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Editorial: Rock physics of unconventional reservoirs: Volume II

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Editorial on the Research Topic
Rock physics of unconventional reservoirs: Volume II

Unconventional oil and gas reservoirs have complex reservoir conditions and different types of resources have their own characteristics. Organic-rich shale and tight sandstone belong to low-permeability reservoirs, with pore structures of strong heterogeneity comprising connected and isolated pores. Coalbed methane reservoirs have the characteristics of low permeability, low reservoir pressure, low gas saturation and strong gas heterogeneity. Due to the diversity of lithology and structural complexity of unconventional reservoirs, the study of their rock properties imposes challenges. Rock physics, a key component of geological and geophysical characterization, establishes the relationship between rock properties and responses of geophysical measurements. Exploring and characterizing different types of unconventional petroleum resources require the development of new rock physics approaches. This theme is intentionally broad in scope, and our special edition provides an overview of 14 articles published in the Research Topic on "Rock Physics of Unconventional Resources: Volume II" which is a sequel to the first volume (Qi et al., 2023). The series addresses a number of key rock physics issues associated with unconventional resources, highlighting laboratory studies, fundamental theories, well-log practices and seismic data processing.

Fracture simulation is important for understanding fluid flow behavior in fractured hydrocarbon reservoirs, especially during the phase of reservoir production. Wang et al. proposed a novel method for Discrete Fracture Network (DFN) modelling constrained by seismic attributes. Compared with the traditional methods, the DFN modelling with the location constraint provides a more realistic fracture model that can accurately reflect the characteristics of fracture distribution. The hydraulic fracturing technique is widely applied to modify the reservoir formation and improving the transport capability in coal seams of low permeability. The evaluation of the hydraulic fracturing process is crucial for hydraulic fracturing operations. Bici et al. addressed the challenges in assessing the location, extension angle, and initial width of fracturing in coal mines. They proposed to evaluate the hydraulic fracturing performance using reflection borehole radar. They also conducted numerical simulations and investigated the response characteristics of borehole radar signals associated with different types of fracturing-induced cracks. Due to growing global energy demands in recent years, intensified oil and gas exploration activities take place. There is great interest among the industry to explore and develop deep carbonate reservoirs. Due to the strong heterogeneity and diversity of pore spaces in deep carbonate reservoir, the challenges exist in accurately identifying various fracture and cavity types. Lai et al. introduced a Multi-Scale Feature Aggregation Pyramid Network model (MFAPNet) for identifying five different fracture and hole types of carbonate rocks from the Core Rolling Scan images. They summarized the relationship between formation characteristics and the wellbore image data, which provides a basis for the formation evaluation based on image logging data.

Shales are composed of various minerals including quartz, clay and organic matter, etc. The individual properties of these minerals are critical in determining the overall strength and macroscopic deformation of shale. De Lacerda et al. proposed to use energy dispersive spectroscopy and atomic force microscopy to identify different shale components and to evaluate the *in situ* tribo-mechanical properties from the individual phases. The presented methodology provides novel information on friction properties at nanoscale. These measurements provide new insights on the shear deformation behavior of individual components in the shale, which is induced by the presence of mineral-scale asperity contacts. On the other hand, the effects of kerogen maturation on the seismic velocity of shales are difficult to characterize. De Lacerda et al. investigated the effects of kerogen maturation on the shale properties, such as pore volume, microsctructure, organic content, and elastic wave velocities. Their analyses show that the porosity increases through pore creation organic matter consumption. The maturation process results in an increase in the elastic modulus of the organic matter and a decrease in the pore aspect ratio. Shale oil, another important member of unconventional oil and gas resources, mainly exists in the storage spaces such as pores and microfractures. The key parameter for describing the storage space of shale oil is porosity. Su et al. measured the porosity of shale oil samples from the Lianggaoshan Formation of the Sichuan Basin. They applied several methods including saturation liquid method, helium gas charging, and nuclear magnetic resonance (NMR). Based on the results, they developed an calculation method for effective porosity of shale reservoirs of the Lianggaoshan Formation. Another important indicator for movable hydrocarbon in shale oil reservoir is the oil saturation index (OSI). OSI is typically measured by rock pyrolysis experiments. Tian et al. developed a new method to quantitatively calculate the OSI of shale using NMR logging. They conducted 2D NMR measurements on shale oil samples under three states including original, dry and kerosene-saturated. They summarized the NMR T1-T2 characteristics associated with different types of hydrogen-bearing components. Their method shows advantages in avoiding the potential influence from movable oil layers.

Tight sandstone reservoirs normally show complex pore structures and strong heterogeneity. This results in less accurate saturation calculations in tight sandstone formations. The corresponding log interpretations often fail to match with the gas test results. Guo et al. proposed an Archie-type model with variable coefficients to improve the well-logging saturation evaluation in tight sandstone. The results indicate that the cementation and saturation components are largely controlled by clay content and large pore structures, respectively. The new model produces more accurate saturation log in the study area. Coalbed methane (CBM) resources, particularly deep coal seams, have great exploration potential in China. 63% of the total proven CBM resources was found deeper than 1,000 m. There is limited understanding of the primary factors on the occurrence state of deep CBM, which poses significant challenges to the effective exploration of this resources. Shi et al. examined the impact of two external geological control factors (formation temperature and pressure) and three internal geological control factors (pore size, water saturation, and specific surface area) on deep CBM and established a theoretical model for gas content. The results have potential importance in providing key parameters for optimizing deep CBM exploration.

Granite is primarily composed of quartz and feldspar minerals and mainly distributes in crustal strata. Granite exhibits stable structure and high strength under room temperature. With temperature increasing, granite can undergo thermal damages that affect its rock composition, microstructure and pore sizes. This can result in significant change of its mechanical properties. Huang and Li investigated the biotite granite at the Gaoligongshan tunnel site and addressed the relationship between the changes in the mineral composition of granite and mechanical properties at the micro-scale under high-temperature conditions. Tectonogenetic pseudotachylytes are often formed under seismic activities that generate high strain rates within seismic fault zones and/or shear zones. Zhang et al. analyzed the occurrence of ultramafic pseudotachylytes from the Luobusha ophiolite complex in the Yarlung Zangbo suture zone, providing fault-rock evidence of paleo-earthquakes. They presented mineral chemical, microtextural and petrographic data of the ultramafic pseudotachylyte at Luobusha area. Their results provides insights on the interaction mechanism of high-pressure metamorphism and co-seismic deformation. The information of fault gauge properties is important as they greatly affect both the fault slide stability and frictional strength. Ren designed a steady-state velocity step test, and successfully determined the values of friction stability parameter (FSP) for both the gypsum fault gauge and the fault gauge consisting of different components of the kaolinite/calcite mixture. He established a functional relationship between the mass fraction of kaolinite and FSP values of the mixture fault gauge. The study serves as a useful reference for designing future experiments and numerical simulations on fault stability.

Quantitative characterization of reservoir fluid distribution is important for activities such as monitoring of CO_2 geological storage and enhanced oil and gas recovery. Seismic waves can be sensitive to fluid saturation and its distribution and therefore, it is essential to establish the relationship between seismic signatures and reservoir fluid properties. Dispersion and attenuation of partially saturated rocks are primarily due to wave-induced fluid flow mechanism. Sun et al. proposed a new method for numerically predicting seismic dispersion and attenuation due to mesoscopic flow using a 3D fluid distribution obtained by a micro-CT image as input. There is a good match between the experimental data and numerical simulations, which confirms the validity and accuracy of their method. The quality of seismic data directly affects the results of quantitative seismic interpretation. One of the primary tasks of seismic data processing is to improve the signal-to-noise ratio (SNR). Zhang et al. proposed a joint denoising method using seismic velocity and acceleration signals. The method achieves effective seismic signal and noise suppression by conducting Independent Component Analysis (ICA) based on velocity and acceleration signals of the same trace. The joint denoising method shows advantages in enhancing the dominant frequency and time resolution of seismic data.

In this editorial, we present the main highlights of the 14 articles published in the Research Topic "Rock Physics of Unconventional Reservoirs: Volume II" of the journal Frontiers in Earth Science. While unconventional resources typically are very complex to model, the underlying rock physics plays an important role in integrating geophysical measurements across different scales, i.e., core, well-log, and seismic, to improve the accuracy of formation evaluation and reservoir characterization. We summarize the recent findings on unconventional rock physics and hope they will be useful for petrophysicist, geophysicist, and petroleum engineers to gain deep insights in this field.

Author contributions

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