T13I-0356

The Doty Fault Network: 3D regional deformation applied to seismic hazard characterization in the forearc of Washington State

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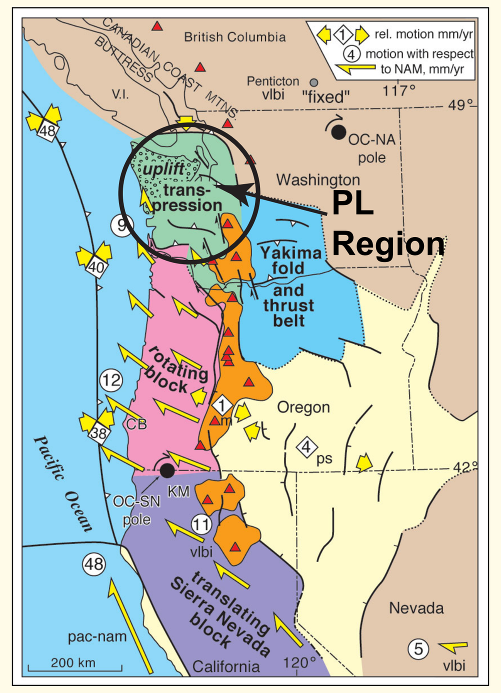
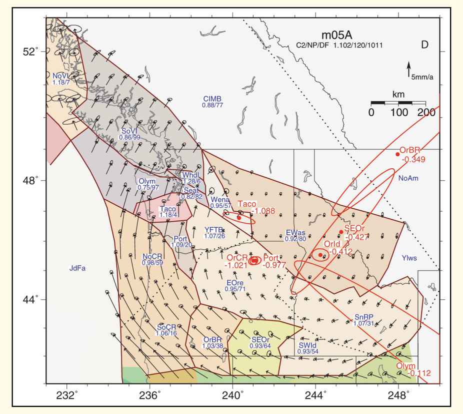
WASHINGTON STATE DEPT OF NATURAL RESOURCES
WASHINGTON GEOLOGICAL SURVEY

Tectonic Setting



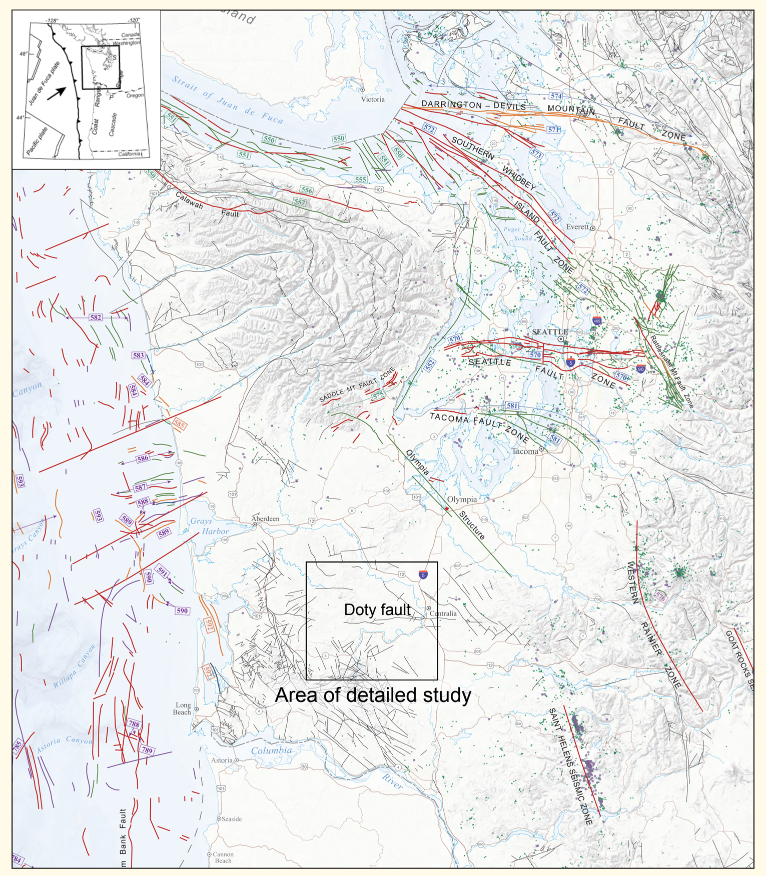
The Doty fault is one of several east-trending compressional structures in the Puget Lowland (PL), seemingly at odds with the northeasterly oriented compression along the Juan de Fuca subduction zone. The existence of these faults is likely related to the northward movement of a strong Oregon forearc block. A weaker PL block accommodates north-south shortening between Siletzia and the slower-moving Canadian Coast Mountains to the north. The limits of the deforming PL block are not well-known.



◀ GPS data is constraining more precise models of present day crustal movement (McCaffrey and others 2007; 2013). The PL region (circle) is still an area of complexity in these newer models.

▲ Block rotation model for the Pacific Northwest from Wells and others (1998). The pink Oregon block rotates about the OC-NA pole. Rotational motions are constrained by very long baseline interferometry, paleoseismology, magmatic spreading and Pacific-North America motions.

Previously Mapped Fault Network



▲ Active fault map for western Washington state (Czajkowski and Bowman, 2014). Green faults show signs of pre-Quaternary activity and purple/blue/orange/red faults show evidence of Pleistocene and later seismic activity.

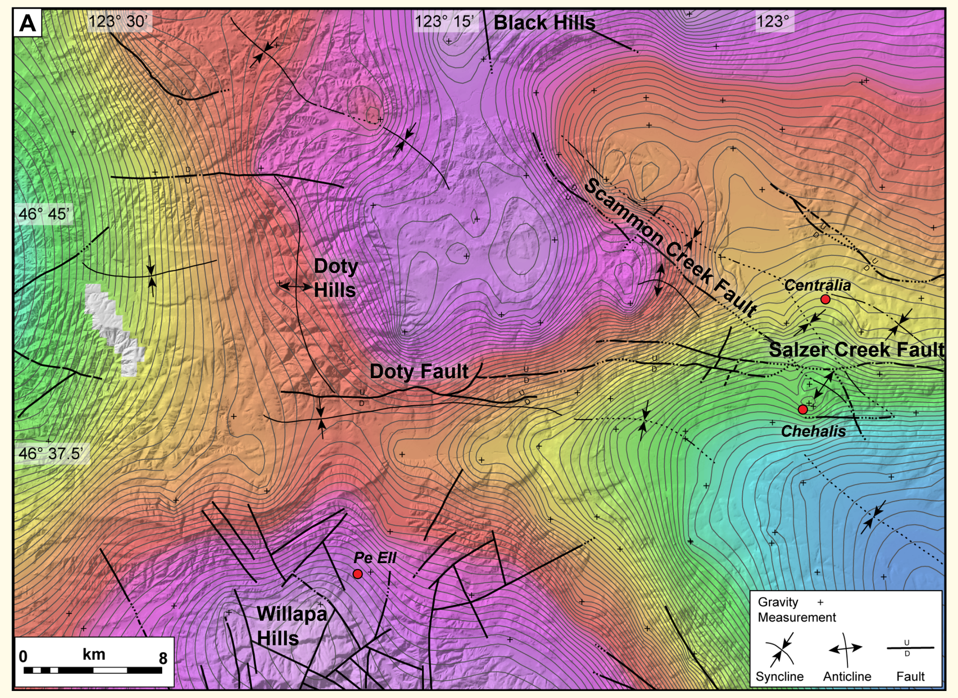
The upper crust in the forearc of the Cascadia subduction zone hosts a complex network of faults that accommodate trench-parallel and trench-normal shortening. Outside of the Seattle area, the seismic potential of major faults, as well as how they connect in a 3D network, is poorly known. The trench-normal Doty fault—a major, north-dipping forearc fault—crosses the I-5 corridor south of the Centralia–Chehalis urban area. Its length, orientation, and hypothesized total offset are comparable to the active Seattle Fault, but it is unclear if the Doty fault poses a similar modern seismic hazard.

Major Questions:

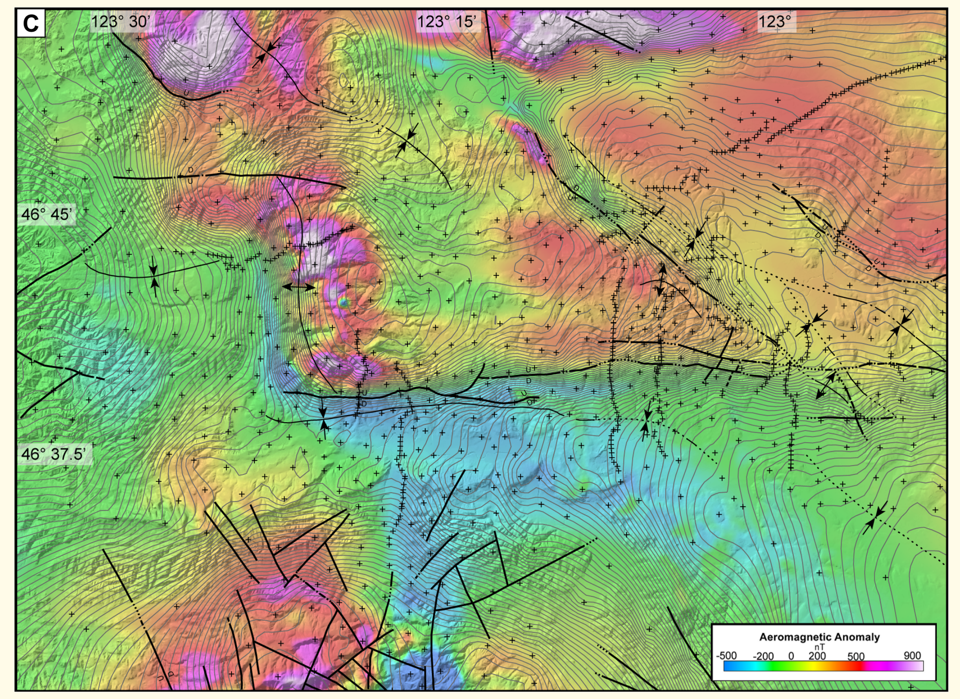
1. What is the Doty fault's length, structure and dip?
2. Is the fault composed of one or several strands?
3. Is the Doty fault active?
4. How does it link with neighboring faults to form a network that accommodates 3D regional tectonic strain?

New Observations from Potential Field Mapping

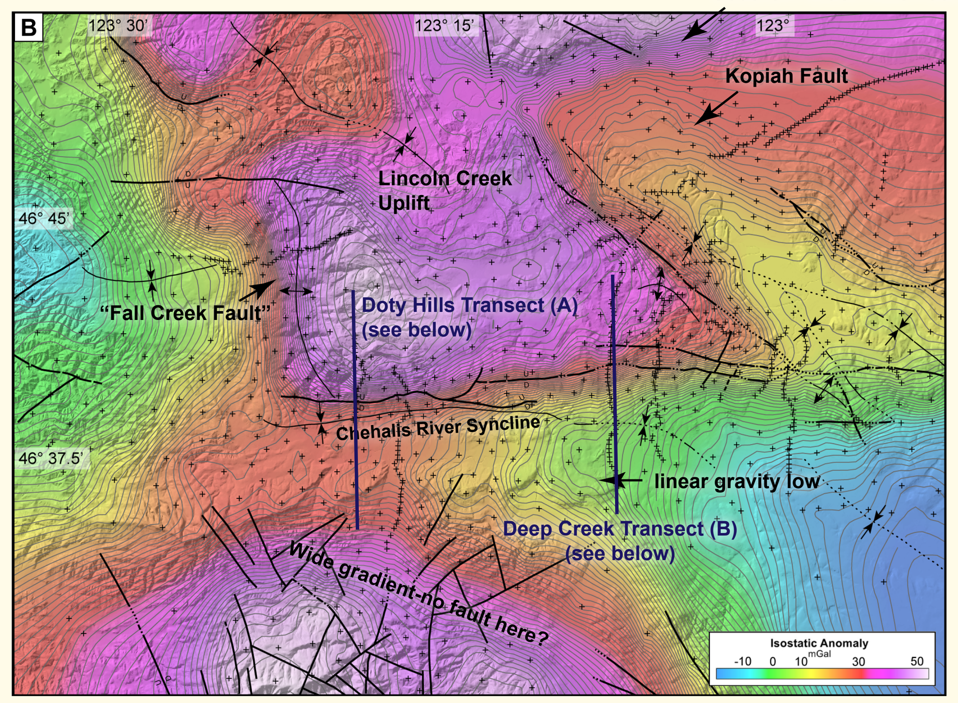
We are applying aeromagnetic and ground magnetic data, a regional gravity grid, high-resolution gravity lines, seismicity from a local broadband network, targeted geologic mapping, provenance characterization of Quaternary to Neogene sediments, dating, lidar interpretation and field reconnaissance of geomorphic features to our research questions. Here we present initial results largely from the potential field work (see T13I-0355 for methods and additional results).



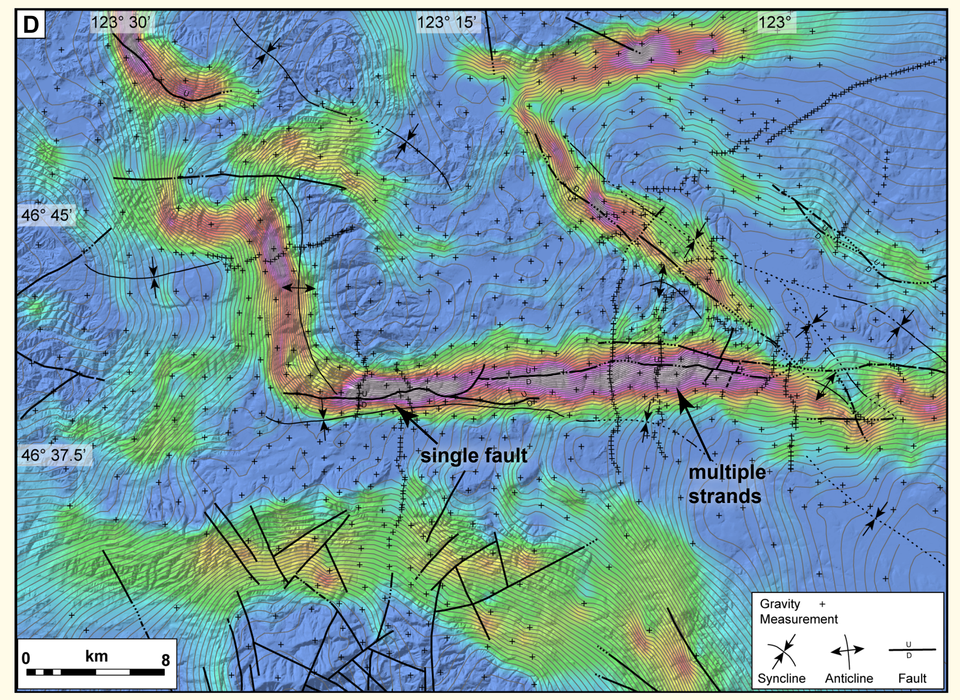
▲ Isostatic gravity map in 2016 with 1 mGal contours. Average gravity station spacing is ~7 km (Finn and others, 1991). Gravity highs do indicate Crescent Formation at or near the surface and lows indicate zones with generally thicker sedimentary cover, but most strong gradients are not linear and do not follow 100K mapped faults (Logan, 1987).



▲ Aeromagnetic map with 1 mGal isostatic gravity contours. Strong gravity gradients are clearly associated with strong magnetic gradients indicating a similar source. The strength of these correlated gradients further supports deep-seated fault interpretation with kilometers of displacement.



▲ Isostatic gravity map with new data added (2017-2018), 1 mGal contours. As expected, the Doty and Scammon Creek faults correspond with strong, linear gradients, as does the probable extension of the Kopiah fault. Gravity high over the entire Lincoln Creek uplift indicates Crescent Formation at or near the surface. The gradient at the northern edge of the Willapa Hills is more gradual and likely not fault-related. Three unexpected features are apparent from the new data: **1)** A north-trending gradient of similar magnitude to the Doty fault bounds the western edge of the Doty Hills. The simplicity and strength of this gradient suggest that this is a fault, not a fold as suggested by the 100K mapping. We informally name this the Fall Creek fault. **2)** A strong, linear gradient also bounds the southern edge of the Black Hills, which we informally name the Southern Black Hills fault. **3)** A linear gravity low exists south of the mapped axis of the Chehalis River syncline. This could be associated with a blind strand of the Doty–Salzer Creek fault system.

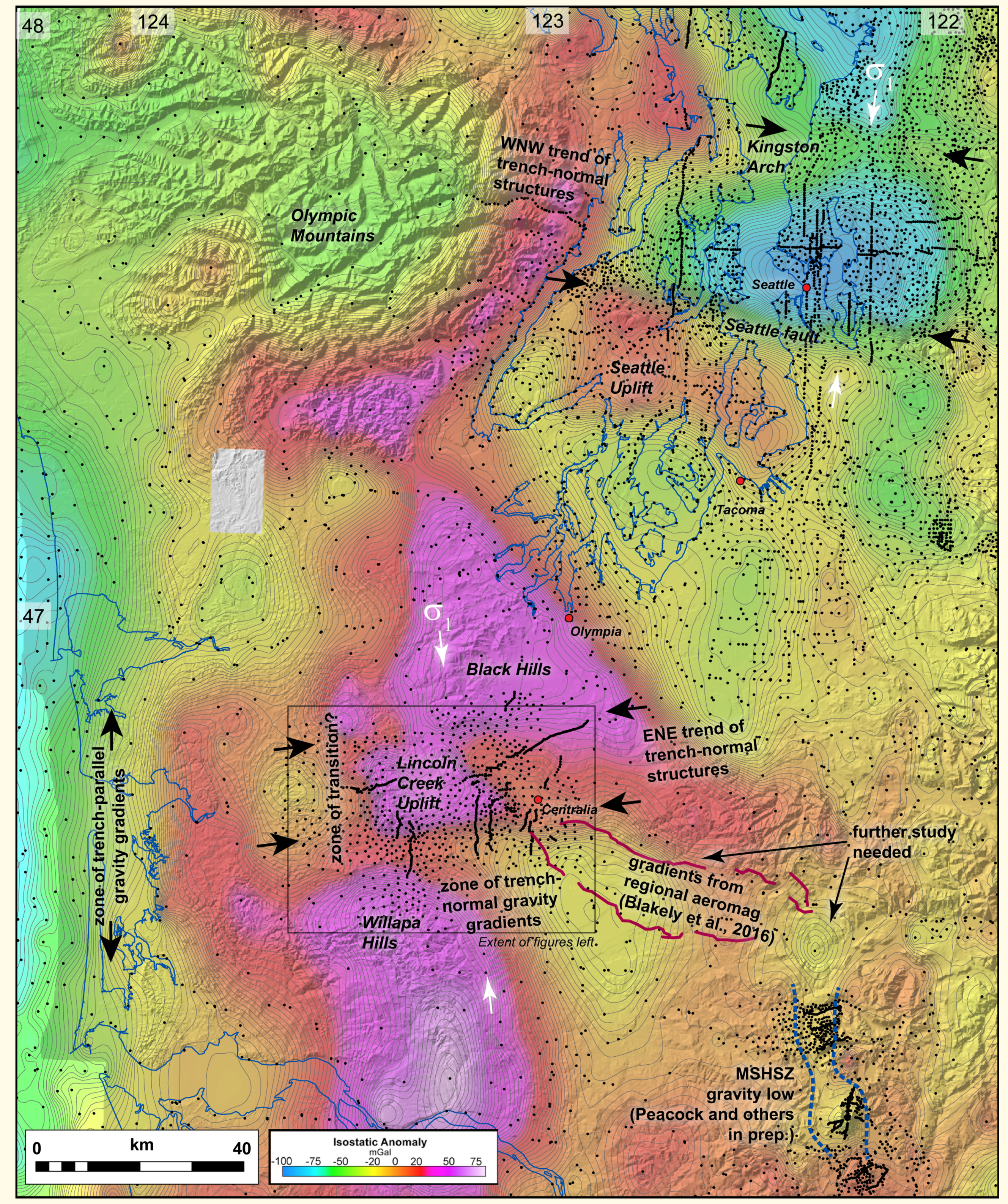


▲ Horizontal gradient of the isostatic gravity with 1 mGal contours. Linearity of the Doty, Fall Creek and Southern Black Hills faults are immediately apparent. Note the similarity in gradient strength between the Doty and Fall Creek faults. There is a marked difference in the width and strength of the Doty fault gradient from west to east. Westward, a single strong gradient suggests a single, deep-seated fault extending to the surface (see below). Eastward, the gradient widens, sometimes with steps, indicating more than one fault strand. In comparison, Salzer Creek fault shows the widest gradient, indicating either multiple, widely-spaced faults and(or) fault complexities arising from interactions with the Scammon Creek fault. The Scammon Creek fault gradient has a bend, which may arise from a couple of en echelon strands, typical of oblique transfer structures.

Regional Relationships

An eventual goal of the WGS is to understand the connectivity of all active faults in the PL. Such full knowledge will help us understand how quickly elastic strain builds on faults in different orientations and how they might release such strain in the event of an earthquake on a neighboring fault or the subduction interface. The understudied Doty fault is farther west and south than other well-studied faults in the greater Seattle urban area and will give us new understanding of strain at the southern end of the PL block. We have the following observations thus far:

1. ENE trending Doty and Southern Black Hills faults are parallel to the maximum compressive stress direction (σ_1) predicted by rotation of the forearc. Our regional gravity map shows a similar result for the Seattle fault and Kingston arch. This indicates that eastern forearc structures are dominated by trench-parallel tectonic driving forces.
2. The NNW-trending Fall Creek fault has major vertical offset, therefore west of the Lincoln Creek uplift, trench-perpendicular σ_1 may dominate. This is further supported by sparse gravity data showing largely N–S trending gradients closer to the coast, likely reflecting broadly north-trending structures.
3. Gravity studies along the Mount Saint Helens seismic zone (MSHSZ) show active seismicity within a gravity low bounded by NNW-trending faults (Peacock and others, in prep). An outstanding question is how this activity might relate to the long-term earthquake potential of the MSHSZ or connected faults. The Doty-Salzer Creek fault system may connect through a series of other faults east of our study area, as suggested by aeromagnetic lineaments in the region (Blakely and others, 2016). Further study is needed to understand the connection.



Continuing Work

Dating deposits critical for fault mapping and determining activity/provenance.

Continued drafting of new geologic maps.

Cross section construction and quantitative modeling in association with existing seismic data.

Analysis of regional seismic network data (including 14 campaign broadband stations)

Additional gravity data collection east and(or) west of current study area.

We propose new active seismic data across Chehalis River syncline contingent on our modeling results.

Conclusions

The Doty fault is at least 32 (and probably 34) km long and may extend west of the southwest corner of the Lincoln Creek uplift.

The Doty fault connects to both N- and NW-trending faults to bound a discrete Lincoln Creek uplift. Magnitudes of gravity gradients for these connecting faults (the Fall Creek fault, in particular) indicate vertical offsets comparable to the Doty fault.

The northern edge of the Willapa Hills uplift does not appear to be associated with a single, distinctive fault and may be folded instead.

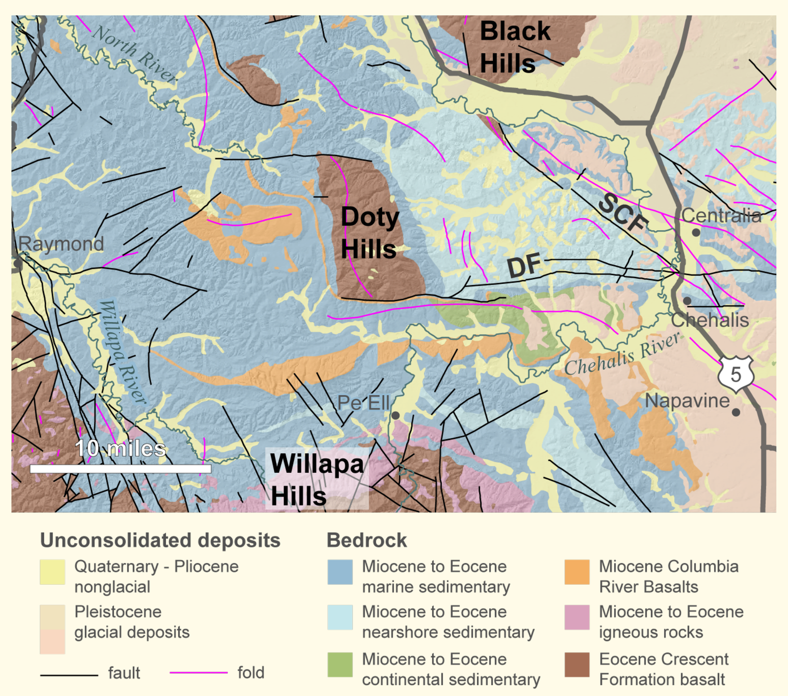
Orientation of the Doty and the Southern Black Hills faults appear exactly perpendicular to the σ_1 predicted by rotation of the Washington forearc. Further, the slightly different orientation of the Seattle fault and Kingston arch reinforce this observation.

The orientation of the Fall Creek fault and significant vertical offset are unusual in the PL and indicate that west of the Doty Hills the forearc is undergoing significant east–west shortening on geological time scales. Therefore, the Doty Hills may mark a significant transition zone from crust dominated by trench-parallel shortening to the east and crust dominated by trench-perpendicular shortening to the west. Identifying this transition may be an important constraint for pinpointing the locked region of the subduction interface and(or) triggering of earthquakes on crustal faults due to stress changes on the subduction interface.

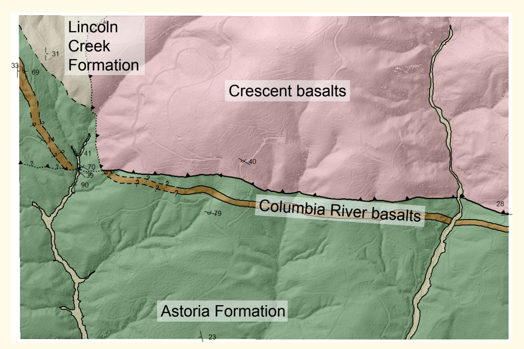
We have found no clear evidence that the Doty fault is currently active. The lack of Quaternary surfaces crossing or near the fault makes the task more difficult than in other regions of the PL; thus the lack of evidence does not preclude fault activity. Our continuing work may resolve this. However, if the Doty fault is not active, then the southern boundary of the deforming PL block would be farther north, indicating a shift over geologic time and more concentrated seismic hazard in the central and northern Washington forearc.

Geology

The crust of southwestern Washington is composed predominantly of basalts of the Crescent Formation, the local Siletzia lithology. Eocene to Miocene onshore and coastal sedimentary strata blanket the basalt. Fault offsets juxtaposing these two lithologies provide an excellent target for gravity and geomagnetic mapping because of their contrasting density and magnetic properties. Crescent Formation is magnetic and dense (~3 g/cc) and sedimentary units are nonmagnetic and less dense (~2.2 g/cc).



◀ Simplified geologic map of the Chehalis Basin region (Logan, 1987). Crescent Formation is exposed in the Willapa Hills, Doty Hills and Black Hills. Few Quaternary deposits exist in this region, in contrast to the NE where glacial outwash is prevalent.



◀ Preliminary geologic map of the southwest corner of the Lincoln Creek uplift and Doty Hills. See map to the left for location.

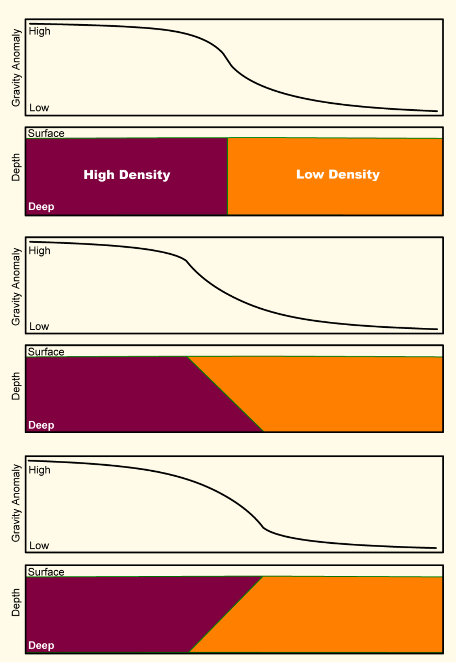
Faulted contact relationships along the trace of the Doty fault and their relationship to topography suggests that the Doty fault is a moderately to steeply dipping structure. At the southwestern corner of the Lincoln Creek uplift, relatively well constrained contact relations suggest a dip of 65°.

As mapped, the Doty–Saltzer Creek fault system is ~34 km long, terminating at the southwest corner of the Lincoln Creek uplift. However, the Miocene sedimentary section appears to thicken north and west of here. Further, attitude data demonstrate a disparity in the position and orientation of a Grande Ronde Formation basalt flow on the north and south limbs of the Chehalis River syncline (not shown) and across the Doty fault. Either growth stratigraphy or an extension of faulting further west could explain these observations.

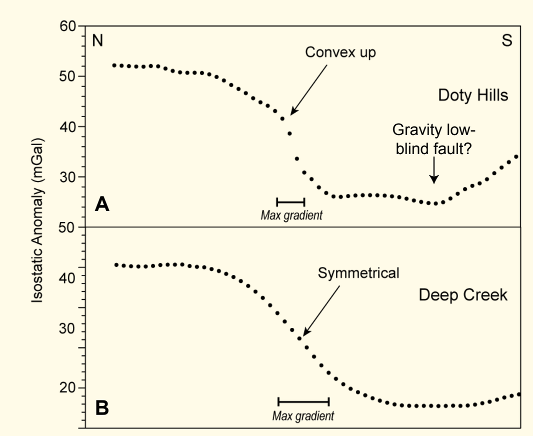
Fault Structure

With enough data, gravity gradients can show the approximate dip of a fault, assuming the faults are simple and not multi-strand. The western end of the Doty–Salzer Creek fault (Doty Hills transect A) is simple enough for this analysis. A convex-up shape with a sharp inflection at the base of the steepest part of the gradient indicates a fault dipping to the north with more dense Crescent Formation basalt over lower-density Eocene/Miocene sedimentary rocks.

The Doty Hills transect also shows a second inflection, which may be due to a blind fault at depth. Future investigations will both quantitatively model these transects and more closely image the southern gravity low.



◀ Simple models showing how the shape of the gravity gradient relates to fault structure/dip.



▲ Transect across two locations of the Doty fault (see map C above for location). The western (Doty Hills-A) data show a convex up shape, typical of simple fault extending to the surface with high density rocks over low (here, a reverse fault dipping north). The eastern (Deep Creek-B) data show a more symmetrical pattern typical of vertical or multi-strand systems. We prefer the latter interpretation.

Is the Fault Active?

Survey of lidar data suggests no active fault scarps along the Doty fault where recognized within the study area. Further, geomorphic markers (such as terraces) are primarily distributed on the downthrown side of the fault. Thus, few geomorphic markers cross the fault, to be potentially offset, and no offset geomorphic markers have been identified in the field or in lidar.

In minor fracture zones and where subsidiary faults or secondary structures have been observed, slickenlines seem to indicate a significant component of lateral motion. However, it is unclear if these kinematic indicators have been rotated from their original orientations as they have been found primarily in older, dipping Eocene- and Oligocene-aged units.

Acknowledgements

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