SCICON 2016 - Thin Ice field trip

Shifting shorelines: sea-level change - past, present and future

Cliff Atkins
School of Geography, Environment and Earth Sciences
Victoria University of Wellington

This guide provides an outline of our planned itinerary and comments on the features we will see and points for discussion. Locations are shown in Figure 1.

ITINERARY:

12.05-12.45pm	Lunch
1.00-1.45pm	**Stop 1:** Wainuiomata Hill lookout
2.00-2.45pm	**Stop 2:** Petone Beach
2.45-3.30pm	Drive through Wellington CBD-old shoreline to VUW
3.30-5.00pm	Thin Ice screening and discussion at VUW

Figure 1. Oblique aerial photograph of Wellington region with fieldtrip stops and other localities mentioned. Photo by D.L. Homer modified (from Begg and Mazengarb, 1996).

Introduction:
This aim of this field trip is to explore and discuss one of the most direct impacts of climate change- sea level variation - and how this influences the position of the shoreline and low-lying coastal areas. Site 1 is the Wainuiomata Hill lookout where we can observe Wellington Harbour and the dramatic consequences of sea level change over longer time scales (1000's to 100's of thousands of years). Site 2 is Petone foreshore where we will consider issues related to historical and near-future changes in sea level (decades to centuries). We will then drive through the Wellington CBD along part of the 1840 shoreline to Victoria University for a screening of key parts of the 'Thin ice' film and discussion session.

Sea level:
We commonly think of sea level as being stable. We measure the height of the land (topography) in metres above sea level, and depth of water (bathymetry) in meters below sea level. However, sea level has fluctuated throughout geological history. It depends on local and global factors. Global (or eustatic) sea level is controlled by the volume of ocean basins and the volume of water which is linked to the amount of ice as well as temperature of the water. Local sea level is measured relative to a particular (local) piece of the Earth's surface. Local sea level changes can be due to tectonic uplift or subsidence, sedimentation or isostatic effects. The interplay of eustatic and local effects determines *relative* sea level in any particular place.

Climate and sea level on glacial/interglacial scales:
Over the last 800,000 years, the Earth's climate has fluctuated through regular 100,000 year Glacial/Interglacial cycles. Figure 2 shows the remarkable correlation between atmospheric CO_2 levels, temperature and sea level which has fluctuated over 100m through each climate cycle. For example, 15-20,000 years ago (Last Glacial Maximum), global sea level was about 130m lower than it is now because the ice sheets in Antarctica and high latitude northern hemisphere locked up large volumes of water as ice. CO_2 has risen dramatically in the last 200 years to 400ppm, higher than any point in last 800,000 years and possibly last 3 million years.

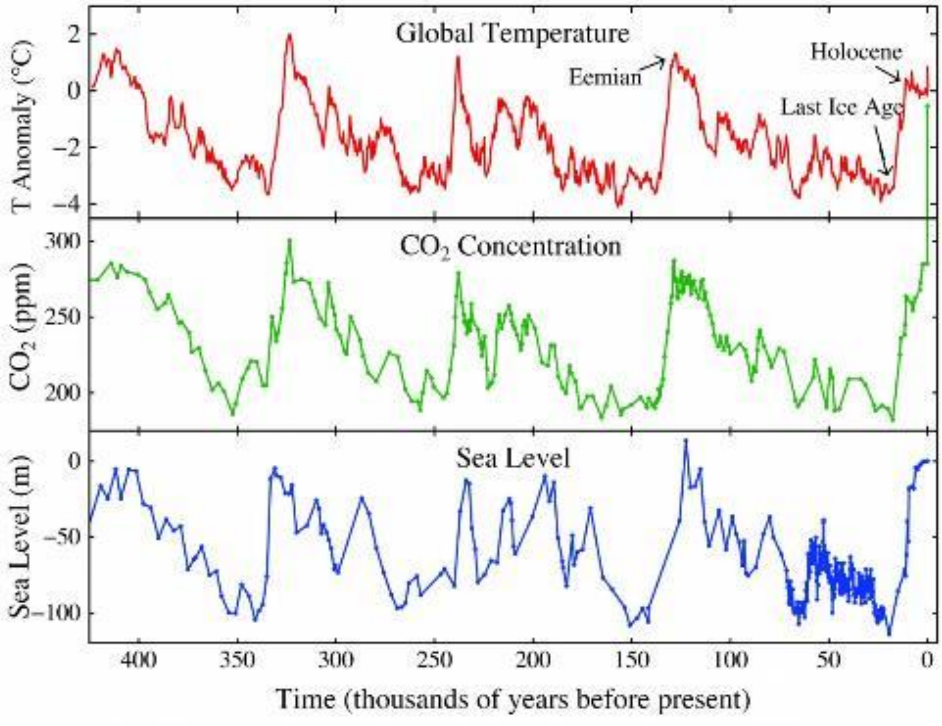

Figure 2. Relationship between CO_2, temperature and sea level showing clear 100,000 year cyclicity over the last 400,000 years (http://johnenglander.net based on data from Hansen and Sato, 2012).

Wellington Tectonic setting:

The Wellington Region is a tectonically active area, situated over a plate tectonic boundary and broken by many faults (fig 3). Most are thrust faults and when they move, the land on one side is uplifted relative to the other. The location of faults has a major influence on the shape of the Wellington landscape, giving the dominant northeast-southwest alignment of hills and valleys and dictates the shape of Wellington Harbour. Movement of the faults (earthquakes) only occurs every few centuries, but the uplift or subsidence that occurs is on a scale of several metres and occurs in a matter of minutes. This is an important local factor in determining where the land meets the sea. Uplift on the Wairarapa Fault (e.g. 1855) uplifts and tilts entire Wellington Region. Movement on the Wellington Fault uplifts the hills on the western side of the fault but also causes localised subsidence immediately east of the fault (fig 4).

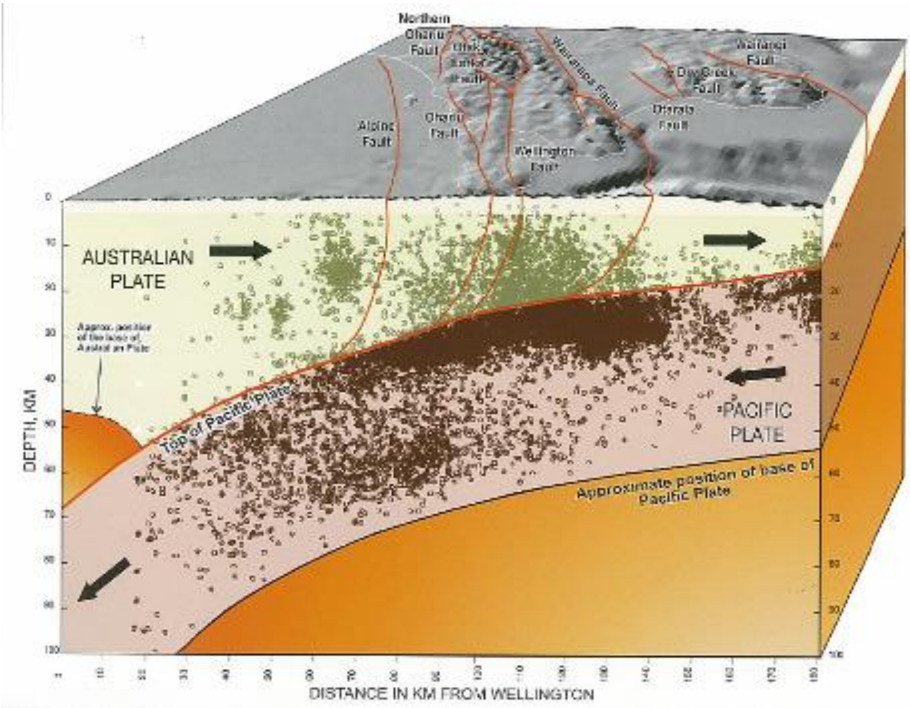

Figure 3. Cross section though the Wellington showing the relationship between the Pacific and Australian plates and location of main earthquake generating faults. Black arrows indicate relative plate motion and small circles indicate microseismic activity between 1987 and 1993 (from Begg and Johnston, 2000).

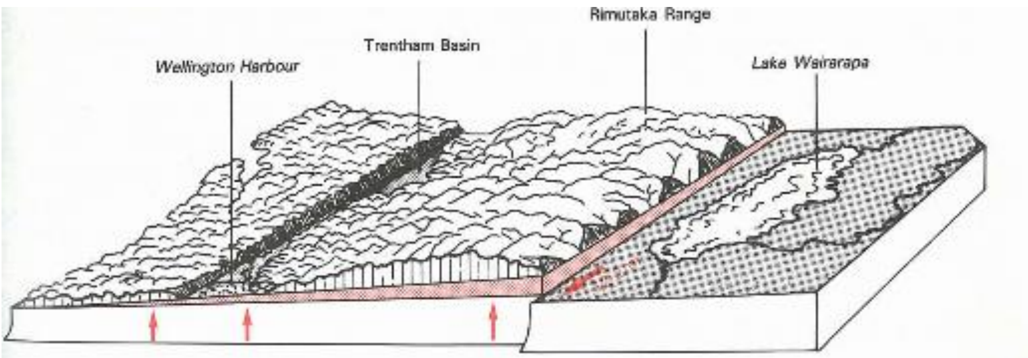

Figure 4. Cross section though the Wellington and Wairarapa Faults showing how the uplift and tilting affects the landscape (from Stevens 1991).

STOP 1: Wainuiomata Hill Lookout 1.00-1.45pm

Wainuiomata Hill lookout provides us with a good view of Wellington Harbour. From here we can identify several major features of the landscape such as faults, uplifted hills, valleys and shoreline. It is also an opportunity to consider the effect of changing global sea level on a 1000s to 100s of thousands of years timescales. Features to note and list on Figure 5.

- Wellington Fault and motorway/railway. The motorway and railway is built on the platform uplifted during previous earthquake events (1855 Wairarapa Earthquake and 1460 Wellington Earthquake). The Wellington Fault has uplifted the hills on the western side of the harbour and caused localised subsidence on the western side of the Hutt Valley where the extensive Te Mome swamp existed prior to 1855.

- Wellington Harbour. The deepest point is only 30-40m deep. During the Last Glacial Maximum (20,000 years ago), global sea level was 130 m lower due to ice build up at the poles. As a result, there was no harbour and the Hutt River had to flow out through the Hutt/Wellington Valley to get to the coast.

- The Petone shoreline marks the edge of the Hutt delta that is slowly building out into Wellington Harbour. The Hutt Valley is underlain by thick gravels interbedded with thinner layers of marine mud. Much of the water from the Hutt River flows underground through these gravels and emerges as springs in Wellington Harbour -more on this later.

- Reclaimed land at Wellington (Wellington waterfront and port in distance) and at Seaview (left foreground industrial buildings and marina). The pre-1855 shoreline was positioned roughly half way across the flat land in left foreground).

- Site of the original settler township of Britannia on the far side of the Shandon golf course (pine trees).

- Matiu -Somes Island, noting three distinct levels (fig 6). The same sequence of terraces is present at Baring Head which is coincidentally the site of New Zealand's longest CO_2 recording station. The terraces were cut by the sea during past high sea levels, and then tectonically uplifted. Higher terraces record older sea levels (fig 7).

Figure 5. Panorama of Wellington Harbour and Petone shoreline from Wainuiomata Hill lookout.

Figure 6. Matiu-Somes Island showing three distinct interglacial wave-cut terraces eroded into the bedrock. The youngest terrace was cut during the last interglacial 125,000 years ago and has been uplifted about 30 m above present sea level.

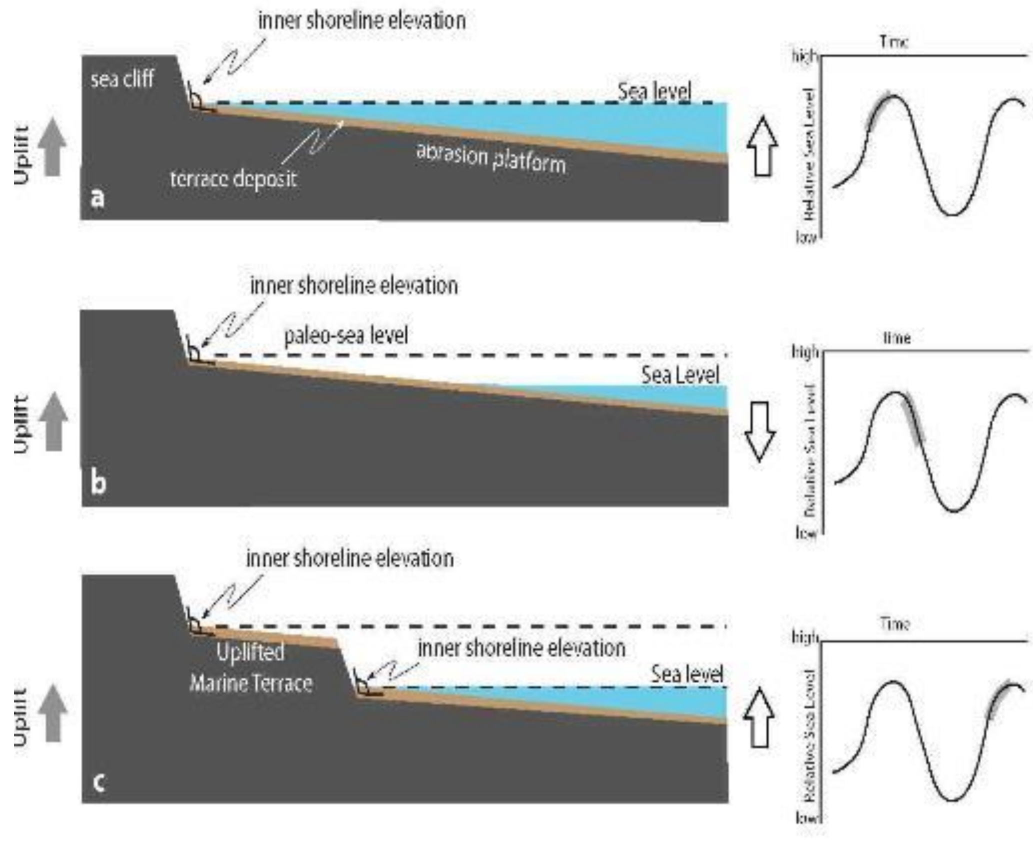

Figure 7. Model of marine terrace formation due to a combination of wave abrasion during high sea level of interglacials and long-term tectonic uplift.

Discussion Points:

- *Links between CO_2, temperature and global sea level change are well understood. We know what happens to temperature, ice volume and sea level when CO_2 increases. We are now outside the 'natural envelope' of variation in CO_2 over the last 800,000 years.*
- *Paleo evidence gives clear record of long term climatically driven variations in sea level.*
- *Relative sea level is a complex mix of eustatic and local factors and has a fundamental impact on low lying coastal areas.*

STOP 2: Petone Beach 2.00-2.45pm

The stop at Petone foreshore is a good place to consider issues related to historical and near-future changes in sea level (decades to centuries).

- **Hutt Valley (Waiwhetu) aquifer and Te Puna wai ora springs (Spring of life)**

Before going to the modern beach, we will pause at the Te Puna wai ora springs on Buick Street to enjoy a cup of pristine artesian water and consider how long-term sea level changes have produced a natural aquifer that is critical to Lower Hutt and Wellington water supply.

The Hutt valley is underlain by sediment deposited in a basin formed by localised subsidence adjacent to the Wellington Fault. On the western margin, the sediment is over 300m thick. Repeated changes in sea level have resulted in marine flooding of the Hutt Valley, depositing thin layers of marine mudstone alternating with thick layers of permeable river gravel and forming an excellent aquifer system (Figure 8). The aquifer is recharged by water infiltration in the Taita-Avalon area and forms a pressurised artesian water system that supplies about 25-30% of water consumed in Wellington and Hutt Valley. Some water re-emerges as springs (e.g. Te Puna wai ora in Buick Street and also below sea level near Matiu-Somes Island (Begg and Johnston, 2000). The water takes several years to flow through the aquifer before emerging at the surface and is considered to be very high quality drinking water. However, if sea level rises then the aquifer becomes susceptible to salt water contamination. Modelling indicates that there will be a 15% reduction in fresh water yield for a 0.75m rise in sea level and 31% reduction for a 1.5 m rise (Gyopari, 2014, cited in the PCE report).

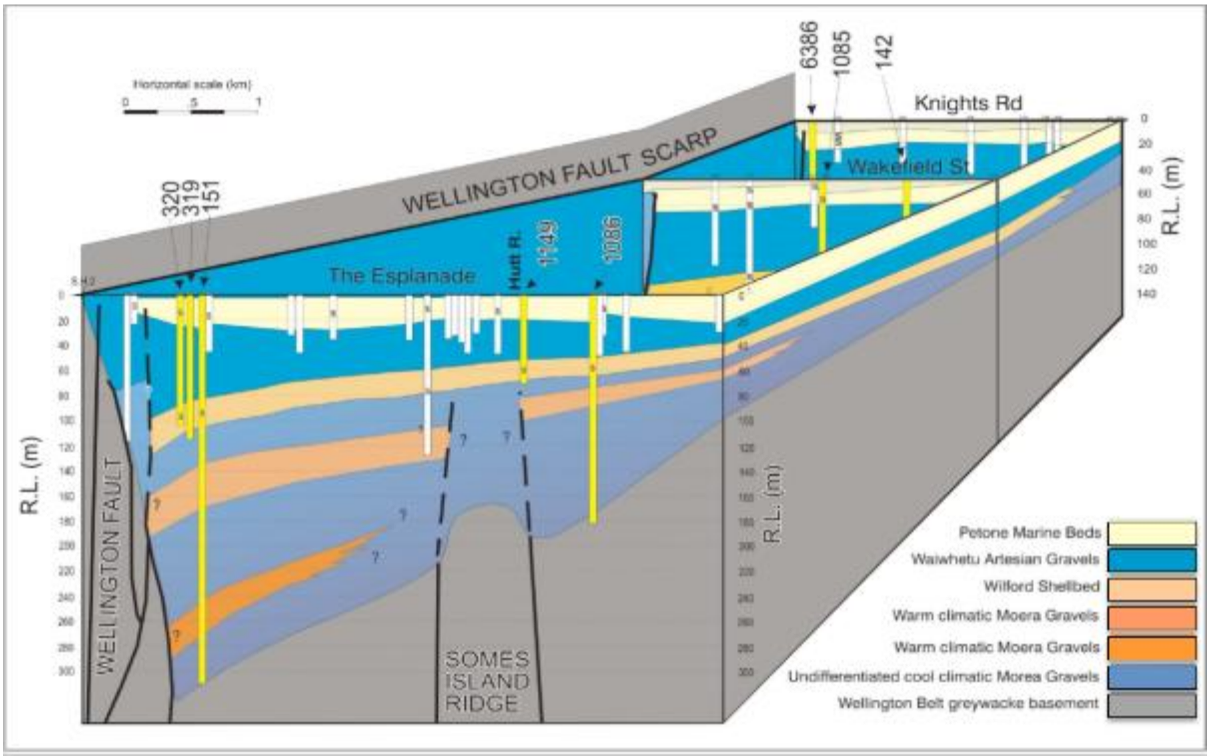

Figure 8. Three dimensional cross section across Lower Hutt-Petone showing thick accumulation of sediment in the fault angle depression. Layers of permeable gravel are interbedded with finer-grained impermeable 'marine deposits' forming the Hutt Valley aquifer. Numerous drill holes are shown (after Begg and Mazengarb, 1996).

- **Petone Beach and past relative sea level change.**

Sea level rise after the LGM was rapid until about 6000 years ago, when the rate slowed considerably and stabilised in the last 2000 years (fig 9). Since then the Hutt delta has built out (prograded) into the harbour, due to deposition of sediment from the Hutt River and regional tectonic uplift and localised subsidence. A complex series of gravel beach ridges, swamps and estuaries has formed over time as the shoreline has generally built out into the harbour (fig 10). Prior to the 1855 earthquake on the Wairarapa Fault, much of Petone was low lying swamp at sea level and the beach was about 100m inland of its present position (fig 11).

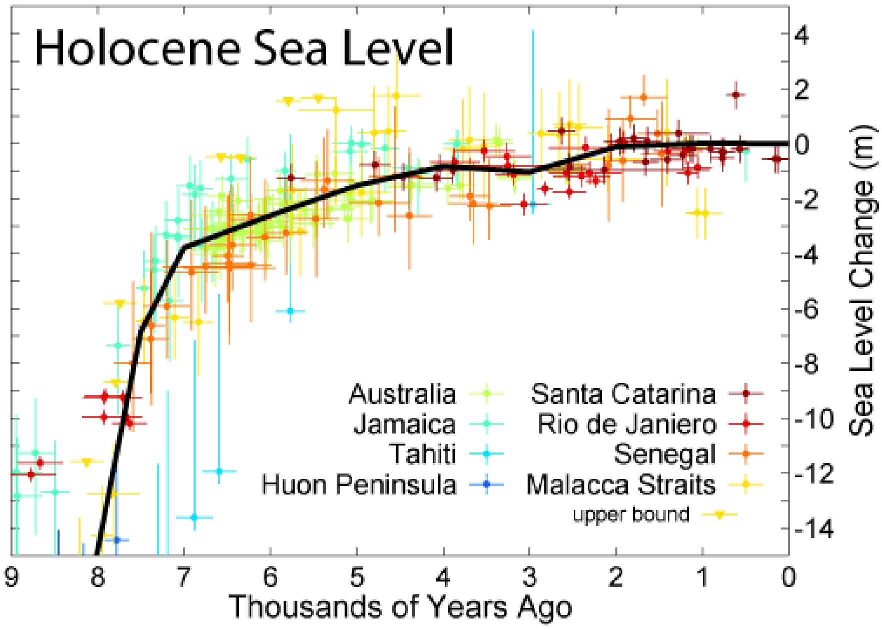

Figure 9. Holocene (last 10,000) years showing rapid sea level rise until about 6000 years ago and then only slow rise and stabilisation at about 2000 years ago. Sourced from https://commons.wikimedia.org/ and based on data from Fleming et al 1998 and Milne et al 2005.

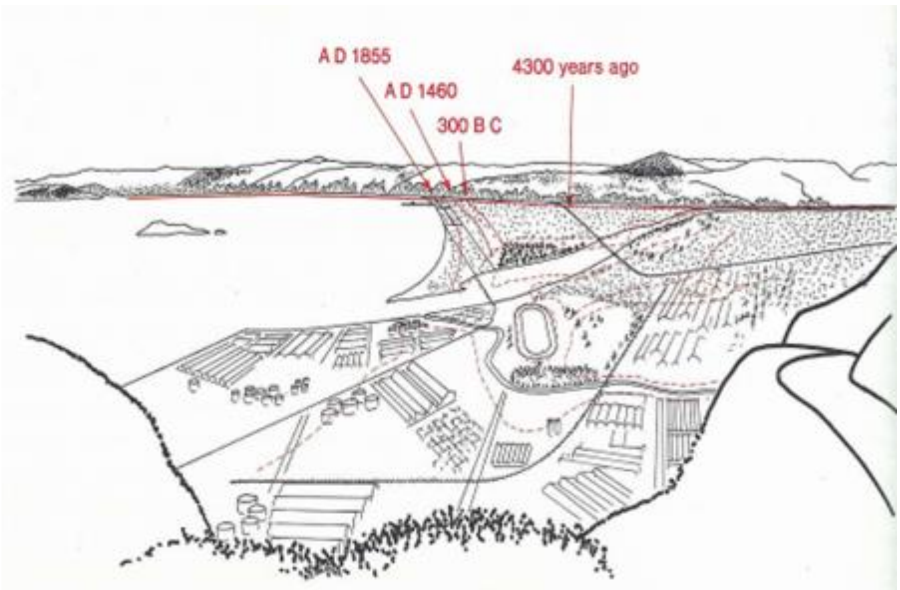

Figure 10. Past positions of the shoreline in Petone influenced by sedimentation and tectonic uplift and subsidence (from Stevens 1991).

Figure 11. Moerings Creek, Petone showing low-lying swampy conditions. Painting by Samuel Brees ca. 1843 ATL. B-031-002 (from Johnston, W 1999).

- **Future sea level rise and impact of Petone and Wellington Harbour:**

Sea level has risen about 20cm since the beginning of the 20th Century and is now rising at 3mm per year. Sea level rise under a 'business as usual' scenario is expected to accelerate to 15mm/yr by the middle of the century leading to projected sea level rise of between 0.5 and 1.2 m rise by 2100 (Figure 12).

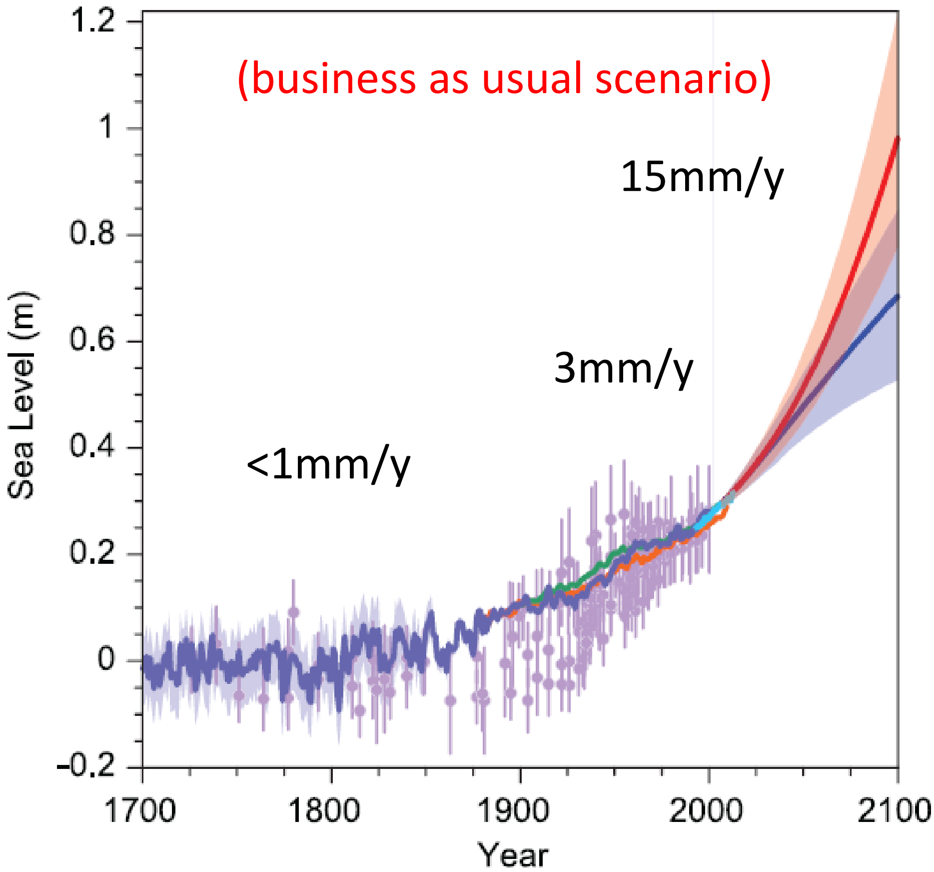

Figure 12. Sea level rise over the last 300 years and modelled projections of sea level rise to the year 2100 (IPCC, 5th AR 2013).

Compounding the issue of sea level rise is the tectonic subsidence at the western end of Petone adjacent to the Wellington Fault. Recent modelling has shown that there is likely to be up to 1.9m of rapid subsidence during an earthquake which will effectively raise relative sea level instantaneously (fig 13).

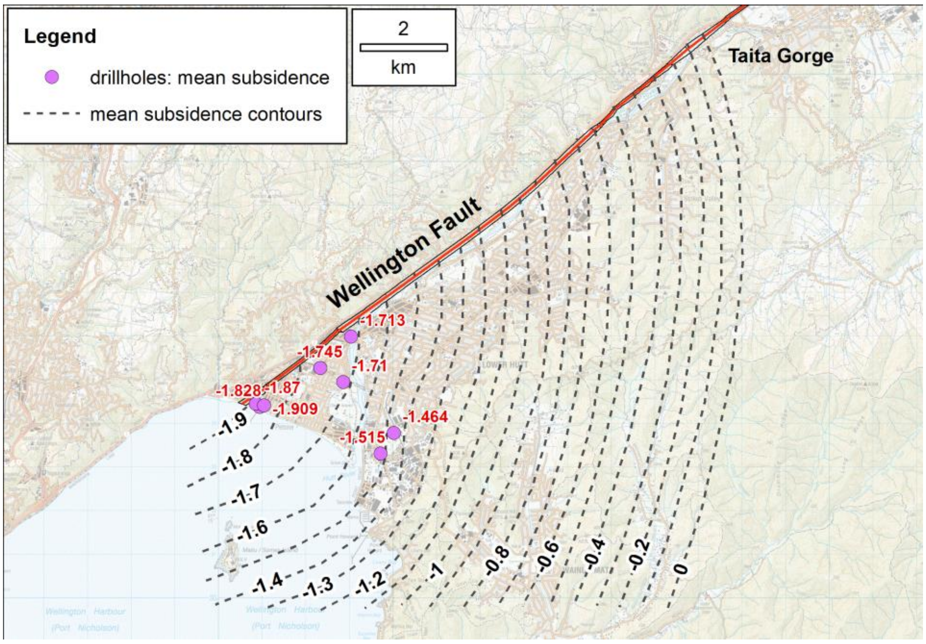

Figure 13. Drillhole locations and contours of mean co-seismic subsidence (in metres) resulting from rupture of the Wellington Fault (From Townsend et al 2015).

Relative sea level rise in the Wellington Region is likely to exacerbate existing coastal hazards such as surface flooding, coastal erosion and groundwater levels. At Petone, significant infrastructure, industry and housing are built close to sea level and already prone to flooding during high rainfall and storm surge conditions.

Numerous studies are now being prepared to understand the impact of rising sea level of low lying areas. One example, is a report by the Parliamentary Commissioner for the Environment (PCE report) entitled “Preparing New Zealand for rising seas” published in 2015 aims to map out low-lying areas around the country, describing some of the planning measures that have been adopted by various councils and identify problems, gaps in governmental guidance.

For the Wellington Region, the report identifies that the low-lying areas of Wellington are mostly around the Hutt River, Petone, Seaview and Waiwhetu as well as pockets around the Wellington CBD, Kilbirnie, Eastbourne and Porirua. It identifies over 5000 homes, 160 businesses and 58 km of roads under 1.5m above sea level (fig 14).

Figure 14. Map highlight low-lying areas at risk from rising relative sea level. (PCE report 2015).

Discussion Points:

- *Future sea level rise is expected to accelerate on coming decades.*
- *Tectonic subsidence contributes to relative sea level rise risk.*
- *Significant areas and infrastructure occur within mapped low-lying coastal areas.*
- *Future sea level rise will exacerbate existing coastal hazards and threaten local aquifers.*
- *The question now is; what steps do communities need to take to address the new driver of sea level rise –greenhouse emissions – and the already inevitable future rise in the pipe line.*
- *Solutions are complex and require discussion of the scientific, environmental, economic and social considerations by communities at all levels but especially local and central government.*

Wellington CBD drive-by: 2.45- 3.00pm

From Petone Beach, we will drive along the Wellington Fault to the Wellington CBD and follow the old shoreline prior to the regional uplift associated with the 1855 Wairarapa earthquake and subsequent land reclamation (figs 15 and 16). The railway yards, wharf, Westpac Stadium, Frank Kitts Park, the events centre, Te Papa and Waitangi Park are sited on reclaimed land seaward of the 1840 shoreline.

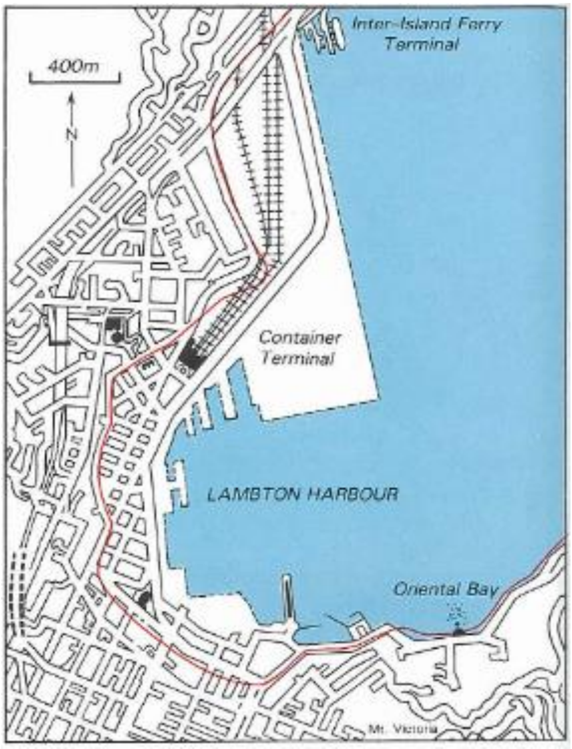

Figure 15. Position of the pre 1855 shoreline (red line). It follows the edges of the old terraces in the Thorndon Quay and Bowen Street areas and then curves across Te Aro flat, roughly following today's Wakefield Street (from Stevens, 1991). On right; brass plaque set into the pavement on Lambton Quay indicating the position of the shoreline in 1840.

Figure 16. The beach near Thorndon, ca 1841 by Samuel Brees, ATL-109-037 (from Johnston, W 1999).

Sea level rise impacts for Wellington CBD:
The Wellington city Council recently commissioned a 'Climate Change Action Plan' report on sea-level rise by Tonkin & Taylor. It is intended to provide the first step in a process of understanding and adapting to sea level rise in the Wellington area in terms of social, cultural, environmental and economic factors. This report analysed five sea level rise scenarios ranging from 0.6 metres (m) to 3.0 m (fig 17). A key conclusion is that a 1.5 m rise in sea level has a widespread impact. In the CBD alone, there would be significant inundation and damage to land, buildings and infrastructure estimated to be around $5 billion.

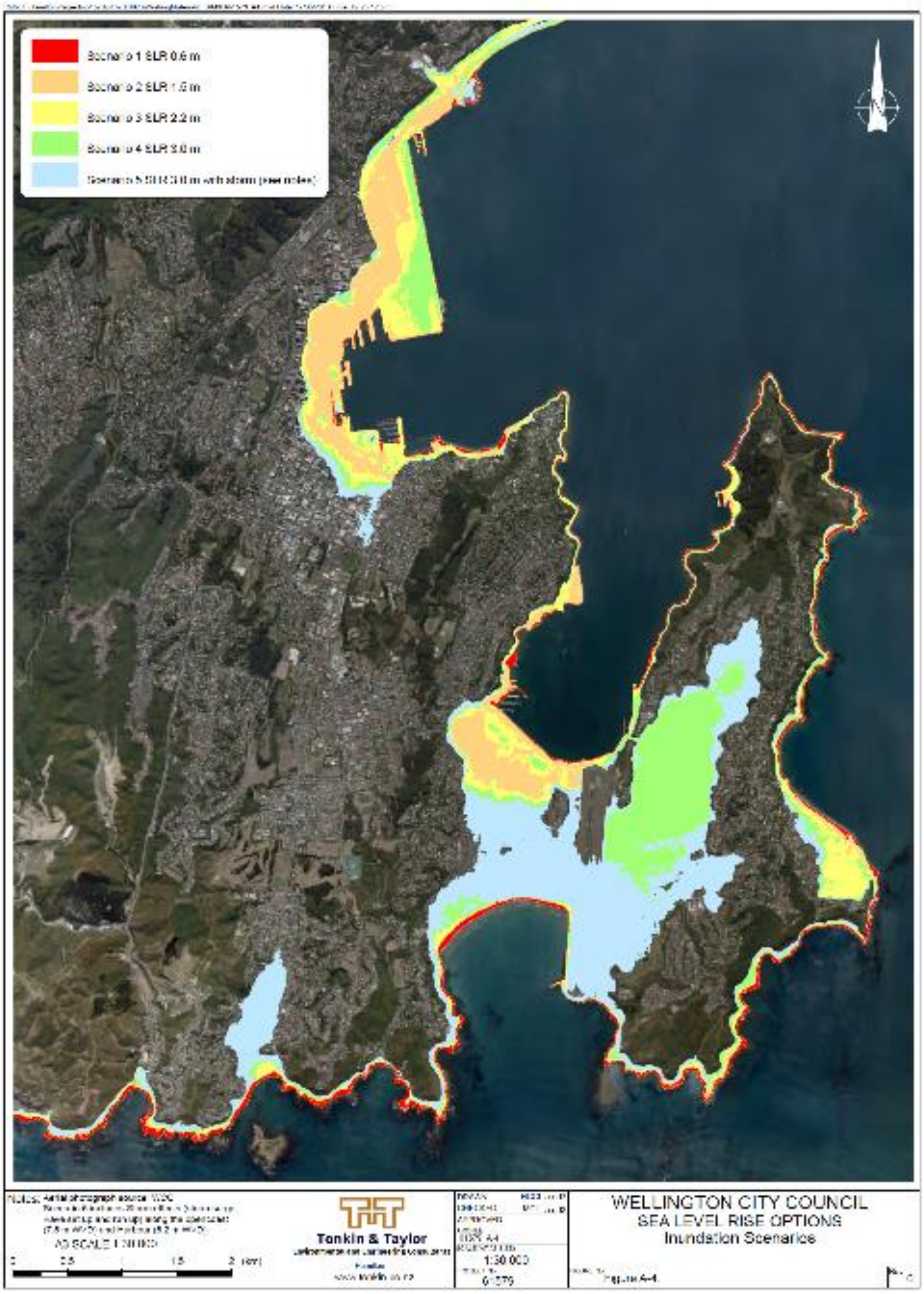

Figure 17. Sea inundation zones for different sea level rise scenarios from Tonkin and Taylor report.

VUW Beacon Room: Thin Ice Screening and discussion: 3.30-5.00pm

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"*The farther backwards you can look the farther forwards you are likely to see*"

Winston Churchill