The dual nature of fault zones as seen in seismic images

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The presence of fault-plane reflections in seismic images, besides indicating the location of faults, offers a possible source of information on these poorly understood zones. Advanced seismic data acquisition and processing can often image reflections from dipping fault-planes under favorable conditions, such as above salt in the Gulf of Mexico. Such faults pose a challenge to seismic interpreters by virtue of their dual nature as both hydrocarbon traps and, in some cases, preferential pathways for hydrocarbons. Any light that seismic data can shed on the situation would be useful.

A 3D seismic survey shot by Shell in 1992 at Blocks 314, 315, 330, and 331 of the South Eugene Island field, offshore Louisiana, contains reflections from a minibasin-bounding growth fault system. Differences in pore pressure of up to 1800 psi across a growth fault known as the A-fault give rise to fault-plane reflections over a large portion of the fault. The pressure differences are detectable since pore pressures that exceed hydrostatic pressure, or overpressures, lower the seismic impedance. Thus, the reflections point to the A-fault providing a significant seal. The ability of the reflected waves to sense such sharp onsets of overpressure has implications for pre-drill prediction of potential hazards. Over a limited portion of another, nearby growth fault, known as the B-fault, strong reflectivity correlates with high pore pressures that are known from well log data to be limited to the fault zone itself. The strong reflectivity supports a previous interpretation, from the drilling records, that the high pore pressure constitutes a spatially-limited fluid pulse caught in the act of ascending the B-fault. Further evidence obtained by comparing the Shell-acquired data from 1992 with a 1985 3D seismic survey shot by Pennzoil in the same location supports the claim that the high reflectivity arises from a moving fluid pulse confined to the fault-plane. The ability to detect such a spatially-limited, high fluid pressure anomaly has implications for the understanding of hydrocarbon migration mechanisms and the time scale of reservoir-recharge in the Gulf of Mexico.

To gain a stronger grasp on the mechanisms giving rise to fault-plane reflectivity in compacting sedimentary basins, I numerically model the full elastic wave field via the spectral element method (SEM) for several different fault models. Well log data from the South Eugene Island field enable the derivation of empirical relationships between elastic parameters (e.g., compressional velocity and density) and effective-stress along both normal compaction and unloading paths. These empirical relationships guide the numerical modeling and allow the investigation of how differences in fluid pressure modify the elastic wave field. Examples and combinations of three basic models giving rise to fault-plane reflectivity are considered: juxtaposition contacts, pressure jumps across a fault, and locally weak fault zones.