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Evidence for tidal triggering of earthquakes as revealed from statistical analysis of global data

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[1] We observe tidal triggering of earthquakes by measuring the correlation between the Earth tide and earthquake occurrence. We used the times, locations, and focal mechanisms of the 9350 globally distributed earthquakes with magnitude 5.5 or larger from the Harvard centroid moment tensor catalog. The tidal stress was theoretically computed by using the Preliminary Reference Earth Model and a recent ocean tide model, NAO.99b. We considered the shear stress on the fault plane and the trace of stress tensor, J1. Defining the tidal phase angle at the occurrence time for each earthquake, we statistically tested the phase selectivity using the Schuster's method. For all the earthquakes, no significant correlation is found between the Earth tide and earthquake occurrence both for the shear stress and for J1. By classifying the data set according to fault types, however, we find a high correlation with the shear stress for reverse fault type. The correlation is particularly clear for shallow and smaller earthquakes of this type. Significant correlation with J1 also appears for larger earthquakes of reverse fault type and for shallow and larger ones of normal fault type. We find no correlation for strike-slip type. For all the cases of high correlation, earthquakes tend to occur when the tidal stress accelerates the fault slip, indicating that high correlation is not coincidental but is physically justified. This result strongly suggests that a small stress change due to the Earth tide encourages earthquake occurrence when the stress in the future focal area is near a critical condition. *INDEX TERMS:* 7230 Seismology: Seismicity and seismotectonics; 1249 Geodesy and Gravity: Tides—Earth; 7223 Seismology: Seismic hazard assessment and prediction; 7209 Seismology: Earthquake dynamics and mechanics; 1223 Geodesy and Gravity: Ocean/Earth/atmosphere interactions (3339); *KEYWORDS:* tidal triggering, statistical test, Earth tide, ocean loading, Harvard CMT catalog

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1. Introduction

[2] The stresses due to the Earth tide oscillate and are superimposed on tectonic stresses. Although the amplitude of the tidal stress change, of order 10^3 Pa, is much smaller than the average stress drop of earthquakes, its rate is generally larger than that of tectonic stress accumulation. Therefore tidal triggering of earthquakes may be expected when the stress in the focal area is near the critical level to release an earthquake. Measuring tidal triggering may give us a clue to solve the physical mechanism of initiation of fault rupture. Since we can predict the stress change due to the Earth tide, there have been numerous searches for the relation between the Earth tide and earthquake occurrence.

[3] Most studies with global catalogs have reported no correlation between the Earth tide and earthquake occurrence [*Schuster*, 1897; *Morgan et al.*, 1961; *Simpson*, 1967; *Heaton*, 1982; *Curchin and Pennington*, 1987; *Hartzell and Heaton*, 1989] with few exceptions [*Heaton*, 1975; *Ding et al.*, 1983; *Tsuruoka et al.*, 1995]. Regional catalogs have also been investigated; a significant correlation has been reported by some studies [*Young and Zurn*, 1979; *Ulbrich et al.*, 1987; *Shirley*, 1988], but no correlation by some other studies [*Knopoff*, 1964; *Shlien*, 1972; *Shudde and Barr*, 1977; *Vidale et al.*, 1998]. On the other hand, an especially high correlation has been found for aftershock sequences [*Berg*, 1966; *Ryall et al.*, 1968; *Mohler*, 1980; *Souriau et al.*, 1982], earthquake swarms [*Sauck*, 1975; *Klein*, 1976; *Rykunov and Smirnov*, 1985; *Oike and Taniguchi*, 1988], and earthquakes occurring in volcanic areas [*McNutt and Beavan*, 1984; *Rydelek et al.*, 1988]. *Emter* [1997] gives an elaborate review of past studies.

[4] At first, lunar and solar periodicities were sought in the time series of earthquake occurrence [*Schuster*, 1897; *Morgan et al.*, 1961]. In the following studies, the earthquake occurrence times were related to theoretical time functions of tidal changes, which include the tidal potential [*Shlien*, 1972; *Shirley*, 1988], gravity [*Knopoff*, 1964; *Simpson*, 1967; *Sauck*, 1975; *Shudde and Barr*, 1977; *Rykunov and Smirnov*, 1985], and strain [*Klein*, 1976; *Young and Zurn*, 1979; *McNutt and Beavan*, 1984; *Oike and Taniguchi*, 1988; *Rydelek et al.*, 1988]. However, the most likely component to control the earthquake occurrence is the stress, and the

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