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The Effect of Shale Mineralogy on Anisotropy in Unconventional Resources Settings - A Rock Physics Modeling Study

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SUMMARY

Rock physics modeling provides a mathematical framework that links rock volumetric and microstructural parameters to effective elastic properties. Shales, which are elastically anisotropic, provide a special challenge for rock physics modeling due to the complex nature of their fabric and pore space and the large variations in depositional and diagenetic settings that affect the mineralogical composition, porosity and fabric of the rock.

Introduction

Rock physics modeling provides a mathematical framework that links rock volumetric and microstructural parameters to effective elastic properties. Shales, which are elastically anisotropic, provide a special challenge for rock physics modeling due to the complex nature of their fabric and pore space and the large variations in depositional and diagenetic settings that affect the mineralogical composition, porosity and fabric of the rock.

In unconventional reservoir settings, shales may play the role of source, reservoir and seal. Moreover, in many cases, organic-rich shale is surrounded by mudrocks, wackstones and other types of clay/shale rich sediments. Therefore, proper modeling of the elasticity in unconventional reservoir systems needs to take into account the heterogeneous nature of both the reservoir and surroundings.

Although shale anisotropy plays a major role in the seismic signature and geomechanical properties of the reservoir, it is often neglected in applications such as reservoir characterization or geomechanical modeling. The simplest anisotropic model for shales is transverse isotropy (TI), which needs five independent parameters to completely describe the elastic response of the sediment. Unfortunately, even in simple TI cases, in-situ estimation of anisotropic parameters is challenging. Very rarely are anisotropic parameters directly logged in the borehole. Most of the time we try to infer them using various inversion tools (Horne and Leaney 2000), analysis of deviated wells (Hornby et al. 2003) and joint analysis of checkshot and seismic data (Bakulin et al. 2008).

Clearly, better understanding of the ranges of anisotropy expected in shales will improve our ability to account for them. Therefore, anisotropic rock physics modeling can in principle be used to supplement modeling by providing a way to bridge the gap between the lack of in-situ information and the growing needs to better characterize the subsurface using anisotropic realistic models.

In this paper I show that in unconventional settings, where porosity is small, the most important control on the anisotropic response of the media is the shale mineral properties. Variation in mineralogy and silt content also will have large effect when the contrast between the host media and the mineral is large.

Mineral	C11(GPa)	C33(GPa)	C44(GPa)	C66(GPa)	C13(GPa)	ϵ	δ	γ	ρ (gr/cc)
Kerogen	6.5	6.5	2.7	2.7	1.1	0	0	0	1.25
Shale A: Vernik and Liu	85.6	65.5	24.6	29.7	21.1	0.15	0.075	0.1	2.73
Shale B: Illite	119.7	66.7	32.7	48.2	16.4	0.39	0.28	0.24	2.7
Shale C: Greenhorn	34.3	22.7	5.4	10.6	10.7	0.26	-0.05	0.48	2.4
Calcite	108.86	108.86	29.0	29.0	50.87	0	0	0	2.71
Quartz	95.6	95.6	44	44	7.6	0	0	0	2.65

Table 1 Material properties used in this modeling study.

Figure 1 Results of Backus averaging and anisotropic DEM modeling for kerogene shale mixtures for the three shales defined in Table 1. From left to right: C33, C44 and Thomsen's ϵ , δ and λ . Top: Shale A. Middle: Shale B. Bottom: Shale C.

Figure 2 Plots of ϵ vs λ (left) and ϵ vs δ (right) for organic-rich shale models for all aspect ratios and kerogen concentrations presented in Figure 1.

Figure 3 Results of Backus averaging and anisotropic DEM modeling for calcite/shale mixtures for the three shales defined in Table 1. From left to right: C33, C44 and Thomsen's ϵ , δ and λ . Top: Shale A. Middle: Shale B. Bottom: Shale C.

Figure 4 Plots of ϵ vs λ (left) and ϵ vs δ (right) for calcareous shale models.