Mapping the Susceptibility to Amplification of Seismic Ground Motions in the Montney Play Area, Northeast British Columbia

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Introduction

Seismicity in northeast British Columbia has increased significantly due to hydraulic fracturing and subsurface fluid disposal (Atkinson *et al*., 2016). Recent work by Babaie Mahani and Kao (2018) in this area has focused on the attenuation of seismic ground motions with distance. However, seismic ground motions can also be amplified on sites underlain by soft sediments relative to sites on bedrock or firm ground (Idriss, 1990). The objectives of this study were to assess and map the susceptibility to amplification of ground motions in the Montney play area of northeast BC, and to generate a V_S database and model of the stratigraphic units in the shallow subsurface for future studies (Monahan et *al*., 2019).

Amplification of seismic ground motions due to shallow geological conditions can be estimated by the average shear-wave velocity of the upper 30 m (V_{S30}) The National Earthquake Hazards Reduction Program (NEHRP) in the United States has defined five site classes based on V_{s30} and these have been adopted by the National Building Code of Canada (Table 1; Building Seismic Safety Council, 2003). Significant amplification can occur in Site Classes D and E.

Site Class	General description	Definition by V_{s30} (m/s)	Susceptibility Rating
A	Hard rock	V_{s30}>1500	Nil
B	Rock	760<V_{s30}<1500	Very Low
C	Very dense soils and soft rock	360<V_{s30}<760	Low
D	Stiff soils	180<V_{s30}<360	Moderate
E	Soft soils	V_{s30}<180	High

Table 1. National Earthquake Hazards Reduction Program (NEHRP) Site Classes (Building Seismic Safety Council, 2003). Susceptibility ratings from Hollingshead and Watts, 1994.

Methodology

Our approach was to compile a surficial geological map from existing sources at a scale of 1:250,000, and collect sufficient shallow geological data to characterize the surficial map units. Our shallow borehole database comprised 2427 gamma-ray logs run to surface and normalized for surface casing effects, 1831 water well logs, and 885 geotechnical boreholes at 200 sites. New V_S data were acquired at 22 sites and were used to create a V_s model of the shallow stratigraphic units. The V_s model and the subsurface geological database were used to assign NEHRP Site Classes and amplification susceptibility ratings to each surficial geological map unit (Figure 1).

The amplification mapping was then compared with recorded ground motions of recent small events. Amplification for each record was estimated by dividing the recorded ground motion by that predicted by the Babaie Mahani and Kao (2018) ground motion equations.

Results

The geological and V_s data show that areas underlain by recessional-phase sediments of the last glaciation and Holocene deposits, where sufficiently thick, are in NEHRP Site Class D, and potentially susceptible to amplification of seismic ground motions. The principal areas underlain by these deposits are:

- level benches adjacent to the major river valleys underlain by glaciolacustrine silts and glaciodeltaic sands deposited in lakes that formed as retreating Laurentide ice blocked the drainage of the Peace and other major rivers;
- glaciofluvial sands and gravels deposited on terraces on the walls of major valleys; and
- Modern fluvial deposits in the valley floors.

Rolling uplands, in which topography is controlled by bedrock, have a relatively thin cover of till and are in NEHRP Site Class C, with low amplification susceptibility.

The amplifications observed in the ground motions of recent small seismic events are generally consistent with these conclusions. In the two areas examined, the mean amplifications of peak ground velocity for Site Class D map units are up to 5 times greater than for Site Class C map units. However, considerable variability occurs. Some stations in the Site Class D map units show little amplification, whereas at some Site Class C stations significant amplification occurs. This variability is likely due in part to resonance and three-dimensional effects. Amplification due to resonance could be expected locally where Holocene or recessional phase deposits of the last glaciation are thin, such as along the boundaries of map units dominated by these deposits with map units dominated by shallow till or bedrock.

Next Steps

Recommended further work includes:

- Collection of more geotechnical and other borehole data, to prepare new geological mapping of surficial sediments that better reflects geological conditions in the shallow subsurface, rather than just at the surface; and
- Acquisition of additional shear-wave velocity data to definitively establish the V_S profiles at critical seismograph stations, to better understand the factors controlling amplification of seismic ground motions.

Conclusions

Although most induced seismic events are too small to be damaging, rare stronger events up to M4.6 have occurred in the region (Babaie Mahani et *al*., 2017). By identifying areas where seismic ground motions may be amplified, this study provides a high-level tool for planning and mitigating the effects of induced seismicity to public safety and industrial infrastructure, as well as on public concerns about petroleum industry activity.

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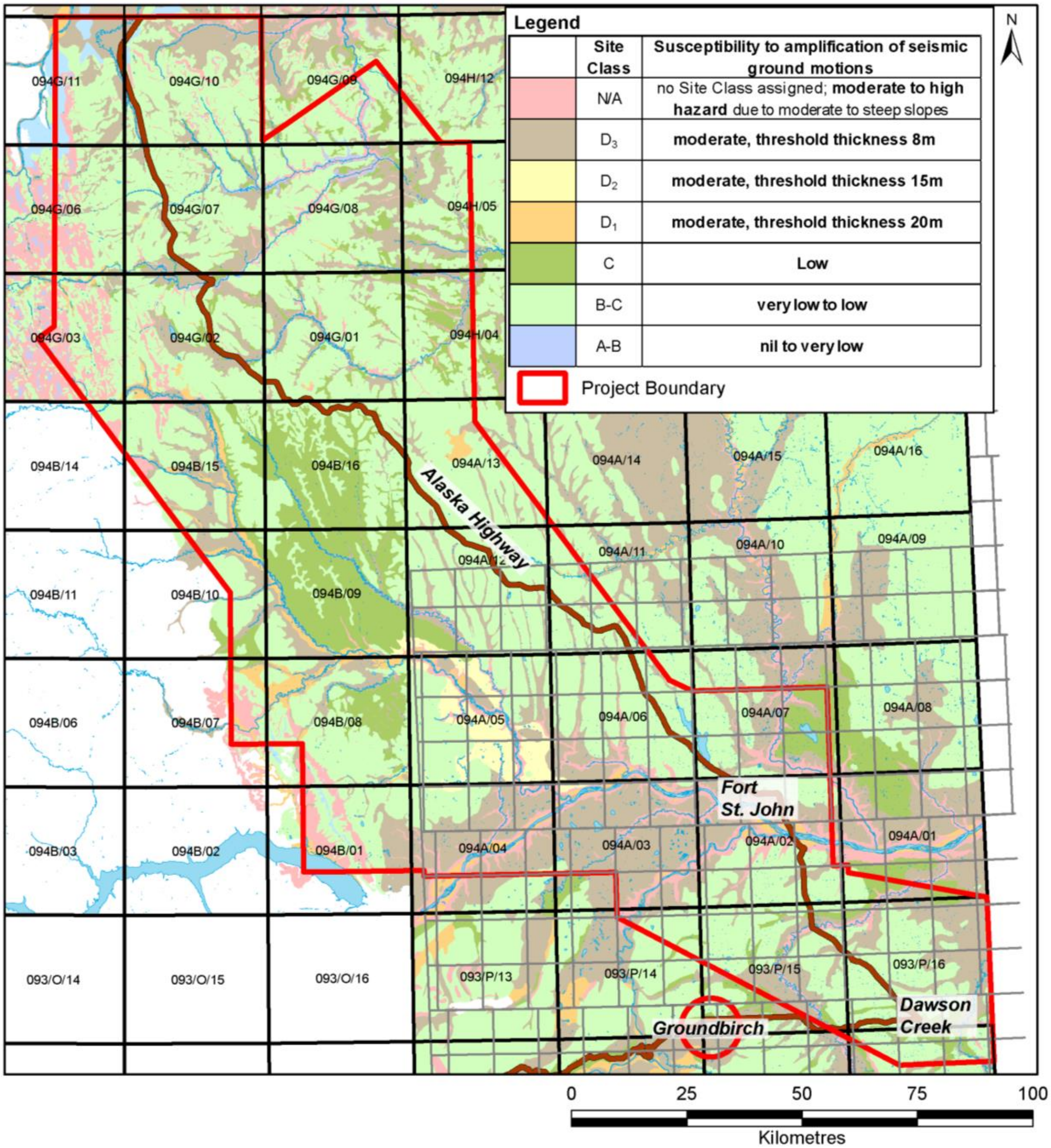

Figure 1. Site Class Map of the Montney play area. The threshold thicknesses referred to in Site Class D refer to the minimum thickness of recessional phase deposits of the last glaciation and Holocene deposits for a site to be in Site Class D. If the thickness is less, then sites would be in Site Class C.