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Earthquake-induced seismic tremor explained by Krauklis wave resonance in fractured reservoir rocks: A case study of Salse di Nirano mud volcanic field (Italy)

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For seismic studies of fractured fluid-filled reservoir rocks, the so-called Krauklis wave is of particular interest. It is a special guided wave mode that is bound to and propagates along fluid-filled fractures. It can repeatedly propagate back and forth along a fracture and eventually fall into resonance. This resonant behavior has been speculated to be the source of narrow-band seismic tremor and long-period events in volcanic areas. However, it remains unstudied whether Krauklis waves may be initiated by body waves and therefore be relevant for active seismic surveys or earthquake signals in fractured reservoir rocks.

The presented study consists of two parts:

1. A combined theoretical-numerical study on the possible initiation of Krauklis wave resonance in fractures by an incident body wave
2. Application of the theoretical resonance frequency of Krauklis waves to narrow-band seismic tremor signals recorded above a mud volcanic system to determine fracture size within the fluid-filled reservoir.

In the first part, we study Krauklis wave initiation by an incident plane P- or S-wave using numerical finite-element simulations. Both wave modes initiate two Krauklis waves, one at each fracture tip, with significant amplitudes that strongly depend on the orientation of the facture. S-waves generally lead to larger-amplitude Krauklis waves, with maximum amplitudes at fracture angles of 50º, while P-waves initiate large-amplitude Krauklis waves at moderate (12°–40°) and high (>65°) fracture angles. The fact that large-amplitude Krauklis waves are initiated by body waves has severe implications for earthquake signals propagating through fractured reservoirs, because Krauklis wave-related signals are expected to be present in seismic recordings.

The second part is a case study of the Salse di Nirano mud volcanic field in northern Italy. Immediately after a M4.4 earthquake with a dominant frequency of 2 Hz, the recorded seismic tremor increased significantly with a frequency-peak at around 18 Hz. We assume the tremor to be due to Krauklis wave resonance (i.e., propagating back and forth along fractures) triggered by the passing body waves. Because the Krauklis wave velocity is a function of the dominant earthquake frequency, we can translate the observed dominant tremor frequency to the mean fracture length. We visualize this relationship in a phase diagram, which helps reading the respective variables of the analytical solution. In the Salse di Nirano mud volcanic field, we find the mean fracture length to be in the order of few 10's of meters.

We propose that body waves may initiate Krauklis wave resonance in fractured reservoirs with a frequency peak distinctively different from the dominant frequency of the earthquake. The fractured reservoir traps certain frequencies of the incoming seismic energy and acts as a frequency-filter to body waves.

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