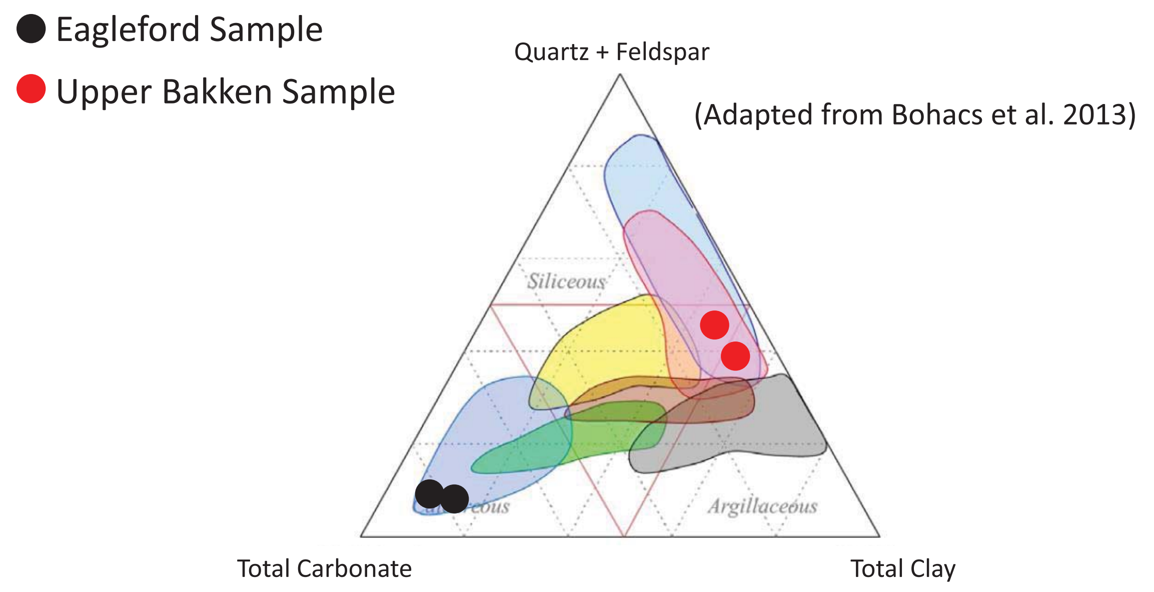
III. METHODOLOGY AND SAMPLES (continued)

Samples

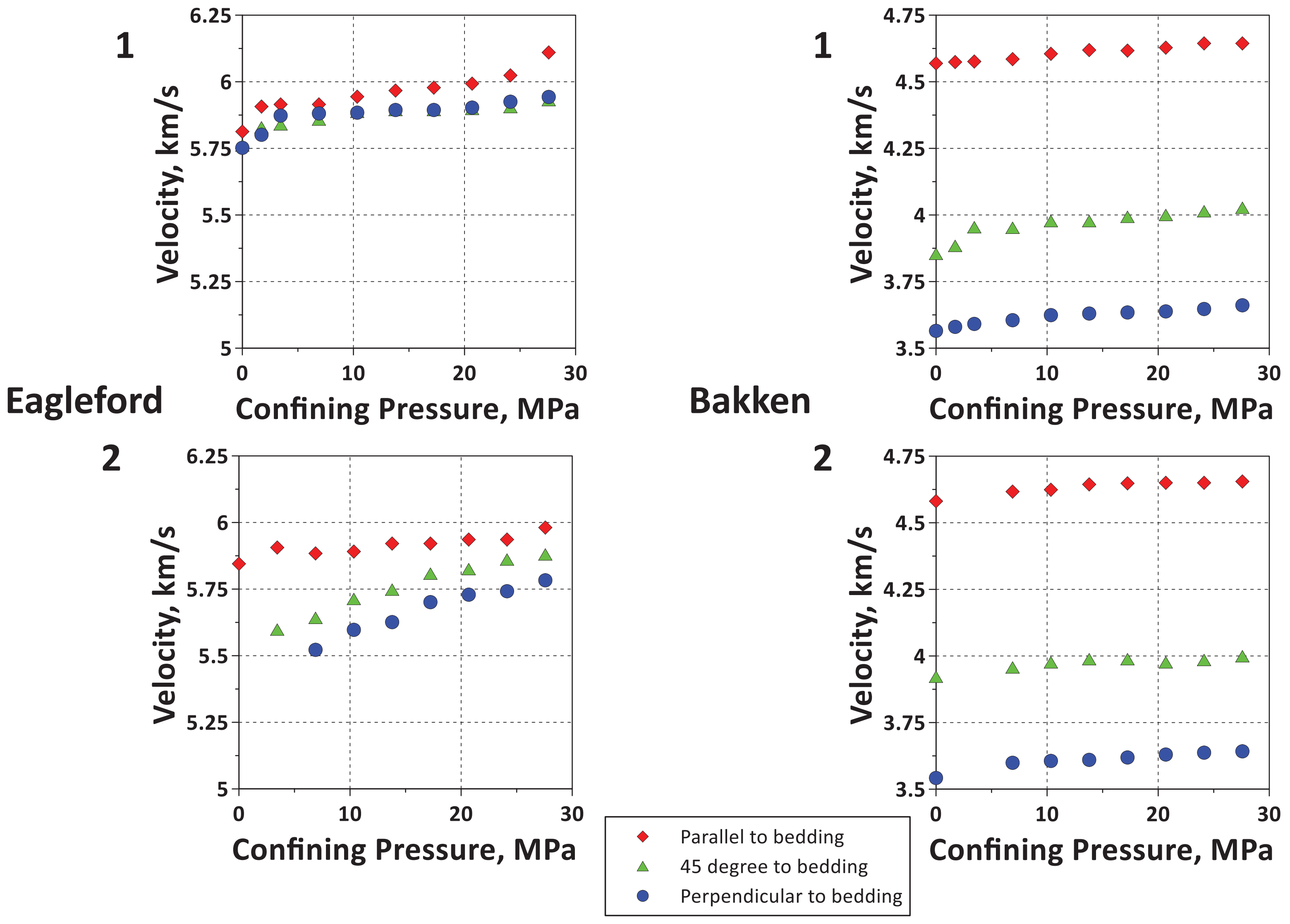


(Adapted from Bohacs et al. 2013)

IV. RESULTS

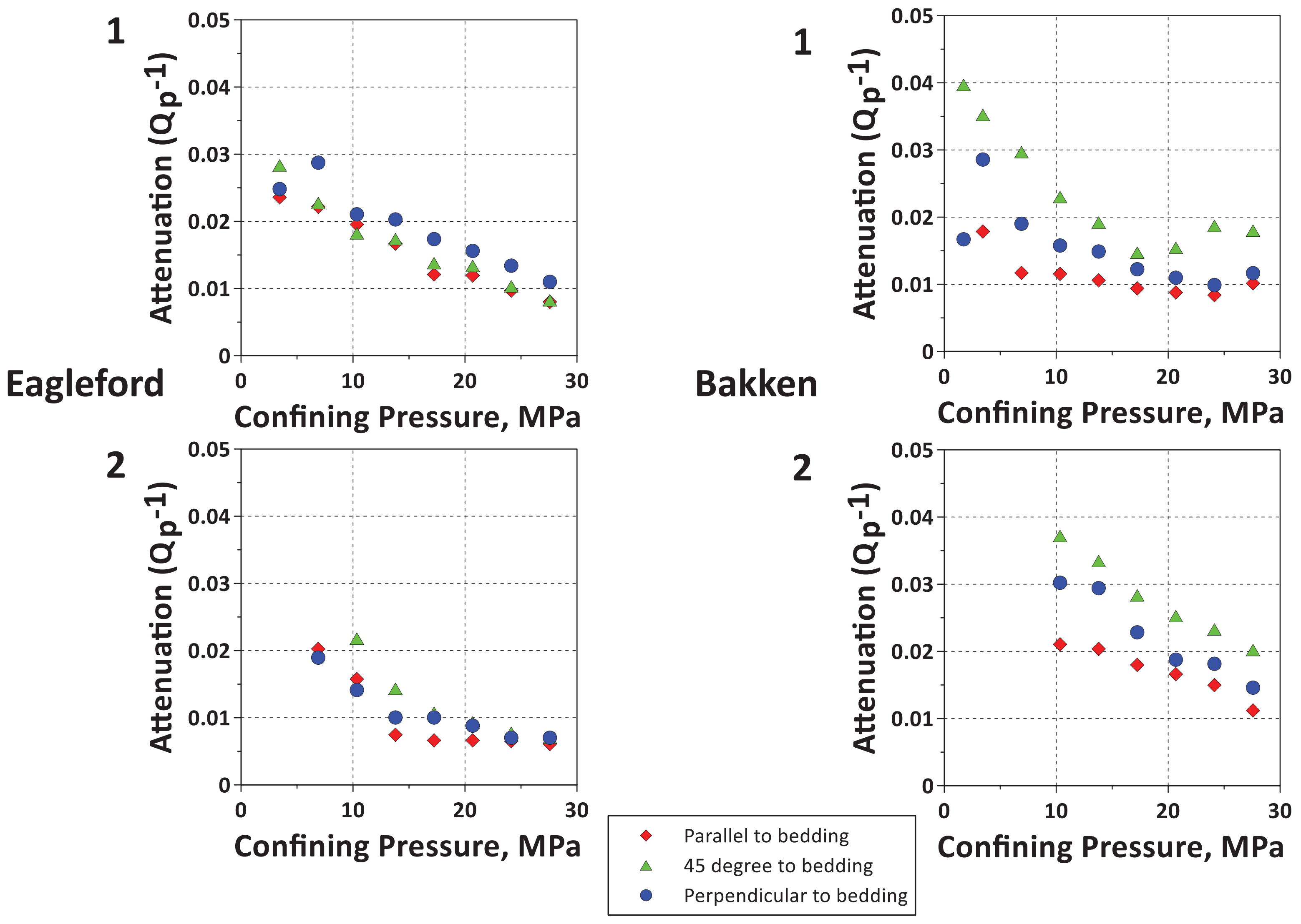
Velocity as Function of Pressure

Pressurized measurement up to 28 MPa (4,000 psi):



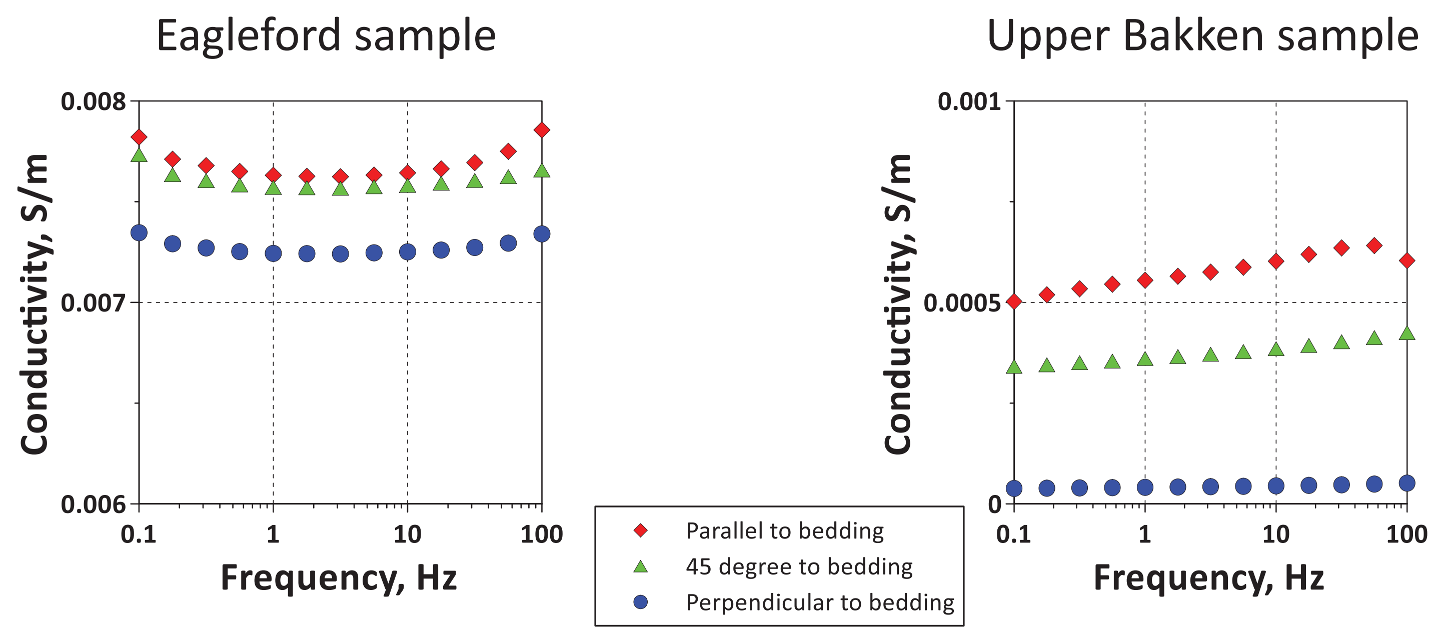
P-wave Attenuation as Function of Pressure

Qp was calculated by spectral ratio method using reference signals through an aluminum sample of similar size as a non-attenuating medium:



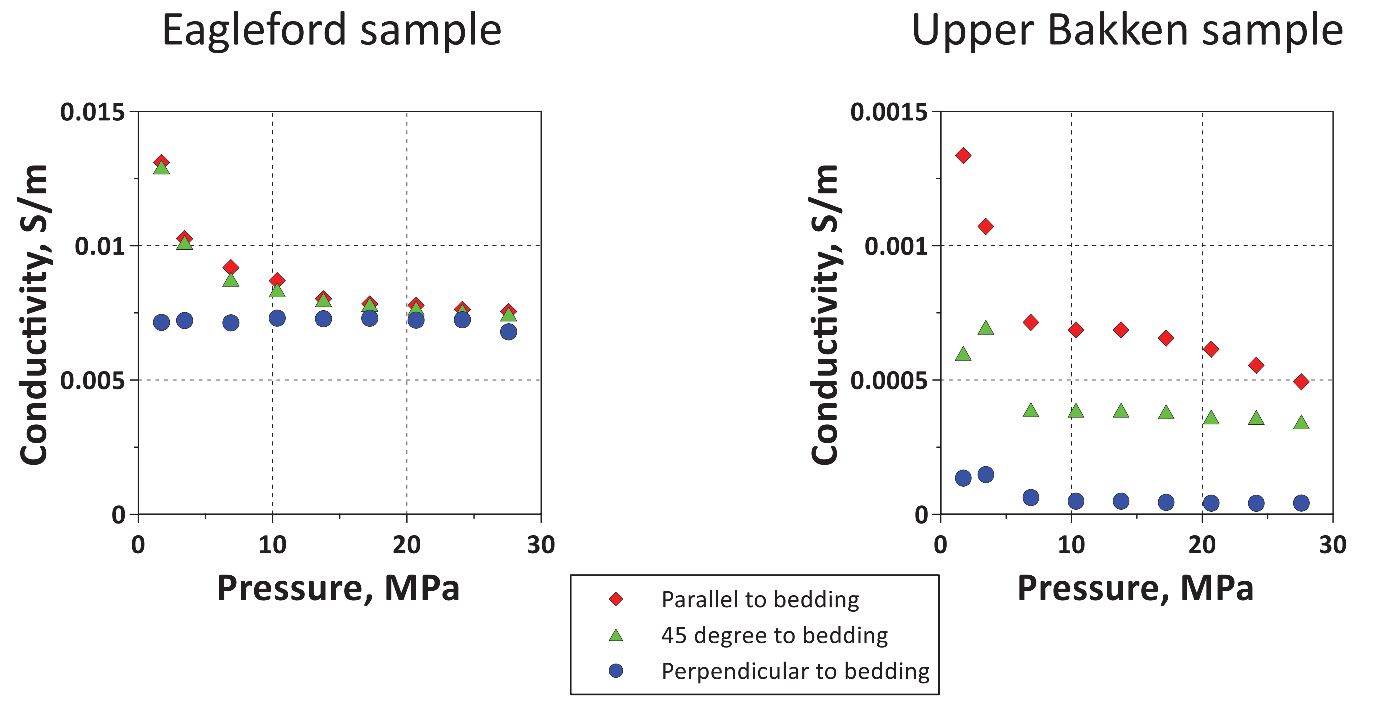
Complex Conductivity Anisotropy

In phase conductivity as function of frequency at 24.1 MPa (3,500 psi):



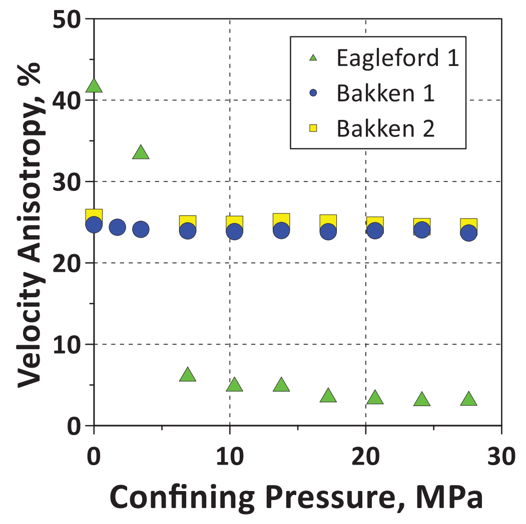
Complex Conductivity Anisotropy (continued)

In phase conductivity as function of pressure at 1 Hz:

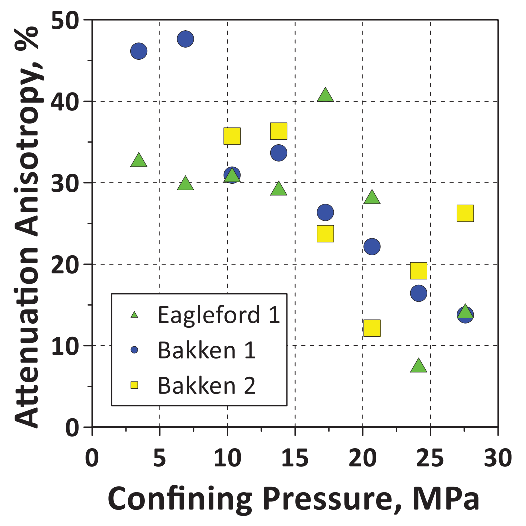


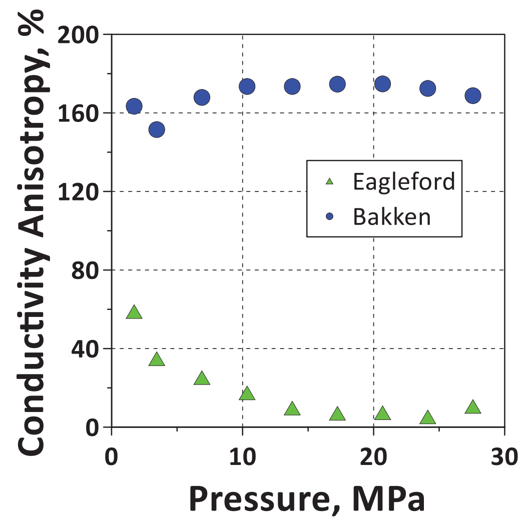
Anisotropy Ratio as Function of Pressure

$$A_{Vp} = 200 \cdot \frac{(V_{ph} - V_{pv})}{(V_{ph} + V_{pv})}$$



$$A_{Qp} = 200 \cdot \frac{(Q_{ph} - Q_{pv})}{(Q_{ph} + Q_{pv})}$$





$$A_{\sigma p} = 200 \cdot \frac{(\sigma_{ph} - \sigma_{pv})}{(\sigma_{ph} + \sigma_{pv})}$$

V. CONCLUSIONS

- The sensitivity of attenuation and conductivity changes with confining pressure is more conspicuous than velocity change.
- Attenuation anisotropy is more significant than velocity anisotropy and could be high even in samples lacking velocity anisotropy.
- Electrical conductivity and anisotropy vary with frequency; the measurements indicate that shales contain more electrical anisotropy than acoustic anisotropy.

VI. ACKNOWLEDGEMENT

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VII. REFERENCES

Revil, A., et al., 2013, Complex conductivity tensor of anisotropic hydrocarbon-bearing shales and mudrocks: Geophysics 78 (6): D403-D418.

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