Interactions between earthquakes and fluids: An overview of non-seismological observations

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Earthquakes and fluids are linked by a variety of processes that don't generate seismic waves, and whose associated deformation is often below the resolution of GPS or InSAR. These processes can be studied by interpreting seismic data as proxies for deformation or fluid flow. This overview will, however, emphasize field observations where fluid pressure and/or deformation have been measured directly.

Poroelasticity can account for static fluid pressure "steps" in response to "permanent" earthquake-imposed strain, as well as oscillatory pressure transients in response to seismic waves. Less easy to understand are "persistent" fluid pressure changes caused by seismic waves that, once past, leave no net strain. Such step-like fluid-pressure responses to an oscillatory stimulus might help explain how seismic waves can trigger microseismicity or seismic tremor hundreds of km from a large earthquake. Evidence is strong that seismic waves change permeability, but a variety of mechanisms appear possible. A key outstanding question is whether these mechanisms can operate at the depths where earthquakes nucleate and where tectonic tremor takes place.

Settings where faults apparently fail under stress increments minute compared with stress drops are inferred to have low effective confining stresses, resulting from high fluid pressure. Seismicity induced by waste fluid injection in the uppermost few km of the crust potentially provides opportunities to investigate the mechanical role of fluids in faulting, and would seem consistent with the law of effective stress. However, fluid withdrawal can also stimulate seismicity, suggesting that poroelastic stresses can link fluid processes with earthquakes. In the absence of strain or GPS data, earthquake hypocenters are typically presumed to illuminate fault-controlled fluid flow paths. We have even less information about where fluid is accommodated in the subsurface at aseismic injection sites. High-resolution deformation measurements would help characterize these situations.

What roles do fluids play in natural earthquakes? Actual fluid pressure data near a nucleating natural earthquake are nearly nonexistent. There are, however, relevant and intriguing observations of linked seismic-aseismic-fluid flow processes in the shallow hydrothermal systems of the Yellowstone and Long Valley restless calderas. Recurrent swarm seismicity typifies these relatively well-instrumented magmatic centers. When very detailed seismic data have been available, hypocenters can be seen to migrate vertically following certain of the larger events in swarms. The faults ruptured during such sequences open paths for upward fluid flow. Competition between mineral deposition that reduces permeability and increases fault strength, versus a sustained fluid pressure source to prevent fault healing, determines whether the path reaches the surface. Fluid pressure and borehole strain observations have revealed aseismic components of two such "fluid-driven" swarms.

Accumulating observations of aseismic deformation, fluid pressure, and temperature, and improved capabilities to measure these in deep, hot, high-fluid-pressure boreholes, will add greatly to the understanding of earthquake-fluid linkages gained from seismology.

Brief reading list:

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