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Evaluation of Fluid Viscosity on Seismic Wave Attenuation in Rocks

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Introduction

The relationship between porous rocks and saturating fluids is fundamental in the interpretation of seismic data, especially in hydrocarbon exploration. To better explain the interaction between the rock matrix and fluids, Biot developed the theory of poroelasticity (1941; 1956a; 1956b), which describes how seismic waves propagate in saturated media, influenced by factors such as fluid viscosity and rock anisotropy. Therefore, the study of wave attenuation in porous media is essential, since attenuation—associated with energy dissipation—depends on fluid mobility and the properties of the medium (BATZLE et al., 1999; QUINTAL et al., 2013). As the main method for hydrocarbon exploration, the seismic method, although effective, presents limitations in fluid discrimination (KEAREY, BROOKS, and HILL, 2002), which highlights the importance of rock physics. This study experimentally investigates the effect of fluid viscosity on seismic attenuation in anisotropic sandstones from the Botucatu Formation, aiming to improve the accuracy of reservoir characterization.

Method

The laboratory test used in this work follows the experimental model developed by Mikhaltsevitch et al. (2014) and applied by Ritchie (2020), employing a forced oscillation apparatus operating at low frequencies, assembled at the Structures and Materials Laboratory of PUC-Rio. Two sandstone samples from the Botucatu Formation, with different degrees of anisotropy, were tested in directions parallel and perpendicular to the bedding. The tests were conducted under three saturation conditions: dry, saturated with water (η = 1 mPa·s), and saturated with mineral oil (η = 30 mPa·s), under confining pressures of 10, 15, and 20 MPa. The experimental setup includes a Hoek cell, piezoelectric actuators, strain gauges, hydraulic pumps, and data acquisition sensors, operating in a frequency range from 1 to 100 Hz. Attenuation was obtained from the phase lag between stress and strain, and elastic moduli were determined from their ratio, allowing correlation with the Kramers-Kronig causality principle.

Results and Conclusions

After analyzing the results, it was observed that rock anisotropy plays a significant role in the seismic response, with samples tested perpendicular to the bedding showing lower attenuation values compared to those tested parallel to it. In some cases, negative attenuation values were recorded, attributed to noise and limitations of the experimental system (such as temperature control and electrical interference), as also reported by Mikhaltsevitch et al. (2014) and Ritchie (2020). Therefore, it is evident that fluid viscosity does influence seismic wave attenuation—especially under low-pressure conditions—however, it is not the primary factor governing the observed behavior. Rock anisotropy and permeability are equally determining factors. Thus, the research reinforces the importance of laboratory tests with strict variable control for real-world applications, proving relevant for seismic reservoir characterization. For future work, it is recommended to implement fiber optic sensors and temperature-controlled equipment, as well as to include fluids such as CO_2 for comparative evaluation.