Structure and estimated phsyical properties of the Cascadia subduction zone accretionary wedge, Grays Harbor, Washington

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Abstract

While the Cascadia margin has experienced large historical earthquakes, the lack of seismicity along the margin makes the updip limit of the locked seismogenic zone unknown. Detailed structural interpretation of multichannel seismic data from the Cascadia Open Source Seismic Transect (COAST) offshore Grays Harbor, Washington, allows us to document the position and relative activity of large thrust faults within the accretionary prism. As seen in previous studies, this portion of the Cascadia margin is characterized by a thick incoming sediment section, landward fault vergence in the outer wedge, and a low wedge taper angle. High rates of sedimentation and deformation of slope basins on the actively deforming wedge allows us to determine the relative timing of fault activity. This analysis points to out-of-sequence faulting in the outer wedge, as well as potential fluidized sediment movement in the lower-slope terrace, where the taper angle of the wedge is zero. To complement the structural interpretation of the accretionary prism, porosity estimates from velocity models are used to calculate effective stress through the wedge, including at depth where a detachment is inferred. By combining structural and sedimentary interpretation of the accretionary prism with physical properties and stress estimations, we may shed light on the development of the outer wedge of the accretionary prism.

COAST Project

In July of 2012, 11 multichannel seismic lines were shot off Grays Harbor, Washington, as part of the Cascadia Open Access Seismic Transect. Lines 1 through 9 are perpendicular to the trench, while lines 10 and 11 are trench parallel. Multibeam bathymetry was also collected on the cruise, and is used to correlate features across lines 1 through 9.

Two lines, 3 and 4, were commercially time migrated by GeoTrace. Work done by colleagues at the University of Wyoming (W. Fortin and E. Everson) has produced pre-stack depth migrations of lines 3,4, and 5, as well as velocity models used in the migrations.

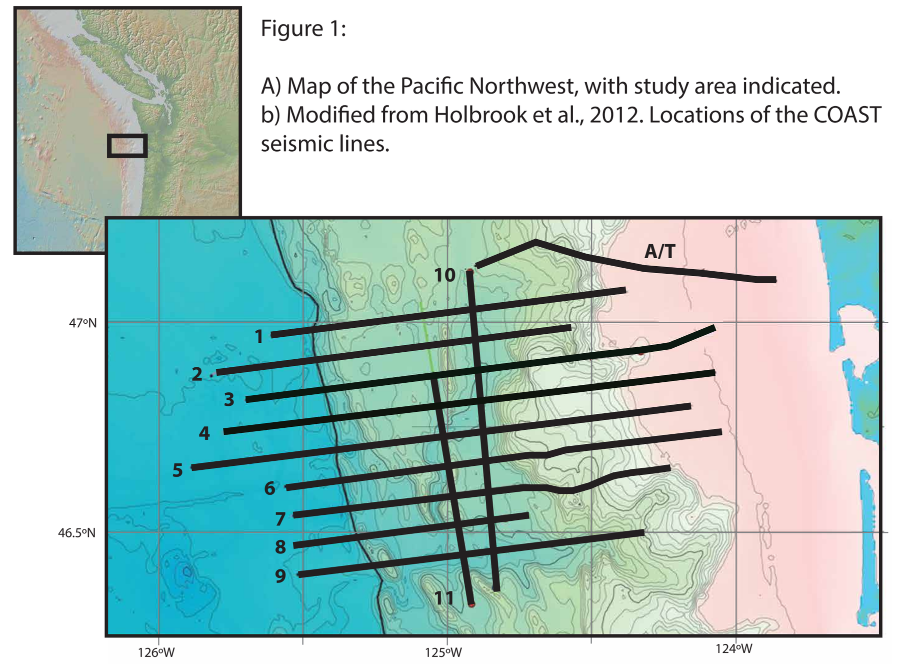
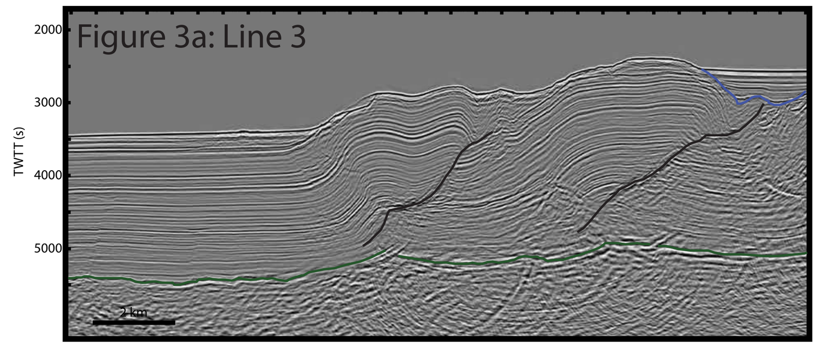
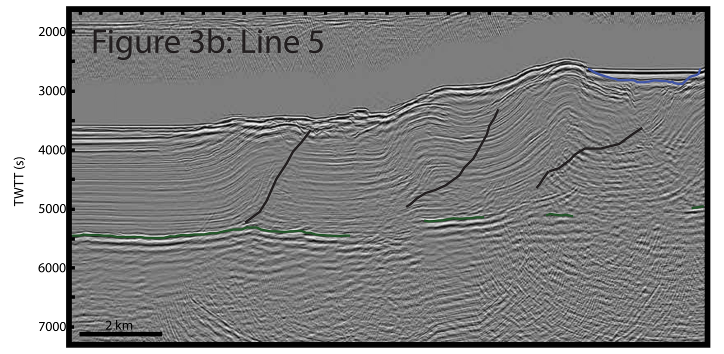


Figure 1:

A) Map of the Pacific Northwest, with study area indicated.
b) Modified from Holbrook et al., 2012. Locations of the COAST seismic lines.

Structure of the wedge





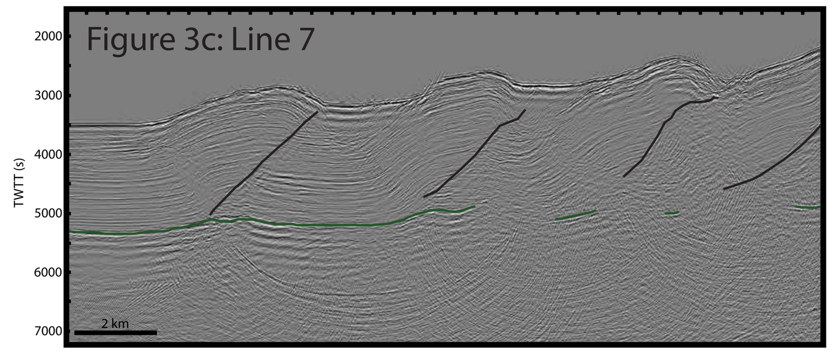


Figure 3 a,b,c:Evolution of the prism and frontal thrust

The northern portion of the COAST survey is characterized by a large, relatively shallow accretionary prism, with interconnected slope basins covering all of the thrust sheets. The thrust sheets are often duplexed, and the frontal thrust typically piggybacks onto the second thrust sheet, as seen in Line 3. In Line 5, however, a new frontal thrust is seen, soling into the oceanic crust in the incoming sediments. South of line 5, many channels cut across and along the margin. Spacing between the thrust sheets becomes larger, the sheets themselves have less relief, and the connection between the slope basins is harder to determine.

Figure 2: Google Earth image of multibeam swath bathymetry with the locations of lines in figures 3, 4 and 5 indicated. As the dataset is 2D, bathymetry is used to correlate structures across lines (where visible).

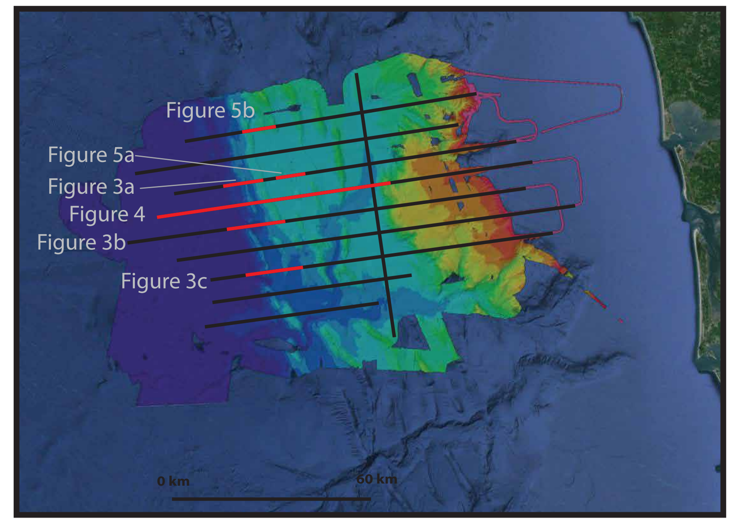
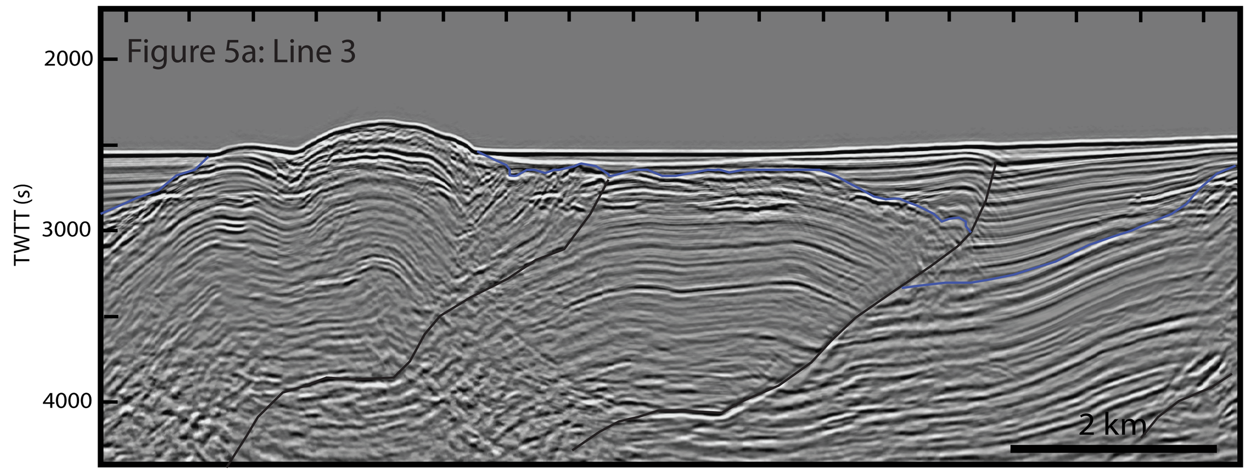
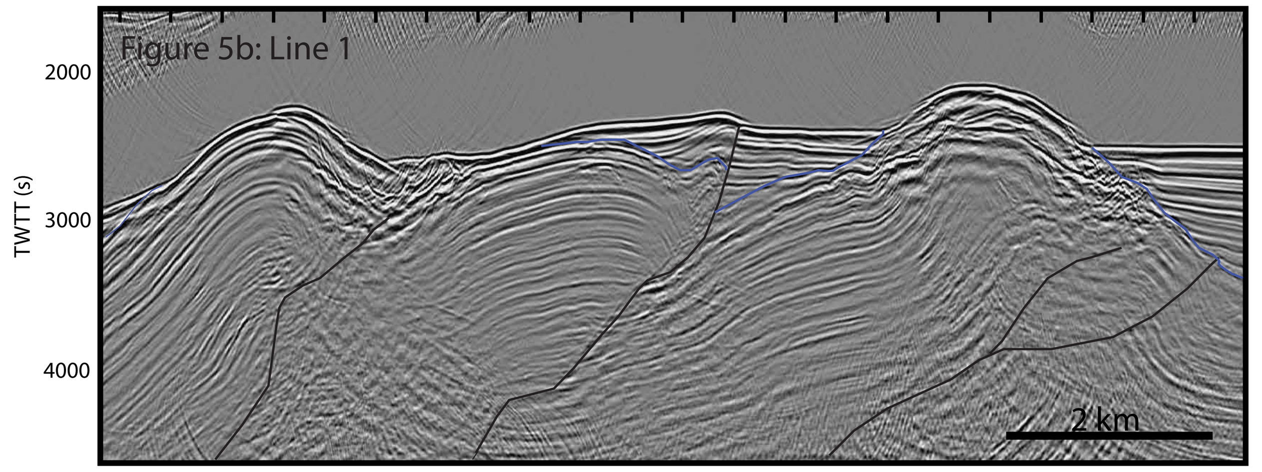
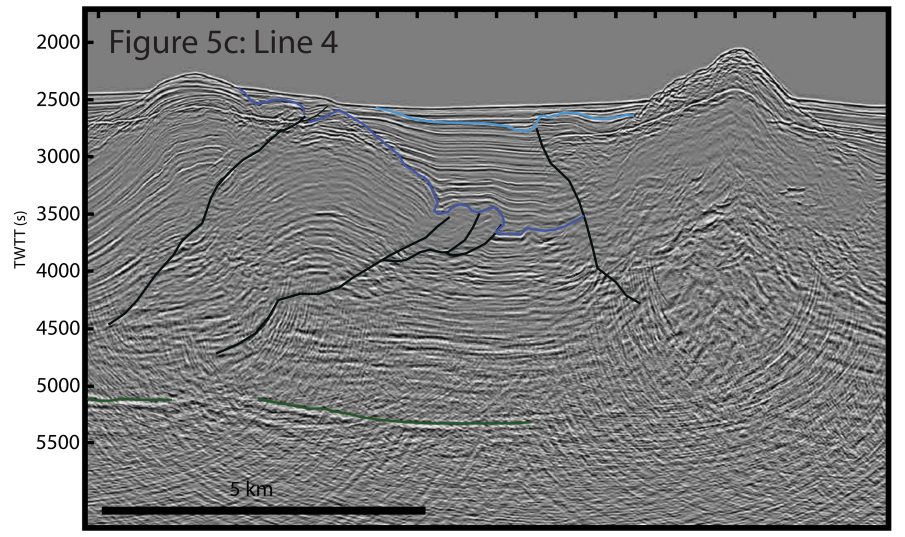


Figure 5 a,b,c: Out of sequence thrust faults

The most recent active faults in this section of the Cascadia margin can be identified as they deform the overlying basins, occasionally reaching the surface (figure 5b). These faults are the three faults in the central portion of the outer wedge, indicating that there is out of sequence faulting in the accretionary prism. The last fault in the outer wedge before the lower-slope terrace appears to have been active, but lapsed into inactivity, shown by the onlapping relationships in basin fill (figure 5c). However, the seaward dripping fault bracketing the structure that separates the outer wedge and the lower slope terrace seems to have been active more recently.

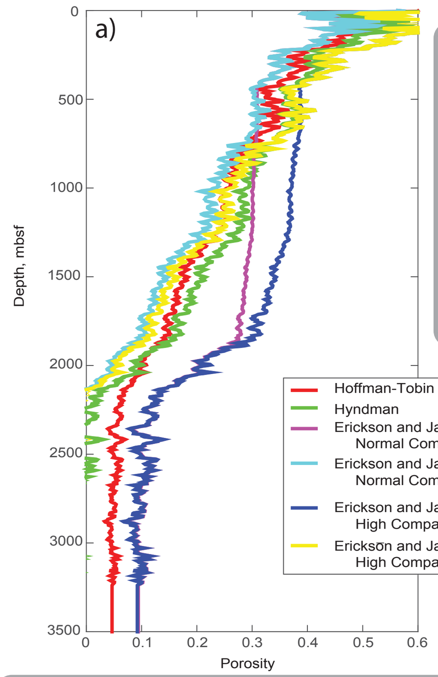






Velocity, Porosity, and Pore Pressure

In order to examine the pore pressure, the Fortin et al. inversion velocity model for Line 5 was converted to porosity. Various velocity-porosity conversions were made using different relationships. The Hoffman-Tobin curve was chosen for the final analysis as it provided realistic values beneath the wedge. Porosity values were extracted along the line every 1000 CMPs. The assumption was made that the incoming sediments were not overpressured, and an Athy compaction curve was fit to the incoming sediment values and compared to the porosity values throughout the wedge.



Athy porosity-depth relationship

$$\phi = \phi_c e^{-\beta z}$$

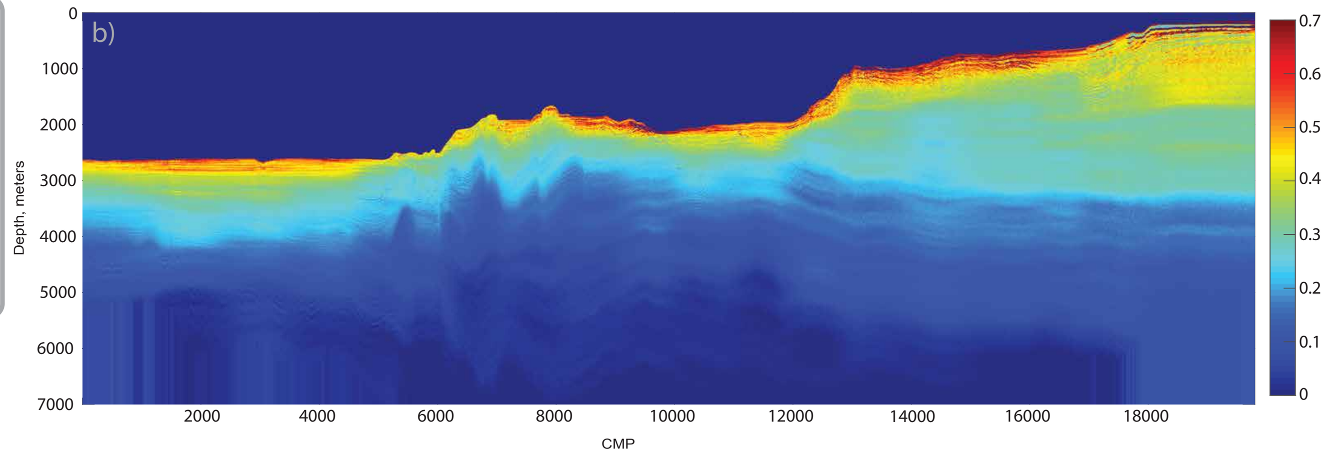
ϕ = porosity
ϕ_c = initial porosity
β = constant
z = depth

Hoffman-Tobin velocity porosity relationship

$$V_P = A + B\varphi + 0.305/[(\varphi + C)^2 + 0.305/(1.51 - A - B) - C^2 - 2C - 1] + 0.61(v_{sh} - 1.123)[X_m]$$

$$X_m = \tanh[40(\varphi - \varphi_c)] - |\tanh[40(\varphi - \varphi_c)]|$$

V_P = p-wave velocity
φ = porosity
v_{sh} = shale volume
φ_c = critical porosity
A, B, C = parameters fit to the data



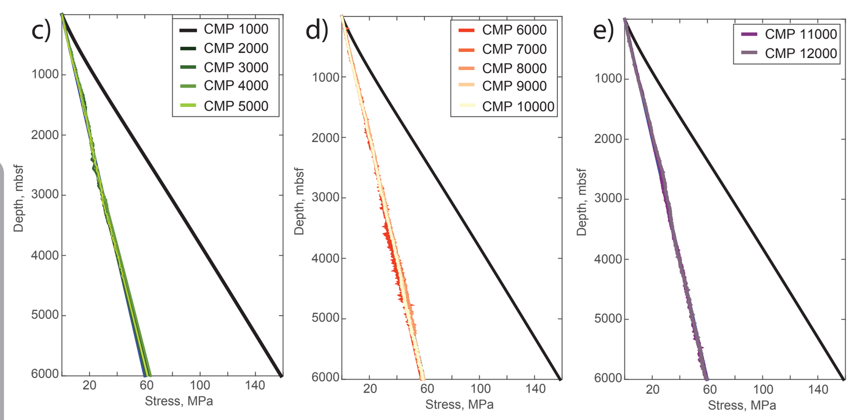


Figure 6: a) comparison between Various velocity models tried for this survey. The Erickson and Jarrard normal compaction and high compaction with a shale term of do not seem to serve in the central portion of the wedge, while the relationships with a shale term of 1 reach 0% porosity before the oceanic crust, as does the Hyndman model. The Hoffman-Tobin curve gives reasonable estimates through the section. b) Inversion velocity model converted to porosity with the Hoffman-Tobin relation. c) Pore pressure calculated for the input sediments. d) Pore pressure calculated for the outer wedge. e) Pore pressure calculated for the mid-slope terrace.

Oceanic crust, underthrust sediments, and faults

The new frontal thrust seen in line 5 (figure 2a) clearly soles into the oceanic crust. However, the lack of a coherent oceanic crust reflector makes it difficult to determine where the other thrusts in the outer wedge sole. The fault reflectors are not apparent in the somewhat incoherent section visible above the oceanic crust, suggesting that the faults may sole into a detachment and some sediment may be underthrust. This section of potentially subducted sediment can be identified at the base of the outer wedge and the lower slope terrace above where the oceanic crust is visible. The frontal thrust in the northern part of the section (north of line 5) does not appear to sole into the oceanic crust, but rather into a layer above the basement, which may indicate that sediment below that layer is underthrust.

Acknowledgements

Support for work on this poster has come from National Science Foundation grant OCE-1334322. Thanks to GeoTrace for their time-migrations of lines 3 and 4, and the participants of the COAST cruise. Thanks also to Jeff Beeson for bathymetry data.

Conclusions

Structure:

Faults in these sections verge landward as seen in previous studies, and the most recently active faults are in the central portion of the outer wedge, while faults farther back are currently inactive. The seaward dipping fault flanking the structure between the outer wedge and the lower slope terrace appears to have been active more recently than the last fault in the outer wedge. The wedge structure changes from the north to the south, from a relatively heavily sedimented series of close thrust sheets to a wedge cut with channels and more eroded in the south.

Effective stress:

Pore pressure estimated from velocity models indicates that the entire prism is well drained, from the incoming sediments to the lower-slope terrace. Interpretation of the seismic data indicates that there may be a detachment above the oceanic crust, and some sediment is underthrust. However, these underthrust sediments do not appear as areas of high porosity or pore pressure in the velocity model-based calculations .

The assumption made with this analysis is that the incoming sediments are losing porosity exponentially with depth, which may not be the case. Heavy sedimentation in the basin could cause the incoming section to be overpressured, making pore pressure calculations based on an Athy model incorrect.

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