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EA Seismic Anisotropy VTI Modeling and Mechanical Properties of Kerogen in Gas Shale*

Anggoro S. Dradjat[1], Agus Djamil[1], and M. Firwan Aprizal[1]

Search and Discovery Article #42486 (2020)**
Posted January 20, 2020

*Adapted from extended abstract based on oral presentation given at 2019 AAPG Asia Pacific Region, The Art of Hydrocarbon Prediction: Managing Uncertainties Technical Symposium, Bogor (Greater Jakarta), Indonesia, August 7-8, 2019
 DOI:10.1306/42486Dradjat2020

[1]Panji Laborta Institute, Jakarta, Indonesia (adradjat.geo@gmail.com)

Abstract

Geology and Geophysics risk uncertainty of shale gas reservoir development could be reduced by understanding the Kerogen fraction, mechanical properties of mineralogy in shale, and seismic amplitude response. Mechanical properties of rocks mineralogy and fraction of kerogen in shale are among the key factors for developing shale gas which may or may not be present as sweet spot on seismic data. The goal of this study is generating deterministic mechanical modeling for predicting seismic sweet spot and selecting mechanical criteria for target fracturing zones of shale gas reservoir. Mechanical properties of shale on surface depend on mineralogy, porosity and fraction of kerogen. Rock strength (UCS) will decrease gradually by increasing fraction of kerogen, quartz + dolomite and porosity. Rock strength will be used for estimate fracturing pressure at certain depth. Young Modulus of shale will increase by increasing fraction of quartz and dolomite, while Poisson ratio will decrease by increasing kerogen. Selecting criteria for shale fraccability are low rock strength, low Poisson ratio and higher modulus Young. Seismic amplitude response of layering shale can be quantified through physical process using seismic P and S wave velocity measurement. Seismic amplitude response of kerogen fractions in shale can be generated through modeling based on AVO VTI anisotropy method by using Thomsen parameter. The result of amplitude modeling using Bakken shale data shows that the response of fraction kerogen in gas shale has negative amplitude reflection and decreasing with offset. Based on this result, it is recommended to use the intercept and gradient method for predicting kerogen sweet spot by using common midpoint seismic gather data.

Introduction

Indonesia has large potential shale gas energy need to be developed in the future. However due to oil prize declining in the last view decade there are no more activity related to shale gas exploration and exploitation. The goal of study is on how to create criteria for development gas shale, two important concern things are fracability and kerogen sweet spot of gas shale using seismic data. For this purpose, it is important to understand mechanical and reflection amplitude sweet spot response of kerogen fraction in shale, to reduce risk uncertainty of shale gas reservoir development. However, there are only a view studies on gas shale in Indonesia, so for this studying we are using data that we found from published papers (Hui et. al., 2012; Sonnenberg, 2012; Lev and Nur, 1992) and using excel spread sheet to create mechanical model and seismic amplitude vertical transfer isotropy (VTI) modeling response on various fraction of Kerogen in layering shale.

Mechanical Modeling of Kerogen in Gas Shale

Two for keys descriptor for mechanical characterizing unconventional gas shale are ductile and brittle; those are related to plastic and elastic behavior. Brittle lithology such as dolomite or sandstone said to be easier to break by stress because having elastic properties, rock strength (UCS) is mechanical word refer to how much force to break rock at earth surface, less rock strength is easier to break. Ductile lithology is described for lithology having mechanical properties like plastic deformation (Slatt and Abousleiman, 2011).

Natural fracture in shale generated by weak tectonic stress because of low stiffness elastic properties, as stress continues higher plastic deformation had occurred. Porosity in shale caused by fracture, shale has high porosity and less permeability because of disorientation of natural fractures in shale; mechanical properties of shale are variated depending on diagenetic had occurred. Mechanical properties of shale are in variation range from elastic to plastic and to become viscous by increasing bound water contain, clay mineralogy such as Smectite of having large internal surface has more mechanical properties changes by bound water, while other clay mineralogy has small internal surface such as Illite having elastic mechanical properties and not changes by bound water (Passey et. al., 2010). Mechanical properties modeling is calculated using excel spread sheet by using well drilling log data and P and S wave and laboratory measurement. Poisson ratio, Young modulus and Shear modulus calculated using P and S wave sonic log while rock strength calculated using P wave sonic log only.

Fracturing pressure at the specific depth are depending on rock strength (UCS) and horizontal minimum stress. Mechanical properties of shale on the surface are depending on porosity, mineralogy and percentage of kerogen. Rock strength will decrease by increasing of percentage quartz and carbonate in shale (Dradjat, 2013). Kerogen in shale shows evident of layering in shale as deposited, total organic contain (TOC) is refer to percentage weight of organic matter while Kerogen is refer to percentage of fraction in volume, 20% of TOC correspondence to about 40% kerogen volume, almost twice value (Passey et. al., 2010). Seismic data is responding to space of elastic properties response in sub surface, so geophysicist will prefer to use terminology fraction volume of kerogen for existence of TOC. The relationship between fraction volume of kerogen and rock strength are rock strength decrease by increasing of kerogen fraction volume (Figure 1).

Mechanical study is using Bakken shale publish paper data (Lev and Nur, 1992), shows increasing kerogen in shale will decrease Poisson ratio, decrease Young modulus (decrease stiffness) and decrease rock strength (Figure 2). Mechanical studied on mineralogy quartz and dolomite contains in shale (Dradjat, 2013) shows that increasing fractions those of two minerals will increase stiffness as increasing modulus Young. In our modeling study shows that three mechanical properties that controlled fraccability which are: Rock strength, modulus Young and Poisson ratio (Figure 3). Those of mechanical properties are controlled by three parameters: shale mineralogy, fraction dolomite/ quartz contains and fraction of Kerogen.

Seismic Amplitude AVO VTI anisotropy Modeling

Shale is deposited in horizontal layering, and grain size controlled by rise and fall of sea water level which is reflected energy and deposition environment. Silty shale with organic material usually developed in active low energy environment that created from clays mineral, quartz, carbonate and organic material. If shale deposited in low energy environment and having steady source sediment and there is not much variation in sea level changes tend to create homogenous shale, in which shale having similar of mechanical properties in horizontal and vertical directions and these shale said to be having isotropic. As shale deposited in layering, mechanical properties of shale in direction perpendicular layering are difference with direction parallel to layering shale, the differences of mechanical properties in both directions called mechanical anisotropy; measuring mechanical response on horizontal stratification is by using seismic P wave velocity traveling vertical to layering is called VTI, Vertical Transfer Isotropic (Ruger, 1997) see Figure 4.

Fundamental of rock mechanical properties mathematically are modeled by stiffness matrix, sonic log measurement by vertical well drilling which is recording P wave velocity are measuring stiffness matrix C33 and density, and 33 stands for source and receiver measurement of P wave velocity are in the vertical. C11 is stiffness matrix of P wave velocity measurement with both of source and receiver in horizontal position; C11 laboratory measurements are using horizontally core data (Lev and Liu, 1997) see Figure 5.

In case C11 equal to C33 the shale is having similar mechanical properties P wave velocity horizontal and vertical, that mean homogeneous shale which is non prospective shale, and P wave velocity Thomsen anisotropy parameter epsilon=(C11-C33)/2C3 are equal zero. If in case of vertical velocity P Wave traveling slower than horizontal due to increasing of fraction volume of kerogen (Lev and Nur, 1992) the epsilon value becomes larger than zero. Second parameters for measuring mechanical anisotropy is gamma or S wave velocity Thomsen parameter which is measuring difference in S wave velocity between horizontal and vertical, the last one is delta parameter (Banik and Egan, 2012) as in Figure 6.

Thomsen parameter are measuring mechanical properties differences between vertical and horizontal; the values are depending on how much vertical velocity changes and it is called Vertical Transfer velocity (VTI), Increasing kerogen in shale will increase Thomsen anisotropy parameter because decreasing vertical velocities. Thomsen (1993) showed that VTI response could be added the AVO (Amplitude Versus Offset) response of Aki-Richards equation and the modified by using parameter anisotropy delta and gamma, and Ruger (2002) gave equation seismic amplitude versus offsets response of VTI anisotropy. By using excel spread sheet shows increasing percentage fraction volume kerogen in shale will increase negative reflection and increasing gradient reflections (Figure 7). It is recommended to use the intercept and gradient method for predicting kerogen sweet spot by using common midpoint seismic gather data of 3D seismic data.

Conclusion

Mechanical properties of shale on the surface are depending on digenetic process, mineralogy, porosity, percentage kerogen. Mechanical shale fracabillity criteria are: Low rock strength, high Young modulus and low Poisson ratio. Increasing quartz and dolomite fractions in shale will increase Young modulus properties and increasing kerogen will decrease Poisson ratio, while shale rock strength will decrease by increase of kerogen. Shale anisotropy is layering shale generated by active sedimentation process; environment energy and source sediments changes create vertical variations on mineral distribution and kerogen contains. Kerogen fraction in shale can be predicted by using seismic Amplitude Versus Offset Vertical Transfer Isotropy Method (AVO VTI). Based on our modeling result we are recommending to proposed intercept and gradient method from 3D Seismic Data for predicting sweet spot kerogen in shale by using seismic CMP gather data.

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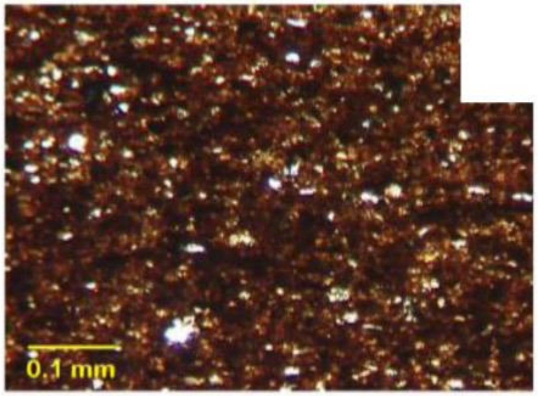
Kerogen and Rock Strength

PS Source Rock Evaluation for the Bakken Petroleum System in the Williston Basin, North Dakota and Montana*

Hui Jin[1], Stephen A. Sonnenberg[1], and J. Fredrick Sarg[1]

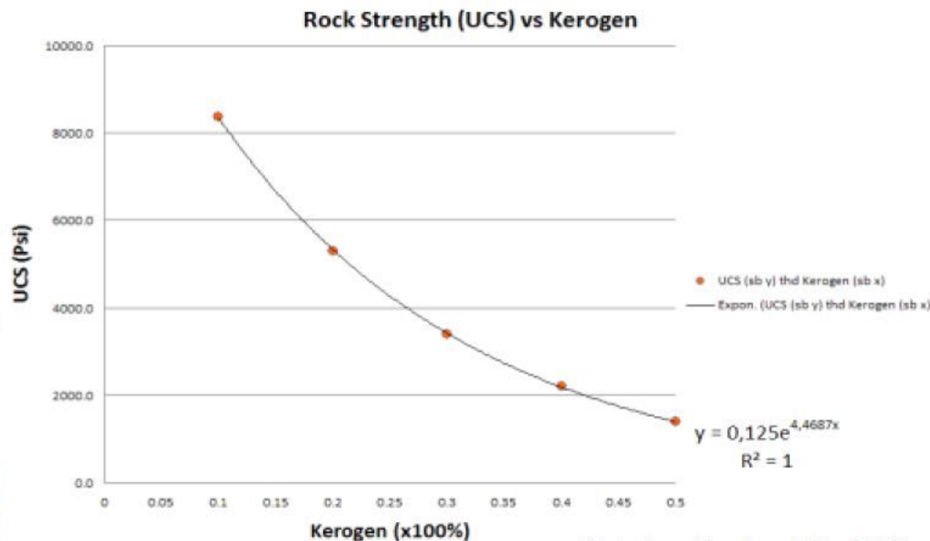
Search and Discovery Article #20156 (2012)**
Posted July 2, 2012



Braaflat 9864
Upper Bakken shale
Sec. 11-T153N-R91W

TOC 14.1
Tmax 431
HI 566
PI 0.07

Figure 7. Petrographic thin section observation of upper and lower Bakken shales (Sec. 11-T153N-R91W) with TOC and pyrolysis results indicated.



(Data from Vernik and Liu, 1997)

Increasing Kerogen, decreasing rock strength

Passey, et al., From oil-prone source rock to gas-producing shale reservoir... (2010) SPE 131350

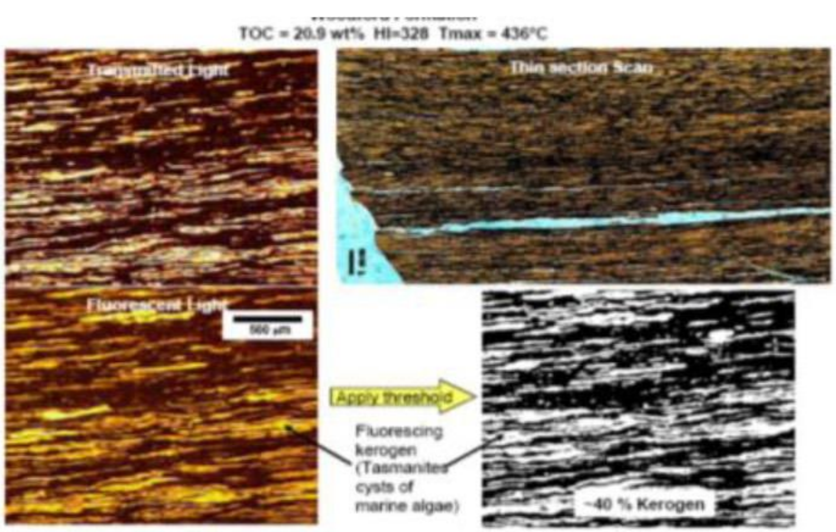


Figure 14 – Woodford shale thin section scan showing kerogen layers; note that 20 wt% TOC corresponds to about 40 vol% kerogen.

20% of TOC correspondence to about 40% kerogen volume, almost twice value.

Seismic data are responding to fraction volume of Kerogen in shale

Figure 1. Relationship Kerogen fraction volume in shale and rock strength.

Mineralogy Shale and Rock Strength

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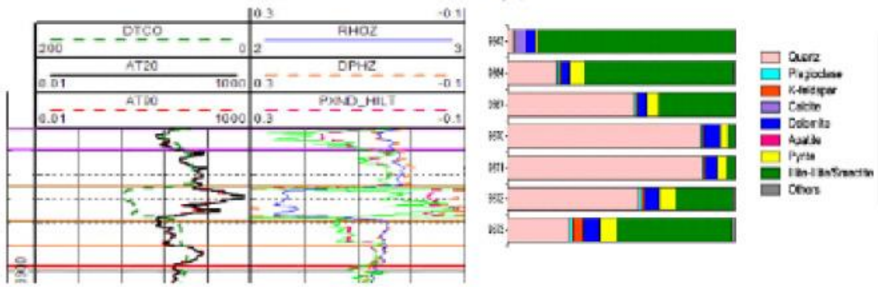
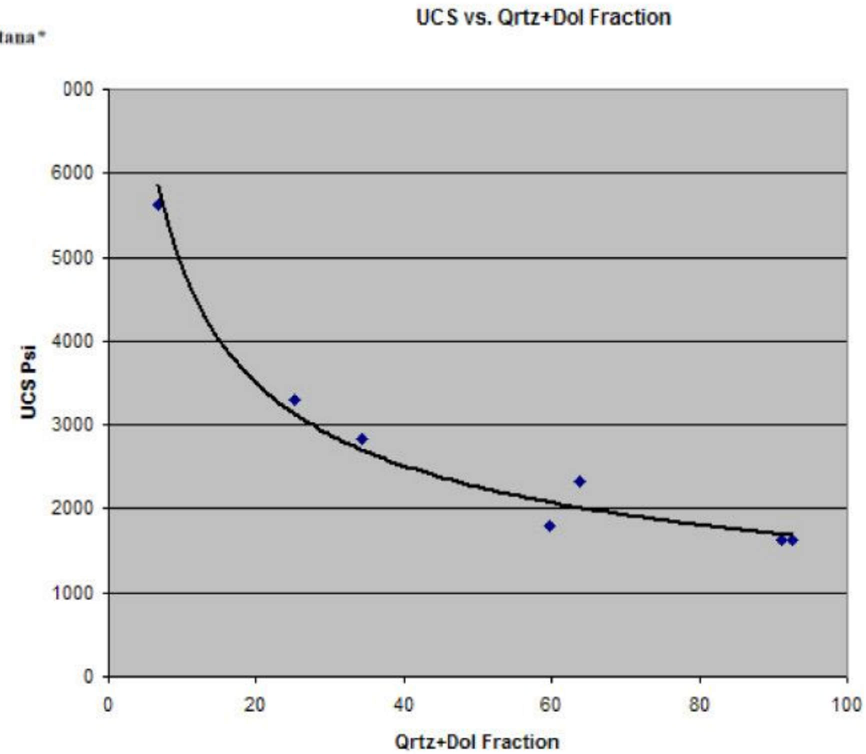


Depth	Sonic (Log)	Vp	Density (Log)	Quartz	Dolomite	Quartz+Dolomite	C33	UCS
9843	80.00	3.811	2.400	2.35	4.41	6.76	34.9	5623
9864	96.00	3.176	2.600	21.76	3.53	25.29	26.2	3296
9867	118.00	2.584	2.850	55.88	3.82	59.71	19.0	1801
9870	122.00	2.499	2.850	85	7.65	92.65	17.8	1633
9871	122.00	2.499	2.820	85.88	5.29	91.18	17.6	1633
9872	108.00	2.823	2.770	57.65	6.18	63.82	22.1	2334
9873	101.00	3.019	2.500	27.35	7.06	34.41	22.8	2840

Digitized of quartz +dolomite fraction, sonic, density of upper Bakken shale data.



Increasing percentage of quartz+ dolomite will decrease rock strength

Mechanical properties: *rock strength are decreasing by increasing percentage of quartz and dolomite*

Figure 2. Quartz and dolomite Fraction in shale and rock strength.

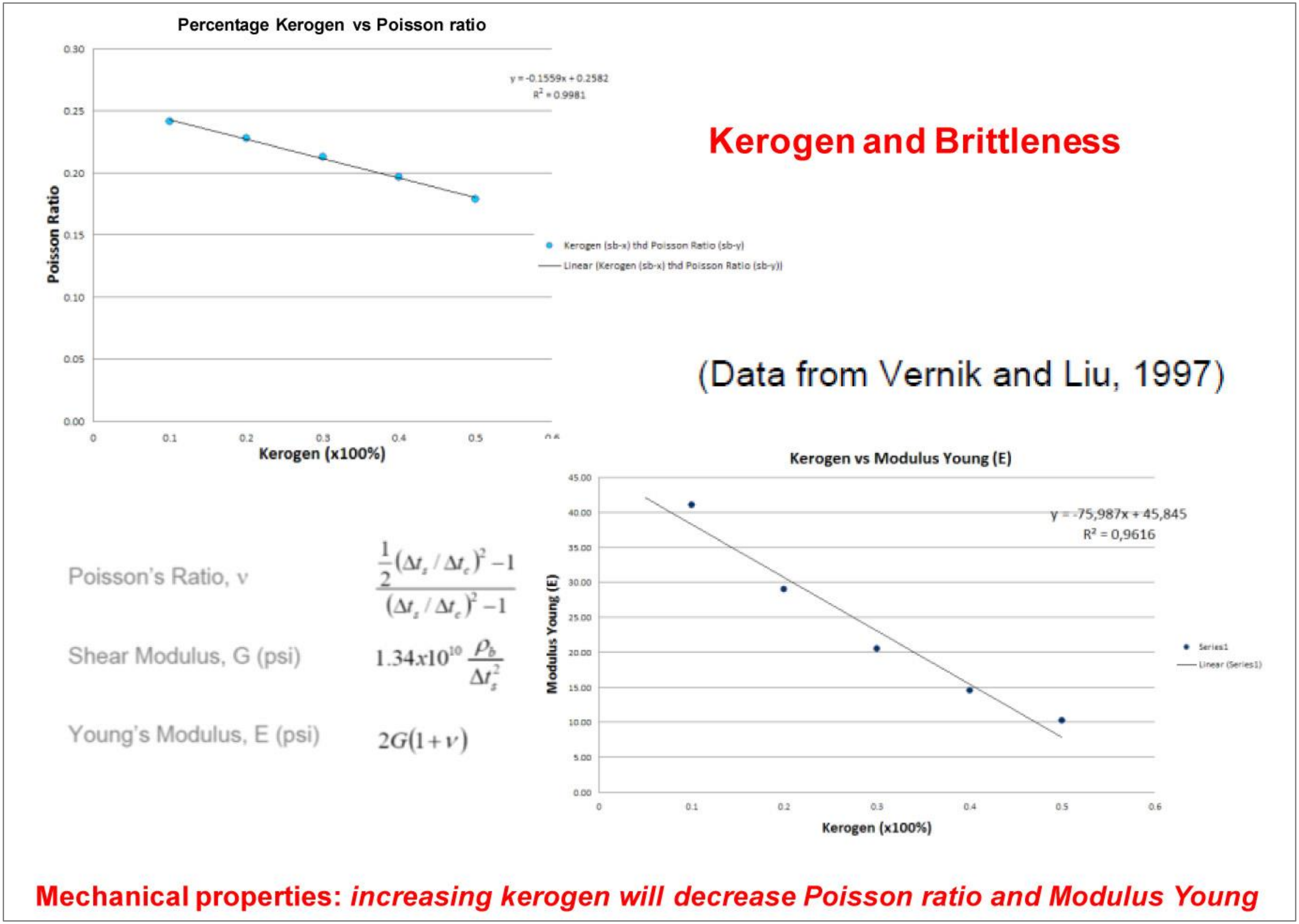


Figure 3. Kerogen fraction and brittleness.

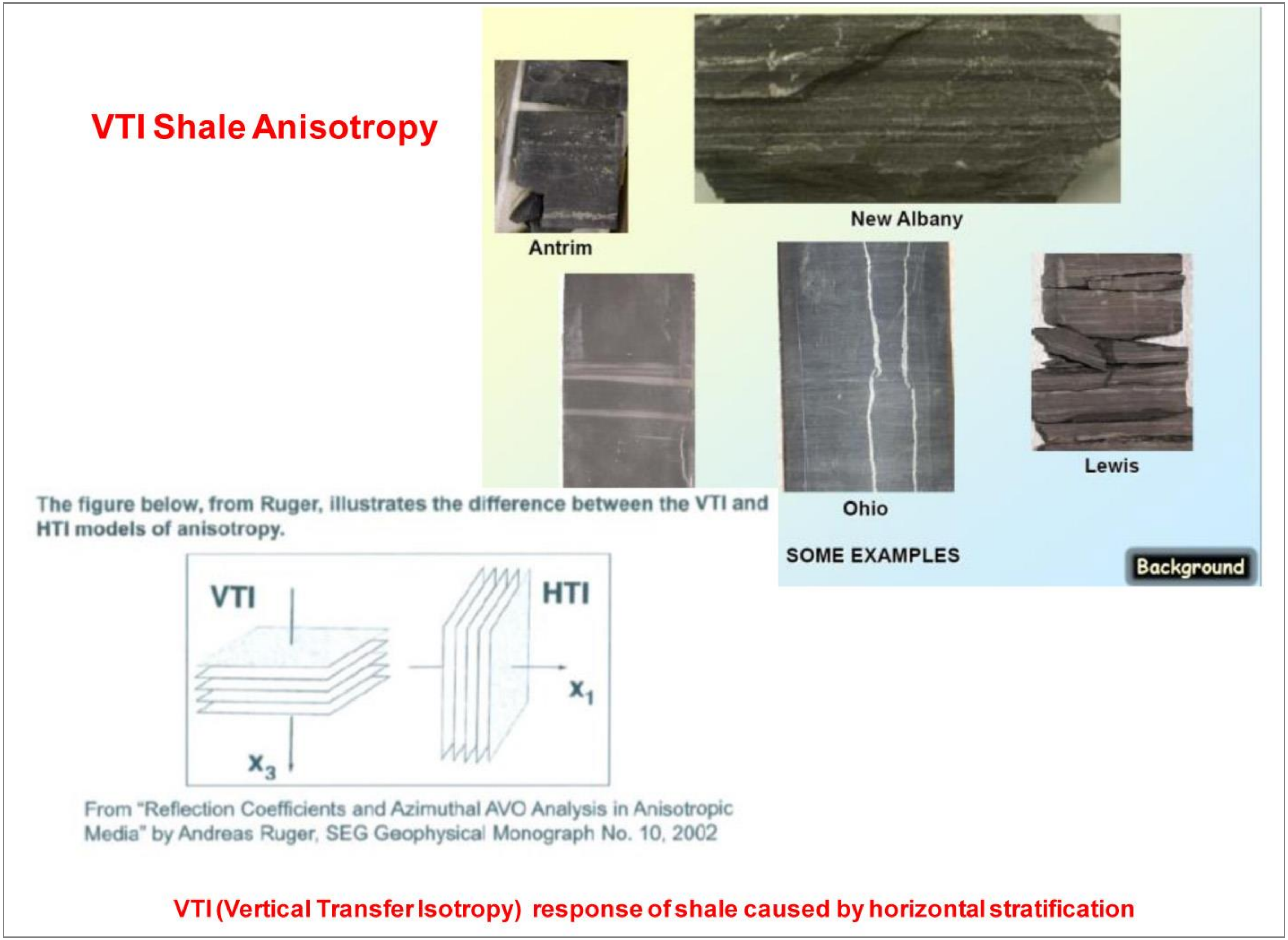


Figure 4. Shale VTI (Vertical Transfer Isotropic).

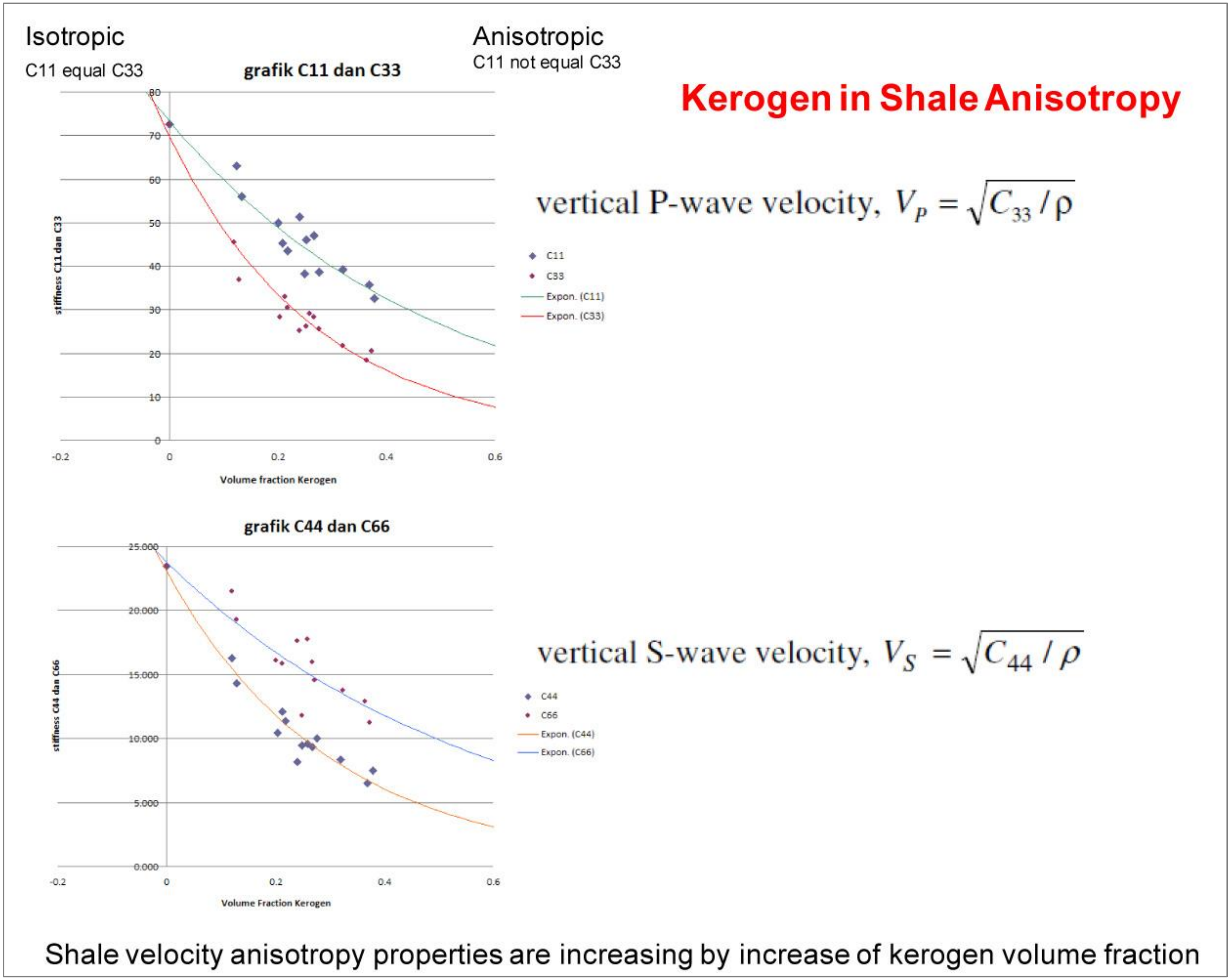
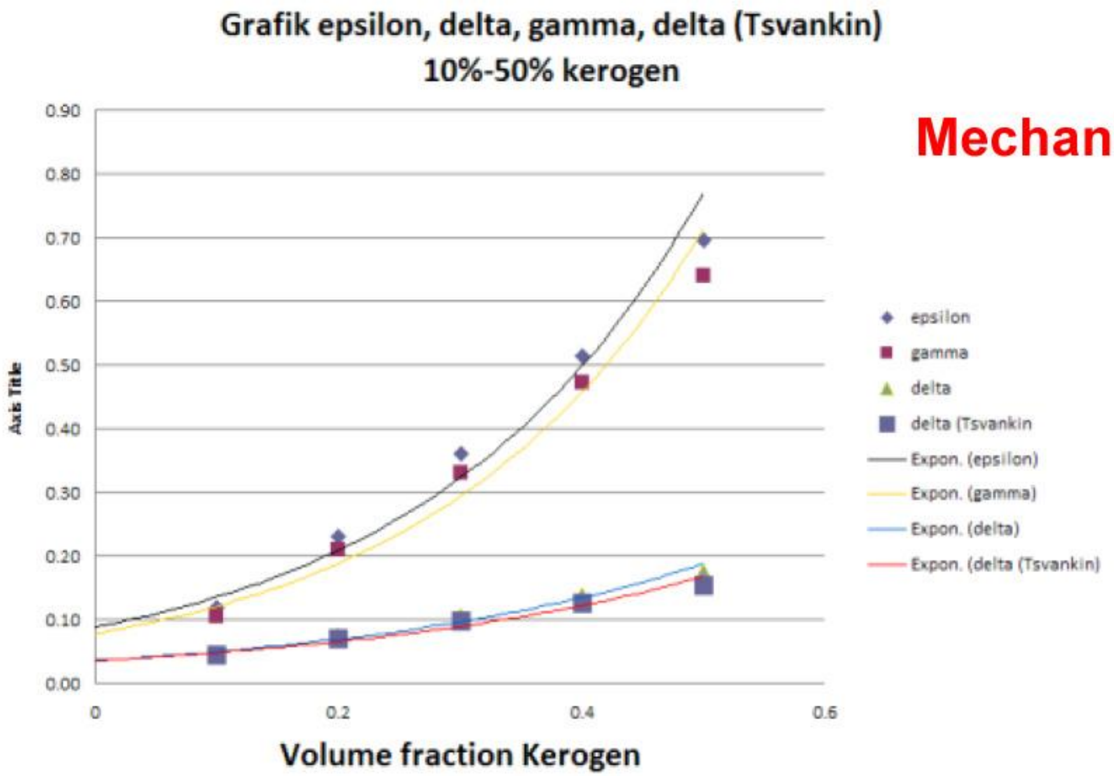


Figure 5. Vp and Vs vertical velocity wave; stiffness matrixes C33 for Vp and for C44 Vs.

Mechanical VTI Anisotropy



P-wave anisotropy parameter, $\varepsilon = \dfrac{C_{11} - C_{33}}{2C_{33}}$

S-wave anisotropy parameter, $\gamma = \dfrac{C_{66} - C_{44}}{2C_{44}}$

$$\delta = \frac{(C_{13} + C_{44})^2 - (C_{33} - C_{44})^2}{2C_{33}(C_{33} - C_{44})}$$

Increasing Kerogen in shale will increase Thomsen anisotropy parameter

Figure 6. Shale mechanical anisotropy of kerogen in shale.

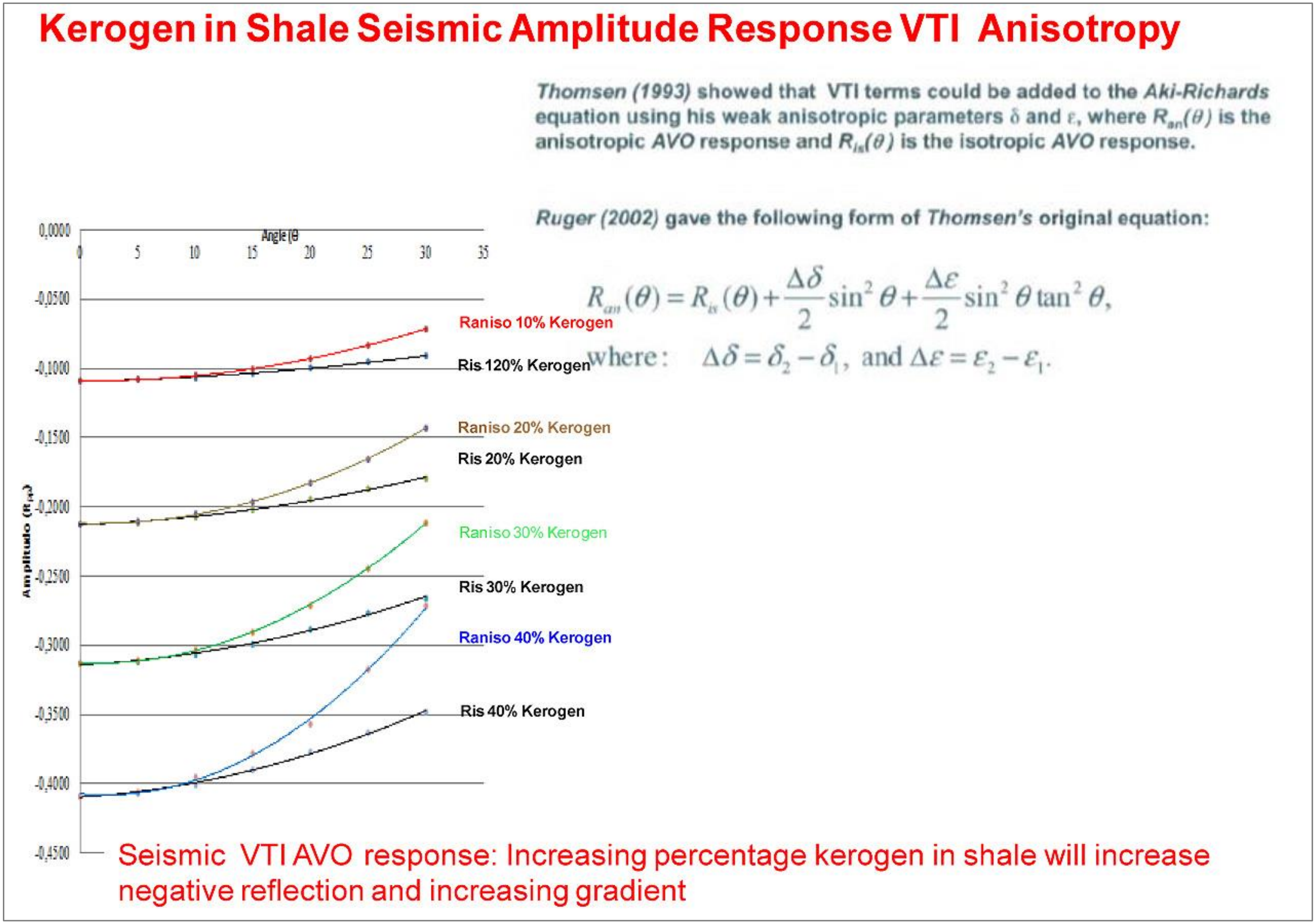


Figure 7. Increasing volume fraction kerogen in gas shale will increase negative reflection and increase gradient amplitude seismic with offset.