USING THE VENUS UNDERWATER NETWORK TO ASSESS CONDITIONS LEADING TO SLOPE FAILURES

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RÉSUMÉ
Les nombreux glissements de terrain survenant dans le Delta de la rivière Fraser en Colombie-Britannique sont déclenchés par de nombreux processus différents, autant anthropiques que naturels. La fréquence de retour de ces différents événements est variable : des tremblements de terre non-fréquents aux marées journalières. Dans les dernières 40 années, au moins sept différentes hypothèses ont été mises de l'avant, mais aucun glissement n'a pu être mesuré directement, en dépit de plusieurs missions en bateau. Par contre, ces événements ont pu être cartographiés grâce à plusieurs levés multifaisceaux. Le Victoria Experimental Netword Under the Sea (Venus), une station d'observation câblée sous-marine, va permettre l'acquisition de nombreuses données en temps réel. Des piézomètres sismiques vont être déployés à plusieurs endroits sur le delta, à des profondeurs variant de 30 à 150m. Cela donnera aux scientifiques, pour la première fois, une méthode pour s'assurer que tous les processus d'intérêt sont mesurés, et ce à toutes les échelles de temps : avant, après, et pendant que des mouvements de masse ont lieu. Ce projet est exécuté par Ressources Naturelles Canada en collaboration avec l'Université de Victoria, et les données recueillies vont être rendues disponibles gratuitement aux scientifiques et ingénieurs intéressés. De plus, pour les chercheurs intéressés, il sera possible de brancher d'autres instruments à ce réseau, afin d'examiner les mouvements de masse ou d'autres processus ayant cours sur les deltas.

ABSTRACT
Failures on the Fraser Delta, British Columbia, have been attributed to a number of natural and human induced processes. Each of these processes occurs at a different time scale, from infrequent seismic events (earthquakes) to daily tidal processes. At least seven different hypotheses have been put forward over the past 40 years, yet despite several ship-based attempts no failures have been directly measured (rather they have been seen in repeat multibeam surveys). The Victoria Experimental Network Under the Sea (VENUS), a submarine cabled observatory, will provide power to the Fraser Delta, and will enable high bandwidth data to be collected and sent to shore in real time. Seismic piezometers will be deployed at various places in an array on the delta to cover both horizontal extent and depths on the delta slope from 30m to 150m This will give scientists, for the first time, a method to ensure that all of the processes of interest are measured at all time scales up to, during and after a failure takes place. The project is being executed by Natural Resources Canada under agreement with the University of Victoria, and as such the data will be made available freely to interested scientists and engineers. Furthermore, instrument ports will be made available on the network for researchers to connect their own specialized instruments for examining slope failures or other delta processes.

1. INTRODUCTION

Coastal communities and infrastructure surrounding the southern Strait of Georgia (Figure 1) would be at risk in the case of a submarine slope failure on the foreslope of the Fraser River delta. Small slope failures on Roberts Bank could rupture power transmission cables that supply electricity to Vancouver Island, while large failures could damage or even destroy important infrastructure such as the Deltaport and Tsawwassen ferry terminal. Furthermore, the tsunami generated by such a failure would propagate across the Strait of Georgia and impact the shorelines of the Gulf and San Juan Islands as well as mainland British Columbia.

Geotechnical analysis has resulted in a design for the installation of an array of instruments to measure liquefaction and failure events. In the past, it has been difficult to measure and capture these relatively long time-scale failure events by using short term moored instruments. Deployment and networking of the present instrument packages will be facilitated by the Victoria Experimental Network Under the Sea (VENUS) Project. The project will install a fibre optic cable from the central Strait of Georgia allowing real time observations so that the parameters described below can be studied in great detail (milliseconds to years). It is hoped that eventually the instruments may be used as an early warning system to large, and destructive, failures which are known to have occurred in this area.

2. CAUSES OF FAILURE

The Fraser River discharges over a million tonnes of sediment per year. This is confined to a relatively small area of the mouth ever since the confinement of the navigation channel by the construction of the Steveston Jetty in the 1930's. Depositional rates are greater at low tide, when the salt wedge is located at the river mouth (Kostachuck *et al.*, 1989). The quickly deposited sediment is loosely packed (Chillarige et al, 1997a, b). This simple oversteeping of the

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Figure 1. Study area showing important infrastructure in the Southern Strait of Georgia.

delta front is probably the main cause of failures in the area. Up to five hundred thousand cubic meters of dredged sediment is deposited per year in the designated disposal site at Sand Heads, which may be further adding to the buildup of loosely packed and unstable sediment.

The buildup and removal of material is shown well using repeat multibeam (sea floor bathymetry) surveys. Figure 2 shows that there was generally a net accumulation (blue) of sediment during the year 2001 to 2002. However, in the year 2002 to 2003 large sections began to fail (yellow and red), including a 10m thick deposit in the upper canyon area (Hill, 2006).

It is known that the bed at shallow depth fails periodically due to tidal drawdown resulting in excess pore pressures (Christian *et al.*, 1997). The seabed in this area contains a significant volume of gas (1%), which leads up to an 80% attenuation in pore pressure within the top 5m, and which also likely affects the shear strength of the soil (Chillarige *et al.*, 1997b; Christian, 1998; Christian *et al.*, 1997, 1998).

The Fraser Delta is in an area of high seismic activity which leads to pore pressure increases and corresponding decreases in sediment strength.

We further hypothesize that pore pressures are affected by seasonal groundwater flows and storm surges. Finally, strong tidal currents have been measured at the toe of the delta slope (Kostaschuk *et al.*, 1995; Barrie and Currie, 2000). These currents are strong enough to erode and undercut the base of the delta area.

3. SLIP INSTRUMENTS

The variety of factors involved in generating slope failures at the Fraser Delta has made investigations difficult. A number of researchers with different expertise have made use of many different classes of instruments over the past two decades. Often, these are in the form of moorings, or battery powered buoyed deployments. To conserve battery power, the moorings are set to sample at long times scales, or the deployments are only short in duration. Either way, the events leading to and during failure on the delta have never been adequately captured.

The Victoria Experimental Network Under the Sea (VENUS) is a cabled observatory operated by the University of Victoria. Its objective is to provide scientists working in the Strait of Georgia a facility to connect instrumentation and log data in near-real time. The data are processed and stored in the Data Managing and Archiving System (DMAS). Researchers can then interrogate the data at whichever time and timescale they desire. This is precisely the type of facility required to study slope stability issues.

Seismic Liquefaction In Situ Penetrometer (SLIP) Instruments are being designed and built in a collaborative agreement between Natural Resources Canada, Environment Canada, Weir Jones Engineering Group, and the University of Victoria. These will penetrate to a depth of 5m beneath the seafloor, at water depths down the delta slope between 15m and 120m. The SLIPS will measure changes in pore pressures within the bed due to the factors described above. Accelerometers will measure seismic activity, and along with inclinometers, will measure associated movements (strain). To measure the extent and variation in gas, geophones will be placed at strategic locations to allow acoustic measurement of gas content and calculation of sediment bulk properties and effective stresses. Seasonal groundwater flows will be measured by the combination of piezometers and thermistors.

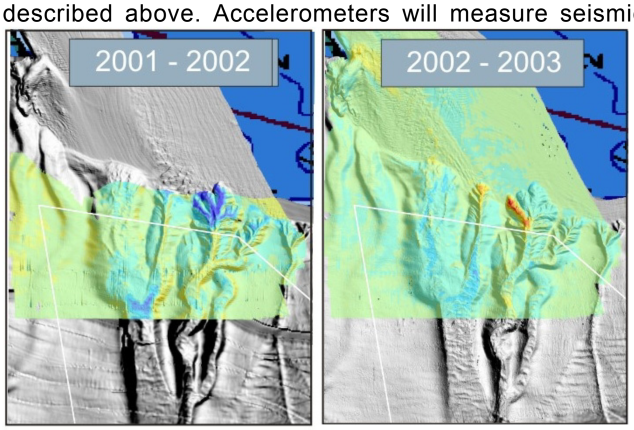

Figure 2. Repeat Multibeam Imagery. Blue areas in the upper canyon show infilling in the year 2001 to 2002. Yellow and red indicate failure at the same areas in the year 2002 to 2003. From Hill (2006).

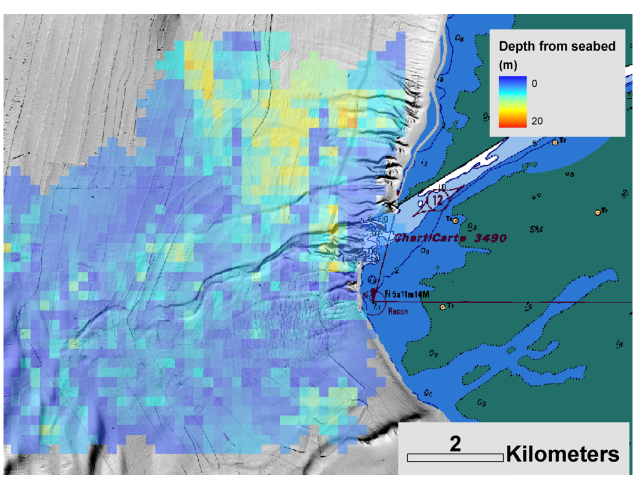

Figure 3. Presence of shallow gas throughout the delta area is generally between 0 and 20m depth.

A SLIP instrument is shown in Figure 4a. The design includes:

1. Trawl-proof housing.
2. Deployment post. This will fit inside a sleeve containing weights for push-in deployment at a controlled drop (1 m/s). The weight sleeve will be removed after deployment.
3. Electronics package. To contain power supply, data acquisition device, data processing device and communications to external network.
4. Optical Backscatter sensor, or other measure of suspended sediment.
5. Absolute pressure gauge/transducer. This will measure hydrostatic pressure at depths between 15m and 150m.
6. Differential transducer. To measure the pore pressure at the bottom of the instrument relative to hydrostatic pressure.
7. Zero volume change valve. This will allow the connection to pressure transducers to be closed, necessary for installment of the instrument, as well as for maintaining a constant hydrostatic pressure for measurement of surface waves at the slip tip.
8. Mudplate. To hold the electronics package and instruments above, and the extension to instrument package below.
9. Rigid extension. Must have internal conduits to allow cabling and/or tubing from lower instrument package to the differential pressure transducer and electronics package.
10. Seismic Pressure Temperature Tip.

The instrumented tip of the SLIP will include (Figure 4b)

- i. Porous (filter) entrance and conduit to sensing face of the pore pressure transducer.
- ii. Pressure transducer conduit. A transducer will be located above the mudplate, and will measure pore pressure at the cone tip.
- iii. Inclinometer- to be used as redundancy to accelerometer tilt.
- iv. thermistor for measurement of pore water temperature.
- v. triaxial accelerometers and tilt sensors. Will be used to measure natural seismic events and imposed conventional seismic signals.
- vi. Triaxial geophones (seismic velocity transducers). Will be used to measure natural seismic events and imposed conventional seismic signals.
- vii. Electronics and amplification.
- viii. Casing with Pipe extension joint. This joint will allow wiring and a pressure conduit to pass through from the SPT tip to the extension shaft.

• ix. Pigtail to carry power to the devices and return amplified signals to the surface (6m).
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4. INSTRUMENT LOCATIONS

A 'sacrificial' package will be placed in an area of known high failure potential (the top of the Fraser Canyon) to capture events leading to failures. A second sacrificial piezometer, and related instrumentation, will be placed in the Sand Heads disposal site (blue outline on Figure 1). Experiments in cooperation with Environment Canada's Disposal at Sea Program and the Fraser River Port Authority's dredging operation will examine the extent to which a hopper discharge affects the local water column and seabed, and will specifically determine the effect of the disposal of dredged sediment on the stability of the upper delta slope. The designated disposal area at sand heads is shown with a blue border.

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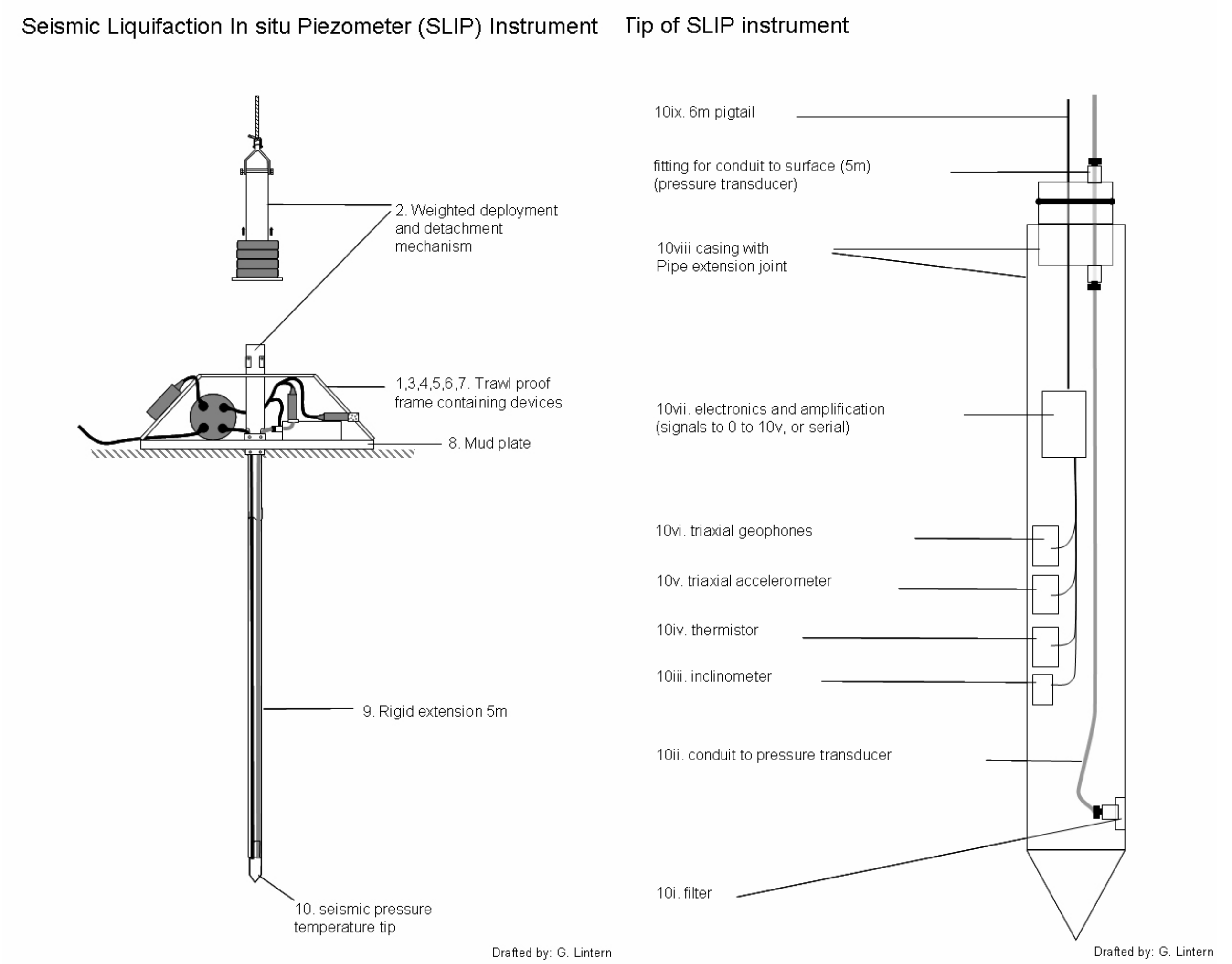

Figure 4. Instrumentation. a Seismic Liquefaction In Situ Penetrometer (SLIP) and
b. Instrumented tip

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