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EVALUATING THE SLIP HISTORY OF CRUSTAL FAULTS UNDERLYING VICTORIA, BRITISH COLUMBIA

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INTRODUCTION

Because subduction zone megathrusts tend to produce the largest and most damaging earthquakes, significant attention has been focused on improving our understanding of the seismic cycle associated with the Cascadia megathrust fault in Canada (e.g. Dragert, 2001; Goldfinger et al., 2003; Wang et al., 2013). This improved knowledge has led to significant advancements in the identification and mitigation of seismic risk for the populated regions of the Pacific Northwest (Halchuk et al., 2015), which include the Canadian cities of Vancouver and Victoria, British Columbia (Fig. 1). Although the seismic hazard associated with the Cascadia megathrust is reasonably well understood, the active crustal faults that must overlie it remain poorly identified, especially in western Canada where active crustal faults have only just begun to be formally recognized (Fig. 1) (Morell et al., 2017).

We undertook a month-long field campaign stationed out of the town of Port Renfrew, British Columbia focused on evaluating the potential Quaternary activity and active kinematics of the Leech River and San Juan Fault systems. These two major crustal fault systems underlie the populated regions surrounding the capital city of Victoria, British Columbia on Vancouver Island (Figs. 1 and 2) and, until recently (Morell et al., 2017), were thought to be last active in the Eocene (MacLeod et al., 1977; *Johnston and Acton*, 2003). Student projects involved geologic mapping, kinematic analyses, and stratigraphic work along a ~45 km long region where the San Juan and Leech River fault systems intersect the Pacific coast in British Columbia.

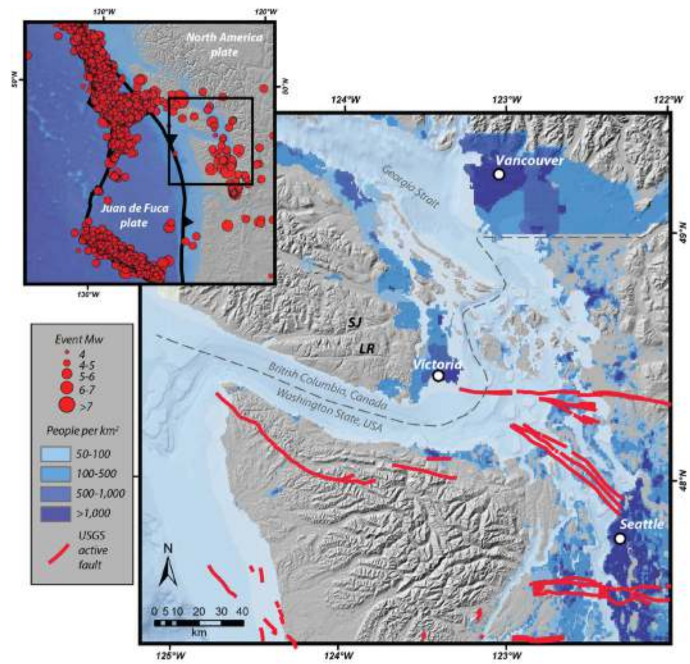

Figure 1. The population centers of the Pacific northwest (Balk et al., 2006) relative to the trace of identified active faults recognized by the US Geological Survey in western Washington state (red lines) (Nelson et al., 2007) and the Leech River (LR) and San Juan (SJ) faults. The inset map shows the plate tectonic setting, with the red circles indicating the locations of historical earthquakes from the USGS National Earthquake Information Center.

Current plate tectonic setting and seismicity on Vancouver Island

The Juan de Fuca plate subducts beneath Vancouver Island at a rate of approximately 45 mm/yr (DeMets et al., 2010) (Fig. 1). Much of this convergence is taken up on the subduction zone thrust, which is currently locked along its shallow portion and is

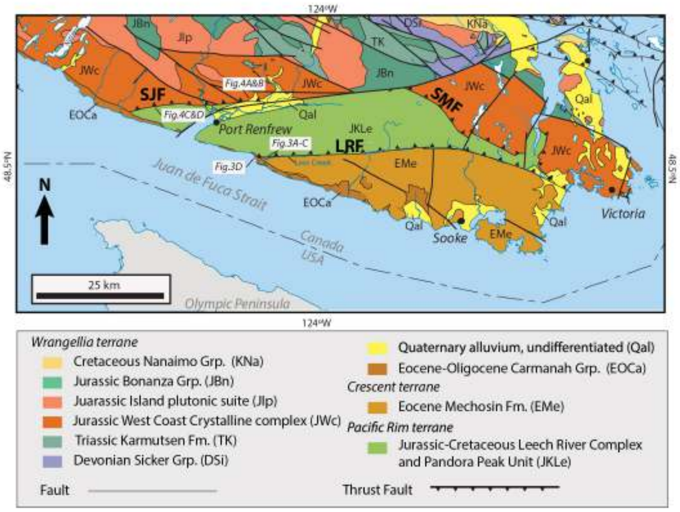

Figure 2. Simplified geologic map of southeastern Vancouver Island, British Columbia, Canada. Based on Massey et al. (2005). SJF = San Juan Fault, LRF = Leech River Fault, SMF = Survey Mountain Fault.

therefore considered capable of producing great earthquakes (McCaffrey et al., 2013). Radiocarbon dating of now-submerged forests suggest that the last great earthquake to have afflicted the region occurred approximately 300 years ago (Atwater, 1987; Atwater and Yamaguchi, 1991). The nature of seismicity within the crust above the megathrust is not as well defined, however, particularly in northern Cascadia where the recent Cordilleran glaciation has removed most sediments older in age than late Quaternary (Clague et al., 1982). But, emerging research suggests that prominent ancient terrane-bounding faults that criss-cross Vancouver Island could be reactivated in the current plate tectonic setting and could be capable of producing large seismic events (Morell et al., 2017).

TERRANE-BOUNDING FAULTS OF VANCOUVER ISLAND

The geologic architecture of Vancouver Island is described as a series of amalgamated terranes that accreted to North America starting in the Cretaceous (Muller, 1977). The Wrengellia terrane, which makes up the majority of Vancouver Island, is bound by the east-west striking San Juan and Survey Mountain Faults, which separate Wrangellia from the Mesozoic Pacific Rim Terrane near the southern tip of the island (Fig. 2) (Massey et al., 2005). The Pacific Rim Terrane is confined to the south by the Leech River Fault, a prominent east-west striking fault with a deep topographic valley that separates the Pacific Rim Terrane from the Crescent Terrane (Fig. 2) (Muller, 1977; Massey et al., 2005). The kinematics and slip history of all of these terrane-bounding faults on Vancouver Island are poorly constrained, with suggestions that they could be either thrusts (Muller, 1977; Clowes et al., 1987) or strike-slip faults with variable slip sense (Fairchild and Cowan, 1982; Johnson, 1984; Yorath et al., 1985; Clowes et al., 1987; Groome et al., 2003). Most past research has suggested that the Leech River and San Juan Faults was last active in the Eocene or older (MacLeod et al., 1977). However, new observations suggest that there are active strands of the Leech River fault system (Morell et al., 2017).

RECENT GLACIAL HISTORY OF VANCOUVER ISLAND

Almost all of the Quaternary sediments now preserved on Vancouver Island are related to the last glaciation which occurred in the late Pleistocene (Clague et al., 1982). At its maximum approximately 22,000 years ago, the Cordilleran ice sheet extended across all of Vancouver Island and the ice was more than 2000 m thick in the Georgia Strait (James et al., 2000, 2009). When deglaciation occurred ~14 ka, relative local sea level fell as much as ~100 meters in the region of southwestern BC (Clague et al., 1982; Shugar et al., 2014), leaving behind an abundance of post-glacial sediments across the Vancouver Island landscape. A large majority of this local sea level fall is attributed to isostatic rebound of the crust following ice retreat; The crust was depressed due to ice loading by more than 150 meters (James et al., 2000, 2009).

STUDENT PROJECTS AND RESULTS

Carlee Akam (University of Victoria) used the distribution and elevation of late Eocene to Oligocene marine sediments of the Carmanah Group to test for changes in vertical tectonism since deposition of these units. Carlee found the Carmanah Group to be more extensive and at higher elevations than previously recognized, especially in the San Juan Fault. Her results imply a significant amount of Olicoene to

Recent vertical tectonism that has been previously unrecognized, and could be caused either by slip along crustal faults or, net uplift associated with interseismic cycles of the Cascadia subduction zone.

John Borah (Colorado College) and Nolan Lescalleet (Union College) both conducted kinematic analyses of the San Juan Fault via analysis of slickenlines, fault orientations, and thin section microstructure. Nolan and John's work found that the San Juan Fault is a sub-vertical fault zone as much as 0.5-1 km wide that contains numerous mesoscale faults within this larger fault zone. Their kinematic analyses show that the San Juan Fault is dominated by a left-lateral slip history, with only a minor dextral component. This left-lateral slip history may be related to active bending of the Olympic orocline and Olympic peninsula, and/or subduction zone strain accumulation.

Brendan Powers (Trinity University) conducted a detailed study of a heavily deformed glacial-marine sediment package exposed in a quarry that lies across the San Juan fault. Brendan found that rather than being related to displacement along the San Juan fault, the deformation exposed in this quarry is instead related to post-glacial processes and collapse of the Cordilleran ice sheet.

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