Core Plug Scale Anisotropy and Geologic Controls on Acoustic Velocity of the Montney and Doig Formations

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Summary

The measurement of ultrasonic velocities in the laboratory is a convenient, quick and non-destructive way of characterizing the factors affecting acoustic velocities in the subsurface. In this study, ultrasonic compressional and shear wave velocities from the Montney and Doig Formations are measured on core plugs of varying lengths, cut parallel and perpendicular to bedding. This technique is used to obtain reliable dynamic elastic moduli on smaller samples, since larger samples suitable for full triaxial tests are not easily obtainable. Most of compressional velocities fall between 2600 and 5700 m/s, and shear velocities, between 2200 and 3200 m/s. Anisotropy is significant, with an average Thomsen's δ parameter of 0.22 and a maximum of 0.49. Porosity is the main factor affecting acoustic velocities, suggesting that compaction is the dominant influence on velocity. The volume of major carbonate minerals exerts a secondary control on velocities, and is also associated with burial and compaction, as these minerals occur primarily as cements. Volume of quartz has an inverse relationship with velocity, as with progressive burial and compaction, quartz is dissolved and replaced by calcite and dolomite. No correlation between velocity and TOC or clay content was observed, raising a question about the adequacy of acoustic well log methods for TOC estimation.

Introduction

The propagation velocity of acoustic waves in the subsurface is a fundamental property for a myriad of disciplines and questions relevant for the petroleum industry, from seismic processing to hydraulic fracturing design and petrophysical models. In geophysics, failure to account for acoustic anisotropy can lead to errors in the velocity model and reservoir properties prediction by seismic inversion (Sayers, 1994). A geomechanical characterization is essential for hydraulic fracturing design, and besides the static elastic moduli typically obtained from triaxial compression tests, an analysis protocol must also include dynamic moduli from ultrasonic velocities (Britt & Schoeffler, 2009). Acoustic properties also affect reservoir properties estimated by petrophysical logs, which often rely on sonic logs for porosity and total organic carbon calculation. The Montney and Doig Formations, which have been historically viewed as a source-rock for conventional reservoirs in the Western Canada Sedimentary Basin, have become the focus of industry attention due to their potential as unconventional gas and natural-gas-liquids reservoirs. In this study, ultrasonic compressional and shear wave velocities from these formations are measured on core plugs cut parallel and perpendicular to bedding. The main factors affecting velocities and anisotropy are determined and explained.

Method

The measurement of ultrasonic velocities in the laboratory is a convenient, quick and non-destructive way of characterizing the factors affecting acoustic velocities in the subsurface. For this study a total of 33 sets of plugs, consisting of horizontal and vertical twins, were selected for ultrasonic compressional and shear wave velocity measurements under three uniaxial stress levels. The samples were machined, so that end surfaces are parallel to within 0.15 mm, and cleaned of soluble hydrocarbons through distillation with toluene for one week in Dean-Stark type apparatuses, and oven-dried at 110 °C for another week. The plugs are 30 mm in diameter and varying lengths between 38 and 65 mm. Due to the effect of sample length and slenderness ratio (length to diameter ratio) on geomechanical and acoustic wave propagation velocities, all velocities were corrected to a 2:1 slenderness ratio standard. The correction was generated from two sets consisting of plugs of varying lengths, of relatively homogenous intervals of the Montney Formation, each taken within a 30 cm interval. The ultrasonic velocity measuring apparatus consists of a pulse generator, a pulse amplifier, a load cell and ultrasonic transducers mounted on a core holder, a multimeter for reading the load cell output, and an oscilloscope to visualize and record the full waveforms. Velocities are calculated from the first arrivals, after correcting for platens face-to-face arrival times. Various other petrophysical and geological properties were also analyzed as part of this study. Porosity was determined by a combination of helium pycnometry, mercury immersion and mercury injection porosimetry. Mineralogy was obtained by X-ray diffraction, using powdered samples smear-mounted on glass slides, according to Munson et al. (2016), using the Rietveld (1967) method. TOC was determined by whole-rock Rock-Eval pyrolysis.

Results and Conclusions

A strong negative correlation was found between plug slenderness ratio and P-wave velocity, and a strong positive correlation between S-wave velocity and slenderness ratio. These trends were used to reduce and increase, respectively, the measured P and S wave velocities by up to 10% to a standard slenderness ratio of 2:1. Most of compressional velocities fall between 2600 and 5700 m/s, and shear velocities between 2200 and 3200 m/s. Anisotropy is significant, with an average Thomsen's δ parameter of 0.22 and a maximum of 0.49, and bedding-perpendicular and bedding-parallel samples following distinct trends (Figure 1).

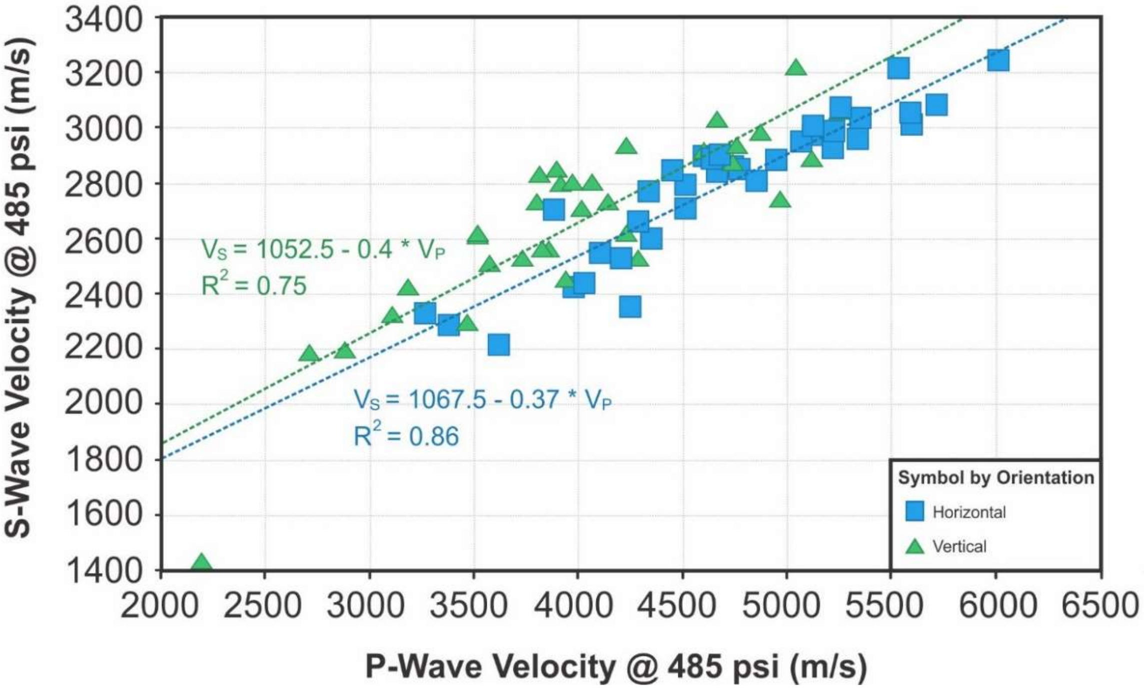

Figure 1 – Crossplot of P and S wave velocities for both bedding-parallel and bedding-perpendicular samples, illustrating the range of velocities, P and S relationship, and overall degree of acoustic anisotropy.

Porosity is the main factor affecting acoustic velocities, with a moderately high correlation to P-wave velocity (Figure 2). Median pore size and thermal maturity, both of which show a good correlation with porosity, also display a correlation with acoustic velocities. This suggest that compaction is an overwhelmingly dominant influence on velocities, obscuring mineralogy relationships. The volume of major carbonate minerals (dolomite and calcite combined) exerts only a secondary control on velocities. The influence of carbonate on velocity is also associated with burial and compaction, as these minerals occur primarily as cements. Surprisingly, volume of quartz has a moderate inverse relationship with velocities, which is interpreted as being a product of diagenetic dissolution of quartz and replacement by calcite and dolomite. Clay content and TOC bear no discernible influence on velocity, which raises a question about the adequacy of methods that rely on acoustic logs for TOC estimation. Anisotropy decreases substantially with compaction, as it can be seen in the smaller spread between bedding-parallel and bedding-perpendicular samples at higher velocities; however, orientation remains one of the most significant factors affecting both P and S velocities.

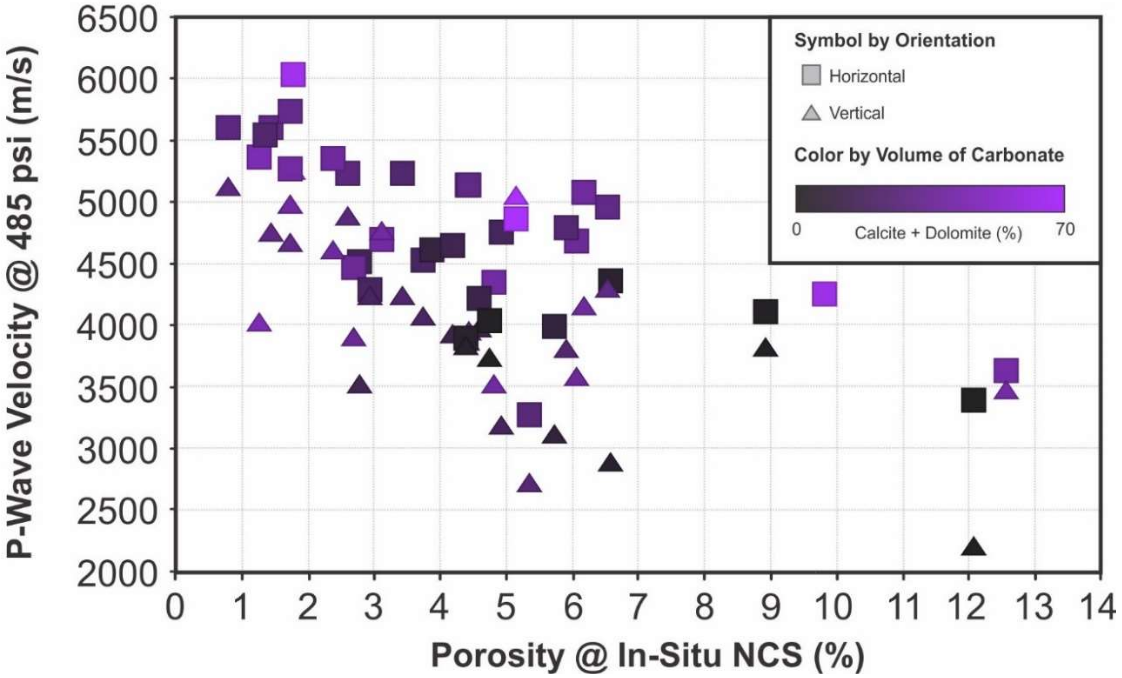

Figure 2 – Crossplot of P-wave velocity and porosity, colored by volume of major carbonates, for both bedding-parallel and bedding-perpendicular samples, showing the two largest controls on acoustic velocities.

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