Fisheries and Oceans Canada / Pêches et Océans Canada
Science / Sciences

Pacific Region

Canadian Science Advisory Secretariat
Science Response 2012/037

MODELLING TSUNAMIS ASSOCIATED WITH RECENTLY IDENTIFIED SLOPE FAILURES IN DOUGLAS CHANNEL

Context

Enbridge Northern Gateway Pipelines Ltd. has proposed to construct and operate the infrastructure for the conveyance and export of diluted bitumen from Alberta to overseas markets and import of petroleum condensates for use in oil sands production.

Fisheries and Oceans Canada (DFO) is participating in an environmental assessment by a Joint Review Panel environmental assessment. A Joint Review Panel is an independent body, mandated by the Minister of the Environment and the National Energy Board. The Panel will assess the environmental effects of the proposed project and review the application under both the Canadian Environmental Assessment Act and the National Energy Board Act.

On August 17, 2012, a Notice of Motion of the Attorney General of Canada Seeking to Tender Supplementary Written Evidence was filed and subsequently granted with the Joint Review Panel “Respecting Two Previously Unrecognized Submarine Slope Failures in the Douglas Channel and A Future Additional Assessment of the Tsunami Potential Associate with these Two Slope Failures”. DFO Science, Pacific Region was requested to provide an additional assessment consisting of modeling of the wave heights and speeds that may have resulted from two previously unrecognized submarine slope failures in the Douglas Channel. This analysis will be provided to the Panel and parties before the Panel to ensure they have the most up to date information of geo-hazards in Douglas Chanel. Due to the urgency of the request a Canadian Science Advisory Secretariat (CSAS) Science Special Response Process (SSRP) was utilized to provide this information.

Specifically, the objective of this assessment is to provide an analysis of numerically simulated tsunami wave heights, current speeds, wave periods, and wave propagation times that would have been generated from a slide of material from the recently identified submarine slope failures in Douglas Channel.

This Science Response report is from the Fisheries and Oceans Canada, Canadian Science Advisory Secretariat, Regional Science Special Response Process (SSRP) of October 29th, 2012. All material contained herein is based on the technical publication Thomson et al. 2012. Numerical simulation of tsunamis generated by submarine slope failures in Douglas Channel, British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/155.

Background

The Enbridge Northern Gateway Project proposes to ship dilute bitumen from Kitimat, British Columbia to markets in China and California with tankers of the class Very Large Crude Carriers (VLCC) (Enbridge Northern Gateway Project Joint Review Panel (ENGPJRP) 2012a). The tanker route from Kitimat through confined waterways in British Columbia and then into open waters of Hecate Strait, Dixon Entrance and Queen Charlotte Sound in British Columbia are illustrated in Figure 1. For assessment purposes Enbridge Northern Gateway defines two areas, the Confined Channel Assessment Area (CCAA) (Figure 2) and the Open Water Assessment

Area (OWA) which is BC waters to the territorial sea limit (Figure 1). Incoming ships will deliver cargoes of condensate. Enbridge Northern Gateway estimates 71 condensate and 149 oil tankers call in at the Kitimat terminal for a total of 440 transits per year (ENGPJRP 2012b). A marine terminal will be constructed near Kitimat with two tanker berths and one utility berth (ENGPJRP 2012a).

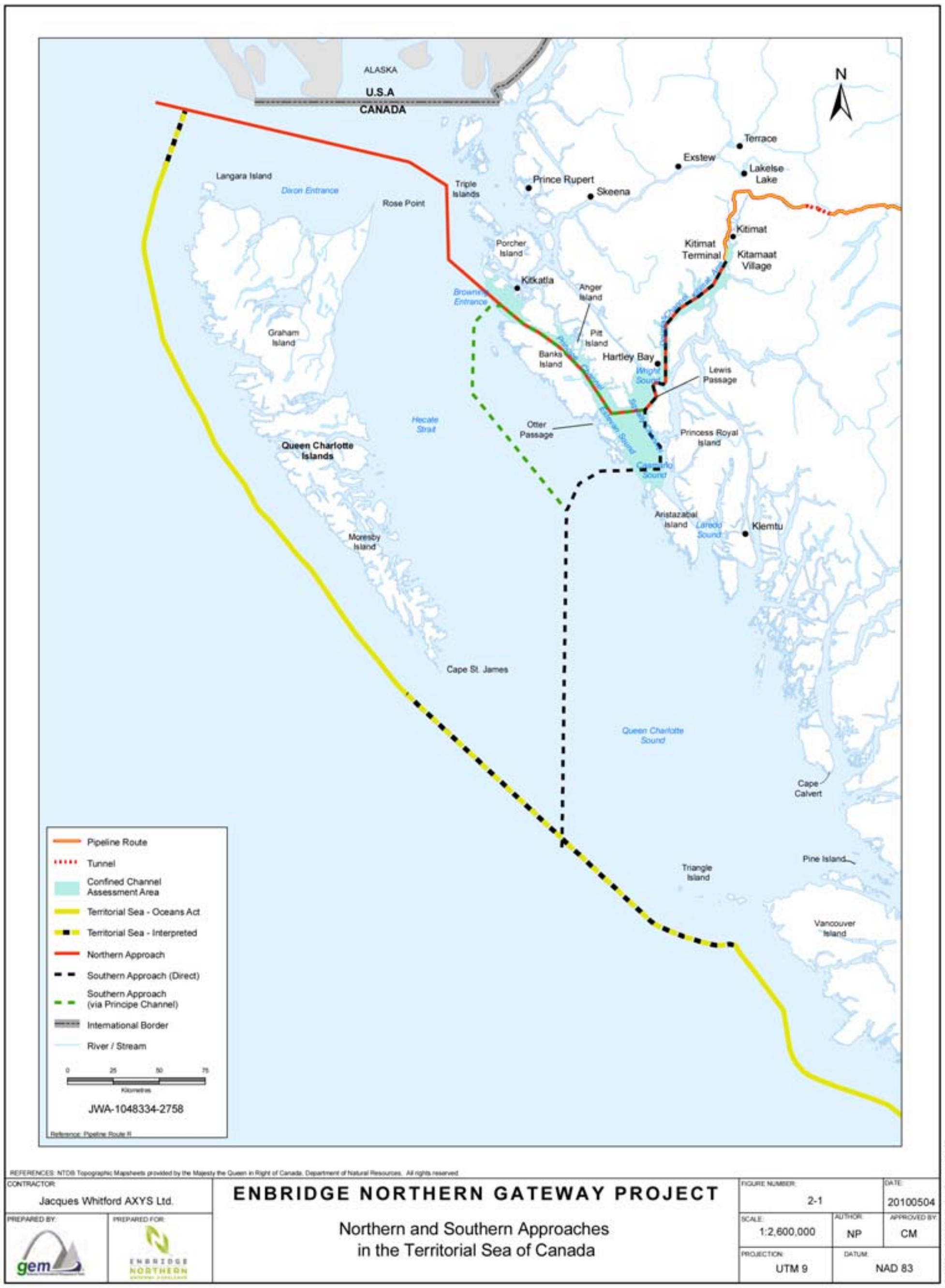

Figure 1 Map illustrating the proposed tanker routes through the Confined Channel and Open Water Assessment Areas (CCAA and OWA). The OWA extends to the territorial sea boundary (ENGPJRP 2012c).

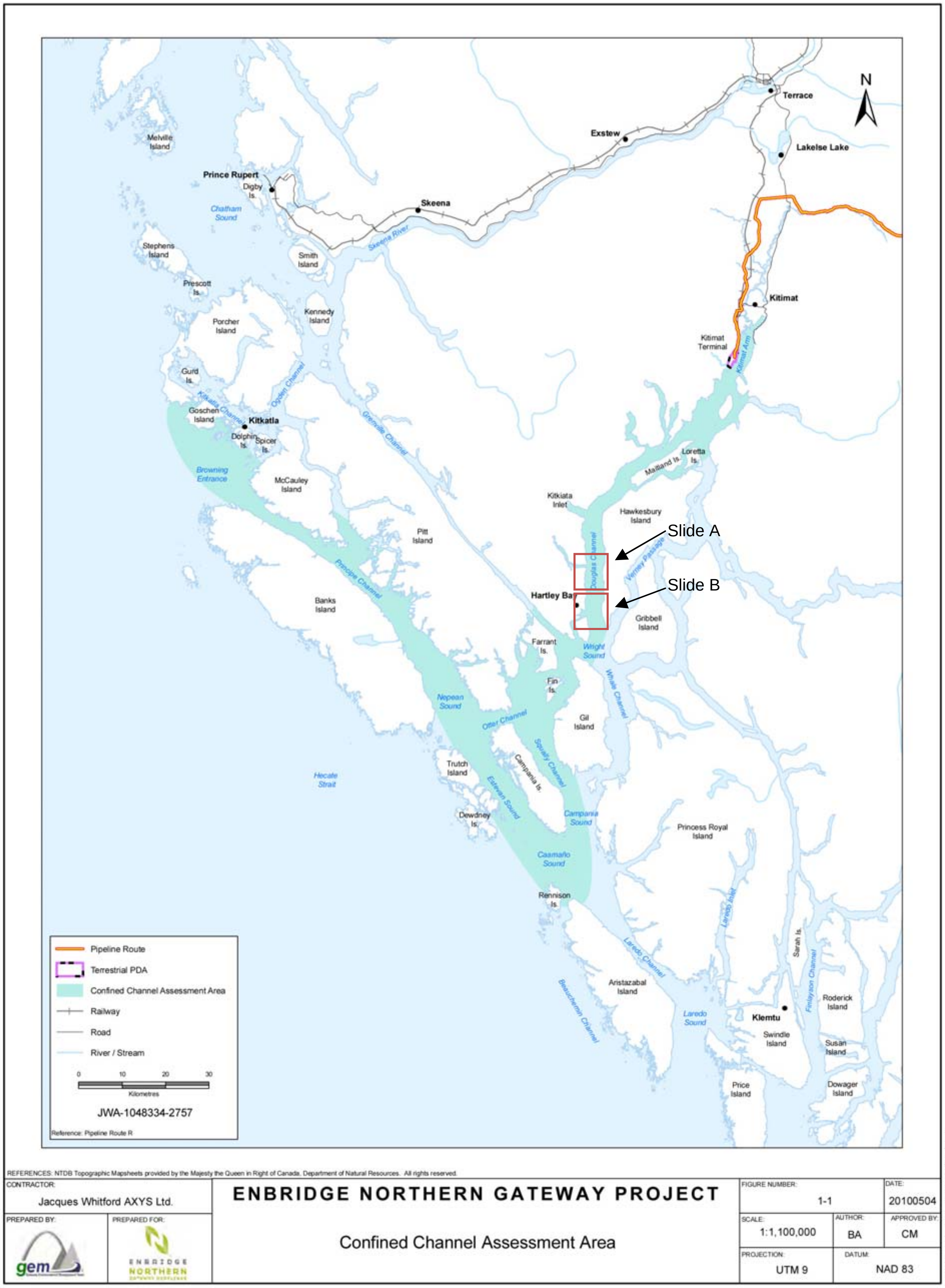

Figure 2 Map illustrating the location and extent of the Confined Channel Assessment Area (CCAA) (ENGPJRP 2012c)

Rationale for Assessment

On August 17, 2012, a Notice of Motion of the Attorney General of Canada Seeking to Tender Supplementary Written Evidence was filed with the Joint Review Panel "Respecting Two Previously Unrecognized Submarine Slope Failures in the Douglas Channel and A Future Additional Assessment of the Tsunami Potential Associate with these Two Slope Failures".

Multibeam bathymetric surveys by the Canadian Hydrographic Service and Natural Resources Canada revealed the presence of two large submarine landslides along the southeastern side of Douglas Channel in northwestern British Columbia. The landslides likely date from sometime in the early to mid-Holocene (10,000 to 5,000 years ago). These failures could have forced landslide-generated tsunamis, and conditions exist for similar failures and associated tsunamis to occur along this segment of Douglas Channel in the future (Conway et al, 2012).

DFO Science, Pacific Region was requested to provide an additional assessment consisting of modeling of the wave heights and speeds that may have resulted from two previously unrecognized submarine slope failures in the Douglas Channel. This analysis will be provided to the Panel and parties before the Panel to ensure they have the most up to date information on geohazards in Douglas Chanel.

Analysis and Responses

Slide Reconstructions

Coastal British Columbia is an area of steep slopes, extreme seasonal variations in soil moisture, large tidal ranges, and the highest seismicity in Canada. Hazards of this form have been well documented for the coastal region of British Columbia, and other fjord regions of the world's oceans, including Alaska and Norway. These factors increase the potential for both submarine and subaerial slope failures in the region. Such events generally take place in relatively shallow and confined inner coastal waterways, and can present hazards in terms of tsunami wave generation.

The two submarine slide regions recently identified are located 10 km apart on the eastern slope of southern Douglas Channel, near the southern end of Hawkesbury Island (Figures 3 and 4 (Conway et al. 2012)). The failures are defined by scallop-shaped hollows located along the edge of the fiord wall and appear to be associated with detached blocks that extend out several hundred metres into the channel. The two block slides identified in Douglas Channel are characteristic of rigid-body submarine landslides, which differ considerably from the well-documented viscous submarine landslides with a lower specific gravity (density relative to water) of about 1.5 that occurred to the north of Douglas Channel along the inner slope of Kitimat Arm in 1974 and 1975.

Conway et al. (2012) estimate the volumes of the two slides to have been 32 million m^3 for Slide A and 31 million m^3 for Slide B (Figure 3 and 4 respectively).

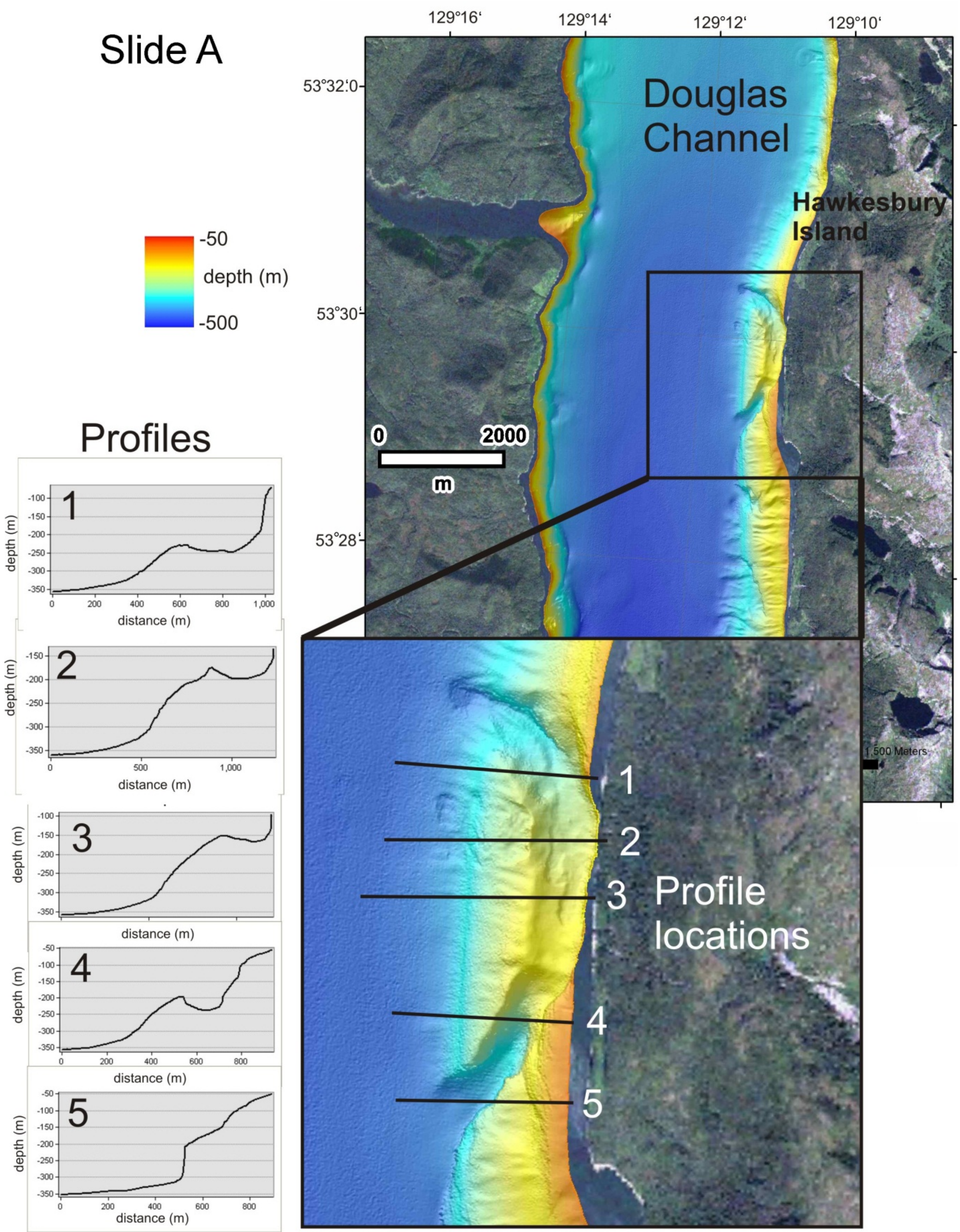

Figure 3. Detailed multibeam imagery of Slide A. Plotted to the left of each slide are numbered bathymetric profiles extracted from multibeam bathymetry; locations for each profile are shown in the slide image. From Conway et al. (2012).

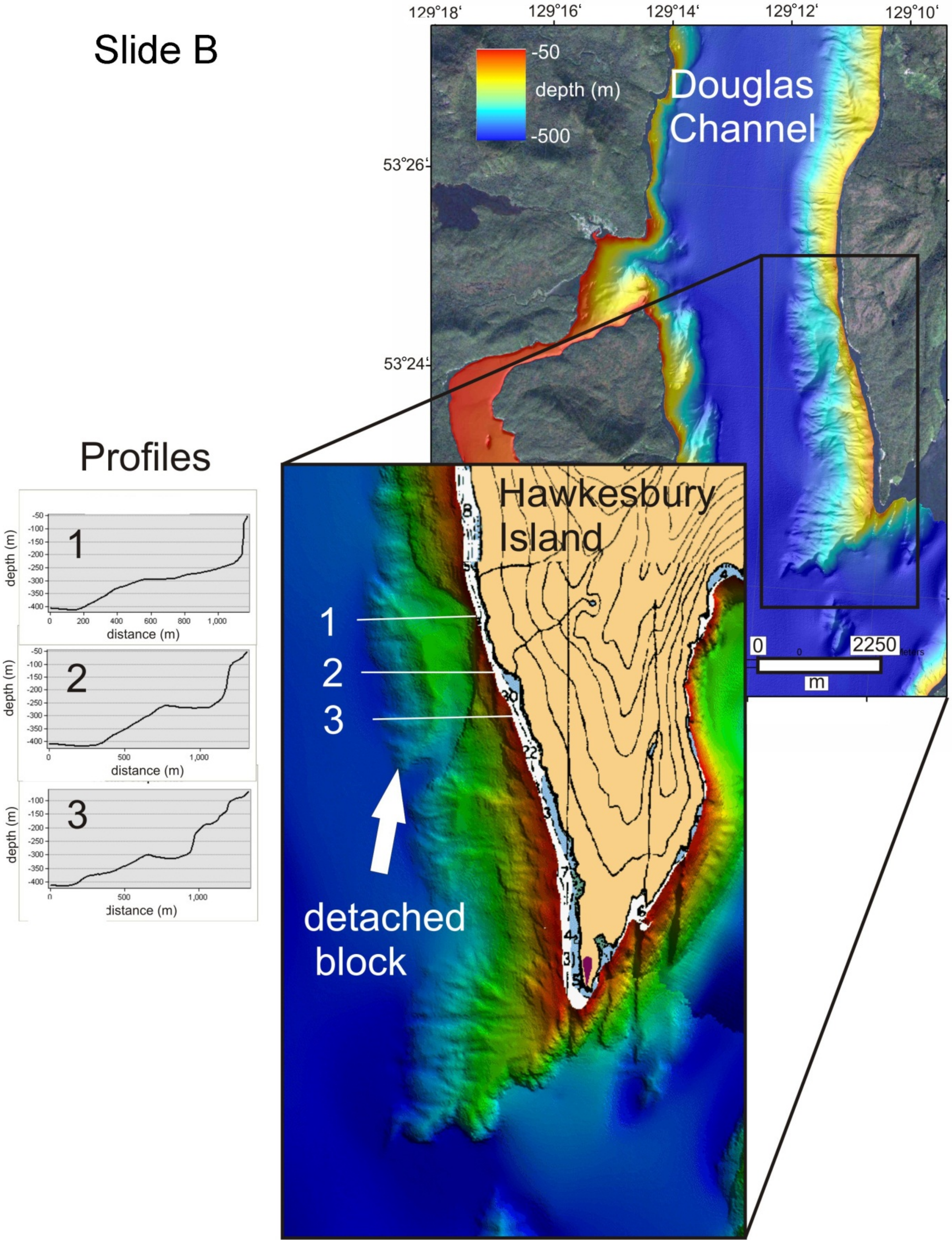

Figure 4 Detailed multibeam imagery of Slide B. Plotted to the left of each slide are numbered bathymetric profiles extracted from multibeam bathymetry; locations for each profile are shown in the slide image. From Conway et al. (2012).

However, these are considered minimum values, as they do not include debris that would have spread into the fiord after initial detachment and block sliding, which is now buried by a thick layer of post-slide sediment. The blocks are thought to be derived directly from the Hawkesbury Island coastal lithology which, according to mapping by Roddick (1970), consists of a diorite (igneous) rock with a specific gravity (density relative to water) of around 2.6.

Although there are insufficient bathymetric data to delineate the exact boundaries of the original failures, a reconstruction of the slide regions immediately prior to failure indicates the slides were wedge-shaped. The head of the more northern slide (Slide A) began at a depth of around 60 to 100 m, while that of the more southern slide (Slide B) began at a depth of 75 to 120 m. Depending on the friction between the slide and the underlying seafloor, the slides would have moved downslope with a peak velocity of approximately 25 m/s before coming to rest after a duration of about 30 seconds. Based on the multibeam data, the slides moved a distance of roughly 250 to 350 m before stopping at the base of the slope in water depths of around 400 m.

Delineations of the slide bodies are based on several assumptions which could be potential sources of error. First, the estimate of the slide thickness is determined by the depth of upper troughs observed in the multibeam data. Sediment accumulation in the region may have occurred at different rates over the slide areas, with troughs possibly filling in faster than crests and slopes. In addition, the downslope (cross-shore) extent of the slides was equated to the observed cross-shore extent of the sloped portion of the seafloor, leading to uncertainty in the estimates of slide dimensions.

Tsunami Modeling Results

A numerical mathematical model was used to simulate the tsunami waves and currents that would be generated in Douglas Channel and adjoining waterways (including Kitimat Arm) by block-like submarine landslides having the dimensions of Slides A and B identified by the recent multibeam bathymetric surveys (Conway et al. 2012). The numerical simulations provide estimates of the tsunami wave amplitudes[1], propagation times, wave periods, and current velocities as functions of time and location within a broad area of the inner coastal waterway.

Slide A

Slide A would have generated extremely large waves in the immediate vicinity of the failure region within a minute of the submarine landslide. Waves in the numerical simulations reach amplitudes of 30 to 40 m at the coast near the slide area (Figure 5).

[1] Amplitude is ½ wave height.

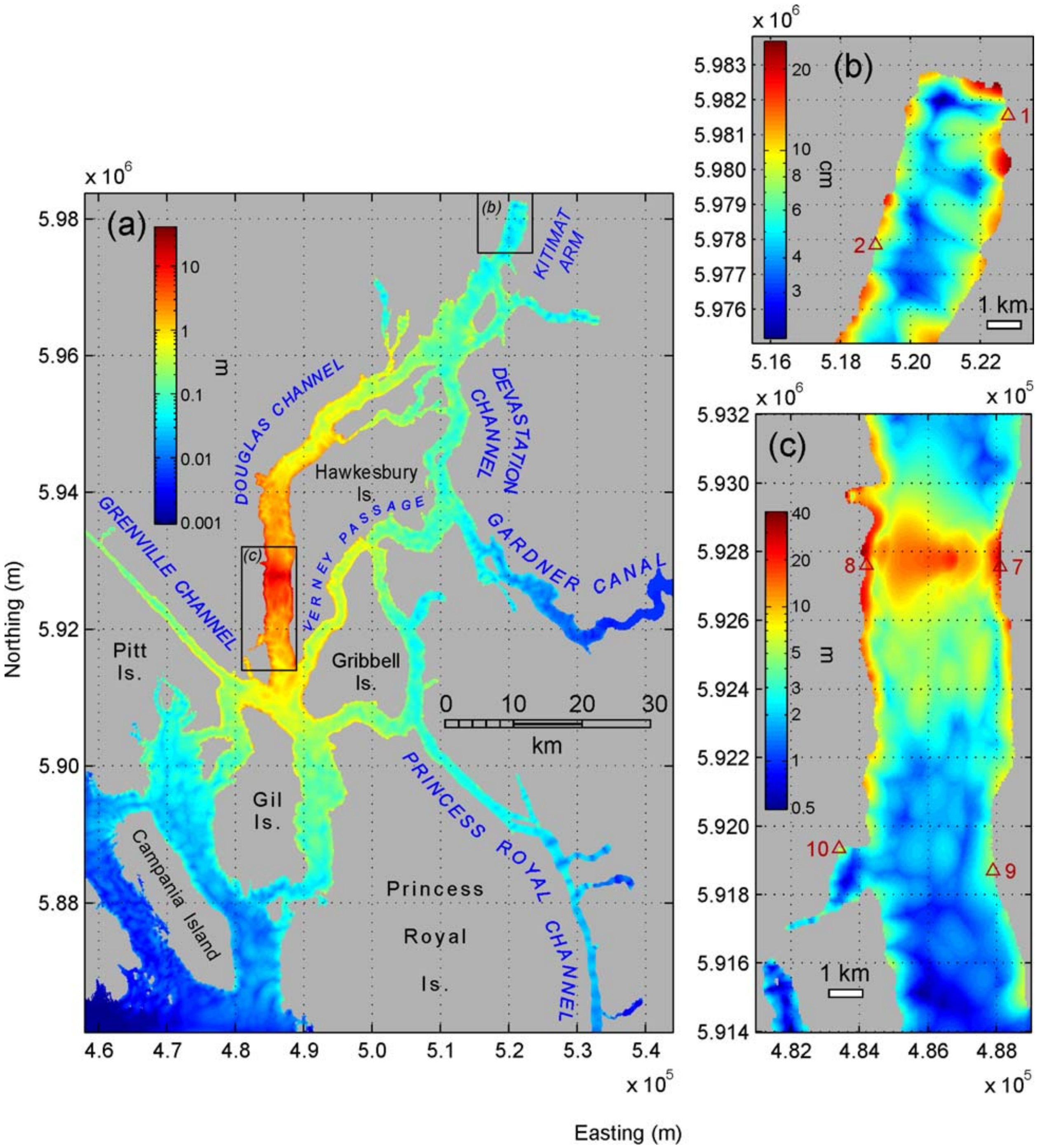

Figure 5 Maximum tsunami wave amplitudes generated by Slide A. Expanded regions are presented in (b) and (c); see (a) for locations. Note change in amplitude units in (b). From Thomson et al. (2012).

A delay between the arrival of the first (or leading) waves and the arrival of the highest (or maximum) waves at a particular point is typical for tsunamis generated by submarine landslides in coastal regions. The delay increases with distance from the slide, because the waves undergo numerous reflections and non-linear interaction *en route*. Numerical results reveal maximum wave amplitudes of 6 m at Hartley Bay. Large amplitude waves with typical periods of around 50 seconds would continue for several tens of minutes.

For regions outside Douglas Channel, the simulated tsunami waves are relatively small, with typical wave amplitudes less than 1 m. The leading tsunami waves generated by Slide A reach Kitimat Arm in roughly 20 min and have small amplitudes of only a few centimetres. Although later waves have higher amplitudes, the maximum wave amplitudes (which occur 50-55 min after the failure event) are still only around 0.09 to 0.12 m.

High tsunami waves are accompanied by strong wave-induced currents. Regions with maximum wave amplitudes are associated with intense currents of up to 15 m/s. According to the model results, especially strong currents occur near the shore and at headlands close to the slide. Tsunami-induced currents are weak throughout Kitimat Arm, with typical speeds of less than 0.01-0.02 m/s. Even at headlands, the speeds of the wave-induced currents do not exceed 0.1 m/s.

Slide B

Analysis for Slide B follows the same procedure as for Slide A. An examination of the bathymetric data shows that Slide B moved roughly 400 m before stopping. Because Slide B began its movement at greater depth than Slide A, the centre of mass of Slide B underwent a smaller vertical displacement than Slide A. This, in turn, caused Slide B to move significantly slower than Slide A, leading to differences in the simulated tsunami waves generated by the two slides.

Slide B would have generated large waves in the vicinity of the failure region. Simulated waves reach the coast adjacent to the slide region within a minute of the failure event, with wave amplitudes of up to 10 m (Figure 6). The waves also hit the opposite site of the channel within a minute of the failure event and then take an additional minute to reach Hartley Bay (Figure 2), where waves reach amplitudes of 15 m. Powerful oscillations in the bay last for tens of minutes. Waves with high amplitudes (more than 2 m) also occur in the southern part of Douglas Channel, and in certain locations of Verney Passage (Figure 2)

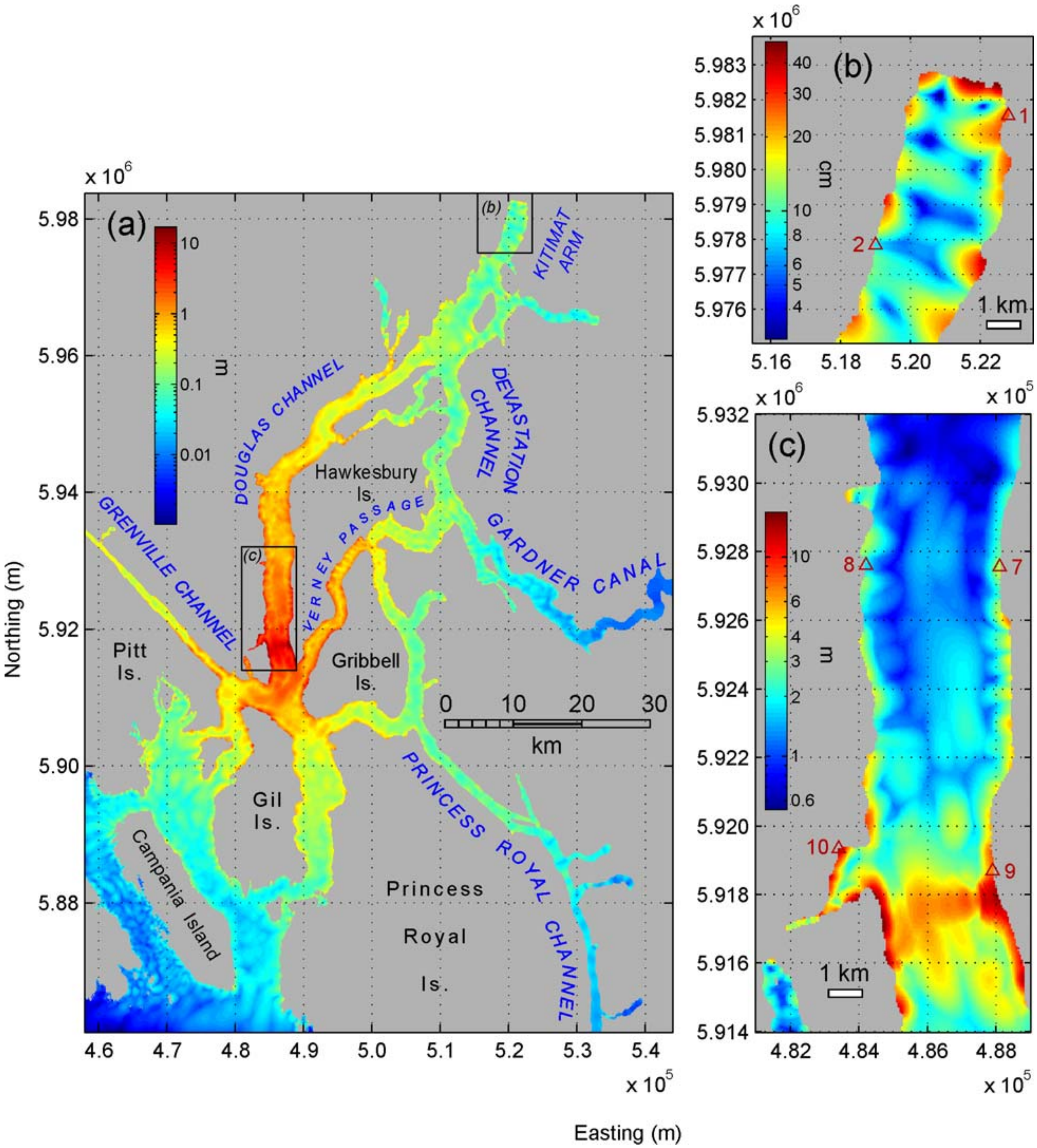

Figure 6 Maximum tsunami wave amplitudes generated by Slide B. Expanded regions are presented in (b) and (c); see (a) for locations. Note change in amplitude units in (b). From Thomson et al. (2012).

In Verney Passage, and in other areas away from the confines of southern Douglas Channel, the tsunami waves are much smaller, with typical amplitudes of less than 0.5 m. The leading tsunami waves reach Kitimat Arm 22 minutes after the start of the slide, while maximum waves with amplitudes of 0.08 m to 0.3 m, reach Kitimat Arm 45 to 60 minutes after the start of the failure event. We note that the tsunami waves generated by Slide B that impact Kitimat Arm, although still of low amplitude, are somewhat higher than those generated by Slide A, despite the fact that Slide B is located further to the south and generates less energetic waves in the source region than Slide A. This seeming paradox is explained by the slower motion of Slide B, which causes it to generate more wave energy in the low frequency band than Slide A. Due to their reduced scattering and reflection, the relatively long and lower frequency waves generated by Slide B propagate more readily through the complex fjord system than the relatively short and higher frequency waves generated by Slide A.

Tsunami waves generated by Slide B in the failure region are accompanied by intense currents, with maximum velocities centred in the source area. Because Slide B generated less energetic tsunami waves than Slide A, current speeds in the source area are generally less than those generated by Slide A. In Hartley Bay, currents reach 3 m/s and exceed 4 m/s in the narrow channel to the south of the bay. Near the slide zone, current speeds reach 2 m/s. In the source region, and at selected capes, the currents can be as strong as 6 m/s.

For sites outside the Douglas Channel and in adjoining channels, the tsunami-induced currents are quite weak. Although currents generated in Kitimat Arm by Slide B are slightly stronger than for Slide A, the currents are still weaker than 0.1 m/s.

Conclusions

The numerical simulations show that the two identified submarine landslides would have generated tsunami waves with peak amplitudes of 30 to 40 m (wave heights of 60 to 80m), current speeds of up to 15 m/s (roughly 30 knots), wavelengths of the order of 1 km, and periods of tens of seconds to several minutes. Highest waves and strongest currents would have occured along the shoreline opposite and adjacent to the failure regions.

Because of their relatively short wavelengths, the tsunami waves undergo multiple reflections and a high degree of scattering from the complex shoreline and bottom topography in Douglas Channel. These effects, combined with the flux of tsunami energy through adjoining waterways and channels, causes rapid attenuation of the waves with distance south and north of the source region. At the estimated propagation speeds of ~65 m/s, it takes roughly 10 to 15 minutes for the simulated waves to propagate approximately 40 to 45 km to the intersection of Douglas Channel and Kitimat Arm, where peak wave amplitudes would be diminished to less than 1 m. It would have then taken another 15 minutes for the waves to reach northern Kitimat Arm, where wave amplitudes would be reduced to a few tens of centimetres and associated currents to speeds of less than a few centimetres per second.

As with the tsunami generation regions, the highest waves and strongest currents in any particular region of the coastal waterway would occur near the shoreline. Based on the numerical findings, Douglas Channel would have experienced large waves and strong currents, while Kitimat Arm would have experienced negligible waves and currents. Additional modeling would be required to assess the characteristics of possible tsunamis originating beyond the area of the two identified slope failures.

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