Tidal triggering of microearthquakes on the Juan de Fuca Ridge

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Abstract. Tidal stresses beneath the oceans can be up to an order of magnitude higher than those found in the continents because of the effects of loading by ocean tides. I have analyzed 1899 microearthquakes recorded during a 55-day experiment on the Endeavour segment of the Juan de Fuca Ridge for tidal triggering. The tidal phase of the full data set and of a declustered subset comprising 987 events appears non-random to a high level of confidence. Earthquakes occur more frequently near low tides, especially the lowest spring tides, when the extensional stresses are a maximum in all directions.

Introduction

Tidal stress variations [*Melchior*, 1983] are orders of magnitude smaller than the typical stress drops that accompany earthquakes [*Kanamori and Anderson*, 1975], but in most settings the rates of stress change due to tides are significantly higher than average rates of tectonic stress buildup. If earthquakes were triggered immediately at a threshold stress, they should occur more frequently near tidal extremes. Although the conclusions of tidal triggering studies are varied [*Emter*, 1997], it is clear that there is not a universally strong correlation between earthquakes and tides

The simplest explanation for a lack of tidal triggering is that earthquakes are preceded by an interval of accelerating stress buildup or fault weakening [*Vidale et al.*, 1998; *Lockner and Beeler*, 1999]. Quantifying weak correlations, or the lack thereof, can constrain the processes that lead to earthquake nucleation. In a recent study of over 13,000 California earthquakes, *Vidale et al.* [1998] find that the rate of earthquakes is 2% higher when the stress favors rupture but that the difference is not statistically significant at the 95% confidence level. They conclude that preseismic stress rates in earthquake nucleation zones are at least 15 kPa/hr, far in excess of the long-term tectonic stress rate of 10 Pa/hr.

The oceans may be a good environment to search for tidal triggering because ocean loading increases tidal stresses [*Emter*, 1997]. In the continents, solid earth tidal stresses have amplitudes of 1-4 kPa [*Melchior*, 1983]. In the oceans, tidal ranges can reach several meters (1 m = 10 kPa). In this paper, I present an analysis of earthquakes recorded by a local network on a mid-ocean ridge that reveals evidence for tidal triggering.

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Microearthquake data set

The data set used in this study was collected in the summer of 1995 on the Endeavour segment of the Juan de Fuca Ridge. The experiment (Figure 1) is described in detail by *Wilcock et al.* [2001]. Fifteen ocean bottom seismometers (OBSs) were deployed near the center of the segment for 55 days. The network spanned a 5-km section of the ridge axis that enclosed two hydrothermal vent fields and extended 15 km off-axis to the west. High levels of seismicity were recorded throughout the experiment both on- and off-axis. A total of 1899 earthquakes were located with at least 4 arrival times. Seismic moments range from 10^9 to 4×10^{13} N m. There are 1498 earthquakes within 5 km of the nearest OBS of which 746 are located in a band of axial seismicity at 1.5-3.5 km depth beneath the vent fields. Focal mechanisms for the better recorded axial earthquakes are quite variable and are characterized by subhorizontal tension axes. On the west flank, the earthquakes occur primarily in swarms, many of which are to the north of the network. Well-constrained focal depths are mostly between 2 and 4.5 km. Focal mechanisms show ridge parallel extension and north-south compression. Several large swarms are also located well outside the network on the east flank and near the ridge axis to the north and south of the network.

Evidence for tidal triggering

The Northeast Pacific Ocean has large tides [*Mofjeld et al.*, 1995]. The experiment coincided with maximum summer tidal ranges that twice exceeded 3.5 m (Figure 2a). A histogram of the earthquake count (Figure 2b) appears to show increased levels of seismicity during intervals with large tidal ranges and more earthquakes near or just after the lowest tides.

In order to search quantitatively for tidal triggering, I first estimated the tidal perturbations to crustal stresses. Horizontal tidal strains at the seafloor were obtained by summing the contributions from solid earth tides [*Berger*, 1969] and ocean-tide loading [*Agnew*, 1997] assuming the tidal model of *Schwiderski* [1980]. Tidal perturbations to the vertical principal stress at the seafloor were obtained directly from predicted variations in seafloor pressure [*Mofjeld et al.*, 1995]. By assuming that the perturbations to vertical stress and horizontal strain are invariant with depth, I estimated the tidal stress tensor at mid-crustal depths (Figure 2c) using elastic constants consistent with $V_P = 6.5$ km/s, $V_S = 3.5$ km/s, and a density of 2800 kg/m^3.

If the fault planes and slip directions are known, it is possible to resolve the tidal stress perturbations on each fault. For the Endeavour data set, focal mechanisms are available for 173 earthquakes [*Wilcock et al.*, 2001]. However, with the exception of a few swarms that were relocated using a