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Stress changes in the Costa Rica subduction zone due to the 1999 M_w=6.9 Quepos earthquake

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Abstract

Stress changes after large earthquakes can trigger substantial seismicity along many fault systems. As subduction zones produce the majority of large earthquakes, it is essential to understand how significant earthquakes may affect stress conditions and aftershock locations. Calculations of stress changes due to large underthrusting earthquakes can be used to examine likely zones of triggered seismicity in subduction environments. However, associations between stress changes and locations of small aftershocks are typically difficult because of large errors on offshore aftershock locations based on land-based seismic observations. After the 1999 Quepos earthquake (M_w=6.9) in the subduction zone offshore Costa Rica, small magnitude earthquakes were located using a local onshore–offshore temporary seismic network, providing a data set of high-quality aftershock locations. In light of these well-located aftershocks, we compute Coulomb stress changes for the 1999 Quepos earthquake for comparison. Our calculations show lobes of increased stress in regions coinciding with most of the small magnitude seismicity following the mainshock, as seen in many cases of large strike-slip earthquakes. Few small earthquakes occur in regions of decreased stress. Within three years, a large (M_w=6.4) earthquake occurred in this region, however based on this modeling, it does not appear that the 2002 earthquake occurred in a zone of stress increase from the 1999 event.

Keywords: earthquakes; stress; subduction zones; Costa Rica

1. Introduction

Subduction zones generate most of the global seismicity and the largest earthquakes. Shallow subduction systems exhibit significant variations in seismicity due to variations in tectonic and stress conditions, thus it is important to examine the stress state for individual subduction zones to begin to

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understand the seismicity variations. The state of stress at any given subduction zone will be influenced by global and regional scale structure and processes as well as by variability in material properties. For example, the effects of mantle flow on the state of stress of any given subduction zone will depend on the geometry of the subducting slab, flow in the mantle wedge, and the degree of coupling (stress transmission) between lithosphere and mantle. The latter is a function of regional rheological properties.

Variations in crustal and lithospheric structure for both the subducting and overriding plate should be of great importance to the overall stress state. The details of the bathymetric structure (aseismic ridges, seamounts, fracture zones) of the subducting plate will likely exert controls over the dynamics of the subduction zone, the overall state of stress, and the local seismicity [1–4]. At the local-scale, variations in seafloor bathymetry and sediment thickness may influence earthquake rupture behavior (e.g. [1–3,5–7]). Variability in the subducted material and its impact on the stress conditions at a subduction zone has clear implications for earthquakes and seismic coupling. Models of seamount subduction vary considerably; Scholz and Small [4] describe significant increases in normal stress and seismic coupling in regions where seamounts are subducted. Others suggest that subducted seamounts only increase seismic coupling and stress when thick sediment blankets the seamount, allowing it to subduct beyond the trench region without being decapitated [8].

In addition, changes in material properties, such as the rheology of the thrust interface and the rheology of the lithosphere of the overriding plate, will have a large effect on how subduction zone stresses are transmitted to the overriding plate and on the overall state of stress on the region. These can be also intimately related with local deformation and seismicity. For example, viscoelastic relaxation in the lower crust or mantle following large earthquakes is likely an important contributor to the local stress (e.g. [9–12]).

The state of stress does influence seismicity, as noted by correlations between occurrence of great earthquakes, seismic coupling, back-arc spreading, and overriding plate velocity (e.g. [13,14]). But exactly how the details of the state of stress at a subduction zone are correlated with seismicity is not obvious or easy to predict. Thus, there is a great need for models that account for the peculiarities and details of a subduction zone system to understand the relationship between stress and seismicity unequivocally.

Subduction zones are in many ways ideal laboratories to examine causation and correlation between state of stress, stress changes, and seismicity. Within subduction zones, large earthquakes typically produce many aftershocks. Numerous thrust mechanism aftershocks are common at the edges of the main event rupture area and along the downdip extension of the rupture zone. In addition, normal faulting earthquakes may occur in the outer rise of the subduction zone after many great underthrusting earthquakes [15]. Recently, Coulomb stress changes due to great earthquake ruptures in subduction zones were presented for the 1960 Chile and 1964 Alaska earthquakes [16]. A comparison between the computed stress patterns and seismicity after the great earthquakes shows that most (~70–80%) of aftershocks occurred in regions of increased Coulomb stress. The suggestion of aftershocks triggered by stress changes for the great Alaska and Chile earthquakes, is the first confirmation of seismicity triggering for subduction zone earthquakes.

Examining stress interaction and triggering of aftershocks in subduction zones can be problematic however, because most aftershock locations are based on observations from land seismometers. Many aftershocks are of small magnitude; thus global catalogs are likely incomplete or the catalog locations may have large errors due to noise, inaccurate velocity models, and poor station coverage. For example, Lin and Stein [16] examined triggering for both the 1960 (M_w=9.5) and 1995 (M_w=8.1) Chile earthquakes. For the 1960 earthquake they used aftershocks with M>5.8 in global catalogs. But for the 1995 earthquake, a more precisely located data set of aftershocks recorded by an onshore–offshore seismometer network was available [17]. As a result, their results for aftershock triggering after the 1995 earthquake are considerably more robust, even though this earthquake, at M_w=8.1, was smaller magnitude than the great 1960 event.

The study of stress changes due to 2 great earthquakes is a valuable contribution to understand-