Coastal Paleoseismology and Paleotsunami Studies in the Eastern Aleutians: A Focus Region for the GeoPRISMS Subduction Cycles and Deformation Plan

Alan Nelson(anelson@usgs.gov)[1], Rich Briggs(rbriggs@usgs.gov) [1], Peter Haeussler(pheuslr@usgs.gov)[2],
Guy Gelfenbaum(ggelfenbaum@usgs.gov)[3], Simon Engelhart(simoneng@sas.upenn.edu)[4],
Rob Witter(robwitter@gmail.com)[2], Tina Dura(dura@sas.upenn.edu)[4],
Andrew Kemp(Andrew.kemp@yale.edu)[5], Rich Koehler(richard.koehler@alaska.gov)[6]

[1]U.S. Geological Survey, Geologic Hazards Science Center, Golden CO
[2]U.S. Geological Survey, Alaska Science Center, Anchorage AK
[3]U.S. Geological Survey, Pacific Coastal and Marine Science Center, Menlo Park CA
[4]Sea Level Research, Dept of Earth and Environmental Science, University of Pennsylvania, Philadelphia PA
[5]Yale Climate and Energy Institute, Yale University, New Haven CT
[6]State of Alaska, Dept of Geological and Geophysical Surveys, Fairbanks AK

Key SCD Questions Addressed:
What governs the size, location and frequency of great subduction zone earthquakes and how is this related to the spatial and temporal variation of slip behaviors observed along subduction zones?
How does deformation across the subduction plate boundary evolve in space and time, through the seismic cycle and beyond?

Subduction zone paleoseismology, as recorded by land-level changes during earthquake cycles and the tsunamis accompanying great earthquakes, directly addresses the above questions because it is the only means to reconstruct the history of individual great earthquakes and accompanying crustal deformation over many earthquake cycles. Few subduction zones have historical records of great earthquakes and accompanying tsunamis that span more than an earthquake cycle. GPS instrumentation coupled with increasingly sophisticated modeling is identifying previously unresolved patterns of megathrust deformation. But because GPS measurements span only fractions of most cycles, many aspects of ongoing plate-deformation lack a unique interpretation (Wang, 2007). Coastal paleoseismology fills the gap between instrumental measurements and long-term geologic studies of plate subduction in the critically important time span of a century to several thousands (typically 3000-7000) of years. This is also the most important time span for assessing hazards from strong earthquake shaking and tsunamis.

It is difficult to understand what controls the lateral, updip, and downdip extent of individual subduction-zone ruptures, how ruptures vary from one earthquake cycle or supercycle to the next, and how rupture patterns change over many cycles, if a subduction zone's earthquake history—in this case at the Aleutian arc—is known only for the past century and a half. At the Shumagin gap, which part of the earthquake cycle are we in now? Did the 1788 earthquake and tsunami reported from a few Russian settlements rupture as large a region as depicted in Figure 1? Chirikof Island near the gap's eastern boundary is currently dropping at 10 mm/yr (Figs. 1 and 2).

To address research questions and assess hazards along southern Alaskan and the west continental U.S. coasts, in 2010 the U.S. Geological Survey began a reconnaissance investigation of the great earthquake and tsunami history of the eastern Aleutians between Sanak Island and Kodiak Island (Figs. 1, 2, and 3). Similar studies in the easternmost segments of the Aleutian-Alaska subduction zone, where the orthogonally subducting plate dips gently beneath a wide forearc, have revealed signs of as many as nine great earthquakes in the past 5000 years at tens of sites spanning 650 km of the subduction zone (Kodiak segment of Fig. 3; Carver and Plafker, 2009; Shennan et al., 2009). But west of central Kodiak Island (Fig. 1) investigation of the record of prehistoric earthquakes and tsunamis began only in the past year.

As in all paleoseismology studies, finding sedimentary archives of prehistoric earthquakes and tsunamis is severely limited by the rarity of productive sites. An additional difficulty in the Aleutians, which largely explains the lack of previous studies, is the cost and logistical problems of working at coastal sites with the greatest potential. Most Aleutian islands lie well arcward of modeled areas of regional forearc uplift during plate-boundary earthquakes. Even the islands closest to the trench—Chirikof, the outermost Shumagins, and the Sanaks—are no closer to the trench than southwest Kodiak Island, which was just arcward of the zone of coseismic uplift during the 1964 earthquake. Oblique subduction and steepening plate-boundary dips westward along the arc suggest that regional zones of coseismic uplift and subsidence are too narrow to intersect many island sites. Prospects for identifying and dating coseismic subsidence are better than for identifying uplift because (1) past zones of regional coseismic subsidence may encompass some southerly islands, (2) some of these islands have tidal marshes likely to preserve a record of sudden subsidence, and (3) new microfossil methods of reconstructing relative sea-level changes (precision $<\pm0.2$ m) allow previously undetectable changes to be measured (e.g., Shennan and Hamilton, 2006). A few weeks ago, cores with probable evidence for rapid relative sea-level changes were collected from Sitkinak Island (Fig. 3). Small lakes at elevations of 2-25 m are common on some islands (e.g., Sanak, Fig. 1) and a detailed relative sea-level history might be reconstructed if cores could be obtained from an elevational succession of lakes.

The best prospects for identifying signs of great earthquakes in the Aleutians lie with detailed mapping and dating (^{14}C, ^{137}Cs, ^{210}Pb, optical stimulated luminescence) of tsunami deposits. Imagery shows many islands have several or more inlets with 300-3000-m-wide beach ridge sequences and(or) adjacent 3-to-25-m-high lakes or sphagnum bogs. On Chirikof Island we are evaluating a sequence of sand beds in two freshwater peat bogs dating from the past 5000 years (Fig. 3) to distinguish among storm, eolian, and tsunami origins. Distinguishing large local tsunamis generated by volcano flank collapse or submarine landslides—such as the 1946 tsunami that obliterated buildings at Scotch Cap on Unimak Island—from tsunamis produced by regional seafloor displacement will depend on the characteristics, number, and location of sites that can be studied. Our recent fieldwork on Sitkinak Island suggests that we will be able to correlate deposits of 2-4 high tsunamis with times of sudden coastal subsidence or uplift identified through microfossil-based paleogeodesy studies in adjacent tidal marshes.

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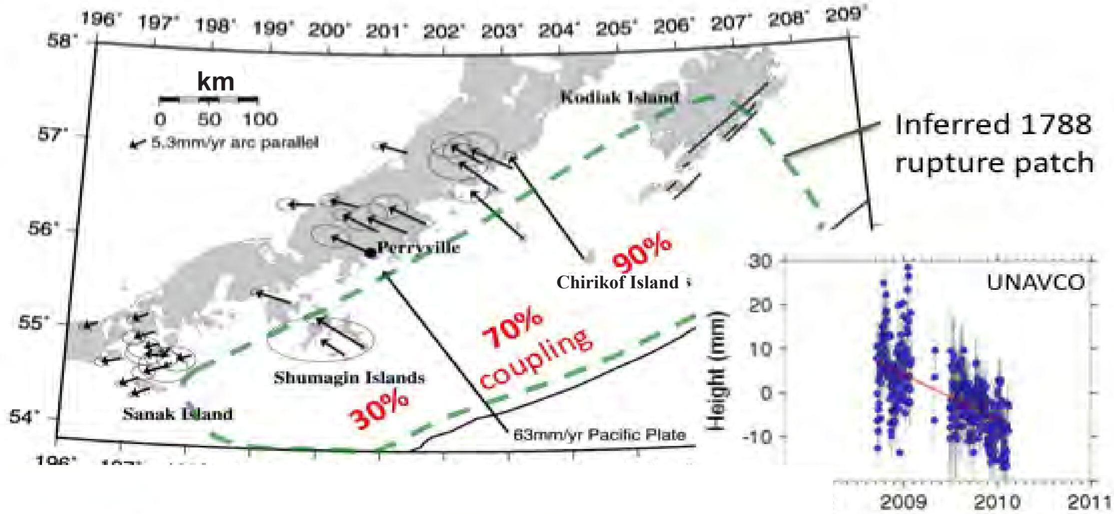

Figure 1. GPS velocities relative to the Pacific plate for sites in the eastern Aleutians (Fournier and Freymueller, 2007), UNAVCO vertical GPS velocities from Chirikof Island (inset) showing ~10 mm/yr subsidence of the island, and a posible rupture area for the great 1788 earthquake inferred from minimum tsunami heights recorded by Russian settlements. Chirikof Island lies above a highly coupled section of the megathrust.

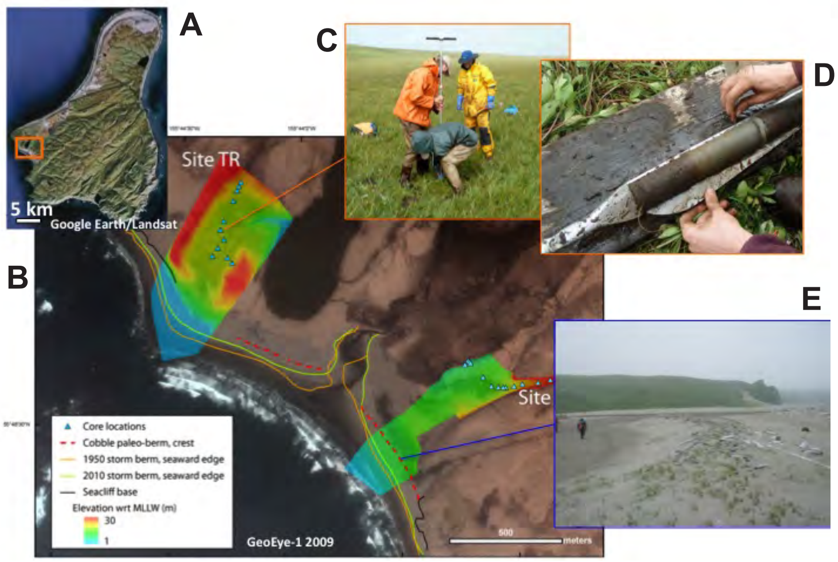

Figure 2. Reconnaisance studies of tsunami frequency and inundation and interseismic land-level changes on Chirikof Island (August 2010). A) Chirikof Island with study area marked by rectangle. B) Elevations, core sites, and geomorphic features at two study sites on the southwest coast of the island. C) USGS team collects a core in a peat bog at 13 m elevation. D) Thick sand and silty sand bed in core deposited by a tsunami about 10.5 ka. E) Beach berms that have moved landward in the past century and other shoreline features suggest that Chirikof Island is currently submerging.

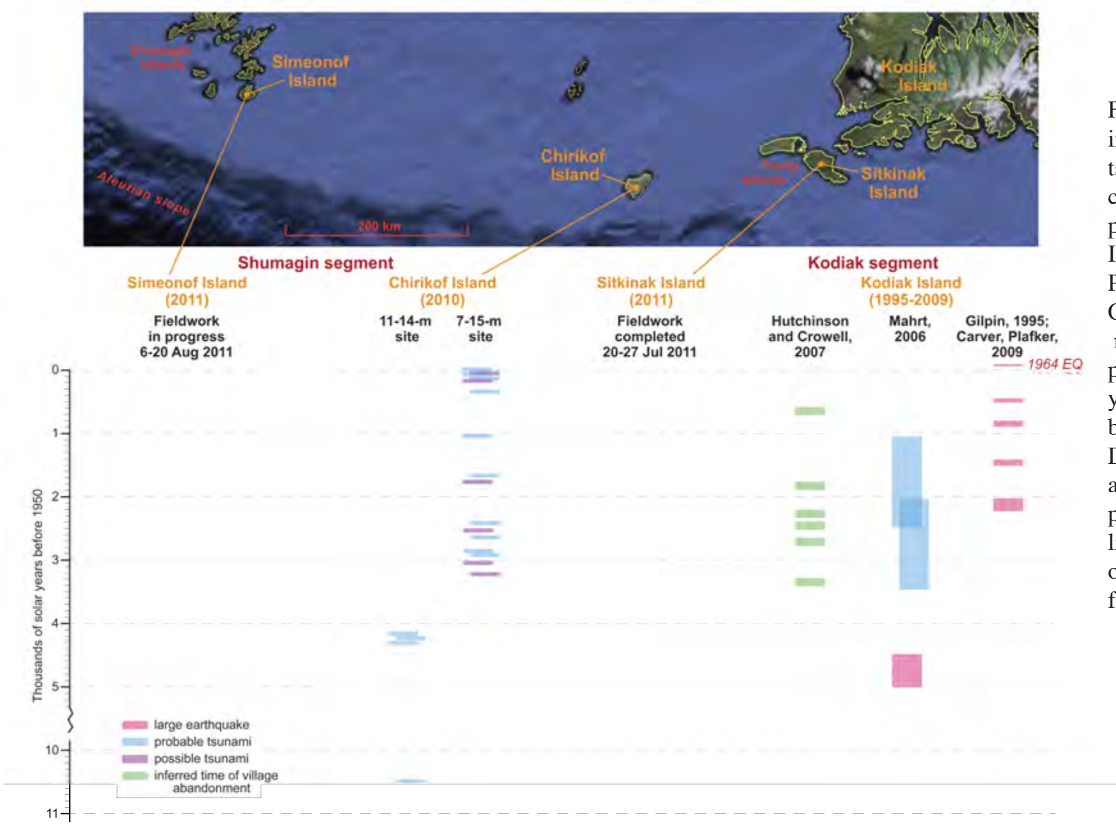

Figure 3. Initial USGS reconnaisance investigations of great earthquake and tsunami history of the past year compared with results of earlier paleoseismic investigations on Kodiak Island east of the area shown on the map. Preliminary 14C ages from two sites on Chirikof Island show an intermittent record of sand bed deposition in freshwater peat bogs over the past 4-10 thousand years. Many of these beds may have been deposited by Aleutian tsunamis. During fieldwork completed a few weeks ago on Sitkinak Island we found sand beds probably deposited by 3-5 tsunamis and lithologic evidence of rapid emergence or submergence of tidal marshes. Similar fieldwork is in progress on Simeonof Island.