Controls upon elasticity and anisotropy in New Zealand's coaly source rocks

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Introduction

Coaly (terrestrial) rocks are important sources of oil and gas in Australasia and Southeast Asia, but their recognition and characterization in seismic profiles are not well advanced. In this study, ultrasonic velocities were measured across a variety of New Zealand coaly rock samples to link their elastic and physical properties. P- and S-wave velocities (Vp, Vs) were found to correlate positively with both mineral matter (MM) content and coal rank (~maturity). The results compare to previous studies, which show increasing elastic wave speed as a function of rank. More specifically, the data demonstrate MM having a first order control on elasticity amongst the measured physical properties with a ΔV >1500 m/s (MM ranging from <0.1% to 97%). This is followed by rank and confining pressure with ΔV's of ~500 m/s and <500 m/s respectively. Similar relationships were observed between increasing mineral content and increasing anisotropy. Attempts to assess the influence of pressure or temperature-induced creep upon select samples add valuable insight into the effects of in-situ conditions upon coaly source rock elasticity. Our study aims to help improve the seismic sensitivity to the interbedded source rocks of New Zealand's sedimentary basins similar to the work of Løseth et al. (2011).

Methodology

P- and S-wave velocities were measured using the ultrasonic pulse transmission method and 1 MHz transducers (Birch, 1960). Saturated samples were tested under confining pressures up to 40 MPa through both loading and unloading cycles to examine hysteresis. Saturation of samples was performed over 48 hr using water equilibrated with sample material.

In this study, coal ranks are characterised using the ASTM classification (subbituminous, bituminous, etc), vitrinite reflectance, and the Suggate rank scale (Suggate, 2000). Mineral matter content is calculated from ash content using the Parr Formula (Parr, 1928). The samples are further divided into three coaly rock lithologies, based primarily on total organic carbon (TOC) content, which correlates negatively with density (e.g., Sykes and Snowdon 2002):

Coal (>50% TOC), mean density <1.50 g/cm^3
Shaly Coal (20–50% TOC), mean density 1.50–2.00 g/cm^3
Coaly Mudstone (<20% TOC), mean density >2.00 g/cm^3

Testing for potential pressure-induced creep was performed by maintaining a confining pressure of ~40 MPa over two weeks on select samples. Temperature-induced creep was assessed using laser-based ultrasonics (Blum et al., 2013) and a heating mantle surrounding the confining vessel.

Results

Figure 1 shows relationships between P-wave velocity (Vp), mineral matter content, and rank (~maturity) at a singular pressure reading amongst measured samples.

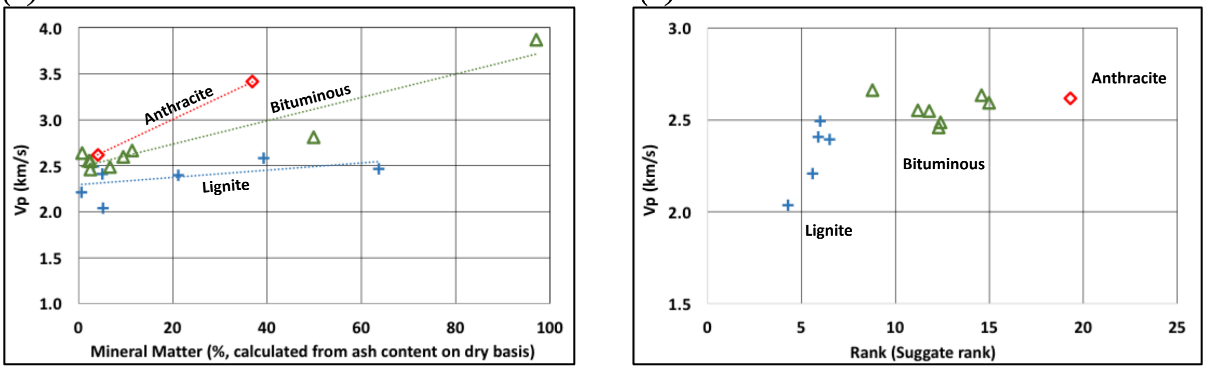

Figure 1: (a) P-wave velocity as a function of mineral matter content for coals (<20% MM), shaly coals (20–50% MM), and coaly mudstones (>50% MM) at 35 MPa confining pressure. Colours are associated with coal rank, and trendlines serve as visual guides not quantitative. (b) P-wave velocity as a function of rank for coal samples at 35 MPa confining pressure.

Conclusions

Elastic and physical properties were measured in the laboratory for samples of coal, shaly coal, and coaly mudstone, and coals of variable rank, from subbituminous to anthracite. Mineral matter content exhibits a first order control over elasticity and anisotropy. P- and S-wave velocities and elastic moduli increase with increasing mineral matter content. Similar trends of increasing velocities and elasticity were observed with both increasing coal rank (~maturity) and confining pressures, which served as second and third order controls respectively. This latter result is consistent with previous studies (e.g., Morcote et al., 2010). Weak anisotropy was observed amongst coal samples across all ranks (ε <5%). Increasing mineral matter content yielded higher intrinsic anisotropy due to the mineralogical layering of organic and inorganic constituents (ε >10%). Observations from testing of pressure and temperature-induced creep add valuable insight into the effects of *in-situ* conditions upon coaly source rock elasticity.

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