A Sequential Methodology for Characterizing short-relaxation Solid Porous Media

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While nuclear magnetic resonance (NMR) enables fluid characterization in short-relaxation porous media (e.g., shale), it remains limited in detecting ultra-short-relaxation solids such as kerogen. To address this, we developed an innovative pulse sequence (Figure 1) that combine magic sandwich echo (MSE) relaxation detection with ultra-short relaxation imaging. The K-space data acquisition in the sequential Imaging module was partitioned into central and peripheral regions. The outer high-frequency spatial data were acquired using radial sampling, while the central region data were collected through Cartesian trajectory acquisition. T_1-T_2 relaxation spectra can be obtained by spatially resolved experiments, the signal can be expressed as:

$$S(r,t,T_W) = S(0)\iint f(T_1,T_2)(1-2\exp(-\frac{T_W}{T_1}))\exp(-\frac{t}{T_2}) \times \rho(r)\exp(-kr)drdT_1dT_2 \quad \text{Eq. 1}$$

where, $f(T_1, T_2)$ is the kernel function, r is the spatial position, T_W is the recovery time, t is the echo time, $S(r, t, T_W)$ is the signal. The 3D imaging of the dry shale sample in Pengshui block (Figure 2), which reveals macroscopic pore architecture with the color-coded represents signal intensity. Figure 3 shows the global T_1-T_2 spectrum, which provides microscopic-scale insights into the compositional heterogeneity of the sample. Comparative analysis with IR-CPMG-derived spectra confirms superior solid-phase signal can be acquired by our method. Furthermore, regional division of the imaging data enables extraction of localized relaxation spectra from specific areas of interest, thereby facilitating precise evaluation of pore structure heterogeneity within shale formations. This study offers a trustworthy experimental technique to benefit short-relaxation solid porous media exploration on the core scale.

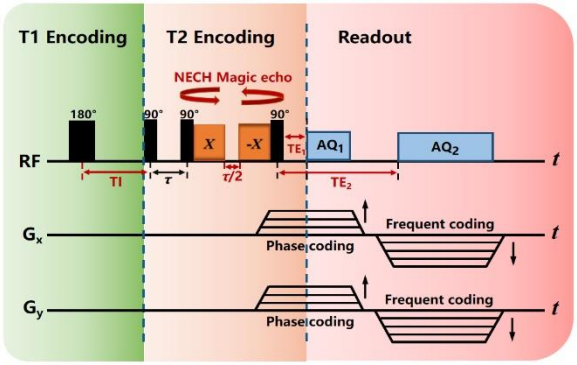

Fig. 1: IR-Magic-PETRA pulse sequence.

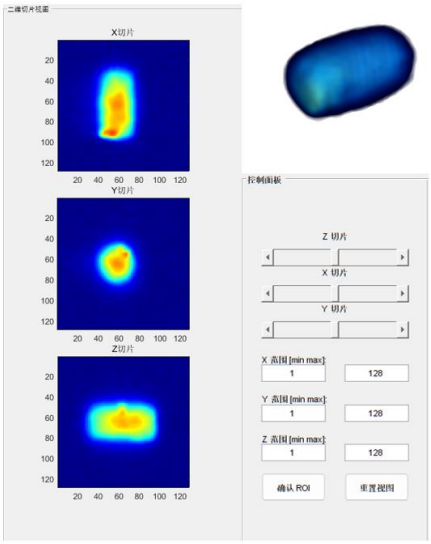

Fig. 2: The 3D imaging of shale in Pengshui block with homemade UI interface for regional division.

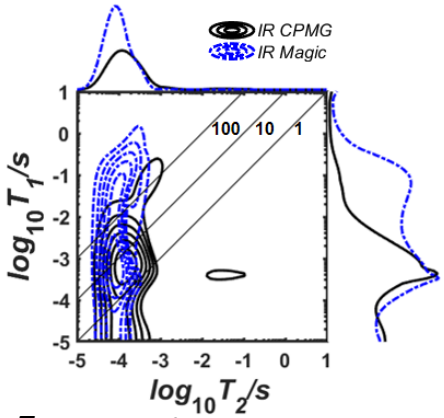

Fig. 3: The T_1-T_2 spectrum of shale in Pengshui block.

References:
[1] Zijian Jia, Energy&Fuels. (2017).
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[3] Zhenshuo Ma, Energy&Fuels. (2025).