Multi-segment earthquakes and the tsunami potential of the Aleutian megathrust

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Girdwood, Alaska May 2006

Spruce trees dying, April 1964
Photo: Gill Mull
Girdwood: 10 peat-mud couplets, 7 great earthquakes
Diatoms in environmental reconstruction

Ocean View, Anchorage
Girdwood reconstructed land / sea-level change

- Co-seismic submergence
- Pre-seismic RSL rise
- Neoglacial RSL change
- Post & inter-seismic RSL fall

Depth (cm)

Cal yr BP

1964 AD

318-515

764-948

Reconstructed elevation (m MHHW)

Post & inter-seismic relative sea-level (RSL) fall

Co-seismic submergence

Pre-seismic RSL rise

Neoglacial RSL change

Post & inter-seismic RSL fall

Co-seismic submergence

Pre-seismic RSL rise

Post & inter-seismic RSL fall
Last 4000yr: 7 great earthquakes
• ~7m net subsidence superimposed on seven earthquake cycles in the past 4000 years.

• EDC model for the Girdwood area with coseismic subsidence (1), followed by rapid post-seismic uplift in the decades after the earthquake (2). This merges into centuries of slower inter-seismic uplift (3) before a period of pre-seismic subsidence (4).

• Great earthquakes: no fixed recurrence interval between great. The shortest interval is between ~180 and 720 years. The longest interval is 790 – 920 years, which is between the penultimate earthquake and the Mw9.2 Alaska earthquake of March 1964.
Zone of co-seismic uplift 1964: Alaganik Slough
Summary
1. Net Subsidence (4m since 1500BP)
2. Coseismic uplift
3. Post-seismic & interseismic subsidence
4. Carver & Plafker (2009) summarise 8 earthquakes in 5000yr (correlate with the 4000yr record from Girdwood)
Near the eastern limit of co-seismic uplift 1964: Cape Suckling & Bering Glacier

Continued retreat since 1995 exposes new sediment sequences each year.
Cape Suckling marsh
Cape Suckling CS/0/2  8th August 2005 - 16-310cm

1964?

~110 BP

~300 BP

1964?
Diatom reconstruction of relative sea-level changes

relative sea-level rise (land submergence)

relative sea-level fall (land uplift)

Possible tsunami sand

units not calibrated (no modern diatom dataset yet)
Beyond the eastern limit of coseismic uplift 1964: Yakataga to Icy Bay, the Forgotten Coast
Rapid Communication

Multi-segment earthquakes and tsunami potential of the Aleutian megathrust

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Late Quaternary sea-level changes and palaeoseismology of the Bering Glacier region, Alaska

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In 1899 a Mw 8.1 earthquake on September 4th produced ~1m uplift at Cape Yakataga, but the pattern of uplift farther east is less certain, and a second earthquake, September 10th Mw 8.2, near Yakutat caused localised uplift ~2 - 14m, though any wider scale deformation has not been recorded.
970±40, 960 to 790BP
Shoreline uplifted ~1500 BP (1520 to 1350 BP)

Shoreline uplifted ~900 BP (910 to 780 BP)

Uplifted beach sand

Paleo-cliff

Alluvium & slopewash, interbedded peat & wood dated
1050±60, 1270 to 690BP
1210±70, 1280 to 980BP
1300±100, 1380 to 980BP

Uplifted lagoon sediments, base dated 970±40, 960 to 790BP, overlain by alluvium & slopewash,

Shoreline uplifted ~1500 BP (1520 to 1350 BP)

17-19 m surface inset into Terrace Surface III on east side of White River

900 BP uplift escarpment?

17 - 19 m surface inset below Terrace Surface III

Modern Beach

Umbrella Reef
Given the structural setting and historical earthquake history of the region we must two scenarios:

1) a rupture scenario like that of the 1899 Yakataga and 1964 earthquakes, where the Yakataga seismic gap and eastern segment of the Aleutian megathrust ruptured independently and

2) simultaneous rupturing of the megathrust from Cook Inlet in the west to the Pamplona – Malaspina thrust front in the east in which the Yakataga seismic gap ruptures in conjunction with the eastern segment of the Aleutian megathrust.

Two lines of evidence support 2) ~900 BP and ~1500 BP great earthquakes

First, greater coseismic deformation at Cape Suckling in ~900 BP than in 1964 suggests that the area of surface deformation extended farther east.

Second, the more widespread evidence for uplift east of Cape Yakataga in both ~900 BP and ~1500 BP than in 1899
Multi-segment earthquakes

Earthquakes ~900 and ~1500 years ago involved rupture of the western/central segment of the Yakutat microplate along with the 1964 rupture zone.

We calculate an additional 23,000 km² to the rupture area and ~15% increase in seismic moment, from Mw 9.2 in 1964 to ~Mw 9.25 for the multi-segment earthquakes.

Modelling of tsunami generation and coastline inundation for single-segment and multi-segment earthquakes at other subduction zones suggests that an increased area of sea-floor uplift with a multi-segment earthquake produces a tsunami with greater wavelength that penetrates farther inland, even though the height of the wave at the coast may be similar.
Summary

1. Seven great earthquake cycles in the past 4000 years.
2. Not a fixed recurrence interval between great, $>\text{Mw9}$, earthquakes. Shortest $\sim 180 - 720$ years, longest interval is 790 – 920 years,
3. Earthquake Deformation Cycle Model for the area of subsidence: coseismic subsidence, rapid post-seismic uplift in the decades after the earthquake; centuries of slower inter-seismic uplift before a period of pre-seismic subsidence.
4. Multi-segment earthquakes $\sim 900$ and $\sim 1500$ years ago involved rupture areas $\sim 15\%$ greater than in 1964, indicating greater magnitude, $>\text{Mw 9.2}$, and increased tsunamigenic potential.
5. Complex deformation within the Yakutat microplate, influenced by both subduction and transform fault motion, controls recurrence of these largest earthquakes.
6. Through multiple seismic cycles this leads to net uplift in the Yakataga microplate, part of the Saint Elias orogen.