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Developing a methodology for imaging stress transients at seismogenic depth

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It is well known that the crust contains cracks down to a depth of several kilometers. The dependence of crustal seismic velocities on crack properties, and in turn, the dependence of crack properties on stress, means that seismic velocity exhibits stress dependence. This dependence constitutes, in principle, a powerful instrument for studying subsurface transient changes in stress. While these relationships and their scientific potential have been known for several decades, time-dependent seismic imaging has not, as of yet, become a reliable means of measuring subsurface seismogenic stress changes. There are two primary reasons for this: 1) lack of sufficient delay-time precision necessary to detect small changes in stress, and 2) the difficulty in establishing a reliable calibration between stress and seismic velocity. These two problems are coupled because the best sources of calibration are the solid-earth tides and barometric pressure, both of which produce weak stress perturbations of order 10^2-10^3 Pa. Detecting these sources of stress requires precision in the measurement of fractional velocity changes $\delta v/v$ of order 10^{-5}-10^{-6}, based on laboratory experiments.

Preliminary field experiments and the analysis of uncertainty from known sources of error suggest that the above precision is now in fact achievable with an active source. Since the most common way of measuring $\delta v/v$ is by measuring the fractional change in travel time along the path, $\delta T/T = -\delta v/v$, one of the dominant issues in measuring temporal changes in velocity between source and receiver is how precisely we can measure travel time. Analysis based on the Cramer-Rao Lower Bound (CRLB) in signal processing provides a means of identifying optimal choices of parameters in designing the experimental setup, the geometry, and source characteristics so as to maximize precision. For example, the optimal frequency for measuring $\delta T/T$ is found to be proportional to the Q of the medium. As an illustration, given a Q of 60 and source-receiver distances of 3 m, 30 m, 100 m and 2000 m the optimal frequencies are 15 KHz, 1.5 KHz, 450 Hz, and 22.5 Hz respectively. We have conducted a series of preliminary experiments to assess the level of precision achievable, and its dependence on a variety of other parameters. The experiments were performed in two 15-meter-deep holes, which are separated by 3 meters inside the Lawrence Berkeley National Laboratory facility, with a piezoelectric source and a 12 string of 24 hydrophone at 0.5m spacing. The parameters tested include: voltage of the applied pulse, duration of pulse and sampling rate. The pulse was repeated 10 times per second and record length was 10 milliseconds. In each case, we recorded 100 single-source pulses in addition to 2 traces consisting of a real-time stack of 100 source pulses. We have measured the delay time between the seismograms of different pulses with a variety of cross-correlation-based algorithms. All methods yielded very consistent measurements of delay time, with precision ranging from 10^{-7} to 10^{-8} s for the 100-record stacks. Since the travel time between the source and receivers is ~2 ms, this corresponds to precision in $\delta T/T$ of order 10^{-4}-10^{-5} after 10 s of recording. With hourly sampling (allowing averaging over an hour of recording) we should be able to achieve a precision (10^{-5}-10^{-6}), which is sufficient for measuring stress changes associated with tides and barometric pressure.