Updating the seismic source model for a new USGS earthquake hazard map of Alaska

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2007 USGS Seismic Hazard Map

A. PGA with 10% probability of exceedance in 50 years

Wesson, Boyd, Mueller, Bufe, Frankel, and Petersen, 2007
Work to refine source model

- Basis of model is the Alaska Quaternary fault and fold database of Koehler et al. (2012)
- Cataloged new work and changes to faults in the database
- We are adding fault dips, if possible
- Refining locations of previously mapped structures with new digital topography

http://maps.dggs.alaska.gov/qff/
Improvements to sources from 2007 hazard map

1) Changes in megathrust earthquake recurrence rates along most of the length of the subduction zone inferred from recent paleoseismology

2) Inclusion of larger intraslab earthquakes, prompted by recent damaging M7.0 to M7.9 events

3) Refined long-term slip rates on megathrust splay faults in the southern Prince William Sound region and near Kodiak Island derived from seismic reflection and thermochronology studies

4) A slip rate of ~5.3 cm/yr on the Queen Charlotte-Fairweather fault system derived from offshore mapping. Moreover, a search for and failure to identify active fault traces to the east implies that virtually all of the plate boundary motion occurs on this fault alone

5) Refinement tectonic models clarify the relationships between the Denali fault, Totschunda fault, and thrust faults on both the north and south sides of the Alaska Range

6) Recognition that activity on the Castle Mountain fault is thrust faulting, not strike-slip

7) New details of contractional structures in the Chugach-St. Elias orogen – Much better understanding of the locus of Quaternary deformation

8) The potential for larger earthquakes in the eastern Brooks Range associated with the westward extrusion of crust revealed by the 2018 M6.4 Kaktovik earthquake.
2007 Hazard Maps:

Megathrust hazard - defined by earthquake magnitude & recurrence

- **Prince William Sound**
  - Magnitude 9.2
  - 650 yr recurrence
  - Ruptures with Kodiak

- **Semidi Islands**
  - Magnitude 8.5
  - 4320 yr recurrence

- **Shumagin Islands**
  - Magnitude 8
  - 95 yr recurrence

- **Aleutians**
  - Magnitude 9.2
  - 820 yr recurrence

- **Yakataga**
  - Magnitude 8.1
  - 1640 yr recurrence

- **Kodiak (breaking alone)**
  - Magnitude 8.8
  - 650 yr characteristic

Wesson, Boyd, Mueller, Bufe, Frankel, and Petersen, 2007
Recent megathrust paleoseismic investigations

Eleven investigations from 2010–2019

- Red: Umnak Island
- Orange: Sedanka Island
- Yellow: Sanak Island
- Green: Unga Island
- Green: Nagai Island
- Blue: Simeonof Island
- Blue: Chirikof Island
- Purple: Sitkalidak Island
- Brown: Kenai Fjords
- Light purple: Solinak Island x 2

Map showing the location of the investigations along the Aleutian Trench.
Example: Umnak Island

Driftwood Bay

Drift logs at 19–23 m above sea level
Example: Umnak Island

- 9 sand sheets in ~2200 yrs
- Sand sheets meet tsunami criteria
- Youngest sand sheet deposited in 1957
- Stranded drift logs indicate >23 m runup in 1957
- 270–340 yr average tsunami recurrence interval
- 2007 hazard map has 820 yr recurrence of M9.2
1) Changes in megathrust earthquake recurrence rates along most of the length of the subduction zone inferred from recent paleoseismology.
2) Inclusion of larger intraslab earthquakes, prompted by recent damaging M7.0 to M7.9 events

November 30, 2018, M7.1 Anchorage earthquake
Alaska intraslab events

- the 2018 M7.1 Anchorage earthquake
- 10 such earthquakes in the historical record
- Average of 1 M7+ event every 11 years
- These are relatively common
- They can be big!
- Important seismic source for Alaska

Earthquakes in Alaska, M7+ and 40+ km Deep

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How often do intraslab earthquakes occur?

- Lakes are recorders of strong ground motion
- Turbidites are deposited with strong ground shaking
- 3 sources: megathrust, intraslab, crustal
- Lakes can provide a high resolution, long record

Turbidites originating from hemipelagic slope failure (reworked lake sediments) = most reliable!
Example: Eklutna Lake Record

- Closest to 2018 Anchorage earthquake epicenter
- Water supply for Anchorage
- Lake has two basins
- Detailed seismics used to map stratigraphy
- Then collected cores based on imaging
Eklutna Lake record of earthquakes and floods

- Cores up to 17-m long
- Find evidence of earthquake and flood deposits
- Discriminated on the basis of: grain size, thickness, mag. susceptibility, spatial, spectral variables
- Up to 19 earthquakes recorded in a core, likely spanning 2300 yrs
- Earthquakes are ~100-150 yrs apart

Praet et al. (in prep)
3) Refined long-term slip rates on megathrust seafloor splay faults in the southern Prince William Sound region and near Kodiak Island derived from seismic reflection and thermochronology studies

Motivating question: How often do splay faults move?
Answer: Often!
From both thermochron and seismic reflection studies

Haeussler et al. (2015)

1964 splay fault coseismic uplift = long-term (~3-6 Ma) pattern of exhumation!
Megathrust splay faults

- Seismics show long term slip pattern also mimics 1964 uplift pattern
- Splay faults move in megathrust events (not independently)

Haeussler et al., 2015 QSR
4) A slip rate of ~5.3 cm/yr on the Queen Charlotte-Fairweather fault system inferred from offshore mapping. Moreover, a search for and failure to identify active fault traces to the east implies that virtually all of the plate boundary motion occurs on this fault alone.

Major earthquakes since 1900:
- 1927 M7.0
- 1949 M8.1
- 1958 M7.8
- 1970 M7.4
- 1972 M7.6
- 2012 M7.8
- 2013 M7.6

1. 2015 *R/V Solstice* continental slope high-resolution MCS and MBES geophysical surveys

2. 2015 *R/V Alaskan Gyre* continental shelf high-resolution MCS and Chirp geophysical surveys

3. 2016 *R/V Medeia* continental slope high-resolution MCS and MBES geophysical surveys

4. 2016 *R/V Norseman* continental slope high-resolution MCS geophysical survey

5. 2017 *R/V Ocean Starr* high-resolution MCS and CHIRP geophysical surveys

6. 2017 *R/V John P. Tully* high-resolution MCS, piston coring and bottom camera surveys

7. 2018 *R/V Fairweather* MBES mapping survey
• Glacier filled Yakobi Sea Valley at Last Glacial Maximum

• Ice retreated from open continental shelf abruptly at ~17 ka and into Cross Sound (Mann and Peteet, 1994; Misarti et al., 2012; Davies et al., 2011; Addison et al., 2012; Praetorius et al., 2015; Lesnek et al., 2018)

• Ice receded into Icy Strait by 13 kyr B.P. (Barron et al., 2009; Mann and Steveler, 2008)

LaDiCaoz offset reconstruction (method based on Zielke et al., 2012)

53±3 mm/yr slip rate
Offset reconstructions for 179 strike-slip piercing points reveal consistent ~5.3 cm/yr slip-rate over 650 km distance.

The entire plate boundary is localized to a single, knife-edge fault.

This is the worlds fastest continent-ocean transform fault!
No evidence for any active faults east of the QCF

- We find no evidence for Holocene movement along the Chatham Strait fault or Coast Shear Zone
- Also find no evidence for Holocene activity along the Lisianski Inlet fault
- The only structure with geologic evidence for Holocene faulting is the Queen Charlotte-Fairweather fault
5) Refinement of interior Alaska tectonic models clarify the relationships between the Denali fault, Totschunda fault, and thrust faults on both the north and south sides of the Alaska Range.

- Studies of the slip rates along the Denali and other faults in the Alaska Range clarify tectonic models and the nature and deformation rates on active faults.
- New work on the Kantishna Hills anticline helps to constrain the rate of NW movement of the southern Alaska block to about 1.2 mm/yr (Bender et al., 2019).

Haeussler et al. (2017)
6) Recognition that Holocene activity on the Castle Mountain fault is predominantly thrust faulting, not strike-slip

- Castle Mountain fault – seen as the most significant crustal fault in the greater Anchorage area
- CMF had long been inferred to be a strike slip fault
- Based on historical earthquakes and regional geology
• Acquisition of recent LiDAR shows no significant lateral offset of the Elmendorf moraine
• The fault is mostly a reverse fault
• Results don’t change the paleoseismic work that has been conducted on the fault – just the fault type
7) New details of contractional structures in the Chugach-St. Elias orogen

- Conclusion of STEEP project has given a much better picture of deformation in the St. Elias orogen
- Have a much better understanding of strain, likely active faults, exhumation rates.
- Also have some Quaternary faults that are conclusively dead.

Enkelmann et al. (2015a, GRL)

- Thermochronology data indicate slip rates of 2-3 mm/yr on Yakutat fault and 3-5 mm/yr on the Esker Creek fault (Enkelmann et al. 2015b, QSR)
8) The potential for larger earthquakes in the eastern Brooks Range associated with the westward extrusion of crust revealed by the 2018 M6.4 Kaktovik earthquake.

- Kaktovik earthquake is the largest ever recorded in the Brooks Range
- Aftershocks outline an E-W striking fault plane
- SAR interferometry shows 35 cm LOS right-lateral strike-slip
- Fault motion was NOT expected
- Tectonic models need revision
- Perhaps related to westward extrusion?
Improvements to understanding sources from 2007 hazard map

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7) **New details of contractional structures in the Chugach-St. Elias orogen** – some Quaternary structures are no longer active

8) **The potential for larger earthquakes in the eastern Brooks Range** associated with the westward extrusion of crust revealed by the 2018 M6.4 Kaktovik earthquake.