The Aleutian-Alaska Subduction Zone Is Prone to Rupture in Great and Giant Megathrust Earthquakes—How Scientific Information Can Mitigate Consequences

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THE FIELD SETTINGS OF LARGE SUBDUCTION ZONE EARTHQUAKES

Great (Mw8.0 and larger) and giant (Mw8.5 and larger) megathrust earthquakes occur repeatedly along certain subduction zones and uncommonly or unkown at others. Why this circumstance should exist has long been the focus of study, wonderment, and debate. But, based on observational information, it seems clear that the nucleation sites and hallmark lengthy, trench-parallel ruptures of great and giant megathrust earthquakes are significantly influenced by physical field relations and settings. Important among these are:

A) For the underthrusting ocean plate:

1) Subducted high bathymetric relief, in particular ridges, fracture zones, and large seamounts, and seafloor roughness generally, and

2) Subducted thick sequences (>1-2 km) of trench sediment, and

B) For the upper plate of the forearc:

1) Forearc structural highs, and

2) Large, forearc basins or plateaus

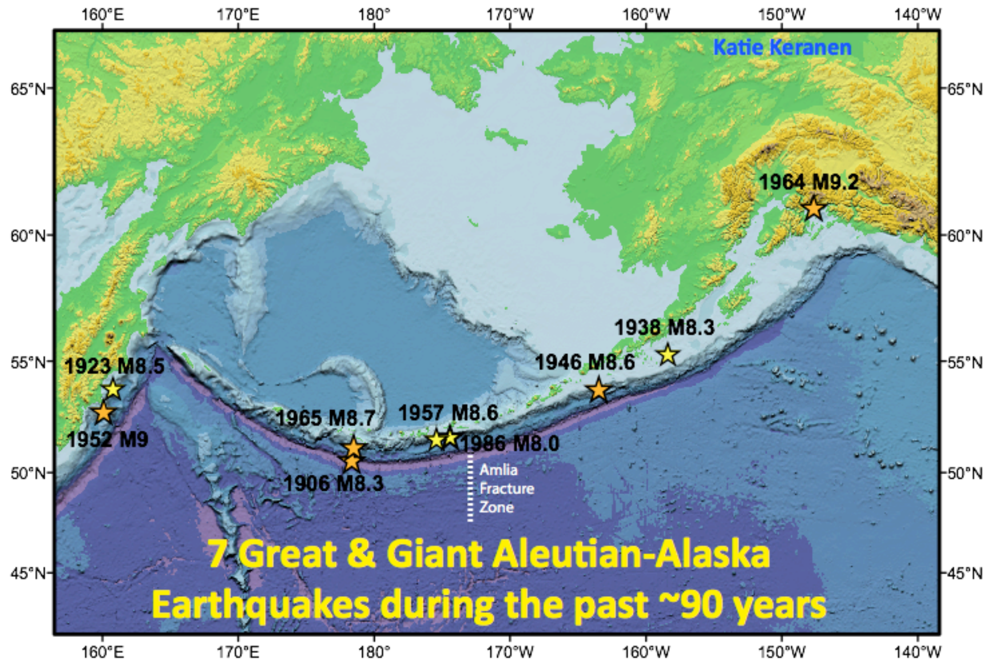
Great and giant megathrust earthquakes characteristically nucleate below a forearc structural high, or atop a subducted ridge or large seamount, and rupture laterally away for distances of 300-1200 km. Rupturing commonly terminates at a subducted ridge, fracture zone, or large seamount. As the table below shows for the best-documented instrumentally and geologically recorded (Cascadia, 1700) great and giant events (23 total--including the 2011 Tohoku Mw9.0), trench sectors with laterally continuous axial deposits thicker than 1.0 km are associated with the occurrence of:

52 % of Mw8.0 and larger megathrust earthquakes (12 of 23)
57 % of Mw8.3 and larger megathrust earthquakes (8 of 14)
67 % of Mw8.5 and larger megathrust earthquakes (8 of 12)
71 % of Mw8.8 and larger megathrust earthquakes (5 of 7)
67 % of Mw9.0 and larger megathrust earthquakes (4 of 6)
100 % of Mw larger than 9.0 (3 of 3).

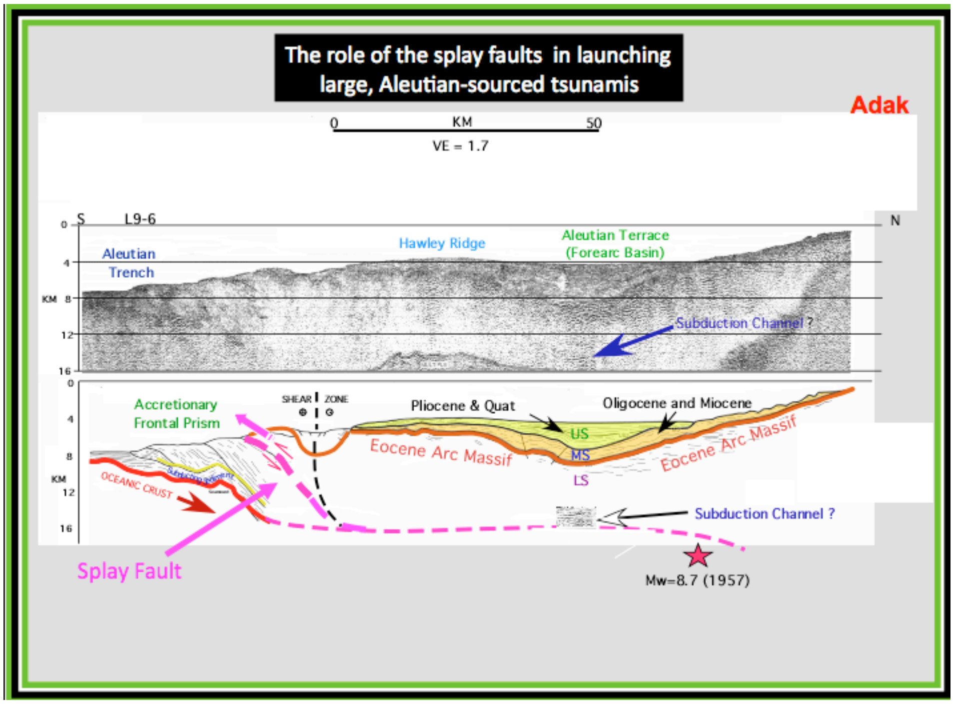
The reason for this relation, as hypothesized by Ruff (1989), is that subduction of a thick section of trench-floor sediment inserts a laterally homogenous layer of material into the subduction channel separating the two plates of the submerged forearc. The interplate surface of rupture probably runs along the top of the subduction channel. A sediment-packed subduction channel mechanically smoothes the roughness of subducted sea-floor relief. During a megathrust earthquake, an even, lateral distribution of interplate strength or coupling would favor lengthy trench-parallel rupturing. Smoothing can also be effected by basal subduction erosion that mechanically inserts upper plate crustal debris into the subduction channel. The setting of the giant Tohoku megathrust, which is not associated with a thick section of subducted sediment, exhibits a subduction channel charged with a >1.0 km-thick layer of tectonically eroded debris overlying an exceptionally smooth, underthrusting sector of Pacific plate.

THE ALEUTIAN-ALASKA MEGATHRUST SETTING

The Aleutian-Alaska subduction zone is one of the world's most seismically active and also the home of repeated great and giant earthquakes and matching tsunamis. Many factors are involved in setting up this reality, but those that promote long run-out megathrust events and rapid seaward interplate slipping can be linked to the observations that:



1) Subducted, high-standing ridges and large seamounts are widely spaced beneath the Aleutian-Alaska forearc—a circumstance favoring long run out ruptures.
2) The trench axis from Middleton Island, eastern Gulf of Alaska, 3200 km westward to Attu Island is, except for the Shumagin sector thickly charged (~2 km) with sediment shed from glaciated Alaskan drainages—a circumstance favoring lateral rupture continuation.
3) Much of the length of the submerged Aleutian-Alaska forearc is underlain by a wide, structurally deep forearc basins or platform—a circumstance that localizes rapid trenchward slip beneath them and the generation of regional and areally larger tsunamis (Wells et al, 2003).
4) Aleutian outer forearc is sheared by splay fault systems (but apparently not everywhere), a circumstance favoring the launching of large near field and/or trans-oceanic tsunamis.



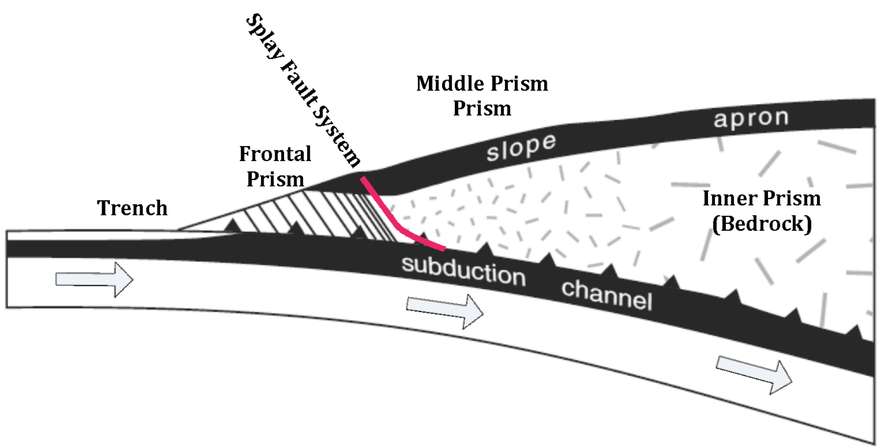
The role of the splay faults in launching large, Aleutian-sourced tsunamis
Adak
0 KM 50
VE = 1.7
S L9-6
N
Aleutian Trench
Hawley Ridge
Aleutian Terrace (Forearc Basin)
Subduction Channel ?
Accretionary Frontal Prism
SHEAR ZONE
Pliocene & Quat
Oligocene and Miocene
US
MS
LS
Eocene Arc Massif
Eocene Arc Massif
OCEANIC CRUST
Subduction Channel ?
Splay Fault
Mw=8.7 (1957)

INFORMATION NEED TO MITIGATE CONSEQUENCES OF SEISMIC GEOHAZARDS

To mitigate the consequence of marine geohazards generated at the Aleutian-Alaska subduction zone, in particular large tsunamis, field knowledge is needed to make probabilistic estimates (forecasts) of their likely future occurrence and source regions. This essential information, which is largely or wholly missing, can be acquired by a blend of coastal and offshore studies to reveal the late Cenozoic paleoseismic and -tsunamic record and to regionally map the location, continuity, and geometry of forearc fault systems.

Specifically, what is needed for the entire length and width of the submerged forearc is:

1) High-resolution, multibeam bathymetric maps adequate, for example, to laterally trace fault scarps, identify middle and frontal prisms and splay faults separating them, slope failures, debris flows, and paths of subducted relief.



2) Information about when and where great and giant megathrust earthquakes nucleated.
3) Information about when, where, and source-cause of local, extra-regional, and trans-oceanic tsunamis.
4) Information about the geometry and shape of the interplate surface and locations of significant along-strike changes.
5) Information about the location, geometry, and lateral continuity of high-angle reverse, splay, and strike slip fault systems.
6) Information about the causes of rupture segmentation (limits and termination).

7) Information about the thickness of sediment and tectonically eroded debris within the subduction channel with respect to the underthrusting seafloor relief and roughness.

REFERENCES

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Wells, R.E., R. J. Blakely, Y. Sugiyama, D. W. Scholl, and P. A. Dinterman, 2003, Basin-centered asperities in great subduction zone earthquakes--a link between sip, subsidence and subduction erosion?: Journal of Geophysical Research, v. 108, No. B10, 2507, doi:10.1029/2002JBOO2072