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Rock Physics Modeling in Montney Tight Gas Play

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Summary

In this paper, we present rock physics modeling in Montney tigh gas play. The model deals with large variety of compositions and pore shapes. The case study by using the model shows good agreement between measurement and model-prediction on S-wave velocity. The model is also utilized to investigate influences of petrophysical paramters on elastic properties. In the Montney formation, acoustic impedance and Vp/Vs decrease as porosity increases, while Vp/Vs increases in calcite and dolomite rich-area. It can be concluded that the estiablished model can be effecvtively utilized for seismic AVO analysis.

Introduction

In unconventional play it is essential to predict distribution of sweet spots for optimizing the development plan. Seismic AVO analysis is expected to be utilized for sweet spot detection. However, although S-wave velocity data are critical for seismic AVO analysis, it is often that S-wave sonic log has not been acquired in the key wells. In the cases, S-wave velocity should be estimated from P-wave velocity along with the petrophysical parameters to obtain synthetic S-wave sonic log in the wells. For S-wave velocity estimation, rock physics models have been reported (e.g., Xu and White, 1995; Sayers, 2008; Xu and Payne, 2009). Many papers reported that the rock physics models well work in the conventional reservoirs. However, rock physics model applicable into unconventional play including tight gas are still poorly understood. Furthermore, it is well known that we should carefully choose optimum rock physics model for each field, because geological characteristics can largely vary with location.

The early Triassic Montney formation forms an enormous tight gas fair way in the western Canadian sedimentary basin (e.g., Wood, 2013). In this study we establish rock physics model for the Montney tight gas fair way. Moreover, the rock physics model is used to obtain synthetic S-wave sonic log and to investigate influences of porosity, richness of calcite and dolomite, and CGR, respectively, on elastic properties.

Rock Physics Model

Figure 1 shows SEM image on rock sample acquired from the Montney formation. One can observe that the rock sample is mainly composed of silt-size particles such as quartz, feldspar, calcite and so on. The spaces between the silt-size particles are almost filled with pyrobitumen and illite-rich clay and so on. The remaining space corresponds to pore. Also, nano-scale pores are observed inside the pyrobitumens. Thus, it is observed that the rock sample has rounded pores and penny-shaped pores, showing large variety of pore shape.

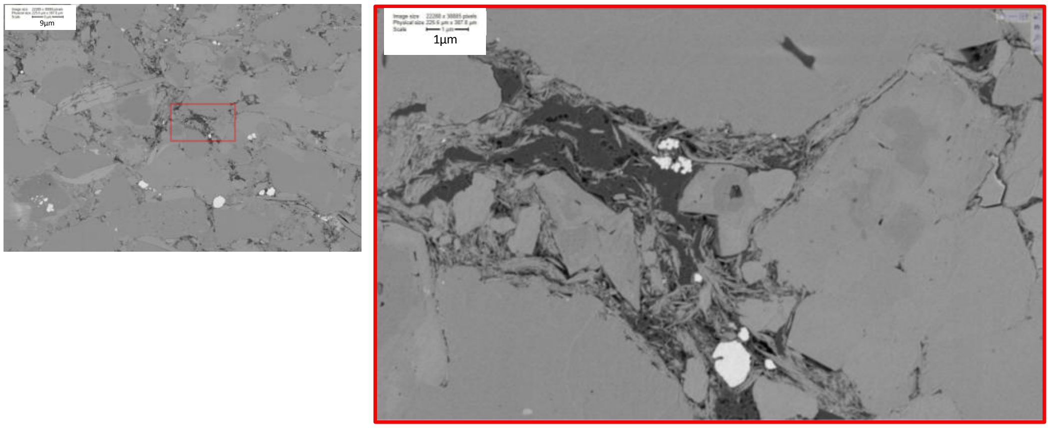

Figure 1 *SEM image on rock sample acquired from Montney formation.*

We established rock physics model which is applicable into the Montney formation, taking into account the large variety of pore shape, as well as large variety of compositions. Our model is an inclusion-based model which embeds inclusions (such as pore, minor compositions) into a homogeneous host material, like Zhu et al. (2012), and effective elastic stiffness of the resulting embedded material is obtained by using effective medium theory. In the modeling aspect ratio of pore is one of key parameters because it can change the effective elastic stiffness. In the some models which are available in literature, single aspect ratio has been used in each depth position. However, it is difficult to determine single aspect ratio because there is large variety in the pore shape in the most cases, for example as we discussed with Figure 1. Thus, like Ruiz and Cheng (2010), we propose that two kinds of representative pore shape are used in the modeling; rounded pore and penny-shaped pore. Rounded pore has larger elastic stiffness as compared to penny-shaped pore, because it is less compressible. Thus, rounded pore is called stiff pore while penny-shaped pore is called soft pore. After the volume ratio between stiff pore and soft pore is defined, stiff pore and soft pore are alternatively embedded into a host material until the embedded volume reaches to the corresponding volume. The model has four steps as follows (Figure 2);

Step-1: Forming rock solid cube composed of pure minerals (quartz, feldspar, calcite, dolomite etc). Bulk and shear moduli of the cube are simply determined by Reuss-Voigt-Hill averaging.

Step-2: The rock solid cube is embedded with illite-water composites. Volume of the embedded composites corresponds to sum of volume of clay and clay-bounded water obtained in the petrophysical analysis. Note that bulk and shear moduli of illite-water composite are 21 GPa and 7 GPa, respectively. The embedded cube is regarded as a homogeneous material and will be treated as a host material (Material-II) in the next step. Effective bulk and shear moduli of the Material-II are calculated by using Differential Effective Medium theory (DEM: Xu and White, 1995).

Step-3: Pyrobitumen and dry pore are embedded into the Material-II. Calculations of effective bulk and shear moduli are performed by using DEM. Bulk and shear moduli of pyrobitumen are assumed to be 5.5 Gpa and 3.2 GPa, respectively. For dry pores there are two kinds of pore shape: rounded (stiff) and penny-shaped (soft) pores. Aspect ratios of the stiff and soft pores are assumed to be constant in the analyzed interval.

Step-4: The dry pores are filled with fluids (gas and brine composite) by using Biot-Gassmann equation. Bulk modulus and density of each fluid is obtained using FLAG program (e.g., Liu, 2006) and Wood's equation is used to obtain effective properties of gas-brine mixture.

The model has free parameters, such as the volume ratio between stiff and soft pores, to adjust effective elastic stiffness of the model output. The free parameters are optimized in the well in which S-wave sonic log is available, as discussed in the next section.

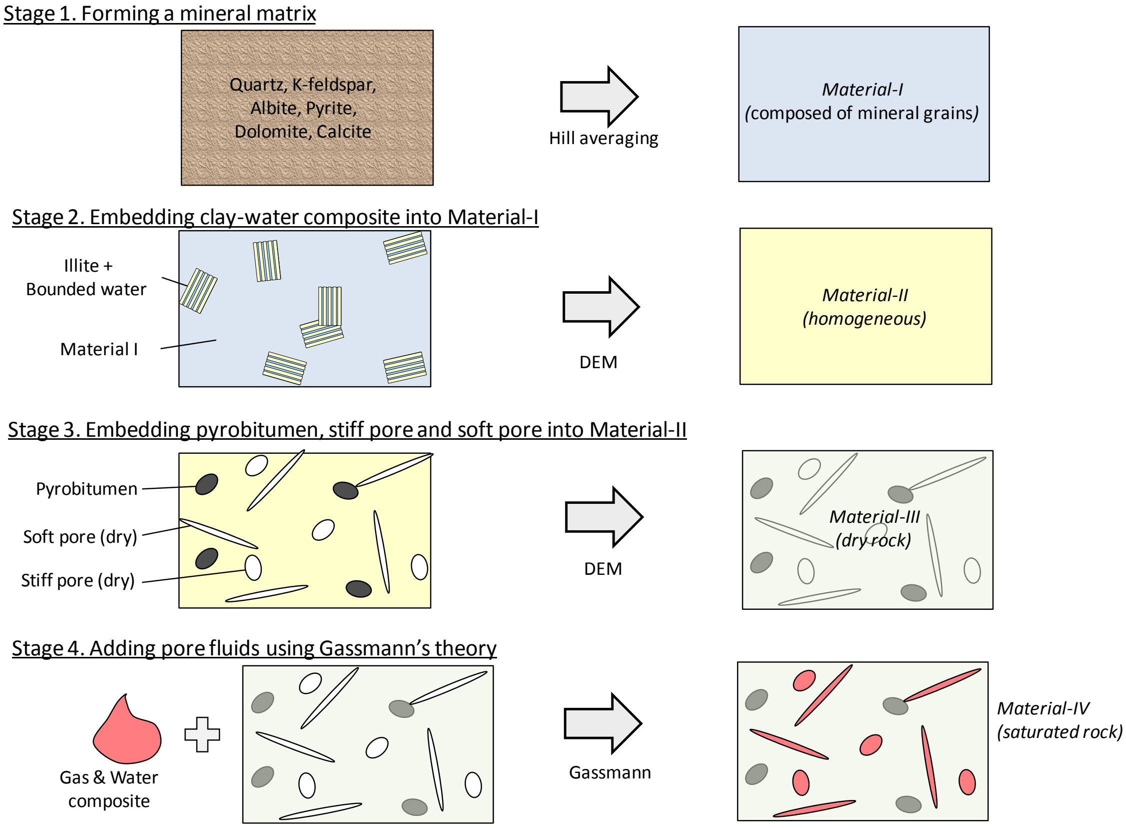

Figure 2 *Constructed rock physics model. The model consists of 4 steps. In the 2nd and 3rd steps inclusions are embedded into a host material using DEM theory. Ratio of stiff pore to soft pore is determined in inversion process, minimizing discrepancies between Vp measurement and Vp model prediction. Note that the model assumes an isotropic medium.*

Example

We applied the established rock physics model into the Montney tight gas play. Figure 3 shows example of the estimated elastic property in the well in which not only P-wave velocity but also S-wave velocity measurements are available. The black and red curves represent the actual measurement and model prediction, respectively. Petrophysical analysis was well performed in the well to obtain porosity, gas saturation, TOC, and volume ratio of minerals and so on. The petrophysical parameters are used as an input in the rock physics modeling. The volume ratio between stiff pore and soft pore is determined by iteratively minimizing difference between Vp measurement and Vp model-prediction. Thus, Vp prediction is virtually overlapped with Vp measurement. In addition, one can observe that predictions of Vs and density, as well as Vp/Vs, are well consistent with the corresponding measurement. The correlation coefficients between the measurement and prediction in the Montney interval for Vs and Vp/Vs are 0.98 and 0.90, respectively. Note that aspect ratios of stiff and soft pores are assumed to be 0.8 and 0.01, respectively. It is expected that the model with the optimized parameters can be applied into the wells in which S-wave velocity measurement is unavailable, in order to obtain synthetic S-wave sonic log, if geological characteristic does not change largely.

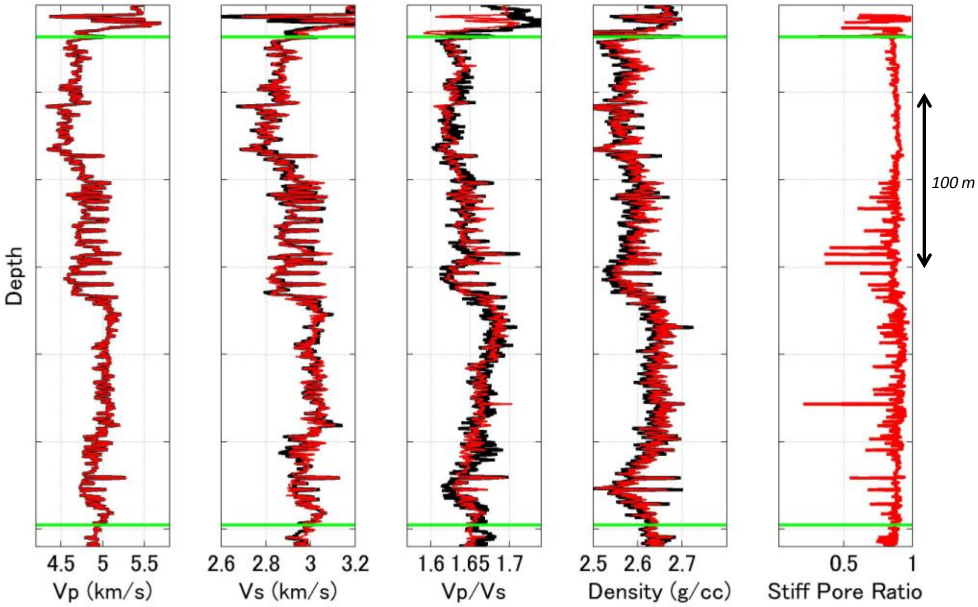

***Figure 3** Comparison between model prediction (red) and actual measurement (black) for Vp, Vs, Vp/Vs and density and ratio of stiff pore to soft pore determined in the inversion process.*

In addition to Vs estimation, once the parameters are optimized, the model can be used to investigate influences of petrophysical parameters on elastic properties. Figure 4 shows the estimated changes in P-wave velocity, acoustic impedance (AI) and Vp/Vs due to changes in porosity, richness of calcite and dolomite and CGR, respectively. In the porosity change, only porosity changes, while other petrophysical parameters remain constant. As porosity increases, P-wave velocity and AI monotonically decrease. Furthermore, Vp/Vs also decreases with porosity, because magnitude of decrease in Vp is larger than that of Vs. Next, in the change of calcite and dolomite, as volume of calcite and dolomite increases, volume of remaining minerals (such as quartz, feldspar, clay, etc) decreases, keeping relative volume ratio among the remaining minerals remain constant. P-wave velocity and AI are almost insensitive to volume change of calcite and dolomite, while Vp/Vs largely increases, because S-wave velocity substantially decreases. As the last case, when we change only gas properties to change CGR, P-wave velocity, AI and Vp/Vs show only subtle changes. Thus, as a conclusion of this exercise, it may be implied that seismic attribute associated with P-wave velocity, as well as Vp/Vs, is a potential one which can estimate porosity distribution, and that Vp/Vs may be utilized for estimating distribution of calcite and dolomite rich-area. Moreover, it is very challenging to obtain CGR distribution map only from these seismic attributes.

Conclusions

We present rock physics model which is applicable into the Montney formation. The model is inclusion-based model. Unlike many models reported in literature, two types of pore shape (stiff and soft pores) are treated as representative one. The volume ratio between stiff pore and soft pore is determined by inversion process. In the case study, the estimated S-wave velocity is consistent with the corresponding measurement. Also, the model can be used to investigate influences of petrophysical parameters on elastic properties.

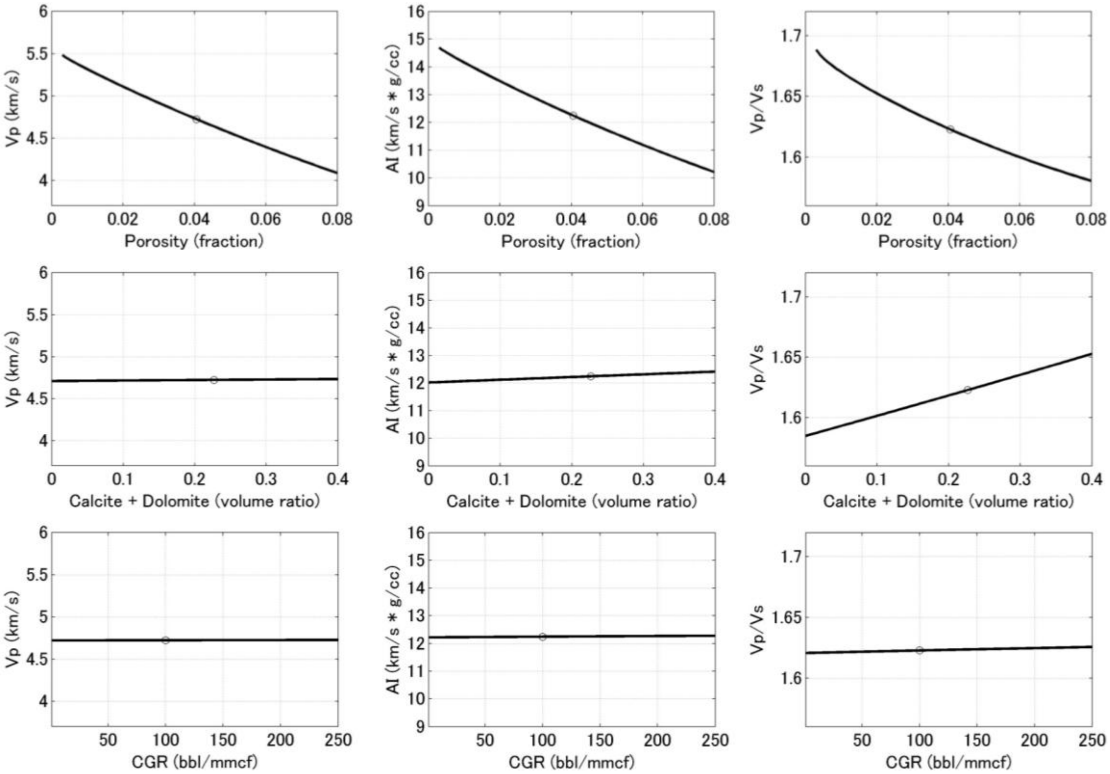

Figure 4 *Estimated P-wave velocity (left), acoustic impedance (AI: middle) and Vp/Vs (right) changes due to change in porosity, volume ratio of calcite and dolomite and CGR, respectively, by using the constructed rock physics model. Upper, middle and lower figures correspond to changes in porosity, volume ratio of calcite and dolomite and CGR, respectively.*

Acknowledgements

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References

Wood, J., 2013, Water distribution in the Montney tight gas play of the western Canadian sedimentary basin: significance for resource evaluation: SPE Reservoir Evaluation & Engineering, 290-302.

Liu, J., 2006, Description of models used in the programs FLAG: 2006 annual meeting of Fluids/DHI consortium.

Ruiz, F., and Cheng, A., 2010, A rock physics model for tight gas sand: The Leading Edge, **29**, 1484-1489.

Sayers, C.M., 2008, The elastic properties of carbonates: The Leading Edge, **27**, 1020-1024.

Xu, S., and White, R. E., 1995, A new velocity model for clay-sand mixtures: Geophysical Prospecting, **43**, 91-118.

Xu, S., and Payne, M. A., 2009, Modeling elastic properties in carbonate rocks: The Leading Edge, **28**, 66-74.

Zhu, Y., Xu, S., Payne, M., Martinez, A., Liu, E., Harris, C., and Bandyopadhyay, K., 2012, Improved rock-physics model for shale reservoirs: SEG Technical Program Expanded Abstracts 2012, pp1-5.