Changes in physical properties of the Nankai Trough megasplay fault induced by earthquakes, detected by continuous pressure monitoring

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One primary objective of Integrated Ocean Drilling Program (IODP) Expedition 365, conducted as part of the NanTroSEIZE project, was to recover a temporary observatory, termed the “GeniusPlug“ emplaced to monitor formation, pore fluid pressure and temperature within a major splay fault that branches from the main plate interface, at a depth of ˜400 m below sea floor (mbsf). The instruments were installed in Dec. 2010 and recovered in April 2016, yielding 5.3 years record of formation pressure and temperature within fault zone. Here, we use the pressure timeseries, and in particular the response to ocean tidal loading, to evaluate changes in physical properties of fault zone induced by several regional earthquakes. To accomplish this, we quantify: (1) the amplitude of the formation’s response to tidal loading, defined in terms of a tidal loading efficiency, governed primarily by the formation and fluid elastic properties; (2) the phase lag between the ocean tidal signal and the measured response in the observatory, which is governed by a combination of formation hydraulic diffusivity and the relative compressibilities of the formation and sensing volume; and (3) pressure steps associated with earthquakes, identified in formation pressure after removal of the tidal signal. We observe essentially no phase lag, but in for many events we detect both pressure steps and transient decreases in loading efficiency. To reveal the cause of these changes, we investigate the effects of static and dynamic crustal strains. Changes in theoretical static volumetric strain and the associated expected pressure step for each event are calculated based on Okada (1992), and using a conversion from volumetric strain to pore pressure based on formation properties defined by laboratory experiments. We find that, there is no clear correlation between observed pressure steps and predicted static volumetric strain; furthermore, the predicted pressure steps are ten to hundreds of times smaller than observed. As a proxy for dynamic strains, we calculate the integrated “pressure energy density” over a 30 minute window for each event, and show a positive correlation with both step changes in pressure and changes in loading efficiency.
Most of the detected changes represent pressure increases and loading efficiency decreases. We speculate that disruption of grain contacts and subsequent pore collapse induced by dynamic strain produces changes of hydraulic properties in the fault zone. Alternatively, these changes could reflect exsolution of gas from pore fluids that drives pore pressures up while simultaneously reducing loading efficiency by increasing the compressibility of pore-filling fluids.
Finally, the observed amplitude response and negligible phase lag of the formation pressure response to ocean tidal loading, taken together, allow an estimate of the minimum hydraulic diffusivity of splay fault of 8.9×10^{5} m^2/s.