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Evidence of late glacial paleoseismicity from submarine landslide deposits within Lac Dasserat, northwestern Quebec, Canada

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ABSTRACT

An integrated seismo- and chronostratigraphic investigation at Lac Dasserat, northwestern Quebec, identified 74 separate failures within eight event horizons. Horizons E and B, and H and G have strong or moderately-strong multi-landslide signatures, respectively, composed of 11–23 failures, while horizons F, D, C, and A have minor landslide signatures consisting of a single or pair of deposit(s). Cores collected at six sites recovered glacial Lake Ojibway varve deposits that are interbedded with the event horizons. The correlation of the varves to the regional Timiskaming varve series allowed varve ages or ranges of varve ages to be determined for the event horizons. Horizons H, G, E, and B are interpreted to be evidence of paleoearthquakes with differing levels of interpretative confidence, based on the relative strength of the multi-landslide signatures, the correlation to other disturbed deposits of similar age in the region, and the lack or possibility of alternative aseismic mechanisms. The four interpreted paleoearthquakes occurred between 9770 ± 200 and 8470 ± 200 cal yr BP, when glacial Lake Ojibway was impounded behind the Laurentide Ice Sheet during deglaciation. They probably represent an elevated period of seismicity at deglaciation that was driven by crustal unloading.

Introduction

Numerous studies demonstrate that late Holocene lake-bottom deposits can contain multiple submarine landslide and/or turbidity current deposits at a common stratigraphic level that formed during modern or historical earthquakes (Shilts, 1984; Siegenthaler et al., 1987; Shilts and Clague, 1992; Chapron et al., 1999; Nomade et al., 2005). Occurrences of such multi-deposit signatures within prehistoric portions of lake sediments have also been interpreted to be evidence of paleoearthquakes (Schnellmann et al., 2002; Strasser et al., 2013). Because of the high potential for deposit preservation, paleoseismic investigations of lake deposits have yielded long-term earthquake records at many locations globally (e.g., Doig, 1990, 1998; Karlin et al., 2004; Becker et al., 2005; Monecke et al., 2006; Schnellmann et al., 2006; Moernaut et al., 2007, 2014; Upton and Osterberg, 2007; Bertrand et al., 2008; Anselmetti et al., 2009; Beck, 2011; Morey et al., 2013; Smith et al., 2013; Strasser et al., 2013; Kremer et al., 2015; Praet et al., 2016). Studies of lake deposits are especially applicable to intracratonic areas where primary evidence of paleoseismicity can be difficult to recognize (Stewart et al., 2000).

During the recession of the Laurentide Ice Sheet, substantial areas of eastern Canada were inundated by large glacial lakes or by extensions of the sea onto isostatically depressed areas (Dyke et al., 2003). These water bodies subsequently drained or receded, but thick accumulations of glaciolacustrine and glaciomarine deposits are preserved in modern lakes basins (e.g., Kaszycki, 1987; Lazorek et al., 2006; Brooks and Medioli, 2012; Normandeau et al., 2013; Eyles et al., 2015). Submarine landslide deposits have been recognized within glaciolacustrine or early post-glacial lacustrine deposits and some have been interpreted to be evidence of paleoearthquakes (Adams, 1982; Shilts et al., 1992; Ouellet, 1997; Doughty et al., 2014; Lajeunesse et al., 2016). The latter landslide deposits may be evidence of deglacial seismicity that is related to crustal unloading from the retreat of the ice sheet. Although elevated deglacial seismicity in areas of low historical seismicity is well established in Fennoscandia, as indicated by fault scarps, subaerial landslides, liquefaction structures, and tsunami layers (Lundqvist and Lagerbäck, 1976; Lagerbäck, 1990; Mörner, 2003, 2004, 2005; Smith et al., 2014), there are no similar well-documented examples in eastern Canada (Adams, 1989, 1996; Johnston, 1996; Stewart et al., 2000).

Investigating paleoseismicity is important to understanding the long term seismic hazard of the intracratonic setting of eastern

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Canada, which is poorly understood in part because the instrumental and historical records of earthquakes are short, spanning very locally only into the 17th century (Gouin, 2001; Lamontagne et al., 2008). Lake basins in eastern Canada containing interbedded submarine landslide deposits within well-stratified glaciolacustrine or glaciomarine deposits are ideal locations to apply an integrated seismo- and chrono-stratigraphic methodology that has been used successfully to investigate younger post-glacial paleoseismicity elsewhere (Brooks, 2015).

This paper assesses the possible seismogenic origin of submarine landslide deposits within the late glacial stratigraphy of Lac Dasserat, northwestern Quebec (Fig. 1). The interpretations utilize sub-bottom acoustic profiling data collected within a high-density sampling grid to map eight landslide event horizons in the upper portion of the lake stratigraphy. Glaciolacustrine varve deposits that are interbedded with the mapped landslide beds provide chronological control. As presented below, four multi-landslide event horizons are interpreted as evidence of paleoearthquakes with differing levels of interpretative confidence; aseismic origins best explain the four single and paired deposit horizons. This study, thus, presents evidence of paleoseismicity that occurred during deglaciation within an area previously inundated by a large glacial lake and which experienced a low level of historical seismicity.

Study area

Lac Dasserat, Quebec, is located ~425 km northwest of Ottawa, Ontario (Fig. 1A). The lake covers ~28 km^2 and, is up to 12.4 km long, 6.5 km wide and 17 m deep. Typical of many lakes on the Canadian Shield, the lake is irregular in shape and the bathymetry reflects the relief of the underlying bedrock. The immediately surrounding area consists of hilly terrain with relief up to 20 m high. The local surficial geology is mapped predominately as deep water glaciolacustrine sediments with numerous outcrops of bedrock, pockets of glacial deposits, and wetlands (Veillette et al., 2010). Submarine landslide deposits within Lac Dasserat were discovered initially within sub-bottom acoustic profile returns collected for an investigation of environmental metal contamination from a nearby former mining site (Alpay, 2016).

Lac Dasserat is located within an intracratonic setting ~150 km north of the concentrated belt of historical seismicity within the Western Quebec Seismic Zone, which encompasses parts of western Quebec, eastern Ontario, and northern New York State (Fig.1A; Basham et al., 1982; Adams and Basham, 1989, 1991). The 1935 Temiskaming earthquake (*M* 6.1) is the most significant historical earthquake within the northern portion of the seismic zone (Lamontagne et al., 2008); its epicenter is located about 165 km to the south of Lac Dasserat.

The lake is situated within a large area of northwestern Quebec-northeastern Ontario that was inundated by a glacial lake impounded against the retreating Laurentide Ice Sheet located to the north. This water body, referred to at different stages as lakes Barlow, Barlow-Ojibway and Ojibway, evolved within the isostatically-depressed landscape of the Timiskaming and Hudson Bay basins between roughly 11.0 and 8.4 ka cal BP (Vincent and Hardy, 1979; Veillette, 1994; Dyke et al., 2003; Breckenridge et al., 2012; Roy et al., 2015). The succession of lake stages ended when glacial Lake Ojibway, which existed in the area north of the modern drainage divide, drained catastrophically northwards into the James and Hudson basins through a breach in the impounding Laurentide Ice Sheet (Hardy, 1982; Barber et al., 1999; Roy et al., 2011; Daubois et al., 2015).

The Lac Dasserat area was inundated by proglacial lake water, up to ~80 m deep, during the Temiskaming and Anglier phases of glacial lake sequence (Vincent and Hardy, 1979; Veillette, 1994).

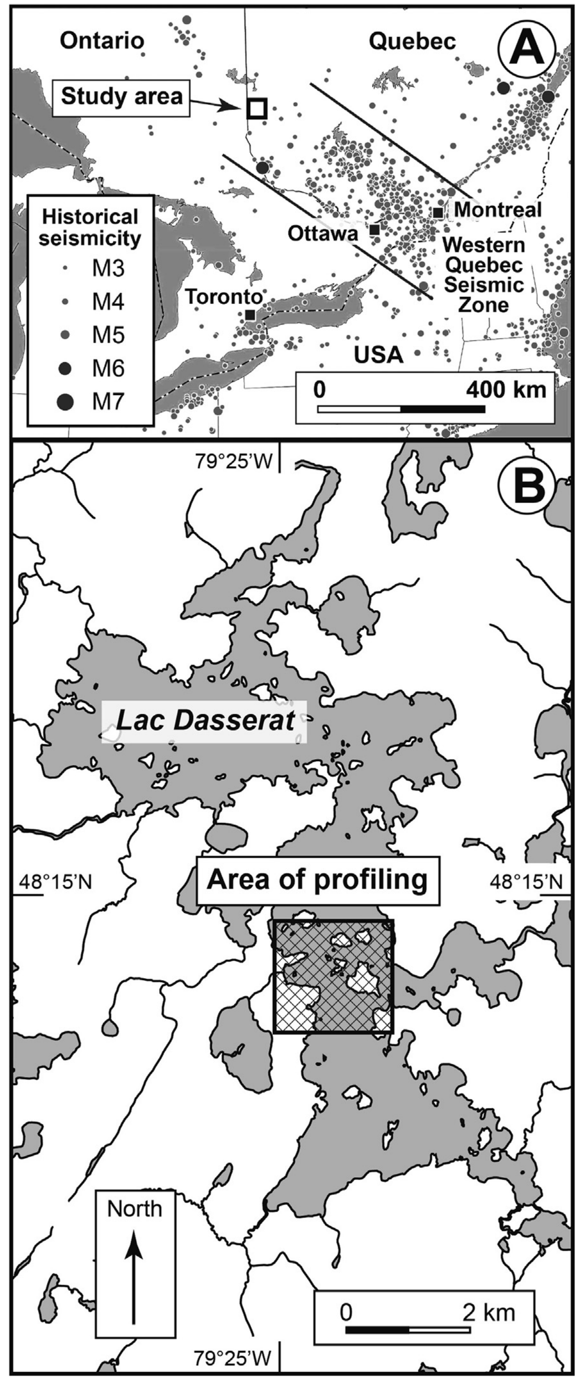

Figure 1. A) Map showing the study area location within eastern Canada and with respect to the historical seismicity of the Western Quebec Seismic Zone. B) Map showing the Lac Dasserat study area, northwestern Quebec.

Water levels subsequently declined to the early and late Kinojévis phases, as the ice front retreated farther northwards and the landscape rebounded (Roy et al., 2015). During these later stages, the Dasserat basin was located initially within one of several low interfluve areas that funneled outflow southward from glacial Lake Ojibway and later within one of several outlet channels (Vincent and Hardy, 1979).

A legacy of the glacial lakes is the regional occurrence of glaciolacustrine deposits that form the Great and Lesser clay belts areas of northwestern Quebec-northeastern Ontario. About 2100 rhythmic laminations within these deposits form the 'Timiskaming

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