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Local and regional slope instability inferred from sea-floor morphology at accretive and erosive convergent margins: case studies of the offshore Hikurangi and Peru fore-arcs

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The mechanics of a forearc, a wedge-shaped part of the overriding plate between the trench and the volcanic arc, are elegantly and in a straightforward way described in terms of the critical taper concept. Based on the Mohr-Coulomb failure criterion and applying an elasto-plastic rheology, it describes the state (sub-critical, stable, super-critical) of any point of the wedge as a function of its geometry (slope and dip), basal and internal friction as well as basal and internal fluid pressure parameter. Subduction erosion or the subduction of seamounts and other lower plate topographic features such as basement ridges lead to temporarily increasing surface slope and therefore may facilitate mechanical instability.

Here we study the causes of local and regional failure at the central Hikurangi wedge offshore New Zealand's North Island and along the Peruvian margin. The geometry of both margins is well known from seismic studies and swath bathymetry coverage and therefore allows to quantify local slope gradients and other curvature attributes.

New high-resolution swath bathymetry data show a complex seafloor morphology from the Rock Garden area, offshore Hikurangi Margin, that coincides with the subduction of a seamount presently located beneath the summit of Rock Garden. Another ridge-shaped lower plate feature is initially colliding with Rock Garden, forming a re-entrant at is seaward flank. The slopes of the accretionary ridges are steeper than 10° and often more than 20° regionally. Slumping mostly occurs on the trench-ward slopes, with individual failures up to several km2. Critical taper analysis shows that much of the seaward slopes probably are outside the stability field and therefore subject to failure. The most prominent feature of seafloor maps is the trench-ward flank of Rock Garden with a height of 1800 to 2000 m and an average slope of more than 10°. Extensional faults arranged in two sub-circular arcs indicate that Rock Garden may be on the verge of failure. Critical taper analysis also supports this claim and shows that if basal fluid pressure approach lithostatic, during a large Mw>8 earthquakes, then a complete failure of the entire trench-ward flank of Rock Garden would potentially affect an area as large as 150 km^2 and a rock volume of 150 to 170 km^3. This worst case scenario would generate a tsunami wave some 10s of meters high. Therefore, the observation that numerous seamounts are entering the Hikurangi wedge and identified beneath Rock Garden other accretionary ridges along the margin, suggests a thorough assessment of these features needs to be undertaken and incorporated into tsunami hazard models along the East Coast of North Island.

A transtensional fault system, identified from swath bathymetry data acquired during the GEOPECO campaign, is extending for more than 200 km forming the boundary between the lower and middle submarine continental slope off Peru Normal faults have been identified in the entire submarine forearc up to the shelf and also onshore raising the question of their tectonic significance and their role as a potential stress regime indicator in a convergent margin setting. Swath bathymetry reveals that the lower slope is locally very rough and suffering from numerous local scale slumping. This observation suggests that the lower slope is at the verge of failure throughout the entire Peruvian margin. The middle and upper slopes have a relatively smooth topography, but still comprise locally steep slopes. To analyse the mechanics of the Peruvian offshore wedge, we performed a classical critical taper analysis along several transects across the margin for which we have the precise geometry from swath bathymetry, wide angle seismic, and seismology. We identified wedge segments according to the morphological segmentation of the continental slope. Using realistic estimates for the basal and internal friction as well as the basal and internal fluid pressure ratios we find that the lower slope and some unusually steep portions of the upper slope are close to extensional failure whereas the shelf seems to be unconditionally stable. Employing the dynamical wedge concept we suggest that fluid pressure built up during a seismic cycle is the most likely means to weaken the basal interface beneath the lower slope and cause failure, such that it would be in a conditionally unstable state. This may also be locally the case for the middle and upper slope. However, this still leaves it difficult to explain the large number of normal faults. Therefore we include subduction erosion and gravitational collapse of the Peruvian fore-arc, which has the largest topographic gradient between the trench and the top of the juxtaposed Andes ($>$ 12 km) worldwide, in our discussion of potential causes of normal faulting.

The strength of the plate interface as well as the amount of over-pressuring play a crucial role for the mechanical stability of both margins. Fluid pressure fluctuations within the seismic cycle are well capable to bring large parts of the lower and middle slopes outside the taper stability field. Our comparison highlights that, while the causes of individual small and very large slumps are different at both types of margins, seismic behavior, and local as well as regional mechanical stability are intimately linked.