## A Proposed 'Megathrust Megaswath' OBS Deployment In Southern Alaska

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The Alaska-Aleutian margin is a vast subduction zone capable of producing giant megathrust earthquakes and devastating tsunamis. It has generated earthquakes with equivalent magnitudes as those experienced in the 2011 M9.0 Tohoku and 2004 M9.2 Sumatra-Andaman megathrust earthquakes. Broad offshore segments of the subduction zone are currently locked, accumulating strain, and increasing megathrust earthquake potential. However, geodesy also reveals broad zones of creep where strain accumulation and earthquake potential is likely reduced. In the central Aleutians, there is significant along-strike variability in rates of recently identified tectonic tremor that may be related to variable slip behavior along the deeper megathrust, toward the downdip end of the seismogenic zone. Consequently the diversity in plate coupling, slip, and historical rupture behavior along the Aleutian-Alaskan subduction zone (AASZ) offer opportunities to examine what controls these aspects of the megathrust in an effort to advance earthquake and tsunami hazard assessments.

We suggest a 'megathrust megaswath' OBS deployment along the southern Alaska margin between the Semidi Islands and the eastern Aleutians (Figure 1). A long duration deployment of broadband OBSs across this wide region is ideal for studying an array of earthquake processes that would help us better understand historical seismicity, crustal deformation, and crustal structure. It spans the M8.2 1938, M7.3 1948, ~M8.6 1946, and the M8.6 1957 megathrust ruptures, the Shumagin seismic gap, and it likely includes much of a region that ruptured during the enigmatic 1788 earthquake(s) that destroyed Three Saints Bay on southwestern Kodiak Island. There is abundant seismicity, with 3556 teleseismically recorded earthquakes in the area of Figure 1 in just the last two years—which is typical of the earthquake activity in this region. The region spans megathrust rupture areas in different parts of their cycles, and regions that have different locking behavior and variations in seismicity. The most notable of these is the Shumagin seismic gap (Fournier and Freymueller, 2007). The 'megaswath' region also contains several places with deep low frequency earthquakes at the down dip end of the seismogenic zone (Brown et al., 2013). With the abundant seismicity, it appears likely

that an OBS deployment in this region will illuminate these variable behaviors, which cannot be observed with seismometers on land. Lastly, this region has past, ongoing, or proposed geophysical studies, which will provide an extensive structural, tectonic, and historical framework for establishing the regional context for passive OBS seismic studies. In the following paragraphs, we briefly discuss these topics in more detail.



Figure 1. Proposed megathrust megaswath OBS study area. Black triangles are Aleutian arc volcanos, pink blobs show rupture areas of significant historical earthquakes, yellow dots show all recorded earthquakes (n=3556) in the last two years. Red stars show locations with clusters of Low Frequency Earthquakes (LFE) from Brown et al. (2013). Lighter colored stripes on the Pacific Plate show marine magnetic anomalies, and Chron 25 is labeled.

The historical earthquakes record is notable. The 1957 Andreanof Islands M8.6 earthquake ranks as the third largest recorded in North America, and it produced a tsunami that destroyed two villages in Hawaii. The 1938 M8.2 earthquake is one of the most poorly known large earthquakes in Alaska in the last 100 years. It generated a small tsunami that was recorded locally and in Hawaii. The 1946 earthquake and tsunami was the deadliest ever on US soil. It is famous for a 40-m wave run up at Scotch Cap where it wiped away a concrete lighthouse, and for the tsunami that killed 165 people, mostly in Hawaii. This earthquake initially had a magnitude of 7.4, but it is now seen as a type example of a 'tsunami earthquake' and the tsunami magnitude is considered ~8.6 (Lopez and Okal, 2006). The 1788 earthquake affected the region from near Sanak Island to the Kodiak Island region and was documented by Russian Orthodox clergy and boat captains. If the accounts reflect a single rupture, it was likely about M9, or, if two earthquakes occurred they may have attained M8+ (Soloviev, 1990). The earthquake(s) source was likely east of the 1946 rupture.

The long-term earthquake magnitude-frequency distribution is crucial to earthquake and tsunami hazard assessment, because the expected rate of future moderate to large events strongly depends on it, as does the maximum magnitude. Structural rupture barriers may play a key role in defining this fundamental question, but unfortunately, the modern earthquake catalog is too short to resolve the issue. The 2011 M9.0 Tohoku earthquake in Japan ruptured through inferred rupture barriers, and caused some rethinking about the magnitude distribution in the Japan Trench, and subduction zones in general. When studied comprehensively, the Alaskan subduction megaswath and its islands has the potential to reveal its hidden paleoearthquake and tsunami history. In combination with structural observations, repeated and cross-referenceable earthquake and tsunami signatures, complimented by an OBS and onland earthquake catalog, promise an unparalleled opportunity to apply constraints on the regional extent of past and future large ruptures, and thus their tsunami and earthquake magnitude distribution.

There are remarkable differences in locking behavior along strike in this region. Based on GPS geodesy, Fournier and Freymueller (2007) showed that locking varies from about 2% trenchward of Sanak Island to 90% near Chirikof Island (Figure 2). Ongoing marsh stratigraphic studies focused on tsunami occurrence and land-level change being conducted on islands in the region are beginning to provide information on relative strain accumulation that complement the GPS results. For example, Witter et al. (2014a), based on tidal marsh stratigraphy, argued that there has been little strain accumulation at the Shumagin Islands in all of late Holocene time, indicating this is not a transient feature. Quaternary stratigraphic results are also providing information on rupture models (Briggs et al., 2014; Witter et al, 2014b) that will certainly complement and better calibrate potential models of earthquake behavior based on OBS data derived from the proposed megathrust megaswath experiment.

The region contains places with abundant deep low frequency earthquakes (LFEs; Brown et al., 2013; see red stars on Figure 1). These clusters of tremor are located at, or near, the downdip extent of the historical surface ruptures, but they also occur across the width of the region, from the continental part of the subduction zone to the oceanic part, and also from regions with high coupling to low coupling. Ongoing research using land-based seismic arrays is exploring the link between fault properties, seismogenesis, plate coupling and tremor genesis in the region of our proposed study area that would benefit from improved structural characterization. Three discrete tremor patches south of Unalaska Island are being targeted by the FlexArray Aleutian Array of Arrays (AAA) experiment (Ghosh, Thurber, and Prejean, 2014-2016) in which land-based seismic arrays on Unalaska will image the full spectrum of seismic behavior occurring along the deeper portion of the subduction megathrust, including non-volcanic tremor, low frequency earthquakes, and regular earthquakes (Figure 3).



Figure 2. Geodetically derived coupling in the Shumagin Islands region from Fournier and Freymueller (2007). "Data (red) and model (black) velocity vectors are shown. All of the data have been corrected for arc translation, except CHIR. The blue vector shows the velocity at CHIR if an arc translation correction is applied at that site. The surface projections of the locked interfaces are shown as black rectangles with the amount of coupling shown on each plane as the percentages. The planes are numbered according to Table 1. For planes 1, 2, and 3 the locked area of the fault can be decreased to the area of the stipple pattern with the amount of coupling increased to 100%, 80% and 40% respectively. The gray region on interface 4 is the widest possible fully locked interface."

The crustal structure of this megaswath region changes from a continental subduction zone to the east, to an intraoceanic subduction zone to the west. The change in the nature of the overlying crust is one of the factors that can control fundamental differences in the physical properties of the subduction zone in the two regions, which may lead to underappreciated differences in earthquake behavior. Additional changes along strike that may play a role in the observed differences in coupling and recorded difference in seismogenesis/tsunamigenesis include sedimentary inputs, prism morphology, and subducting plate structure providing a fertile ground for research by the community.

Past, ongoing, and proposed marine geophysical surveys provide excellent structural context for proposed OBS work (Figure 3). The most recent significant survey in this region was the 2011 ALEUT survey, and a group has proposed a community experiment to the west of the ALEUT survey. If this is funded and completed, there would be a framework of active-source marine seismic reflection and refraction data that could contribute significantly to a better understanding of the crustal geometry and velocity structure of this region. These data and models spanning this large area provide significant advantages for interpreting OBS data.

Finally, we should note there is a significant probability of recording an important megathrust earthquake. Given an average of one M7+ earthquake in Alaska per year and an M8+ every 13 years, there is a reasonable probability of recording an important megathrust earthquake during the duration of a deployment. If the OBSs had pressure

sensors for vertical motion detection, it could provide an unprecedented record of a significant earthquake.



Figure 3. Regional view of the Alaska-Aleutian Subduction Zone (AASZ) with locations of previous crustal-scale seismic studies (ASE-1994; ALEUT-2011; Law of the Sea-2011; EDGE-1989; TACT-1984). Note increasing sparseness of cross-trench data to the west. Transparent blue regions outline approximate rupture areas of previous large megathrust earthquakes. Inset: Proposed GeoPRISMS community experiment survey area (red lines). Basic GPS geodetic data (Freymueller et al. 2008) is depicted as locked (yellow lines) and creeping (blue lines. Note that the proposed survey area includes recent rupture zones, seismic gaps, locked and creeping zones, and the transition from continental to oceanic overriding plate composition.

In summary we suggest that this 'megathrust megaswath' region is ideal for understanding a broad range of earthquake behaviors in a subduction zone. The proposed region is of great interest for understanding the relationship of modern seismicity to megathrust locking behavior. The region spans the rupture areas of several historical earthquakes in various stages of the earthquake cycle, the region has low frequency earthquakes which we would like to better understand, and there is significant active source marine seismic data (already acquired and proposed) that will enable much better crustal geometry and velocity models of the margin to better interpret the OBS data. This is one of the best places on the planet to study variables related to subduction zone earthquake behavior, and it is an ideal place to redeploy the Cascadia Amphibious Array. The outcome of such a deployment is likely to lead to a significant improvement of our understanding of subduction zone and megathrust earthquake processes, which will be utilized by researchers around the globe.

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