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Probing the damage zone on the San Andreas Fault at Parkfield

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Rocks are heterogeneous materials that exhibit nonlinear elastic (anelastic) behavior in both the laboratory and Earth. In the laboratory, investigators have observed complex relationships between stress and strain that include hysteresis, finite relaxation times, and rate and stress path dependence. These behaviors are linked to stress, porosity, permeability, material integrity and material failure, many of the characteristics we care about in the upper crust. A limited number of studies in the Earth have confirmed that nonlinear elasticity can be measured in situ, but due to logistical challenges these investigations have not achieved the full potential of what can ultimately be learned from this type of investigation. We adapted a 'pump-probe' type experiment common in laboratory studies, using solid earth tides as the low frequency pump and empirical Green's function as the high frequency probe. By probing the velocity at different points in the pump cycle, we constrain some important information about the stress-strain relationship. Near the San Andreas Fault, we observe strongly nonlinear elastic behavior that increases with decreasing distance to the fault that characterizes the damage zone. We also constrain important aspects of hysteretic behavior that are related to damage properties and possibly pore pressure.