Integrated Geophysical Investigation and 3D Fault Characterization of the Rochester and Adna 7.5-Minute Quadrangles, Thurston and Lewis Counties, Washington

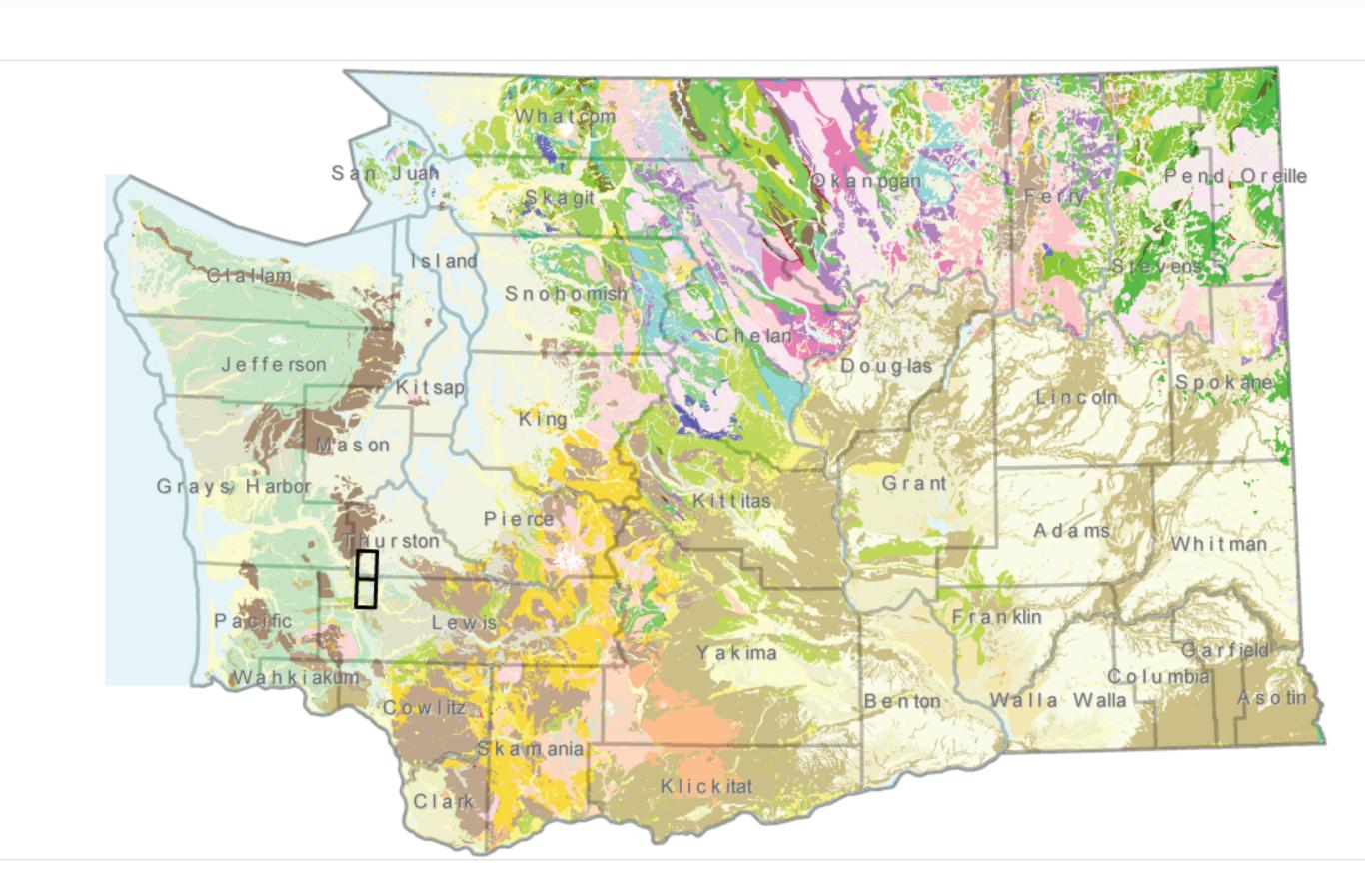
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I. Abstract

The Rochester and Adna 7.5-minute quadrangles in the Washington forearc of the Cascadia subduction zone encompass the Doty fault, a large forearc fault crossing the I-5 corridor south of Centralia. We have begun a cooperative geological and geophysical study of the area to assess the seismic hazard to a water retention facility that has been proposed to mitigate flooding along the Chehalis River and the I-5 corridor. This region between Olympia and Portland is undergoing north-south compression, clockwise rotation, and regional uplift associated with subduction processes and the northward migration of the forearc block. Past studies identified multiple faults that strike northwest-southeast and east-west in the northern and southern parts of the study area, respectively. The Kopiah, Scammon Creek, Salzer Creek, and Doty faults all interact within our study area, in ways that are poorly understood. An integrated geophysical investigation will assist the state-federal cooperative mapping program (STATEMAP) efforts to produce detailed 1:24,000-scale geologic maps of the area. Geophysical field work in the summer of 2018 includes a roughly 15 x 32 km gravity grid with ~2 km station spacing. Station spacing along known geologic structures is ~1 km to provide greater resolution. Results from our coarse gravity grid will provide targets for additional high-resolution profiles. A high-resolution ground magnetic grid also extends across both quadrangles, and preliminary results demonstrate its efficacy at elucidating structure. Seismic profiles acquired by the USGS across the Doty fault will constrain our geophysical modeling, which will combine the high-resolution gravity and magnetic profiles in a geologic model of the subsurface to support the mapping efforts of the STATEMAP program. The data and models will provide insight about total offset across these faults, precisely identify locations of faults that are not exposed at the surface, and allow us to better understand the structure of these faults. These interpretations will allow us to more accurately understand the potential seismic risk these faults pose to nearby population centers and sensitive infrastructure.



II. Methods

Gravity data collection methods

Gravity surveys were conducted using a LaCoste Romberg Model G-908 gravimeter at a total of 950 stations this summer. A 20 x 30 km grid was created with a maximum spacing of ~2 km. Spacing was increased ~1 km in structurally significant areas that were identified using current observations, previous studies, and aeromagnetic anomalies. High-resolution (~0.25 km spacing) profiles were selected across structure that we intended to model using Oasis Montaj. A regional gravity base station called Chehalis B (46.394169°N, 122.580970°W)(Nilsen, 1976) was selected for calibration of the readings, specifically to correct for tidal effects and instrument drift. Station elevation was obtained using a Javad Triumph-2 GPS. GPS recording last ~10 minutes at one sample per second. GPS readings were then differentially corrected using Javad's Justin post-processing software. Gravity readings were reduced using standard techniques, with codes produced by the USGS Geophysical unit at Menlo Park. Corrections that were made include, free-air, bouguer, terrain, drift, tidal, and isostatic. An assigned crustal density of 2.67 g/cm³ was used. An isostatic gravity grid was created in OasisMontaj using minimum surface curvature. The grid contains data collected from this study, the Centralia quadrangle (Sadowski and others, 2018), and the Violet Prairie quadrangle (Polenz and others, 2018), and additional stations from Finn (1970).

Density measurements

Grain density, saturated bulk density, and dry bulk density are being measured with an A&D Company, Ltd. FX-3000i WP balance. More than 100 samples were selected to give representative densities across all formations within our study area. Outcrops in areas of structural importance were specifically sought out to give geophysical controls during our modeling process. Where magnetic susceptibility measurements were made, density samples were collected as

Ground Magnetic data collection methods

A total of 183 km of high-resolution ground magnetic surveys were conducted using two portable magnetometers: a roving G-859 Cesium Vapor magnetometer and a G-857 Proton Procession base station magnetometer (both manufactured by Geometrics, Inc.) The former was used for survey lines at a 0.5 Hz sample rate while the latter was used at a 0.2 Hz sample rate for the base station measurements. Internal clocks on both instruments were synchronized daily. The base station used for both the Rochester and Adna 7.5 minute-quadrangles was located at 46.70163°N, 123.08149°W. Ground magnetic measurements were then completed with efforts to minimize the interference of cultural effects. Before modeling, ground magnetic data were pre-processed using Geometrics Magmap2000 software. Data was de-spiked and corrected for diurnal variations measured at the base station.

Magnetic Susceptibility measurements

Forty-three magnetic susceptibility measurements were made at select outcrops (~20 measurements per outcrop) across the field area using a Terraplus KT-10 v2 magnetic susceptibility meter. Outcrops were selected to give representative susceptibilities across all formations within our study area. Outcrops within areas of structural importance were sought out to give geophysical control during our modeling process. Where density samples were collected for geophysical modeling purposes, magnetic susceptibility measurements were made as well.

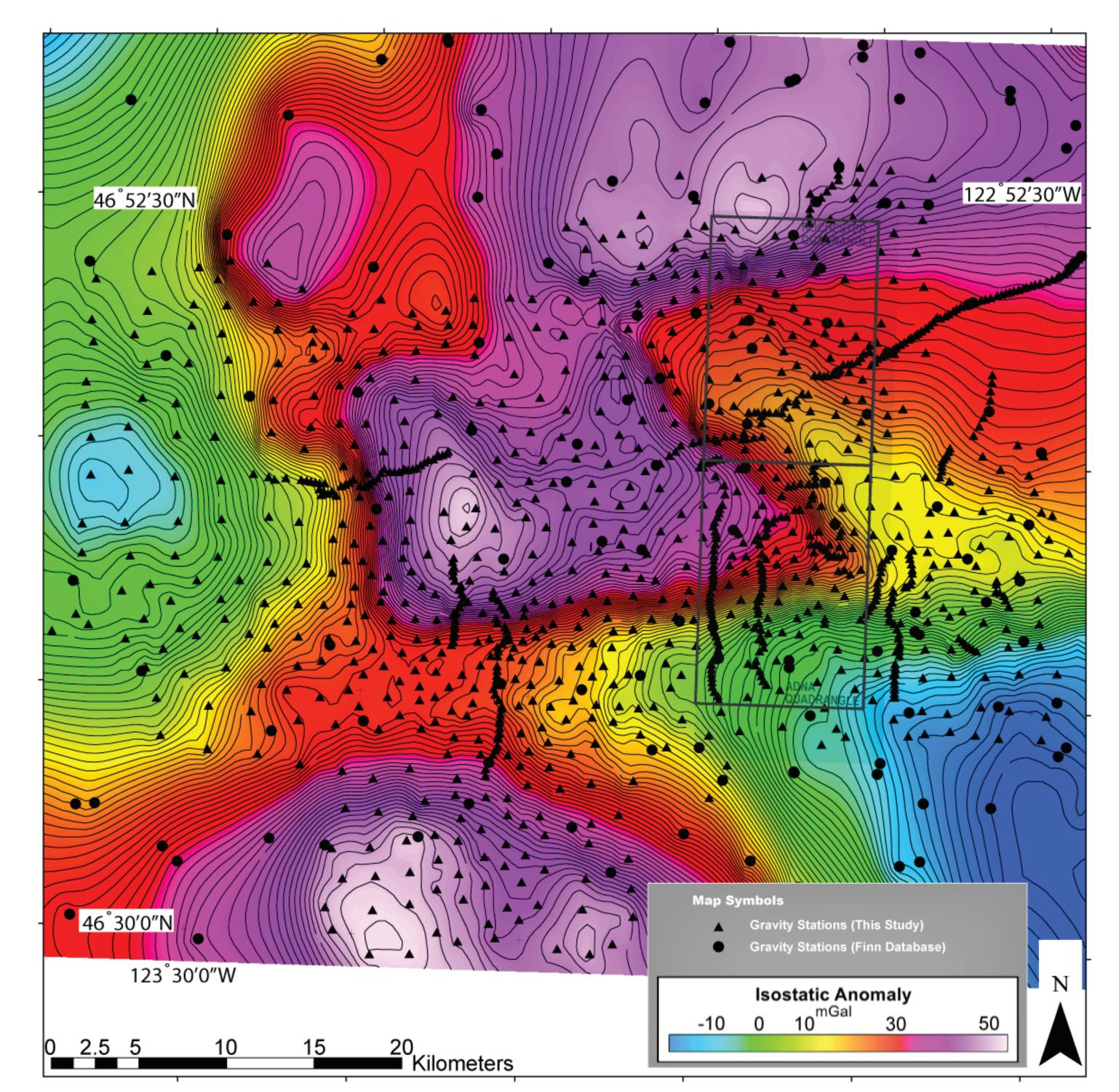


Figure 1. Location of newly collected gravity stations (this study) with previously collected gravity stations from Finn and others (1991) over isostatic gravity anomaly with 1 mgal contours. The Lincoln Creek uplift is in the central portion of the figure, representing a gravity high as a result of exposed, dense, Eocene Crescent Formation basalt. The gravity lows west of the uplift represent Miocene continental and marine sediments. To the southeast of the Adna quadrangle lies the deep sedimentary Chehalis basin, represented by a gravity low. To the north of the Lincoln Creek uplift you see the gravity highs of the Southern Black Hills, composed of dense Eocene Crescent Formation.

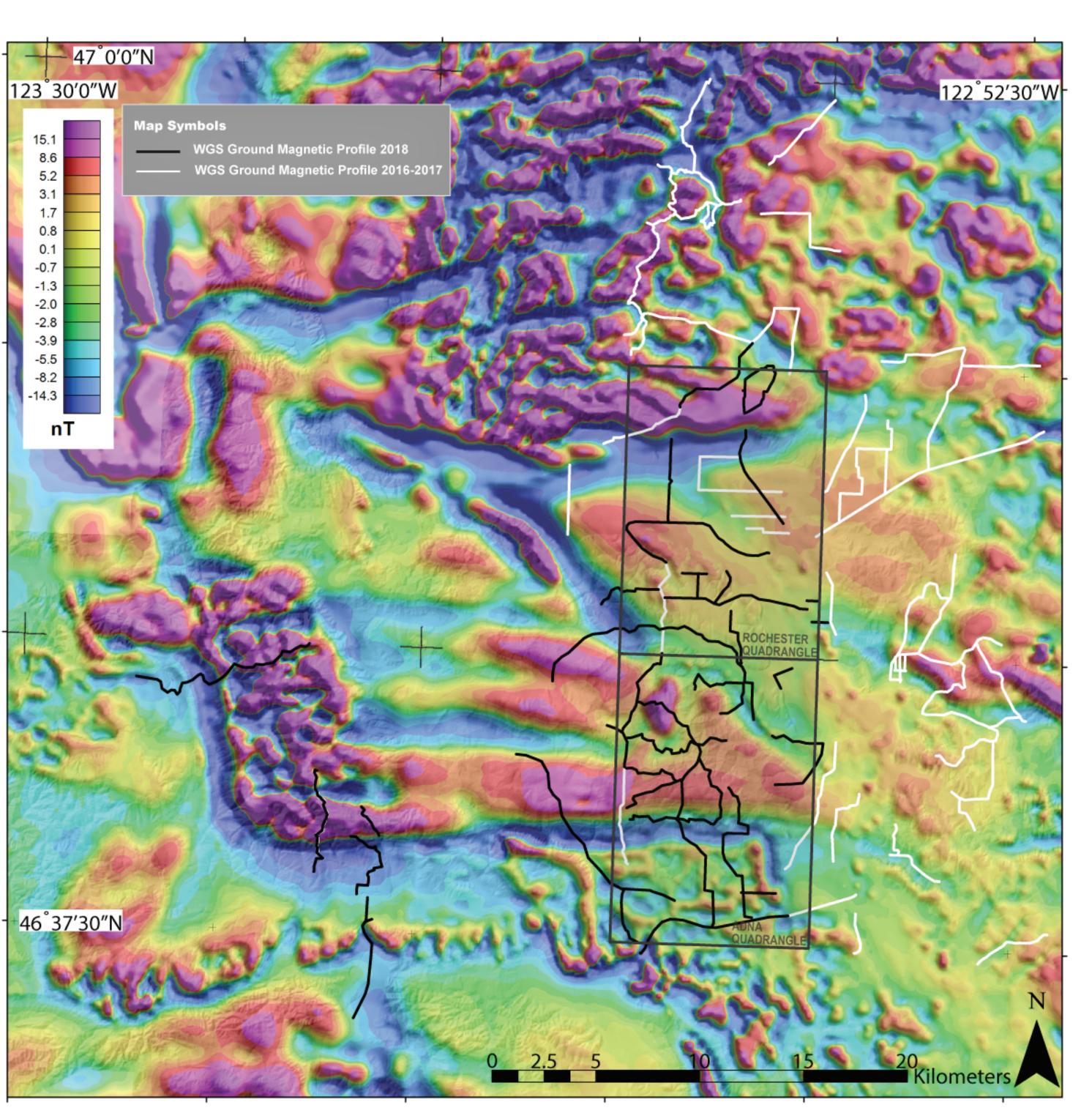


Figure 3. Unprocessed ground magnetic profiles collected by WGS, this study (black lines), with previously collected processed WGS ground magnetic profiles on a reduced-to-pole, residual (50 m), aeromagnetic anomaly map from Blakely and others (2016). The Doty fault system is marked by a strong aeromagnetic anomaly, trending east-west through the south-central portion of the Adna quadrangle. The Scammon Creek fault is marked by a prominent northwest-southeast trending anomaly through the northern portion of the Adna quadrangle to just west of the Rochester quadrangle. Southwest of the Scammon Creek fault and north of the Doty-Salzer Creek fault system appears to be a magnetic high likely indicating that the magnetic Crescent Formation is uplifted due to compressional forces. The Southern Black Hills fault (informal) appears to trend west-southwest and east-northeast through the northern portion of the Rochester quadrangle. The Kopiah fault is not easily identified in the magnetics, suggesting minimal

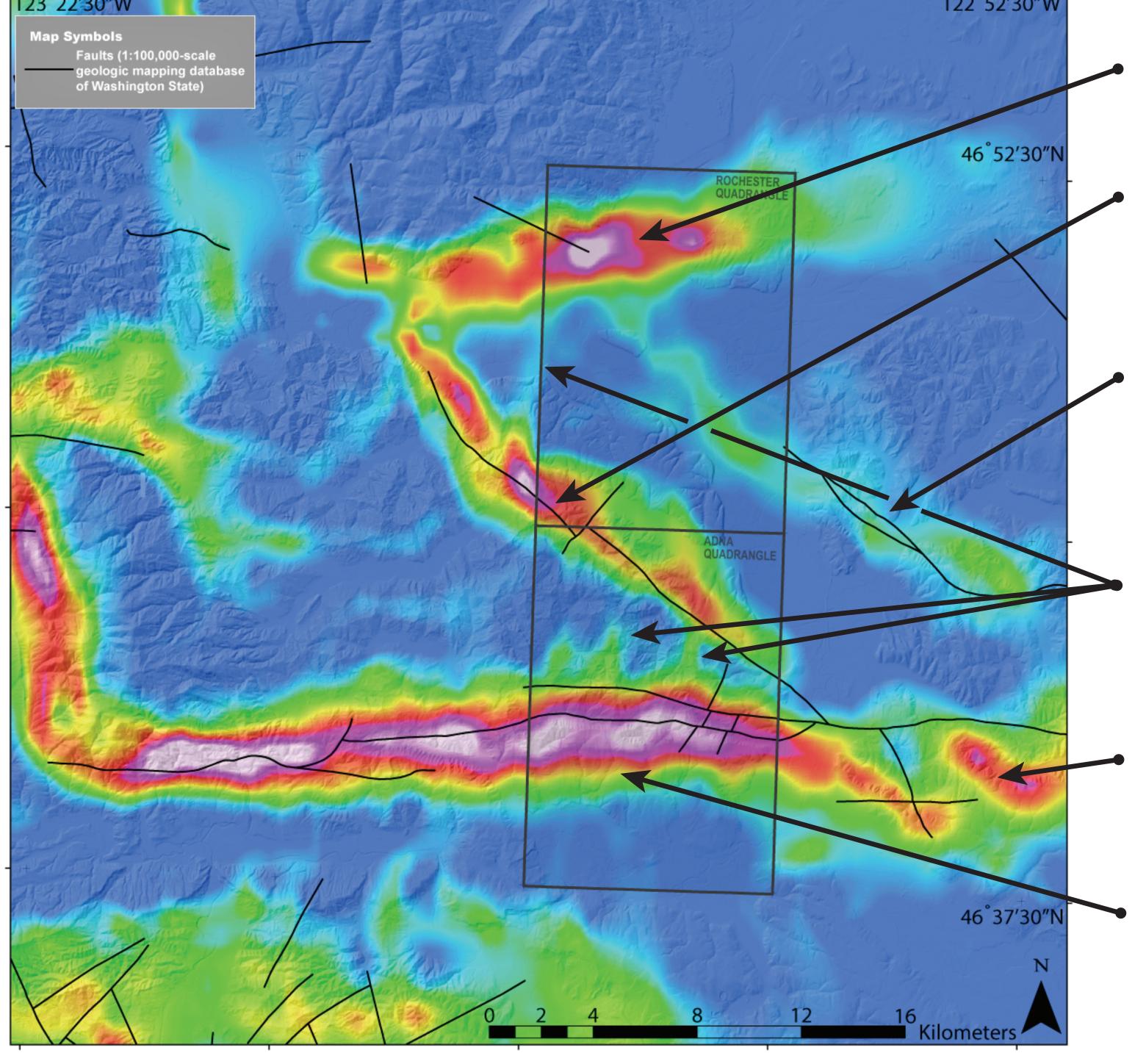


Figure 2. Faults from the 1:100,000-scale geologic mapping database of Washington State on an image of the horizontal gravity gradient from this study. Warm colors mark area where gravity changes rapidly across a horizontal area. Horizontal gravity gradients align with previously mapped faults

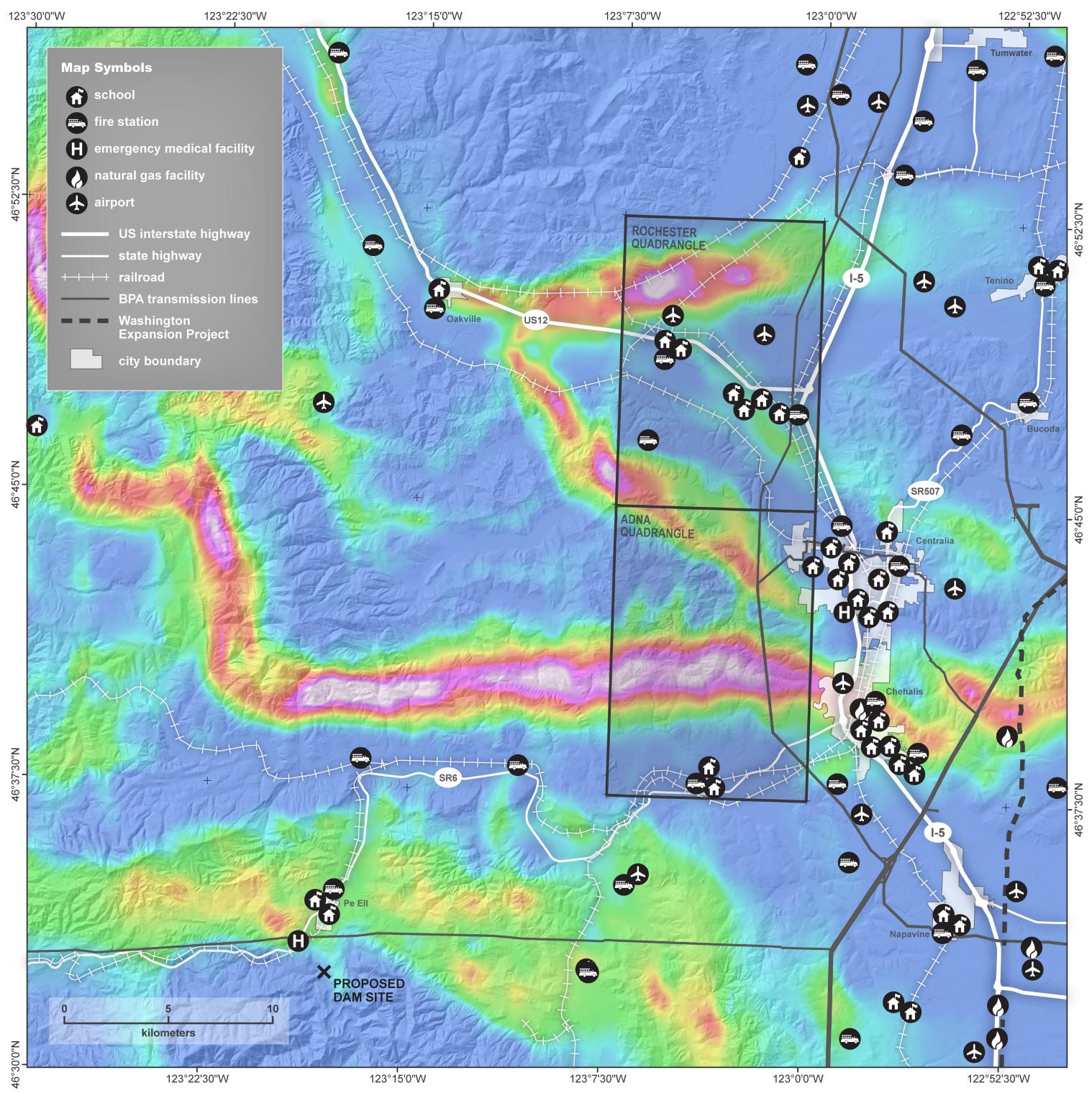


Figure. 4. The location of a proposed dam site and other sensitive infrastructure on an image of the horizontal gravity gradient from this study. The I-5 corridor runs normal to

the gradient of the Doty-Salzer Creek fault system. The fault potentially poses a risk to this vital economic corridor.

III. Local Faults

Southern Black Hills Fault (informal)

We infer this previously unmapped structure to be a fault due to the similarity of its magnitude of horizontal gravity gradient, its linearity, and its orientation compared to that of the Doty and Scammon Creek faults.

Scammon Creek Fault

Northwest-striking, southwest-dipping, reverse fault (southwest side upthrown). Originally identified by Snavely and others (1958) as a down-to-the-northeast, normal fault. Based on current geologic mapping (this study), and recent mapping (Sadowski and others, 2018) and our interpretations of the geophysical patterns, we interpret the Scammon Creek fault as a southwest up reverse fault in the current tectonic

Kopiah Fault

Northwest-striking, dextral reverse fault with a short, blind, west-striking, north-dipping segment with reverse-to-thrust motion. The poorly exposed fault was originally identified from changes in bedding orientation within the Skookumchuck Formation. Recent geologic mapping (Polenz and others, 2018; Sadowski and others, 2018) and our geophysical study support the existence of a fault. A consistent trend in the gravity near the mapped fault suggests that the fault continues farther to the northwest than previously mapped (Snavely and others, 1958; Logan,

Possible Cross Faults?

Northeast-southwest-orientated lineaments in the horizontal gravity gradients on either side of the Scammon Creek fault hint at possible complex interaction between the Scammon Creek fault and the Salzer and Southern Black Hills faults. Anomalous valley floor morphology in the Tertiary sediments northeast of the Scammon Creek fault adds geologic field evidence for one such cross fault between the Scammon Creek and the Southern Black Hills fault.

Salzer Creek Fault

West-striking, steeply north(?)-dipping, oblique-slip reverse fault with sinistral movement. Recent geophysical surveys suggest that the basement is shallower north of the Salzer Creek fault and deeper south of the fault. The proximity and orientation of this fault to the Doty fault suggests a possible genetic relationship, and strain may transfer between the two structures east of the Adna quadrangle.

Doty Fault

West-southwest-striking, steeply to moderately north-dipping, reverse fault with en echelon southward bends. The fault geometry is supported by WGS geologic mapping and USGS seismic reflection profiles. Our geophysical study shows a broad horizontal gradient that suggests sub-parallel west-striking faults. Our study also suggests that the Doty fault is at least 34 km long and may extend farther east and west. Its activity is unknown (see poster T13I-0356 for additional details). Lidar has not yet led to recognition of active fault scarps along the Doty fault, and no offset has been recognized within the Logan Hill Formation (U/Pb dated at ≤1.68 Ma). However, Quaternary drainages do align with mapped faults, suggesting structural control of its fluvial pattern.

IV. Geologic Hazard

We calculated the moment magnitude (Mw) of hypothetical earthquakes generated from the Doty fault. Geophysical analysis and geological observation allow us to estimate that the Doty fault has a length of 34 km. Assuming this fault could have a displacement similar to that of historical earthquakes on nearby faults that	Mw	Scalar Seismic Moment (N*m)	Shear Modulus (Gpa)	Displacement (m)	Rupture Length (m)	Rupture Depth (m)	Ruptur Area (m
	6.62	1.06×10^{19}	31.2	2	34,000	5,000	1.70 × 1
	6.82	2.12×10^{19}	31.2	2	34,000	10,000	3.40×1
share similar geometry and orientation (Seattle Fault, Tacoma fault), it is reasonable to estimate an anticipat-	6.94	3.18×10^{19}	31.2	2	34,000	15,000	5.10 × 1
ed displacement of around 2 m (Geist and Yoshioka, 2004; Washington Military Department, 2013).	7.02	4.24×10^{19}	31.2	2	34,000	20,000	6.80×1
	7.08	5.30×10^{19}	31.2	2	34,000	25,000	8.50×1

The crustal basement in the area consists of Eocene basalt of the Crescent Formation. Geist and Yoshioka (2004) reported a Crescent Formation shear modulus of 31.2 GPa. The depth of the Doty fault is unknown. This study calculates Mw for different depths, from 5 km to 25 km, which is the approximate depth to the subduction zone in this area. Using the equation by Shearer (2009)[$M_W = 2/3[\log_{10} M_0 - 9.1]$, we calculated the Mw of possible earthquakes on the Doty fault.

The activity of the Doty fault remains unresolved. The length of the fault suggests that a strong to major earthquake is possible. A shallow crustal earthquake could cause serious damage to the nearby communities (Fig. 4). The I-5 corridor serves as a main economic artery that connects Seattle and Tacoma, WA to Portland, OR (Fig. 4). Severing railroad lines and damaging bridges on I-5 would have serious economic impact. Nearby schools, hospitals, and fire stations could also suffer damage. Further work will be needed to understand possible effects on the proposed water-retention facility.

V. Conclusions Gravity and magnetic anomaly analy-

sis has proven to be effective at locating concealed faults in our study area.

The Doty fault, if active, could possibly generate a strong to major earthquake (Mw 6.6 to 7.1).

The Kopiah fault is longer than previously mapped and likely extends to the Southern Black Hills fault (informal) through the Rochester quadran-

VI. Moving Forward

Geophysical Work

- Finalize gravity reduction.
- Finish pre-processing ground magnetic data.
- Finish density measurements.
- Subsurface modeling using new data in Geosoft's Oasis Montaj.
- Finalize interpretations.
- Finalize publication in fall 2019

Geological Work

- Major and trace element chemical analysis is pending.
- Analysis of detrital zircons is pending.
- Luminescence samples from Quaternary terraces have been sent out to determine rates of uplift if possible.
- Analysis of macro/micro biostratigraphy samples is pending Radiocarbon analysis is pending.

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