Signature of Fractures on Seismic Data

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Summary

Accurate identification of fractures and their associated properties using seismic data have significant impact on the reservoir development. In the presence of irregularly spaced fractures, individual scattering occurs, and the validity of the effective medium theory assumption is violated.
Through numerical modeling, we treat fractures as individual explicit interfaces with displacement discontinuing. We examine the fracture signature on seismic data in confined setting, where the fracture cuts through a portion (top or bottom). We also examine the signature due to unconfined fracture which cut through the whole layer. In the all cases, we compare random and constant spacing fractures in the isotropic medium.
We find that the effect of the fracture location variation within the reservoir (confined to the top or bottom) and spacing can result in deviation of the amplitude between the constantly and randomly spaced fractures. We also find that the bottom reflection shows bigger deviation because it sees more of fracture scattering.

Introduction

In this study, we analyze the scattering due to individual fracture using Linear Slip Theory (LST). LST describes the fracture as a thin layer inside an isotropic host medium. As the thickness of the layer inserted approaches zero, the constructed layer medium transformed into a medium that is effectively equal to a linear slip interface. We represent the fracture as discrete joints with a stiffness resembling gas filled fracture.

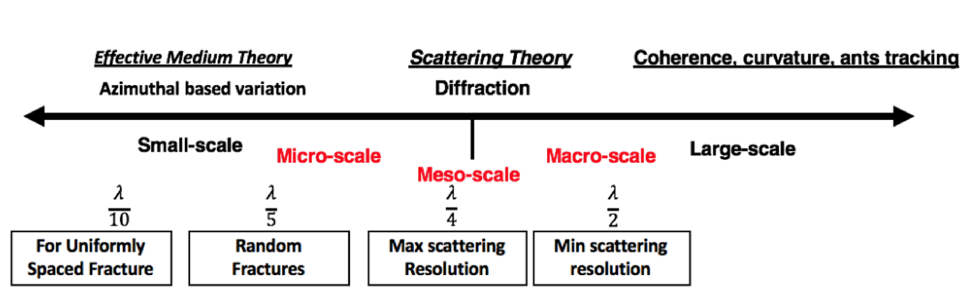

Figure 1: Different scale fractures are detected using different methods. Larger scales can be detected through seismic attributes such as coherence. Meso-scales can be detected using diffraction imaging. Micro-scale can be detected through AVAz and AVO. n this poster, we focus on the Meso-scale which violates the LST theory.

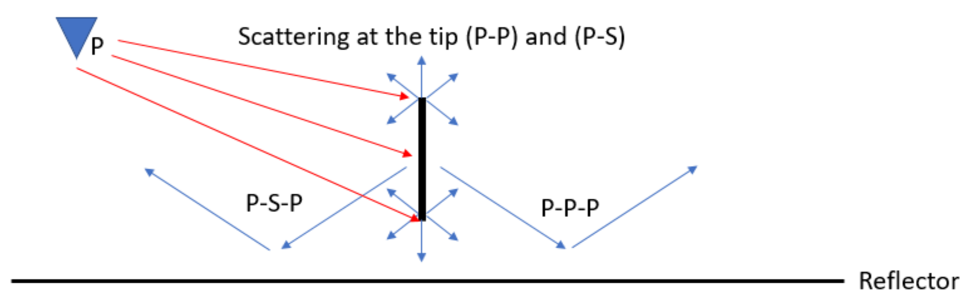

Figure 2: Different arrivals due to a single fracture. Modified after (Fang, et al., 2013). Depending on the fracture properties such as stiffness, elastic properties and angle of incident, different arrivals dominate the response. P-P stands for a P-wave that reflects as a P-wave. P-S is a P-wave that reflects as a S-wave.

Models of Fracture Media

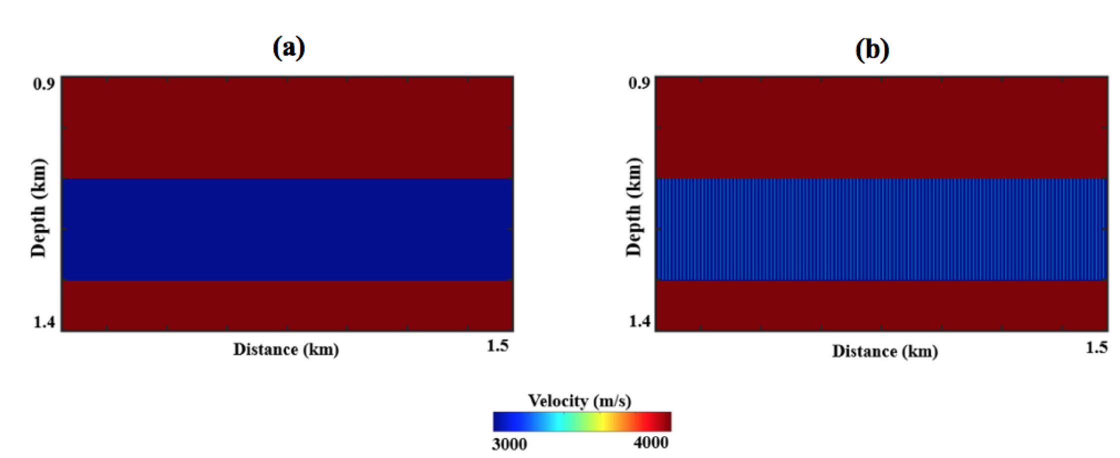

Figure 3: The model used to generate the data under the effective medium theory (EMT) (a) and as discrete joints (b). In b the spacing between the fracture is 12 m. The thickness of the fractured layer is 200 meters and the fractures extend through the whole layer (unconfined fractures).

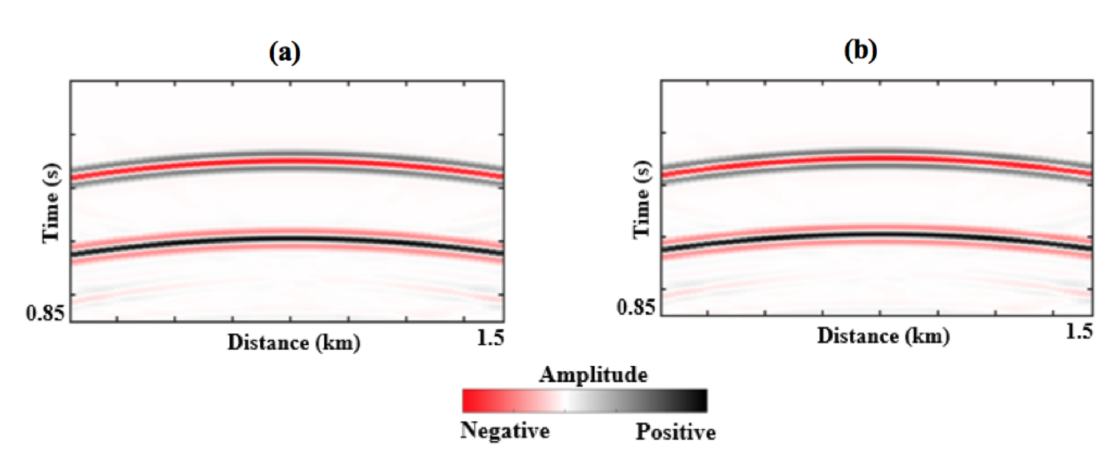

Figure 4: (a) Shot gather modeled using the model in Figure 3a. (b)Shot gather modeled using the model in Figure 3b. A wavelet with a peak frequency of 30 Hz, grid size is 4 meters and dt =1.4 ms. The two shot gathers are identical which confirms that discrete joints give similar results to EMT when the fractures are uniformly spaced.

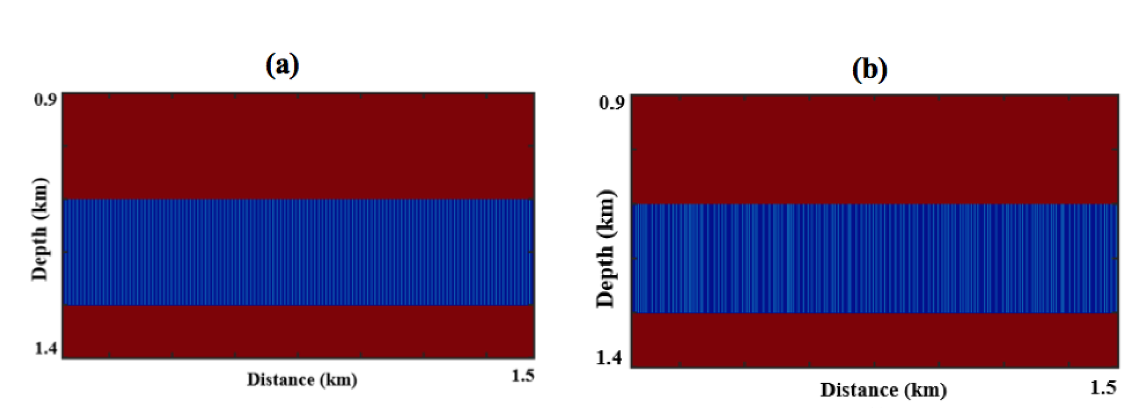

Figure 5: The model used to generate the data using constant spacing discrete joints (a) and random spacing ranging between 8 and 24 m. The thickness of the fractured layer is 200 meters and the fractures extend through the whole layer (unconfined fractures).

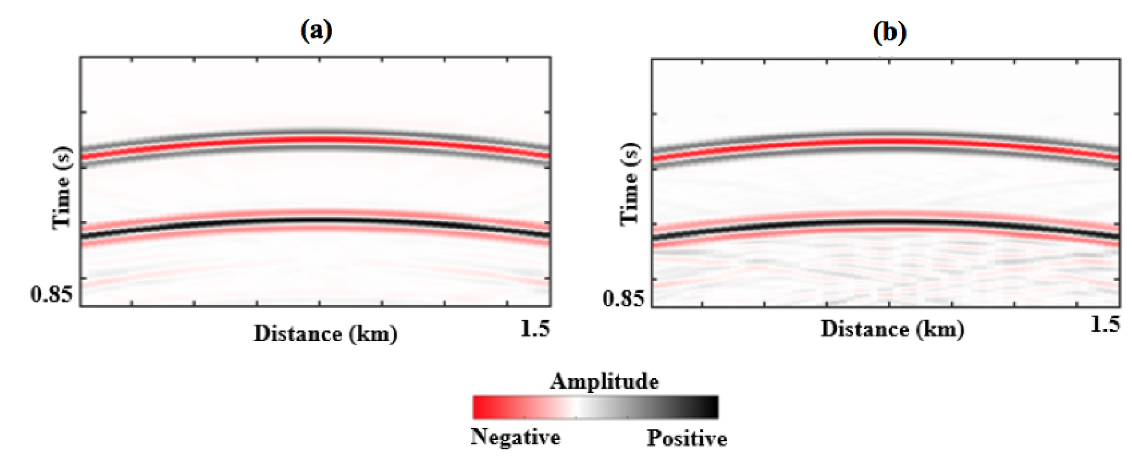

Figure 6: (a) Shot gather modeled using the model in (5.a). (b)Shot gather modeled using the model with irregular fracture spacing (5.b). The gather generated using the irregular fracture model shows scattering under the second reflection. The factors that control the scattering include the fracture stiffness, frequency of the wavelet, fracture spacing and elastic properties of the host medium.

CMP Amplitude Analysis

In this section, we analyze the seismic amplitude on CMP stacked data in three different scenarios: isotropic, consent spacing fractures, and irregularly spaced fractures. We also vary the location of the fractured zone within the reservoir Figure 7. The acquisition geometry is shown in Figure 7.d. This setting will represent the signature observed on conventional data.
We computed 30 simulations for each scenario to get a statistical range of the signature on the seismic amplitude. We show the normalized P wave amplitude comparison in between the three models in Figure 8. The red and yellow curves indicate the response of the constant and irregularly spaced fracture models. The blue dashed curves indicate the response due to an isotropic case.

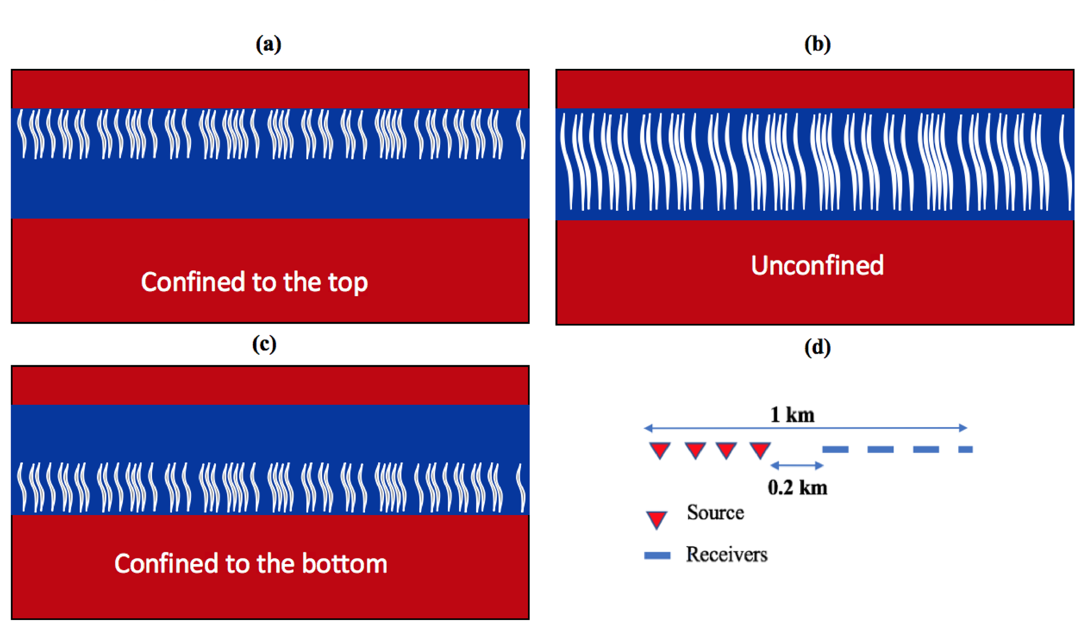

Figure 7: Velocity models in depth with irregularly spaced fractures (a) unconfined. (b) confined to top of the formation. (c) confined to bottom of the formation. (d) acquisition geometry.

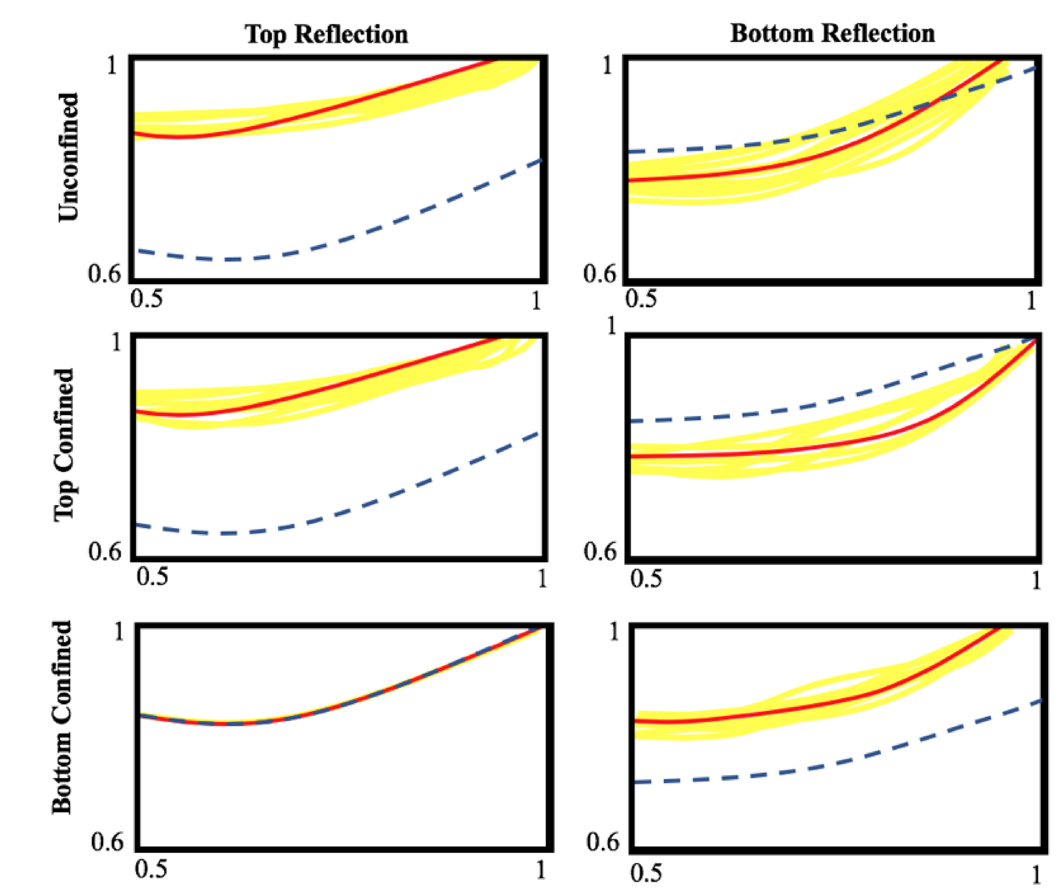

Figure 8: The P-wave normalized amplitude comparison between the isotropic (blue), regular fracture spacing of 12 meters (red) and irregular fracture spacing (yellow) for 30 simulation models.

Conclusions

Using numerical we find that when fractures are irregularly spaced, clustering occurs, and the response is different from the seismic amplitude predicted from EMT theory. This amplitude deviation is stronger for the bottom reflections. The top reflection is less influenced by fracture scattering and by comparing it to isotropic modeled AVO can establish whether fractures are confined to the bottom of the reservoir. It remains a future research area to study the effect of scattering in a thinner more realistic formation thickness and predict fracture distribution from fracture scattering directly. Also, studying the signature of random fracture length can spark ideas to using fracture scattering directly to analyze the anisotropic properties.

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