Collaborative Geological-Engineering Integration for Unconventional Reservoir Development

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Petrophysical model for conversion of dynamic and static elastic parameters of deep coal rock

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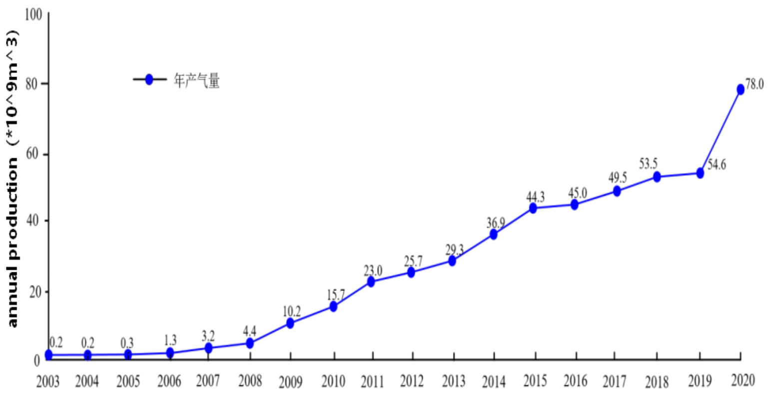
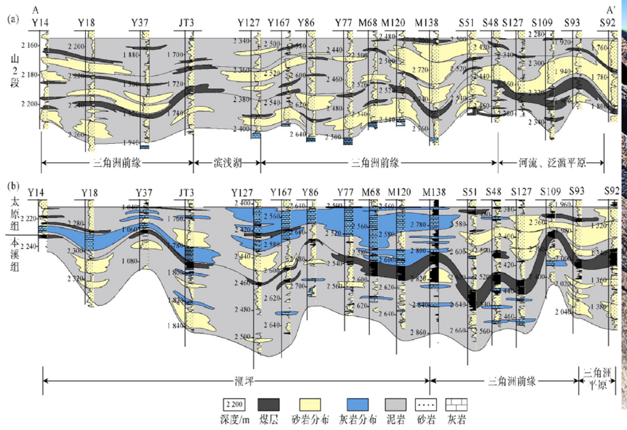
Research background

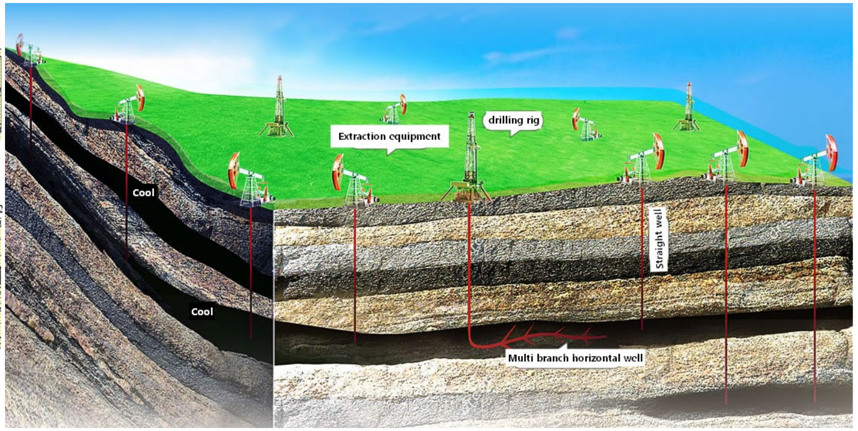
- Coal rock gas, as a clean energy source, can effectively supplement the development of conventional natural gas.
- The low strength, low porosity, low permeability, low gas saturation, high gas content, and strong heterogeneity of coal and rock hinder their efficient development.
- Hydraulic fracturing has become a necessary means of its development.
- Predicting the mechanical parameters of coal and rock has significant implications for guiding construction.



Annual production of coalbed methane



Distribution of underground coal seams

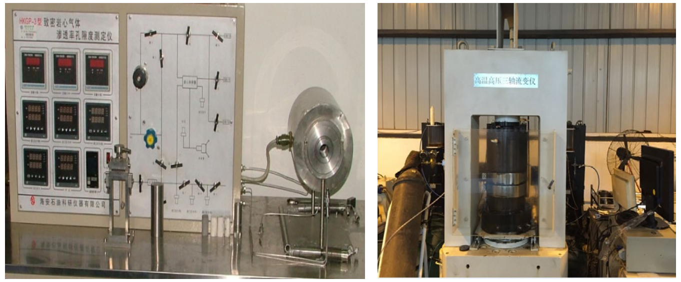


Coalbed methane extraction via hydraulic fracturing

Experimental testing of deep coal and rock formations

Core sampling for target geological formations

Experimental equipment



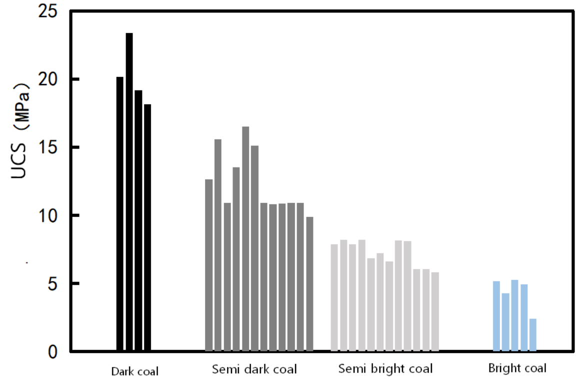
Experimental project

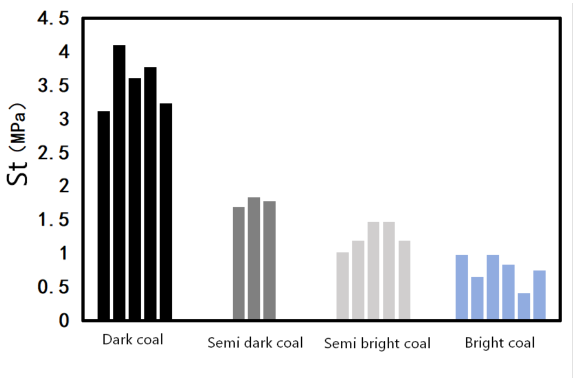
Mechanical test (UCS,St,K_{IC}...)

Acoustic testing

XRD

Experimental results





Characteristics of deep coal rock cutting

- The development characteristics of deep coal rock gas reservoirs in the research area vary greatly, ranging from undeveloped to highly developed. The degree of development of coal rock fractures is mainly "developed".

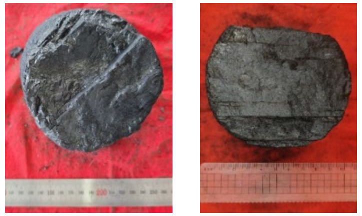
Undeveloped

This type of coal cleat density is sparse, mainly in the form of short cracks, isolated and dispersed, with poor connectivity. That is, the developed surface coal cleat and end coal cleat are not developed, and the coal cleat is generally not developed.

More developed

This type of coal cleat has a relatively dense density, mainly in the form of short cracks, isolated and dispersed, and poor connectivity,

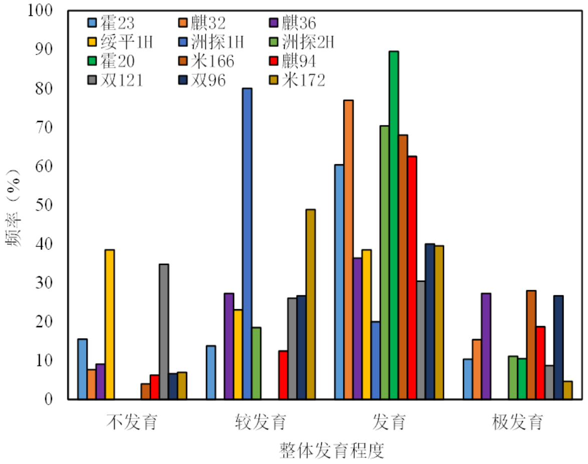
Developed



This type of coal cleat has a relatively dense density, mainly consisting of a set of parallel arranged fissures with moderate connectivity, indicating the development of mainly planar coal cleat, with overall coal cleat development.

Ex-developed

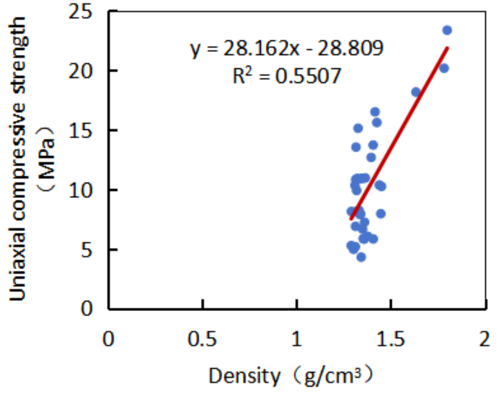
This type of coal cleat has a dense density, a network like structure, and good connectivity, with both surface and end coal cleat developed, and overall highly developed fissures.

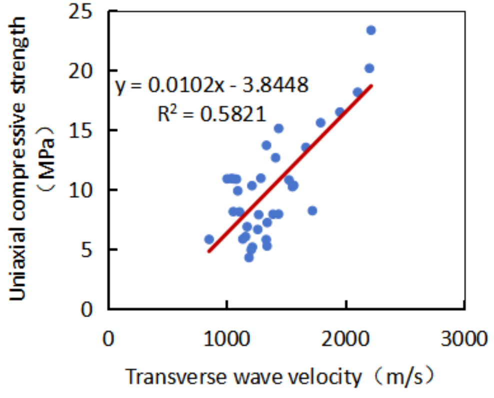


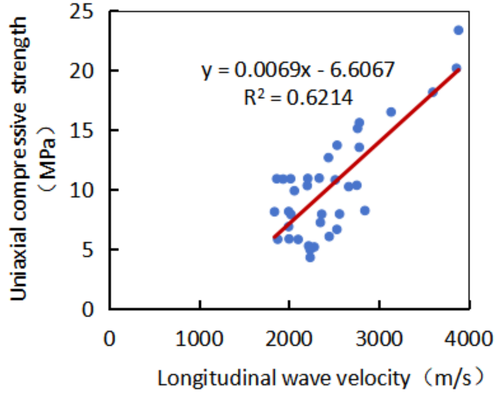
Histogram of development degree of coal rock section coal cleat

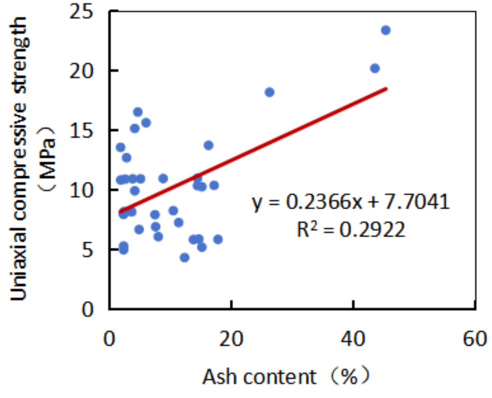
Analysis of Factors Influencing Coal Rock Mechanics

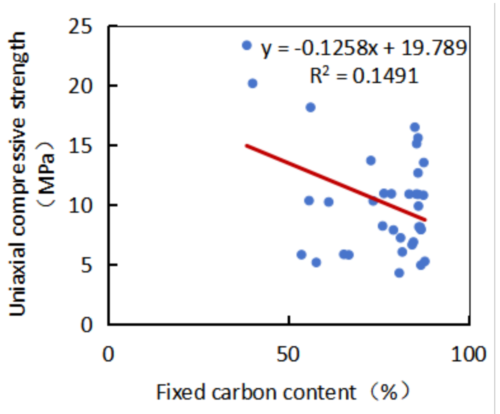
- The uniaxial compressive strength of coal rock is positively correlated with its density, longitudinal wave velocity, transverse wave velocity, ash content, etc., and negatively correlated with its fixed carbon content, degree of coal cleat development, and clay mineral content; Among them, there is a strong correlation with density, acoustic velocity, and degree of coal cleat development.

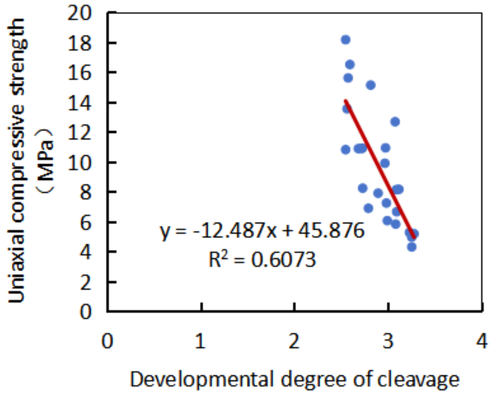


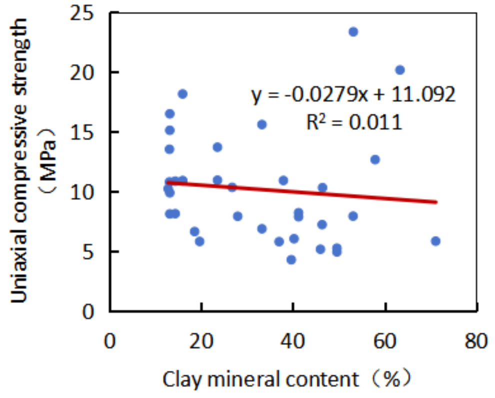


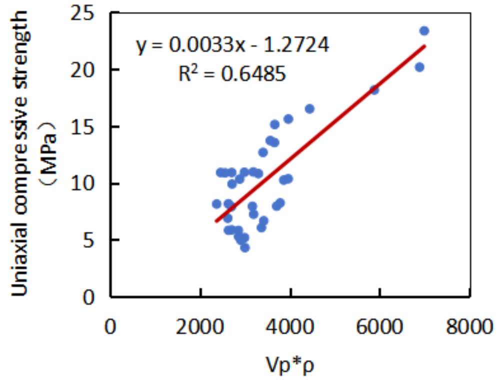








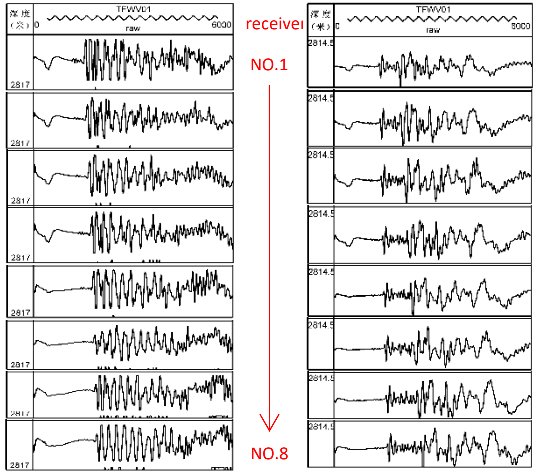




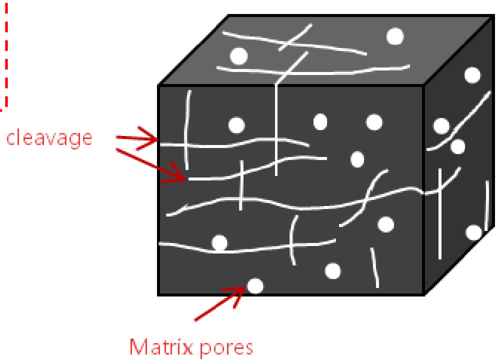
Prediction of coal cleat development degree

core1： 2816.8m
coal cleat: Undeveloped
attenuation coefficient：6.06

core2： 2814.7m
coal cleat: Ex-development
attenuation coefficient：14.02



core1 **core2**



Double pore structure coal rock model diagram

1、Establishing equivalent elastic modulus of coal rock with dual pore structure based on the theory of fractured media

2、Calculation of attenuation factor based on Squirt flow theory

3、Comparison between theoretical calculation attenuation factor and logging measured attenuation factor

4、Iterative determination of the degree of development of coal cleat

1、Squirt flow theoryy:

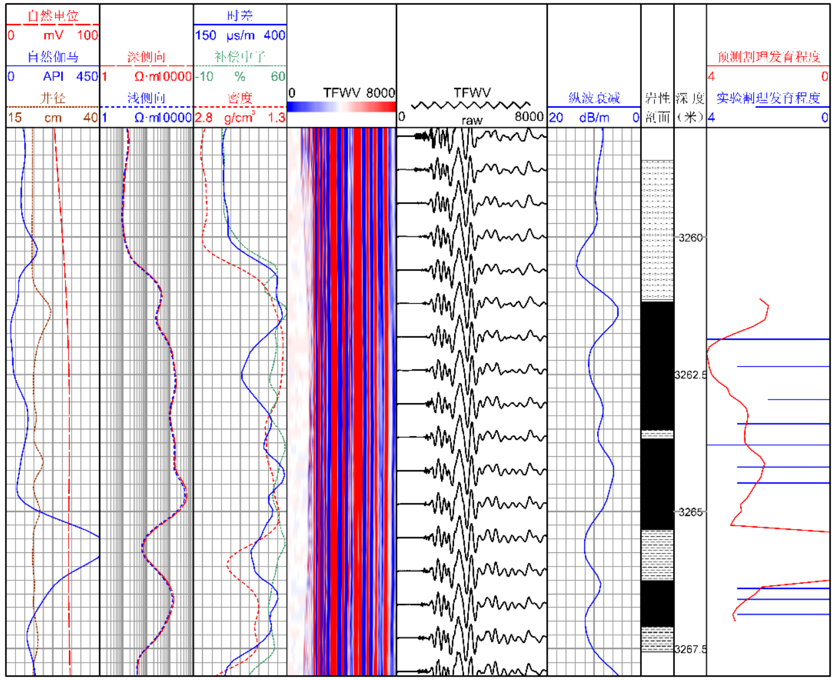
$$\frac{1}{K_{\mathrm{mf}}(\omega)}=\frac{1}{K_h}+\frac{1}{\dfrac{1}{\dfrac{1}{K_d}-\dfrac{1}{K_h}}+\dfrac{3i\omega\eta}{8\phi_c\alpha_c^2}}$$

$$\frac{1}{\mu_{\mathrm{mf}}(\omega)}=\frac{1}{\mu_{\mathrm{d}}}-\frac{4}{15}\left(\frac{1}{K_{\mathrm{d}}}-\frac{1}{K_{\mathrm{mf}}(\omega)}\right)$$

2、Attenuation factor calculation:

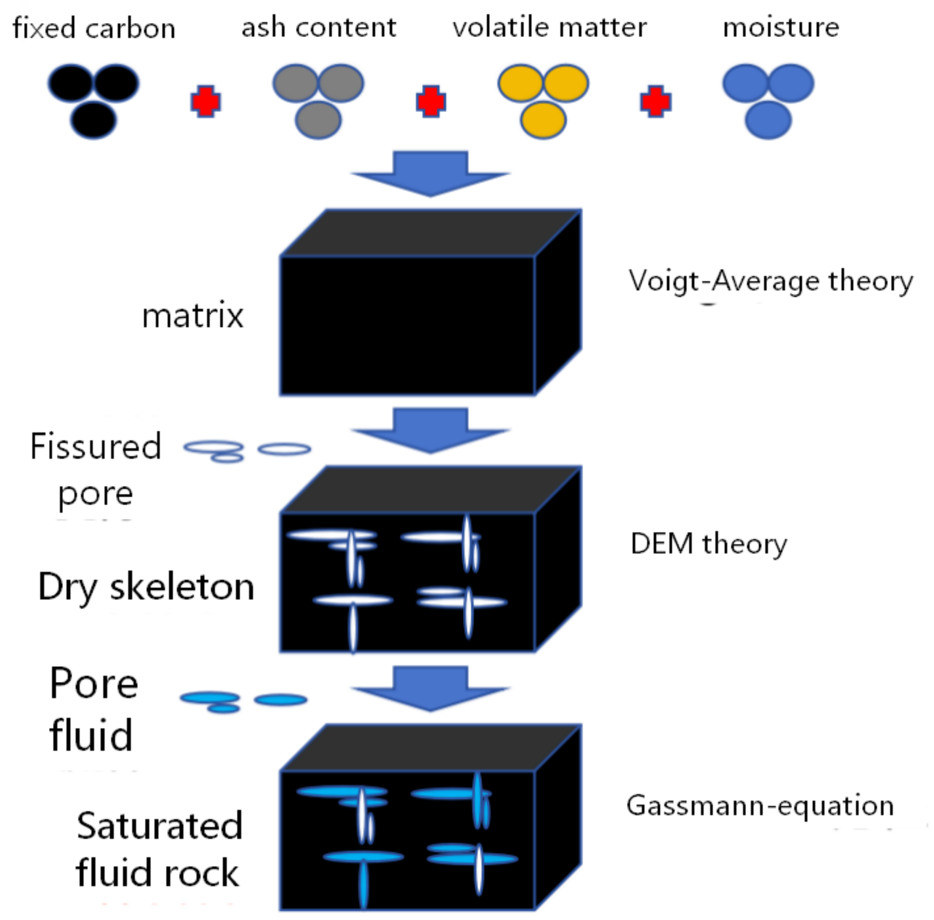
$$Q_1^{-1}=Im\left(\frac{K_{\mathrm{mf}}+4\mu_{\mathrm{mf}}/3}{\rho}\right)/Re\left(\frac{K_{\mathrm{mf}}+4\mu_{\mathrm{mf}}/3}{\rho}\right)$$

$$ATTU=\frac{\omega}{2vQ_2}$$



Prediction results of coal cleat

Construction of Coal Rock Physical Model



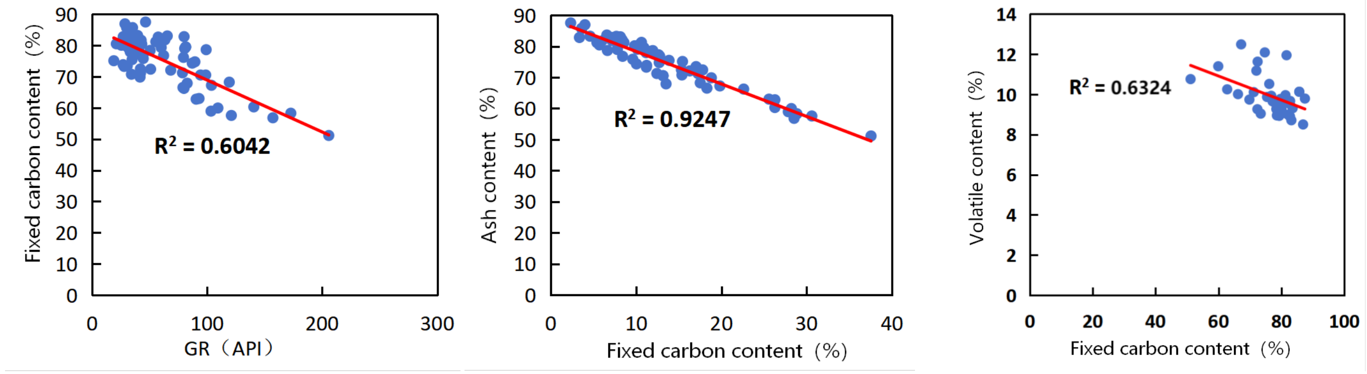
Construction of conventional rock physics models

Fixed carbon content prediction model: $Cad = -0.1664GR + 85.527$

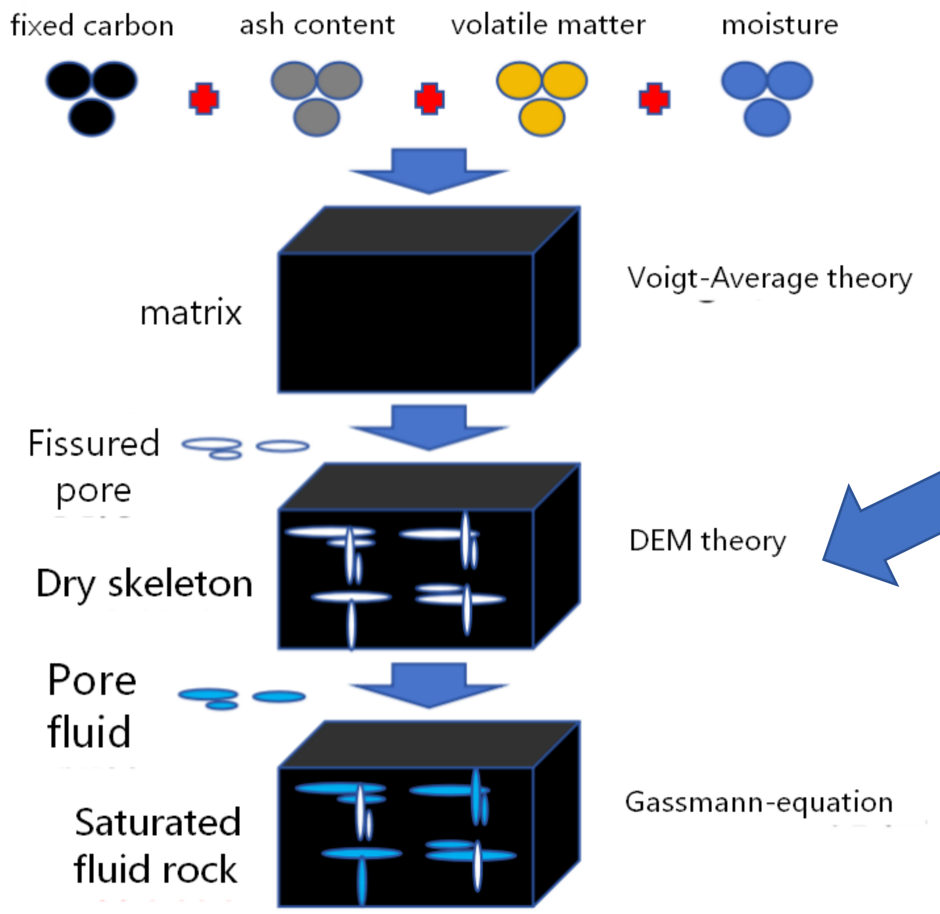
Ash prediction model: $Aad = -1.0463Cad + 88.797$

Volatile Component Prediction Model: $Vad = -0.0597Cad + 14.498$

Moisture prediction model: $Mad = 1 - Cad - Vad - Aad$



Construction of Coal Rock Physical Model



Construction of a new rock physics model

Obtaining coal rock cleat density based on squeezing jet flow

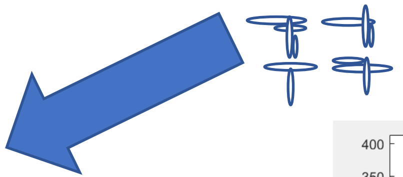
$$\varepsilon = \frac{3}{4\pi a}\varphi_c$$

ε: Coal rock cutting density

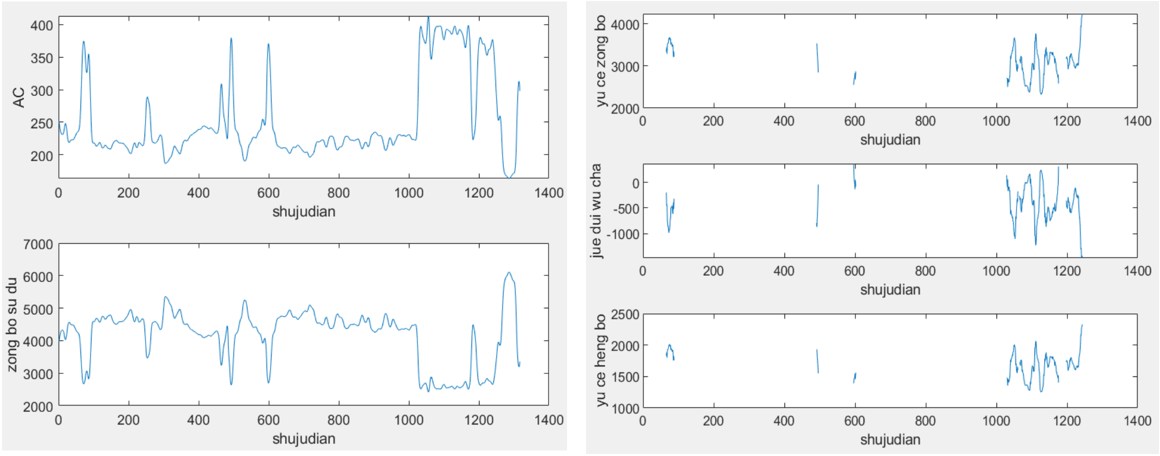
φ_c: Critical porosity of coal rock

Hudson model:

$$C_{ij} = C_{ij0} + C_{ij1} + C_{ij2}$$



The Hudson model divides the cracks into 90 ° and 0 ° and adds them to the coal rock matrix.



Acoustic velocity inversion results

Conversion of dynamic and static modulus of coal rock

Dynamic modulus of elasticity

↓ Dispersion effect

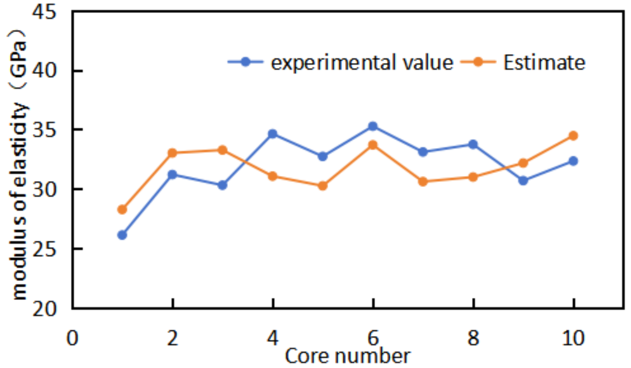
Quasi-static modulus

↓ Drainage effect

Drained modulus

↓ Strain seismic pair

Static modulus of elasticity



The elastic modulus of saturated rock at high frequency limit is:

$$\frac{K_m}{K_{HF}^{sat}} = 1+\varphi\frac{3(1-\upsilon_m)}{2(1-2\upsilon_m)}\left(\frac{\delta_p}{1+\delta_p}\right)+e\frac{16(1-\upsilon_m^2)}{9(1-2\upsilon_m)}\left(\frac{\delta_c}{1+\delta_c}\right)$$

$$\frac{\mu_m}{\mu_{HF}^{sat}} = 1+\varphi\frac{15(1-\upsilon_m)}{7-5\upsilon_m}\left(\frac{\delta_p}{1+\delta_p}\right)+e\left[\frac{16(1-\upsilon_m)}{15(1-\frac{\upsilon_m}{2})}+\frac{32(1-\upsilon_m)}{45}\left(\frac{\delta_c}{1+\delta_c}\right)\right]$$

The bulk modulus of saturated rock at low frequency limit is:

$$K_{LF}^{sat} = K_{HF}^{dry}+\frac{\beta^2 K_f}{\varphi+(\beta-\varphi)\frac{K_f}{K_o}}$$

$$\beta = 1-K_{HF}^{dry}/K_m$$

Using parameter Disp to characterize the magnitude of dispersion and attenuation between high-frequency and low-frequency moduli：

$$Disp = \frac{M_{HF}^{sat}-M_{LF}^{sat}}{M_{LF}^{sat}}$$

Dispersion effect correction

$$K_{LF}^{sat} = K_{dra}+K_f\frac{(1-\frac{K_{dra}}{K_m})^2}{\varphi+\frac{K_f}{K_m}(1-\varphi-\frac{K_{dra}}{K_m})}$$

$$\mu_{LF}^{sat} = \mu_{dra}$$

Drainage correction

$$\upsilon_{dra} = \frac{3K_{dra}-2\mu_{dra}}{2(3K_{dra}+\mu_{dra})}$$

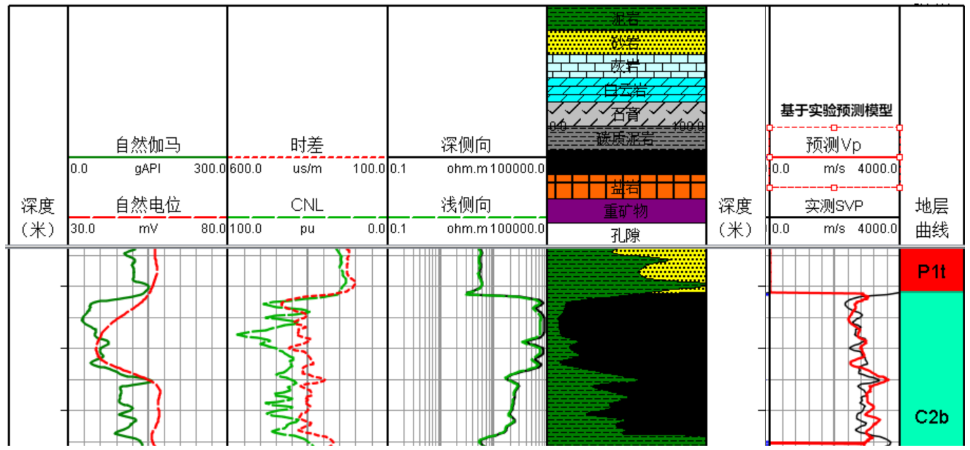
$$E_{dra} = \frac{9K_{dra}\mu_{dra}}{3K_{dra}+\mu_{dra}}$$

Strain amplitude correction

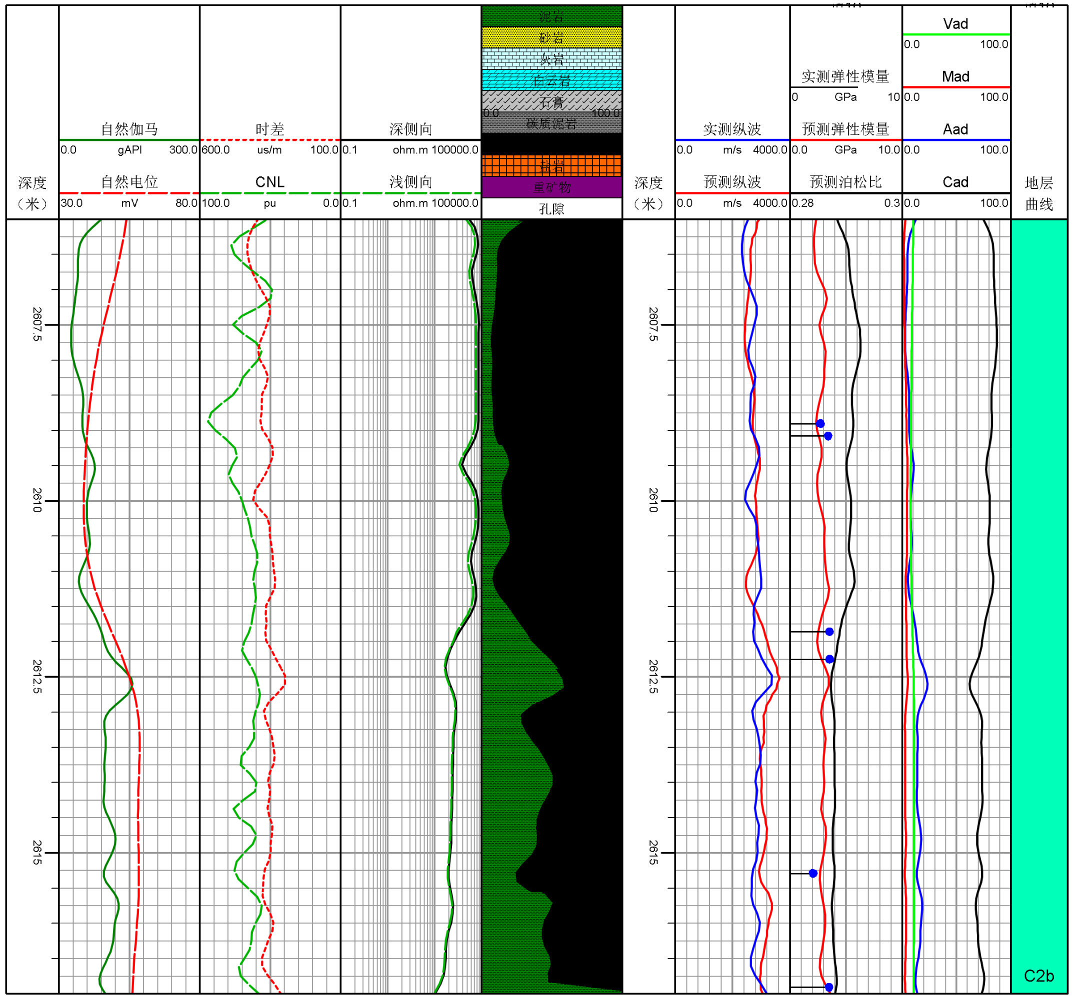
Petrophysical model for conversion of dynamic and static elastic parameters of deep coal rock

Prediction results of rock mechanics parameters for deep coal rock reservoirs

- Compared to traditional methods of converting dynamic and static modulus, the method that considers physical factors during the conversion process is more reasonable, and the predicted results are more similar to the measured results.



Inversion of acoustic velocity in coal rock reservoirs



Inversion results of rock mechanics parameters in coal rock reservoirs