Forearc Deformation and Great Subduction Earthquakes: Implications for Cascadia Offshore Earthquake Potential

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The maximum size of thrust earthquakes at the world’s subduction zones appears to be limited by anelastic deformation of the overriding plate. Anelastic strain in weak forearcs and in weak forearc sediments can cause forearc failure even for the magnitude of thrust earthquakes by inhibiting the bulkup of elastic strain energy or slip propagation or both. Recently discovered active strike-slip faults in the submarine forearc of the Cascadia subduction zone show that the upper plate there deforms rapidly in response to arc-parallel shear. Thus, Cascadia, as a result of its weak, deforming upper plate, may be the type of subduction zone at which great (moment magnitude ~ 9) thrust earthquakes do not occur.

The largest known earthquakes result from the thrusting of oceanic lithosphere beneath the forearc of the overriding plate at subduction zones. Some subduction zones have produced earthquakes in the century with moment magnitudes $M_w$ in excess of 9, whereas others have had events of only $M_w \approx 8$ or less. At the Cascadia subduction zone (CSZ) off the coast of Oregon and Washington, no great thrust earthquakes have occurred in historical times and it is debated whether one can occur. A recently discovered feature of the CSZ relevant to this debate is upper plate deformation evident in several faults that cut the forearc at a high angle to the trench (1-3). To understand the significance of such faults for earthquake potential, we examined subduction zone around the world and found a trend that suggests that deformation within the leading edge of the overriding plate limits the size of thrust earthquakes. These observations and a great number of the deformation rate within the upper plate at Cascadia suggest that the CSZ is more like the arc of subduction zone that does not produce thrust earthquakes significantly larger than $M_w \approx 8$ than like the type that does. We estimate that the offshore arcuate strike-slip faults within the forearc will produce earthquakes smaller than $M_w \approx 7.5$ and pose a smaller hazard to onshore areas than $M_w \approx 8$ or greater subduction events. We do not assess the seismic hazards due to onshore crustal faults or those due to earthquakes in the subducted lithosphere beneath Oregon and Washington (4). Karaman (5) proposed that the observed variation in seismic energy release among subduction zones is due to coupling between the plates: strong coupling produces large earthquakes, whereas weakly coupled zones slip aseismically. Coupling was thought to be enhanced by first subduction rate, low and young age of the subducting plate, and thick trench sediments (6). Using such reasoning, it was proposed that the CSZ is of the type that is characterized by great thrust earthquakes, largely because the subducting lithosphere there is very young, the dip is gentle, and the trench sediments are thick (7).

From a global examination of subduction zones, we find that forearc deformation rates limit the maximum sizes of thrust earthquakes (Fig. 1). Anelastic, arc-parallel motion of the leading edge of the upper plate relative to the backarc region deflects the slip directions of subduction-zone thrust earthquakes away from expected plate-convergence directions (8). The magnitudes of these slip deviations provide the arc-parallel rate of the forearc motion relative to the upper plate. Deviations of slip are relatively small in regions where $M_o > 8$ subduction thrust earthquakes have occurred in this century (9) (Fig. 1A), suggesting that great earthquakes tend to occur in subduction zones characterized by uniform forearc forearc.

Two possible explanations are that thrust faults beneath weakly deforming forearcs are more heterogeneous (10) than those beneath uniform forearcs or that deforming forearcs respond to stress by anelastic (11), rather than elastic, strain.

The size of the largest earthquake observed at subduction zones decreases both with the rate of forearc deformation (Fig. 1B) and with this rate normalized by the full plate-convergence rate (Fig. 1C). Forearc motion that moves along the arc at rates of more than half the arc-parallel component of plate mo-
When do not have earthquakes greater than about $M_0 = 8$ (Fig. 10). Maximum earth-
quake size increases with convergence rate (Fig. 12), simply because larger earthquakes are
more probable in faster subduction zones (22). Subduction zone that have had $M_0 > 8$
earthquakes have generally larger seis-
ic-magnitude dips than do subduction zones with smaller $M_0$ earthquakes (Fig. 13). A measure of
the similarity of faulting during moderate-size
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Arguing for the possibility of great
interplate thrust earthquakes at the CSZ
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faults on the interplate boundary and the accretionary wedge are
characterized by a narrow, linear, subhorizontal zone of coseismic slip (Fig. 11). This pattern is
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