Integrating laboratory, geophysical and geological data to understand the Aleutian megathrust from the trench to the base of the seismogenic zone

Demian Saffer, Donna J. Shillington, Geoffrey A. Abers, Anne Bécel, Katie M. Keranen, Jiyao Li, Mladen Nedimović

The largest earthquakes and most powerful tsunamis are generated on subduction zone megathrusts, many of which are associated with sediment-rich trenches. Variations in the in situ conditions and physical properties of the megathrust plate interface are primary controls on great earthquake rupture, the mode of fault slip, and the manner in which slip might reach the trench to produce tsunamis. Our ongoing project is integrating laboratory data from modern oceanic sediment and exhumed metapelites with existing, multi-resolutional geophysical data to improve our understanding of in situ conditions and processes along the plate boundary megathrust from the trench to ~30-40 km depth. Our study focuses on the Alaska subduction zone, the portion of the Alaska/Aleutian Margin Primary Site chosen by the GeoPRISMS community for focused studies of the subduction megathrust, where several existing geophysical datasets and DSDP/IODP cores can be leveraged (Fig. 1). We seek to develop an improved quantitative understanding of the conditions and materials along the megathrust, their relationship to seismicity, and provide a template for similar studies at other margins.

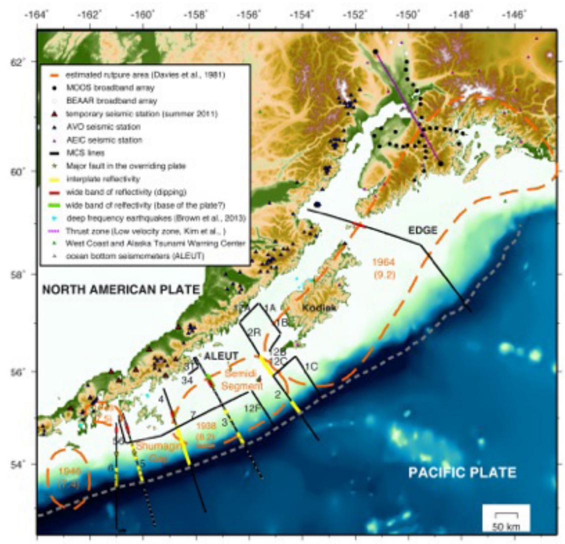

Figure 2. Map showing existing drilling and seismic data along the Alaska subduction zone.

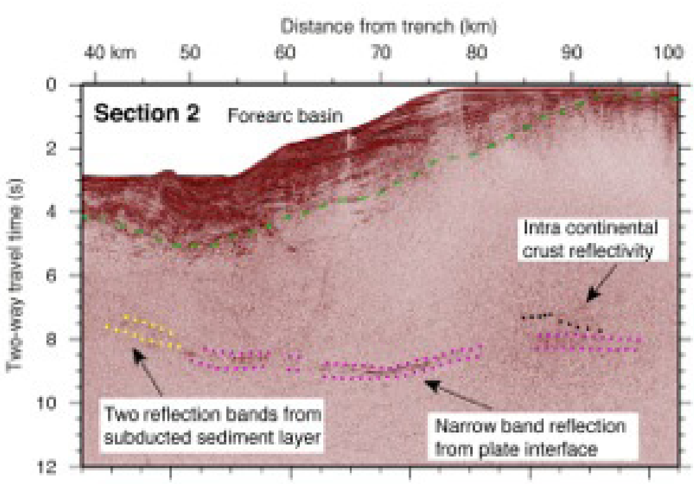

Figure 2. Seismic reflection image from the Semidi segment offshore the Alaska Peninsula within the rupture zone of the 1938 8.2 earthquake, which is characterized by a bright, narrow reflection.

The properties of the megathrust vary with depth in multi-resolutional seismic imaging datasets. In seismic reflection data from the ALEUT dataset, the megathrust is represented by a narrow, bright reflection within the center of past great earthquake ruptures (Fig. 2). Deeper and farther landward, the plate interface transitions to a wide band of multiple reflections, where it appears to intersect the forearc mantle wedge and where abundant seismicity is observed at its updip end and tremor is observed at its downdip end (Li et al., JGR, in review). Synthetic seismograms indicate that the narrow band reflection is best explained by a ~100-250 m thick low-velocity zone (Fig. 2) while the wide band of multiple reflections requires a 3-5 km thick zone comprising a series of thin layers of variable velocities (Li et al., JGR, in review). Thus, the downdip end of the locked zone and transition to tremor appears to be marked by a broadening of deformation based on seismic reflection data. Receiver functions indicate that the megathrust is associated with a few km wide zone with 20-30% slower Vs than its surroundings and anomalously high Vp/Vs ratios both within and downdip of the main rupture zone of the 1964 earthquake (Fig. 3, Kim et al., 2014).

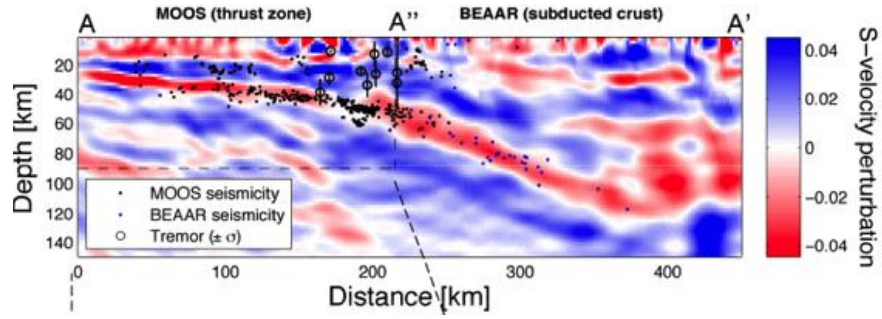

Figure 3. Receiver function image across Alaska subduction zone, showing low velocities along the megathrust.

Low velocity zones, high Vp/Vs and high reflectivity observed in seismic data in Alaska and in other subduction zones have been interpreted to represent very high pore-fluid pressures along different parts of the plate boundary, but could also arise from changes in sediment porosity and lithology with depth, or from anisotropy in elastic properties.

To link the observations from seismic imaging with in situ state, we are using laboratory measurements on samples from the recent IODP cruise off Alaska and from underplated metasediments exhumed from ~12-15 km depth collected from Kodiak Island, to constrain and calibrate relationships between Vp and Vs, porosity and effective stress (Fig. 4). Our initial dataset defines clear relationships between velocity and stress, and indicates substantial (15-20%) anisotropy.

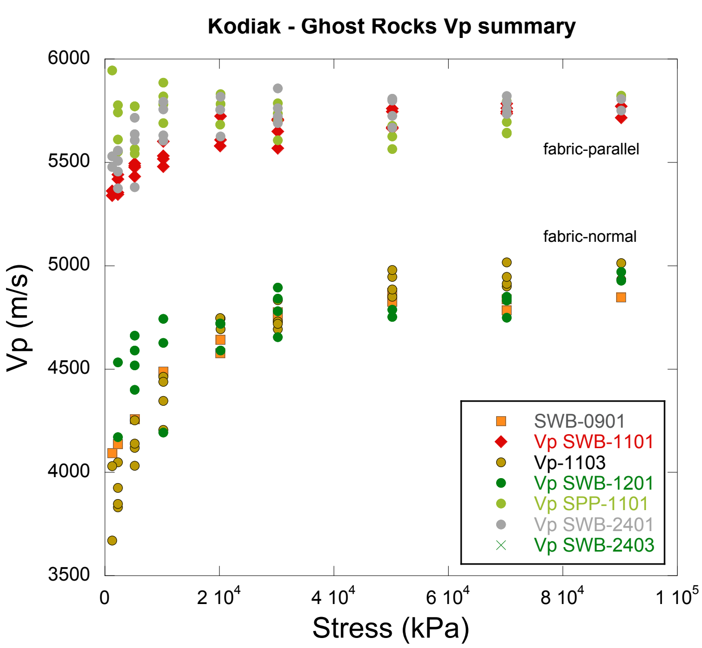

Figure 4. Compilation of Vp-porosity trends showing data from: DSDP sites along the Alaska/Aleutian margin that span porosities from ~70% to ~35%, including sites on the subducting plate (178 & 183) and the shallow accretionary wedge (186)

Our next steps are to: (1) extract more detailed information on the velocity structure of the plate boundary to depths of ~20 km with pre-stack depth migration and amplitude analysis of seismic reflection data and waveform modeling of wide-angle seismic data, and integrate these with the laboratory measurements to quantify in situ porosity and stress conditions, to ultimately determine the underlying cause(s) of bright reflections and low velocity zones along the shallower part of the plate boundary; and (2) link waveform modeling, laboratory measurements on exhumed rocks, and theoretical mineral-based predictions of elastic moduli and seismic wavespeed at greater depths (>~20 km) to assess the contributions of crack geometry, anisotropy, and composition, to better constrain the cause of the kms-thick low velocity zone.