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Constructing Three-Dimensional Digital Rock of Continental Shale with Multi-Mineral Components Using Machine Learning Segmentation Algorithms

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Continental shales are characterized by their highly developed laminations and a high clay content, which pose significant challenges in terms of sample preparation and fluid saturation process for traditional rock physics experiments. Digital rock physics (DRP) has been emerged as an alternative method for unconventional reservoir. The establishment of a high-precision three-dimensional digital rock is crucial to ensure the accuracy of numerical simulations for determining rock physics properties. While continental shale reservoirs exhibit numerous nanopores, indistinct clay particle boundaries, and small fractures in bedding planes, which pose challenges to the segmentation of two or three dimensional grayscale images.X-ray Computer Tomography (CT), Scanning Electron Microscope Mineral Quantitative Evaluation (QEMSCAN), and Multi-spectral Automated Petrographic System (MAPS) tests are performed sequentially on continental shale samples. The scanning resolutions for these tests are 1.35μm, 1μm, and 10nm, respectively. Initially, the grayscale ranges for different mineral components were identified by combining QEMSCAN with CT scans images. Afterwards, a machine learning image segmentation algorithm was employed to partition the CT scan grayscale images into five components: pores, organic matter, clay minerals, feldspathic minerals, carbonate minerals, and pyrite. Subsequently, the same machine learning segmentation algorithm was applied to the two-dimensional MAPS images of the shale sample. This was done to identify pore spaces that were smaller than the CT resolution present in the carbonate minerals, organic matter, and clay minerals, and to calculate the surface porosity.The segmentation results of the X-ray CT scan images indicate that the machine learning segmentation algorithm improve the accuracy in identifying the boundaries of the matrix and pores compared to traditional grayscale-based segmentation method. The machine learning-based image segmentation algorithms can also accurately identify unidirectionally extended microcracks. The contents of the main mineral components calculated from digital rocks agree well with those measured by X-ray Diffraction (XRD). However, the porosity identified in CT images was considerably lower than helium porosity of the samples because only large intergranular pores and fractures can be resolved by CT. There are lots of sub-resolution pores in continental pores as illustrated in MAPS images compared to marine shale gas reservoirs, the organic matter pores in continental shale oil reservoirs are not well developed, and the microporosity is about 5%. The intercrystalline pores in clay minerals are the main reservoir space for continental shale oil, with a microporosity of 10%. The total porosities of the multi-mineral component digital rocks were calculated by considering the volume fractions of the main minerals and their corresponding microporosities. The porosity values obtained from the digital rocks exhibit excellent correlation with those derived from laboratory measurements. The three-dimensional digital rock model serves as a precise representation of the pore structure, enabling quantitative analysis of the microstructure and numerical simulation of the physical properties of continental shale.

Key words: Digital Rock Physics, Continental Shale, Machine Learning Image Segmentation, Pore Structure Characterization, X-ray Computer Tomography (CT) scans Imaging

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