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A guide to landslides in sensitive clay along the north side of the Ottawa River, west of Ottawa-Gatineau, southwestern Quebec

G.R. Brooks and H.L. Crow

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Introduction

Fine-grained Champlain Sea sediment (silty-clay and clayey-silt) is a late Quaternary glaciomarine deposit important to the engineering geology of the Ottawa Valley. Known informally as 'Leda clay' or 'Champlain Sea clay', the deposits typically are 'soft' in the geotechnical sense. Buildings constructed on thick deposits of soft clay can experience settlement problems, particularly those designed with an asymmetrical foundation loading. The Canadian Museum of Nature (formerly the Victoria Memorial Museum Building) in downtown Ottawa is a well-known example of such a structure. Differential settlement caused major structural issues that were mitigated by lowering a prominent central tower by 28 m, just three years after the building opened in 1912. Also affected are smaller structures with asymmetrical loading, including houses.

Thick, soft deposits of Champlain Sea clay amplify seismic shaking, whereby the wavelength and amplitude of shear ('s') waves shorten and increase, respectively, when travelling from depth to surface, as they pass across the impedance boundary between thin glacial deposits or hard bedrock, and overlying clay. Also, the duration of shaking over such areas is extended by the repeated oscillation of s-wave energy between the ground surface and underlying impedance layer. The net effect is that areas of thick, soft Champlain Sea clay generally experience stronger and longer shaking during a given earthquake than areas where bedrock is at (or near) the surface, other factors being equal.

Champlain Sea clay can be geotechnically sensitive, meaning they can lose strength when remoulded (or disturbed). They can also experience large, retrogressive landslides. Such landslides occur throughout the Ottawa Valley, can happen rapidly and without warning, and have caused significant loss of lives and property. Many residents of the Ottawa Valley are familiar with the term "Leda clay" and recognize that it is prone to significant landslides.

This guidebook presents a one-day, self-guided tour that highlights landslides in sensitive clay at five locations situated just north of the Ottawa River within the municipalities of Pontiac, Bristol and Clarendon, Québec, to the west of Ottawa-Gatineau (Figure 1). The landslides form major geomorphic features in the landscape that are easily overlooked, but readily apparent on shaded relief maps. The sites include the Quyon Valley landslide, one of the largest landslides in sensitive clay in eastern Canada. All five locations are easily accessed and viewed along roads without intruding onto private property. The guidebook is intended to help raise awareness of landslides in sensitive clay that form an important part of the local geology and geomorphology.

The guidebook consists of two sections. The first provides background information on the late Quaternary history of the region, sensitive clay deposits, landslides in sensitive clay, and the seismicity of the region. The second section provides summaries of the five stops, and includes driving directions and GPS coordinates. The **driving directions begin at the intersection of Highway 148 and Chemin Eardley in Aylmer** (45.4078°N; 75.8658°W), and are current as of May 23, 2020. At all of the stops, the landslide features are large and require an observer to 'think big'!

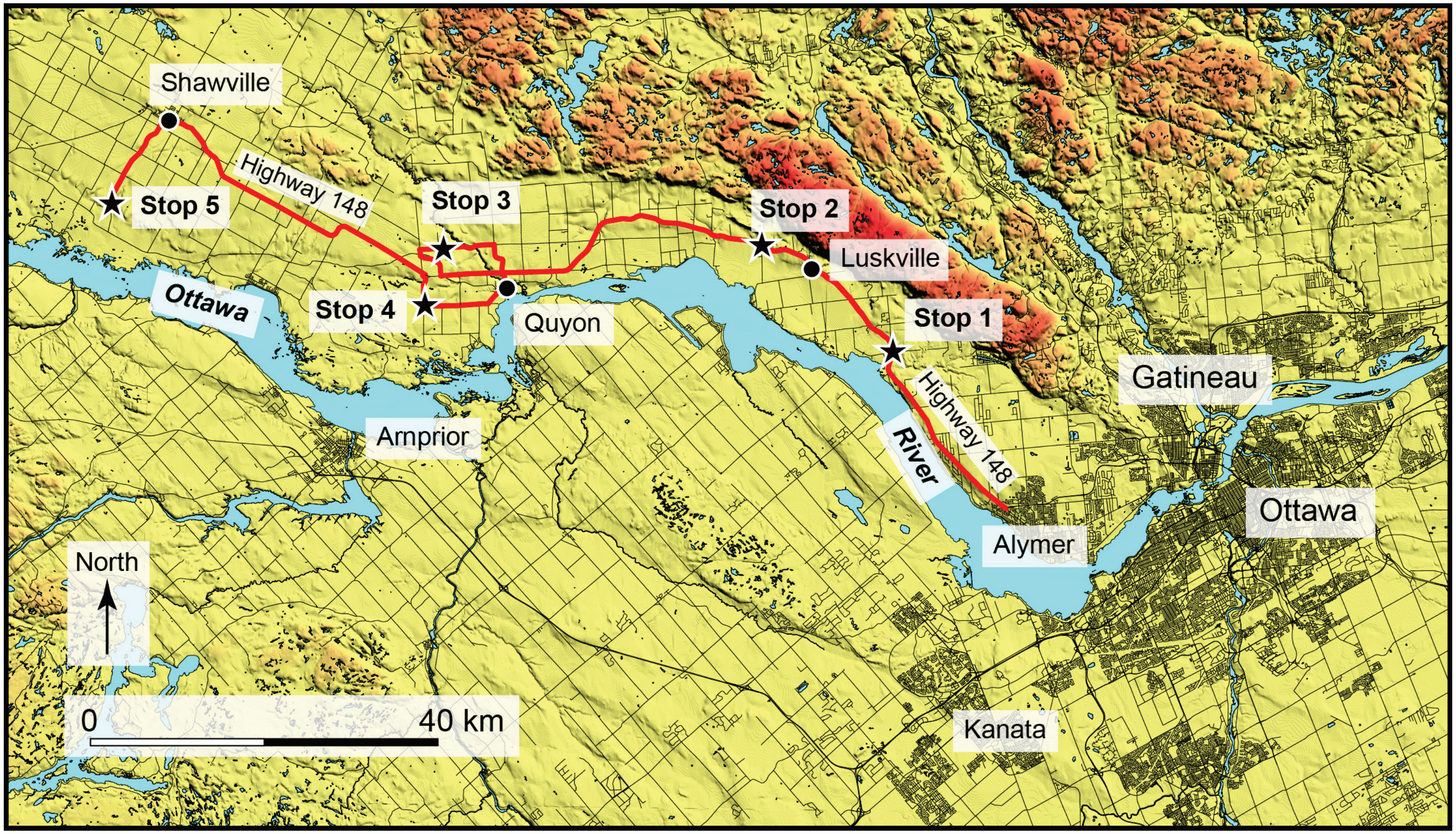

Figure 1 Map showing the stop locations along the about 80 km long field trip route. Refer to the individual Stop summaries for driving directions.

Background

Champlain Sea clay

Extensive deposits of glaciomarine silty-clay and clayey-silt (referred to generally as 'clay' in this guidebook) underlie large areas of the low-lying terrain in the Ottawa Valley. The sediments accumulated within the Champlain Sea that inundated the isostatically depressed landscape of the St. Lawrence Lowlands and Ottawa Valley, between 14,000 and 10,500 calibrated years before present (cal yr BP), or about 12,000 and 9500 radiocarbon years before present (^{14}C yr BP; Dyke, 2004; Figure 2). Champlain Sea clay forms the thickest and most extensive late Quaternary deposits in the area, and imparts a flat topography in many areas of the Ottawa Valley. Locally, where overlying deep, buried bedrock valleys or basins, Champlain Sea clay can be up to 150 m thick. The sediments extend many tens of kilometers up the larger tributary valleys draining from north of the Ottawa River, for example, the Gatineau and Lièvre rivers (Figure 3). The Champlain Sea receded from the Ottawa Valley during the early Holocene due to isostatic uplift, resulting in the postglacial stream network developing upon, and incising into, the landscape (Figure 3).

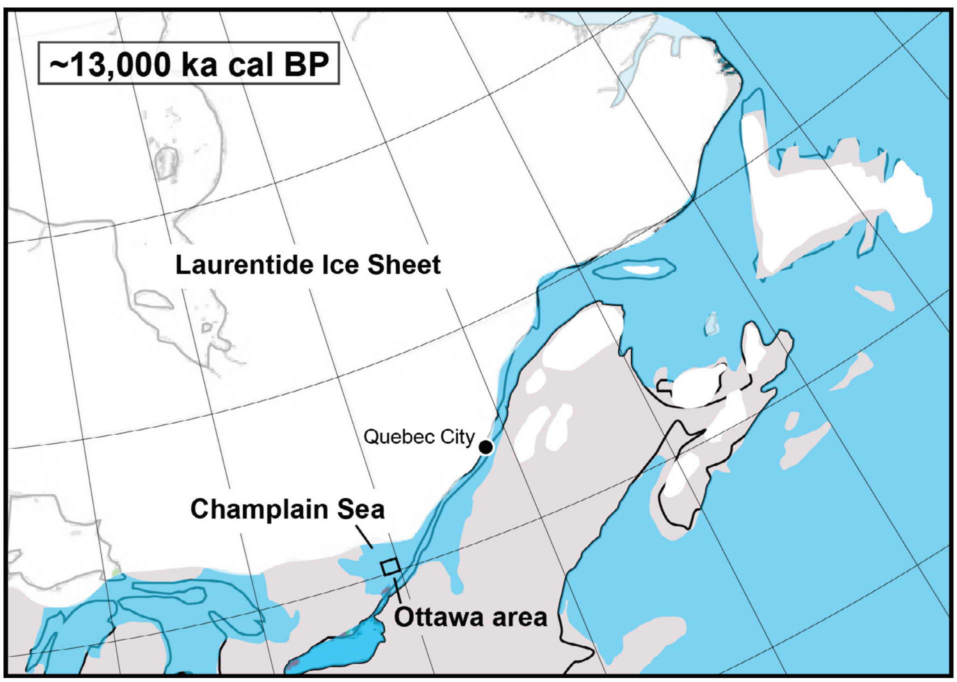

Figure 2 Map of eastern Canada showing the position of the Laurentide Ice Sheet at about 13,000 cal yr BP (about 11,000 ^{14}C yr BP; after Dyke, 2004). An arm of the sea extends up the isostatically-depressed landscape of the St. Lawrence Lowlands and Ottawa Valley. The Champlain Sea specifically refers to the portion of the sea west of Québec City; the portion to the east is the Goldthwaite Sea. The Champlain Sea inundated the Ottawa Valley between about 14,000 and 10,700 cal yr BP.

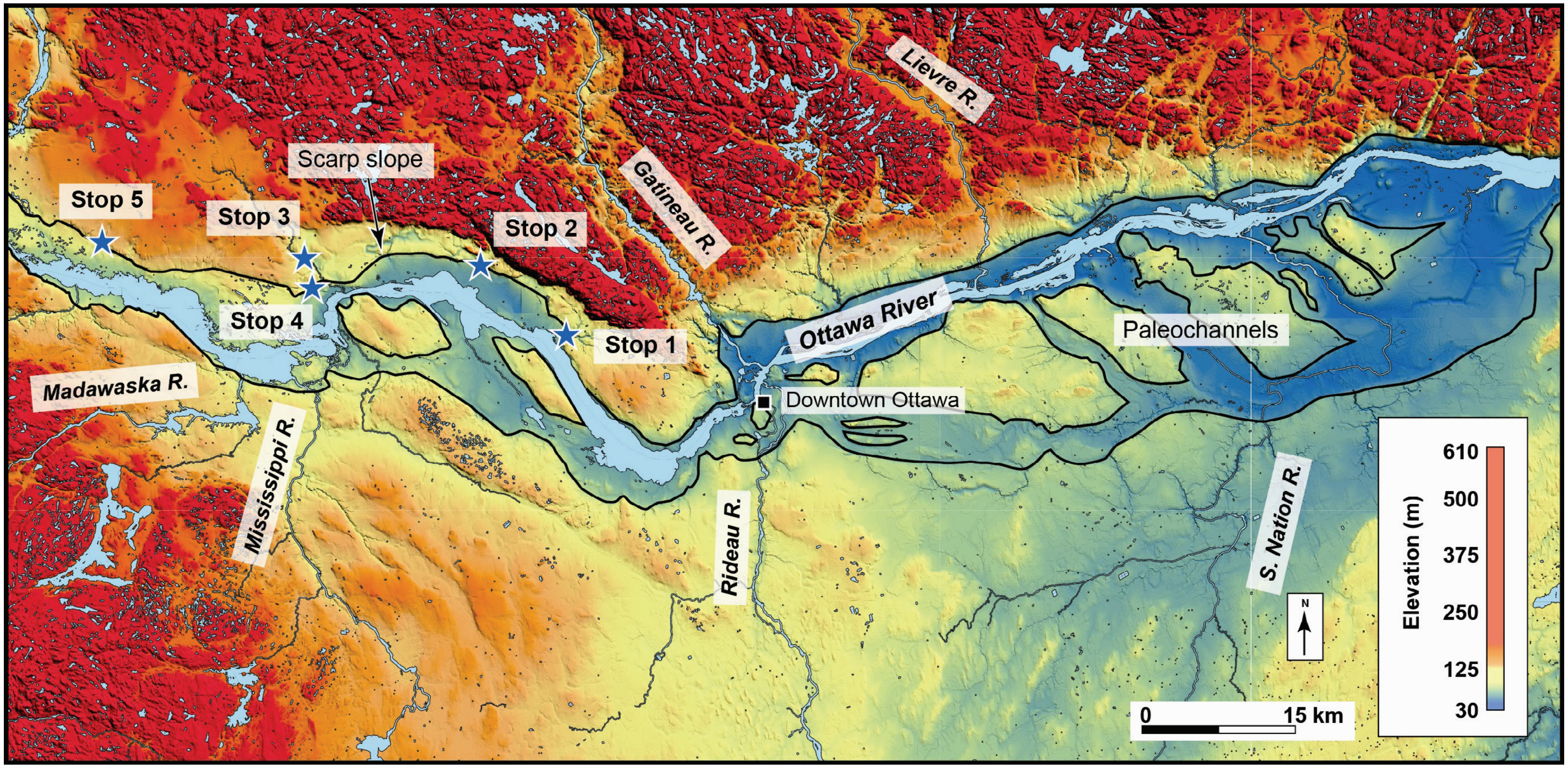

Figure 3 Shaded relief map of the greater National Capital portion of the Ottawa Valley. Black lines delineate the margins of the Ottawa River paleochannels incised into the Champlain Sea deposits. Blue stars mark the field trip stops. The scale of the paleochannel(s) greatly exceeds that of the modern Ottawa River channel, reflecting the discharge of outburst floods routed down the Ottawa Valley from glacial Lake Agassiz, northwestern Ontario, via the Upper Great Lakes and Mattawa Valley (see Lewis and Anderson, 1989). To minimize obstruction of the geomorphology, only the central area of downtown Ottawa is shown for reference.

Typically, the silt- and clay-sized sediments that comprise Champlain Sea clay are predominantly quartz, feldspar, amphibole, illite and chlorite minerals, which represent glacial rock flour rather than clay minerals (Torrance, 1988, 2012). These fine-grained particles flocculated by attraction to sodium ions within the saline-to-brackish marine waters of the Champlain Sea, producing a sediment fabric with a porous, loose structural framework.

In the modern landscape, Champlain Sea clay can be geotechnically ‘sensitive’, whereby the shear strength of a disturbed (or remoulded) deposit is significantly lower than its undisturbed shear strength. In cases where remoulding yields a very low residual strength and the natural moisture content exceeds the liquid limit, the sediment may liquefy rapidly upon disturbance and flow because of the collapse of the loose sediment fabric. Sediment sensitivity is defined quantitatively by the ratio of undisturbed to remoulded shear strength (at the same moisture content). The Canadian Foundation Engineering Manual (2006) classifies sensitivity ranges as ‘low’ (ratios of 2-10), ‘medium’ (10-40) and ‘high’ (40-100), although numerous other sensitivity scales do exist (see L’Heureux et al. 2014).

In the Ottawa Valley, sensitivities are variable locally and are reported as high as 175 (e.g. Eden et al., 1971; Mitchell and Markell, 1974; Law et al., 1985; Medioli et al., 2012; Crow et al., 2017). The development of sensitivity generally relates to a high natural moisture content in the deposits, the flocculated fabric of the fine-grained particles, low electrical attraction between the particles, low overburden pressures during deposition, and post-depositional leaching of sodium from the clay (Torrance, 1988, 2012; Carson and Bovis, 1989). The leaching of sodium is a particularly important factor influencing the development of sensitivity.

Geophysical properties of Champlain Sea sediments

Over the past two decades, shallow geophysical data have been collected to measure overburden properties in Champlain Sea sediments for geohazard studies (Hyde and Hunter, 1998; Benjumea et al., 2003; Pugin et al., 2007, 2009; Pullan et al., 2011; Crow et al., 2011, 2014; Hunter et al., 2012). The ranges of geophysical and geochemical properties in the guidebook area west of Ottawa are exemplified by data from a Geological Survey of Canada borehole drilled near Stop 1. The borehole is situated at the top of the Champlain Sea clay plain, and intersects 75 m of silty, clayey sediments within Breckenridge Valley (Figure 4; see Crow et al., 2017). Sampling included the collection of 20 undisturbed samples recovered from up to 65 m depth for geotechnical testing, pore water extraction, and grain size and mineralogical analyses. Downhole geophysical logging of the cased borehole collected data on physical and chemical properties of the sediments. The borehole data are presented in Figure 5 and summarized below:

Grain size analyses: Grain size analyses show the sediment samples are a mix of silt (0.063-0.002 mm) and clay-sized (less than 0.002 mm) particles, both typically ranging between 30 to 70%, with a small amount of sand (2-0.063 mm), varying between 0 to 5%.

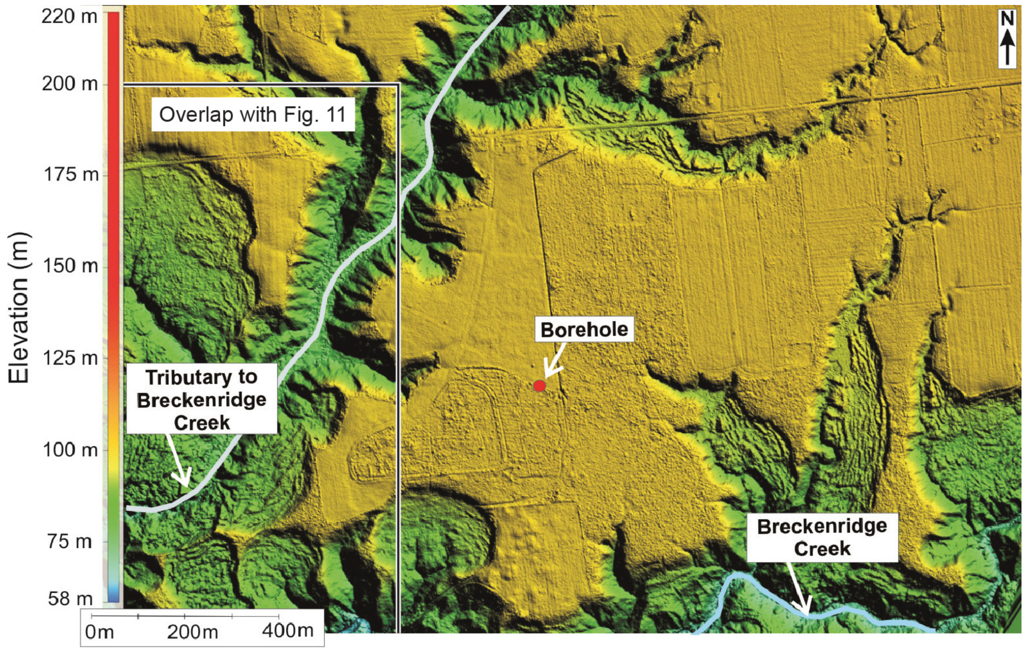

Figure 4 Shaded relief map showing the location of the Geological Survey of Canada borehole in the central area of Breckenridge Valley. The borehole is located about 1.5 km east of Stop 1 (part of this figure overlaps with Figure 11, which shows Stop 1). Note, the numerous scars of landslides in sensitive clay (i.e., the green-shaded areas with irregular surface topography) along Breckenridge Creek and a tributary.

The core sediments are massive (lacking visible bedding or rhythmitic laminations) with a dark grey to greenish-grey color. Sediment is more silt-rich (65-70%) and has a higher sand content (1-4%) in the lower part of the borehole (40-65 m deep) than the upper. Between 3-40 m depth, the clay and silt alternate as the dominant grain size (both typically 45-55%). The decrease in coarser grain sizes (silt and sand) from the lower to upper half of the core sediments probably reflects a transition from a more proximal to distal, deep-water depositional setting within the Champlain Sea.

Clay and silt mineralogy: The core sediment samples contain a high proportion of clay-sized grains (less than 0.002 mm), but a paucity of clay minerals (e.g., chlorite and illite). The primary minerals in the sediment are plagioclase (35%), biotite (18%), quartz (16%), amphibole (13%), and potassium feldspar (12%), as indicated by x-ray diffraction analysis. These proportions remain relatively consistent throughout the borehole. This mineralogy reflects the origin of the sediment as glacial flour eroded from granitic-gneissic bedrock of the Precambrian Shield that was transported into the Champlain Sea by glacial meltwater. Due to the low amount of clay minerals, the gamma counts in Figure 5 are relatively low compared to typical mineralogical clay (or shale) deposits, which contain significant amounts of clay minerals (e.g. vermiculite, smectite).

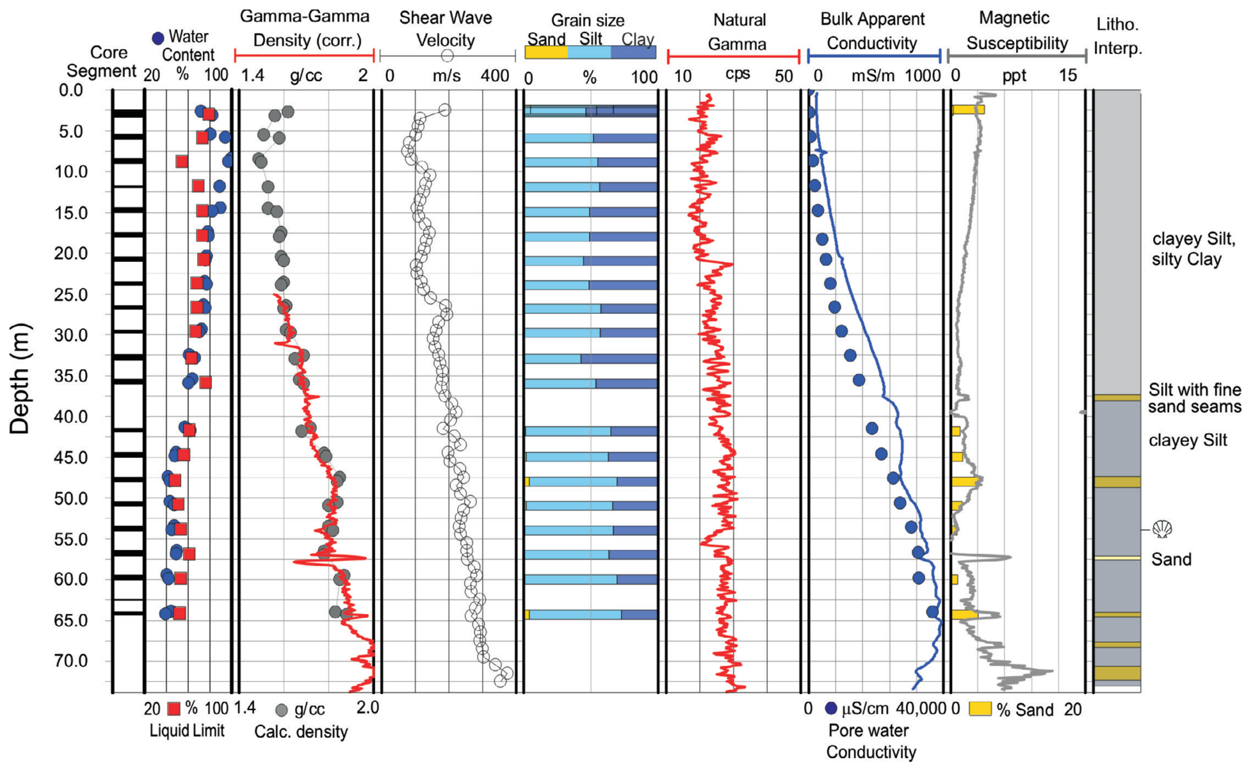

Figure 5 Comparison of geophysical logs with selected core analyses for the Geological Survey of Canada borehole located within Breckenridge Valley (see Figure 4; adapted from Crow et al., 2017).

Water content: Gravimetric water (or moisture) contents (mass of water per mass of dry soil) in the borehole samples range from 40-99%, decreasing with depth as pore space decreases with increasing sediment loading. The water content shows an inverse relationship with density (1.5-2.0 g/cm^3) and shear wave velocity (80-375 m/s). Within the upper 30 m, the water content exceeds the liquid limit, indicating the sediment may behave as a liquid when disturbed. The local occurrence of large retrogressive landslides provides empirical evidence of disturbed sensitive clay deposits behaving as a liquid near the borehole within the Breckenridge Valley area (see Figure 4).

Pore water conductivity: The conductivity of the pore waters range between 176-38,500 µS/cm and decreases upward, reflecting a decreasing proportion of residual saline Champlain Sea water within the pore water (Figure 5). The downhole bulk conductivity log (a measure of both sediment grain and pore water conductivity) mirrors this trend, indicating that local conductivities span two orders of magnitude (25-1000 mS/m). The highest conductivity pore water was sampled at 65 m depth, near the bottom of the core. The replacement of the original saline pore water with fresher meteoric water is a site specific, post-depositional factor that can affect sediment sensitivity differently from location to location.

Magnetic susceptibility: Magnetic susceptibility (MS) log response increases in the presence of magnetic minerals within the sediments immediately surrounding the borehole. The increase in MS below 40 m depth, and especially below 55 m (Figure 5), is inferred to reflect an increased sand content, as heavier (denser) iron oxides (primarily magnetite) are found generally in greater concentrations within this size fraction than in silt- or clay-rich sediments. This interpretation is supported by the sand content in the sediment samples (Figure 5). However, as iron oxides were seen in small quantities under an electron scanning microscope within the clay- and silt-sized fractions, the MS log will also reflect the downhole change in fine-grained magnetic minerals.

Sensitivity: Although not shown in Figure 5, lab testing indicates a sensitivity range of 5 to 42 in the core samples. By the standards of the Canadian Foundation Engineering Manual, sediment samples are within the ranges of high and medium sensitivities in the near surface (8 – 18 m depth), and medium to low sensitivities below 20 m depth. Sediments in the surface crust (<6 m depth) are of low to medium-low sensitivity.

Comprehensive borehole studies, like the one in Breckenridge Valley, provide important data on the subsurface geophysical and mineralogical properties of Champlain Sea sediment and the chemistry of the pore water. Such data help identify areas for follow-up geotechnical testing (e.g. low density or shear wave velocity and low conductivity). Analyses of pore water also provide insights into the evolution of chemical properties of Champlain Sea sediment over time.

Landslides in sensitive clay

Retrogressive landslides in sensitive clay occur as a rapid succession of rotational failures, the lateral translation of large blocks of soil, or a combination of both processes. Landslides dominated by rotational failures are termed earthflows and those by translating blocks are called earthspreads. Both processes result in the rapid extension of the landslide area by the retreat of the headwall. The flow of clay liquefied by the failure process promotes the evacuation of intact blocks of soil debris from base of the failed slope, and thus the continued instability of the headwall and/or sidewall(s). From an initiating failure on a slope, up to about 30 m high, earthflows and earthspreads can retrogress many 100s of metres (or more) at speeds of 5 m/s (or faster) into a relatively flat plain along a low-angled failure plane (Figure 6). All of the landslides in sensitive clay seen or mentioned at the five stops are the product of this retrogression process.

Landslide debris consisting of liquefied clay, rafted blocks of intact sediment, vegetation, and anything else engulfed in the failure, will flow into a valley bottom or onto an adjacent low-lying surface. Where a landslide occurs along the side of a narrow valley, in many cases, the debris crosses the valley and stops, but in others, where there is a higher proportion of liquefied material, it may flow a considerable distance upstream and downstream of the source area. For example, debris from the 1993 Lemieux landslide flowed about 1600 m both upstream and downstream along the valley of the South Nation River (Evans and Brooks, 1994). Where the failed debris crosses a relatively narrow valley, it may impound drainage causing flooding upstream. Once overtopped, there is the potential of rapid fluvial erosion into the debris that could generate a substantial and potentially dangerous flood downstream. Because of the cohesive character of the failed deposits that can be resistant to fluvial erosion, residual

Figure 6 Photographs of recent landslides in sensitive clay in the Ottawa Valley; the 1993 Lemieux (top) and the 2010 Notre-Dame-de-la-Salette (bottom) landslides. Both landslides were initiated by a shallow failure along the side of a river valley that triggered a succession of rotational slumps and/or translating blocks, causing the enlarging source area to retrogress rapidly, about 680 m (Lemieux) and 470 m (Notre-Dame-de-la-Salette), into a quasi-flat plain. The generated landslide debris flowed out of the source areas, into, and then upstream and downstream along the adjacent steam valleys. (Photos by S.G. Evans, GSC 1993-296 (top), and C. O'Dale (bottom.)

impoundments along small streams can persist for months and even several years after the debris is overtopped.

The sensitive clay sediments throughout the Ottawa Valley are prone to rapid, large (> 1 hectare), retrogressive earthflows and earthspreads. The scars of landslides in sensitive clay are common in the area, and approximately 250 landslide polygons appearing on surficial geology maps (Figure 3; see, for example, Fransham et al. 1976; Richard, 1980; 1982a, b; 1984a, b; 1990; 1991; Richard et al., 1978; St. Onge, 2009). Many of these polygons encompass multiple landslides, thus 250 is a minimum of the number of landslides in sensitive clay within the area. Some of these landslides occurred historically; well documented examples include the 1903 Pourpore landslide (Ells, 1904; Aylsworth et al., 1997), the 1908 Notre-Dame-de-la-Salette, which caused 34 fatalities (Ells, 1908; Locat et al., 2017), the 1971 South Nation River landslide (Eden et al., 1971), the 1993 Lemieux landslide (Evans and Brooks, 1994; Brooks et al., 1994), and the 2010 Notre-Dame-de-la-Salette and Mulgrave-Derry landslides both of which were triggered by the M_w 5.0 Val-des-Bois earthquake (Perret et al., 2011, 2017). At the time of writing, the most recent significant landslide in sensitive clay in the Ottawa Valley occurred along the Bonnechere River, near Renfrew, on the night of March 28-29, 2016 (Haaima, 2016; Spears, 2016). Most of the landslides in the area, however, are prehistoric failures of unknown age.

As shown on Figure 7, landslides in sensitive clay in the Ottawa Valley occur in five basic geomorphic settings: 1) along the valley sides of major tributaries of the Ottawa River, particularly those draining from north of the Ottawa River; 2) along the valley sides of minor tributaries of the major tributaries and the Ottawa River; 3) along the scarp slope of erosional terraces along the Ottawa River; and 4) along scarp slopes forming the margins of the multiple paleochannels located east of Ottawa (Fig 2). The landslides vary considerably in scale; historic failures range up to 2.8 million m^3 with retrogression distances of many hundred of metres (Evans and Brooks, 1994). The largest landslide in the area is prehistoric in age, and originated from a source area along the lower Quyon Valley that is 11.5 km long, up to 4.5 km wide, and about 28 km^2 in area (Brooks, 2013; see Stop 4).

Ages of landslides in sensitive clay

There are 50 dated landslides in sensitive clay in the Ottawa Valley (figures 8 and 9). Dating utilized the radiocarbon analysis of terrestrial vegetative materials that were buried within or beneath landslide debris, or sampled from the base of ponds or wetlands that developed in depressions on a landslide surface (Brooks et al., 2013; Brooks, unpublished data). The ages of 21 landslides are represented by single radiocarbon dates, while between two and 17 radiocarbon dates represent the ages of the other 29 failures.

As shown on Figure 9, the calibrated ages of the sensitive landslides span about 8000 years, which extends back close to the time of the final recession of the Champlain Sea from the Ottawa Valley. The ages occur regularly over this timespan, but there are two distinct age groupings occurring between approximately 5000-5400 and 980-1060 cal yr

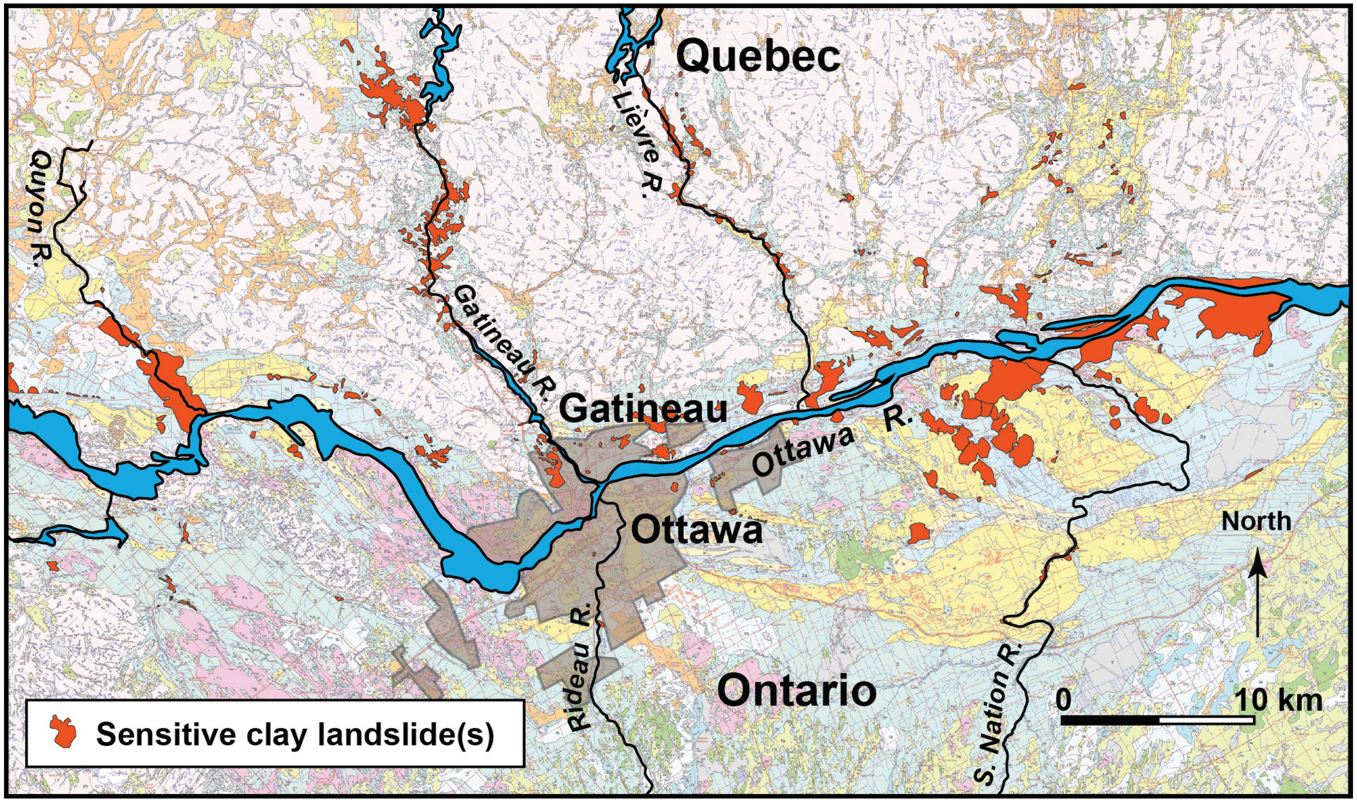

Figure 7 Map showing the locations of major landslides and landslide areas near Ottawa-Gatineau, superimposed on a local surficial geology map (modified after St. Onge, 2009). Polygons represent both large, single landslide features as well as areas consisting of multiple, closely-space failures. The landslides are located: along the valley sides of major tributaries of the Ottawa River; along the valley sides of minor tributaries of the major tributaries and the Ottawa River; along the scarp slope of erosional terraces along the Ottawa River; and along scarp slopes forming the margins of a network of paleochannels east of Ottawa. See Figure 3 for the delineation of the Ottawa River paleochannels.

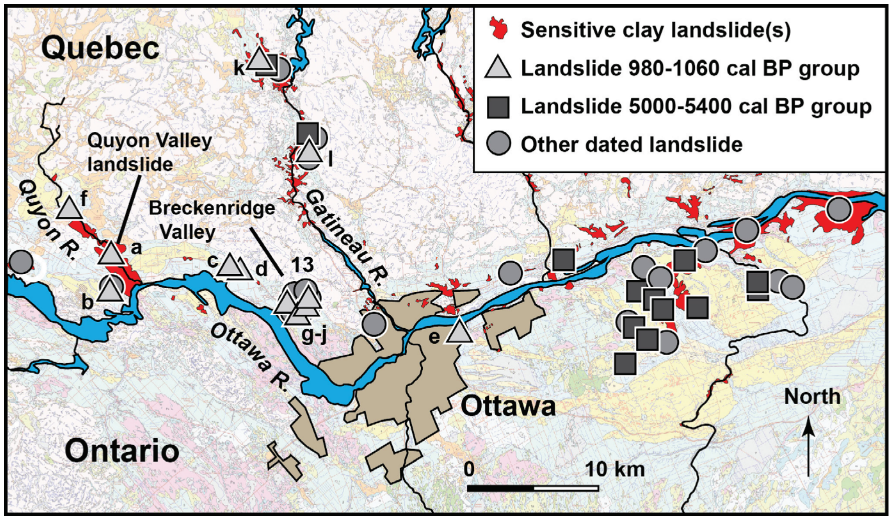

Figure 8 Map showing the locations of the 50 dated landslides in sensitive clay in the Ottawa Valley (data from Brooks et al., 2013; Brooks unpublished). The landslides are grouped into three categories: ages in the 980-1060 or 5000-5400 cal yr BP ranges, and other dated landslides. The letters beside the landslides in the 980-1060 cal yr BP group are keyed to Figure 16. The '13' beside a cluster at Breckenridge Valley denotes thirteen closely-spaced landslides with overlapping symbols.

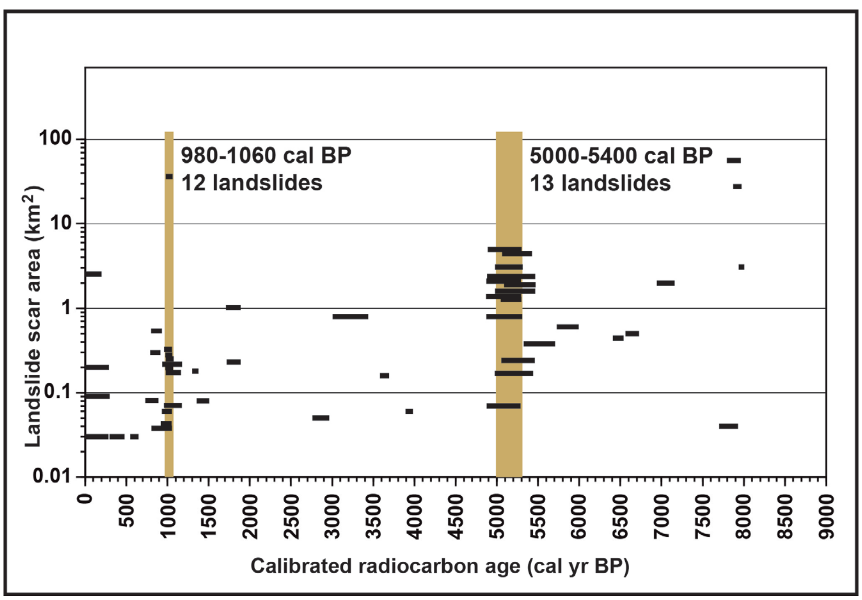

Figure 9 Plot of landslide scar area versus calibrated radiocarbon age for the 50 dated landslides in sensitive clay in the Ottawa Valley. The ages of 21 landslides are represented by single radiocarbon dates, while those of 29 failures are interpreted from between two and 17 radiocarbon ages relating to a given landslide. Twenty five (i.e., 50%) of the dated landslides fall with one of the two shaded groupings of landslide ages that are interpreted to contain landslides triggered by paleoearthquakes. (Modified from Brooks, 2014.)

BP consisting of 13 and 12 landslides, respectively. The greater age ranges within the older group reflect uncertainty from the calibration of the radiocarbon ages to calendar (sidereal) years, rather than being analytical uncertainty from the radiocarbon laboratory analysis. These groups of landslides are interpreted to be evidence of paleoearthquakes by Aylsworth et al. (2000) and Brooks (2013), after considering the geomorphology of the failure locations, the locations of the landslides with respect to one another, and possible aseismic mechanisms. The minimum magnitude of these earthquakes is estimated to be moment magnitude (M_w) ~6.1 and ~6.4 for the 980-1060 and 5000-5400 cal yr BP events, respectively, based on an empirical relationship between the area affected by landsliding versus earthquake moment magnitude (Brooks, 2015).

Western Québec Seismic Zone

The Ottawa Valley is situated within the Western Québec Seismic Zone (WQSZ), which encompasses parts of western Québec, eastern Ontario, and northern New York State (Figure 10; Basham et al., 1982). In Canada, most earthquakes in the WQSZ occur within two areas: a southeast-northwest oriented band extending from Montreal to the Baskatong Reservoir, and a less active, parallel, southern band trending along the Ottawa River from the Ottawa area to near Lake Timiskaming (Figure 10; Adams and Basham, 1989; 1991). The route of the field trip is within the southern band. Seismicity along this

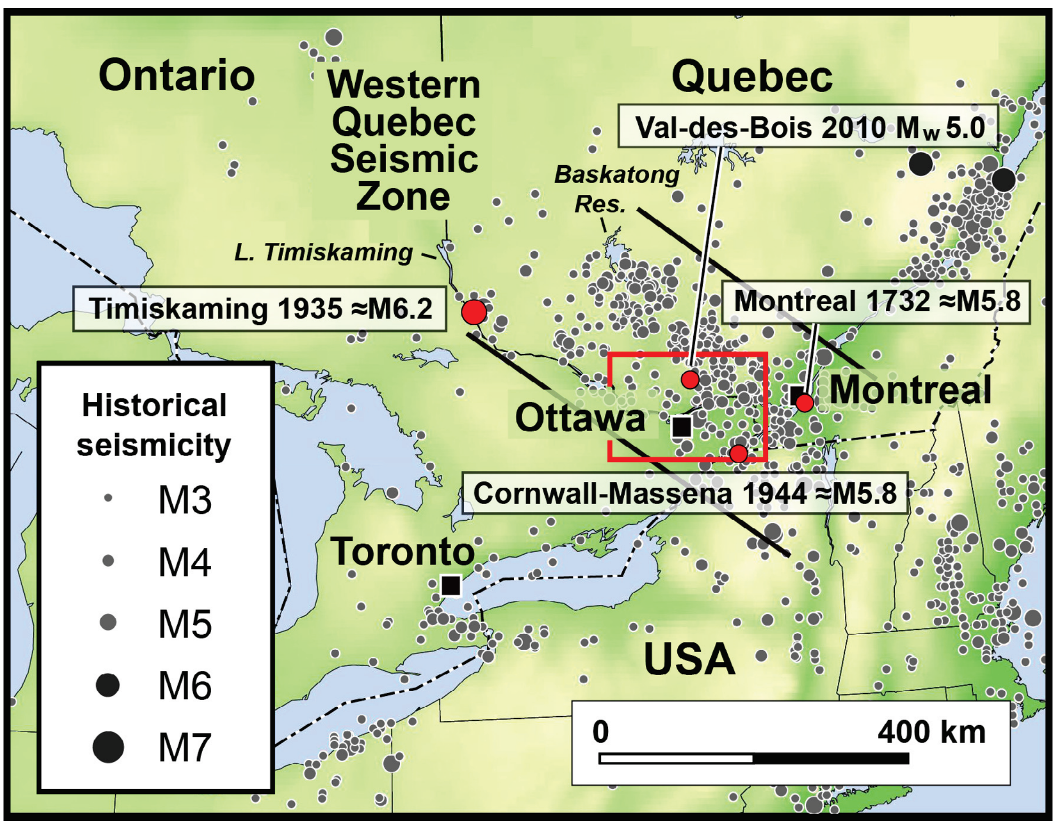

Figure 10 Map showing the historical seismicity of the Western Québec Seismic Zone with significant historical earthquakes highlighted. The red rectangle shows the location of the map in Figure 1.

portion of the WQSZ is associated with Paleozoic rift faults within the Ottawa-Bonnechere graben, while that of the northern band may relate to crustal fractures caused by the passage of the crust over a hot spot during the Cretaceous. Significant historic seismic events in the WQSZ include the 1732 Montreal (M 5.8), 1935 Timiskaming (M 6.1), and 1944 Cornwall (M 5.8) earthquakes (Lamontagne, 2010). At the time of writing, the most recent, widely-felt earthquake was the 2010 Valle-de-bois (M_w 5.0) with an epicenter located about 58 km NNE of downtown Ottawa. As is apparent in the Stop 3 summary, there is a connection between earthquakes and the occurrence of large landslides in sensitive clay in the Ottawa Valley.

Stop 1 Truncated landslide scars (45.4883°N; 75.9508°W)

From the intersection of Highway 148 and Chemin Eardley *in Aylmer (Fig. 1),* ***proceed west along Highway 148 for about 11.6 km****. You are getting near to the first stop when the road descends down an obvious long hill, and then crosses Breckenridge Creek.* ***Turn right onto Chemin Smith Leonard****, which is the first road past the bridge over Breckenridge Creek (see Figure 11).* ***Park along the shoulder of Chemin Smith Leonard about 100 m from the highway****. Use Figure 11 to orient yourself. The steep hill further up Chemin Smith Leonard is the prominent scarp mentioned in the following text.*

West of Gatineau, a prominent scarp, 20-30 m high, is present along the north side of the Ottawa River that extends about 65 km more or less continuously from the mouth of Breckenridge Creek to Portage-du-Fort (figures 1 and 3). Numerous scars of landslides in sensitive clay are present that formed by failures retrogressing into this scarp (Figure 5). The resulting landslide debris flowed onto the adjacent, lower, alluvial terrace surface. Two distinct generations of landslides in sensitive clay are present along this scarp.

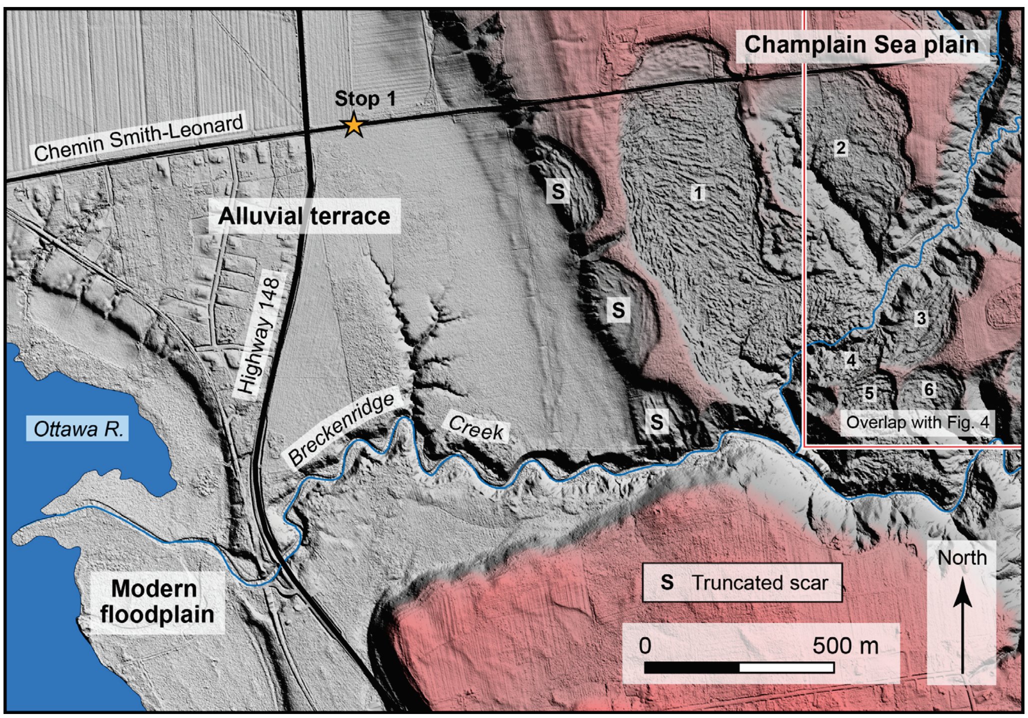

Figure 11 Shaded relief map showing three truncated scars of landslides in sensitive clay (marked by S's) along the scarp slope at the margin of a wide Ottawa River terrace. The orange star marks the location of Stop 1. Note, the six landslide scars (numbered 1 to 6) that formed by retrogression into the valley side along Breckenridge Creek and a tributary (these scars are not visible from Stop 1). The red rectangle on the right side of the figure marks the overlap with the shaded relief map in Figure 4, which shows additional landslide scars in Breckenridge Valley and the location of the Geological Survey of Canada borehole mentioned above.

Each of the older generation of landslides have a distinct source area eroded into the scarp, but the debris fields are truncated abruptly along the margin of the scarp slope (Figure 11). In contrast, each of the younger generation of landslides have a well-preserved debris lobe extending from the source area onto the surface of an adjacent alluvial terrace (see Stop 2). The difference in debris lobe preservation distinguishes failures that happened when the Ottawa River channel was still actively flowing on the alluvial terrace (i.e., those with a truncated debris field) versus failures that happened after the terrace was abandoned by the river (i.e., those with a preserved debris lobe). The age of the alluvial terrace is not dated precisely, but likely was abandoned by the Ottawa River when the river incised to a low level between 8.5-6.5 ka cal yr BP. This age range corresponds to the development of a shallow lake at the Mer Bleue bog within a paleochannel of the Ottawa River (Elliott et al., 2012), and the oldest age of a dated landslide debris lobe splayed onto the alluvial terrace surface (see Stop 5). Based strictly on the presence or absence of a debris lobe, landslide features along the scarp slope can be readily identified as being pre-6.5 or post-6.5 ka cal yr BP in age.

As shown in Figure 11, this stop provides a good view of the scarp slope and three landslide scars with truncated debris fields. Viewed from Chemin Smith-Leonard on the level of the terrace surface, the scars are visible as ledges in the upper portion of the scarp slope. The top of the scarp slope is the surface of the plain that represent the former bottom of the Champlain Sea (i.e., the Champlain Sea plain).

The three scars are undated, but are inferred to pre-date 6.5 ka cal yr BP, because of the truncated debris fields. These scars are difficult to date more accurately because the surfaces have been worked by earthmoving equipment to smooth out the original hummocky surface and improve the land for agriculture. Any wetlands that might have been present between the hummocks on the landslide surfaces would have been drained and/or infilled. The triggers of the three landslides are unknown. Toe erosion of the scarp slope by the ancestral Ottawa River is the obvious cause, although this is unsubstantiated. The landslides are assumed to be of different age.

Turn your vehicle around, ***turn right onto Highway 148*** *and* ***proceed to Stop 2****.*

Stop 2 Landslide scars with preserved debris lobes - Alary Road and Luskville landslides (45.5410°N; 76.0490°W)

***After returning to Highway 148, travel for about 10.3 km west**, and **turn left** (south) **onto Chemin Alary (the turn is the first left past the end of the four-lane section of Highway 148**; see Fig. 2). **Stop along the side of Chemin Alary about 250 m from the highway**. You are parked on the Alary Road landslide. Orient yourself using Figure 12.*

The Alary Road landslide, and the nearby Luskville landslide, are examples of landslides in sensitive clay that retrogressed into the scarp slope, described at Stop 1, and have preserved debris lobes splayed onto a broad, flat alluvial terrace of the Ottawa River (Figure 12). The preserved debris lobes indicate that the Ottawa River had abandoned this portion of the terrace before either failure occurred. The river, thus, had no role in triggering the landslide through toe erosion of the scarp slope (see Stop 1).

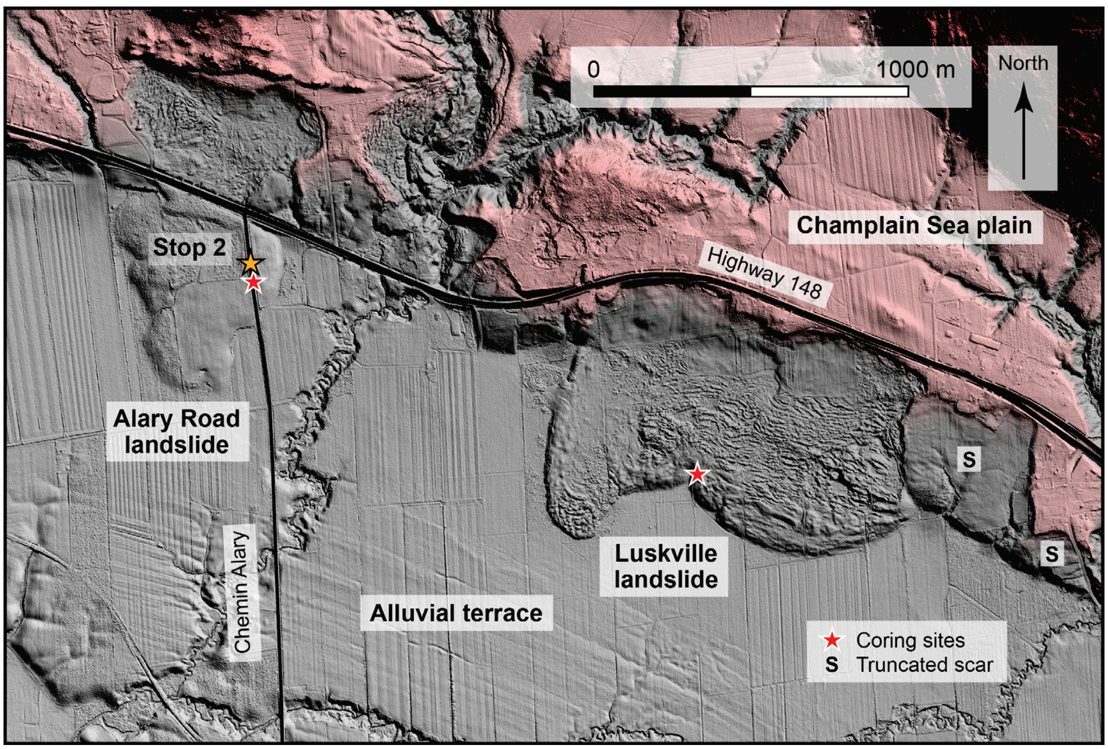

Figure 12 Shaded relief map showing the Alary Road and Luskville landslides, near Luskville, Québec. The orange star marks the location of Stop 2. Failures at both locations retrogressed into the scarp slope and the resulting landslide debris splayed onto the adjacent alluvial terrace surface of the Ottawa River. Red stars mark the locations of coring sites where buried organic materials underlying landslide debris were recovered. Note the truncated scars (marked by 'S's) to the right of the Luskville landslide that are part of an older generation of landslides that also retrogressed into the scarp slope (see Stop 1).

The source area of the Alary Road landslide is located just north of Highway 148 (Figure 12), but is not visible from Stop 2 nor is it not accessible. The failure retrogressed about 400 m into the scarp slope, producing a source area up to 650 m wide and of about 0.19 km^2. The resulting landslide debris flowed southwards forming a debris lobe that is splayed about 600 m onto the alluvial terrace. Highway 148 and the northern-most portion of Chemin Alary cross the debris lobe (Figure 12). The morphology of the debris lobe is subtle on the ground and easily overlooked, but is readily apparent on the shaded relief map (Figure 12). Along Chemin Alary, the fringe of the debris lobe is marked by a gentle dip southward in the road topography, and a minor drop in the agricultural field towards the east. The original hummocky topography of the landslide has been subdued greatly by earthmoving equipment to improve the land for agricultural purposes.

The age of the Alary Road landslide was determined by coring through the landslide debris to intersect and sample buried organic materials, which are part of a vegetation layer growing on the terrace surface that was overridden by the flowing landslide debris. Three wood samples, located 5.89-6.20 m deep, yielded accelerator mass spectrometry (AMS) radiocarbon ages of 1150 ± 15, 1145 ± 15 and 1155 ± 15 BP (UCIAMS-106656, UCIAMS-106657 and UCIAMS-106658, respectively; Brooks et al., 2013). These ages are interpreted to represent the age of the landslide and indicate that it occurred in the Late Holocene between 980-1170 cal yr BP.

The Luskville landslide is located nearby, about 1 km east of the Alary Road landslide, and is readily apparent on the shaded relief map (Figure 12). From Chemin Alary, the Luskville landslide is visible to the east as a gentle rise on the alluvial terrace surface adjacent to the scarp slope. The feature is entirely on private land and is not accessible. The landslide retrogressed up to 390 m across a 1600 m length of the scarp slope, forming a source area about 0.36 km^2, which is about twice as large as that of the Alary Road landslide. The preserved debris lobe of the Luskville landslide is splayed up to 570 m onto the alluvial terrace of the Ottawa River.

Coring at two adjacent sites on the Luskville landslide debris lobe recovered organic materials, buried 5.89-6.0 m deep, which are part of a vegetation layer growing on the terrace surface that was overridden by the flowing landslide debris (Figure 12). Three organics samples yielded AMS radiocarbon ages of 1095±20, 1120±15 and 1100±15 yr BP (UCIAMS-122468, UCIAMS-122469 and UCIAMS-122467, respectively; Brooks et al., 2013). These ages are interpreted to indicate that the landslide occurred in the late Holocene between 960-1060 cal yr BP.

The calibrated radiocarbon ages of the Alary and Luskville landslides overlap closely, which seems more than coincidental. Both are part of a set of 12 dated landslides with similar age ranges that are located west, north, and within Ottawa (see Figure 8). Brooks (2013) hypothesized that this group of 12 similarly-aged landslides is evidence of a local paleoearthquake within the Western Québec Seismic Zone that occurred between 980-1060 cal yr BP with an estimated minimum magnitude of M_w ~6.1, as explained at Stop 3.

Turn your vehicle around, turn left onto Highway 148*, and proceed to Stop 3.*

Stop 3 The enormous Quyon Valley landslide (45.5386°N; 76.2928°W)

Continue west down Highway 148 towards Quyon*. Keep an eye out for the turn to the Quyon ferry at Rue de Clarendon (located about 13.8 km from Chemin Alary Road), but stay on Highway 148. About 1.2 km past Rue de Clarendon, notice that the wooded terrain on either side of the highway gives way to agricultural land. This transition marks the approximate eastern edge of the Quyon Valley landslide. Also, notice that the fields develop gentle hummocks as you travel westward. The hummocky topography reflects the presence of landslide debris forming the underlying terrain.*

Continue along Highway 148 past the turn to Quyon – Lac-des-Loups*. A short distance down the highway, the road drops down gently, crosses the Quyon River, and then rises up again to the hummocky surface. Continue along the highway.* ***The far (western) edge of landslide debris is eventually marked by an obvious rise to the highway*** *and adjacent land surface. You have been driving on landslide debris for about 4.6 km.*

Near the west side of the landslide, watch for the sign marking the Chemin MacKenzie intersection, and turn right*. The turn is about 400 m beyond the top of the rise marking the western side of the landslide.* ***Proceed along Chemin MacKenzie for about 1.9 km to Chemin Gold Mine and turn right****.* ***After about 400 m, turn right onto the 5th Concession****.* ***Continue down the 5th Concession for about 600 m****, and pull onto the shoulder just before the road descends down an obvious hill.* ***Walk partway down the hill*** *to get a good view of the plain below you. You are standing at the western side of the Quyon Valley landslide and looking across the southern part of the lower scar area. Orient yourself using Figure 13.*

Characteristics of the landslide

The Quyon Valley landslide is enormous in size, and one of the largest landslides in sensitive clay in eastern Canada. The landslide source area extends about 11.5 km along the lower Quyon Valley, and covers about 28 km^2. The source area consists of distinct upper and lower scar zones, separated by a narrow, about 300 m wide, constriction, as delineated by a heavy black line on Figure 13. This constriction reflects the proximity of subsurface bedrock in combination with a localized change in lithology of the Champlain Sea deposits. The depositional area is blanketed by landslide debris splaying about 2.6 km from the mouth of the lower scar, across an alluvial terrace, and to the edge of the Ottawa River channel (Figure 13). The preserved depositional area is up to about 4.6 km wide and about 11.2 km^2. The modern Quyon River is incised 10 to 35 m deep, within a mostly narrow, steep-sided valley eroded into the landslide debris along its course through both the source and depositional areas (Figure 13).

The great scale of the Quyon Valley landslide is difficult to visualize, but Stop 3 provides a good impression of this. From the stop, look eastwards down the 5th Concession, which is oriented approximately across the width of the lower scar zone. In the distance, notice

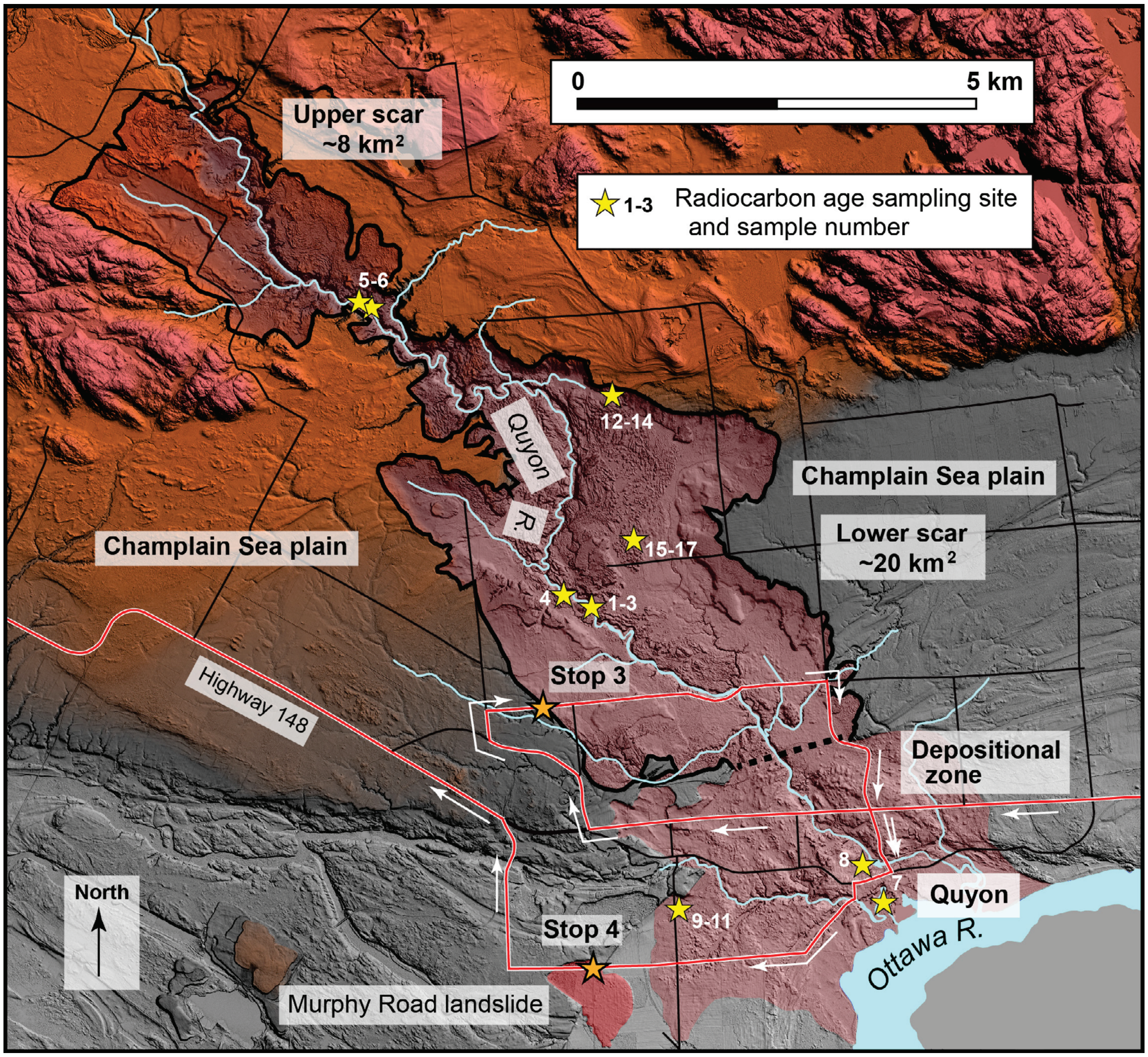

Figure 13 Shaded relief map of the Quyon Valley landslide, one of the largest landslides in sensitive clay in eastern Canada. The described route through the Quyon area is marked by the red line and white arrows; see the text for directional instructions. The Quyon Valley landslide originated from the upper and lower scar areas, which are outlined by a heavy black line and separated by a narrow constriction. The debris forming the depositional area is splayed from the lower scar area across a terrace surface of the Ottawa River. The numbers beside the yellow stars relate to calibrated radiocarbon age ranges in Figure16. Note, the proximity of the debris fields of the Quyon Valley and Murphy Road landslides (see Stop 4), both of which have similar radiocarbon ages. (Modified after Brooks, 2013.)

that there is a similar rise in the road to the hill at Stop 3. This is the far side of the lower scar zone, located about 4 km away. Also, look up valley (toward the left) into the broad expanse of the lower scar zone. Use the shaded relief map in Figure 13 to help interpret what you are seeing.

Figure 14 Photograph of the hummocky surface on the Quyon Valley landslide, looking east along the 3rd Concession near Chemin Bronson-Bryant. The original, highly-irregular topography of the hummocks has been subdued by earthmoving equipment to improve the land for agriculture. (Photo by Greg Brooks.)

The lower Quyon River Valley was recognized initially as a landslide area in the 1920s by Wilson (1924). Subsequently, the landslide area appeared on soil, landslide, and surficial geology maps published in the 1960s and 1970s (see Lajoie, 1962; Richard, 1976; Fransham et al., 1976). All of the maps delineate an area of landsliding along the lower Quyon River, but do not indicate whether the area is comprised of a single or multiple failures. These maps were compiled by interpreting aerial photographs, but forest cover on aerial photographs would have obscured the landslide features, thus hampering the interpretation of the geomorphology. A recent regional surficial geology map (St.-Onge, 2009) shows seven separate landslide polygons along the lower Quyon Valley that partially cover the larger landslide area depicted on earlier maps, implying that the area is comprised of a mosaic of different failures. In the early 2010s, the examination of a high-resolution, digital elevation model derived from a LiDAR survey, revealed that the landslide area is, in fact, primarily the product of a single, massive landslide (the “Quyon Valley landslide”; Brooks, 2013). The surface of the debris in the upper and lower scar zones and the depositional area is characterized by hummocks of varying topographic expression (figures 13 and 14). The hummocks have been subdued artificially within the Village of Quyon, or to improve land for agriculture in the surrounding areas. In wooded areas, however, the hummocky topography is well preserved, and commonly consists of well-defined, irregularly-shaped, sub-angular debris blocks, and elongated ridges and depressions, where local relief is up to 5 m.

Exposures of the landslide debris are present along the incised courses of the Quyon River and several tributaries within both scar zones, but none are easily accessible. These reveal large, tilted to horizontal, and vertically-displaced slabs of intact Champlain Sea clay-silt, sand and, less commonly, sand and gravel deposits (see Figure 15). Buried organic materials, and deformed or tilted organic layers are found occasionally at the contact between slabs or within disturbed deposits. No stratigraphic evidence of superimposed landslide deposits of different ages has been found; all of the exposures inspected to date contain deposits of a single landslide in both the upper and lower scar zones. Within the lower scar zone, several large debris blocks form elevated areas, up to 20 m high and over several hundred meters long (Figure 13). These large blocks evidently translated laterally and experienced subsidence during the failure, because they are lower than the projected Champlain Sea plain.

The surface characteristics of the debris field are also consistent with a large-scale, single landslide event. The debris surface is paired (i.e., the same height) along both sides of the Quyon River. In addition, the surface of the debris field lacks features indicative of multiple, coalesced failures occurring at different times, for example, in both the upper and lower scar zones, there are no large, distinct landslide lobes that originate from obviously different source areas that are separated by distinct medial ridges, levees or overridden margins. Overall, the scale and continuity of the debris field, the presence of large, translated debris blocks, and the thick deposits of a single landslide exposed along the Quyon River are consistent with a massive failure of Champlain Sea sediments within both the upper and lower scar zones.

As estimated from the source area topography, the volume of debris that flowed out of the upper and lower scar zones is about 600 million m^3 (Brooks, 2013). Debris exiting the lower scar zone flowed onto and across the alluvial terrace underlying the depositional area and undoubtedly into, across, and downstream along the Ottawa River channel. The presence of the erosional terraces that truncate the depositional area adjacent to the Ottawa River (Figure 13) suggests that the landslide temporarily impounded the river.

Age of the landslide

The age of the landslide is interpreted from seventeen AMS radiocarbon ages derived from: i) logs buried within the landslide debris from the lower and upper scar zones (samples 1-4 and 5-6, respectively; see figures 13 and 16); ii) one of several buried logs encountered in an excavation within the depositional zone (sample 7); iii) a buried organic layer, 5 to 10 mm thick, at the interface between oxidized sand and an overlying mudflow deposit exposed within an aggregate pit within the village of Quyon (sample 8); and iv) core samples that penetrated a buried vegetation layer underlying the western fringe of the depositional area (samples 9-11). Dated samples 1 to 11 all represent maximum ages for the landslide. Six dated samples (12 to 17) were sub-sampled from

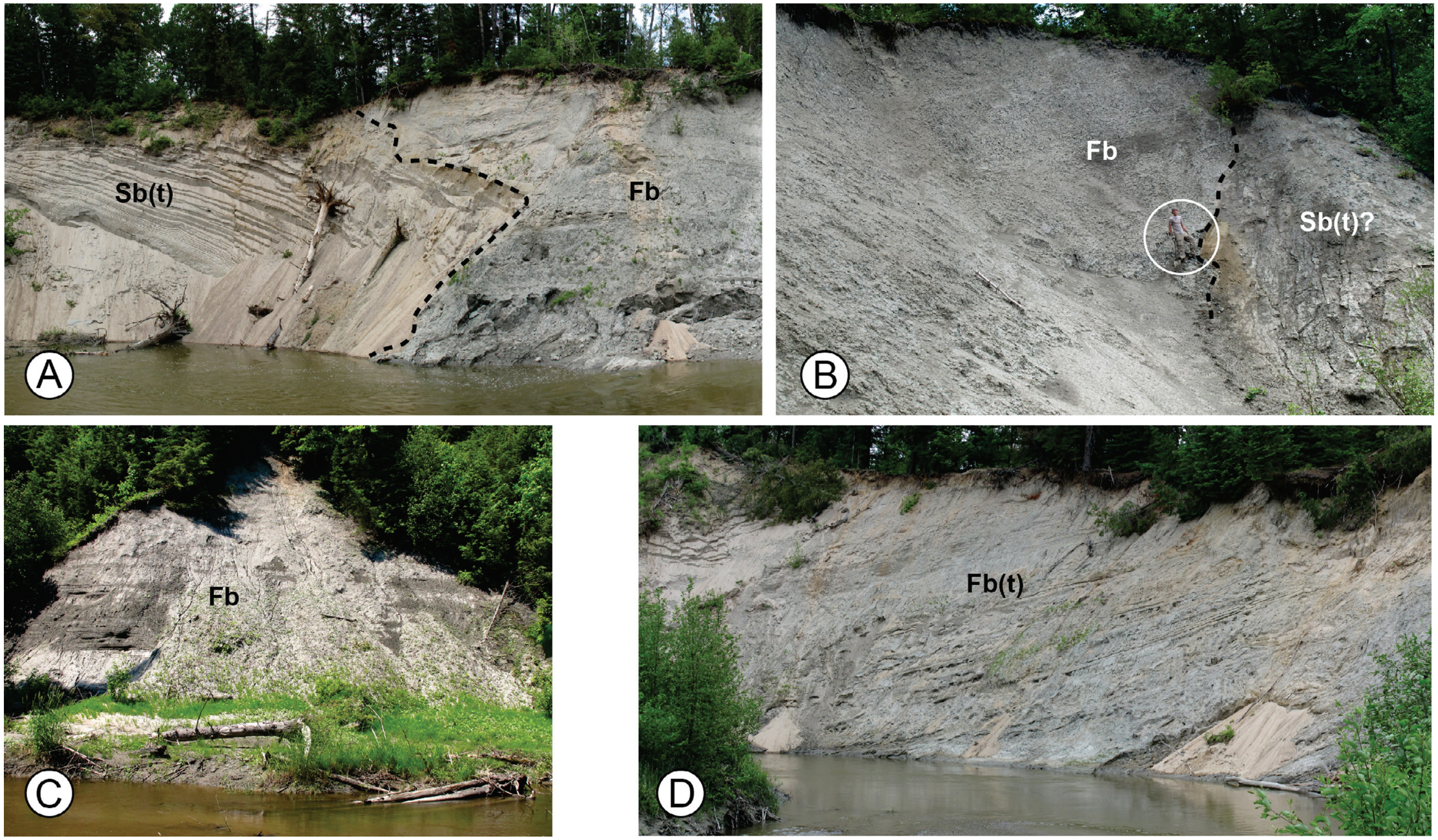

Figure 15 Photographs of landslide debris exposed along the Quyon River; A) and D) are located in the lower scar zone, B) and C) are in the upper scar zone. Note, the large slabs of intact Champlain Sea sediments extending from the river surface to the top of the banks in A) and D). The character of the deposits in all four exposures is consistent with the occurrence of a single large-scale failure. Dashed lines mark the approximate location of contact between sediment slabs. Note, the circled person for scale in B). Facies coding: Sb(t) – sand, bedded (tilted) and Fb(t) – fine sediments (silt, clay), bedded (tilted). (Photos by Greg Brooks.)

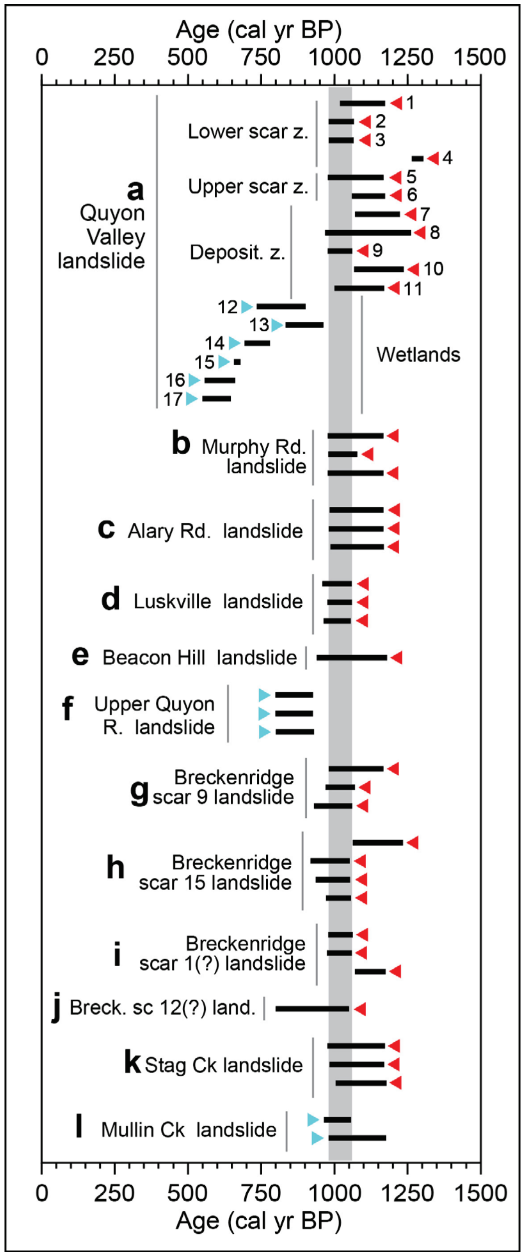

Figure 16 Diagram showing the 2 standard deviation error range of calibrated radiocarbon ages related to the age of the Quyon Valley landslide and eleven other local landslides, including the Alary Road, Luskville and Murphy Road landslides. See Figure 8 for the landslide locations. The shaded bar is the interpreted 980-1060 cal yr BP age range of the Quyon Valley landslide. The question marks associated with Breckenridge scars 1 ('i') and 12 ('j') reflect uncertainty about the source scar of the debris overlying the dated organic layer and not with the radiocarbon ages. Note, the good correlation of the 980-1060 cal yr BP age range to the other landslide radiocarbon ages. The triangles indicate whether a given radiocarbon age range represents a maximum (red) or minimum (blue) determination of a landslide age. (Modified after Brooks, 2013.)

sediments collected in cores extracted from two wetlands (three samples for each coring site) within the lower scar zone (see figures 13 and 16). These represent minimum ages for the landslide.

The similarity of ten of the maximum ages and the oldest minimum age is consistent with the dated materials representing a common landslide deposit extending across the two scar zones and the depositional area. It is thus interpreted that the debris field is the product of failures in both the upper and lower scar zones that coalesced during a single, massive landsliding event. Based on the overlap of the age ranges of samples 2, 3, 5, 8 and 9 (Figure 16), the massive Quyon Valley landslide is interpreted to have occurred between 980-1060 cal yr BP.

Evidence of a paleoearthquake

Brooks (2013) interpreted that the Quyon Valley landslide was likely triggered by a paleoearthquake of minimum magnitude M_w ~6.1. This interpretation is based on the collective and circumstantial evidence relating to a group of 12 similarly-aged landslides (figures 8 and 16) that are located west, north, and within Ottawa (Figure 9), including the Quyon Valley landslide. Of the other 11 landslides, four originated from a scarp slope along the margin of a fluvial terrace and have preserved debris lobes. This subset includes the Alary, Luskville and Murphy Road landslides (see stops 2 and 4), and the Beacon Hill landslide in east Ottawa (see Brooks et al., 2013). Four landslides are within Breckenridge Valley, located about 25 km east of Quyon (Figure 8), where at least 26 prehistoric landslide scars are clustered closely within an about 10 km^2 area of a confined, incised stream network (figures 4 and 11; see Brooks and Medioli, 2011). Two others are located along tributaries of the Gatineau River (Figure 8). The ages from these 10 landslides overlap closely with the interpreted 980-1060 cal yr BP age range of the Quyon Valley landslide. The 11th dated landslide ('f' in figures 8 and 16) is represented by minimum radiocarbon ages of organic materials obtained by coring a post-failure wetland in the source area. The oldest of these minimum ages is about 50 yr younger than the 980-1060 cal yr BP age range, but overlaps with the oldest of the wetland ages from the Quyon Valley landslide (Figure 16).

As summarized in Table 1, the paleoearthquake interpretation considers the number of similarly-aged landslides, the geomorphic setting and morphology of individual landslides, the location of a given landslide with respect to other similarly-age landslides, and consideration of reasonable aseismic mechanisms. Overall, the paleoearthquake interpretation is considered to represent the best explanation for the group of 12 similarly-aged landslides occurring at about 980-1060 cal yr BP, which includes the Quyon Valley landslide.

The estimated minimum magnitude for the paleoearthquake of M_w ~6.1 is derived from an empirical relationship between the area affected by landsliding and earthquake magnitude (see Keefer, 1984, 2002; Rodríguez et al., 1999). For the group of 12 similarly-aged landslides, the area affected by landsliding is represented by the area of an encompassing circle the diameter of which is defined by the locations of the two most-distant landslides. M_w ~6.1 is considered a minimum estimate of the paleoearthquake

Table 1 Summary of circumstantial evidence supporting the interpretation for a paleoearthquake at 980-1060 cal yr BP age.

	Evidence	Comment
1	Of the 50 dated landslides in sensitive clay within the Ottawa Valley, 12 have a similar age of between 980-1060 cal yr BP. (13 of the remaining landslides fall within a group aged between 5000-5400 cal yr BP.)	The high proportion of the dated landslides falling within one of two age groups is suggestive of there being a common failure triggering mechanism within each group.
2	There is no historical occurrence in eastern Canada of a severe rainstorm or high-magnitude flood event triggering multiple, large retrogressive landslides within a relatively small area.	Evidence is suggestive that meteorological mechanisms are inefficient at triggering multiple, large-scale retrogressive failures.
3	Four of the landslides retrogressed into scarp slope along margins of river terraces and have well-preserved debris lobes splayed onto terrace surface.	A preserved debris lobe indicates that a failure was not triggered by toe erosion of scarp slope by the Ottawa River, which had abandoned terrace surface prior to the landslide.
4	Several subsets of landslides of similar age are located in close-proximity to one another (Alary Road and Luskville landslides, Quyon Valley and Murphy Road landslides, Quyon Valley and upper Quyon Valley landslides).	Very coincidental to have occurred randomly.
5	Scale and morphology of the massive Quyon Valley landslide is the product of failures occurring simultaneously along both sides of Quyon River and within two distinct zones of the valley.	Simultaneous failures along both sides of Quyon River and within two distinct zones are difficult to explain by a meteorological mechanism.
6	Historical earthquakes in eastern Canada have triggered multiple, large retrogressive landslides within a relatively small area (e.g., 1663 Charlevoix earthquake).	Seismic shaking is a viable mechanism for triggering multiple, large retrogressive landslides.
7	Ottawa Valley is located within the Western Québec Seismic Zone.	Moderately-large to large earthquakes are expected to occur over a long timescale within the Ottawa Valley.

magnitude because the actual area affected by landsliding is undoubtedly greater than the spatial footprint of the group of 12 landslides defined by an encompassing circle. This magnitude is subject to revision as new landslide chronological data that expand this spatial footprint become available.

Continue down the 5th Concession *across the surface of the lower scar zone. Exercise caution crossing the one-lane bridge over the incised course of the Quyon River.* ***At the first intersection, turn right (south) onto Chemin du Lac-des-Loups****. The eastern edge of the lower scar zone is just beyond this intersection.* ***Continue down Chemin du Lac-des-Loups****, note the gently hummocky topography to the landslide surface on right side of the road. The hummocks become more pronounced as you get closer to Highway 148, which is 2 km from the 5th Concession-Chemin du Lac-des-Loups intersection.*

Stop 4 Murphy Road landslide (45.5093°N; 76.2838°W)

Continue down Chemin du Lac-des-Loups to Highway 148. Cross the highway *and enter into the Village of Quyon, which is located on landslide debris. Here, the name of the road changes to Rue Egan.* ***Cross the Quyon River and then turn right onto Rue de Clarendon****.* ***Watch for the Onslow Elementary School*** *within the village* ***on the left****, and* ***turn left onto Chemin Pontiac immediately past the school****.* ***Continue about 1.1 km down Chemin Pontiac****, then* ***bear right onto the 3rd Concession****, which leads to Stop 4 located 2.7 km away.*

Stop 4 is located on the 3rd Concession about 1 km past the intersection with Chemin Bronson-Bryant *(the street sign was missing at this intersection on May 23, 2020).* ***Pull over to the side of the 3rd Concession just before the intersection with Murphy Road****. You are parked just within the source area of the Murphy Road landslide. Note that the route from Stop 3 to about 0.5 km of Stop 4 has been upon the debris field of the Quyon Valley landslide (see Figure 13). Use Figure 17 to orient yourself at Stop 4.*

The Murphy Road landslide is located about 4 km west-southwest of the village of Quyon, Québec (Figure 1). The landslide is crossed by the northern portion of Murphy Road and part of the 3rd Concession (Figure 17). The failure retrogressed 600 m into and 550 m across the scarp slope that extends along the north side of the Ottawa River (see Figure 3), forming a source area of about 0.24 km^2. The landslide debris is splayed onto a broad terrace of the Ottawa River, and forms a well-preserved debris lobe. The eastern edge of the debris lobe is situated about 230 m from the edge of the debris field of the enormous Quyon Valley landslide (Figure 17). The two debris fields, however, are from distinctly separate landslide source areas.

Like many landslides in the Ottawa Valley, most of the topography of the Murphy Road landslide has been subdued by earthmoving equipment to improve the land for agricultural purposes. However, a section of the original landslide topography is preserved within the wooded area just to the north of the 3rd Concession. This can be viewed from the fence line along the edge of the road, but ***watch out for poison ivy along the road side and along the fence!*** Within the wooded area, notice the irregular and, in places, steeped-sided mounds up to several metres high. The large cultivated areas of the debris field adjacent to Murphy Road once had a similar topography to this.

The age of the Murphy Road landslide was determined by coring at two sites on the southern fringe of the debris lobe to recover organic materials from a buried vegetation layer, 4-5 m deep (Figure 17). Three organics samples yielded AMS radiocarbon ages of 1145 ± 20, 1140 ± 15 and 1145 ± 20 (UCIAMS-106650, UCIAMS-106651 and UCIAMS-106652, respectively; Brooks et al., 2013). These dates are considered representative of the time of burial of a vegetated surface beneath the debris lobe, and thus indicate that the landslide occurred in the late Holocene between 980-1070 cal yr BP.

The calibrated radiocarbon ages of the Murphy Road landslide overlap closely with those from the adjacent Quyon Valley landslide (see Figure 16), which is remarkable

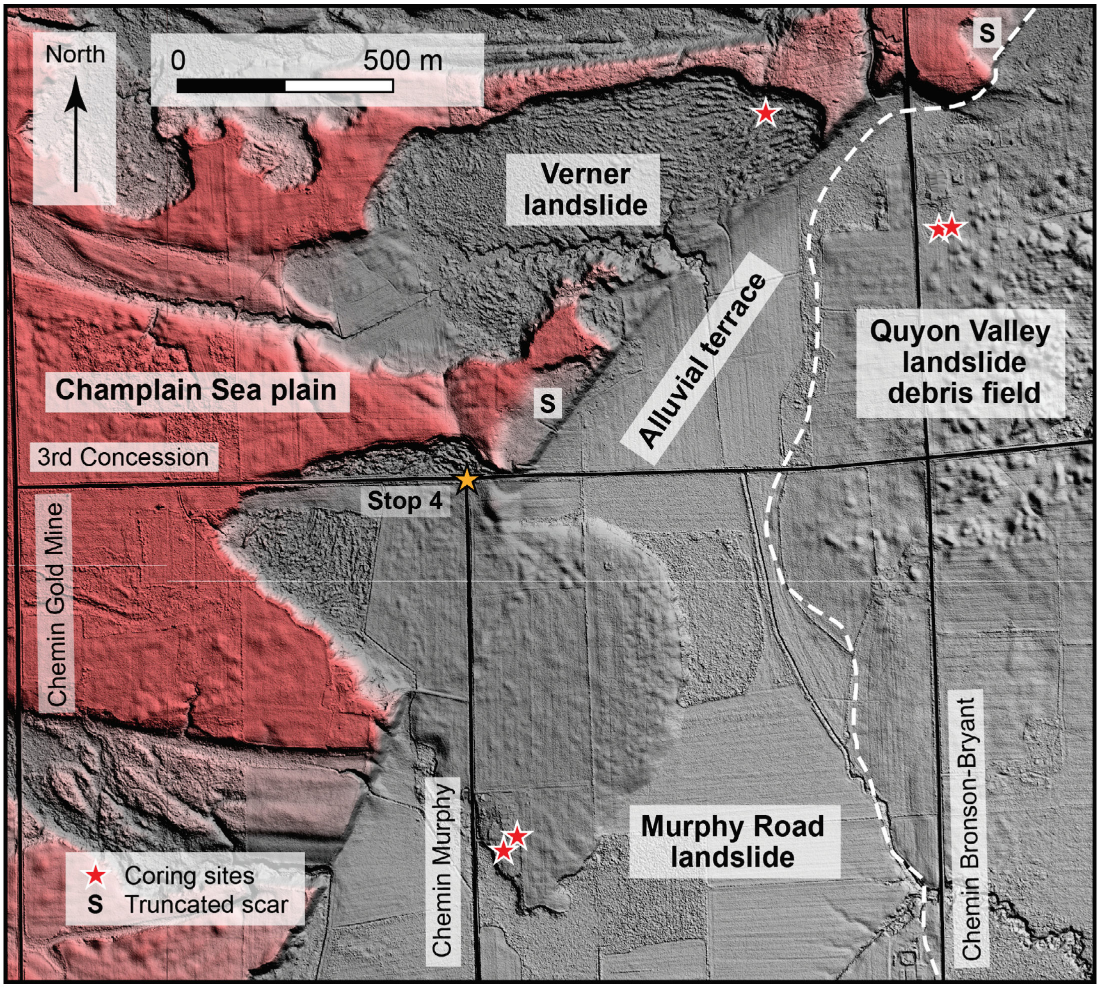

Figure 17 Shaded relief map of the Murphy Road landslide showing the source area, preserved debris lobe, and coring locations. Readily apparent within the source area are zones of preserved (rough appearing) and subdued hummocky topography representing wooded and agricultural lands, respectively. The source area of the Verner landslide is located on the northern portion of the map, but the debris field has been truncated by the ancestral Ottawa River. The hummocky area in the right-centre area of the map is a portion of the debris field from the massive Quyon Valley landslide (see Stop 3).

considering their vastly different scale and morphology. Consequently, the Murphy Road landslide is interpreted to be part of the group of 12 landslides that occurred at 980-1060 ca yr BP, and triggered by a M_w ~6.1 earthquake (see Stop 3; Brooks, 2013).

The Verner landslide is located roughly 1 km north of Stop 4 and originated from a failure retrogressing into the same scarp slope as the Murphy Road landslide (see Figure 17). The source area covers 0.49 km^2, and is the product of a failure extending about 430 m along the scarp slope and which retrogressed about 1180 m. The Verner landslide has a truncated debris lobe, and thus is one of the older generation of landslides that retrogressed into the scarp. Organic materials collected by coring a narrow wetland formed between ridges within the source area, yielded AMS radiocarbon ages of 5830 ± 20, 5790 ± 25, 5740 ± 20 BP (UCIAMS-106581, UCIAMS-106582 and UCIAMS-106583, respectively; Brook et al., 2013). These dates represent minimum ages for the landslide, which is interpreted to have occurred at or before 6560-6730 cal yr BP. At the time of writing, the Verner landslide is the youngest dated landslide in sensitive clay with a truncated debris field. The scar of a small, undated, landslide source area is situated between the Verner and Murphy Road landslides scar, also with a truncated debris lobe (see 'S' on Fig, 17).

The ages of the Verner and Murphy Road landslides confirm that there can be a great disparity in age between landslides with a truncated debris field versus preserved debris field.

Proceed west along the 3rd Concession *and* ***turn right (northward) onto Chemin Gold Mine S***. ***Continue for 2 km to Highway 148 and turn left*** *(westward) and head toward Shawville, located about 18.2 km away.*

Stop 5 Heath Road landslide (45.5578°N; 76.5302°W)

***Continue down Highway 148 to Shawville**. **Turn left onto Chemin Heath**, which is **the first left turn past the Canadian Tire store** within Shawville. **Follow Chemin Heath through the intersection with the 5th concession, and then through the intersection with 4th concession**. **Approximately 1.7 km south of the 4th Concession**, the topography on the left side of the road drops markedly. This is the source area of the Heath Road landslide. **Continue another several 100 m along the road** to the south end of the source area and stop where the road is situated immediately at the edge of the drop to a lower surface of pasture (see Figure 18).*

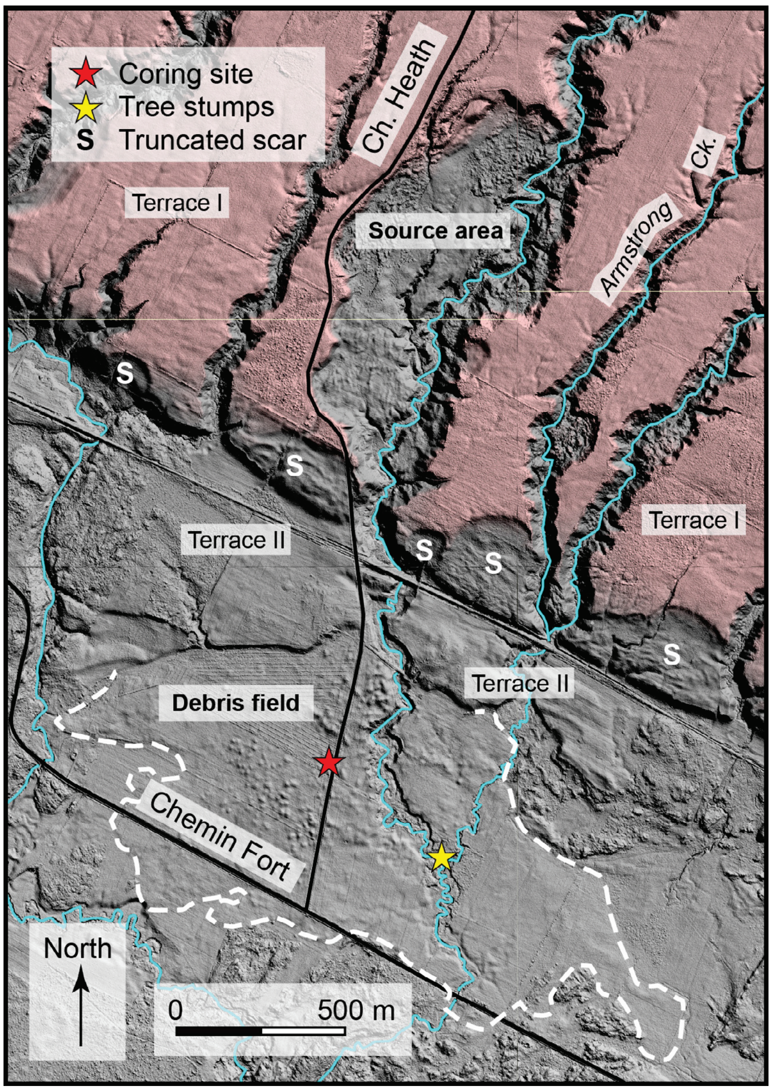

Figure 18 Shaded relief map showing the source area and debris field of the Heath Road landslide. Also shown are the locations of the tree trunks protruding through an incised creek course, and a coring site, as mentioned in the text. Note, the five truncated scars of older, undated landslides (marked by 'S's) that retrogressed into scarp slope at the edge of Terrace I. Terrace II is a lower and younger alluvial surface than Terrace I, and it predates the debris field.

The Heath Road landslide is an excellent example of a landslide in sensitive clay where there is a panoramic view of the source area, as Chemin Heath is located immediately adjacent to the landslide headwall (Figure 18). The southern portion of the source area is pasture, which provides an unobstructed view of much of the feature. The scale of the Heath Road landslide is obvious from the view point, and readily demonstrates how large landslides in sensitive clay can be, yet this source area is only a fraction of the size of the enormous Quyon Valley landslide (see Stop 3).

The source area of the Heath Road landslide is situated along the valley of a creek incised into Champlain Sea sediment (Figure 18). The failure retrogressed into the western side of the creek valley, and therefore occurred within a different geomorphic setting than the Alary Road, Luskville, Murphy Road and Verner landslides (see stops 2 and 4), which retrogressed into the scarp slope that extends along the north side of the Ottawa River (see Stop 1). The Heath Road failure retrogressed up to 440 m along a length of valley side about 1100 m long, forming a source area about 0.5 km^2 (Figure 18). The original hummocky topography of the debris field has been subdued artificially to improve the land for agriculture.

Landslide areas in sensitive clay are often referred to erroneously as 'sinkholes'. As is evident from the Stop 5 viewpoint, it certainly appears that the ground surface dropped in place. A true sinkhole, however, is formed by the sudden collapse of the ground into an underground cavity, and creates depressed ground that has no external drainage (USGS, 2020). In contrast, the Heath Road landslide source area is drained by the incised creek course that passes southwards through the eastern side of the source area, and eventually flows into the Ottawa River (Figure 18). Consistent with a landslide origin for the source area, a large debris field is splayed onto a terrace of the Ottawa River below the level of Terrace II that is inferred to have originated from the Heath Road landslide source area, as shown on Figure 18. Thus, it is apparent that the depressed topography is the product of landslide debris vacating the source area rather than sinking in place *per se*.

The age of the Heath Road landslide is represented by three AMS radiocarbon ages from two different sources of organic materials. Radiocarbon ages of 5745±20 and 5700±20 BP (UCIAMS-122453 and UCIAMS-122454) were yielded from the outer rings of vertical tree trunks protruding through a creek bed incised into the Heath Road landslide debris field (figures 18 and 19). The tree trunks are interpreted to be part of a forest that was buried by landslide debris, when it splayed across the terrace surface of the Ottawa River. The trees were later exhumed by incision of the creek course into the landslide debris. A third radiocarbon age of 5760±20 (UCIAMS-122466) is from wood recovered in the cuttings on auger blades from the coring site shown on Figure 18. This sample originated from a buried organic layer, 6.43-6.48 m deep, underlying the landslide debris. All three ages are identical statistically and indicate that the tree trunks and the buried organic layer were overridden by the same landslide deposit. Based on the three ages, the landslide is interpreted to have occurred between 6480-6540 cal yr BP. This age range is close to, but slightly younger than the minimum age range of the Verner landslide (see stop 4). The two landslides are considered unrelated in age.

Figure 19 Tree trunk protruding through a creek bed within the debris field of the Heath Road landslide. The tree trunk is rooted in a paleosurface that was buried by the landslide. The outer rings of this tree trunk yielded a radiocarbon age of 5745±20 BP (UCIAMS-122453). (Photo by Greg Brooks.)

Turn your vehicle around *and* ***follow Chemin Heath northward back to Shawville*** *and Highway 148.* ***Turn right on Highway 148*** *to return to Ottawa-Gatineau.*

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