Effects of the in situ stress on the mechanical anisotropy in the Longmaxi gas shale

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Abstract

For over half a century, the bedding plane orientation was believed to be the main cause of the mechanical anisotropy in shales. However, the in situ stress may also play an important role on the mechanical anisotropy. In this paper, shales from the Longmaxi formation were sampled from Fulin, Chongqing, China. The axial orientations of all the cylinder samples (50mm, 100mm height) of Longmaxi Shale are parallel to the bedding plane. The cylinder samples were compressed in a triaxial apparatus of under confining pressures from 0 to 25MPa and at a strain rate of 4*10-2mm*min-1. The only difference of the samples in this study is the in situ stress orientations in the way that the samples in the X group are along the major principle stress while those in the Y group are along the minor principal stress. The Young's modulus, failure strength, and Poisson's ratio as a function of confining pressure were determined for both the two groups of samples. The result shows that, for all confining pressures, Young's moduli in the X group are higher than those of Y group if confining pressures are the same and the differences are 2.89 GPa in average. For confining pressures within 20MPa, the failure strengths and Poisson's ratios are higher in the X group. The differences of failure strengths and Poisson's ratios between the two groups for the same confining pressures decrease with the increase of confining pressures. When confining pressures exceed 20MPa, the failure strengths and Poisson's ratios in the Y group are higher than those in the X group, and the differences of failure strengths and Poisson's ratios between the two groups for the same confining pressures increase with the increase of confining pressures. Therefore, the differences of mechanical properties of the samples along different directions of in situ stress suggest the Longmaxi gas shale is not transversely isotropic but anisotropic in three dimensions. Considering that all samples have the same bedding plane, the mechanical anisotropy of samples detected in the experiments may be owing to the divergences of the minerals and micro-cracks in the bedding plane. As there were changes of the differences between X group and Y group, the variations might be an indicator of the in situ stress.

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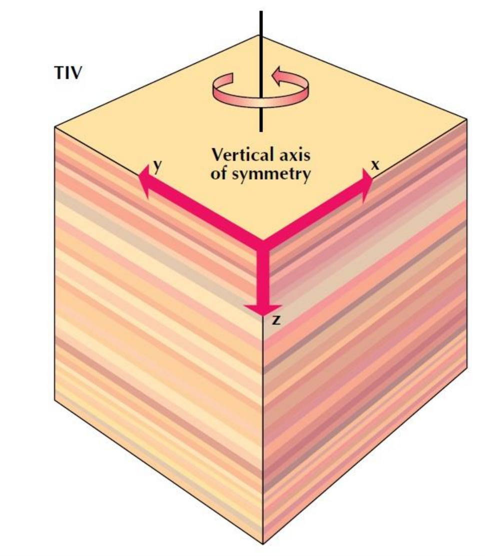
INTRODUCTION

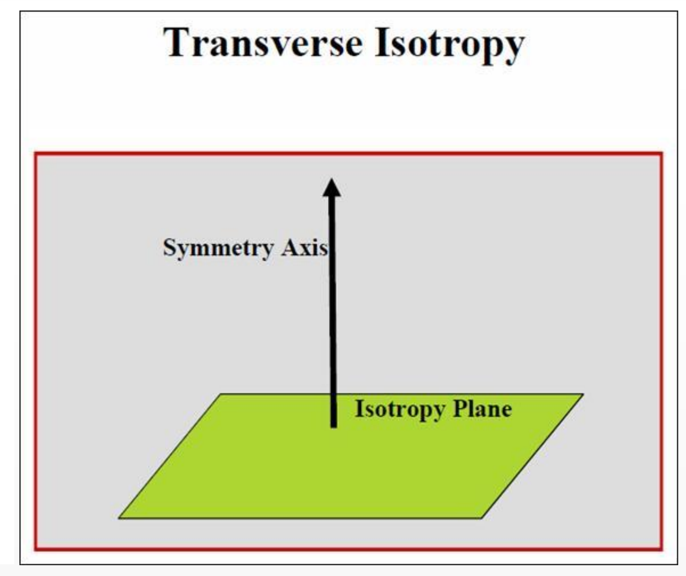
Transverse isotropy theory has long history

- First reported by [*Chenevert and Gatlin*, 1965]
- Symmetry of Poisson's ratio and similar Young's modulus within the bedding plane were found [*Chenevert and Gatlin*, 1965]

Transverse isotropy model has limitations

- Complex crack patterns observed in the experiments cannot completely be accounted by transversely isotropic models [*Na et al.*, 2017].
- Different people put forward different methods to increase accuracy.





➢ Transverse Isotropy: properties are **uniform** horizontally within a layer, but vary vertically and from layer to layer(Schlumberger definition).

Transverse isotropy or 3D anisotropy?

- Is bedding plane the only factor affects the properties ?
- Do X and Y **always** have the same properties?

Can stress anisotropy cause anisotropy?

- In situ stress is anisotropic.
- Relation between velocity and mechanical properties has been found[*Holt et al.*, 2012].
- Velocity difference is greatly influenced by stress anisotropy in triaxial compression tests[*Anon*, 2011].
- In situ stress may be another factor affect mechanical properties in shale.

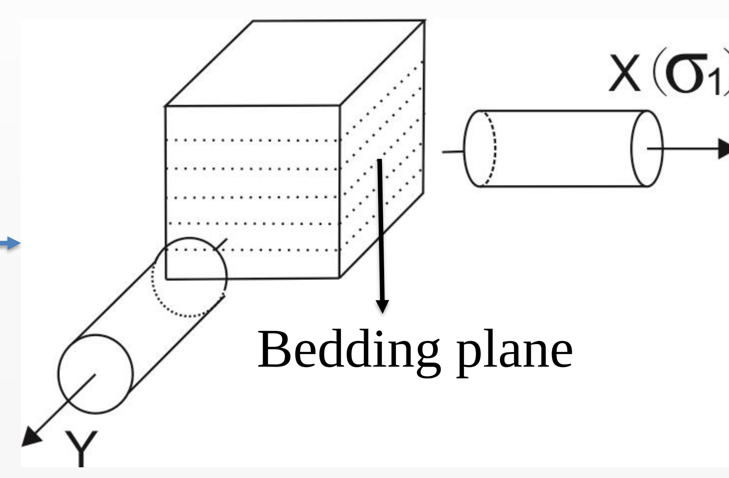
METHODS

Sample Location

- N29° 52′47.8″, E108° 17′06.6″
- Shizhu County, Chongqing, China
- Longmaxi formation (shale): NW330° ∠35°

Sample Orientation

- Same bedding plane
- **X: major principle stress**
- Y: perpendicular to X



Experiment Overview

- Sample size: Φ50mm×100mm
- Experiment apparatus: TAW 1000
- Location: China University of Petroleum

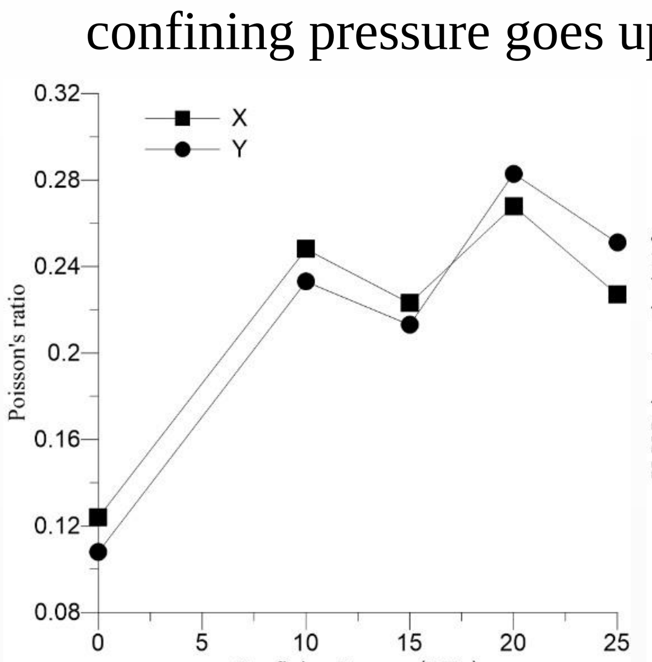
Experiment Design

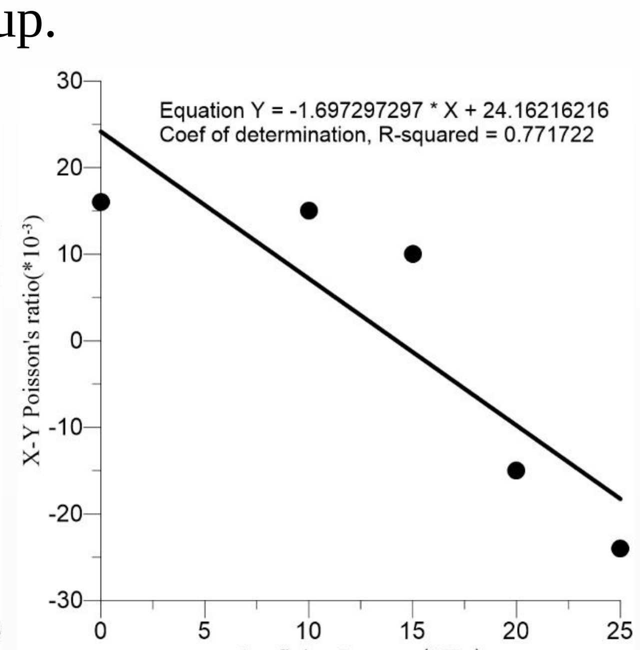
- Confining pressure(MPa):
  0 10 15 20 25
- Experiment target:
  Young's modulus
  Poisson's ratio
  Peak strength
- Compare experimental results from X and Y group
- Analyze friction angle and cohesion according to the sample direction

RESULTS AND DISCUSSIONS

Poisson's ratio differs in two directions

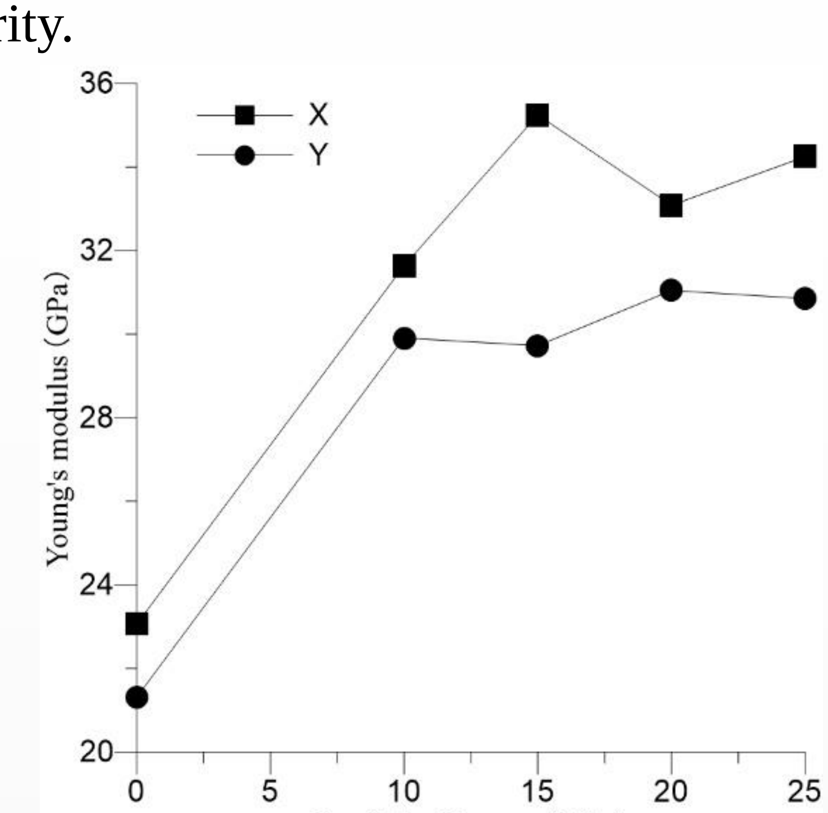
- A **intersection point** exists between the confining pressure of 15MPa and 20MPa.
- Values in X group are bigger than Y group before the intersection point.
- Difference between X group and Y group rises as confining pressure goes up.





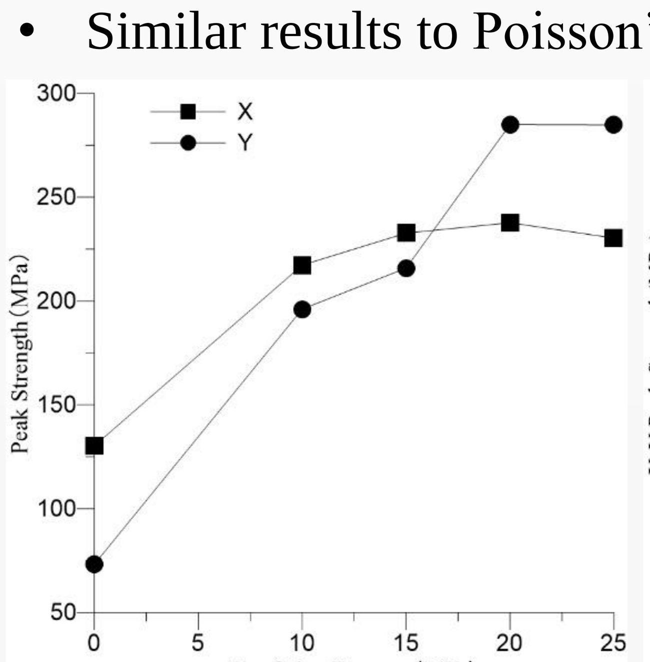
Young's modulus differs two direction

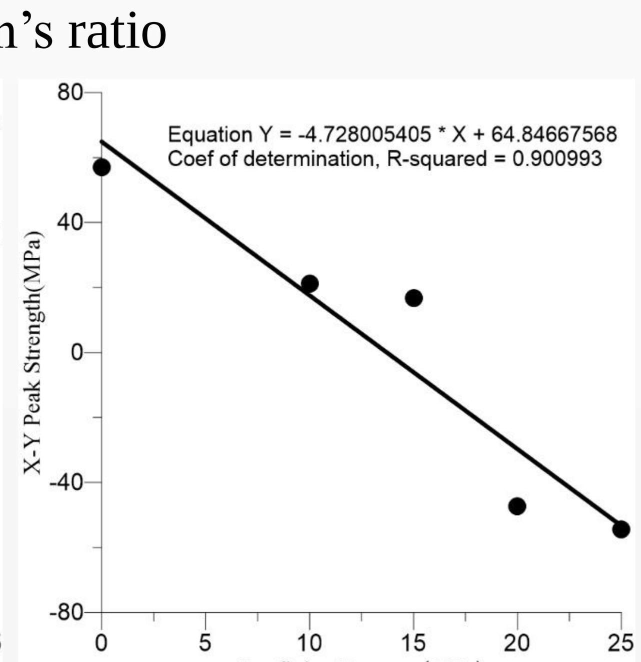
- Young's moduli in X group are **always** bigger than those in Y group.
- Difference between two directions shows no regularity.



Peak strength differs in two directions

- **A intersection point** exists between the confining pressure of 15MPa and 20MPa.
- Similar results to Poisson's ratio





Different cohesion and friction angle in two directions

➢ X direction has higher cohesion but lower friction angle compared with Y direction.
➢ If data from X and Y groups are analyzed together, the results are different from the results in single group.

	Cohesion(MPa)	Friction Angle(°)
X	29.305	43.34
Y	14.713	53.16
X and Y	19.091	50.03

CONCLUSIONS

Regular difference of peak strength and Poisson' ratio

Young's modulus in X group>Young's modulus in Y group

Different cohesion and friction angle in two groups

Different mechanical properties in X and Y directions

In situ stress has impact on the anisotropy

Not transverse isotropy but anisotropy in three dimensions

More proof in our latest research:
◆ X plane has 1.32 million microfractures.
◆ Y plane has 0.71 million microfractures.

Open question:
◆ Why peak strength and Poisson's ratio has similar intersection point while Young's modulus not?
◆ The meaning of the intersection point in the Poisson's ratio and peak strength diagrams?

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