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Sensitive clay landslide detection and characterization in and around Lakelse Lake, British Columbia, Canada

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ABSTRACT

The Lakelse Lake area in northwestern British Columbia, Canada, has a long history, and prehistory, of rapid sensitive clay landslides moving on very low gradients. However, until now, many landslides have gone undetected. We use an array of modern tools to identify hitherto unknown or poorly known landslide deposits, including acoustic subbottom profiles, multibeam sonar, and LiDAR. The combination of these methods reveals not only landslide deposits, but also geomorphic and sedimentologic structures that give clues about landslide type and mode of emplacement. LiDAR and bathymetric data reveal the areal extent of landslide deposits as well as the orientation of ridges that differentiate between spreading and flowing kinematics. The subbottom profiles show two-dimensional structures of disturbed landslide deposits, including horst and grabens indicative of landslides classified as spreads. A preliminary computer tomography (CT) scan of a sediment core confirms the structures of one subbottom profile. We also use archival data from the Ministry of Transportation and Infrastructure and resident interviews to better characterize historic landslides.

1. Introduction

Sensitive clays are largely restricted to uplifted glaciomarine sediments in a few areas of the globe, but they are most common in Canada, Alaska, and Norway (Torrance, 1983). Clays may be described as sensitive when the undisturbed strength is greater than the disturbed (remoulded) strength, where the remoulded material can behave as a fluid (Geertsema and Torrance, 2005). Sensitivity is defined as the ratio of the undisturbed shear strength and the disturbed shear strength. When remoulded shear strength is <0.5 kPa and sensitivity exceeds 30, the deposits are called quick clays and sensitivity develops due to the removal of salt from the porewater (Torrance, 1983).

Landslides involving sensitive clays typically occur as spreads or flows (flowslides) depending in part on the degree of remoulding of the displaced material (Demers et al., 2014; Geertsema et al., 2017). Spreads display both extensional ridges and depressions, typically referred to as horsts and grabens, oriented perpendicular to movement direction (Fig. 1) (Carson, 1977, 1979; Geertsema, 2004; Geertsema et al., 2006b; Demers et al., 2014, 2017). Spreads often involve movement along and remoulding of thinner sensitive zones. Flows may have ridges parallel to movement direction and lobate forms (Geertsema, 2004). Mobile flows often evacuate more material from the zone of depletion (Cruden and Varnes, 1996; Locat et al., 2017), involve a greater percentage (or thickness) of remoulding, retain less undisturbed sediment with preserved bedding, and have greater travel distances. Composite landslides (Cruden and Varnes, 1996) may occur that display both spreading and flowing behaviour (Geertsema et al., 2006b). The landslides may be triggered by bank erosion and move retrogressively, or by external loads and display progressive movement (Locat et al., 2013, 2017). Whether these sensitive clay landslides initiate at a break in the valley slope, or are triggered some distance behind the break in slope, the scarps usually migrate landward. As the landslide retrogresses into the slope in one direction, the mobilized debris travels in the opposite direction downslope.

The Lakelse Lake area in northwestern British Columbia (Fig. 2) is subject to sensitive clay landslides that suddenly and rapidly travel on extremely low gradients, sometimes less than one degree, often with trees rafting in the upright position. Although the landslides can cover many hectares of ground, because of their low gradients they are difficult to detect in forested landscapes. The primary objective of this

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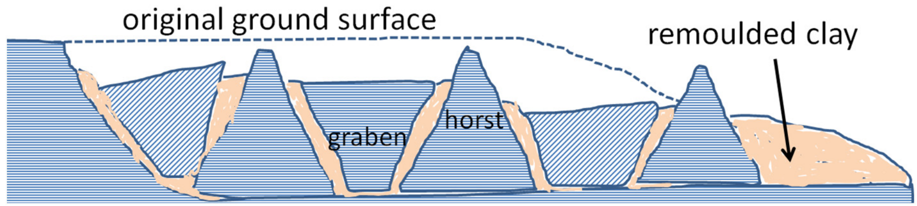

Fig. 1. Schematic representation of a spread in sensitive clays (Carson, 1977; Locat et al., 2017). The horsts, also referred to as ridges or hummocks, are often between 4 and 5 m high and preserve the bedding of the source area. Landslide rupture surfaces tend to occur along bedding.

paper is to use a suite of methods, including historic interviews, government archives, LiDAR from around Lakelse Lake and multibeam bathymetry, acoustic subbottom profiling, and preliminary coring of Lakelse Lake sediments to detect and characterize landslides that occur in sensitive clay. Evidence for historic and pre-historic landslides comes from mapping (Clague, 1978; Geertsema and Schwab, 1997; Geertsema et al., 2017) and from oral reports (Geertsema et al., 2017). Large historic landslides in the area include two on the east side of Lakelse Lake that occurred in 1962 and another at Mink Creek around December 1993 or January 1994 (Geertsema et al., 2017) (Fig. 2).

2. Setting

Lakelse Lake is located in the Kitimat-Kitsumkalum trough within the northwest-southeast trending Kitimat Ranges of the Coast Mountains in northwestern British Columbia, Canada (Holland, 1976; Clague, 1984). Mountain peaks rise to some 1500 m above sea level (m asl). Local bedrock consists of granodioritic intrusions of Cretaceous to Eocene age (Duffel and Souther, 1964).

The conifer forest-covered Kitimat–Kitsumkalum trough is characterized by rolling to flat terrain, composed of gullied glacial and post-glacial sediments and isolated bedrock hills. Valley fill consists of thick glaciomarine mud, glaciofluvial gravel and till, while postglacial deposits include alluvium, bogs and fens, and slopes mantled with colluvium (Clague, 1984).

During the latest Pleistocene, ice flowing down the Skeena River valley bifurcated near the city of Terrace with one lobe flowing southward towards the town of Kitimat and the other westward down Skeena valley (Fig. 2). Isostatic depression allowed the sea to transgress landward with retreating ice. The terminus of the south-flowing glacier retreated from the present location of Kitimat towards Terrace about 12,500 years ago. Isostatic rebound continued for about another 2000 years following deglaciation. Local sea level fell from its highest level at about 200 m asl to at or below present sea level by 9000–8500 years ago (Clague, 1984).

3. Methods

We obtained archival data from the British Columbia Ministry of Transportation and Infrastructure (MOTI) and from interview records from the Terrace Museum. Data from MOTI include reports, drill logs, photographs and letters from the two 1962 Lakelse landslides including a Department of Highways report (Brawner, 1962). We also use the recorded interviews conducted by the Terrace Museum staff in 1979

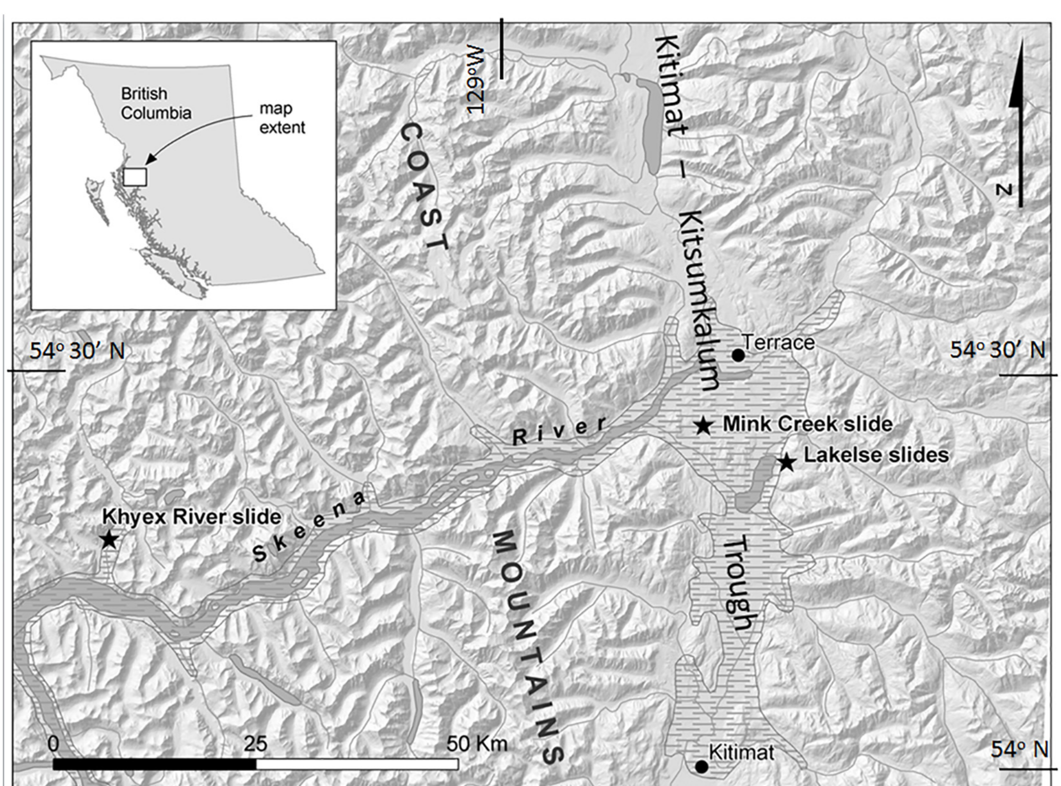

Fig. 2. Sensitive clay landslides (black stars) near Lakelse Lake, British Columbia. Stippled pattern indicates maximum sea level elevation (200 m asl) during deglaciation.