Identifying forearc faults in coastal southwestern Washington, Cascadia Subduction Zone

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Abstract

Offshore mapping indicates possible deformation of Holocene sediments and recent onshore mapping shows that late Pleistocene marine sediments are uplifted above sea level. Yet, onshore surface mapping in southwestern Washington has not revealed active faults or folding of Quaternary sediments. New geophysical modeling using observations from potential fields reveals previously unmapped faults underlying Quaternary deposits in coastal southwestern Washington while confirming mapped faults in Eocene-Miocene rocks. We assess the Quaternary deposits for recent deformation through geomorphic analyses of streams and regional lineaments.

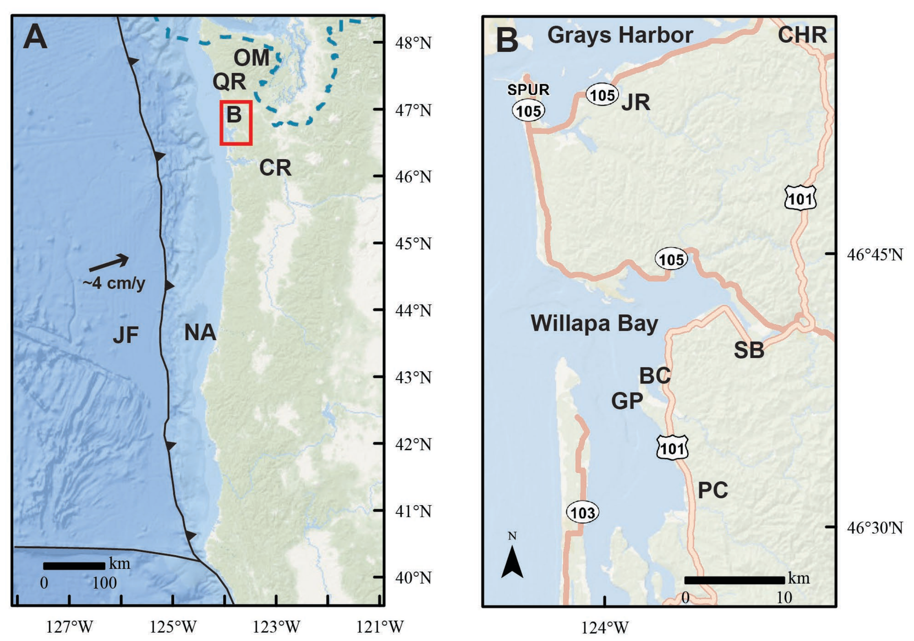


Figure 1: (left) Location of the field area with respect to the Cascadia subduction zone margin. A.) The Juan de Fuca plate subducts beneath North America at about 4 cm/yr toward the northeast. Blue dashed line indicates the extent of ice of Cordilleran ice sheet during the last glacial maximum. Red box indicates extent of B. OM – Olympic Mountains, QR – Quinault River, CR – Columbia River, NA – North America plate, JF – Juan de Fuca plate. B.) Geographic features of the study area. Quaternary deposits mapped south of Grays Harbor and east of Willapa Bay record Pleistocene uplift. Circled numbers are state highways. CHR – Chehalis River, JR – Johns River, SB – South Bend, BC – Bay Center, GP – Goose Point, PC – Pickernell Creek. Map base layer credits: Esri, Garmin, GEBCO, NOAA, NGDC and others.

The Problem

- Quaternary marine sediments on coastal southwestern Washington near Grays Harbor and Willapa Bay (Fig. 1) are at elevations above sea-level, indicating uplift, possibly associated with the Cascadia subduction zone or crustal faults/folds.
- Recent mapping (Fig 2.; Stanton, 2021) differentiates nine new units in what was previously mapped as a single Quaternary unit. Late Pleistocene estuarine units (Qt1, Qt2) record an **uplift rate of 0.4 ± 0.1 mm/yr**.
- **What is accommodating that uplift?** No mapped faults or folds in the Quaternary deposits although offshore seismic studies indicate a fault zone in Willapa Bay (McCrory et al., 2002).

How else might we identify possible subsurface faults or folds that are not evident in the geologic record?

Our approach:

- Potential fields geophysical modeling using aeromagnetic and gravity measurements
- Geomorphic analyses of lineaments and regional stream steepness

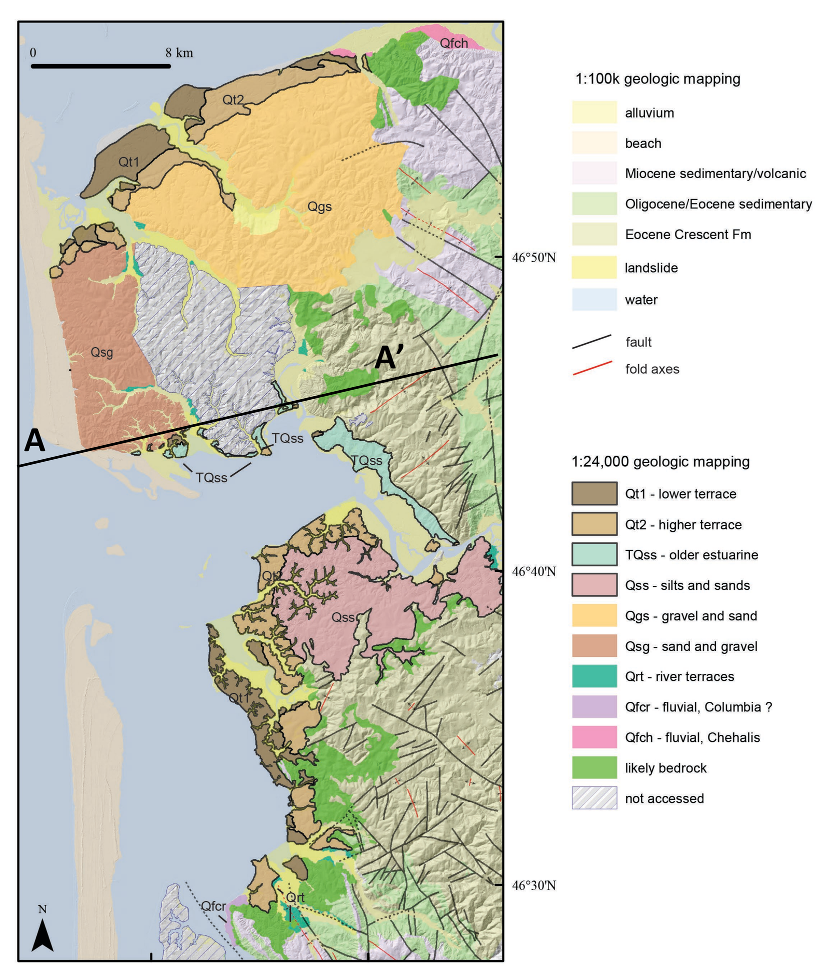


Figure 2: (above) Geologic map showing Quaternary deposits mapped at 1:24k near Grays Harbor and Willapa Bay labeled and in bright colors, with units from regional 1:100k mapping in muted colors (Stanton, 2021). Units in bold outline are uplifted marine terrace deposits that record 0.4 ± 0.1 mm/yr uplift rate.

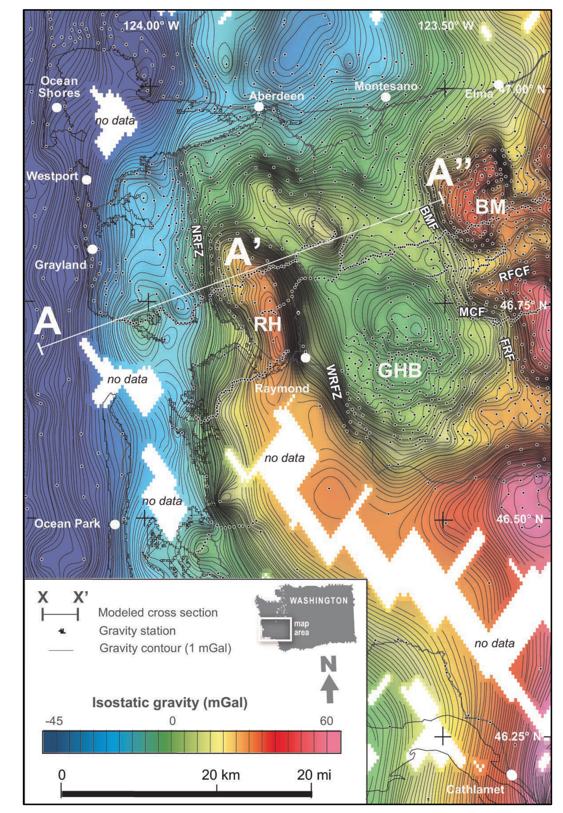


Figure 3: (left) Regional gravity grid with 1-mGal contours, station locations, and labels for geophysical model locations. Location of figure 3 shown by line A-A'. Abbreviations are as follows: BM – Blue Mountain, BMF – Blue Mountain fault, GHB – Grays Harbor basin, MCF – Martin Creek fault, NRFZ – North River fault zone, RH – Raymond Hills, RFCF – Red Field Creek fault, WRFZ – Willapa River fault zone. Map modified from Steely et al. (2021).

Table 1: Model unit properties used in geophysical model (Fig. 4).

Unit	Density (kg/m³)	Magnetic susceptibility (x10⁻³SI)	Magnetic remanence (A/m)
Q	2,000-2,200	0	---
Mms_a	2,200	0	---
Mvb	2,670	0	1.3-4
Em_{lc}	2,240-2,270	0-20	---
Es	2,350-2,430	0-7	---
Ev_c	2,670-2,880	11-73	0.13-0.5
Ev_{cr}	2,820-2,880	0-55	0.2-0.4

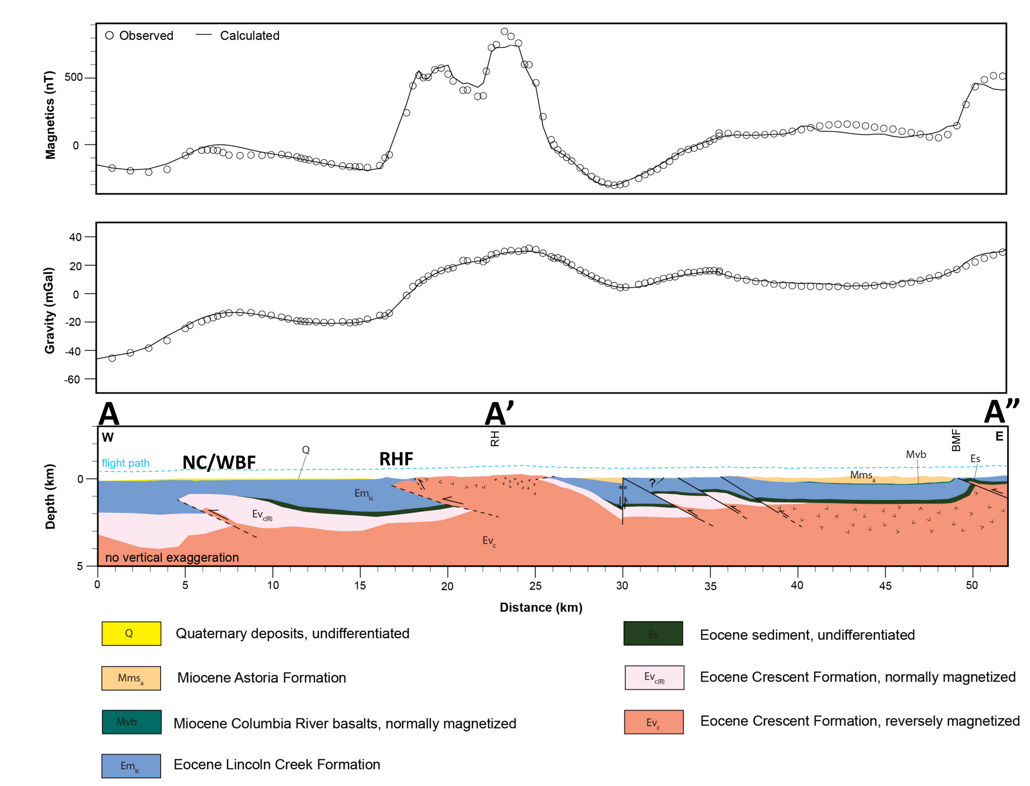


Figure 4: (above) Potential-field model from Willapa Bay, across the Blue Mountain fault, to the Blue Mountains. Location shown in Figure 3. The cross-sectional model shown in the bottom panel creates the calculated anomalies in the gravity and magnetics windows. Zero depth is sea level. Flight path shows the elevation of the airplane that flew the aeromagnetic survey above topography. The model continues well beyond the extent shown to avoid edge effects. Faults are depicted as thick black lines, well-constrained by the model and/or surface geologic observations where solid, poorly constrained where dotted and queried where existence is uncertain. Thin black lines represent contacts. Model unit properties are listed in Table 1. The patterned blocks of Crescent Formation have lower density ('v's) or higher magnetism and density ('x's) than adjacent areas. RH – Raymond Hills, BMF – Blue Mountain Fault RHF – Raymond Hills fault, NC/WBF – North Cove/Willapa Bay fault.

Do modeled faults co-locate with geomorphic features or uplifted deposits ?

- LiDAR show northwest trending lineament on west side of Raymond Hills and a north trending lineament near North Cove (Fig 5a).
- Raymond lineament co-locates with modeled thrust fault west of Raymond Hills from Fig. 4.
- Raymond lineament likely NOT a marine terrace back edge since is not at same elevation (Fig. 5b).
- North Cove lineament (Fig. 5a) co-locates with modeled western-most thrust fault from Fig. 4. Uplifted marine terrace deposits (Fig. 2) are located east of the modeled east-dipping thrust fault and lineament.
- North Cove lineament also aligns with Willapa Bay Fault Zone, identified from offshore seismic studies (McCrory et al., 2002).

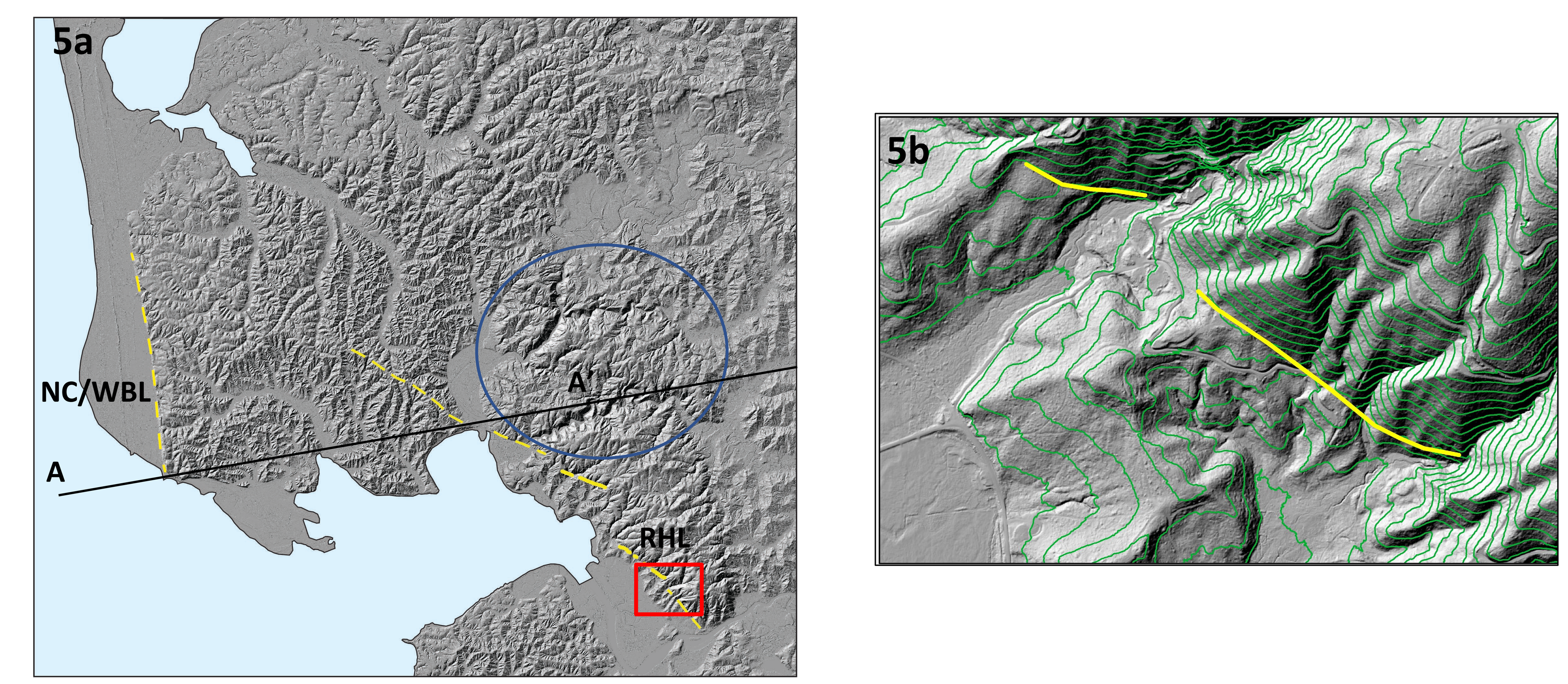
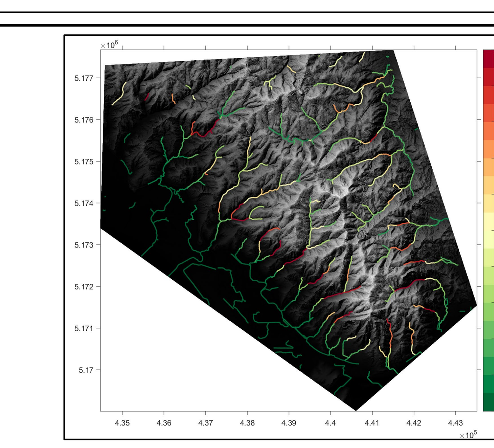


Figure 5: (above) Geomorphic lineaments are visible in DEMs derived from LiDAR (Washington DNR, 2022). a.) The Raymond Hills lineament (RHL) co-locates with a modeled thrust fault labeled RHF in Fig. 4. The lineament near North Cove (NC/WBL) co-locates with a modeled thrust fault labeled NC/WBF in Fig. 4. Uplifted marine terrace deposits (Fig. 2) are all located east of the North Cove/Willapa Bay lineament, consistent with uplift on the east-dipping modeled North Cove/Willapa Bay fault (NC/WBF) Fig. 4. Red box indicates the general extent of Fig. 5B and Fig. 6. Blue circle shows region of stream incision north of RHL and modeled thrust fault RHF. NC/WBL – North Cove/Willapa Bay lineament, RHL – Raymond Hills lineament. b.) The Raymond Hills lineament is not at a consistent elevation and thus is not a marine back edge, which would have the same elevation along its entire length. Green lines are topographic contours of elevation with 20-foot interval.

Figure 6: (below left) Normalized channel steepness index (ksn) analysis for streams northeast of the Raymond lineament, as well as northeast of the modeled thrust fault from Fig. 4. General analysis region is outlined in red in Figure 5a.

Do other geomorphic features support existence of regional faults?

- Preliminary stream analyses indicate stream profiles steepen northeast of Raymond lineament (Fig. 6), consistent with up-to-northeast movement on modeled thrust fault (Fig. 4).
- ~400-500-feet incision on streams in northern Raymond Hills (Fig. 5a).



Methods

- We use the **forward-modeling** method in Oasis montaj software extension GM-SYS to produce a 2-D cross-sectional model (Fig. 4). This method calculates the gravitational and geomagnetic field responses to subsurface blocks possessing user-defined physical properties (density and magnetics).
- We use regional isostatic gravity data from Steely et al. (2021), Finn et al.. (1991) and PACES (Fig. 3), and aeromagnetic data from Blakely and Sherrod (2020).We use density and magnetic characteristics measured for rocks in the region (Table 1; Steely et al., 2021).
- Geologic maps provide surficial constraints for rock distributions and fault geometry used in the modeling process (Steely et al., 2021; Walsh et al., 1987).
- We **identify lineaments** using LiDAR collected in 2019 (Fig. 5; Washington DNR, 2022)
- **Stream analyses** use DEMs from LiDAR as input with analyses completed with standard user interface of Topographic Analysis Kit (TAK) for Topo ToolBox (Fig. 6; Forte and Whipple, 2019).

Conclusions

- Lineaments in southwestern Washington Quaternary deposits appear to **co-locate with modeled faults** from potential fields geophysics.
- Raymond lineament does NOT appear to be a marine terrace back edge based on contours.
- Stream profiles steepen directly upslope of Raymond lineament **consistent with uplift to NE.**
- Uplifted late Pleistocene marine terrace deposits are located east of North Cove lineament, **consistent with modeled east dipping thrust fault**.

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Questions? Talk to Kelsay Stanton from 4:30-5:30 p on Tuesday January 10th . QR code links to a UW-hosted zoom call.