Contact stiffness in gas-bearing shales estimated from velocity measurements under pressure

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SUMMARY

- Pore pressure has a direct influence on gas production from shale gas reservoirs. Most pore pressure estimation methods are based on the effective pressure principle. Grain contact models such as Digby's model have been used to understand velocity variation with effective pressure in dry rocks. Using velocity measurements under pressure, we estimated the contact stiffness ratio of 73 samples from gas-bearing shale reservoirs in Sichuan basin, China.
- v_p, v_s, D_n, and D_t all increase with pressure, while v_p/v_s ratio and D_n/D_t ratio are nearly constant.

METHODS

- Digby's model

$$D_n = \frac{4\mu a}{1-\vartheta} \qquad D_t = \frac{8\mu b}{2-\vartheta}$$

$$v_p^2 = \frac{3C}{20\pi R\rho}\left(D_n + \frac{2}{3}D_t\right)$$

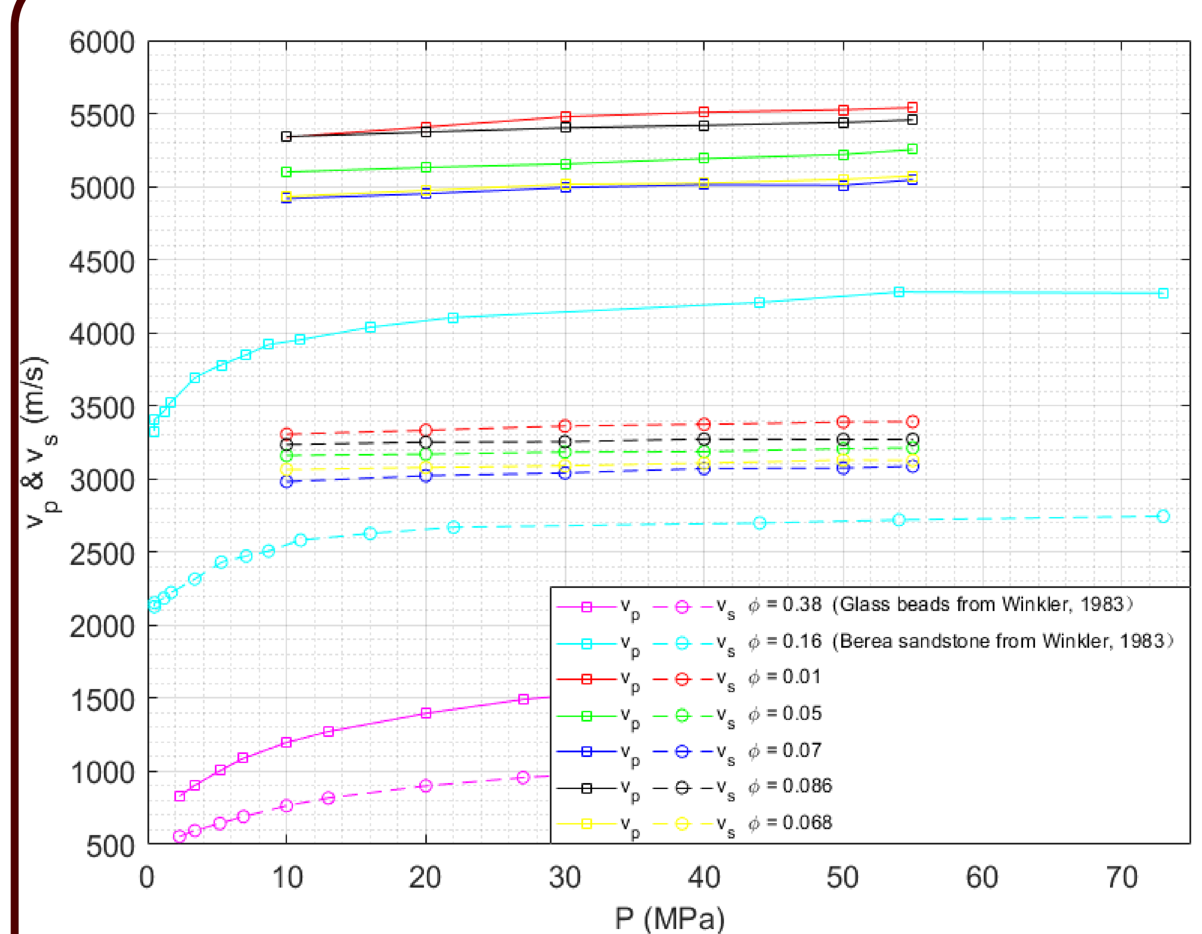
$$v_s^2 = \frac{C}{20\pi R\rho}\left(D_n + \frac{3}{2}D_t\right)$$

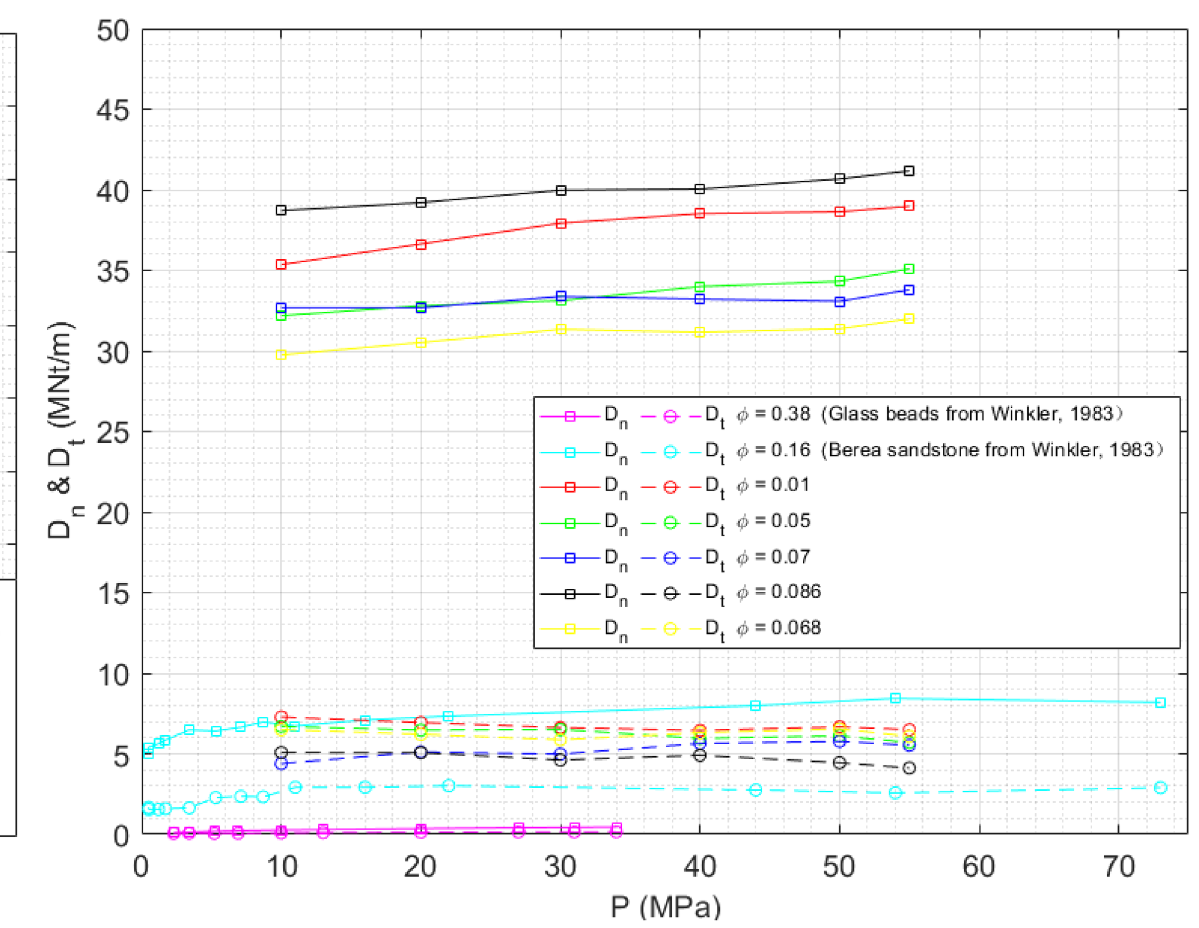
$$\left(\frac{v_p}{v_s}\right)^2 = \frac{6(D_n/D_t)+4}{2(D_n/D_t)+3}$$

$$\frac{D_n}{D_t} = \frac{3(v_p/v_s)^2-4}{6-2(v_p/v_s)^2}$$

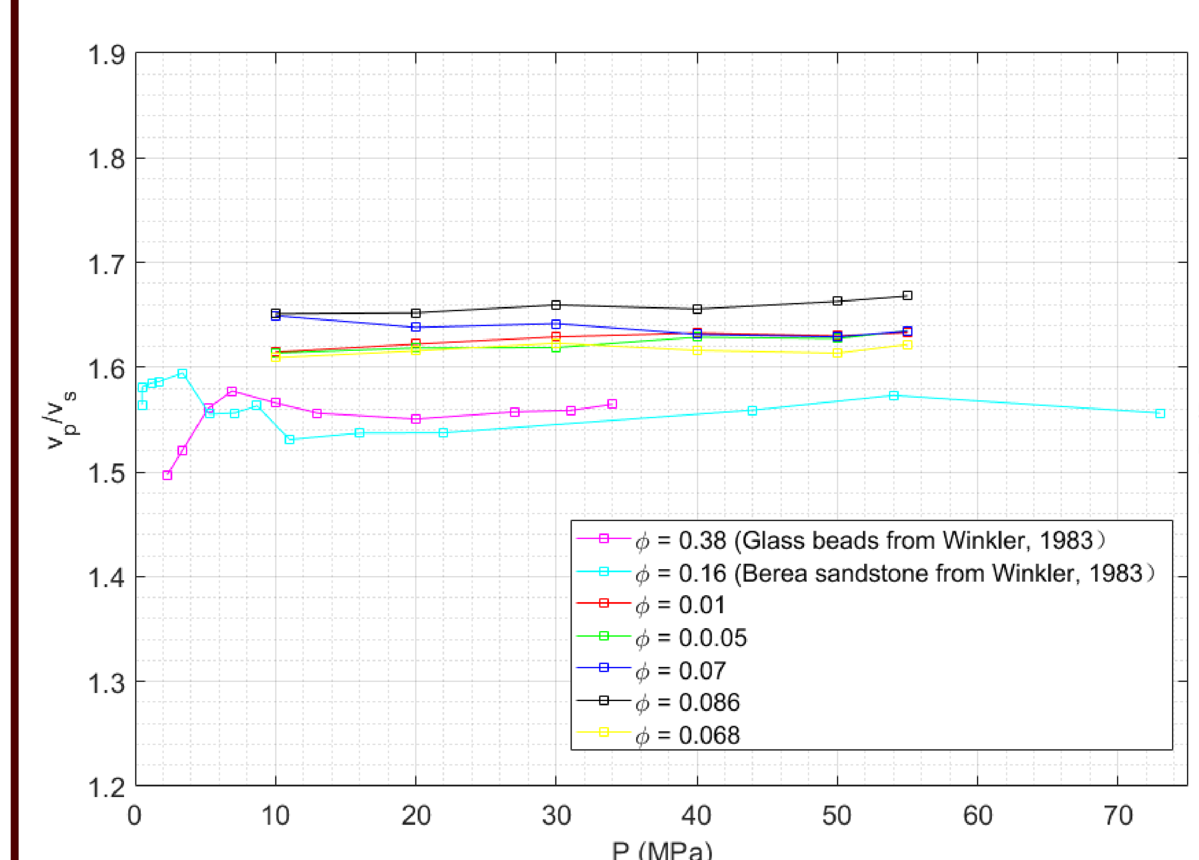
- D_n, D_t are normal and shear contact stiffness, respectively. v_p and v_s are measured P-wave and S-wave velocity, respectively.
- a and b are final and initial contact radius respectively, R is grain size, ρ is grain density, C is coordination number, μ and v are the grain shear modulus and Poisson's ratio.

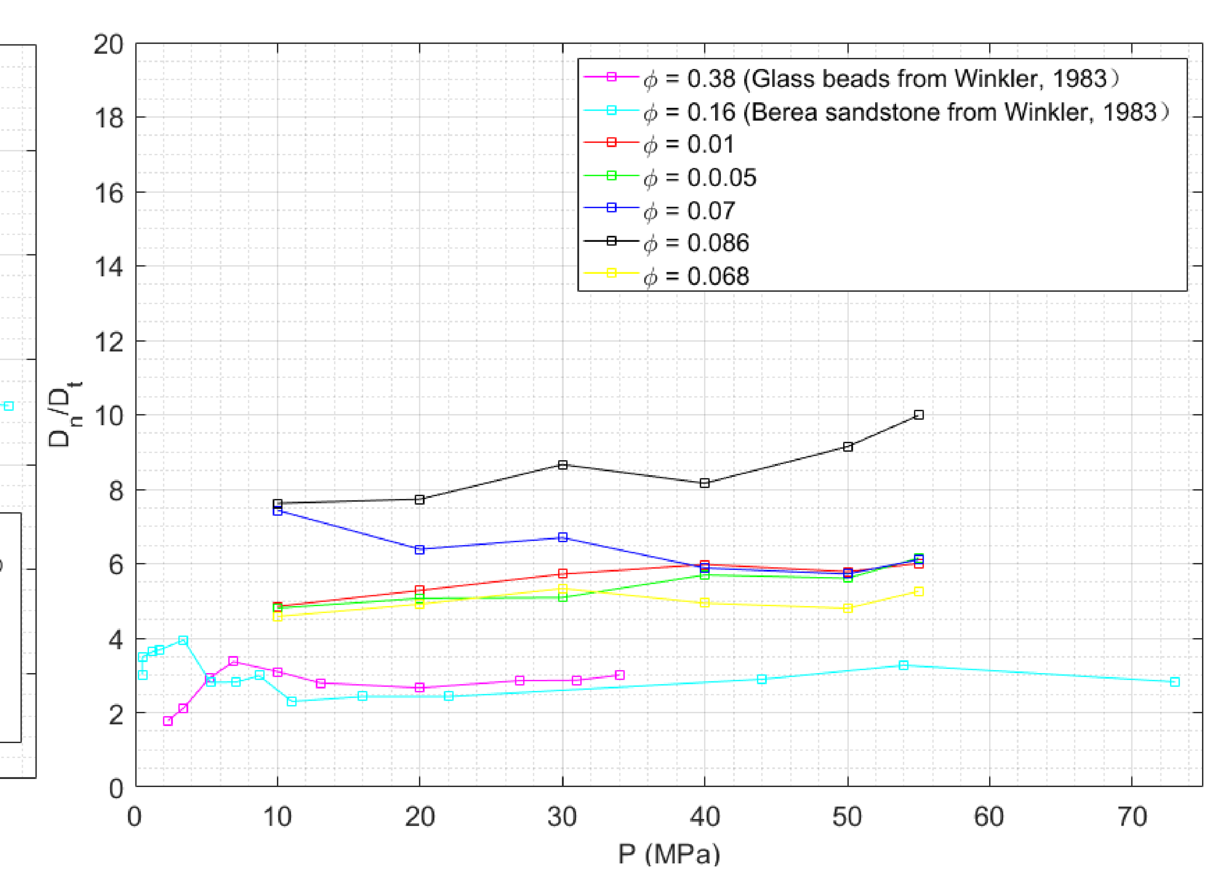
RESULTS





- v_p, v_s, D_n, and D_t all increase with pressure, fastly at low pressure (< 10 MPa) while slowly at high pressure (> 10 MPa).
- Velocities and contact stiffness of shale in this study are the highest, then are those of Berea sandstone. Glass beads have the smallest velocities and contact stiffness.
- Velocities and contact stiffness show nonzero values at zero pressure, which agrees with Digby's Model.





- The v_p/v_s ratio and D_n/D_t ratio of shale samples are nearly constant even though v_p, v_s, D_n, and D_t increase with pressure individually.
- The v_p/v_s ratio and D_n/D_t ratio of shale samples are larger than those of glass beads and Berea sandstone.

- v_p/v_s ratio varies from 1.5 to 1.9, depending mainly on mineralogy composition.
- Contact stiffness ratio varies in general from 3 to 40.
- v_p/v_s ratio larger than 1.73 will result in negative D_n/D_t ratio, which is unrealistic.
- Digby's packing model gives reasonable estimation of D_n/D_t ratio for the majority of studied samples, while the complete Digby's model including the contact model only gives reasonable estimation for the glass beads. For Berea sandstone and shale samples, the theoretical calculated contact stiffness severely underestimated the value from velocity measurements.
- Digby's model is able to give nonzero elastic properties of granular media at zero pressure, which is an improvement compared with Hertz-Mindlin model.
- Further improvements are needed for real practical application of contact models to estimate effective pressure from seismic velocity.

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