

Probable surface ruptures along the San Juan fault in the recently-deglaciated northern Cascadia forearc

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Abstract Forearc crustal faults pose significant risks within the Cascadia subduction zone, and a wealth of new lidar data allow for their identification and characterization. In the northern Cascadia forearc, the E–W-striking, terrane-bounding San Juan fault (SJF) displays topographic lineaments that are more conspicuous in lidar imagery than those along other known active faults in the region, but it remains unresolved whether the fault has ruptured in large prehistoric earthquakes and poses a risk to the ~600,000 people living on southern Vancouver Island. We map a relatively continuous and linear set of 2–150 m high, north-facing scarps along the fault trace, but find limited evidence of clear offset of Quaternary sediment that would be diagnostic of neotectonic activity. An alternative hypothesis is that the scarp formed due to differential glacial erosion of the distinct bedrock units juxtaposed by the fault. We argue against this hypothesis using Schmidt hammer measurements, which reveal harder rocks on the lowered (north) side of the scarp than on the raised (south) side, suggesting that south-side-up motion is tectonically driven. In combination with the vertical scarps, curved channel offsets are consistent with dextral-reverse slip, which would invert the sinistral offsets accrued by the fault in its early history. We also use electrical resistivity tomography to investigate one prominent, uphill-facing scarp. Disruption beneath the scarp to otherwise continuous subsurface structure is further evidence of late Quaternary rupture. Though somewhat equivocal, these results strongly motivate future paleoseismic investigations along the SJF.

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1 Introduction

Crustal faults within subduction zone forearcs can host large, shallow earthquakes that pose significant risks to nearby populations. The damaging April 2016 Kumamoto, Japan and November 2016 Kaikoura, New Zealand earthquakes are recent examples of these types of events (Hata et al., 2016; Hamling, 2020). In the northern Cascadia forearc of Vancouver Island and northern Washington State, characterizing such faults is made challenging by a Global Navigation Satellite System (GNSS) velocity field dominated by loading of the megathrust (Figure 1), by low rates of seismicity (Figure 2a), by dense vegetation which often obscures fault-related geomorphology, and by late Quaternary glacial scouring that has reset the landscape and removed previously-existing tectonic landforms. Nevertheless, paleoseismic trenching guided by newly-available airborne lidar imagery has led to recent discovery of Holocene surface ruptures along several Vancouver Island faults (Figure 2a) including the terrane-bounding Leech River fault (Morell et al., 2017, 2018; Harrichhausen et al., 2021), the XEOLXELEK–Elk Lake fault (pronounced *hul-lakl-lik*, Harrichhausen et al., 2023), and the Beaufort Range fault (Lynch et al., 2025). This follows similar work in neighbouring Washington along

the Darrington–Devil’s Mountain, Utsalady Point, Birch Bay, Sandy Point, Southern Whidbey Island and Lake Creek–Boundary Creek faults (Figure 2a; Johnson et al., 1996, 2004; Kelsey et al., 2012; Personius et al., 2014; Nelson et al., 2017).

Active upper plate faults across northern Cascadia share common ~E–W and ~SE–NW trends and strike-slip to oblique-transpressional kinematics, but how they accommodate deformation of the forearc remains an open question. The Juan de Fuca plate subducts northeastwards at ~4 cm/yr beneath North America (Figure 1, DeMets et al. (2010)), with the northern Cascadia forearc experiencing elastic interseismic strain induced by partial coupling of the subduction zone interface (e.g., Savage and Lisowski, 1991; Dragert and Hyndman, 1995; Miller et al., 2001) and permanent strain from subduction zone coupling and far-field tectonic forces (e.g., Delano et al., 2017; Finley et al., 2019; Harrichhausen et al., 2024; Nelson et al., 2017). Correcting the GNSS velocities for modelled elastic strain due to megathrust locking shows that southern Vancouver Island and northern Washington are undergoing margin-parallel shortening (Figure 1b), but there are too few GNSS stations and the associated uncertainties are too large to resolve strain rates across individual faults (Mazzotti et al., 2011; McCaffrey et al., 2013). The limited available focal mechanisms for small to mod-

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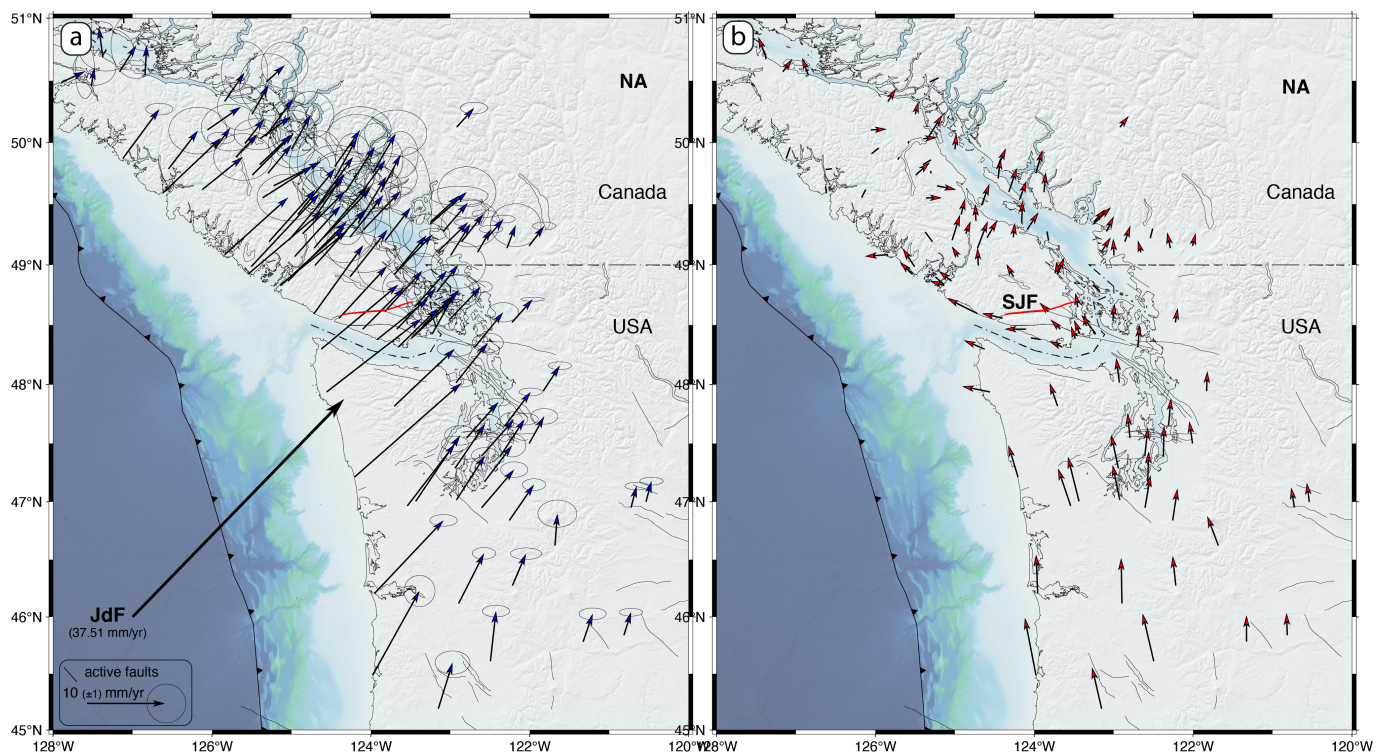


Figure 1 a) Global Navigation Satellite System (GNSS) velocities for northern Cascadia relative to stable North America (ITRF2000) with 95% confidence ellipses, from Mazzotti et al. (2011). Black lines are active upper plate fault traces from Bahavar et al. (2025); the red line is the San Juan fault. Motion of the Juan de Fuca (JdF) plate relative to North America (NA) is from the EarthScope Consortium's GAGE plate motion calculator (<https://www.unavco.org/software/geodetic-utilities/plate-motion-calculator/plate-motion-calculator.html>) for 46° N and 127° W using the MORVEL 2010 model (DeMets et al., 2010). b) Residual GNSS velocities after correction for interseismic strain accumulation along plate-boundary faults, from Mazzotti et al. (2011). Residual strain shows margin parallel shortening across southern Vancouver Island.

erate earthquakes across southern Vancouver Island predominantly have right-lateral, right-lateral oblique, and reverse nodal planes along W–E to NW–SE trends (Brocher et al., 2017), consistent with NW–SE- to N–S-oriented maximum horizontal compressive stresses (Figure 2a; Balfour et al., 2011). Figure 2b shows a conceptual model for how margin-parallel shortening could be accommodated by such structures via vertical-axis block rotations, consistent with paleomagnetic, geologic, and geodetic data that show counterclockwise rotation of the Cascadia forearc north of the strait of Juan de Fuca (Miller et al., 2001; McCaffrey et al., 2007; Prothero et al., 2008; Wells and McCaffrey, 2013; Finley et al., 2019). Regional active faults that fit this model include the Leech River fault (Harrichhausen et al., 2021; Morell et al., 2018) and the North Olympic fault zone (Nelson et al., 2017; Schermer et al., 2021). However, there are other active faults along similar trends with different kinematics, including the left-lateral Utsalady Point fault (Johnson et al., 2004), the Southern Whidbey Island reverse fault (Johnson et al., 1996), and a network of steeply-dipping structures beneath the Salish Sea tentatively interpreted as left-lateral based on offset bathymetry (Greene and Barrie, 2022). These apparent contradictions strongly motivate the identification and characterization of other active faults in the forearc as a means to understand regional neotectonics.

The San Juan fault (SJF) is a notable candidate whose

earthquake potential is important to address because of the considerable risks to Shawnigan Lake (population ~10,000) directly along the fault trace and to Victoria (~400,000), Nanaimo (~90,000), Cowichan Valley (~84,000) and other towns along Vancouver Island's populous Trans-Canada Highway corridor. The SJF transects southern Vancouver Island from Port Renfrew on the west coast to Saanich Inlet ~80 km to the ENE and can be structurally subdivided either side of its intersection with the NW–SE-trending Survey Mountain fault (Figure 2c). The longer (~50 km), ~E–W-trending western section of the SJF occupies the prominent San Juan river valley ~10 km north of and sub-parallel to the well-studied Leech River fault (Morell et al., 2017; Li et al., 2018; Harrichhausen et al., 2021), and brings the Wrangellia terrane into contact with accretionary prism and mélange rocks of the Pacific Rim terrane. The shorter (~30 km), ~ENE–WSW-trending eastern section of the SJF partially occupies the upper Koksilah river valley, and separates the intrusive Mesozoic West Coast Crystalline Complex from the extrusive Jurassic Bonanza Group of the Wrangellia terrane (Harrichhausen et al., 2022). There are numerous interpretations of the timing and kinematics of slip along the SJF, including reverse or oblique left-lateral faulting accommodating late Mesozoic to early Cenozoic accretion of the Pacific Rim terrane to Wrangellia (Rusmore and Cowan, 1985; Brandon, 1989), or re-activated left-lateral

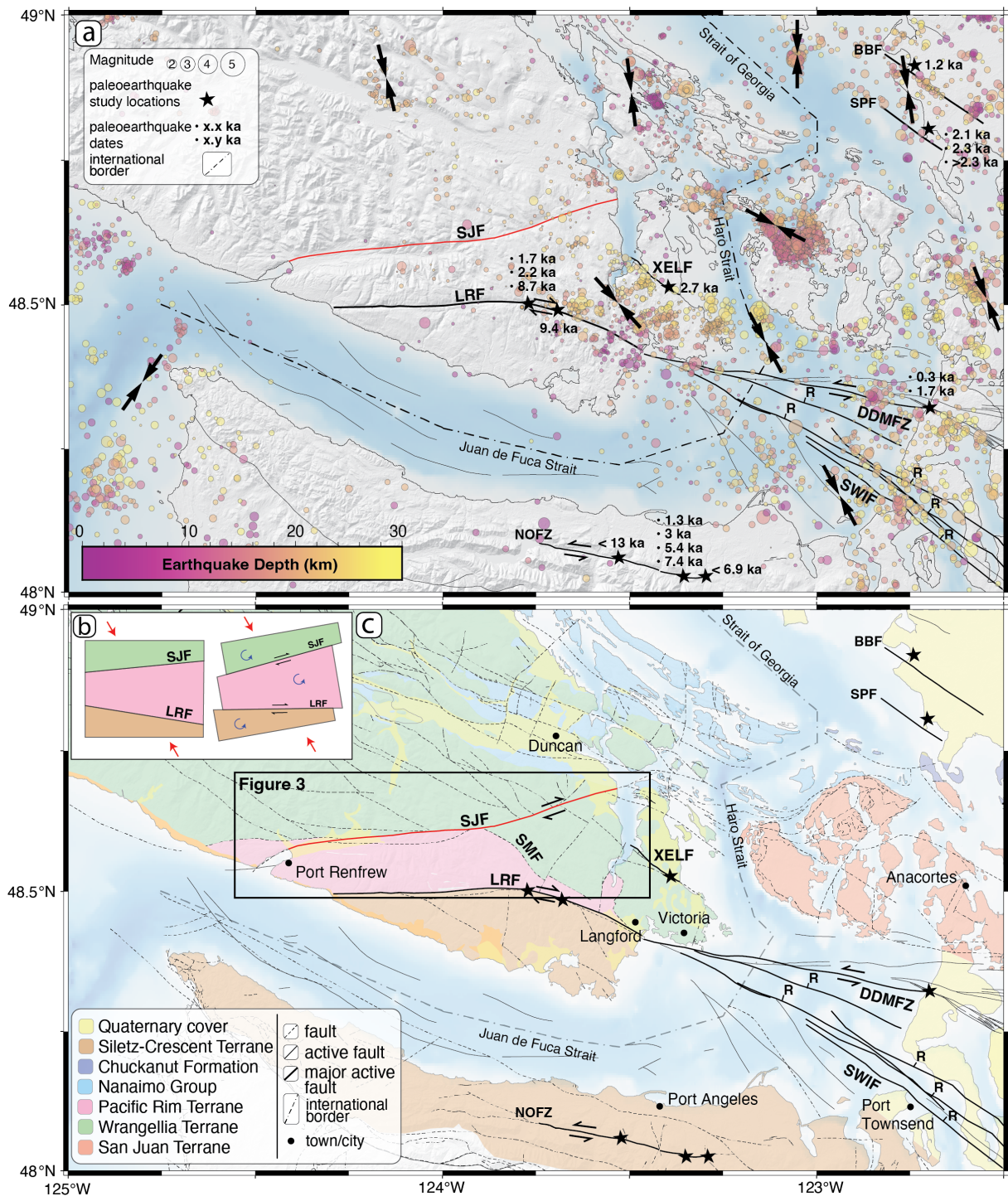


Figure 2 a) Crustal seismicity, stresses, and active faults of southern Vancouver Island, with the San Juan fault (SJF) marked in red. Circles are shallow (0–30 km) earthquakes for the period 1985–2024, coloured by focal depth (Natural Resources Canada, 1985). Black arrows are regional S_{Hmax} directions (Balfour et al., 2011). Stars are paleoseismic study sites with earthquake ages from the literature. Other active faults are labelled as follows: BBF = Birch Bay Fault (Kelsey et al., 2012), DDMFZ = Darrington-Devil’s Mountain Fault Zone (Johnson et al., 2004; Personius et al., 2014), NOFZ = North Olympic Fault Zone (Nelson et al., 2017; Schermer et al., 2021), LRF = Leech River Fault (Morell et al., 2018; Harrichhausen et al., 2021), SPF = Sandy Point Fault (Kelsey et al., 2012), SWIF = Southern Whidbey Island Fault, XELF = XEOLXELEK–Elk Lake Fault (Harrichhausen et al., 2023). b) Cartoon with simplified geology and fault traces showing how margin-parallel shortening may be accommodated on southern Vancouver Island via right-lateral fault slip and counterclockwise, vertical-axis block rotation. c) Simplified geology of southern Vancouver Island, adapted from Cui et al. (2017). Faults and geology in Washington State are from the Washington Geological Survey (2022).

faulting during Eocene accretion of the Siletz terrane (England and Calo, 1991) as supported by ~60 km of apparent left-lateral offset to Wrangellia terrane rocks

(Muller, 1977; DeBari et al., 1999). Recent work by Harrichhausen et al. (2022) confirmed that the SJF accommodated left-lateral slip during the Eocene, which was

temporally and kinematically consistent with the formation of the Cowichan fold and thrust belt and accretion of the Siletz ocean island plateau. The SJF crosses a landscape affected by several glaciations throughout the Quaternary, though evidence of antecedent ice cover has largely been scoured from the landscape by the most recent (Marine Isotope Stage 2) Fraser glaciation (Jackson et al., 2024). This began around 19,000 yr BP (Alley and Chatwin, 1979) as the Cordilleran ice sheet spread southwards, reaching a maximum at $\sim 14,000$ ^{14}C yr BP (Clague and James, 2002; Clague and Ward, 2011). This was followed by rapid de-glaciation, the ice sheet diminishing into a series of valley glaciers, which produced streamlines, drumlins, and scours before fully retreating from the area by $\sim 12,000$ ^{14}C yr BP (Alley and Chatwin, 1979; Clague and James, 2002). Such landforms are evident both along and across the SJF trace in the San Juan and Koksilah River valleys.

The proximity of the SJF to other known active forearc faults and its sharp, linear trace along a pre-existing structure favourably-oriented for reactivation (Figure 3a) support the hypothesis that it is active, but no convincing evidence of such reactivation has been found. Here, we test this hypothesis using recently acquired airborne and drone lidar imagery, data that have proven highly effective for mapping active faults in other densely-vegetated parts of the northern Cascadia forearc. Examination of lidar data along the mapped SJF trace reveals a sharp, continuous topographic lineation cutting through bedrock on the northern side of the upper San Juan valley. We do not observe the fault crossing any laterally-extensive, post-glacial, depositional landforms that would serve as unequivocal indicators of late Quaternary activity and help constrain the slip rate. However, we do map three sections of scarps that, with further testing, could be indicative of active faulting. The first of these is a N-facing scarp that crosses a glacially scoured surface 16 km west of Shawnigan Lake on the south side of the Koksilah River valley (Figures 3 & 4). The second is a smaller set of uphill-facing scarps that appear to offset colluvial sediments in the upper reaches of the San Juan valley. We further investigate the origin of these uphill-facing scarps by imaging the shallow subsurface using electrical resistivity tomography (ERT). The third section includes fault scarps within the Koksilah river valley; while these do not directly cross-cut glacial deposits, some drumlins appear to drape across the fault scarp, which could make them suitable sites for future geophysical work. On a more regional scale, we test whether these scarps could have been formed as a result of differential weathering or glacial scouring by using Schmidt hammer measurements of bedrock hardness on either side of the fault, a novel application within the Cascadia region that will strongly motivate future paleoseismic trenching.

2 Methods

2.1 High-resolution topography

To map the fault geomorphology, we collated all available airborne lidar datasets from the open access

provincial LidarBC portal, Capital Region District local government, and private collections of forestry companies. Collectively, these cover an area of $>1,000$ km^2 along the fault (Figure 3a) with an average point density of ~ 5 pts/ m^2 . We rasterized the ground returns to digital terrain models (DTMs) with a uniform cell resolution of 1 m for consistency, from which we derived hillshade, slope and topographic position index maps using QGIS software v. 3.28 (QGIS Association, 2018). Together, these were used as the basis for mapping topographic lineaments including fault scarps, sackungen, landslide scars, and glacial scours, measuring vertical separations across the fault scarps, and looking for evidence of lateral offset. We were aided in our interpretations by regional maps of surficial geology (Alley, 1975a,b; Senyk, 1975; Veness et al., 2024). In addition to our mapped lineaments, we also plot faults (black dashed lines on Figures 2–5) from the British Columbia Geological Survey's (BCGS) Digital Geology dataset (Cui et al., 2017). This province-wide integrated geological dataset is useful for identifying major structures and lithological changes. As this dataset was compiled from a range of mapping scales (1:50,000 to 1:250,000), structures and geological units can be misplaced when looking at the scale of local field sites. We include these data to highlight general structures and highlight where refinements could be made to the existing map.

Additionally, where we thought higher resolution topographic data would augment the airborne lidar in the analysis of particularly subtle tectonic landforms, we surveyed the fault with a novel drone lidar system described in Salomon et al. (2024). Here, ground returns of ~ 15 pts/ m^2 enable DTMs with raster resolutions of 0.5 m, four times finer than airborne equivalents (Supplemental Figures S1–S4). We conducted four drone surveys (Figure 4b), each targeting a feature of potential tectonic origin identified in coarser imagery. The UP-SCARP site is centred on an isolated uphill-facing scarp along the mapped SJF trace and very near an outcrop of a bedrock shear zone. The SLIDE dataset covers a suite of uphill-facing scarps that we initially interpreted as slope instabilities. The GSS dataset includes a glacially scoured surface cut by a ~ 6 km long, ~ 30 m high scarp. The EAST dataset includes several streams which appear offset in satellite images.

2.2 Fault scarp measurements

Scarps of suspected tectonic origin at the UPSCARP and GSS sites were further analysed using the Monte Carlo Slip Statistics Toolkit (MCSST, Wolfe et al., 2020), which makes use of the Monte Carlo method for calculating dip slips developed by Thompson et al. (2002). Scarp-perpendicular topographic profiles were constructed at intervals along the fault trace (yellow, blue and green lines on Figures 4 & 5), and vertical separation was estimated by projecting the hanging and foot wall slopes to the fault and measuring their vertical offset. We then applied a Monte Carlo approach to estimate dip-slip and its uncertainty, through sampling allowable ranges in fault dip, fault position on the scarp, and the topographic surfaces of the hanging and footwalls. Fault

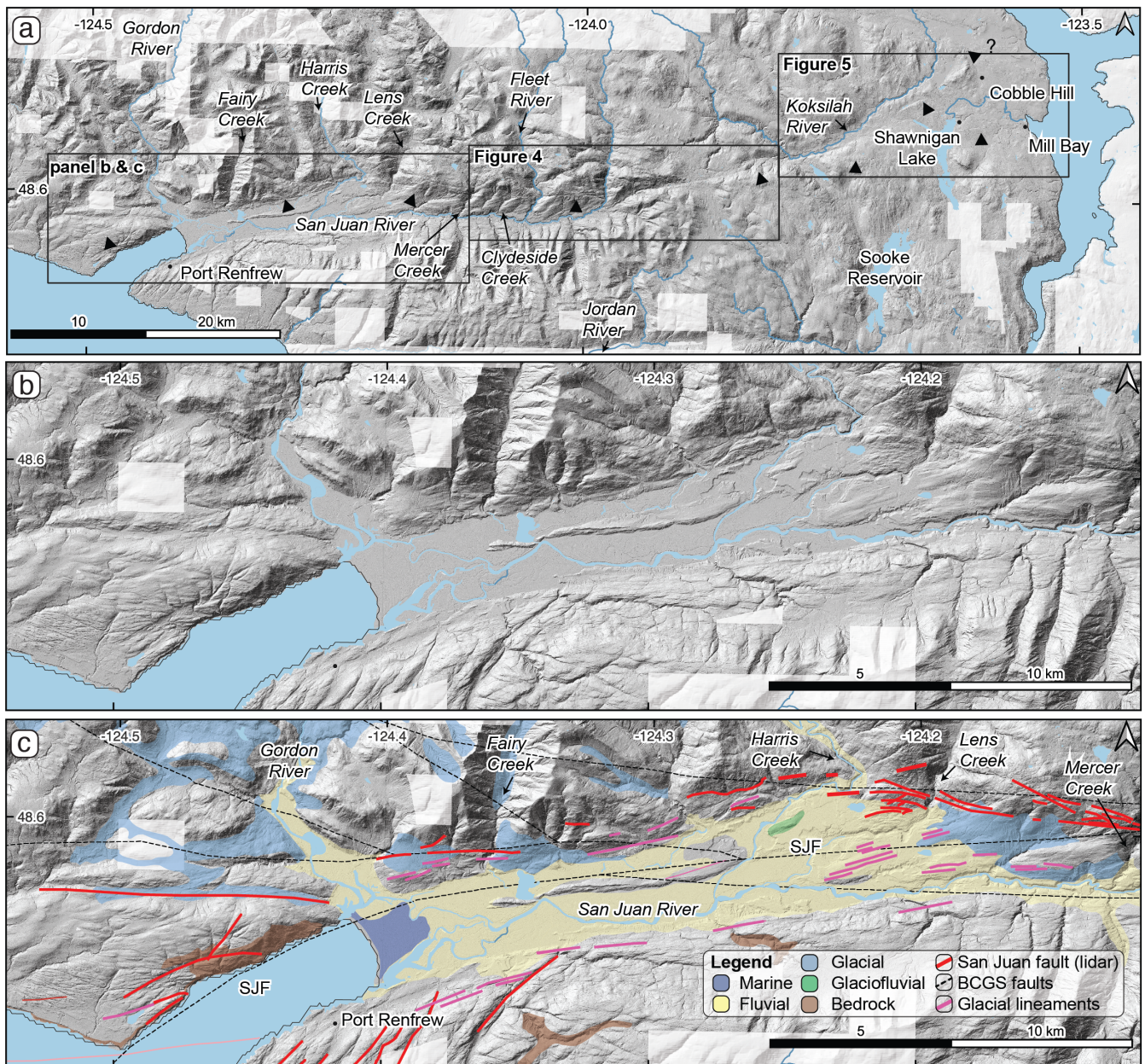


Figure 3 a) Overview of lidar coverage (high-contrast hillshaded areas) along the San Juan fault (black triangles). The western, central and eastern boxes show the extents of panels b and c, Figure 4, and Figure 5, respectively. b) Uninterpreted hillshaded lidar along the western SJF in the lower San Juan River valley. c) Simplified surficial geology (coloured by sedimentary source with uncoloured areas mapped as colluvium) with our interpreted fault traces (red) and glacial lineaments (pink) as well as geological faults mapped by Cui et al. (2017) (black dashed lines). Surficial geology is modified from Alley (1975a,b) and Veness et al. (2024).

dip and position were each assigned a trapezoidal uncertainty distribution, with the wide base of the trapezoid containing all possible values and the narrow top including the likeliest range. Because the fault trace cuts linearly across steep, undulating topography, we assigned a steep dip angle ranging between 70° N and 70° S with the highest probability between 80° N and 80° S. At the UPSCARP site, we also used the dip estimated from ERT profiling (see below), but found no substantial difference in the dip-slip calculated. For the fault position, we allowed the fault tip to sample the entire width of the scarp and assigned the highest probability to the middle third. Final uncertainties in both vertical separation and dip-slip rarely exceed a few me-

tres, except for a few profiles in which hanging and foot wall slopes are markedly different.

The fault scarp measurements were categorized according to the geomorphic equivalence of the surfaces on either side of the scarp. If the surfaces were interpreted to be equivalent, the dip-slip was measured. In cases where they were not equivalent, apparent dip-slip was measured. To allow for easy identification, we have coloured dip slip profiles yellow, and apparent dip slip profiles blue.

2.3 Schmidt hammer rock hardness measurements

To explore whether observed scarps along the central SJF might have formed via differential erosion as opposed to recent earthquake activity, we used a Schmidt hammer to measure the hardness of bedrock exposures on either side of the fault. Initially developed for testing the strength of concrete, Schmidt hammers have been used by geologists to take in-situ, non-destructive measurements of material hardness for use as a proxy for erosive resistance, degree of weathering, or exposure age (Stahl and Tye, 2020; Matthews and Winkler, 2022) and may prove useful for studying cryptic faults in recently glaciated terrain. We used an N-type hammer that delivers a controlled 2.207 Nm blow when pressed onto a surface; the resulting rebound is recorded as an R-value, a unitless measure of compressive strength (Matthews and Winkler, 2022).

We targeted each of the three major lithologies found along the central SJF. (1) The Leech River schist is a metapelitic schist containing metapsammitic layers (Seyler et al., 2022), interpreted to have formed from a turbidite sequence near a continental margin and a spreading ridge (Muller, 1977; Fairchild and Cowan, 1982) with a maximum depositional age of 103 Ma (Groome et al., 2003). (2) The Survey Mountain volcanics contain greenschist to amphibolite facies, green, weakly foliated, fine-grained volcanic flows with phenocrysts of epidote, chlorite and actinolite (Fairchild and Cowan, 1982). Both the Leech River schist and Survey Mountain volcanics make up the Leech River Complex of the Pacific Rim terrane (Harrichhausen et al., 2022). (3) The Bonanza Group, of the Wrangellia terrane, is composed of volcanics (basaltic andesite-rhyolite) and interbedded sediments which contain early Jurassic fossils (Andrew and Godwin, 1989). Descriptions of the units observed during fieldwork can be found in Table 1. Since there are limited natural bedrock outcrops within the study area, most of our measurements were from near-vertical surfaces exposed in road cuts (see Supplemental Figure S19 for example photographs). We chose solid, unfractured sections of outcrop, avoiding loose fragments that might respond differently to impact, as well as fresh, smooth surfaces without lichen cover and cleaned of soil or dust. We oriented the hammer at a perpendicular angle to the outcrop surface; for schistose rocks, we measured rebound values in two orientations, both parallel and perpendicular to foliation. We collected 5 rebound values for each measurement site from which we calculated the mean. Instrument drift during the measurement period was controlled by calibrating the hammer on a steel test anvil (R-value 80) before and after use.

2.4 Electrical resistivity tomography

To investigate the origin of uphill facing scarps at the UPSCARP site, we used electrical resistivity tomography (ERT) to profile the shallow subsurface resistivity structure (e.g. Harrichhausen et al., 2023; Improtta et al., 2010; Mojica et al., 2017). Using an Advanced Geosciences Inc. (AGI) MiniStingTM R1 resistivity me-

ter with a 28 electrode cable and a dipole-dipole configuration (Supplemental Figure S5), we collected two, partially co-located profiles perpendicular to and centred on the uphill-facing scarp. The first, coarser resolution profile used two overlapping 81 m-long lines (total length ~120 m) with an electrode spacing of 3 m, which yielded a resolvable depth of approximately 15 m at the profile centre. The second, finer resolution line reoccupied the central part of the first, with an electrode spacing of 1.5 m and a total length of ~40.5 m yielding a resolvable depth of ~8 m. Electrode coordinates were surveyed using a Trimble R12 system set up in a base and rover configuration. The apparent resistivity data were inverted using a damped least-squares method within AGI's EarthImager 2D software (Advanced Geosciences Inc., 2009). The inversion was iteratively repeated up to 15 times, or until the root-mean-square misfit between the modelled and measured values was lower than 5%. Resistivity data files are provided in Data Files C1–C4.

3 Results

3.1 Fault mapping

We mapped >80 discrete fault scarps and topographic lineaments from north of Port Renfrew on the west coast to near Mill Bay on the east coast of the island (Figure 3a). These cross a total of 18 streams visible in the lidar data including several within the EAST drone survey footprint, but while we observe cryptic evidence for right-lateral deformation of some of these channels (see below and Section 4.2), lateral offsets are insufficiently sharp to be quantifiable via back-slipping and so our measurements focus on the dip-slip component. Below, we summarize our observations, working from west to east. Hillshades at 1 m resolution along the entire fault length are included in the supplemental data repository.

West of Port Renfrew, field mapping by Harrichhausen et al. (2022) suggests that late Eocene–early Oligocene Carmanah Group marine clastic sediments unconformably overlie the SJF, implying minimal activity since the Eocene. The lidar data support this interpretation, with only sporadic, bedrock-associated lineaments. A more pronounced uphill-facing scarp emerges east of Fairy Creek, with an apparent offset of ~10 m (Figure 3c). Where it intersects the fault trace, Fairy Creek changes from a southward to westward flow direction, before turning southwards again 250 m past the mapped fault. In the context of similar deflections further east (described below), we interpret this as tectonic. Between Fairy and Harris Creeks, we map a broad (<1 km) zone of deformation with short, discontinuous lineations and generally north-facing scarps extending northwards from just above the valley floor (Figure 3c). Between Harris Creek and Lens Creek, there are several large (~1–10 m), curvilinear, uphill-facing scarps at a prominent fault bend. West of this inflection point mapped features generally trend ENE, while east of it they trend ESE before gradually curving back towards ENE east of Mercer Creek (Figure 4a, b).

East of Mercer Creek, the main fault can be traced

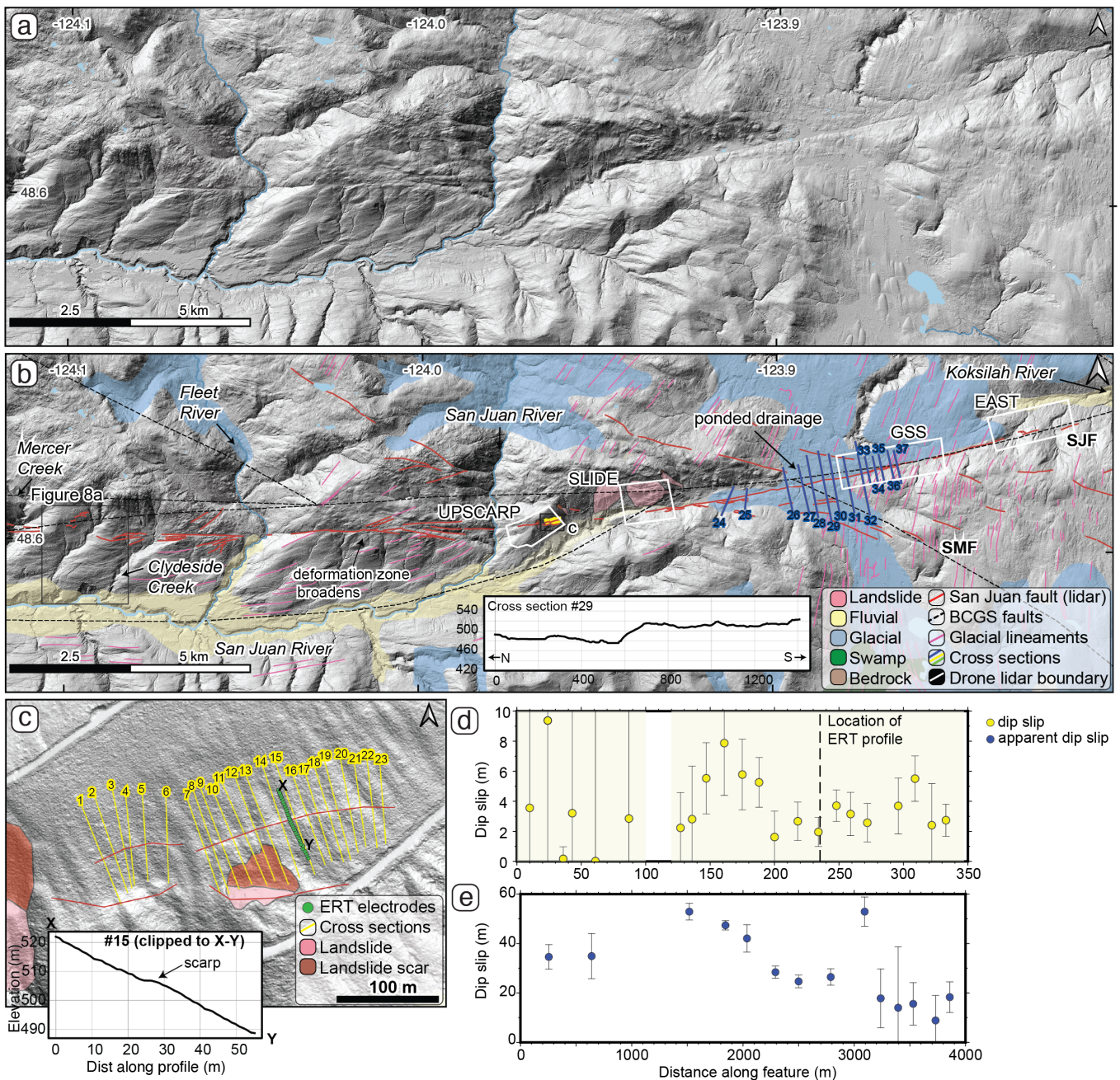


Figure 4 a) Uninterpreted hillshaded lidar along the central San Juan fault (map extents shown in Figure 3a). b) Simplified surficial geology (coloured by sedimentary source with uncoloured areas mapped as colluvium) with our mapped fault traces (red) and glacial lineaments (pink) as well as geological faults from Cui et al. (2017) (dashed black lines). Blue lines mark topographic profiles used in panel (e) to measure apparent dip slip, with an example profile shown in the inset. White polygons indicate finer-resolution drone lidar surveys, labelled UPSCARP (uphill-facing scarp), SLIDE (several uphill-facing features associated with some slope instabilities), GSS (glacially scoured surface), and EAST (several channels which appear offset in aerial imagery). Surficial geology is modified from Alley (1975b); Senyk (1975); Veness et al. (2024). Note: NW trending lineaments visible in the hillshade south of SLIDE are likely the bedrock structural grain of the Leech River Schists. c) Zoom-in of the UPSCARP site. Yellow lines are topographic profiles used to estimate dip-slip across the uphill-facing scarp (see panel d), with an example profile shown in the inset. Green points are ERT electrode locations used in Figure 7. d) Dip-slip estimates across the uphill-facing scarp, with ± 2 standard deviation error bars. The location of the ERT profiles is marked by the dashed line. e) Apparent dip-slip across the scarp crossing the glacially scoured surface, with ± 2 standard deviation error bars (profile locations in panel b). Since there is a change in geology across this scarp, these measurements relate merely to the scarp height and do not necessarily record tectonic offset of any given age.

more continuously halfway up the northern side of the San Juan valley, with a prominent lineation and secondary faults forming an approximately 250 m-wide de-

formation zone (Figure 4a, b). East of Clydeside Creek the scarp becomes consistently N-facing, and east of Fleet River the deformation zone broadens to ~ 500 m.

Surficial material in this area is mapped mainly as a thin veneer of colluvium, although the fault may pass through some fluvial sediments where it crosses Fleet River. Though this central SJF section crosses numerous secondary channels and interfluvies at high angles, we do not observe any sharp, lateral offsets. However, several of these channels (e.g. Mercer Creek, Clydeside Creek, Fleet River) do change from southerly to more westerly flow directions close to where they cross the mapped fault trace, before switching back again shortly afterwards to create an overall arctangential deflection pattern consistent with right-lateral deformation. This will be discussed further in Section 4.2.

Of particular interest along this central SJF section is the UPSCARP site, where an isolated, uphill-facing scarp disrupts a steep, S-facing slope with colluvial cover overlooking the upper reaches of the San Juan valley (Figure 4a, b). This feature is quite distinct from the swarms of interconnected uphill-facing scarps found both to the east (the SLIDE site at the San Juan–Koksilah drainage divide) and west (between Mercer Creek and Clydeside Creek) and which we interpret as sackungen caused by slope instability (see Section 4 for further discussion). At UPSCARP, we extracted 26 densely-spaced topographic profiles of the scarp from which we estimated dip-slip (Figure 4c and Supplemental Figures S6–S9). The main set of profiles (#7–#23) yielded a mean dip-slip of 3.6 m (up to the south) with a range of 0.1–7.7 m (Figure 4d); profiles #1–#6 across a tentative western scarp extension had large error bars and were excluded from this calculation. There are two landslides located south of the uphill-facing scarp (Figure 4c), whose potential relation to the fault is discussed in Section 4.

Further east, the main fault can be traced continuously across the drainage divide with the upper Koksilah valley, where at the GSS site ~15 km west of Shawnigan Lake it forms a conspicuous N-facing scarp cutting across a glacially scoured surface. Since this surface is described as a >1 m-thick blanket of glacial till (Senyk, 1975), we identified it as one of the prime locations for assessing late Quaternary fault activity. For ~4 km along strike, the N-facing fault scarp crosses a field of NNE–SSW-oriented scours and drumlins with peak-to-trough relief of ~1–2 m indicative of southward ice flow (Figure 4). However, perhaps because the change in slope likely affected the direction of ice flow, no single scour or drumlin can be correlated across the fault, depriving us of any means to estimate lateral offset since the last glaciation. Fourteen fault-perpendicular topographic profiles (Figure 4b) yielded apparent dip-slip of 8–52 m with a mean of 30 m (Figure 4e and Supplemental Figures S10–S12). The wide range in apparent dip-slip reflects how slopes on either side of the fault are unlikely to be correlative, with undulating topography on the southern side of the fault making it hard to pick the scarp extents, particularly for profiles #33–#37. We discuss the significance of this offset in Section 4.

Moving east, the fault trace descends into the main Koksilah River valley where it outcrops discontinuously in bedrock on the southern valley slopes (Figures 4 & 5). At about Grant Lake, the fault trace splits, with a

large north-facing escarpment south of the river and a smaller south-facing bedrock scarp at the top of this escarpment (Figure 5). This section of several sub-parallel fault traces (Figure 5c) could be explained as a flower structure with primary and secondary faults facing in opposing directions. Thirteen profiles across the larger escarpments (Figures 5b and S13–14) yielded apparent dip-slip of 21–165 m and a mean of 92 m. However, with the Koksilah River running parallel to the escarpment, surfaces on either side of the fault may not be correlative, with the northern side consisting of fluvial terraces and the southern side scoured bedrock. Additionally, ten profiles drawn over the south-facing bedrock scarp (Figures 5c, S15–16) yielded apparent dip-slip of 4–22 m with a mean of 10 m. Further east, where the scarp becomes more diffuse and is potentially draped by glacial drumlins, it becomes possible once again to measure an offset within a single surface (Figure 5b, S17–18). Nine profiles across this diffuse scarp yield dip-slip of 21–56 m with a mean of 36 m (Figure 5d).

The fault zone widens further as it approaches Shawnigan Lake, with mapped lineaments along the southern branch continuing eastward towards Mill Bay and those along the northern branch curving northeastward towards Cobble Hill (Figure 5). There has been significant anthropogenic modification of the landscape east of Shawnigan Lake which makes it difficult to trace subtle topographic lineaments in this area, and where visible, fault traces are generally expressed as linear furrows with neither side clearly uplifted. Some of these southeast trending lineaments are along strike of the active XELF (Harrichhausen et al., 2023).

3.2 Schmidt hammer results

We focused our Schmidt hammer measurements on the central SJF because of its clear geomorphology and the relative ease of road access to suitable outcrops of all of the representative lithologies (Table 1). We calculated average R-values from 405 individual measurements at 81 sites, most of them along two ~N–S, fault-perpendicular transects, with the remainder distributed more broadly wherever outcrops were accessible (Figure 6a). Of the two most sampled lithologies, Survey Mountain volcanics yielded an average R-value of 49 from 32 sites and Leech River schist yielded an average R-value of 33 from 27 sites (Figure 6b). The Bonanza Group and Island Plutonic Group were measured at six and seven locations each with average R-values of 55 and 62, respectively. Lastly, we sampled the West Coast Crystalline complex in one locality, yielding an average R-value of 55.

In relation to the SJF trace, the north side mostly comprises extrusive igneous rocks of Survey Mountain and the Bonanza Group, combining for an average R-value of 54 (Figure 6b). Rocks to the south are mostly Leech River schist, with a few outcrops of Survey Mountain volcanics, together yielding an average R-value of 36, significantly lower than on the northern side. The lowest R-values of all belong to some of the rocks right along the fault trace. We return to discuss the implications of these differences in rheological strength in Section 4.

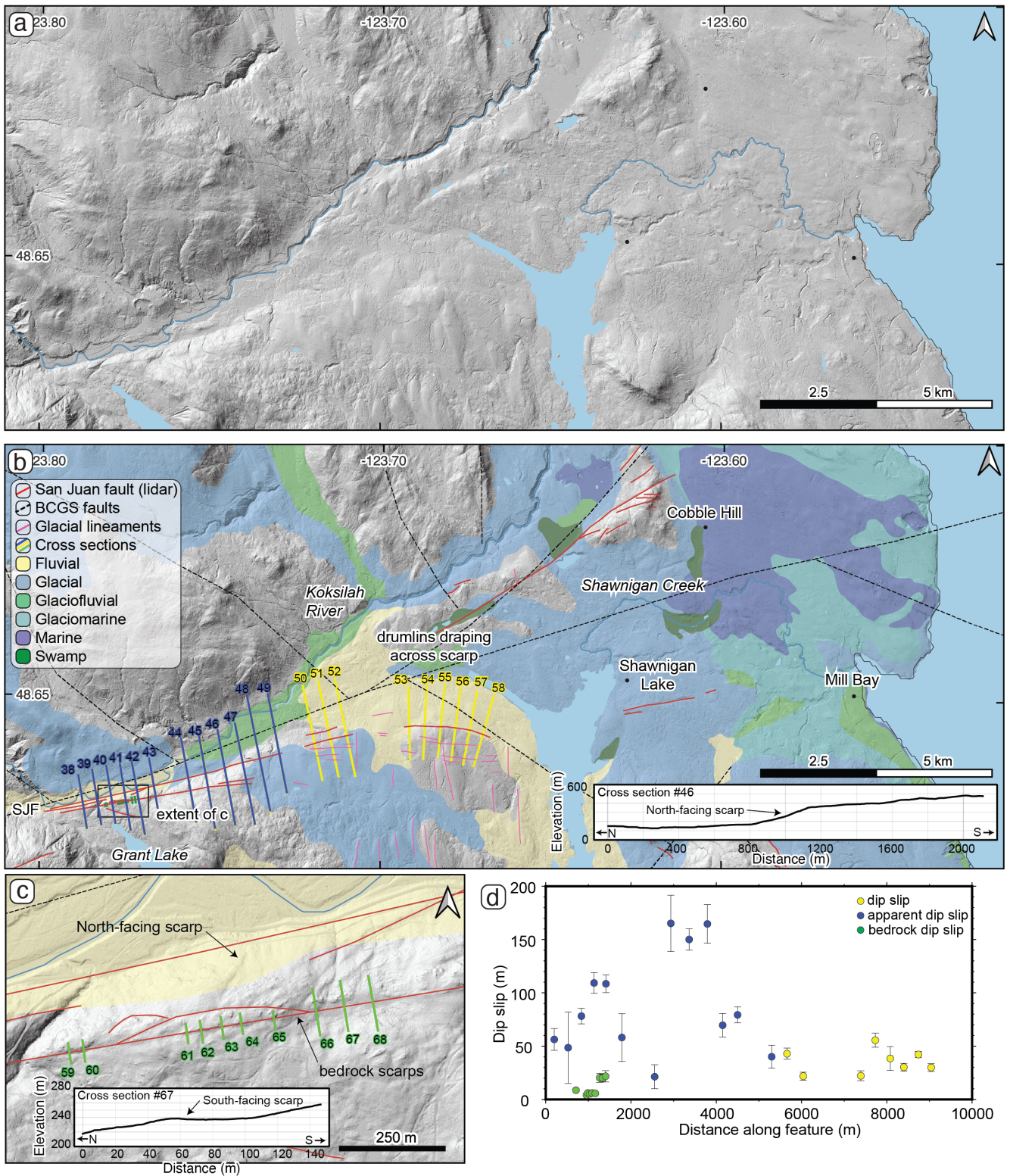


Figure 5 a) Uninterpreted hillshaded lidar along the eastern San Juan fault. b) Simplified surficial geology (coloured by sedimentary source with uncoloured areas mapped as colluvium) with our mapped fault traces (red) and glacial lineaments (pink) as well as geological faults from Cui et al. (2017) (dashed black lines). Blue and yellow lines mark topographic profiles used in panel (d), with an example profile shown in the inset. Surficial geology is modified from Senyk (1975) and Veness et al. (2024). c) Locations of topographic profiles of a bedrock scarp north of Grant Lake (green lines), with an example profile shown in the inset. d) Dip-slip estimates from all topographic profiles in (b) and (c), with ± 2 standard deviation error bars. Points are coloured based on the geomorphic equivalence of the surfaces on either side of the fault. Yellow points are for profiles where the surface on either side of the fault is interpreted to be the same, blue are for profiles where this is not the case. Green was used for measurements of bedrock outcrops.

Terrane	Unit Name	Description
Pacific Rim	Leech River schist	Metamorphosed pelites; slate, phyllite, quartz-biotite schists, minor interbedded volcanics. Varied levels of weathering and friability. Foliation direction highly variable.
	Survey Mountain volcanics	Massive mafic volcanics, sometimes with minor lenses of limestone. Occasionally serpentinized in shear zones (scaly).
Wrangellia	Island Plutonic Group	Granodiorite.
	Bonanza Group	Massive basalts and rhyolites. Green and maroon tuffs, breccias.
	West Coast Crystalline Complex	Granodiorite, quartz diorite.

Table 1 Descriptions of geologic units from which Schmidt hammer rock hardness measurements were taken.

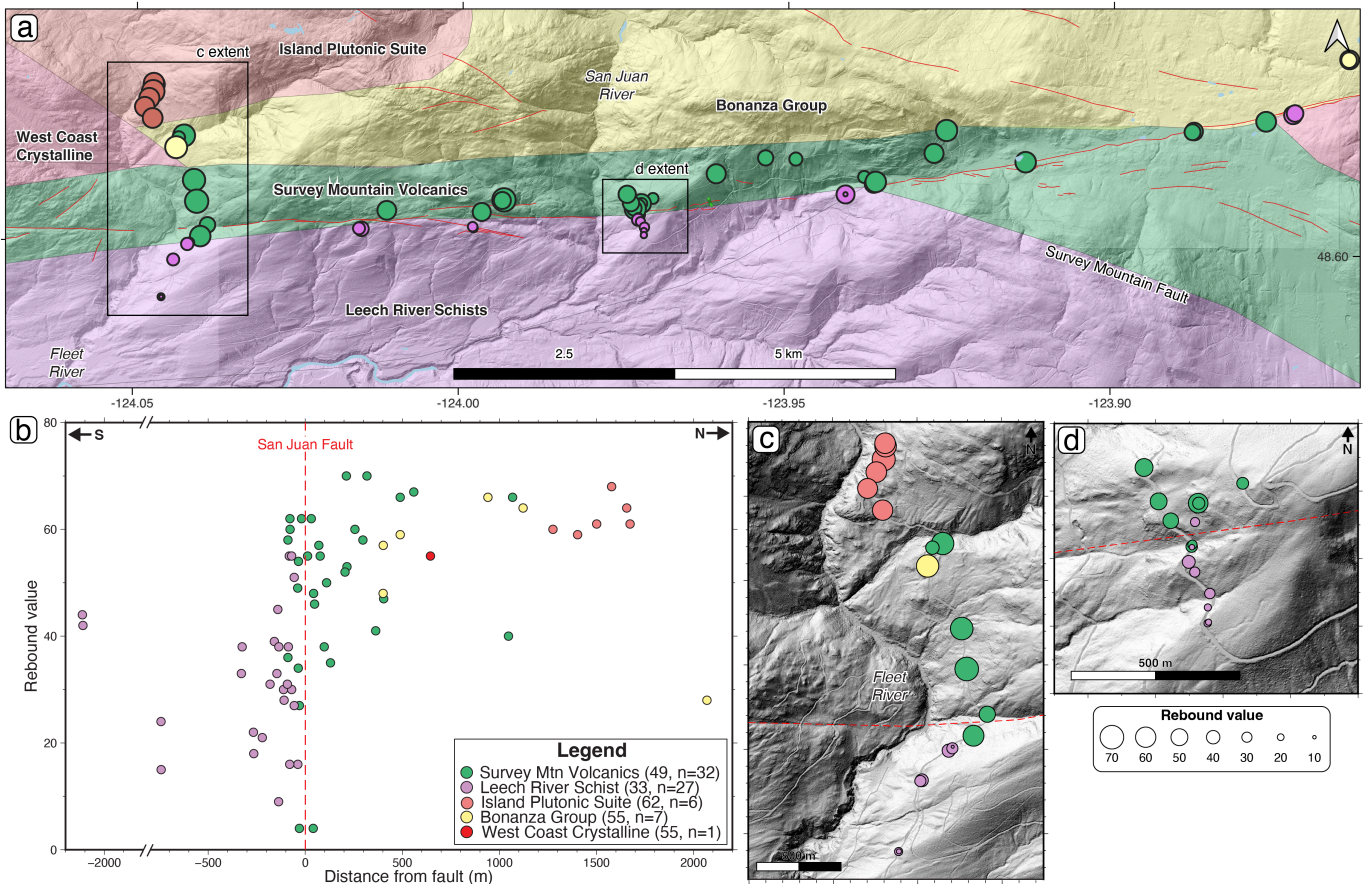


Figure 6 a) Geological map of study area from the British Columbia Geological Survey digital collection, with the SJF trace in red and Schmidt hammer measurement locations marked by circles, coloured by lithology and scaled by R-value. b) Schmidt hammer measurements plotted by distance from the fault (dashed red line) and coloured by lithology as in (a). Left is southwards. Legend shows average R-values and number of measurements for each lithology. c) Transect 1 and d) transect 2 across the SJF, with measurements (circles) coloured and scaled as in (a). Note how R-values diminish rapidly both along and south of the fault.

3.3 Electrical resistivity tomography

ERT profiles across the uphill-facing scarp at the UP-SCARP site show an apparent N-side-down offset in slope-parallel high- and low-resistivity units (Figure 7). In the longer profile (Figure 7a), the base of a ~2 m thick, surficial high-resistivity layer (HR1) is offset at the scarp by ~1.4 m, south side up. The offset is best

explained by a fault dipping approximately 73–82° to the north (Figure 7). The shorter high-resolution profile (Figure 7b) is consistent with these interpretations, showing a similar offset and fault dip angle. South of the uphill-facing scarp, there is a slightly smaller offset (SF1), with the opposite sense of slip (reverse). This is evident in the lidar as a very subtle shallowing of the

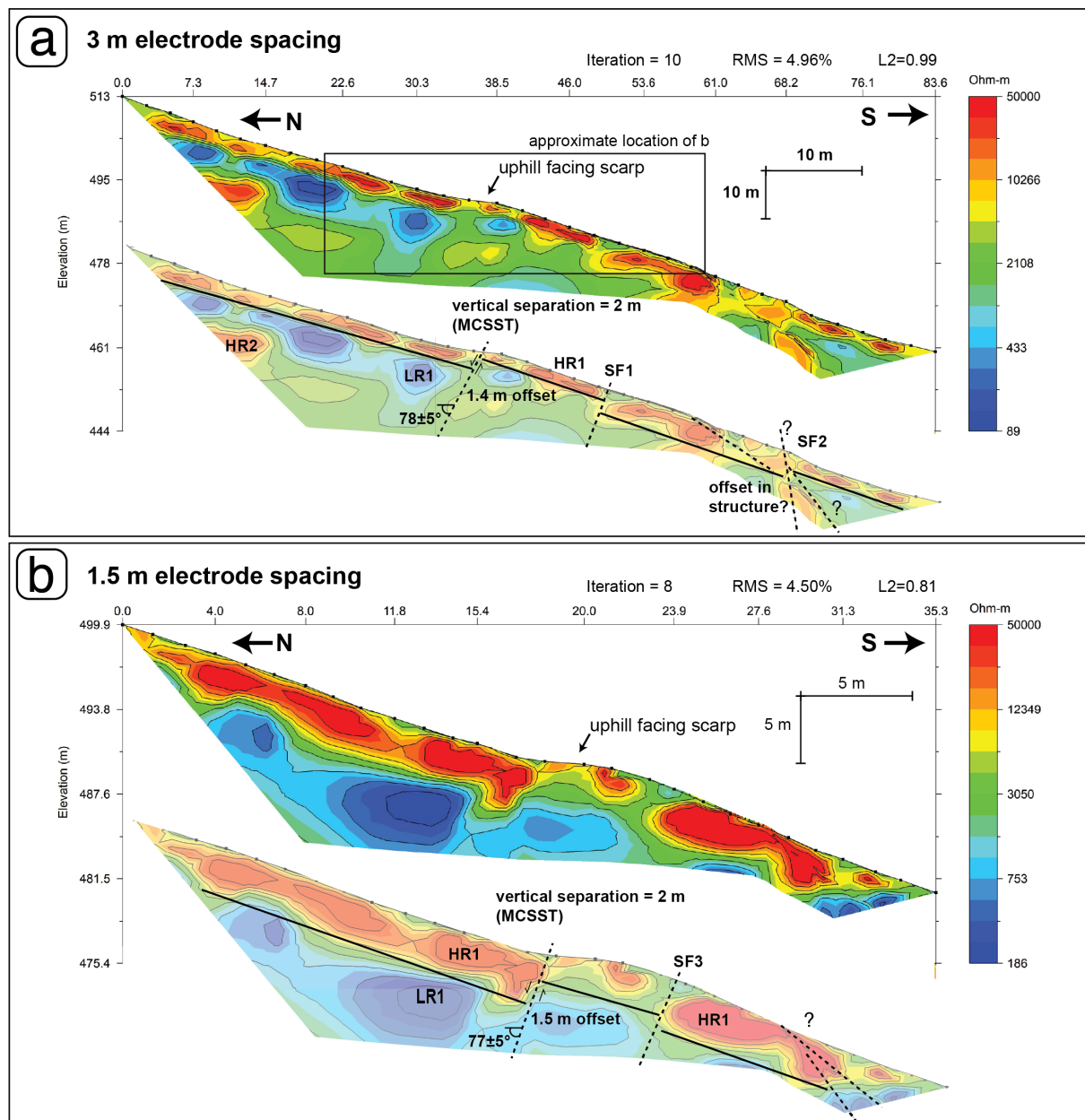


Figure 7 a) 3 m-spaced electrical resistivity tomography profile across the uphill-facing scarp at the UPSCARP site (Figure 4b, c), with box showing approximate location of higher-resolution profile in panel (b). Lower transparent profile includes interpretations. Vertical separation of the base of the HR1 unit is similar to that of the ground surface as measured using MCSST (Figure 4c, d). HR = high resistivity layer, LR = low resistivity layer, SF = secondary fault. b) 1.5 m-spaced high-resolution electrical resistivity tomography profile with interpretations below. Note that both profiles are horizontally stretched in order to highlight features in the resistivity structure (see “L”-shaped scale markers on right).

hillslope, followed by similarly subtle steepening (Figure 8c). There are additional offsets and discontinuities further downslope (SF2), near the southern end of the long profile. However, we are less confident that these are fault-related since several measurements in this area had to be discarded during the inversion and cleaning iterations, resulting in the resolved profile being much shallower.

We paired the ERT profiles with a 0.5 m-deep test pit located on the uphill-facing scarp (Figure 8e) to determine the composition of the surface layer (HR1). The test pit exposed a clast-supported assortment of sub-angular to sub-rounded clasts (5–10 cm) with a fine silty matrix. The clasts were of a variety of lithologies, but

mainly volcanic in origin. This is consistent with colluvium in the area, as are the measured resistivity values of up to 50,000 ohm-m (Palacky, 1988). On the regional surficial geology map, this hillslope is described as a ~1 m veneer of colluvial material overlying bedrock (Senyk, 1975). We interpret the lower resistivity unit below the colluvium to be weathered bedrock, with measured resistivities of 100–400 ohm-m consistent with typical values for weathered volcanics (Palacky, 1988) as are expected at this location (Survey Mountain, Table 1).

4 Discussion

4.1 Cryptic evidence of Quaternary activity

The San Juan fault displays a remarkably clear surface trace expression in the hillshaded DTM (Figures 3–5) with north-facing scarps and lineaments that are more continuous along strike than those along neighbouring active faults on southern or central Vancouver Island. By comparison, the Leech River fault (Morell et al., 2017), the XEOLXELEK–Elk Lake fault (Harrichhausen et al., 2023), and the Beaufort Range fault (Lynch et al., 2025) each exhibit subtle, discontinuous surface traces, yet all three have been shown to have ruptured during the Holocene, largely because they fortuitously intersect and cross-cut late Quaternary-aged unconsolidated sediments that provide an unequivocal record of recent activity. The SJF presents a greater challenge because, despite its clear geomorphic expression, there are no post-glacial strain markers or piercing points with which to quantify Quaternary or Holocene offsets. Below, we make the case for why the geomorphic, geomechanical, and geophysical evidence points towards Quaternary activity on the SJF.

We consider various non-tectonic explanations for the prominent N-facing bedrock scarps mapped across the glacially-scoured landscape. A first possibility is that rock strengths differ systematically across the fault, with differential erosion lowering the surface north of the fault relative to that south of it. However, this is inconsistent with our Schmidt hammer measurements, which show highest compressive strengths in rocks north of the fault (Figure 6b). Since compressive strength is positively correlated with erosive resistance (Stahl and Tye, 2020; Matthews and Winkler, 2022), we would expect that, subject to the same intensity of glacial scouring, the stronger rocks north of the fault should be less eroded than those south of it. This reflects how lithologies south of the fault are mainly metamorphosed sediments and volcanics, which typically have erosion rates of $0.011\text{--}0.020\text{ mm.yr}^{-1}$, while those north of the fault are mainly intrusive igneous rocks, which typically erode at slower rates of 0.009 mm.yr^{-1} (Portenga and Bierman, 2011). A second possibility is that the scarps formed via glacial plucking across an existing fault and fracture zone with its associated lithologic contrasts. However, the southward direction of ice-flow indicated by drumlins at the GSS site is unlikely to have contributed to the formation of the N-facing scarp there, as plucking generally occurs on the leeward side of positive relief landforms (Alley et al., 2019). We therefore argue that neither differential weathering nor glacial plucking can explain the prominence of the largely north-facing scarps.

Our preferred explanation is that the scarps were produced by a component of dip-slip along a sub-vertical fault, with south-side-up motion counteracting and exceeding the effects of any differential erosion. However, with apparent dip-slip of $\sim 30\text{ m}$ at the GSS site (Figure 4e) and $\sim 36\text{ m}$ west of Shawnigan Lake (Figure 5d), the scarp is in places too large to have been generated within the Holocene and since the end of the

latest glaciation: vertical slip rates would need to be $> 2.5\text{ mm.yr}^{-1}$, considerably higher than most other upper plate faults in the Cascadia forearc (Kelsey et al., 2012; Personius et al., 2014; Morell et al., 2018; Schermer et al., 2021). Such a slip rate would also imply numerous $M\text{ }6\text{--}7$ earthquakes in the Holocene, each with several meters of slip (Anderson et al., 1996), for which the evidence is scant. We therefore suggest that the scarp is a product of a much longer period of tectonic activity extending before the Holocene, and that successive glacial cycles within the Quaternary have not fully reset the landscape. Constraining glacial erosion is challenging, as rates can vary significantly both spatially and temporally (Alley et al., 2019; Patton et al., 2022). It is possible that the glaciers on southern Vancouver Island had high erosion rates (on the order of several mm.yr^{-1}) as warmer temperatures and higher precipitation are correlated to greater erosion (Cook et al., 2020). On the other hand, the Fraser glaciation was not particularly long-lived, and the Cordilleran Ice Sheet had a late onset and an early, rapid retreat from the Pacific coastal region (Alley and Chatwin, 1979; Clague and James, 2002; Clague and Ward, 2011). Pre-Holocene tectonic landforms may have been partially denuded, but not entirely removed from the landscape.

Although the prominent, continuous scarp is suggestive of pan-Quaternary fault activity, we must look to smaller, more subtle scarps for evidence of more recent, post-glacial Holocene rupture. As these features are shorter-lived than the bedrock scarps, they preserve smaller scale offsets, but as with the bedrock scarps, it remains a challenge to distinguish tectonically-generated offsets from features with other origins. For example, on slopes overlooking the San Juan River west of Clydeside Creek, swarms of short, ridge-parallel, uphill-facing scarps are likely sackungen, the result of gravitational slumping within thick accumulations of till in response to San Juan River incision (e.g. Figure 8a, d). This interpretation is supported by landslide scars at the slope base, a potential cause of formation of the sackungen directly up-slope. Alternatively, the sackungen here could be bedrock features formed by gravitational spreading of the ridge (Savage and Varnes, 1987).

However, we interpret that the uphill-facing scarp at the UPSCARP site (Figure 8b) is tectonic, since contrary to the sackungen it is an isolated escarpment, oblique to the ridgeline, subparallel to the SJF trace and along strike from a significant bedrock shear zone. Furthermore, the normal offsets in our ERT profiles are inconsistent with models of sackungen formation in which compressive flow or thrust faulting occurs midway down the hillslope and extensional features are located at the ridgetop (Savage and Varnes, 1987). Additionally, the offset in subsurface strata observed in our ERT profiles rules out an anthropogenic origin, such as an abandoned roadbed. The uphill-facing scarp may provide evidence for a post-glacial Holocene earthquake along the SJF, since it has not yet been removed by erosion by the many small channels crossing it (Figure 8b,e). The offset colluvium and potentially till could be a target for a future paleoseismic trench, though backhoe access would be challenging. The sackungen

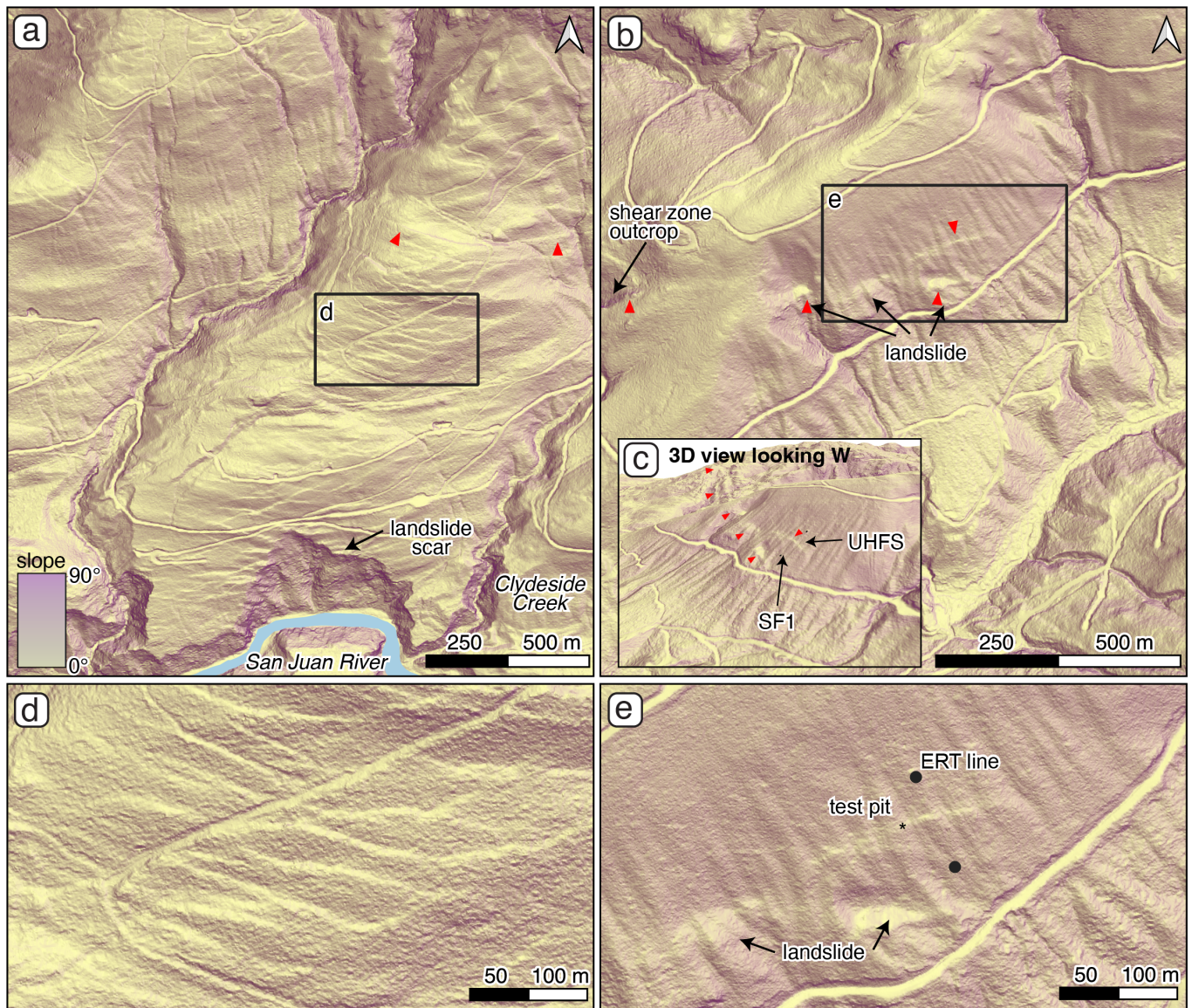


Figure 8 Lidar hillshades, coloured by slope angle, comparing (left) features interpreted as sackungen with (right) the uphill-facing scarp at the UPSCARP site interpreted as surface faulting. a) Sackungen west of Clydeside Creek (Figure 4b). Red triangles mark location of the SJF. b) Uphill-facing scarp (UHFS). c) 3D view of the uphill-facing scarp, showing how it is located just off strike of the main fault trace. SF1 is the location of the secondary offset in Figure 7. d) Zoom in of the sackungen, which are generally parallel to topographic contours. e) Zoom in of the uphill facing scarp. Black points mark the ends of the ERT profile. Note: drainage channels crossing the uphill-facing scarp do not appear to be laterally offset.

west of Clydeside Creek and the landslides at the UPSCARP site (Figure 8) could both be related to the fault, perhaps even triggered by strong coseismic ground accelerations, since similar features are absent on the south side of the San Juan valley. This is additional, circumstantial evidence for earthquake activity along the SJF.

4.2 Fault kinematics: right-lateral reactivation of a left-lateral geological fault?

If the SJF is Quaternary active, then what are its likely kinematics? Firstly, we consider its tectonic context. The fault is generally interpreted to record predominantly left-lateral motion in its earlier history (Johnson, 1984; Rusmore and Cowan, 1985; England and Calon, 1991; Harrichhausen et al., 2022), which implies that

the modern fault should have inherited a relatively steep dip angle. This is consistent with its highly linear surface trace across rugged relief. Purely strike-slip faults can exhibit vertical offset, but the ubiquity of the S-side up sense of vertical separation across the SJF does also imply a component of dip-slip. The modern day stress field has maximum horizontal compressive crustal stresses orientated $\sim$ N–S on central Vancouver Island, close to fault-normal, but $\sim$ NW–SE on southern Vancouver Island, more consistent with right-lateral kinematics (Balfour et al., 2011, Figure 2a). All of this points to the modern SJF having a dextral-reverse sense of slip, similar to its closest neighbour to the south, the sub-parallel Leech River fault (Morell et al., 2017, 2018; Harrichhausen et al., 2021). This also fits with the conceptual model in which northern Cascadia upper plate faults accommodate margin-parallel shorten-

ing of the forearc via right-lateral slip and counterclockwise, vertical-axis block rotation (Finley et al., 2019, Figure 2b).

However, despite several channels and glacial flutes crossing the fault at high angles, we found no unequivocal geomorphic evidence for right-lateral offset across the SJF. Several factors can hinder interpretation of offset markers including the superimposed nature of tectonic landscapes, transient variations in fault slip, and climate variability (Reitman et al., 2019). However, along the central SJF we did observe curved drainages (including Fairy Creek, Mercer Creek, Clydeside Creek, and Fleet River) with consistently right-lateral senses of deflection (Figure 9). This subtle expression of right-lateral slip might suggest distributed deformation (Duvall and Tucker, 2015; Gray et al., 2017), a long elapsed time since the latest earthquake (Reitman et al., 2019), or simply poor preservation of lateral offsets in the high precipitation climate (Reitman et al., 2022). For comparison, the Sadie Creek fault on the nearby Olympic peninsula (a branch fault of the NOFZ, Figure 2b) has sharper channel offsets and a slip rate of around 1–2 mm/yr (Nelson et al., 2017) on very similar hillslopes to those found along the San Juan valley. As such, a slip rate of 1 mm/yr could be the upper bound for the SJF, however, other factors may be at play, such as the different underlying geology (Siletz terrane basalts in the case of the Sadie Creek fault, Nelson et al. (2017); Schermer et al. (2021)).

4.3 Implications for seismic hazard and risk

To approximate the maximum magnitude earthquake that the San Juan fault could realistically accommodate, we use the full length of the mapped fault trace (80 km) and the following equation from Wesnousky (2008):

$$M_w = A + B \cdot \log(\text{Length}(km)) \quad (1)$$

where constants $A = 5.56$ and $B = 0.87$ for strike-slip earthquakes. Substituting these values into the equation, the SJF could potentially produce an earthquake of $M_w \sim 7.2$, which would have considerable impacts for the nearby population centres of Shawnigan Lake, Mill Bay, and Greater Victoria, and infrastructure including the Trans-Canada Highway. This motivates consideration of whether and how to include the SJF in seismic hazard models.

A challenge here is that despite the lines of evidence from lidar mapping, scarp analysis, rock strength tests, and ERT surveys, it is difficult to wholly and unequivocally demonstrate that the SJF is an active fault. Similar to other shallow faults within the northern Cascadia forearc (e.g. Nelson et al., 2017; Morell et al., 2018; Harrichhausen et al., 2021, 2023), such evidence has been largely obscured by dense vegetation, high precipitation rates and recent glaciations, without narrow concentrations in instrumental seismicity or geodetic strain as independent evidence for activity. Including these structures in seismic hazard models is difficult since most such models require that the slip rate is well-constrained. The 6th Generation Seismic Hazard Model of Canada (CanadaSHM6) includes only a

limited number of simple fault sources (and most of these are for plate boundary faults), and relies largely on areal sources based on recorded seismicity, assuming maximum magnitudes based on a truncated Gutenberg-Richter relationship (Kolaj et al., 2020, 2023). Importantly, the only Cascadia forearc crustal faults included in CanadaSHM6 are the Leech River and Devil's Mountain faults (Kolaj et al., 2020, 2023). While overall, hazard is still dominated by the Cascadia megathrust and the intraslab seismic zone, incorporation of these two upper plate faults marginally increased seismic hazard for Victoria compared to earlier versions of the model, with the 'excess' decreasing rapidly away from their surface traces (Halchuk et al., 2019; Kukovica et al., 2019; Goda and Sharipov, 2021). Mendoza et al. (2025) similarly found that source-to-site distances were an influential factor for hazard increases from upper plate faults near Vancouver, but noted that even small increases in hazard could be impactful for critical facilities such as airports, bridges, dams and energy infrastructure (e.g. McCann and Addo, 2012).

This brings into question the acceptable criteria for considering cryptic faults like the SJF in seismic hazard models: should they remain excluded until absolute evidence of rupture is found? In New Zealand, fault zones that have experienced considerable displacement in the recent geologic past (Neogene) but lack preserved evidence of late Quaternary movement are considered to be 'capable' fault zones, with the potential to generate earthquakes greater than M_w 6 in the present tectonic regime (Seebeck et al., 2024, 2022). Another potential approach could be to designate fault source polygons, similar to those found in the United States national seismic hazard model (Petersen et al., 2024), where zones of faulting capable of hosting multiple large magnitude events are included in the hazard calculation even as specific fault sources remain unidentified.

Fault hazard assessments in environments such as Vancouver Island require a multi-faceted approach, combining seismological, geological and geophysical techniques. In our case, additional work is necessary to demonstrate conclusively that the SJF is active, and constraining the ages of paleoseismic earthquakes will be vital in this respect. Follow-up research could aim to estimate the slip rate and other rupture constraints, to enable incorporation of the SJF into seismic hazard models, if warranted. In the absence of clear geomorphic offsets, the best option for this would be paleoseismic trenching. There are several potential trench sites, including the UPSCARP site discussed above or the drumlin cross-cut by the fault west of Shawnigan Lake (Figure 5). Alternatively, sediment cores could be taken from nearby lakes or from ponded sediment along the scarp at the GSS site (Figure 4), in the hopes of finding dateable earthquake related deposits.

5 Conclusions

The San Juan fault is one of the major terrane-bounding faults on southern Vancouver Island in the northern Cascadia forearc. Several lines of evidence indicate that it has been active as a dextral-reverse fault during

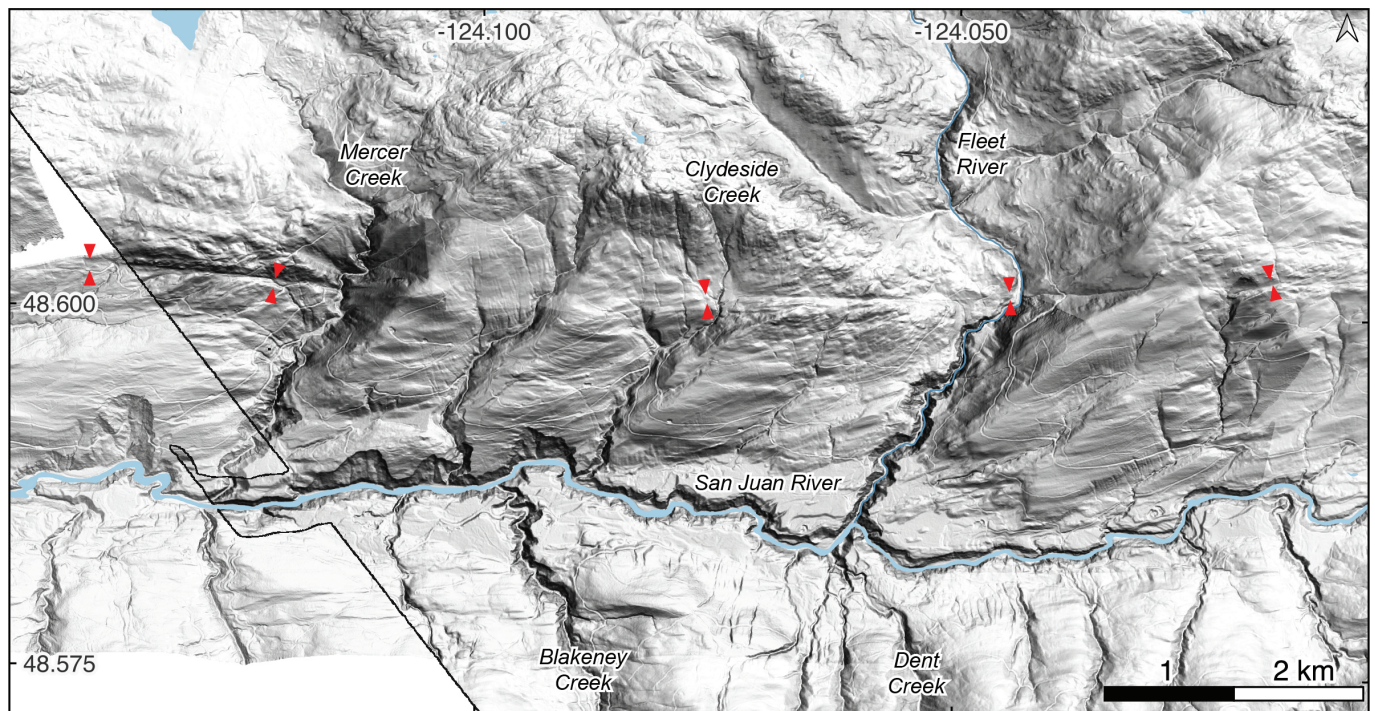


Figure 9 Hillshaded topography showing curved drainages crossing the central SJF with a consistently right-lateral sense of deflection, perhaps our best indication of right-lateral Quaternary slip. Red triangles indicate the fault surface trace.

the Quaternary, and likely as recently as the Holocene, thus inverting its left-lateral geological origins. For one, the surface expression of the SJF is remarkably clear and continuous, preserved within numerous bedrock outcrops and in places across the intervening till- and colluvium-mantled slopes. Although there is a lack of sharp lateral offsets along this surface trace, several channels exhibit curved deflections of a consistently right-lateral sense as they flow across the fault. Additionally, using our novel Schmidt hammer approach, we rule out differential erosion as the cause of a prominent N-facing scarp across a glacially-scoured surface. For the scarp to have built up to ~ 30 m of vertical offset, we interpret that it instead represents multiple earthquake cycles on a slow (<1 mm/yr) slip rate fault, and that it must partially predate the most recent glaciation. We have also identified a possible Holocene surface rupture, which may be a suitable site for future paleoseismic trenching, likely required in order to assign a slip rate to the SJF and include it in seismic hazard models. Although currently poorly quantified, the potential for a large, surface-rupturing earthquake on the SJF has important implications for the nearby population centres of Shawnigan Lake, Mill Bay, and Greater Victoria.

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6 Data Availability

While some of the lidar data used in this study are from private sources, comparable coverage has recently been made available on the British Columbia government's open lidar portal (LidarBC, 2023). The supplemental material is comprised of 19 figures (Figures S1–S19) and 12 data files. The figures show cross sections from the vertical separation measurements, hillshaded plots of the drone lidar collections, photographs of the Schmidt hammer data collection, and photos of the ERT profile set-up. The data files include hillshaded topography for data available on the LidarBC portal, a shapefile of the mapped lineaments, DTMs for the drone lidar sites, and ERT measurement and terrain files. They are available in the Zenodo repository (<https://doi.org/10.5281/zenodo.18023344>). Digital geology (faults and geological units) used in this study are from the British Columbia Geological Survey (Cui et al., 2017) and the Washington State Geological Survey (Washington Geological Survey, 2022). Earthquake locations are from the Canadian National Earthquake Database (Natural Resources Canada, 1985). GNSS velocities relative to stable

North America are from McCaffrey et al. (2013). S_{Hmax} directions are from Balfour et al. (2011). River vector files and population centres are from OpenStreetMap (OpenStreetMap contributors, 2025). We used the MC-SST toolkit (Wolfe et al., 2020) to measure vertical separation. Figures were prepared using QGIS (QGIS Association, 2018), GMT (Wessel et al., 2019), and Adobe Illustrator.

Competing interests

The authors have no competing interests.

References

- Advanced Geosciences Inc. AGI EarthImager 2D, 2009. (version 2.4.0) [Software] AGIUSA. Retrieved from <https://www.agiusa.com/agi-earthimager-2d>.
- Alley, N. Carmanah Surficial Geology 92/C10, 1975a. <https://coms.api.gov.bc.ca/api/v1/object/10ac82d8-26be-4226-b88c-e2f1626f740f>.
- Alley, N. San Juan Surficial Geology 92C/9, 1975b. <https://coms.api.gov.bc.ca/api/v1/object/840b6605-a53e-4cda-9308-b464a6f2011f>.
- Alley, N. F. and Chatwin, S. C. Late Pleistocene history and geomorphology, southwestern Vancouver Island, British Columbia. *Canadian Journal of Earth Sciences*, 16(9):1645–1657, 1979.
- Alley, R. B., Cuffey, K. M., and Zoet, L. K. Glacial erosion: status and outlook. *Annals of Glaciology*, 60(80):1–13, 2019. doi: 10.1017/aog.2019.38.
- Anderson, J. G., Wesnousky, S. G., and Stirling, M. W. Earthquake size as a function of fault slip rate. *Bulletin of the Seismological Society of America*, 86(3):686, 1996. doi: 10.1785/BSSA0860030683.
- Andrew, A. and Godwin, C. I. Lead- and strontium-isotope geochemistry of Paleozoic Sicker Group and Jurassic Bonanza Group volcanic rocks and Island Intrusions, Vancouver Island, British Columbia. *Canadian Journal of Earth Sciences*, 26(5): 894–907, 1989. doi: 10.1139/e89-072.
- Bahavar, M., Styron, R., Streig, A., Thomas, A., Bachelot, L., and the CRESCENT CFM working group. The Cascadia Region Earthquake Science Center (CRESCENT) Community Fault Model viewer, 2025. doi: 10.5281/zenodo.15092744.
- Balfour, N., Cassidy, J., Dosso, S., and Mazzotti, S. Mapping crustal stress and strain in southwest British Columbia. *Journal of Geophysical Research: Solid Earth*, 116(B3), 2011. doi: 10.1029/2010JB008003.
- Brandon, M. T. Origin of igneous rocks associated with melanges of the Pacific Rim Complex, western Vancouver Island, Canada. *Tectonics*, 8(6):1115–1136, 1989. doi: 10.1029/TC008i006p01115.
- Brocher, T. M., Wells, R. E., Lamb, A. P., and Weaver, C. S. Evidence for distributed clockwise rotation of the crust in the northwestern United States from fault geometries and focal mechanisms. *Tectonics*, 36(5):787–818, 2017. doi: 10.1002/2016TC004223.
- Clague, J. J. and James, T. S. History and isostatic effects of the last ice sheet in southern British Columbia. *Quaternary Science Reviews*, 21(1-3):71–87, 2002. doi: 10.1016/S0277-3791(01)00070-1.
- Clague, J. J. and Ward, B. Chapter 44 - Pleistocene Glaciation of British Columbia. In Ehlers, J., Gibbard, P. L., and Hughes, P. D., editors, *Developments in Quaternary Sciences*, volume 15, pages 563–573. Elsevier, 2011. doi: 10.1016/B978-0-444-53447-7.00044-1.
- Cook, S. J., Swift, D. A., Kirkbride, M. P., Knight, P. G., and Waller, R. I. The empirical basis for modelling glacial erosion rates. *Nature Communications*, 11(1):759, 2020. doi: 10.1038/s41467-020-14583-8.
- Cui, Y., Miller, D., Schiarizza, P., and Diakow, L. British Columbia digital geology. *British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey Open File 2017-8*, 2017.
- DeBari, S. M., Anderson, R. G., and Mortensen, J. K. Correlation among lower to upper crustal components in an island arc: the Jurassic Bonanza arc, Vancouver Island, Canada. *Canadian Journal of Earth Sciences*, 36(8):1371–1413, 1999. doi: 10.1139/e99-029.
- Delano, J. E., Amos, C. B., Loveless, J. P., Rittenour, T. M., Sherrod, B. L., and Lynch, E. M. Influence of the megathrust earthquake cycle on upper-plate deformation in the Cascadia forearc of Washington State, USA. *Geology*, 45(11):1051–1054, 2017. doi: 10.1130/G39070.1.
- DeMets, C., Gordon, R. G., and Argus, D. F. Geologically current plate motions. *Geophysical Journal International*, 181(1):1–80, 2010. doi: 10.1111/j.1365-246X.2009.04491.x.
- Dragert, H. and Hyndman, R. D. Continuous GPS monitoring of elastic strain in the Northern Cascadia Subduction Zone. *Geophysical Research Letters*, 22(7):755–758, 1995. doi: 10.1029/95GL00469.
- Duvall, A. R. and Tucker, G. E. Dynamic Ridges and Valleys in a Strike-Slip Environment. *Journal of Geophysical Research: Earth Surface*, 120(10):2016–2026, 2015. doi: 10.1002/2015JF003618.
- England, T. and Calon, T. The Cowichan fold and thrust system, Vancouver Island, southwestern British Columbia. *Geological Society of America Bulletin*, 103(3):336–362, 1991. doi: 10.1130/0016-7606(1991)103<0336:TCFATS>2.3.CO;2.
- Fairchild, L. H. and Cowan, D. S. Structure, petrology, and tectonic history of the Leech River complex northwest of Victoria, Vancouver Island. *Canadian Journal of Earth Sciences*, 19(9): 1817–1835, 1982. doi: 10.1139/e82-161.
- Finley, T., Morell, K., Leonard, L., Regalla, C., Johnston, S. T., and Zhang, W. Ongoing oroclinal bending in the Cascadia forearc and its relation to concave-outboard plate margin geometry. *Geology*, 47(2):155–158, 2019. doi: 10.1130/G45473.1.
- Goda, K. and Sharipov, A. Fault-Source-Based Probabilistic Seismic Hazard and Risk Analysis for Victoria, British Columbia, Canada: A Case of the Leech River Valley Fault and Devil's Mountain Fault System. *Sustainability*, 13(3), 2021. doi: 10.3390/su13031440.
- Gray, H. J., Shobe, C. M., Hopley, D. E., Tucker, G. E., Duvall, A. R., Harbert, S. A., and Owen, L. A. Off-fault deformation rate along the southern San Andreas fault at Mecca Hills, southern California, inferred from landscape modeling of curved drainages. *Geology*, 46(1):59–62, 2017. doi: 10.1130/G39820.1.
- Greene, H. G. and Barrie, J. V. Faulting within the San Juan–southern Gulf Islands Archipelagos, upper plate deformation of the Cascadia subduction complex. In Asch, K., Kitazato, H., and Vallius, H., editors, *From Continental Shelf to Slope: Mapping the Oceanic Realm*, page 0. Geological Society of London, 2022. doi: 10.1144/SP505-2019-125.
- Groome, W. G., Thorkelson, D. J., Friedman, R. M., Mortensen, J. K., Massey, N. W. D., Marshall, D. D., and Layer, P. W. Magmatic and tectonic history of the Leech River Complex, Vancouver Island, British Columbia: Evidence for ridge-trench intersection and accretion of the Crescent Terrane. In Sisson, V. B., Roeske, S. M., and Pavlis, T. L., editors, *Geology of a transpressional oro-*

- gen developed during ridge-trench interaction along the North Pacific margin, pages 327–354. Geological Society of America, 2003. doi: 10.1130/0-8137-2371-X.327.
- Halchuk, S., Allen, T., Adams, J., and Onur, T. Contribution of the Leech River Valley-Devil's Mountain Fault System to Seismic Hazard in Victoria, BC. In *Proceedings of the 12th Canadian Conference on Earthquake Engineering, Quebec City, QC, Canada*, pages 17–20, 2019.
- Hamling, I. J. A review of the 2016 Kaikōura earthquake: insights from the first 3 years. *Journal of the Royal Society of New Zealand*, 50(2):226–244, Apr. 2020. doi: 10.1080/03036758.2019.1701048.
- Harrichhausen, N., Morell, K. D., Regalla, C., Bennett, S. E., Leonard, L. J., Lynch, E. M., and Nissen, E. Paleoseismic trenching reveals Late Quaternary kinematics of the Leech River fault: Implications for forearc strain accumulation in northern Cascadia. *Bulletin of the Seismological Society of America*, 111(2): 1110–1138, 2021. doi: 10.1785/0120200204.
- Harrichhausen, N., Morell, K. D., Regalla, C., Lynch, E. M., and Leonard, L. J. Eocene Terrane Accretion in Northern Cascadia Recorded by Brittle Left-Lateral Slip on the San Juan Fault. *Tectonics*, 41(10), 2022. doi: 10.1029/2022TC007317.
- Harrichhausen, N., Finley, T., Morell, K. D., Regalla, C., Bennett, S. E. K., Leonard, L. J., Nissen, E., McLeod, E., Lynch, E. M., Salomon, G., and Sethanant, I. Discovery of an Active Forearc Fault in an Urban Region: Holocene Rupture on the XEOLXELEK-Elk Lake Fault, Victoria, British Columbia, Canada. *Tectonics*, 42 (12), 2023. doi: 10.1029/2023TC008170.
- Harrichhausen, N., Morell, K. D., and Regalla, C. Inner forearc faults in northern Cascadia do not accommodate elastic strain driven by the megathrust seismic cycle. *Seismica*, 2(4), 2024. doi: 10.26443/seismica.v2i4.1177.
- Hata, Y., Goto, H., and Yoshimi, M. Preliminary analysis of strong ground motions in the heavily damaged zone in Mashiki town, Kumamoto, Japan, during the mainshock of the 2016 Kumamoto earthquake (Mw 7.0) observed by a dense seismic array. *Seismological Research Letters*, 87(5):1044–1049, 2016. doi: 10.1785/0220160107.
- Improta, L., Ferranti, L., De Martini, P. M., Piscitelli, S., Bruno, P. P., Burrato, P., Civico, R., Giocoli, A., Iorio, M., D'Addezio, G., and Maschio, L. Detecting young, slow-slipping active faults by geologic and multidisciplinary high-resolution geophysical investigations: A case study from the Apennine seismic belt, Italy. *Journal of Geophysical Research: Solid Earth*, 115(B11), 2010. doi: 10.1029/2010JB000871.
- Jackson, L. E., Ward, B. C., Hicock, S. R., Gromig, R., Clague, J. J., and Turner, D. G. New insights into the glacial and relative sea-level history of the western Fraser Lowland based on sediment cores from geotechnical drilling for the Evergreen Tunnel, British Columbia, Canada. *Quaternary Research*, 122:40–61, 2024. doi: 10.1017/qua.2024.9.
- Johnson, S. Y. Evidence for a margin-truncating transcurrent fault (pre-late Eocene) in western Washington. *Geology*, 12(9):538–541, 1984. doi: 10.1130/0091-7613(1984)12<538:EFAMTF>2.0.CO;2.
- Johnson, S. Y., Potter, C. J., Miller, J. J., Armentrout, J. M., Finn, C., and Weaver, C. S. The southern Whidbey Island fault: An active structure in the Puget Lowland, Washington. *GSA Bulletin*, 108(3):334–354, 1996. doi: 10.1130/0016-7606(1996)108<0334:TSWIFA>2.3.CO;2.
- Johnson, S. Y., Nelson, A. R., Personius, S. F., Wells, R. E., Kelsey, H. M., Sherrod, B. L., Okumura, K., Koehler, III, R., Witter, R. C., Bradley, L.-A., and Harding, D. J. Evidence for Late Holocene Earthquakes on the Utsalady Point Fault, Northern Puget Lowland, Washington. *Bulletin of the Seismological Society of America*, 94(6):2299–2316, 2004. doi: 10.1785/0120040050.
- Kelsey, H. M., Sherrod, B. L., Blakely, R. J., and Haugerud, R. A. Holocene faulting in the Bellingham forearc basin: Upper-plate deformation at the northern end of the Cascadia subduction zone. *Journal of Geophysical Research: Solid Earth*, 117(B3), 2012. doi: 10.1029/2011JB008816.
- Kolaj, M., Adams, J., and Halchuk, S. The 6th generation seismic hazard model of Canada. *17th World Conference on Earthquake Engineering*, 2020.
- Kolaj, M., Halchuk, S. C., and Adams, J. Sixth Generation seismic hazard model of Canada: final input files used to generate the 2020 National Building Code of Canada seismic hazard values. *Geological Survey of Canada, Open File*, 8924, page 12, 2023. <https://ostrnrcan-dostrncan.canada.ca/handle/1845/135527>.
- Kukovica, J., Ghofrani, H., Molnar, S., and Assatourians, K. Probabilistic Seismic Hazard Analysis of Victoria, British Columbia: Considering an Active Fault Zone in the Nearby Leech River Valley. *Bulletin of the Seismological Society of America*, 109(5): 2050–2062, 2019. doi: 10.1785/0120180330.
- Li, G., Liu, Y., Regalla, C., and Morell, K. D. Seismicity relocation and fault structure near the Leech River fault zone, southern Vancouver Island. *Journal of Geophysical Research: Solid Earth*, 123 (4):2841–2855, 2018. doi: 10.1002/2017JB015021.
- LidarBC. Open LiDAR Data Portal, 2023. <https://lidar.gov.bc.ca/>.
- Lynch, E., Regalla, C., Morell, K., Harrichhausen, N., and Leonard, L. Evidence for an active transtensional Beaufort Range fault in the northern Cascadia forearc. *Seismica*, 2(4), Aug. 2025. doi: 10.26443/seismica.v2i4.1163.
- Matthews, J. A. and Winkler, S. Schmidt-hammer exposure-age dating: a review of principles and practice. *Earth-Science Reviews*, 230, 2022. doi: 10.1016/j.earscirev.2022.104038.
- Mazzotti, S., Leonard, L. J., Cassidy, J. F., Rogers, G. C., and Halchuk, S. Seismic hazard in western Canada from GPS strain rates versus earthquake catalog. *Journal of Geophysical Research: Solid Earth*, 116(B12), 2011. doi: 10.1029/2011JB008213.
- McCaffrey, R., Qamar, A. I., King, R. W., Wells, R., Khazaradze, G., Williams, C. A., Stevens, C. W., Vollick, J. J., and Zwick, P. C. Fault locking, block rotation and crustal deformation in the Pacific Northwest. *Geophysical Journal International*, 169(3): 1315–1340, 2007. doi: 10.1111/j.1365-246X.2007.03371.x.
- McCaffrey, R., King, R. W., Payne, S. J., and Lancaster, M. Active tectonics of northwestern U.S. inferred from GPS-derived surface velocities. *Journal of Geophysical Research: Solid Earth*, 118(2): 709–723, 2013. doi: 10.1029/2012JB009473.
- McCann, M. W. and Addo, K. O. Dam safety probabilistic seismic hazard analysis (PSHA) model. Engineering Report No. E658 Vol. 1, BC Hydro, 2012. <https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/corporate/safety/probabilistic-seismic-hazard-analysis-volume%201%20.pdf>.
- Mendoza, R. B., Hobbs, T. E., and Bostock, M. G. Exploring Seismic Hazard Scenarios of Potentially Active Faults in the Southern Coast Mountains of British Columbia, Canada. *Bulletin of the Seismological Society of America*, 115(5):2002–2020, 2025. doi: 10.1785/0120250089.
- Miller, M. M., Johnson, D. J., Rubin, C. M., Dragert, H., Wang, K., Qamar, A., and Goldfinger, C. GPS-determination of along-strike variation in Cascadia margin kinematics: Implications for relative plate motion, subduction zone coupling, and permanent deformation. *Tectonics*, 20(2):161–176, 2001. doi: 10.1029/2000TC001224.
- Mojica, A., Pérez, T., Toral, J., Miranda, R., Franceschi, P., Calderón,

- C., and Vergara, F. Shallow electrical resistivity imaging of the Limón fault, Chagres River Watershed, Panama Canal. *Journal of Applied Geophysics*, 138:135–142, 2017. doi: 10.1016/j.jappgeo.2017.01.010.
- Morell, K., Regalla, C., Amos, C., Bennett, S., Leonard, L., Graham, A., Reedy, T., Levson, V., and Telka, A. Holocene surface rupture history of an active forearc fault redefines seismic hazard in southwestern British Columbia, Canada. *Geophysical Research Letters*, 45(21):11–605, 2018.
- Morell, K. D., Regalla, C., Leonard, L. J., Amos, C., and Levson, V. Quaternary rupture of a crustal fault beneath Victoria, British Columbia, Canada. *GSA Today*, 7(3), 2017. doi: 10.1130/GSATG291A.1.
- Muller, J. E. Evolution of the Pacific Margin, Vancouver Island, and adjacent regions. *Canadian Journal of Earth Sciences*, 14(9): 2062–2085, 1977. doi: 10.1139/e77-176.
- Natural Resources Canada. Canadian National Earthquake Database, 1985. doi: <http://doi.org/10.17616/R3TD24>.
- Nelson, A. R., Personius, S. F., Wells, R. E., Schermer, E. R., Bradley, L., Buck, J., and Reitman, N. Holocene Earthquakes of Magnitude 7 during Westward Escape of the Olympic Mountains, Washington. *Bulletin of the Seismological Society of America*, 107(5):2394–2415, 2017. doi: 10.1785/0120160323.
- OpenStreetMap contributors. OpenStreetMap, 2025. Available as open data under the Open Data Commons Open Database License (ODbL) <http://openstreetmap.org/>.
- Palacky, G. Resistivity Characteristics of Geologic Targets. In *Electromagnetic Methods in Applied Geophysics: Volume 1, Theory*, pages 52–129. Society of Exploration Geophysicists, 1988.
- Patton, H., Hubbard, A., Heyman, J., Alexandropoulou, N., Lasabuda, A. P. E., Stroeve, A. P., Hall, A. M., Winsborrow, M., Sugden, D. E., Kleman, J., and Andreassen, K. The extreme yet transient nature of glacial erosion. *Nature Communications*, 13(1), 2022. doi: 10.1038/s41467-022-35072-0.
- Personius, S. F., Briggs, R. W., Nelson, A. R., Schermer, E. R., Maharrey, J. Z., Sherrod, B. L., Spaulding, S. A., and Bradley, L. A. Holocene earthquakes and right-lateral slip on the left-lateral Darrington–Devils Mountain fault zone, northern Puget Sound, Washington. *Geosphere*, 10(6):1482–1500, 2014. doi: 10.1130/GES01067.1.
- Petersen, M. D., Shumway, A. M., Powers, P. M., Field, E. H., Moschetti, M. P., Jaiswal, K. S., Milner, K. R., Rezaeian, S., Frankel, A. D., Llenos, A. L., Michael, A. J., Altekruze, J. M., Ahdi, S. K., Withers, K. B., Mueller, C. S., Zeng, Y., Chase, R. E., Salditch, L. M., Luco, N., Rukstales, K. S., Herrick, J. A., Giro, D. L., Aagaard, B. T., Bender, A. M., Blanpied, M. L., Briggs, R. W., Boyd, O. S., Clayton, B. S., DuRoss, C. B., Evans, E. L., Haeussler, P. J., Hatem, A. E., Haynie, K. L., Hearn, E. H., Johnson, K. M., Kortum, Z. A., Kwong, N. S., Makdisi, A. J., Mason, H. B., McNamara, D. E., McPhillips, D. F., Okubo, P. G., Page, M. T., Pollitz, F. F., Rubinstein, J. L., Shaw, B. E., Shen, Z.-K., Shiro, B. R., Smith, J. A., Stephenson, W. J., Thompson, E. M., Thompson Jobe, J. A., Wirth, E. A., and Witter, R. C. The 2023 US 50-State National Seismic Hazard Model: Overview and implications. *Earthquake Spectra*, 40(1):5–88, 2024. doi: 10.1177/87552930231215428.
- Portenga, E. W. and Bierman, P. R. Understanding Earth's eroding surface with 10Be. *GSA Today*, 21(8):4–10, 2011. doi: 10.1130/G1111A.1.
- Prothero, D. R., Draus, E., Cockburn, T. C., and Nesbitt, E. A. Paleomagnetism and counterclockwise tectonic rotation of the Upper Oligocene Sooke Formation, southern Vancouver Island, British Columbia. *Canadian Journal of Earth Sciences*, 45(4): 499–507, 2008. doi: 10.1139/E08-012.
- QGIS Association. QGIS Geographic Information System, 2018. <https://www.qgis.org/>.
- Reitman, N. G., Mueller, K. J., Tucker, G. E., Gold, R. D., Briggs, R. W., and Barnhart, K. R. Offset Channels May Not Accurately Record Strike-Slip Fault Displacement: Evidence From Landscape Evolution Models. *Journal of Geophysical Research: Solid Earth*, 124(12):13427–13451, 2019. doi: 10.1029/2019JB018596.
- Reitman, N. G., Klinger, Y., Briggs, R. W., and Gold, R. D. Climatic influence on the expression of strike-slip faulting. *Geology*, 51(1):18–22, 2022. doi: 10.1130/G50393.1.
- Rusmore, M. E. and Cowan, D. S. Jurassic–Cretaceous rock units along the southern edge of the Wrangellia terrane on Vancouver Island. *Canadian Journal of Earth Sciences*, 22(8):1223–1232, 1985. doi: 10.1139/e85-124.
- Salomon, G., Finley, T., Nissen, E., Stephen, R., and Menounos, B. Mapping fault geomorphology with drone-based lidar. *Seismica*, 3(1), 2024. doi: 10.26443/seismica.v3i1.1186.
- Savage, J. C. and Lisowski, M. Strain Measurements and the Potential for a Great Subduction Earthquake Off the Coast of Washington. *Science*, 252(5002):101–103, 1991. doi: 10.1126/science.252.5002.101.
- Savage, W. Z. and Varnes, D. J. Mechanics of gravitational spreading of steep-sided ridges («sackung»). *Bulletin of the International Association of Engineering Geology - Bulletin de l'Association Internationale de Géologie de l'Ingénieur*, 35(1):31–36, 1987. doi: 10.1007/BF02590474.
- Schermer, E. R., Amos, C. B., Duckworth, W. C., Nelson, A. R., Angster, S., Delano, J., and Sherrod, B. L. Postglacial Mw 7.0–7.5 Earthquakes on the North Olympic Fault Zone, Washington. *Bulletin of the Seismological Society of America*, 111(1):490–513, 2021. doi: 10.1785/0120200176.
- Seebeck, H., van Dissen, R. J., Litchfield, N. J., Barnes, P. M., Nicol, A., Langridge, R. M., Barrell, D. J. A., Villamor, P., Ellis, S. M., Rattenbury, M. S., Bannister, S., Gerstenberger, M. C., Ghisetti, F., Sutherland, R., Fraser, J., Nodder, S. D., Stirling, M. W., Humphrey, J., Bland, K. J., Howell, A., Mountjoy, J. J., Moon, V. G., Stahl, T., Spinardi, F., Townsend, D. B., Clark, K. J., Hamling, I. J., Cox, S. C., de Lange, W. P., Wopereis, P., Johnston, M., Morgenstern, R., Coffey, G. L., Eccles, J. D., Little, T. A., Fry, B., Griffin, J., Townend, J., Mortimer, N., Alcaraz, S. A., Massiot, C., Rowland, J., Muirhead, J., Upton, P., Hirschberg, H., and Lee, J. M. New Zealand Community Fault Model – version 1.0. *Science Report 2021/57*, 2022. doi: 10.21420/GA7S-BS61.
- Seebeck, H., Van Dissen, R., Litchfield, N., Barnes, P. M., Nicol, A., Langridge, R., Barrell, D. J. A., Villamor, P., Ellis, S., Rattenbury, M., Bannister, S., Gerstenberger, M., Ghisetti, F., Sutherland, R., Hirschberg, H., Fraser, J., Nodder, S. D., Stirling, M., Humphrey, J., Bland, K. J., Howell, A., Mountjoy, J., Moon, V., Stahl, T., Spinardi, F., Townsend, D., Clark, K., Hamling, I., Cox, S., de Lange, W., Wopereis, P., Johnston, M., Morgenstern, R., Coffey, G., Eccles, J. D., Little, T., Fry, B., Griffin, J., Townend, J., Mortimer, N., Alcaraz, S., Massiot, C., Rowland, J. V., Muirhead, J., Upton, P., and Lee, J. The New Zealand Community Fault Model – version 1.0: an improved geological foundation for seismic hazard modelling. *New Zealand Journal of Geology and Geophysics*, 67(2):209–229, 2024. doi: 10.1080/00288306.2023.2181362.
- Senyk, J. Shawnigan Surficial Geology 92B/12, 1975. <https://coms.api.gov.bc.ca/api/v1/object/a480f164-24f0-48bb-9e16-9a9e0f66f87d>.
- Seyler, C. E., Kirkpatrick, J. D., Faber, C., Licht, A., Šilerová, D., and Regalla, C. Structural and Metamorphic History of the Leech River Shear Zone, Vancouver Island, British Columbia. *Tectonics*, 41(11), 2022. doi: 10.1029/2021TC007132.
- Stahl, T. and Tye, A. Schmidt hammer and terrestrial laser scanning

(TLS) used to detect single-event displacements on the Pleasant Valley fault (Nevada, USA). *Earth Surface Processes and Landforms*, 45(2):473–483, 2020. doi: 10.1002/esp.4748.

Thompson, S. C., Weldon, R. J., Rubin, C. M., Abdrakhmatov, K., Molnar, P., and Berger, G. W. Late Quaternary slip rates across the central Tien Shan, Kyrgyzstan, central Asia. *Journal of Geophysical Research: Solid Earth*, 107, 2002. doi: 10.1029/2001JB000596.

Veness, H., Elia, E., and Ferbey, T. A digital update of Open File 1992-13: Surficial Geology map index of British Columbia. Technical Report 2024-09, British Columbia Ministry of Mining and Critical Minerals,, 2024. <https://www2.gov.bc.ca/gov/content/industry/mineral-exploration-mining/british-columbia-geological-survey/publications/openfiles%23OF2024-09>.

Washington Geological Survey. Surface geology, 1:500,000 scale-GIS data, February 2022: Washington Geological Survey Digital Data Series 25, 2022. previously released June 2010, https://fortress.wa.gov/dnr/geologydata/publications/data_download/ger_portal_surface_geology_500k.zip.

Wells, R. E. and McCaffrey, R. Steady rotation of the Cascade arc. *Geology*, 41(9):1027–1030, 2013. doi: 10.1130/G34514.1.

Wesnowsky, S. G. Displacement and Geometrical Characteristics of Earthquake Surface Ruptures: Issues and Implications for Seismic-Hazard Analysis and the Process of Earthquake Rupture. *Bulletin of the Seismological Society of America*, 98(4): 1609–1632, 2008. doi: 10.1785/0120070111.

Wessel, P., Luis, J. F., Uieda, L., Scharroo, R., Wobbe, F., Smith, W. H. F., and Tian, D. The Generic Mapping Tools Version 6. *Geochemistry, Geophysics, Geosystems*, 20(11):5556–5564, 2019. doi: 10.1029/2019GC008515.

Wolfe, F. D., Stahl, T. A., Villamor, P., and Lukovic, B. Short communication: A semiautomated method for bulk fault slip analysis from topographic scarp profiles. *Earth Surface Dynamics*, 8(1): 211–219, 2020. doi: 10.5194/esurf-8-211-2020.

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