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Abstract

Based on recently collected seismic-reflection survey data, the western extent of the active Devils Mountain Fault where it meets the Leech River Fault has been mapped for the first time, just offshore of the cities of Victoria and Esquimalt, British Columbia. This combined approximately 180 km long fault has now been mapped from the interior of Washington State, USA onto southern Vancouver Island, BC, Canada. The occurrence of such an active fault zone poses a high possibility of a significant crustal earthquake occurring near the cities of Victoria and Esquimalt.

Introduction

Geological mapping from mainland Washington State across Whidbey Island and along the eastern Strait of Juan de Fuca has revealed extensive active crustal faulting (Figures. 1 and 2) that trend westward towards the Canada/USA boundary (Johnson et al., 2001). These faults occur within a converging Cascadia forearc that is caught between a northward migrating forearc sliver and a stationary buttress of older crust (McCaffrey et al., 2013). The area is subject to earthquakes from sources on the subduction zone interface, in the down-going slab, and on shallow crustal faults in the upper plate. Until recently, little was known of the western extent of these crustal fault zones as they cross into Canada towards the cities of Victoria and Esquimalt, nor their potential for generating a sizable earthquake. Recent research indicate that active faults such as the 60 km long Leech River Fault (LRF) system trends toward Victoria (Morell et al., 2017) and likewise offshore, the Devils Mountain Fault Zone (DMFZ) extends 125 km eastward from Victoria into Washington State (Barrie and Greene, 2018) (Figure 1). Both Barrie and Greene (2018) and Morell et al. (2017) suggest that the Devils Mountain Fault and the reactivated Leech River Fault are one fault. However, we still lack the evidence to confirm this interpretation off the cities of Victoria and Esquimalt, where mapping of the two faults meet. If the Devils Mountain and Leech River fault zones are in fact one fault zone, a rupture would have the potential to generate a much larger earthquake and is a greater risk to the nearby populations and infrastructure of Victoria and Esquimalt.

The objectives of this marine geohazard evaluation is to map fault features in the near shore sedimentary environment to determine if there is a single fault zone extending from Washington State to Vancouver Island and to make observations on the occurrence of recent fault activity.

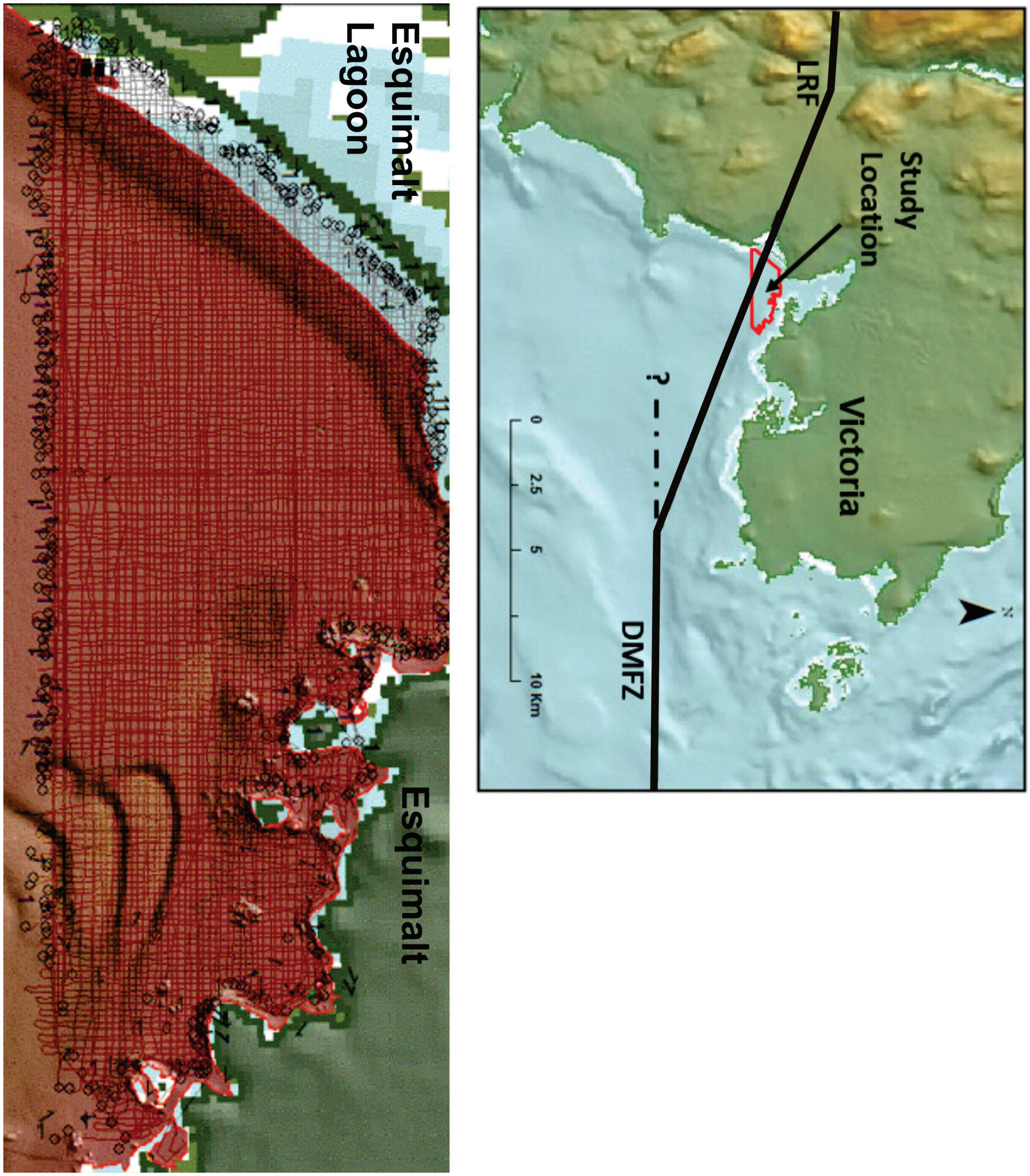

Figure 1: Location map of detailed survey undertaken near the cities of Victoria and Esquimalt, including locations of the Devils Mountain Fault Zone (DMFZ) and Leech River Fault (LRF). Lower panel shows the seismic-reflection survey lines overlain on multibeam bathymetry.

Data acquisition and methods

A high-resolution seismic-reflection geophysical survey was undertaken offshore of Victoria in 2010 for evaluation of a wastewater treatment pipeline. The survey grid used a very tight spacing (20-35 m) and covers an area of ~4 km x 3 km, and includes 241 acoustic profile lines (shown in Figure 1).

The survey was acquired using an electric pulser source, with 250 Hz centre frequency. The receiver (hydrophone) was placed astern the survey vessel and 15 m behind the source (Sub-marine pipeline crossing CRD wastewater treatment program Report, 2010).

IHS Kingdom Suite was used for the interpretation and mapping of the sub-bottom acoustic data. Criteria for the identification of active faults are: 1) the juxtaposition of acoustic characteristics such as displaced well-layered reflections; 2) truncation of layered reflections against acoustically transparent or chaotic reflections; 3) deformed reflections along a vertical or slanting plain; and 4) hyperbolic diffractions associated with truncation of layers (i.e., a probable fault plain), or a combination of one or more of the above criteria. Using these criteria, the locations of fault features on each seismic line was mapped (red ticks on Figure 2). Major fault zones were identified from clustering of these fault features along linear trends.

Results

Based on the resolution of seismic-reflection methods that were employed, several subsurface features related to the presence of faults were identified and mapped. The features include identifiable faults, stratigraphic deformation and gas related structures. Figure 2 shows the distribution of features identified within the seismic-reflection survey data set.

The features occur within three main sedimentary units observed within the seismic-reflection data. Fault related features can be divided into relative age (older/younger) based on which stratigraphic reflectors have been affected. The sedimentary units have been described by Mosher and Hewitt (2004) and Barrie and Greene (2018) and include three units that overlie bedrock. From the top down they are, upper post-glacial (Holocene) sediment, lower post-glacial sediment (Holocene), and glacial-marine sediment. The upper post-glacial and lower post-glacial sediments are separated by an unconformity interpreted as an erosional surface carved into early post-glacial deposits that has an age of approximately 9,800 ^{14}C BP (Barrie and Greene, 2018). The unconformity and underlying glacial-marine horizons create high amplitude reflectors within the high-resolution seismic-reflection data, shown in Figures 3 and 4.

Faults

Faults were identified in seismic-reflection profiles by vertical displacement of stratigraphic reflectors through both the glacial-marine unit and younger overlying post-glacial units. Though there are indications of sediment disturbances within the upper post-glacial unit, it has weak stratification and is generally unreliable for fault interpretation. However, multiple observations of broken stratigraphy were made, with deformation that appears to extend upward to the seabed (Figure 3). Because the upper post-glacial features are poorly defined in this data set, further study would be beneficial for a reliable analysis of how recently active the faults were (see Recommendations).

Faulting is widespread within the lower post-glacial unit, and though many faults do not trace line to line, general trends were interpreted and mapped (Figure 2). In seismic-reflection profile (Figures 3 and 4) faults < 3.5 m of vertical displacement can be seen to displace seismic reflectors in the glacial-marine and lower-post glacial units. The primary strand is orientated in a northwest–southeast direction and correlates with the mapped primary fault across the Strait of Juan de Fuca (Barrie and Greene, 2018). Secondary splays run parallel to the primary fault and form part of the fault zone, with at least two of these coming ashore in the city of Esquimalt. Based on past research (Barrie and Greene, 2018; Morell et al. 2017; Bednarski, 2016), the location of the primary fault through the survey area appears to be consistent with the intersection of the Devils Mountain and Leech River faults, suggesting that they are part of the primary zone. The occurrence of multiple parallel fault features is consistent with previous terrestrial findings along the Leech River fault, where a 1 km wide steeply dipping fault zone had been described (Morell et al.,2017) and along the Devil's Mountain fault where a fault zone of up to 6 km occurs (Barrie et al., 2018).

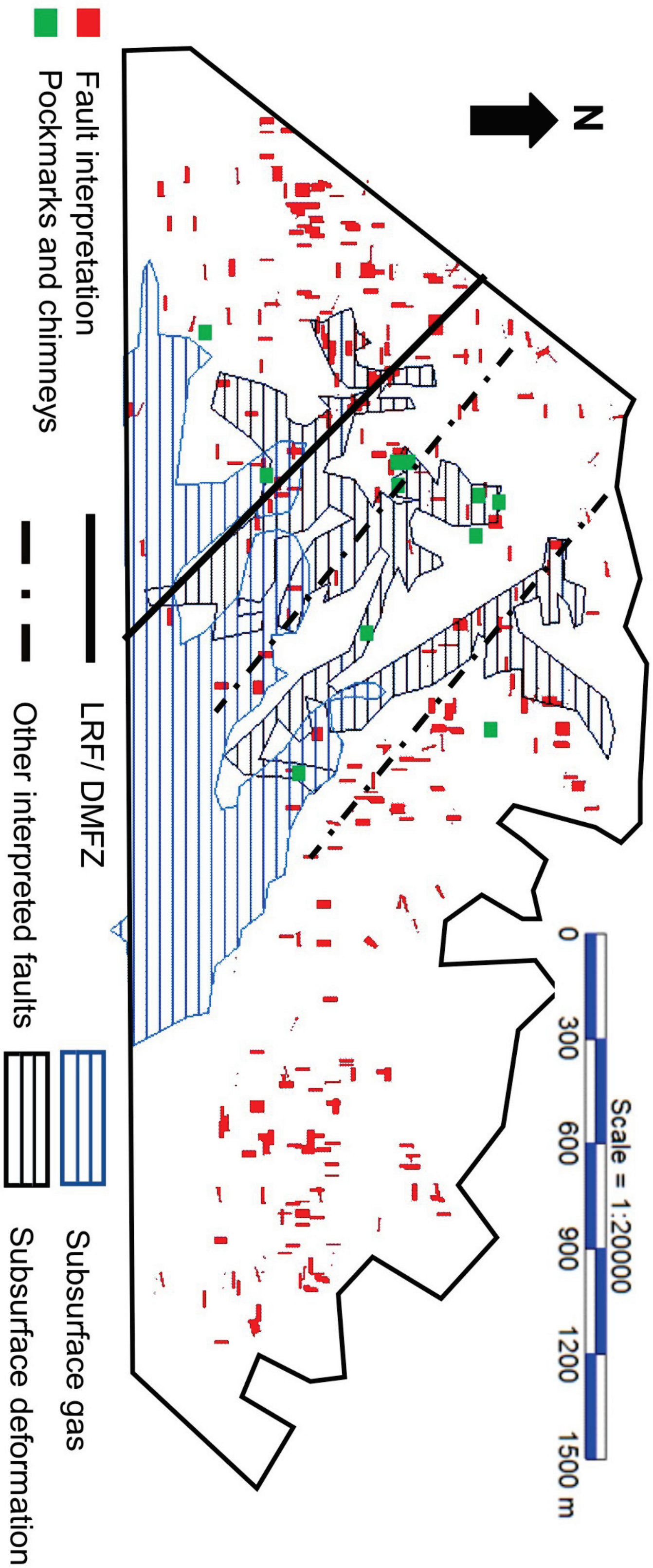

Figure 2: Interpretation of the primary fault (DNFZ/LRF) location from dataset and the location of secondary faults, substrate deformation (folding) and shallow gas.

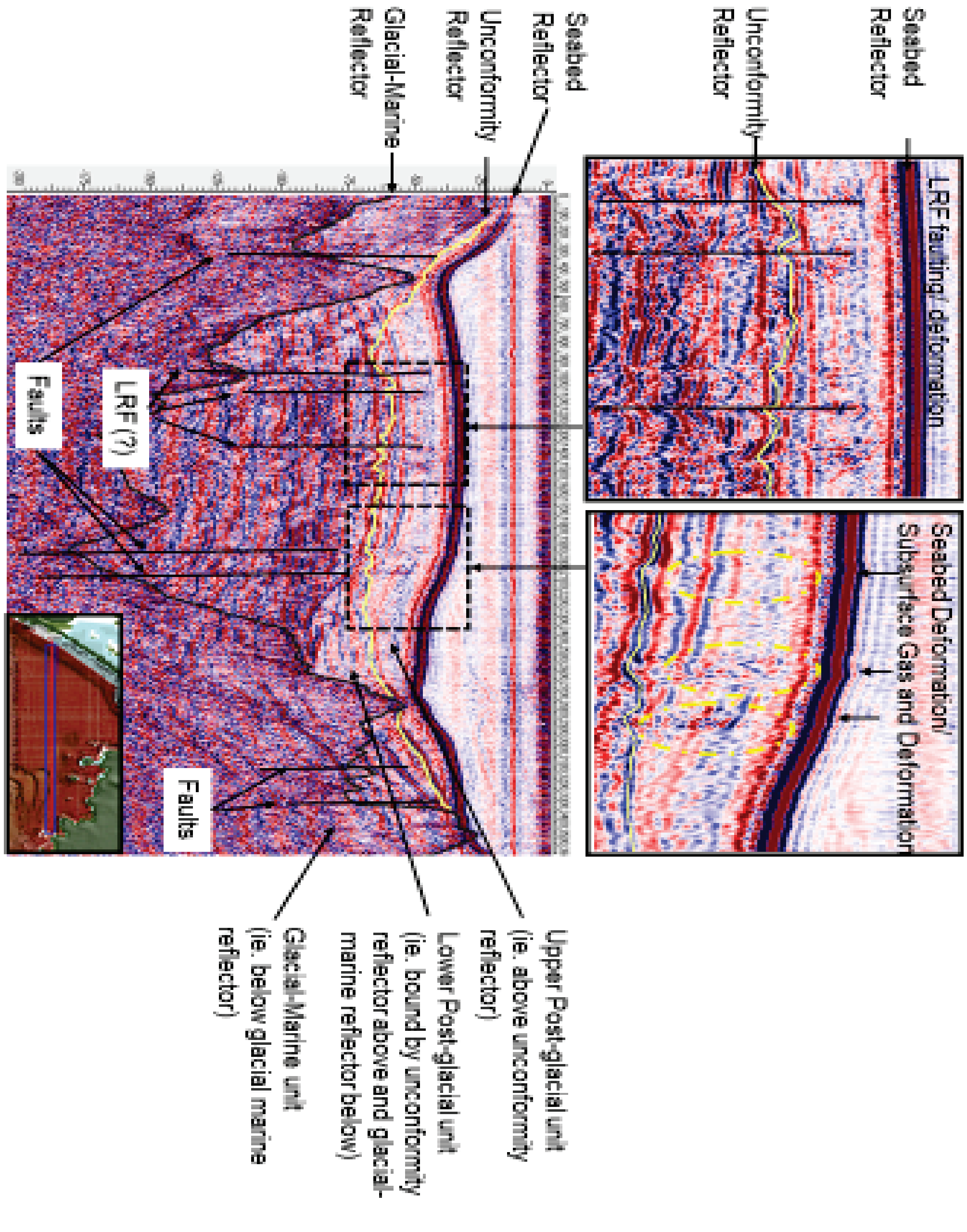

Figure 3: A west-east seismic reflection profile showing the unconformity reflector and glacial-marine reflector. There are multiple examples of faulting in this seismic reflection profile. The faults interpreted as Leech River Fault appear to cross the unconformity in this example. In other locations, deformation and gas above the unconformity also may relate to faulting. X and Y axis of the seismic reflection profile is in meters. Location of survey line is shown on small map in lower right corner.

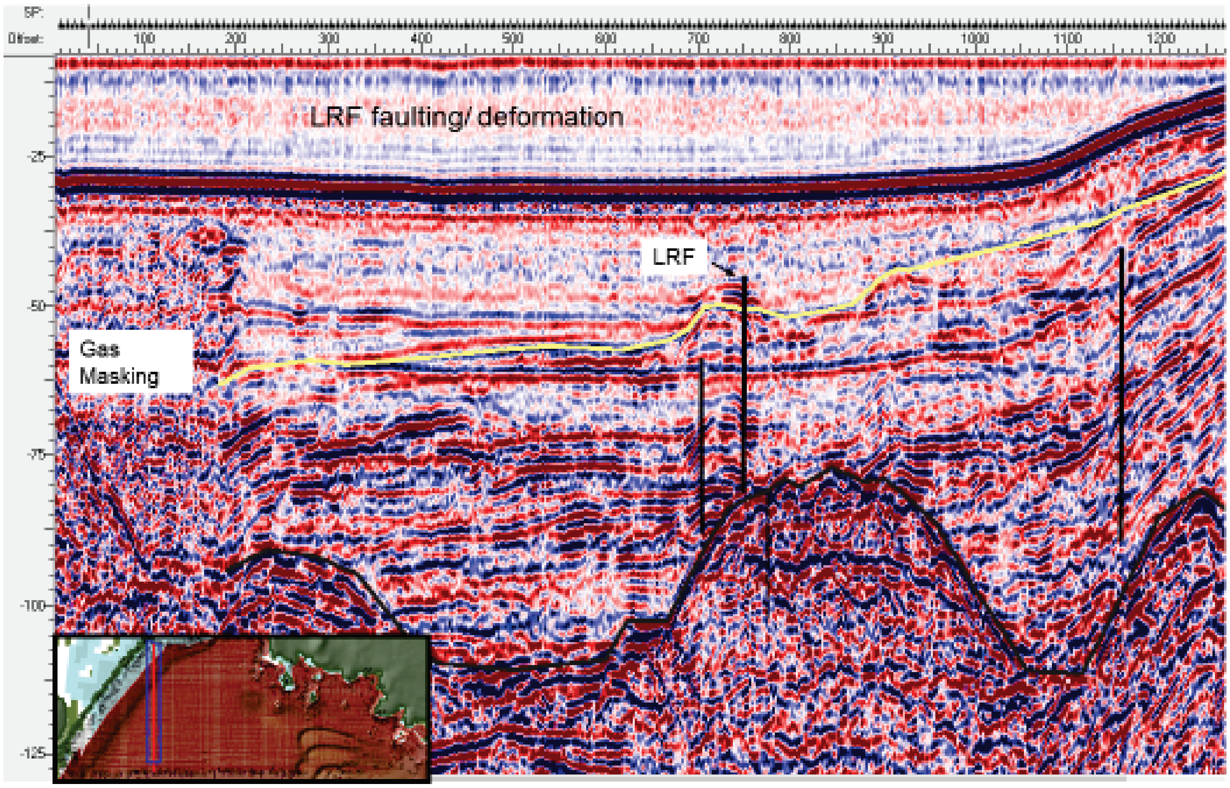

Figure 4: A south-north seismic reflection profile shows Leech River Fault associated with deformation. In this example a mound structure can be observed above the glacial-marine boundary upward to the unconformable reflection surface, with ~5-10 m vertical relief. Faults associated with the mound structure displace reflectors from glacial marine unit and cross the unconformity, into the upper post-glacial unit.

Deformation

Widespread fold deformation features are present within the lower-post glacial unit. Mapping of these features indicates a spatial relationship between these deformation features and the primary interpreted faults (Figure 2). These features have linear trends, directed northwest to southeast, extending laterally for ~500 – 1200 m.

Shallow gas

Shallow subsurface gas is present within post-glacial sediment throughout the survey area. Such features as gas masking, gas chimneys and pockmarks are found within lower and upper post-glacial units. Gas masking has obscured much of the southern portion of the seismic-reflection survey, it is also where post-glacial sediments are thickest. It is common for post-glacial sediment to consist of organic rich mud accompanied by biogenic gas, which forms from bacterial decomposition of organic matter at low temperatures. Gas masking features were mapped throughout the survey area, as shown in Figure 2. There is a northwest–southeast linear distribution of subsurface gas that overlaps spatially with deformation and fault trends. There may be a association between faults and gas features, as faults tend to act as vertical conduits for gas through the sedimentary column. This is exemplified in Figure 5, where a fault structure is associated with deformation, gas chimney and surface pockmarks. Gas chimneys and pockmarks were found in 10 locations within the survey area, and are also shown in in Figure 2.

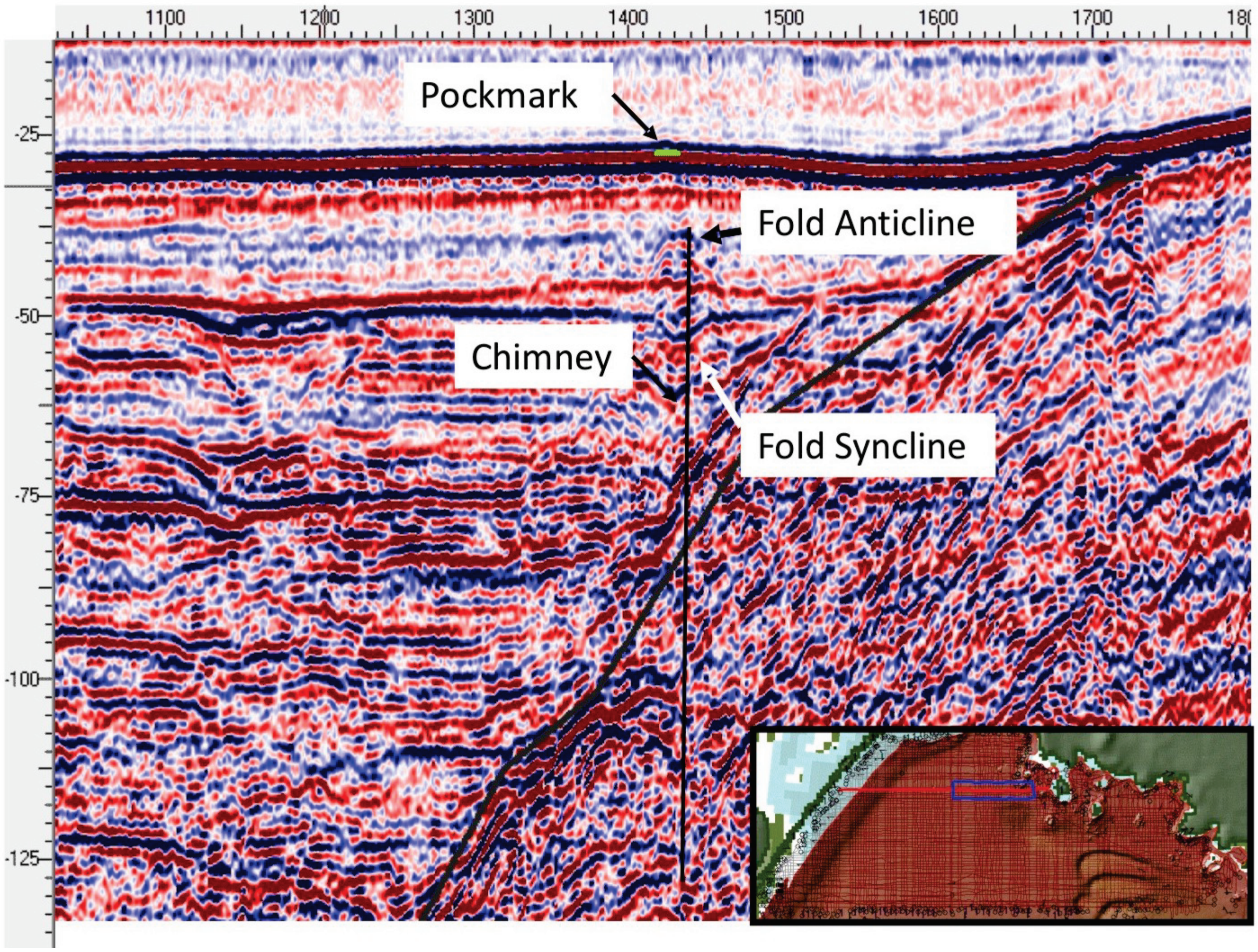

Figure 5: A west-east seismic reflection profile exhibiting deformation, gas chimney and pockmark associated with fault displacement. A fold anticline has formed above the unconformity and fold syncline structure below.

Summary

Based on this recently collected seismic-reflection data, the western extent of the active Devils Mountain has been mapped for the first time, offshore of the cities of Victoria and Esquimalt, British Columbia where it becomes the reactivated Leech River Fault that extends onto Vancouver Island. These two faults are one fault system. This single fault zone consists of a primary strand and secondary splays and conjugate faults with extensive folding (Barrie et al., 2018) that forms a 1 to 6 km wide fold and fault belt extending approximately 180 km from the interior Washington State, USA onto southern Vancouver Island, BC, Canada. The occurrence of this active fault poses a high possibility of a crustal earthquake occurring near the cities of Victoria and Esquimalt.

Recommendations

Based on this preliminary geophysical investigation, results are consistent with the intersection of a complex system of a singular major crustal fault, the Devils Mountain – Leech River Fault Zone. There is still a need to further examine fault risk. Several methods can be applied to better define deeper fault structures and occurrence rates of recent seismic events:

1. Evidence of most recent fault activity, from the upper post-glacial unit, was not reliable in the dataset. Barrie and Greene (2018) suggest that these upper post-glacial sediments are considerably unconsolidated, and as there is no discernable stratigraphy in the geophysical profiles, it is possible that no record of Holocene faulting during an earthquake will be seen acoustically. Better definition could be found using a higher frequency tool. A high-resolution geophysical survey using higher frequency shot output (i.e. 3.5 kHz) would be more suitable for observations within the upper 10-20 m of sediment. An acoustic survey in combination with ground truth coring project targeting upper and lower post-glacial stratigraphy is of most interest to understand frequency of fault activity. Surveys should also be conducted in Esquimalt Lagoon as it may have better preserved sediment record of seismic events due to its isolated location from ocean processes.

2. Fault features mapped in this dataset are consistent with what would be expected in a fault zone, however bedrock observations should be conducted to confirm this interpretation. An ocean bottom seismic survey would be conducive to deeper penetration into bedrock in order to better delineate each fault.

3. In addition, terrestrial based mapping should be designed to investigate the onshore linear trends of faults observed in this study near the city of Esquimalt similar to that undertaken along the Leech River Fault (Bednarski, 2016). One fault that approaches the shoreline of eastern Esquimalt has been identified onshore (T. P. Gallagher, personal communication), while several others that approach the Department of National Defense property need to be mapped.

References:

Barrie, J.V. and Greene, H.G., 2018. The Devils Mountain Fault zone: An active Cascadia upper plate zone of deformation, Pacific Northwest of North America. Sedimentary Geology, 364, 228-241.

Bednarski, J.M., 2016. Preliminary investigations of unconsolidated sediments overlying the Leech River fault zone, southern Vancouver Island, British Columbia. Geological Survey of Canada, Open File Report 8046, doi:10.4095/298808.

Johnson, S.Y., Dadisman, S.V., Mosher, D.C., Blakely, R.J. and Childs, J.R., 2001. Active tectonics of the Devil Mountain fault and related structures, northern Puget Lowland and eastern Strait of Juan de Fuca region, Pacific Northwest. United States Geological Survey, Professional Paper 1643, 45 pp.

McCaffrey, R., King, R.W., Payne, S.J. and Lancaster, M., 2013. Active tectonics of northwestern U.S. inferred from GPS-derived surface velocities. Journal of Geophysical Research, Solid Earth 118, 709-723.

Morell, K. D., Regalla, C., Leonard, L. J., Amos, C., and Levson, V., 2017. Quaternary rupture of a crustal fault beneath Victoria, British Columbia, Canada, GSA Today, 27, 4-10.

Mosher, D.C. and Hewitt, A.T., 2004. Late Quaternary deglaciation and sea-level history of eastern Juan de Fuca Strait, Cascadia. Quaternary International, 121, 23-39.

Sub-marine pipeline crossings CRD wastewater treatment program Report, 2010. Report to the Capital Regional District of Victoria.