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**GEOLOGICAL SURVEY OF CANADA
OPEN FILE 7432**

**An updated compilation of radiocarbon dates relating to the
age of sensitive-clay landslides in the Ottawa Valley,
Ontario–Quebec**

Version 2021

G.R. Brooks, B.E. Medioli, J.M. Aylsworth, and D.E. Lawrence

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Abstract

This Open File is an updated compilation of 167 published and unpublished radiocarbon dates relating directly or indirectly to the ages of 45 landslides or landslide complexes in sensitive clay, and three “disturbed terrain” features in the Ottawa Valley, southeastern Ontario/southwestern Quebec. Twenty-three tables contain dates for individual landslides (or disturbed terrains), or the dates for multiple landslides within a specific geographical area. Each table is preceded by a short summary that overviews the landslide or disturbed terrain, and the associated radiocarbon dates. Each table lists the attributes of the dates, including sampling location, dated material, dating results, and contextual information on the ages and the landslide/disturbed terrain. The geographical coordinates, radiocarbon age, and laboratory number of each date are listed in two spreadsheet files (.xlsx and .csv formats) in the Appendix. The radiocarbon age dataset in this Open File will aid future studies investigating the chronology of prehistoric landslides in sensitive clay within the Ottawa Valley and St. Lawrence Lowlands region.

Preface

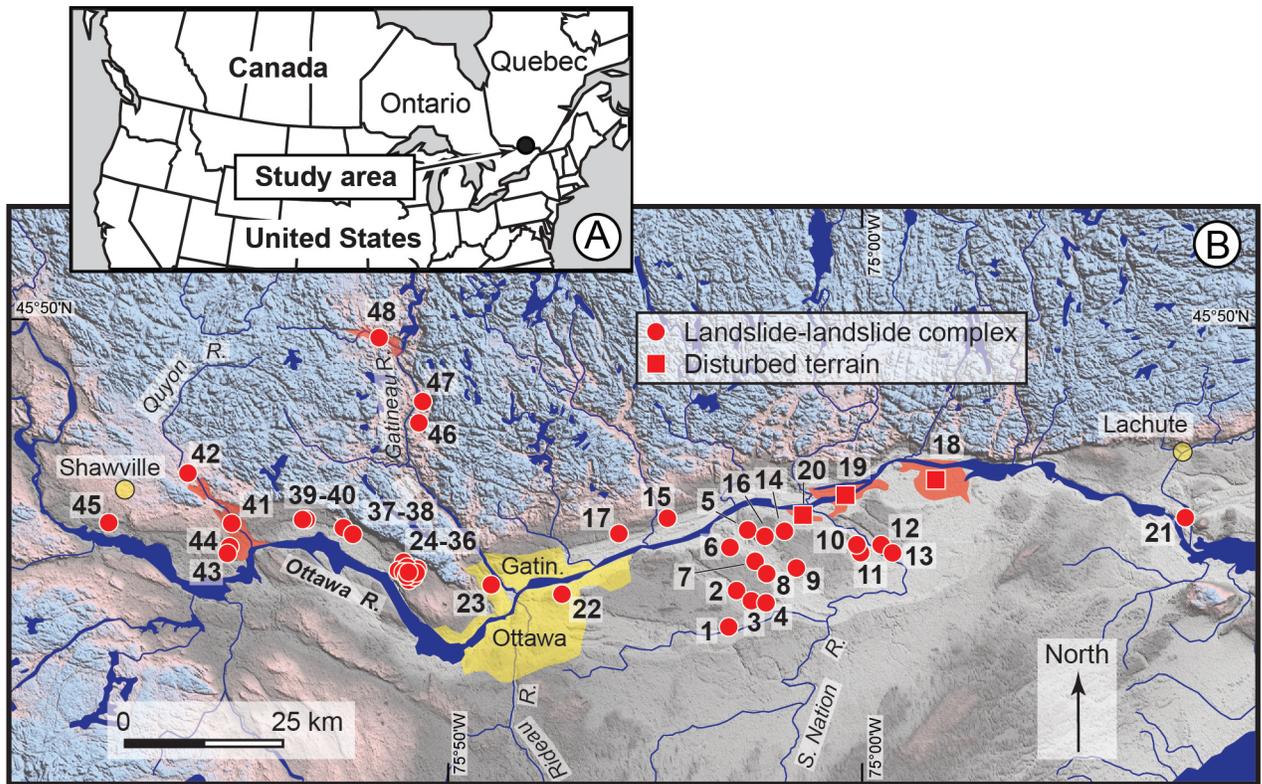
This Open File adds new 44 dates to an earlier version of this report, released as Brooks et al. (2013). Forty one of the new dates are relevant to the age of 7 previously undated landslides or landslide areas; three landslides are located along the Gatineau River valley, Quebec (Daly, Mullins, and Stag valleys), two are located near Eardley, Quebec (Eardley east and west landslides), one near Shawville, Quebec (Heath Road landslide), and one near Lachute, Quebec (Brownsburg landslide). Four of the new dates supplement two previously reported dates for the Lefaivre disturbed terrain, Ontario. The content of the original report remains otherwise unchanged, aside from updating the location map of Fig. 1, and minor updating, rewording, formatting of text, and the addition of an Appendix containing two spreadsheet files (.xlsx and .csv formats) that list the geographical coordinates, radiocarbon age, and laboratory number of each date.

Introduction

Large areas of the Ottawa Valley are underlain by glaciomarine silty-clay and clayey-silt (or ‘clay’) deposits that accumulated in the Champlain Sea between 14.0 and 10.5 cal ka BP (12.0 and 9.5 ^{14}C ka BP; Dyke, 2004). As the Champlain Sea receded during the early Holocene as a result of regional uplift, the postglacial stream network developed and incised into the glaciomarine deposits. The subsequent leaching of Na^+ from the sediments caused some of the clay deposits to become geotechnically sensitive, and thus experience a substantial loss of strength when remoulded or disturbed (see Crawford, 1961; Crawford, 1968; Mitchell and Markell, 1974; Fransham et al. 1976; Fransham and Gadd, 1977; Torrance, 2012). These sensitive sediments are prone to rapid, large (> 1ha), retrogressive earthspreads, earthflows, or combinations thereof, hereafter referred to as ‘landslides in sensitive clay’. Well-documented, historical landslides in sensitive clay within the area are the 1903 Pourpore landslide, Quebec (Ells, 1906; Aylsworth et al., 1997), the 1908 Notre-Dame-de-la-Salette, Quebec (Ells, 1908; Locat et al., 2017), the 1971 South Nation River landslide, Ontario (Eden et al., 1971), the 1993 Lemieux landslide, Ontario (Evans and Brooks, 1994; Brooks et al., 1994), and the 2010 Notre-Dame-de-la-Salette and Mulgrave-Derry landslides, Quebec (Perret et al., 2011; Perret et al., 2017). At the time of writing, the most recent landslide in sensitive clay within the Ottawa Valley occurred along the Bonnechere River, near Renfrew, on the night of March 28-29, 2016.

Approximately 250 landslide polygons representing the locations of landslides in sensitive clay appear on surficial geology maps in the Ottawa Valley (see, for example, Fransham et al. 1976; Richard, 1982a, b; 1984a, b; 1990; 1991; Richard et al., 1978; St. Onge, 2009). The number of individual landslides within the Ottawa Valley, however, undoubtedly far exceeds 250, as the individual map polygons can represent an isolated landslide, or an area of multiple, closely-spaced landslides. A detailed inventory of landslides will eventually be compiled for the Ottawa Valley using high-resolution, bare-earth, digital elevation models, as done within the area of the City of Ottawa (see Brooks, 2019). Regardless of the exact number of landslides, most happened prehistorically, and are of unknown age.

Beginning in the early 1960s, the collection and radiocarbon dating of organic materials yielded ages for a number of landslides in sensitive clay within the Ottawa Valley. Some organic materials were obtained opportunistically, e.g., from construction excavations, but the majority were collected within one of two targeted sampling programs by the Geological Survey of Canada (GSC). In the late 1990s, the first program targeted landslides clustered along Breckenridge Creek valley, Quebec, and within the Mer Bleue, Hammond, Bourget, and Plantagenet paleochannels, Ontario. This sampling originally intended to elucidate climatic factors controlling landslide activity, but it shifted to substantiating a paleoearthquake triggering mechanism, based on the close grouping of the initial set of landslide ages from the paleochannels. Aylsworth et al. (2000) subsequently interpreted that a group of 11 landslides aged roughly 5120 cal BP were triggered by a significant paleoearthquake. A second targeted sampling program spanned 2009 to 2013, to improve the understanding of the paleoseismicity of the West Quebec Seismic Zone. This work identified a grouping of 10 landslides aged about 1020 cal BP in the area west of Ottawa that Brooks (2013a, 2013b, 2015) attributed to being triggered by a second significant paleoearthquake. In the mid-2010s, Ministère des Transports du Québec (Transport Quebec) dated organic materials collected from three additional landslides in the region, as part of their geotechnical investigations.



Landslide/disturbed terrain numbering key

Number	Landslide/dist. terrain	Number	Landslide/ dist. terrain	Number	Landslide dist. terrain
Table 1					
1	Landslide 1	18	Lefavre disturbed terrain	39	Eardley East landslide
2	Landslide 2a, 2b	Table 6			
3	Landslide 3	19	Treadwell dist. terrain	40	Eardley West landslide
4	Landslide 4	Table 7			
5	Landslide 5	20	Wendover dist. terrain	41	Quyon Valley landslide
6	Landslide 6	Table 8			
7	Landslide 7	21	Brownsburg landslide	42	Up. Quyon R landslide
8	Landslide 8	Table 9			
9	Landslide 9	22	Beacon Hill landslide	43	Murphy Rd landslide
10	Landslide 10	Table 10			
11	Landslide 11	23	Jomonville landslide	44	Verner landslide
12	Landslide 12	Table 11			
13	Landslide 13	24-36	Breckenridge Valley scars 1, 2, 3, 4, 9, 11, 12, 13, 15, 17, 18, 19, 22	45	Heath Road landslide
14	Landslide 14	Table 12			
Table 2					
15	Masson landslide	Table 13			
Table 3					
16	Ramp.-Baseln. rd landsl.	37	Lusville landslide	46	Daly Ck. landsl. complex
Table 4					
17	Angers landslide	38	Alary Road landslide	47	Mullin Ck. landsl. comp.
Table 14					
Table 15					
Table 16					
Table 17					
Table 18					
Table 19					
Table 20					
Table 21					
Table 22					
Table 23					
48	Stag Ck. landsl. complex			48	Stag Ck. landsl. complex

Fig. 1 Maps showing A) the general location of the Ottawa Valley study area in eastern Canada, and B) the locations of the landslides and disturbed terrains listed in tables 1 to 20. The map symbols in B) are not to scale.

This Open File compiles 167 published and unpublished radiocarbon dates relating to the age of 45 landslides in sensitive clay or areas representing landslide complexes (i.e., superimposed or interrelated landslides), and three disturbed terrain features in the Ottawa Valley, southeastern Ontario/southwestern Quebec (Fig. 1). The compiled dates range from ‘modern’ to about 8000 cal BP. Tables list the radiocarbon ages, locational coordinates, and provide the contextual information between the dated organic material and a respective landslide. The report updates and expands the content of an earlier version of this report (Brooks et al., 2013b).

The radiocarbon age of a landslide

Interpreting the radiocarbon age of a landslide requires careful consideration of the geomorphic or stratigraphic relationship (or context) between the age of the radiocarbon-dated organic material (wood, peat, macrofossils, etc.) and the timing of the failure (see Lang et al., 1999). Fundamentally, organic material living prior to a failure (e.g., wood buried within or underneath the debris) represents a ‘maximum’ (i.e., older than) age for the landslide, while a ‘minimum’ (i.e., younger than) age is yielded from material that post-dates the landslide e.g., peat accumulated in a depression on the debris field. However, if there is a sound basis for inferring that the dated material was living at the time of, immediately prior to, or immediately after the landslide, then the radiocarbon age is considered to be a ‘direct’ determination of the landslide event i.e., is representative of the landslide age. Examples of such material include, a small tree or shrub branch with bark, the outer rings of a bark covered log, an unopened pine cone, and a well preserved seeds. If this connection cannot be made, or is unclear, then the radiocarbon age must be considered to represent an ‘indirect’ minimum or maximum age of the landslide that may vary substantially from the true landslide age (see Lang et al., 1999). Ultimately, determining whether a specific date is a direct or indirect indication of the age of a given landslide is an interpretative exercise.

Ideally, a landslide should be dated using organic materials that yield a set of direct maximum and minimum ages to bracket the time of failure. Unfortunately, this is not always possible or practical. Where organic materials yielding only maximum or minimum ages are available, the replication of similar ages from several independent samples can increase confidence in their representation of the landslide age. In general, the youngest maximum and/or oldest minimum age(s) should best represent the age of a landslide, assuming a direct or strong indirect link between the dated material and the age of the landslide. However, in cases where the age of a landslide is represented by a single sample, the radiocarbon age commonly is *assumed* to reflect that of the landslide event, but there is always unknown uncertainty with this assumption, even with carefully selected organic material. The possibility of this uncertainty is apparent from the variability of ages within a group of carefully selected materials relating to a given landslide (e.g., the maximum ages of the Quyon valley landslide).

Radiocarbon dates should be calibrated from radiocarbon to sidereal (calendar) years to remove temporal deviations between the radiocarbon and sidereal timescales (see Bartlein et al., 1995). The calibration of a given date may increase or decrease the range of age uncertainty, depending on the shape of the relevant portion of the radiocarbon calibration curve. Interpreting chronology based on uncalibrated radiocarbon ages, however, is ignoring a level of uncertainty intrinsic to radiocarbon dating, and can lead to erroneous chronological interpretations.

Inferences that different landslides occurred simultaneously are made by correlating the two standard deviation (2σ) age ranges of calibrated radiocarbon ages. Overlapping age ranges, however, do not indicate event synchronicity, since the overlap could also be the product of closely-aged failures that occurred at distinctly separate times, even up to many decades (or more) apart. Therefore,

distinguishing synchronously-aged from closely-aged landslides cannot be made definitely based solely on radiocarbon ages because of the range of age uncertainty, which is a limitation of the radiocarbon dating method. An interpretation of synchronicity of two or more radiocarbon-dated landslides must be made as a hypothesis with the careful consideration of the number of similarly-aged landslides, the geomorphic setting and morphology of the individual landslides, the location of a given landslide with respect to other similarly-aged landslides, and consideration of reasonable triggering mechanisms. This has been applied in the Ottawa Valley by Aylsworth et al. (2000) and Brooks (2013a) in their interpretations that sets of 11 and 10 similarly-aged landslides, respectively, were triggered by significant paleoearthquakes.

Radiocarbon date dataset

The dataset in this report lists radiocarbon dates relevant to the age of 45 landslides or landslide complexes, and three “disturbed terrain” features. As shown in Fig. 1, the dated landslides occur in groups along the Mer Bleue, Hammond, Bourget and Plantagenet paleochannels, Ontario (landslides 1 to 14, 16), and within Breckenridge Creek valley (landslides 24 to 36), up the Gatineau Valley (landslide complexes 46 to 48), in the lower Quyon Valley area (landslides 41 to 44), near Luskville (37-38), and Eardley (39-40), Quebec. Six dated landslides are at isolated locations at or near Masson (15), Angers (17), Lachute (21), Gatineau (23), and Shawville (45), Quebec, and east Ottawa (22), Ontario.

The dataset also includes dates from the disturbed terrains at Lefavre, Treadwell-Grand Presquîle, and Wendover (features 18, 19 and 20 in Fig. 1; see Richard, 1984b; 1991; Aylsworth et al., 2000; Aylsworth and Lawrence, 2003). The origins of these features are enigmatic and have been variously interpreted to be landslide deposits (Crawford, 1961; Richard, 1980; 1984b), collapse features (Rodriguez et al., 1987), or “seismically disturbed” terrain (Aylsworth et al., 2000; Aylsworth and Lawrence, 2003). The subsurface deposits, up to ~50 m depth, within these areas are composed of variably deformed, folded, faulted and/or rotated deposits of glaciomarine silt and clay, and fluvial sand deposits, similar to the debris of landslides in sensitive clay. For the purpose of completeness, the dates from these features are included in this report.

Content of the dataset

The landslide radiocarbon dataset consists of 23 tables listing the radiocarbon dates. The dates are organized in tables by individual landslide/landslide complex or as a series of multiple landslides, as deemed appropriate, or as is consistent with a published source. Tables relevant to specific landslides may contain single or multiple dates, depending on how many samples were dated from that feature. A date series relates to multiple landslides within a specific geographical area. There are five date series within the dataset. The date series in Table 1 follows Aylsworth et al. (2000) who originally reported and interpreted the dates for 14 landslides, while Table 11 collates multiple dates collected within Breckenridge Valley, Quebec, which has experienced 29 landslides within a relatively confined area. Tables 21, 22 and 23 list dates from the Daly, Mullin and Stag landslide complexes along the Gatineau Valley.

Content of tables

Each table is accompanied by a summary of background information on the landslide (or disturbed terrain), the dates, and the relationship between the age of the dated material and the landslide age. Key background information related to landslides or the dates are cited in the summary descriptions or within tables, but it should not be assumed that all literature relevant to a given landslide is cited.

Attributes of the dates are listed under nine headings that provide information on location, material dated, dating results, and contextual information between the date and landslide scar or deposit. The column headings are:

Location – this is a succinct statement of the location of the landslide. Some statements reference informal landslide numbers or names, and to a nearby town or road(s). Where used, landslide names and numbers follow those used in publications or in the collector’s notes.

Sample name/number – derived from a publication, a sample submission form, or laboratory analysis summary. These originate from the submitter or collector, and presumably relates to their field notes.

Geographical coordinates – these are particular to each sampling site and more generally to the landslide feature. All of the geographical coordinates have been plotted on Google Earth to verify the location with respect to the descriptive information on the collection site. In several cases, the published coordinates were clearly erroneous (e.g., Quebec collection site, but the coordinates fall on a location in Ontario). Such errors usually are the result of a typo or transposition within one coordinate, which has been corrected, as noted in the respective table. In one case, what are believed to be the correct coordinates were obtained from the unpublished sample submission form. The coordinates listed in such cases are better than those contained in the original published source, but should be considered as an approximation.

Laboratory number – this is a unique number assigned to a date by the radiocarbon laboratory. All of the listed dates are from one of three laboratories: Geological Survey of Canada Radiocarbon Laboratory (GSC), Beta Analytic (Beta), and the Keck-Carbon Cycle Accelerator Mass Spectrometer facility, University of California Irvine (UCIAMS).

Radiocarbon age – the radiocarbon ages were determined by either regular or accelerator mass spectrometry (AMS) radiocarbon analysis procedures. The procedures are not identified in the table, but all of the GSC dates are regular radiocarbon ages, while all of the Beta and UCIAMS dates are AMS determinations. Regardless of the procedure, all of the dates are derived from wood or terrestrial plant materials and are directly comparable to each another. All of the dates are assumed to have been corrected for $\delta^{13}\text{C}$ fractionation, except where noted in a table. Of note, the uncertainty of the ages reported by the GSC radiocarbon laboratory are expressed to 2σ , while those of the other laboratory are reported to 1σ as is convention (see Stuiver and Polach, 1977).

Calibrated radiocarbon age – all of the radiocarbon dates were calibrated to calendar years (years before AD 1950) using Calib 6.1 (see Stuiver and Reimer, 1993) and the calibration datasets of Reimer et al. (2009), or Calib 8.2 (see Stuiver et al., 2020) and the calibration datasets of Reimer et al. (2020). The calibrated ages are expressed as a single range representing the full 2σ calibration ranges, even where there were two or more intercepts on the calibration curve. The calibrated age ranges in the tables are provided as an approximation only. The calibration datasets are updated periodically by the radiocarbon dating community, therefore, users are advised to recalibrate specific dates of interest to ensure that they have the most up-to-date calibration determinations.

Collector – person(s) who collected the submitted organic materials.

Comment – these provide context for the radiocarbon dates. The descriptions indicate the type of material dated, sample source (e.g., from coring or an exposure), and, as much as possible, the stratigraphic and/or geomorphic context between the dated materials and the landslide. Care was taken to retain the meaning and interpretation of the original descriptions, as appropriate, while providing a consistent structure for the comments. Words appearing in quotes are from the original

published or unpublished descriptions. Each comment also includes an assessment of whether the age represents a maximum or minimum age for the failure, as understood from the summarized stratigraphic and/or geomorphic context. Some comments mention whether a radiocarbon age represents a direct or indirect indication of a landslide age. Ultimately, how well an age (or set of ages) is representative of the landslide age is for users of these dates to decide, and *The Radiocarbon age of a landslide* section provides a general perspective towards this. Users of this Open File should consult the original published sources, as available, for possible additional information on the dated organic material(s), the landslides, and the interpretation of the date(s). Surprisingly, there is limited published information on many of the dated landslides *per se*.

References –published and unpublished sources related to the date are cited in this column. Published sources include journals and/or published GSC radiocarbon date lists. The listed references are those used in compiling the information on a respective radiocarbon date. Publications that otherwise mention or make use of the radiocarbon age are not included in the reference list. Unpublished sources include the sample submission forms on file at the GSC as well as field notes (where available) pertaining to the collection of samples. These documents can include sketches of the collection site that are useful in understanding the context between the landslide and the dated material.

Acknowledgements

This Open File report is dedicated to the Alice Telka, Paleotec Services and formerly Geological Survey of Canada employee, who passed away in September, 2019, and provided much appreciated advice over many years to the lead author on organic materials collected for radiocarbon dating. Ministère des Transports du Québec kindly provided permission to report the dates for the Brownsburg and Eardley east and west landslides. A review by Ross Knight provided helpful comments that improved the content and clarity of the document. Sean Morton assisted compiling the published radiocarbon ages in the original version of this report, which was reviewed by Wes Blake. The report was supported by the Public Safety Geoscience Program, Earth Sciences Sector, Natural Resources Canada.

Landslides in the area of the Mer Bleue, Hammond, Bourget and Plantagenet paleochannels, Ontario

A number of large prehistoric landslides (up to 5 km²) are present in the area of the Mer Bleue, Hammond, Bourget and Plantagenet paleochannels, east of Ottawa, Ontario (Figs. 1 and 2; see Lajoie, 1974; Gadd, 1976; Richard, 1982a; 1982b; 1984b; 1991; Aylsworth et al., 2000). Each landslide originated from the steep-sided margin of a paleochannel (or terrace) that is generally composed of fine-grained glaciomarine sediments capped with sand. The debris from the landslides flowed onto the adjacent fluvial surface, forming a splayed debris lobe. Many of the debris lobes are well preserved and have not been truncated by fluvial erosion, indicating that failures occurred after the abandonment of the paleochannel (or terrace) by the ancestral Ottawa River. Some of the landslide deposits are coalesced within the paleochannels, reflecting the close-spacing of the source areas (Aylsworth et al., 2000). Table 1 lists 17 radiocarbon dates collected in the late 1990s from 14 landslides each of which has a preserved debris lobe. The sample numbers in the table follow Aylsworth et al. (2000) and are keyed to the landslides depicted on the map in Fig. 2. Aylsworth et al. (2000) interpreted 12 of the dates to indicate that 10 of the failures occurred at about 4550 BP (roughly 5115 cal BP) and represent evidence of a paleoearthquake event. Table 2 lists a date collected immediately underlying a landslide deposit nearby at Masson, Quebec (landslide 15 in Fig. 2), which has a similar age to many of the dates in this table.

Table 1 List of radiocarbon dates related to the age of landslides within or close to the Mer Bleue, Hammond, Bourget, and Plantagenet paleochannels, Ontario.

Location	Sample number /name	Geographical coordinates	Laboratory number	Radiocarbon age (yr BP)	2σ calibrated age range (cal yr BP)	Collector ^a	Comment	References
Landslide 1, Mer Bleue paleochannel	1; JA98-7-01	N 45.4139° W 75.2792°	Beta-127245	4570 ± 70	4979-5467	JMA	Date derived from isolated pieces of “sticks and bark” sampled at 0.36 m depth from “black organic layer”, ~15 cm (6 in) thick, in “distorted landslide debris” within core recovered from pond on landslide scar. Date represents a maximum age for landslide 1.	Aylsworth et al. (2000).

Landslide 2, Hammond paleochannel	2a; HAM 95-1	N 45.4611° W 75.2611°	Beta-90880	4470 ± 80	4874-5308	DEL	Date derived from wood sampled at 1.30 m depth in core recovered from “large” pond impounded against valley-side wall. Wood contained within “contorted layer of clay and organic material with wood” that is overlain by fibrous peat. Date interpreted to represent maximum age for landslide 2.	Aylsworth et al. (2000); unpublished GSC data.
Landslide 2	2b; HAM 95-3	As above.	Beta-90881	3050 ± 70	3007-3438	DEL	Data derived from wood sampled at 0.80 m depth in same core as above. Wood sample contained within bed of “contorted clay plus organics with wood”, extending from 0.7-1.10 m depth, that is over- and underlain by deposits of stratified, fibrous peat. Date represents maximum age for a possible second failure at site of landslide 2.	Aylsworth et al. (2000); unpublished GSC data.
Landslide 3, Hammond paleochannel	3; LV98-08-04	N 45.4417° W 75.2222°	Beta-122473	4590 ± 40	5055-5460	AG and JG	Date derived from “good sized” piece of wood within sandy clay at 0.57 m depth in core recovered from pond situated between well-defined ridges on landslide. Date represents a minimum age for landslide 3.	Aylsworth et al. (2000).
Landslide 4, Mer Bleue paleochannel	4; LV98-12-02	N 45.4424° W 75.1924° ^b	Beta-122475	2760 ± 50	2759-2963	AG and JG	Date derived from “two twigs and organic matter” sampled from sand at 0.60 m depth in core recovered from pond on landslide. Pond contained between well-defined landslide ridges in wooded area. Date represents a minimum age for landslide 4.	Aylsworth et al. (2000).
Landslide 5, Bourget paleochannel	5; JA98-2-01	N 45.5416° W 75.2416°	Beta-127281	5130 ± 60	5726-5995	JMA	Date derived from large piece of wood sampled from clay at 4.50 m depth in core recovered from landslide deposit. Sample situated near bottom of the landslide debris. Date represents a maximum age for landslide 5.	Aylsworth et al. (2000).

Landslide 6, Bourget paleochannel	6; JA98-6	N 45.5208° W 75.2667°	Beta-127284	4440 ± 80	4867-5295	JMA	Date derived from outer rings of large log (hemlock) buried within the debris lobe. Log collected by local farmer at unknown depth from an excavation. Date represents a maximum age for landslide 6.	Aylsworth et al. (2000).
Landslide 7, Bourget paleochannel	7a; JA98-3A-02	N 45.50° W 75.2028°	Beta-127243	4450 ± 70	4875-5291	DEL	Date derived from a stick at 3.0 m depth in core recovered near toe of debris lobe. Entire core composed of mixed red and grey clay and sand layers that are “very contorted” and “some mixed”; “lots of organic bits” are reported present. Date represents a maximum age for landslide 7.	Aylsworth et al. (2000).
Landslide 7	7b; JA-98-3C-01	As above.	Beta-127244	4570 ± 70	4979-5467	DEL	Date derived from “two small sticks” sampled at 5.33 m depth in same core as above. Date represents a maximum age for landslide 7.	Aylsworth et al. (2000).
Landslide 8, Bourget paleochannel	8; LV98-06-04	N 45.4833° W 75.1917°	Beta-122472	4520 ± 50	4979-5315	AG and JG	Date derived from “small organic bits” within sand sampled from 0.45 m depth in core recovered from pond formed between ridges near headscarp. Sand overlain by thick organic layer. Date represents a minimum age for landslide 8.	Aylsworth et al. (2000).
Landslide 9, Bourget paleochannel	9; JA98-4-01	N 45.475° W 75.1292°	Beta-127282	4540 ± 90	4881-5466	DEL	Date derived from piece of wood sampled at 4.65 m depth in core recovered near toe of debris lobe. Sample contained within “clayey organic layer... surrounded by dense red and grey clay bands”. Date represents a maximum age for landslide 9.	Aylsworth et al. (2000).

Landslide 10, Plantagenet paleochannel	10; JA98-5-01	N 45.525° W 75.0111°	Beta-127283	4530 ± 60	4974-5442	JMA	Date derived from “wood pieces” of a single log that was buried ~1 m deep in black peaty organic layer with numerous logs. Organic layer overlain by clay, 0.5 m thick, and exposed for several hundred meters in ditch excavated into debris lobe. Sampled log was 23 cm long, saturated and very soft. Date represents a maximum age for landslide 10.	Aylsworth et al. (2000).
Landslide 11, Plantagenet paleochannel	11a; LV98-17-03	N 45.5139° W 75.0028°	Beta-122477	4450 ± 50	4878-5288	AG and JG	Date derived from “large seed” sampled at 0.37 m in core recovered from pond contained between well-defined landslide ridges. Sampled material contained within soft grey clay. Date represents a maximum age for landslide 11.	Aylsworth et al. (2000); unpublished GSC data.
Landslide 11	11b; LV98-17-04	As above.	Beta-122478	4700 ± 50	5318-5581	AG and JG	Date derived from “large sample of mixed organic material and seed”, sampled at 0.49 m in same core as above. Sample contained within black organic layer. Date represents a maximum age for landslide 11.	Aylsworth et al. (2000).
Landslide 12, Plantagenet paleochannel	12; LV98-01-02	N 45.5185° W 74.9557° ^c	Beta-122471	1870 ± 40	1712-1890	AG and JG	Date derived from “minute grassy pieces” sampled at 0.42 m depth in core recovered from pond. Pond located between ridges, but impounded by beaver dam. Sampled material contained within very soft grey clay with organic strands; additional layers of sand, and red and grey clay reported in core. Date represents a minimum age for landslide 12.	Aylsworth et al. (2000).
Landslide 13, Plantagenet paleochannel	13; JA98-1A-02	N 45.5138° W 74.9375°	Beta-127242	4820 ± 70	5326-5709	JMA	Date derived from piece of wood sampled at 1.88 m depth in core recovered from landslide lobe, ~45 m (150 ft) from edge of toe. Wood was contained within organic layer, 8 cm thick, buried in clayey debris, near base of landslide deposit. Date represents a maximum age for landslide 13.	Aylsworth et al. (2000).

Landslide 14, Ottawa River Terrace	14; LV98- 09B-02	N 45.5361° W 75.1583°	Beta-122474	4470 ± 50	4891-5302	AG and JG	Date derived from sample of shattered bark and wood, sampled at 0.42 m depth in core recovered from pond contained between well-defined ridges near headscarp. Bark and wood contained within sand. Date represents a minimum age for landslide 14.	Aylsworth et al. (2000).
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- ^a JMA - Jan Aylsworth; AG - Alain Grenier; JG - Joanna Guertin; DEL - Ted Lawrence.
- ^b Coordinates in Aylsworth et al. (2000) fall about 5 km north of the landslide scar. The listed coordinates are based on the sample site shown on an annotated field map and a general description of the location, but they should be regarded as an approximation. The revised coordinates are consistent with the sample location shown on Fig. 2.
- ^c Coordinates in Aylsworth et al. (2000) fall just north of the landslide backscarp. The listed coordinates are based on the sample site shown on an annotated field map and a general description of the location, but they should be regarded as an approximation. The revised coordinates are consistent with the sample location shown on Fig. 2.

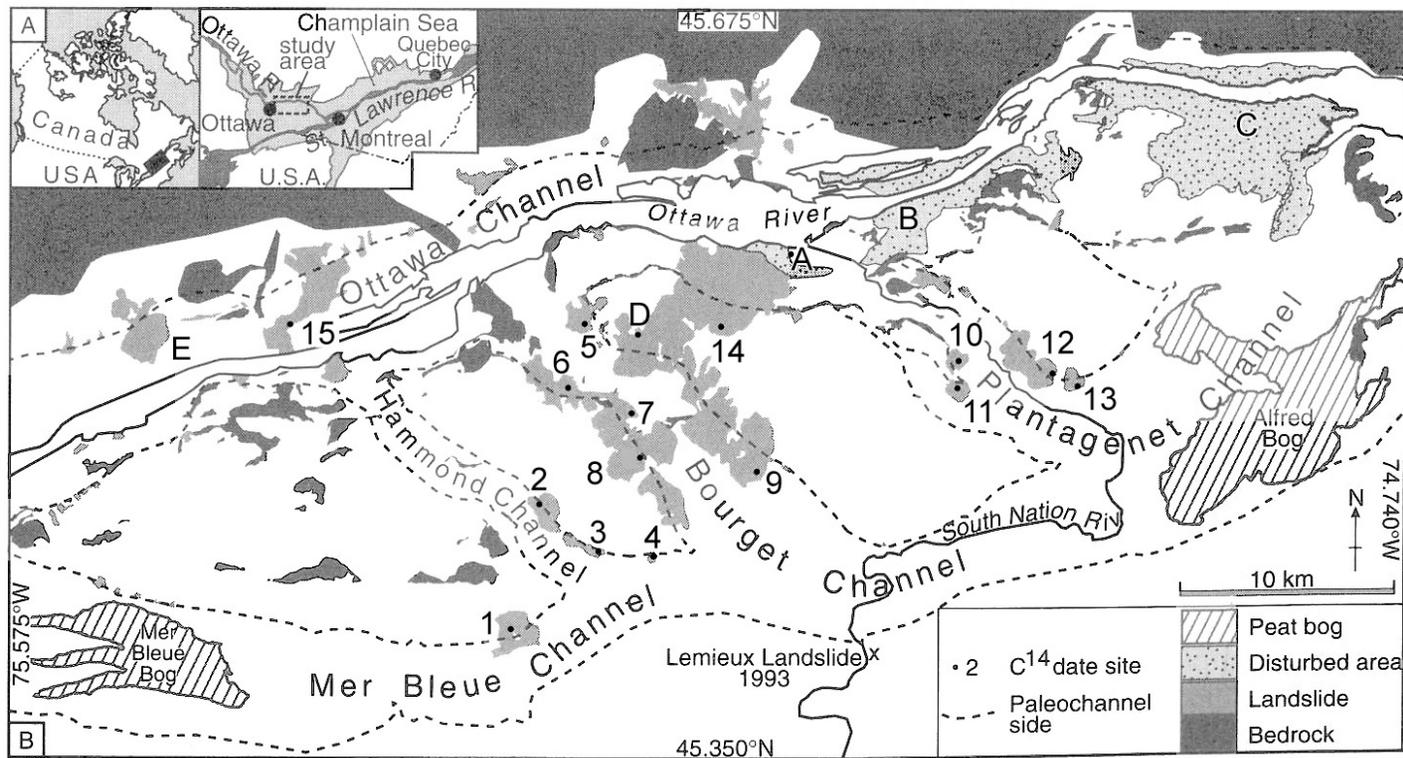


Fig. 2 Map showing the large landslides along the Mer Bleue, Hammond, Bourget and Plantagenet paleochannels, and terraces along the Ottawa River east of Ottawa, Ontario (modified from Aylsworth et al., 2000). The landslide site numbers 1 to 14 correspond to the sample numbers listed with each date in Table 1; a small black dot on the numbered landslides marks the sample collection location. The landslide labeled as '15' is the location of the Masson landslide, listed in Table 2. The areas labeled A, B, C, D and E are the Wendover (Table 7), Treadwell (Table 6) and Lefaivre (Table 5) disturbed terrains, and the Bourget (Table 3) and Angers (Table 4) landslides, respectively.

Landslide just east of Masson, Quebec

A large landslide is present just east of Masson, Quebec (Fig. 1), as shown on Richard (1991), and depicted as landslide ‘15’ on Fig. 2. The landslide retrogressed into fine-grained deposits underlying the surface of the Champlain Sea plain, and flowed onto an abandoned terrace (or terraces) of the Ottawa River and the river floodplain. The map-unit polygon is unusually shaped, with the intermediate portion of the deposit shown with two striking bends in outline. The single date listed in Table 2 provides a maximum age for the landslide, but the collection site location is uncertain, as mentioned in the comment. The age of this landslide coincides with those of 10 of the landslides listed in Table 1. Aylsworth et al. (2000) interpreted these eleven similarly-aged landslides as evidence of a paleoearthquake event at ~4550 BP (~5115 cal BP).

Table 2 Radiocarbon date from landslide east of Masson, Quebec.

Location	Sample name/ number	Geographical coordinates	Laboratory number	Radiocarbon age (yr BP)	2 σ calibrated age range (cal yr BP)	Collector ^a	Comment	References
Landslide just east of Masson, Quebec. Landslide 15 of Aylsworth et al. (2000)	J.D.-1972-1	N 45.5437° W 75.4011° ^b	GSC-1922	4620 ± 80 ^{c,d}	5087-5469	JD	Date derived from wood of white pine (<i>Pinus strobus</i>) sampled from “complete tree” within sandy soil, buried beneath 2 m of “mudflow slide” clay. Tree was exposed along stream course incised through landslide deposit. Date represents a maximum age for landslide 15. Sample collected in 1972.	Unpublished GSC data; Lowdon and Blake (1973).

^a JD - J. Dumanski.

^b This location differs from the geographic coordinates published in Lowdon and Blake (1973). Their geographical coordinates (N 45°31', W 75°25') are identical to those on the GSC sample submission form, but define a location beside the Ottawa River channel in Ontario due south of the village Masson. The sample submission form also includes a grid location of 18TWF 690430 that differs in location from the geographical coordinates. This location is 1.5 km east of the main cross-street in Masson and is situated on the mapped landslide deposit. The location, however, is in the middle of a field rather than along an incised stream, which is the described site on the sample submission form. The geographical coordinates in this table are the decimal degree equivalent of the grid location. While more reasonable than the previously published coordinates, this position must be regarded as an approximation.

^c Radiocarbon age uncorrected for $\delta^{13}\text{C}$ fractionation.

^d The uncertainty of this age is reported to two standard deviations.

Landslide along Bourget paleochannel, east of Ottawa, Ontario

A number of large landslides are present along the Bourget paleochannel in the Rockland-Bourget area, east of Ottawa, Ontario (Fig. 2). Dates related to the age of five of the landslides are listed in Table 1 that were reported by Aylsworth et al. (2000). Table 3 lists a date derived from organic material collected from within the scar of a sixth large landslide along the Bourget paleochannel ('D' in Fig. 2), but which yielded a *modern* radiocarbon age. This should be considered as an unrepresentative, indirect, minimum age for the landslide, until additional chronological data verifies this young age or an account is found confirming the occurrence of a major historical landslide at this site.

Table 3 Radiocarbon date from landslide scar located 5 km southeast of the village of Clarence Creek, Bourget paleochannel, Rockland-Bourget area, east of Ottawa, Ontario.

Location	Sample name/ number	Geographical coordinates	Laboratory number	Radiocarbon age (yr BP)	2σ calibrated age range (cal yr BP)	Collector ^a	Comment	References
Landslide along Bourget paleochannel in area of Rampage and Baseline roads	LV98-14-05	N 45.5361° W 75.1972°	Beta-122476	modern	na	AG and JG	Date derived from "small twigs" sampled from 1.09 m depth in core recovered from pond located between well-defined landslide ridges within landslide scar. Sample material contained within sand. Date represents a minimum age for landslide, but likely is substantially younger than the landslide.	Unpublished GSC data.

^a AG - Alain Grenier; JG - Joanna Guertin.

Landslide at Angers, Quebec

A large landslide is present at the village of Angers, Quebec, as shown on Richard (1991) and as ‘E’ in Fig. 2. The failure originated by retrogressing into fine-grained deposits underlying the Champlain Sea plain along the side of a scarp slope along the margin of an Ottawa River terrace. The landslide debris is splayed across an alluvial terrace of the Ottawa River and is shown to terminate just beyond the margin of a lower alluvial terrace. Table 4 lists two radiocarbon dates that were collected from different locations on the landslide debris; one (GSC-6822) on the upper terrace surface, and the other (GSC-2068) on the lower terrace. The geographical coordinates of GSC-2068 fall just beyond the mapped toe of the landslide, but likely are contained within landslide debris, based on the description of the collection site in Lajoie (2001), and the age similarity with the other date. Both dates are interpreted to represent maximum ages for the ‘Angers landslide’.

Table 4 Radiocarbon dates related to age of landslide at Angers, Quebec.

Location	Sample name/ number	Geographical coordinates	Laboratory number	Radiocarbon age (yr BP)	2 σ calibrated age range (cal yr BP)	Collector ^a	Comment	References
Landslide at Angers, Quebec	PL-73-58b	N 45.5208° W 75.4917° ^b	GSC-2068	6240 ± 70 ^c	2 σ : 7020-7257	PGL	Date derived from “branch of tree” (<i>Quercus sp. cf. Quercus borealis</i>), 9 cm diameter, sampled at ~3.5 m depth from within a trench excavated into landslide debris. Sampled material was coated with a thin layer of sand and embedded in clay. Date represents a maximum age for Angers landslide.	GSC Unpublished data; McNeely (1989); Lajoie (2001).
Landslide at Angers, Quebec	DL-2003-1	N 45.5369° W 75.4861°	GSC-6822	6140 ± 70 ^c	2 σ : 6945-7160	DEL	Date derived from “well-preserved” piece of “trunk or branch”, sampled from excavation site of a new sewer line. Sampled material was retrieved from 3 m depth within landslide debris. Date represents a maximum age for Angers landslide.	Unpublished GSC data.

^a PGL – Paul Lajoie; DEL – Ted Lawrence.

^b These coordinates are from the GSC sample submission form.

^c The uncertainty of this age is reported to two standard deviations.

Lefaiivre disturbed terrain, Ontario-Quebec

The Lefaiivre disturbed terrain, Ontario-Quebec, is characterized by rolling hummocks and closed depressions that covers about 46 km² on both sides of the Ottawa River, near Lefaiivre, Ontario (Fig. 1 and 'C' in Fig. 2; see Aylsworth et al., 2000; Aylsworth and Lawrence, 2003). The terrain is composed of variably deformed, folded, faulted and/or rotated deposits of glaciomarine silt and clay, and fluvial sand. The origin of the ground disturbance is enigmatic and has been interpreted as representing a landslide deposit (Crawford, 1961; Richard, 1984b), collapse features (Rodriguez et al., 1987), and 'seismically disturbed' terrain (Aylsworth et al., 2000; Aylsworth and Lawrence, 2003). Two similar, also enigmatic, areas of rolling hummocky terrain exist nearby at Treadwell-Grand Presquîle, Ontario-Quebec, and Wendover, Ontario (see tables 6 and 7, respectively).

Table 5 lists six dates from four sites that provide chronological control on the Lefaiivre disturbed terrain. One of the dates represents a maximum age for the disturbed terrain, while the other five are minimum ages. There is, however, discord between the ages, indicating that some of the dated materials are poorly related to the disturbance event. In particular, the date (GSC-6470), which should represent a maximum age for the disturbed terrain, is younger than four of the five minimum ages. The reason why a buried log would yield a younger age is not clear, unless the burial of the wood somehow post-dates the age of the terrain disturbance. Also questionable is the oldest of the minimum ages (GSC-6173), obtained from a bulk sample of heterogeneous organic materials that possibly included older materials. Available data indicates that the age of the Lefaiivre disturbed ground is best represented by UCIAMS-137118, -137119, and -137120, which are the oldest of the other minimum ages, and have concordant age ranges. The collection and dating of new materials is required to clarify the age of the Lefaiivre disturbed terrain

Table 5 Radiocarbon dates from the Lefaiivre disturbed terrain, Ontario-Quebec.

Location	Sample name/ number	Geographical coordinates	Laboratory number	Radiocarbon age (yr BP)	Calibrated age range (cal BP)	Collector ^a	Comments	References
Lefaiivre disturbed terrain, Ontario-Quebec	none	N 45.6197° W 74.8480°	GSC-6470	7060 ± 80 ^b	7797-7965	JMA	Date derived from outer 16-18 rings of wood buried, 1.5 m deep, within deformed clay sediments exposed on the side of a ditch near Concession 4 North. Date inferred to represent a maximum age for the formation of the Lefaiivre disturbed terrain. Younger than four of the five minimum ages, this date may be unrepresentative of age of disturbed terrain	Aylsworth et al. (2000); GSC unpublished data.
Lefaiivre disturbed terrain, Ontario-Quebec	none	N 45.6152° W 74.8500°	GSC-6173	7530 ± 90 ^b	8207-8413	TA and DG	Date derived from bulk, basal organic detritus-rich clay recovered in core sampler, between 3.63-3.68 m depth, from the centre of pond, 4.6 km SE of Lefaiivre, Ontario. Date represents a minimum age for the onset of organic deposition within pond, and is inferred to represent a minimum age for the formation of the Lefaiivre disturbed terrain. This age is significantly older than the other minimum ages and may be unrepresentative of age of disturbed terrain.	Unpublished GSC data.
Lefaiivre disturbed terrain, Ontario-Quebec	Lef13-AA-03	N 45.60088° W 74.83688°	UCIAMS-137117	7085 ± 25	7854-7966	GRB	Date derived from seeds of bulrush (<i>Scirpus sp.</i>) sampled from clay and organic material situated about 1 cm below base of peat bed that overlies highly disturbed sand and clay deposits exposed along ditch sidewall of Concession 4 North. Sample located at deeper of two nearby peat beds formed in depressions on surface of deposits. Date represents a minimum age for the disturbance of the underlying deposits.	Unpublished GSC data.

Lefaivre disturbed terrain, Ontario-Quebec	Lef13-AB-02	N 45.60458° W 74.83899°	UCIAMS-137118	7225 ± 25	7971-8155	GRB	Date derived from a short shoot of a Larch (<i>Larix laricina</i> ^c) twig sampled from clay and organic material situated 2-3 cm below base of peat bed that overlies highly disturbed deposits exposed along ditch sidewall of Concession 4 North. Peat bed formed in depression on surface of deposits. Date represents a minimum age for the disturbance of the underlying deposits.	Unpublished GSC data.
Lefaivre disturbed terrain, Ontario-Quebec	Lef13-AB-03	As above	UCIAMS-137119	7225 ± 30	7969-8157	GRB	Date derived from Larch (<i>Larix laricina</i> ^c) needle fragments sampled from clay with abundant organic material situated about 25 cm below base of same peat bed as above. Date represents a minimum age for the disturbance of the underlying deposits.	Unpublished GSC data.
Lefaivre disturbed terrain, Ontario-Quebec	Lef13-AB-04	As above	UCIAMS-137120	7275 ± 25	8021-8164	GRB	Date derived from well-preserved twig with bark buried in clay and situated about 23 cm below base of same peat bed as above. Date represents a maximum age for the disturbance of the underlying deposits.	Unpublished GSC data.

^a JMA – Jan Aylsworth; TA – Thane Anderson; DG – Doug Grant; GRB – Greg Brooks
^b The uncertainty of this age is reported to two standard deviations.
^c Identified by A. Telka, Paleotec Services.

Treadwell disturbed terrain, Ontario-Quebec

The Treadwell disturbed terrain, Ontario-Quebec, is characterized by rolling hummocks covering at least 21 km² on the Ontario side of the Ottawa River near the village of Treadwell, Ontario, and on Grand Presqu'île and Petit Presqu'île, Quebec (Fig. 1 and 'B' in Fig. 2; see Richard, 1984b; 1991). The terrain is composed of variably deformed, folded, faulted, and/or rotated deposits of glaciomarine silt and clay, and fluvial sand. The origin of the ground disturbance is enigmatic and has been interpreted as representing a landslide deposit (Lajoie 1974; Richard 1980; 1984b; Lajoie, 2001) and 'seismically disturbed' terrain (Aylsworth et al., 2000; Aylsworth and Lawrence, 2003). The three radiocarbon dates listed in Table 6 provide the only chronological control on this area, and represent minimum ages for the disturbance. Two similar, also enigmatic, areas of hummocky terrain exist nearby in the areas of Lefavre, Ontario, and Wendover, Ontario (see Tables 5 and 7). The three radiocarbon dates listed in Table 6 represent the only chronological control on the Treadwell disturbed terrain; all represent minimum ages for the feature. The age of the feature is best represented by UCIAMS-71217 and UCIAMS-71216, which are the oldest of the three dates.

Table 6 Radiocarbon dates from the Treadwell disturbed terrain, Ontario-Quebec.

Location	Sample name/ number	Geographical coordinates	Laboratory number	Radiocarbon age (yr BP)	2 σ calibrated age range (cal yr BP)	Collector ^a	Comment	References
Treadwell disturbed terrain, Ontario-Quebec	Tread Log 09-06-B	N 45.5798° W 75.0426°	UCIAMS-71217	7105 ± 20	7871-7971	GRB and BEM	Date derived from five <i>Scirpus</i> achenes (three achenes with partial bristles attached) ^b , sampled between 1.81-1.83 m depth at base of lowest of three peat layers exposed along the side of a drainage ditch at corner of agricultural field. Date represents minimum age for the initiation of peat accumulation, and thus a minimum age for the disturbance of the underlying deposits.	Unpublished GSC data.
Treadwell disturbed terrain, Ontario-Quebec	Tread Log 09-02-4	N 45.5793° W 75.0440°	UCIAMS-71216	7020 ± 20	7795-7932	GRB and BEM	Date derived from seven alder (<i>Alnus incana</i>) nutlets ^b sampled between 2.78-2.80 m depth near base of peat and organic detritus deposit, exposed along the side of a drainage ditch on agricultural field. Date represents minimum age for the initiation of peat accumulation, and thus a minimum age for the disturbance of the underlying deposits.	Unpublished GSC data.
Treadwell disturbed terrain, Ontario-Quebec	Tread Log 09-02-3	As above.	UCIAMS-71215	6790 ± 20	7593-7670	GRB and BEM	Date derived from wood of birch log with bark sampled at 2.68 m depth at same location as date above. Date represents minimum age for the initiation of peat accumulation, and thus a minimum age for the disturbance of the underlying deposits.	Unpublished GSC data.

^a GRB – Greg Brooks; BEM – Barbara Medioli.

^b Identified by A. Telka, Paleotec Services.

Wendover disturbed terrain, Ontario

The Wendover disturbed terrain, Ontario, is characterized by gently rolling hummocks, covering at least 2.5 km² (Fig. 1 and 'A' in Fig. 2). The terrain is composed of variably deformed, folded, faulted, and/or rotated deposits of glaciomarine silt and clay, and fluvial sand. The topography of the Wendover disturbed terrain is similar to, but more subtle than those at Lefaiivre and Treadwell, Ontario (see Tables 5 and 6). The Wendover disturbed terrain, however, is well defined in the sub-surface. The origin of the ground disturbance is enigmatic and has been mapped non-genetically as "deformed marine sediment" by Richard (1991), and interpreted as "seismically disturbed" terrain by Aylsworth et al. (2000) and Aylsworth and Lawrence (2003). The five radiocarbon dates listed in Table 7 represent the only chronological control on the Wendover disturbed terrain; all represent minimum ages for the feature. The feature age is best represented by UCIAMS-71211 and UCIAMS-71212, which are the deepest dated materials from each of two sample collection sites.

Table 7 Radiocarbon dates from the Wendover disturbed terrain, Ontario-Quebec.

Location	Sample name/ number	Geographical coordinates	Laboratory number	Radiocarbon age (yr BP)	2 σ calibrated age range (cal yr BP)	Collector ^a	Comment	References
Wendover disturbed terrain, Ontario	Wendover 09-02-C	N 45.5702° W 75.1156°	UCIAMS-71211	7140 ± 20	7937-8004	GRB and BEM	Date derived from willow (<i>Salix</i> sp.) twig ^b , sampled between 2.98-3.00 m depth, at approximate base of 10 m-wide, depression-filling accumulation of organic detritus (logs, branches, twigs and leaves) exposed at NW corner of rainfall runoff retention basin. Date represents minimum age for the start of accumulation of organic detritus in depression, and thus is a minimum age for the disturbance of the underlying deposits.	Unpublished GSC data.
Wendover disturbed terrain, Ontario	Wendover 09-02-A	As above.	UCIAMS-71210	7015 ± 20	7792-7931	GRB and BEM	Date derived from wood of buried log, 25 cm diameter, sampled at ~2.7 m depth at same site as above. Date represents minimum age for the start of accumulation of organic detritus in depression, and thus is a minimum age for the disturbance of the underlying deposits.	Unpublished GSC data.
Wendover disturbed terrain, Ontario	Wendover 09-03-A	N 45.5681° W 75.1233°	UCIAMS-71212	6950 ± 20	7704-7837	GRB and BEM	Date derived from eastern white pine (<i>Pinus strobus</i>) needles ^b sampled from between 0.68-0.70 m relative depth within reworked clay deposit containing sporadic organic material, situated 0.15 m below base of peat layer exposed along drain ditch, 125 m ENE of corner of Regional Road 19 and Highway 17. Date represents a minimum age for the disturbance of the underlying deposits.	Unpublished GSC data.

Wendover disturbed terrain, Ontario	Wendover 09-03-B	As above.	UCIAMS- 71213	6635 ± 25	7472-7572	GRB and BEM	Date derived from larch (<i>Larix laricina</i>) needle fragments ^b sampled from between 0.57-0.60 m relative depth within reworked clay deposit containing small clumps of organic materials 0.1 m below base in same peat layer, as above. Date represents a minimum age for the disturbance of the underlying deposits.	Unpublished GSC data.
Wendover disturbed terrain, Ontario	Wendover 09-03-C	As above.	UCIAMS- 71214	6615 ± 20	7445-7566	GRB and BEM	Date derived from eastern white pine (<i>Pinus strobus</i>) fascicle ^b with needles attached, sampled at 0.5 m relative depth at base in same peat layer, as above. Date represents a minimum age for the disturbance of the underlying deposits.	Unpublished GSC data.

^a GRB – Greg Brooks; BEM – Barbara Medioli.
^b Identified by A. Telka, Paleotec Services.

Brownsburg landslide, near Brownsburg, Quebec

The Brownsburg landslide is located along the north side of the Ottawa River, Quebec, about 8 km south of Brownsburg and south-west of Lachute (Fig. 1). The landslide is situated along the margin of an anastomosing paleochannel of the Ottawa River that is incised into fluvial terraces. The landslide retrogressed about 640 m towards the north-northwest into a scarp slope to form a source area of 0.35 km² in area (Fig. 3). The debris field is splayed into the paleochannel, and exhibits an irregular, multi-lobe morphology consistent with a single failure episode. The debris field is well-preserved and has not been truncated by fluvial erosion, indicating that the Ottawa River had abandoned this portion of the paleochannel prior to the failure. Table 8 lists two radiocarbon ages obtained from logs buried in the landslide debris that were submitted for dating by the Ministère des Transports du Québec. Collected from sites about 45 m apart, the two samples yielded ages that are similar statistically, and represent, probably direct, maximum ages for the landslide.

Table 8 List of radiocarbon ages from the Brownsburg landslide, near Lachute, Quebec.

Location	Sample name/ number	Geographical coordinates	Laboratory number	C-14 age (yr BP)	2 σ calibrated age range (cal yr BP)	Collector ^a	Comments	References
Brownsburg landslide, near Lachute, Quebec	MTQ-Brown-01 (wood)	N45.604274 ° W74.407688 °	UCIAMS-171456 (ULA-5942) ^b	4485±20	5042-5288	PL	Date derived from wood sampled from outer part of a “large” log, buried 1-2 m deep. Log was unearthed during excavation of a field drainage system. Date represents a maximum age for the encapsulating mass movement deposits.	Unpublished data, Ministère des Transports du Québec
Brownsburg landslide, near Lachute, Quebec	MTQ-Brown-03 (wood)	N45.604634 ° W74.407967 °	UCIAMS-171457 (ULA-5943) ^b	4550±20	5056-5316	PL	Date derived from wood sampled from outer part of a “large” log, buried 1-2 m deep. Log was unearthed during excavation of a field drainage system. Date represents a maximum age for the encapsulating mass movement deposits.	Unpublished data, Ministère des Transports du Québec

^a PL – Pascal Locat, Ministère des Transports du Québec.

^b The second laboratory number is from Laval University (ULA) who pretreated the sample prior to radiocarbon analysis by the University of California Irvine Keck-CCAMS facility.

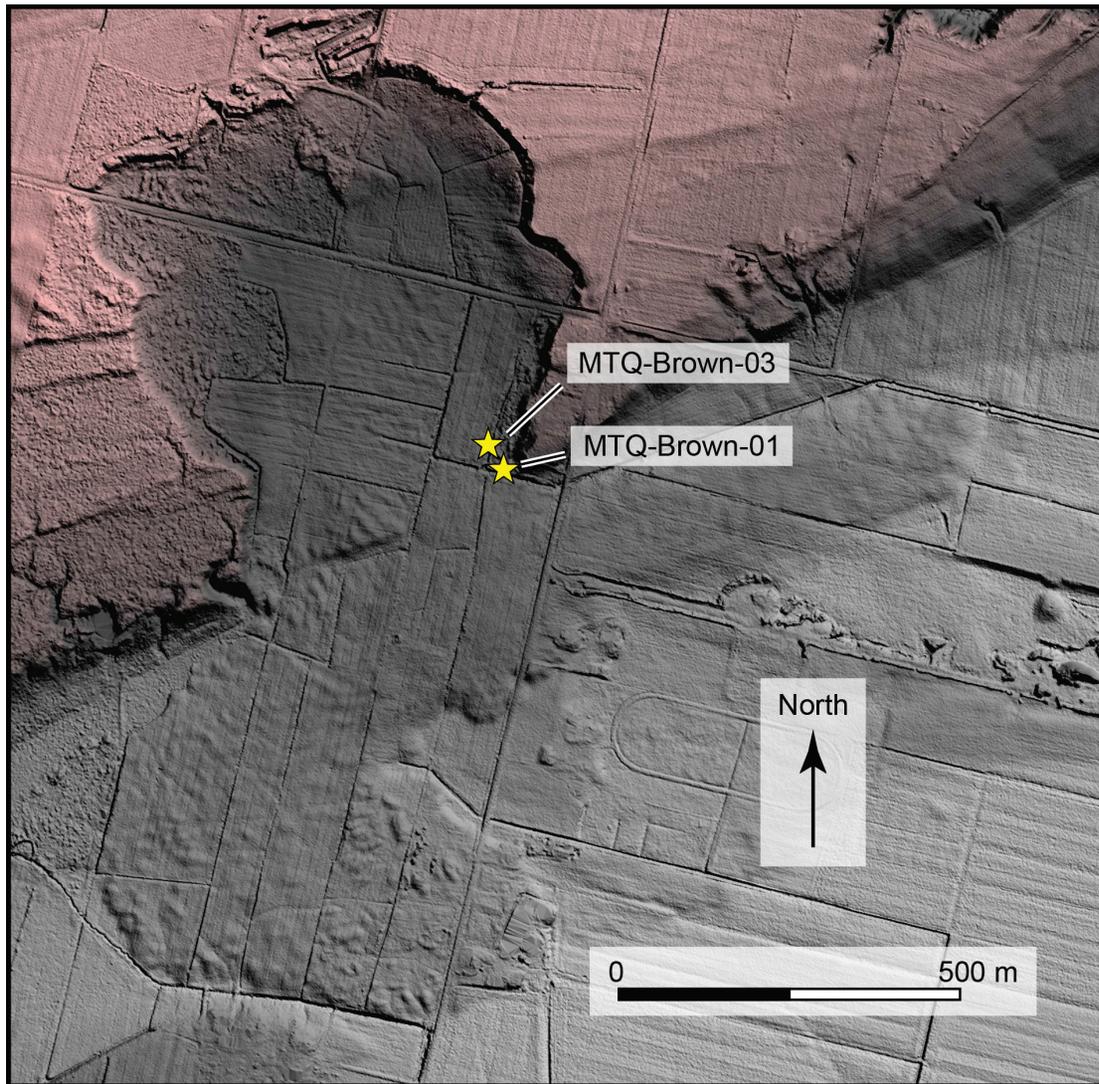


Fig. 3 Shaded relief map of the Brownsburg landslide, Quebec, showing the source area and the multi-lobed debris field that is splayed onto a paleochannel of the Ottawa River. Stars depict the locations of the radiocarbon-dated wood samples listed in Table 8.

Landslide at Beacon Hill, Gloucester, Ottawa, Ontario

The Beacon Hill landslide (~2.0 Mm³), Ottawa, Ontario, is covered completely by urban development (Fig. 1; see summary of landslide by Aylsworth et al., 1997). This landslide is referred as “Green Creek” or “Green Creek slide” in Lowdon et al. (1967) and Eden (1967), respectively, although the landslide did not occur along Green Creek (which is located 1.1 km away.) The landslide originated from a steeply-sloped scarp forming the margin of a broad, flat terrace of the Ottawa River. The debris splayed onto the terrace forming a well-preserved, debris lobe that is visible on pre-development aerial photographs. The site was investigated in the 1960s, as reported by Crawford and Eden (1967), Eden (1967), and Jarrett and Eden (1970). A composite sample of wood recovered in 1960 from a boring yielded the single date listed in Table 9. A deep sewer trench excavated into the landslide deposit in 1966 exposed a buried soil and organic materials (peat, wood, trees) considered to be contemporary with the dated wood (see Eden, 1967). Brooks (2013a) correlated the age of the Beacon Hill landslide to nine other landslides in the Ottawa-Pontiac region (see Tables 11, 12, 13, 16, 17 and 18F) and hypothesized that they represent evidence of a paleoearthquake at ~1020 cal BP.

Table 9 Radiocarbon date from landslide at Beacon Hill, Gloucester, Ottawa, Ontario.

Location	Sample name/ number	Geographical coordinates	Laboratory number	Radiocarbon age (yr BP)	2 σ calibrated age range (cal yr BP)	Collector ^a	Comment	References
Beacon Hill landslide, Gloucester, Ottawa, Ontario	NRC 90-30	N 45.4528° W 75.5960 ^b	GSC-550	1140 ± 150 ^c	938-1176	WJE	Date derived from two wood samples sampled at 6.79 m (22.3 ft), and 7.71 m (25.3 ft) depth in core recovered from the apron of “flowslide” on Ottawa River terrace. The material was enclosed entirely in remolded clay. Wood samples assumed to be from same branch. Wood probably associated with soil buried beneath landslide debris revealed by later excavation in area. Date represents a maximum for landslide.	Lowdon et al. (1967); unpublished GSC data.

^a WJE - W.J. Eden.

^b These coordinates are from the GSC sample submission form and are located on the splayed landslide deposit.

^c The uncertainty of this age is reported to two standard deviations.

Landslide along Jomonville Street, Hull, Gatineau, Quebec

A large area of landsliding in the northern part of Hull (now part of Gatineau), Quebec, is shown on Richard (1982a) that is now covered by urban development. The single date listed in Table 10 and shown on Fig. 1 was collected in 1972 from a geotechnical borehole along Jomonville Street within the mapped landslide area. The context of the collected sample (depth of collection and type of enclosing material) is provided only broadly and there is uncertainty on the location of the boring site, which prevents relating the radiocarbon age to a specific landslide feature. This single date presumably relates to the age of a ‘young’ landslide in the Jomonville Street area that possibly occurred historically.

Table 10 Radiocarbon date from landslide deposit along Jomonville Street, Hull, Gatineau, Quebec.

Location	Sample name/ number	Geographical coordinates	Laboratory number	Radiocarbon age (yr BP)	2 σ calibrated age range (cal yr BP)	Collector ^a	Comment	References
Jomonville Street, Hull, Quebec	PL-72-43	N 45.4650° W 75.7513° ^b	GSC-1741	120 ± 150 ^c	4-285	BH	Single piece of white pine (<i>Pinus strobus</i>) recovered from 10 m depth in borehole “on natural slope”. Sampled material enclosed in saturated clay. Date may represent a maximum age for landslide that is ‘young’.	Lowdon and Blake (1973); unpublished GSC data.

^a BH - B. Hopkins.

^b The geographical coordinates in Lowdon and Blake (1973) and given on the GSC sample submission form fall 2.1 km due south of Jomonville Street, Hull, Gatineau, Quebec. The latitude of the coordinates in the table has been adjusted so that the location is positioned on Jomonville Street (which is oriented east-west) using the original longitude. The location defined by these coordinates, however, must be considered as an approximation.

^c The uncertainty of this age is reported to two standard deviations.

Landslides along Breckenridge Valley, near Aylmer, Quebec

Breckenridge Creek is a small tributary of the Ottawa River, draining ~66 km², and located ~14 km northwest of Aylmer (now part of Gatineau), Quebec (Fig. 1). Thirty-one landslide scars forming distinctly separate failures are clustered within ~11 km², where the creek and its major tributaries are incised up to 30 m deep in fine-grained Champlain Sea deposits (Brooks and Medioli, 2011). Numbers informally assigned to the scars are shown on the landslide map on Fig. 4, and referred to in Table 11 (below). The landslide map includes three scars (numbered 27 to 29) located along a scarp above an erosional fluvial terrace of the ancestral Ottawa River, as well as, the locations of two smaller landslides that occurred historically in 1963 and 2008.

Table 11 lists 55 radiocarbon dates of which 52 are relevant to the age of 13 landslides. In some cases, the relationship of a date (or group of dates) to a specific landslide feature is not known with confidence, because of the density of the scars, and uncertainty of the source area of the landslide debris containing or overlying the dated material(s). In such cases, the connection between a date and landslide scar is based on local geomorphology and/or proximity, and is indicated in the table as an *inferred* relationship. Of note, one date (GSC-3337) is not attributed to any landslide because the collection site is located far from an obvious source scar. Two dates (GSC-6313 and GSC-6315) relate to the age of a mudflow that descended Breckenridge Creek. Brooks (2013a) correlated the age of scars 1, 9, 13, and 15 to the ages of six other landslides in the Ottawa-Pontiac region (see Tables 9, 12, 13, 16, 17 and 18), and hypothesized that they represent evidence of a paleoearthquake at ~1020 cal BP.

Overview of dates in Table 11, and their relation to the Breckenridge landslide scars:

Scar 1 – represented by four dates inferred to be maximum ages for the landslide.

Scar 2 – represented by nine dates, but the four youngest dates are interpreted to be poorly representative of the landslide age. The oldest six dates represent three maximum and three minimum ages that bracket the timing of the landslide.

Scar 3 – inferred to be represented by five dates that are maximum ages for the landslide.

Scar 4 – represented by three dates; one minimum and two maximum dates. The two maximum dates are representative of the landslide age, while the minimum date is substantially younger and interpreted to be unrepresentative.

Scar 9 – represented by three dates that are maximum ages for the landslide.

Scar 11 – represented by a single minimum date that may be significantly younger than the landslide age.

Scar 12 – represented by a single date that is inferred to be a maximum age for the landslide.

Scar 13 – represented by 11 dates that are maximum ages for the landslide.

Scar 15 – represented by four dates that are maximum ages for the landslide.

Scar 17 – represented by a single date that is inferred to be a maximum age for the landslide.

Scar 18 – represented by four minimum dates, two of which are substantially younger than the landslide.

Scar 19 – represented by five dates; one represents a minimum age that is significantly younger than the landslide, and four inferred maximum ages for the landslide.

Scar 22 – represented by one minimum date that may be substantially younger than the landslide.

Unknown scar – this is a single date that is not related to any scar.

Mudflow deposits(s) – two dates represent the maximum age of a mudflow deposit located along the lower course of Breckenridge Valley downstream of the landslide area (Fig. 4). The specific source(s) of the mudflow within Breckenridge Valley is not known.

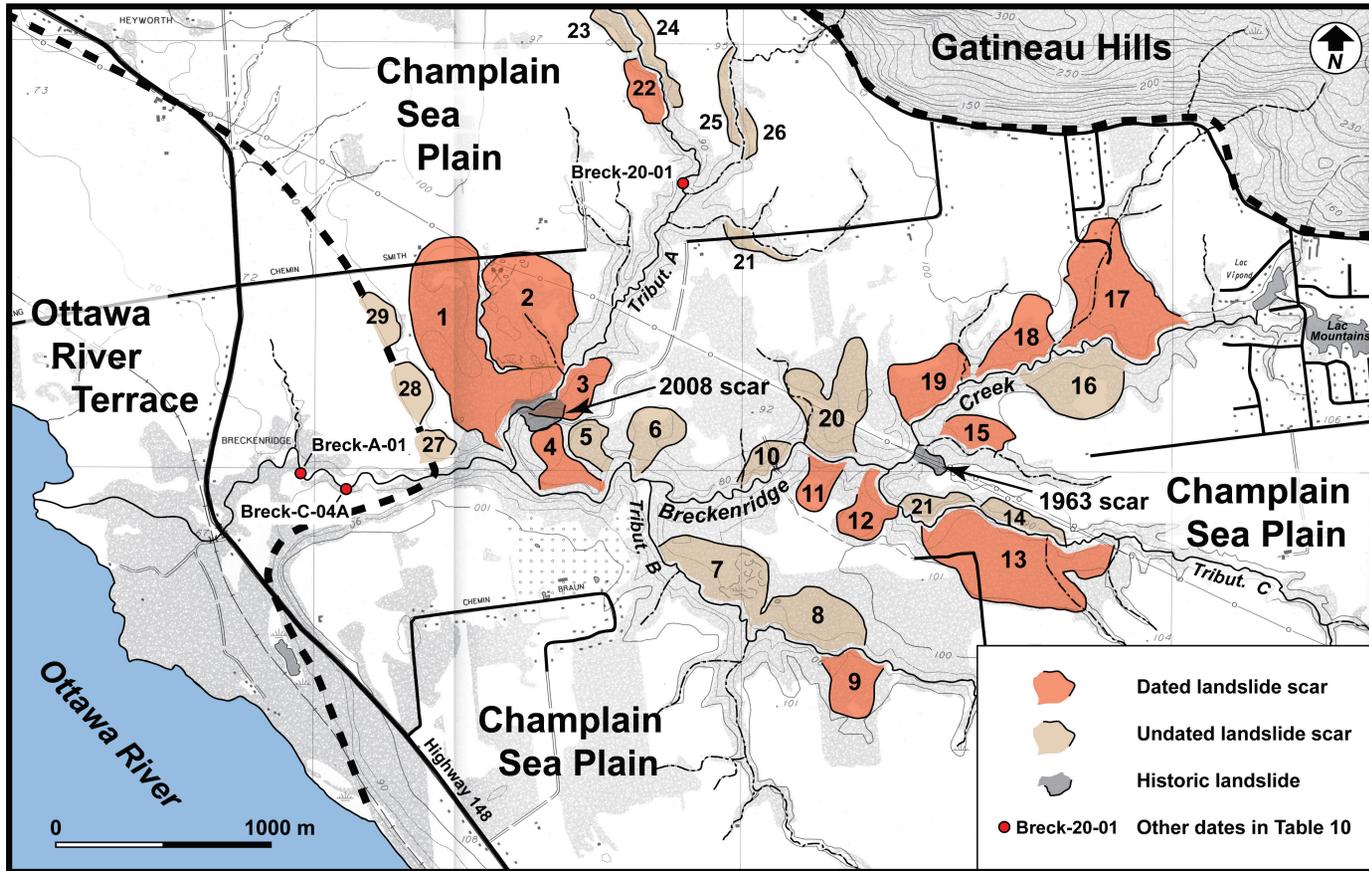


Fig. 4 Map showing the dated, undated and historic landslide scars (with assigned scar numbers or year of failure) along Breckenridge Creek and its major tributaries. The radiocarbon ages in Table 11 are listed under sub-headings of the 13 dated scars. Note, there are three dates on the map labeled by the sample number at the collection site - see Table 11 for explanation (these are the last three dates listed in the table).

Table 11 Radiocarbon dates from Breckenridge Valley, near Aylmer, Quebec.

Location	Sample name/ number	Geographical coordinates	Laboratory number	Radiocarbon age (yr BP)	2 σ calibrated age range (cal yr BP)	Collector ^a	Comment	References
Scar 1, Breckenridge Valley	Brkwood-01, sample 1	N 45.4829° W 75.9349°	UCIAMS- 88796	1125 ± 15	978-1061	GRB and BEM	Date derived from small tree branch with bark contained within buried humic/wood-rich layer exposed along the side scarp of a landslide that occurred in 2008. Organic material is buried beneath landslide debris and situated ~5.7 m below top of terrace surface. Source area of overlying landslide debris is uncertain, but most obvious location is scar 1 on opposite side of creek valley. Date inferred to represent maximum age for scar 1 landslide.	Brooks (2013a).
Scar 1, Breckenridge Valley	Brkwood-01, sample 2	As above.	UCIAMS- 88797	1115 ± 15	974-1058	GRB and BEM	Date derived from outer rings of branch with bark contained within same buried organic-rich layer, as above. Date inferred to represent maximum age for scar 1 landslide.	Brooks (2013a).
Scar 1, Breckenridge Valley	Brkwood-01, sample 3	As above.	UCIAMS- 88798	1205 ± 15	1069-1174	GRB and BEM	Date derived from outer rings of log partially covered with bark contained within same buried organic-rich layer, as above. Date inferred to represent maximum age for scar 1 landslide.	Brooks (2013a).

Scar 1, Breckenridge Valley	Core Breck 21- 01A	N 45.4851° W 75.9339°	Beta- 131934	1190 ± 40	983-1256	JG and RM	Date derived from “large stick” sampled between 0.42-0.45 m depth in 0.48 m long core recovered from pond on margin of scars 1 and 2. Sample encapsulated within “grey clay with mixed organics”. Pond is impounded behind edge of levee formed by landslide debris from scar 2, although modern level of pond is influenced by beaver dam. Date represents minimum age for scar 1 landslide. This corrects Brooks et al. (2013), which erroneously attributed this date to the age of scar 2.	Unpublished GSC data.
Scar 2, Breckenridge Valley	Core Brkcore- 10A, sample 1, 0.79-0.81 m depth	N 45.4853° W 75.9363°	UCIAMS- 88704	2805 ± 20	2856-2956	GRB	Date derived from birch twig with bark sampled from organic layer, between 0.79-0.81 m depth, in 0.94 m long core recovered from perennial wetland on scar 2. Wetland is impounded behind levee of scar 1, although modern level of pond is influenced by beaver dam. Organic layer overlain by bed of clay with organic-rich bands (0.72- 0.79 m depth) and bed of grey silt- clay (0.21-0.72 m depth). Date represents minimum age for scar 2 landslide.	Unpublished GSC data.
Scar 2, Breckenridge Valley	Core Brkcore- 10A, sample 2, 0.92-0.94 m depth	As above.	na ^b	2872 ± 20	2929-3072	GRB	Date derived from branched leafy shoot of <i>Thuja occidentalis</i> (eastern white cedar) ^c sampled from 0.92- 0.94 m depth in same core, as above. Date represents minimum age for scar 2 landslide.	Unpublished GSC data.

Scar 2, Breckenridge Valley	Core Brkcore- 10A, sample 3, 0.92-0.94 m depth	As above.	na ^d	2852 ± 18	2882-3061	GRB	Date derived from terminal twig (with some needles attached) of <i>Tsuga Canadensis</i> (eastern Hemlock) ^e sampled from 0.92-0.94 m depth in same core, as above. Date represents minimum age for scar 2 landslide.	Unpublished GSC data.
Scar 2, Breckenridge Valley	Core Brkcore- 11A, 0.70-0.75 m depth	N 45.4865° W 75.9327°	UCIAMS- 88709	3220 ± 20	3387-3470	GRB	Date derived from wood fragment sampled between 0.70-0.75 m depth in 2.24 m long core recovered from perennial wetland in depression between ridges on scar 2. Sample contained within bed of mottled clay-silt with organic materials and wood fragments situated 23-30 cm above clay. Date represents minimum age for scar 2 landslide, but is stratigraphically higher and therefore less representative than the two older dates from this core (below).	Unpublished GSC data.
Scar 2, Breckenridge Valley	Core Brkcore- 11A, sample 1, 0.96-1.00 m depth	As above.	UCIAMS- 88707	3390 ± 20	3581-3690	GRB	Date derived from twig with bark sampled at 0.96-1.0 m depth from same core as above. Sample situated at base of post-landslide sediments that overlie stiff silt-clay landslide deposit. Date represents minimum age for scar 2 landslide.	Unpublished GSC data.
Scar 2, Breckenridge Valley	Core Brkcore- 11A, sample 2, 0.96-1.00 m depth	As above.	UCIAMS- 88708	3420 ± 20	3595-3811	GRB	Date derived from twig fragment (lacking bark) sampled between 0.96-1.0 m depth in same core as above. Date represents minimum age for scar 2 landslide.	Unpublished GSC data.

Scar 2, Breckenridge Valley	Brkwood-03, sample 3	N 45.4839° W 75.9330°	UCIAMS- 88801	3460 ± 15	3644-3826	GRB and BEM	Date derived from outer portion of log with bark, ~8 cm diameter, that was contained within buried humic /wood-rich layer exposed in terrace along tributary B of Breckenridge Creek. Organic layer is buried beneath landslide debris and located 2.6-2.8 m below top of terrace. Landslide debris containing buried organic layer thought to have been remobilized as part of block in younger failure from scar 1. Date inferred to be maximum age for scar 2 landslide.	Unpublished GSC data.
Scar 2, Breckenridge Valley	Brkwood-03, sample 5	As above.	UCIAMS- 88802	3390 ± 15	3584-3689	GRB and BEM	Date derived from branch with bark, ~3 cm diameter, from same organic rich layer, as above. Date inferred to be maximum age for scar 2 landslide.	Unpublished GSC data.
Scar 2, Breckenridge Valley	Brkwood-03, sample 6	As above.	UCIAMS- 88803	3450 ± 15	3641-3824	GRB and BEM	Date derived from small log with bark, ~5 cm diameter, from same organic rich layer, as above. Date inferred to be maximum age for scar 2 landslide.	Unpublished GSC data.
Scar 3, Breckenridge Valley	96-06-21-01-#1	N 45.4831° W 75.9332°	GSC-6233	7050 ± 80 ^e	7794-7958	GRB and JMA	Date derived from outer portion of log of <i>Pinus strobus</i> (eastern white pine) ^f buried 2.2 m below the top of head scarp of slump that had formed within deposits of scar 3. Date represents maximum age for a landslide originating from scar 3.	Unpublished GSC data.
Scar 3, Breckenridge Valley	96-06-21-02-#2	As above.	GSC-6243	7030 ± 70 ^e	7791-7943	GRB and JMA	Date derived from outer portion of the upper of two logs of <i>Pinus strobus</i> (eastern white pine) ^f buried between 2.0-2.4 m below top of head scarp at same location as above. Date represents maximum age for a landslide originating from scar 3.	Unpublished GSC data.

Scar 3, Breckenridge Valley	96-06-21-03-#1	As above.	GSC-6246	6980 ± 80°	7702-7929	GRB and JMA	Date derived from the outer portion of the lower of two logs of <i>Pinus strobus</i> (eastern white pine) ^f , as above. Date represents maximum age for a landslide originating from scar 3.	Unpublished GSC data.
Scar 3, Breckenridge Valley	Brkwood-02, sample 1	N 45.4834° W 75.9331°	UCIAMS- 88799	7105 ± 20	7871-7971	GRB and BEM	Date derived from the outer rings of ~10 cm diameter log with bark contained within humic/wood-rich layer of buried soil exposed along the incised course of tributary A into debris of 2008 landslide. Organic layer overlain by landslide debris and dips across bank face to below level of observed creek surface. Sampling site situated 2.8 m from top of bank. Date represents maximum age for a landslide originating from scar 3.	Unpublished GSC data.
Scar 3, Breckenridge Valley	Brkwood-02, sample 2	As above.	UCIAMS- 88800	7000 ± 20	7787-7930	GRB and BEM	Date derived from outer rings of <i>in situ</i> stump with bark rooted within buried same soil/organic layer, as above. Date represents maximum age for a landslide originating from scar 3.	Unpublished GSC data.
Scar 4, Breckenridge Valley	Core Brkcore- 02-D, 0.88-0.92 m depth	N 45.4802° W 75.9309°	UCIAMS- 88816	200 ± 15	-1-294	GRB	Date derived from wood fragment sampled from 0.88-0.92 m depth in 1.51 m long core recovered from ephemeral wetland. Sample situated in grey silt-clay deposit ~8 cm below base of buried peat unit, 0.36 m thick. Date represents minimum indirect age for scar 4 landslide.	Unpublished GSC data.

Scar 4, Breckenridge Valley	Core Brkcore- 02-D, 1.40-1.41 m depth	As above.	UCIAMS- 88674	600 ± 15	548-646	GRB	Date derived from wood fragment sampled from 1.40-1.41 m depth in same core as above. Sample is one of several wood fragments at base of grey silt-clay deposit that overlies partially penetrated sand deposit. Date represents maximum age for scar 4 landslide.	Unpublished GSC data.
Scar 4, Breckenridge Valley	Site of Core Breckcore02-E	As above.	UCIAMS- 88675	600 ± 20	545-650	GRB	Date derived from wood fragment extracted from site of core, which had poor deposit recovery. Buried wood at 2.02 m depth encountered by probing and sampled with a soil drill. Date represents maximum age for scar 4 landslide.	Unpublished GSC data.
Scar 9, Breckenridge Valley	Breck-28-02	N 45.4718° W 75.9129°	GSC-6449	1080 ± 70°	932-1056	DEL and JG	Date derived from wood of <i>in situ</i> stump rooted within well-defined organic layer, exposed upstream of scar 9 along tributary B. Organic layer is buried beneath silt-clay deposit and dips under stream surface. Date represents maximum age for scar 9 landslide.	Brooks (2013a).
Scar 9, Breckenridge Valley	Breckwood-20- A	N 45.4722° W 75.9129°	UCIAMS- 106584	1145 ± 15	979-1166	GRB	Date derived from outer rings of truncated, vertical tree trunk, 0.1 m diameter, protruding through side of tributary B channel upstream of scar 9. Enclosing clay sediment excavated several tens of centimeters to exposed portion of tree trunk with intact bark from which sample was obtained. Date represents maximum age for scar 9 landslide.	Brooks (2013a).
Scar 9, Breckenridge Valley	Breckwood-20- B	As above.	UCIAMS- 106585	1130 ± 20	969-1070	GRB	Date derived from outer rings of truncated, vertical, tree trunk, 0.15 m diameter, protruding through creek bed, as above. Date represents maximum age for scar 9 landslide.	Brooks (2013a).

Scar 11, Breckenridge Valley	Brkcore-08A	N 45.4799° W 75.9174°	UCIAMS- 88703	180 ± 20	-2-286	GRB	Date derived from raspberry seeds ^b sampled from between 0.41-0.42 m depth from 0.91 m-long core of perennial wetland on scar 11. Sample situated within stiff clay-silt deposit that extends from 0.37/0.39-0.91 m depth. Date represents minimum age for scar 11, but landslide is probably significantly older.	Unpublished GSC data.
Scar 12, Breckenridge Valley	Breck K-01	N 45.4786° W 75.9118°	GSC-6318	1030 ± 70 ^c	803-1053	DEL and JG	Date derived from root of upright stump of <i>Tsuga canadensis</i> (eastern Hemlock) ^f contained within an organic-rich, woody layer, several cm thick, buried by landslide debris, exposed within scar of recent slump opposite to scar 12 along tributary C. Date inferred to represent maximum age for scar 12 landslide.	Brooks (2013a).
Scar 13, Breckenridge Valley	Brkwood7-1B	N 45.4773° W 75.9028°	UCIAMS- 88806	1895 ± 25	1738-1896	GRB and BEM	Date derived from outer rings of truncated, vertical, tree trunk protruding from incised bed of tributary C. Enclosing clay sediment excavated several tens of centimeters to exposed portion of tree trunk (with intact bark) from which sample was obtained. Tree trunk located ~10 m upstream end of landslide debris along creek course. Date represents maximum age for scar 13 landslide.	Unpublished GSC data.
Scar 13, Breckenridge Valley	Brkwood7-2A	As above.	UCIAMS- 88807	1915 ± 20	1821-1919	GRB and BEM	Date derived from outer rings of root of truncated, vertical, tree stump located immediately beside the tree trunk described above. Sampling site, as above. Date represents maximum age for scar 13 landslide.	Unpublished GSC data.

Scar 13, Breckenridge Valley	Brkwood7-3B	N 45.4775° W 75.9021°	UCIAMS- 88808	1925 ± 15	1825-1920	GRB and BEM	Date derived from outer rings of truncated, vertical, tree trunk protruding from bank of tributary C. Enclosing clay sediment excavated several tens of centimeters to expose portion of tree trunk with intact bark from which sample was obtained. Sampling site located upstream from location where landslide debris from scar 13 crosses creek. Date represents maximum age for scar 13 landslide.	Unpublished GSC data.
Scar 13, Breckenridge Valley	Brkwood7-4A	N 45.4775° W 75.9016°	UCIAMS- 88809	2030 ± 20	1904-2044	GRB and BEM	Date derived from outer rings of log protruding at an angle from organic-rich layer overlain by landslide debris along bed of tributary C. Sampling site located upstream of location where landslide debris from scar 13 crosses creek. Date represents maximum age for scar 13 landslide.	Unpublished GSC data.
Scar 13, Breckenridge Valley	Brkwood7-5A	As above.	UCIAMS- 88810	1920 ± 20	1822-1921	GRB and BEM	Date derived from outer rings of horizontal, buried tree trunk, ~50 cm diameter, rooted in organic-rich layer, as above. Bark preserved on portion of tree trunk. Sampling site, as above. Date represents maximum age for scar 13 landslide.	Unpublished GSC data.
Scar 13, Breckenridge Valley	Brkwood7-6B	N 45.4777° W 75.9010°	UCIAMS- 88811	1885 ± 15	1741-1880	GRB and BEM	Date derived from outer rings of truncated, vertical, tree trunk protruding from bank of tributary C. Enclosing clay sediment excavated several tens of centimeters to expose portion of tree trunk with intact bark from which sample was obtained. Sampling site located upstream of location where landslide debris from scar 13 crosses creek. Date represents maximum age for scar 13 landslide.	Unpublished GSC data.

Scar 13, Breckenridge Valley	Brkwood8-1B	N 45.4754° W 75.9028°	UCIAMS- 88812	2030 ± 15	1929-2038	GRB	Date derived from outer rings of one of two logs protruding from landslide debris exposed along gully incised into scar 13. Enclosing debris excavated several tens of centimeters to expose well-preserved portion of tree trunk from which sample was obtained. Date represents maximum age for scar 13 landslide.	Unpublished GSC data.
Scar 13, Breckenridge Valley	Brkwood8-1D	As above.	UCIAMS- 88813	1925 ± 15	1825-1920	GRB	Date derived from outer rings of second of two logs protruding from landslide debris exposed along gully incised into scar 13. Enclosing debris excavated several tens of centimeters to expose well-preserved portion of tree trunk from which sample was obtained. Date represents maximum age for scar 13 landslide.	Unpublished GSC data.
Scar 13, Breckenridge Valley	Breck I-01	N 45.4794° W 75.9129°	GSC-6317	2100 ± 70 ^c	1954-2291	DEL and JG	Date derived from “mostly bark” sampled from woody organic-rich layer, several cm thick, buried beneath landslide debris, located downstream of scar 13. Date inferred to be maximum age for scar 13 landslide.	Unpublished GSC data.
Scar 13, Breckenridge Valley	Breck J-02	N 45.4789° W 75.9123°	GSC-6316	1880 ± 70 ^e	1721-1890	DEL and JG	Date derived from wood (probably <i>Tsuga canadensis</i> (eastern Hemlock)) ^f sampled from woody, organic-rich layer, several cm thick, buried beneath landslide debris, located downstream of scar 13. Date inferred to be maximum age for scar 13 landslide.	Unpublished GSC data.

Scar 13, Breckenridge Valley	Breckwood-21- A	N 45.4755° W 75.9120°	UCIAMS- 106586	1930 ± 15	1826-1923	GRB	Date derived from root with preserved bark, ~1 cm diameter, that was part of a concentrated zone of wood exposed along tributary C. Woody zone situated ~1 m above modern creek surface and 0.10-0.20 m below discontinuous buried organic layer, several mm thick. Sample site is located downstream of scar 13 near collection site of GSC-6318. Date inferred to be maximum age for scar 13 landslide.	Unpublished GSC data.
Scar 15, Breckenridge Valley	Breck-04-01	N 45.4812° W 75.9067°	GSC-6482	1210 ± 50 ^c	1061-1234	GRB, JG and RM	Date derived from horizontally-oriented log, ~15 cm diameter, buried 0.4 m deep within clay-silt deposits of valley fill that were exposed along incised gully situated upstream of scar 15. Log overlies unexposed base of tree trunk that yielded GSC-6481, located at same site. Date represents maximum age of scar 15 landslide, based on younger ages of GSC-6481, UCIAMS-88804 and UCIAMS-88805.	Brooks (2013a).
Scar 15, Breckenridge Valley	Breck-04-02	As above.	GSC-6481	1040 ± 60 ^c	918-1051	GRB, JG and RM	Date derived from “outside piece” of truncated, vertical, tree trunk buried within clay-silt deposits of valley fill, as above. Date represents maximum age for scar 15 landslide.	Brooks (2013a).
Scar 15, Breckenridge Valley	Brkwood6-1C	N 45.4815° W 75.9068°	UCIAMS- 88804	1080 ± 15	936-1053	GRB and BEM	Date derived from outer rings of truncated, vertical, tree trunk, ~50 cm diameter, exposed along gully incised into landslide debris of scar 15. Enclosing clay sediment excavated several tens of centimeters to exposed portion of tree trunk with intact bark from which sample obtained. Date represents maximum age for scar 15 landslide.	Brooks (2013a).

Scar 15, Breckenridge Valley	Brkwood6-2B	As above.	UCIAMS- 88805	1110 ± 15	971-1056	GRB and BEM	Date derived from outer rings of second truncated, vertical, tree trunk exposed along gully, as above. Enclosing clay sediment excavated several tens of centimeters to exposed portion of tree trunk with intact bark, as above. Date represents maximum age for scar 15 landslide.	Brooks (2013a).
Scar 17, Breckenridge Valley	Breck-11-02	N 45.4854° W 75.8964°	GSC-6433	1440 ± 50 ^c	1299-1375	GRB, JG and RM	Date derived from outer rings of back-tilted log sampled from organic-rich layer, 3.4-3.9 m deep and buried beneath debris, within backslope of recent slump scar on side of Breckenridge creek valley opposite to scar 17. Date inferred to represent maximum age of scar 17 landslide.	Unpublished GSC data.
Scar 18, Breckenridge Valley	Core Brkcore05-A, 0.58-0.62 m depth	N 45.4852° W 75.9060°	UCIAMS- 88818	2755 ± 20	2784-2920	GRB	Date derived from leaves of <i>Thuja occidentalis</i> (eastern white cedar) ^c sampled between 0.58-0.62 m depth in 1.5 m long core recovered from perennial wetland deposit on scar 18. The sample was situated within a silt-clay deposit containing abundant organic detritus that extends between 0.50-0.70 m depth. Date represents minimum age for scar 18, but is interpreted to be significantly younger than landslide.	Unpublished GSC data.
Scar 18, Breckenridge Valley	Core Brkcore05-A, 0.91-0.96 m depth	As above.	UCIAMS- 88677	3455 ± 20	3641-3827	GRB	Date derived from needles with fascicle attached of <i>Pinus strobus</i> (eastern white pine) ^c extracted from peaty silt-clay deposit between 0.91-0.96 m depth in same core as above. Peaty silt-clay deposit extends from 0.66 m depth to base of recovered core. Date represents minimum age for scar 18 landslide.	Unpublished GSC data.

Scar 18, Breckenridge Valley	Core Brkcore05-A, 1.39-1.41 m depth	As above.	UCIAMS- 88676	3600 ± 15	3847-3970	GRB	Date derived from needles with fascicle attached of <i>Pinus strobus</i> (eastern white pine) ^c extracted between 1.39-1.41 m depth from same core as above. Sample situated within peaty silt-clay deposit immediately above wood at base of recovered core. Date represents minimum age for scar 18 landslide.	Unpublished GSC data.
Scar 18, Breckenridge Valley	Core Brkcore05-A, 1.39-1.41 m depth	As above.	UCIAMS- 88817	3625 ± 15	3890-3980	GRB	Date derived from leaves of <i>Thuja occidentalis</i> (eastern white cedar) ^c extracted between 1.39-1.41 m depth from same core, as above. Date represents minimum age for scar 18 landslide.	Unpublished GSC data.
Scar 19, Breckenridge Valley	98-14-2A	N 45.4825° W 75.9118°	GSC-6355	1170 ± 50 ^c	990-1173	JMA and JG	Date derived from branch contained within a well-defined layer of logs and woody debris, several tens of centimeters thick, buried beneath 9.5 m of debris exposed in scar of a recent slump along Breckenridge Creek. Age is anomalously young relative to four other ages from same organic layer. Date inferred to represent minimum age for scar 19 landslide, but is believed to be significantly younger than the age of the landslide.	Unpublished GSC data.
Scar 19, Breckenridge Valley	98-14-3	As above.	GSC-6357	1570 ± 90 ^c	1359-1545	JMA and JG	Date derived from outer portion of log from same well-defined layer of logs and woody debris, as above. Date inferred to represent maximum age for scar 19 landslide.	Unpublished GSC data.
Scar 19, Breckenridge Valley	98-14-1A	As above.	GSC-6311	1530 ± 50 ^c	1351-1517	JMA and JG	Date derived from outer ~30 rings of large log from same well-defined layer of logs and woody debris, as above. Date inferred to represent maximum age for scar 19 landslide.	Unpublished GSC data.

Scar 19, Breckenridge Valley	Brkwood10-1A	As above.	UCIAMS- 88814	1525 ± 15	1355-1509	GRB and BEM	Date derived from branch, ~1 cm diameter, situated about 20 cm above same well-defined layer of logs and woody debris, as above. Date inferred to represent maximum age for scar 19 landslide.	Unpublished GSC data.
Scar 19, Breckenridge Valley	Brkwood10-1D	As above.	UCIAMS- 88815	1565 ± 15	1409-1518	GRB and BEM	Date derived from branch, ~1 cm diameter, immediately overlying same well-defined layer of logs and woody debris, as above. Date inferred to represent maximum age for scar 19 landslide.	Unpublished GSC data.
Scar 22, Breckenridge Valley	Core Breck-27- 01A	N 45.4965° W 75.9278°	Beta- 139135	310 ± 40	297-478	JG and RM	Date derived from “mix of very small wood bits embedded in clay” sampled between 0.15-0.16 m depth in 0.37 m long core recovered from small pond on scar 22. Sample encapsulated by grey clay with silt clasts. Date represents minimum age for scar 22 landslide, but landslide may be significantly older.	Unpublished GSC data.
Unrelated to any landslide?	Breck-20-01	N 45.4926° W 75.9254°	GSC-6437	1220 ± 70 ^c	1061-1262	JG and RM	Date derived from barkless log, 25 cm diameter, sampled from a buried layer of woody debris within silt-clay sediment 2.5 m below top of bank and 0.5 m above the observed stream of tributary A. Relationship to any landslide scar along tributary A is uncertain.	Unpublished GSC data.

Mudflow deposit along lower reach of Breckenridge Creek	Breck-C-04A	N 45.4796° W 75.9456°	GSC-6313	1070 ± 50 ^e	931-1053	DEL and JG	Date derived from outer rings of 0.5 m diameter log of <i>Tsuga canadensis</i> (eastern Hemlock) ^f exposed by a recent slump along the lower portion of Breckenridge Creek, where stream is incised into terrace of ancestral Ottawa River. The solitary log was encapsulated by landslide debris and located ~2 m below top of ~7 m high bank. Date interpreted to represent maximum age of a mudflow that descended Breckenridge Creek.	Unpublished GSC data.
Mudflow deposit along lower reach of Breckenridge Creek	Breck-A-01	N 45.4803° W 75.9483°	GSC-6315	1060 ± 50 ^e	928-1052	DEL and JG	Date derived from log of <i>Tsuga canadensis</i> (eastern Hemlock) ^f protruding from a cutbank exposure along lower reach of Breckenridge Creek, as above. Sample was part of an “apparent horizon of organic material” overlain by “slide clay”, ~1 m below top of ~2 m high bank. Date interpreted to represent maximum age of a mudflow that descended Breckenridge Creek.	Unpublished GSC data.

- a JMA – Jan Aylsworth, GRB – Greg Brooks, JG – Joanna Guertin, RM – Rick McNeil, BEM – Barbara Medioli, DEL – Ted Lawrence.
- b Average of 2895 ± 20 (UCIAMS-88705) and 2850 ± 20 (UCIAMS-88819) yr BP which are duplicate measurements of same organic material.
- c Identified by A. Telka, Paleotec Services.
- d Average of 2855 ± 20 (UCIAMS-88706) and 2850 ± 15 (UCIAMS-88820) yr BP which are duplicate measurements of same organic material.
- e The uncertainty of the age is reported to two standard deviations.
- f Identified by C. Keith.

Luskville landslide, near Luskville, Quebec

The Luskville landslide is located ~1 km west of the village of Luskville, Municipality of Pontiac, immediately to the south of Highway 148, which parallels the head scarp (Fig. 5). The landslide retrogressed into a scarp slope that extends above a broad, flat terrace of the Ottawa River. The debris splayed onto this terrace forming a large, well-preserved, depositional lobe, indicating that the Ottawa River had abandoned this portion of the terrace prior to the failure. The eastern edge of the scar is situated immediately adjacent to a smaller, but older scar (of unknown age), the deposits from which have been truncated by river erosion. Table 12 lists three dates obtained from organic materials buried beneath the landslide debris that were recovered at a coring site located in the middle portion of the toe of the landslide debris (Fig. 5). Brooks (2013a) correlated the age of the Luskville landslide to nine other landslides in the Ottawa-Pontiac region (see Tables 9, 11, 13, 16, 17 and 18) and hypothesized that they represent evidence of a paleoearthquake at ~1020 cal BP.

Table 12 List of radiocarbon dates collected from the Luskville landslide, near Luskville, Quebec.

Location	Sample name/ number	Geographical coordinates	Laboratory number	Radiocarbon age (yr BP)	2 σ calibrated age range (cal yr BP)	Collector ^a	Comment	References
Luskville landslide, near Luskville, Quebec	BaieAA-01, Sample 1	N45.5353° W76.0306°	UCIAMS-122468	1095±20	959-1059	GRB	Wood fragment subsampled from the upper 3 cm of a 7 cm-thick buried organic layer contained in core sample between 5.98-6.05 m depth. Organic layer buried beneath soft landslide clay. Coring site situated ~5 m from core BaieAB-01. Date represents maximum age for Luskville landslide.	Brooks (2013a).
Luskville landslide, near Luskville, Quebec	BaieAB-01, Sample 3	As above	UCIAMS-122469	1120±15	976-1060	GRB	Eastern white cedar leafy shoot (<i>Thuja occidentalis</i>) ^b subsampled from the upper 1 cm of an 11 cm-thick buried organic layer contained in core sample between 5.89-6.0 m depth. Organic layer buried beneath soft landslide clay. Coring site situated ~5 m from core BaieAA-01. Date represents maximum age for Luskville landslide.	Brooks (2013a).

Luskville landslide, near Luskville, Quebec	BaieAB-01, Auger sample C	As above.	UCIAMS-122467	1100±15	963-1056	GRB	Twig fragment from buried organic material recovered in cuttings on auger blades. Inferred depth of organic layer is between 5.89-6.0 m depth, based on core log. Organic layer buried beneath soft landslide clay. Coring site situated ~5 m from core BaieAA-01. Date represents maximum age for Luskville landslide.	Brooks (2013a).
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a GRB – Greg Brooks
b Identified by A. Telka, Paleotec Services.

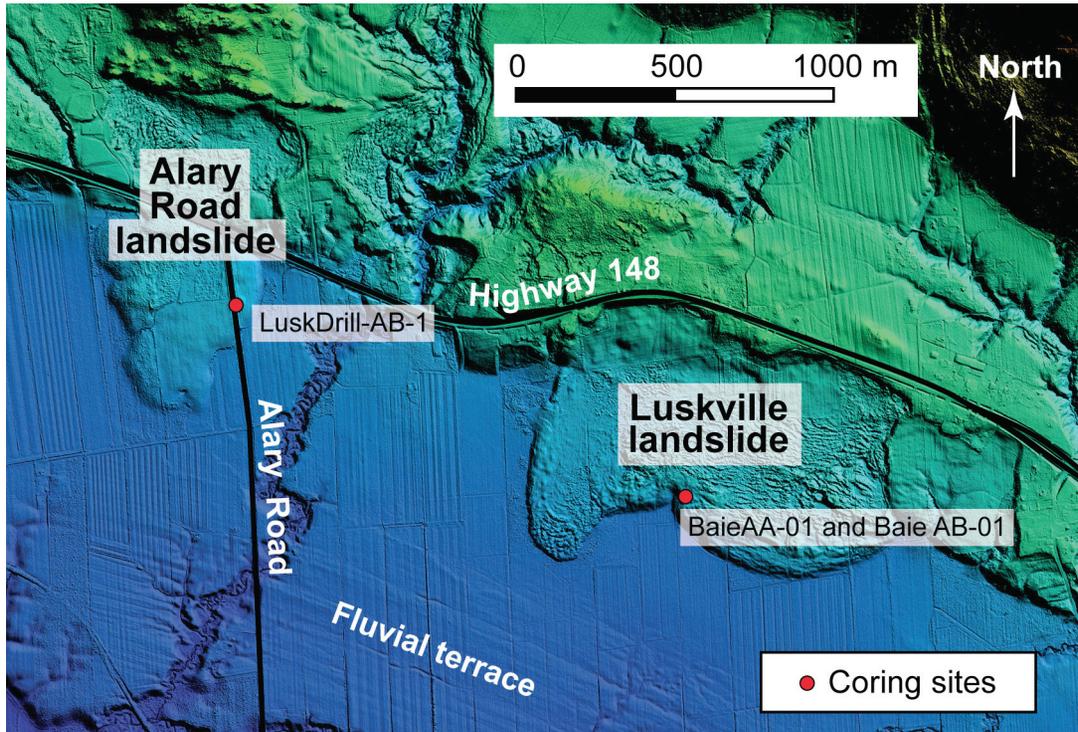


Fig. 5 Shaded relief map showing the coring sites on the Luskville (Table 12) and Alary Road (Table 13) landslides, near Luskville, Quebec.

Alary Road landslide, near Luskville, Quebec

The Alary Road landslide is located ~3 km west of the village of Luskville, Municipality of Pontiac (Fig. 1), and is crossed by Highway 148 and the northern portion of Alary Road (Fig. 5). The landslide retrogressed into a slope that forms a scarp above a broad, flat terrace of the Ottawa River. The debris splayed onto this terrace, forming a large, well-preserved lobe that indicates that the Ottawa River had abandoned this portion of the terrace prior to the failure. Table 13 lists three dates obtained from organic materials buried beneath the landslide debris that were recovered in core samples at a site along the eastern shoulder of Alary Road (Fig. 5). Brooks (2013a) correlated the age of the Alary Road landslide to nine other landslides in the Ottawa-Pontiac region (see Tables 9, 11, 12, 16, 17 and 18) and hypothesized that they represent evidence of a paleoearthquake at ~1020 cal BP.

Table 13 List of radiocarbon dates collected from the Alary Road landslide, near Luskville, Quebec.

Location	Sample name/ number	Geographical coordinates	Laboratory number	Radiocarbon age (yr BP)	2 σ calibrated age range (cal yr BP)	Collector ^a	Comment	References
Alary Road landslide, near Luskville, Quebec	LuskDrill-AB-1, 5.87-5.89 m depth	N45.5409° W76.0489°	UCIAMS-106656	1150 ± 15	982-1167	GRB	Date derived from wood fragment sampled between 5.87-5.89 m depth in 6.71 m long core sample recovered from near toe of landslide. Wood overlain by clay-rich landslide debris. Date represents maximum age for Alary Road landslide.	Brooks (2013a); Brooks and Crow, (2020)
Alary Road landslide, near Luskville, Quebec	LuskDrill-AB-1, 5.89-5.94 m depth	As above.	UCIAMS-106657	1145 ± 15	979-1166	GRB	Date derived from wood fragment sampled from buried organic-rich clay situated between 5.89-5.94 m depth in same core sample, as above. Date represents maximum age for Alary Road landslide.	Brooks (2013a); Brooks and Crow, (2020)
Alary Road landslide, near Luskville, Quebec	LuskDrill-AB-1, 6.17-6.20 m depth	As above.	UCIAMS-106658	1155 ± 15	985-1168	GRB	Date derived from isolated wood fragment sampled between 6.17-6.20 m depth in same core sample, as above. Date represents maximum age for Alary Road landslide.	Brooks (2013a); Brooks and Crow, (2020)

^a GRB – Greg Brooks

Eardley east landslide

The Eardley east landslide is located ~2 km west of Eardley, Municipality of Pontiac (Fig. 1) and is adjacent to the Eardley west landslide (Fig. 6). The landslide retrogressed about 220 m northwards into a scarp slope that forms the northern margin above a broad terrace of the Ottawa River. This is the westward extension of the same scarp into which the Alary and Luskville landslides retrogressed. Originating from a source area of 0.1 km², the debris field is splayed up to about 310 m onto the alluvial terrace (Fig. 6). The lobe is well-preserved and has not be truncated by fluvial erosion, indicating that the Ottawa River had abandoned had this portion of the terrace prior to the failure. Table 14 lists two dates obtained from organic materials sampled by the Ministère des Transports du Québec along an incised course of the small creek along the western side of the debris lobe (Fig. 6). There is an obvious discord between the two ages; the substantially younger ‘modern’ age is deemed unrepresentative of the landslide. The older age is inferred to represent a maximum age for the landslide. In 2011, the Geological Survey of Canada drilled two boreholes on the landslide debris lobe, but neither intersected a buried organic layer.

Table 14 List of radiocarbon ages from the Eardley east landslide, near Eardley, Quebec.

Location	Sample name/ number	Geographical coordinates	Laboratory number	C-14 age (yr BP)	2σ calibrated age range (cal yr BP)	Collector ^a	Comments	References
Eardley east landslide, near Eardley, Quebec	MTQ-EARD03-01 (wood)	N45.553863 ° W76.130177 °	UCIAMS-171460 (ULA-5946) ^b	1305±20	1177-1287	PL	Data derived from wood sampled at 0.5 m depth under the clay bed of a creek incised into the western side of the debris lobe, at the same location as below. Date represents a maximum age for the encapsulating mass movement deposits.	Unpublished data, Ministère des Transports du Québec
Eardley east landslide, near Eardley, Quebec	MTQ-EARD03-02 (wood)	As above	UCIAMS-171461 (ULA-5947) ^b	modern	na	PL	Data derived from wood sampled at 0.5 m depth under the clay bed of a creek incised into the western side of the debris lobe, at the same location as above. Date is unrepresentative of the landslide age.	Unpublished data, Ministère des Transports du Québec

^a PL – Pascal Locat, Ministère des Transports du Québec.

^b The second laboratory number is from Laval University (ULA) who pretreated the sample prior to radiocarbon analysis by the University of California Irvine Keck-CCAMS facility.

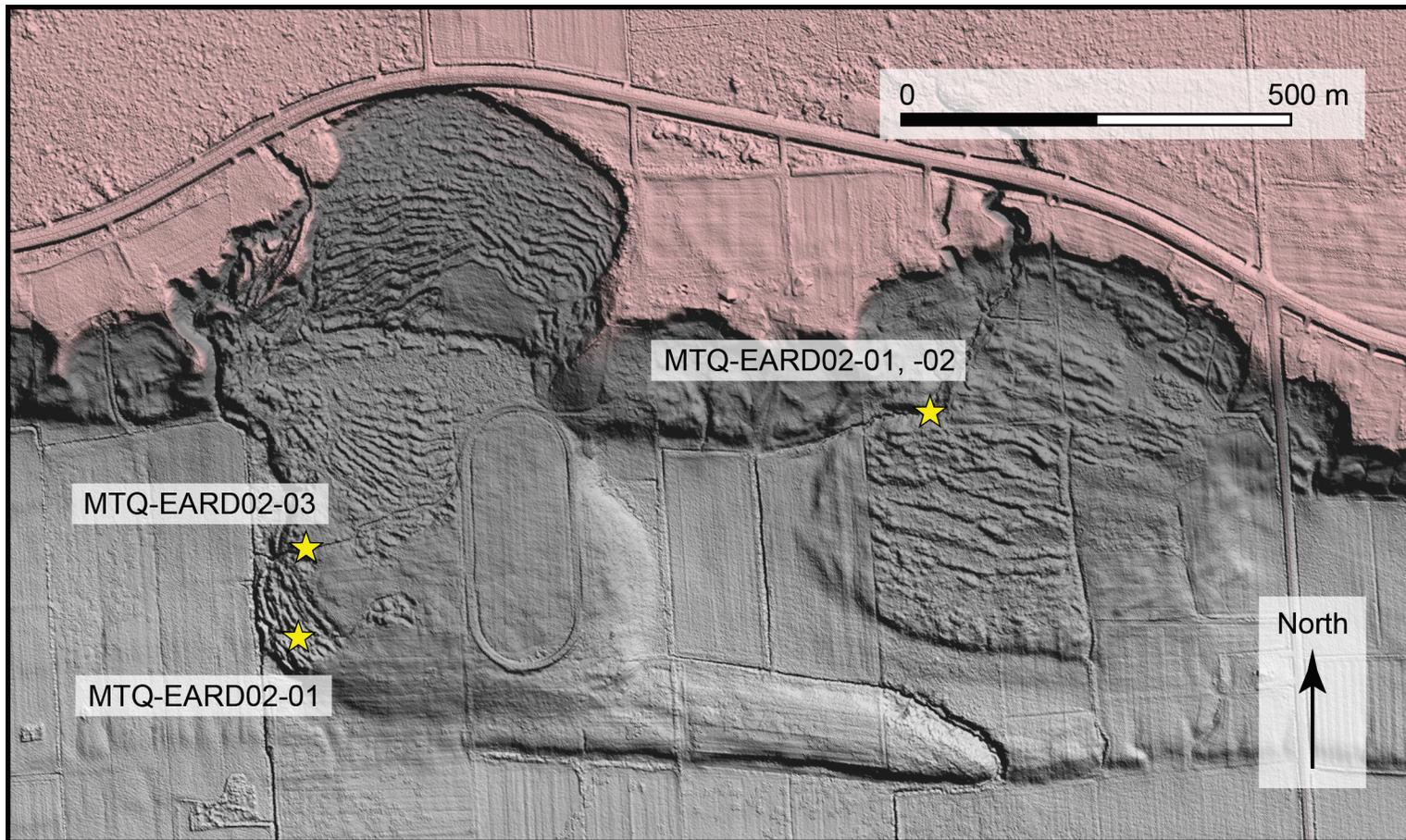


Fig. 6 Shaded relief map showing the locations of the radiocarbon date sampling sites on the Eardley east (right) and Eardley west (left) landslides, near Eardley, Quebec.

Eardley west landslide

The Eardley west landslide is located ~3 km west of Eardley, Municipality of Pontiac, and immediately to the west of the Eardley east landslide (Figs. 1 and 6). The landslide retrogressed about 390 m northwards into a scarp slope forming a source area of about 0.16 km². The debris field is splayed up to about 410 m onto an alluvial terrace, and has not been truncated by fluvial erosion. This well-preserved morphology indicates that the Ottawa River had abandoned this portion of the terrace prior to the failure. Table 15 lists two dates obtained from organic materials sampled by the Ministère des Transports du Québec along an incised small creek courses along the western side of the debris lobe (Fig. 6). The ages are very young and inferred to be unrepresentative of the landslide age; at the very least, both probably represent indirect, minimum ages for the landslide.

Table 15 List of radiocarbon ages from the Eardley west landslide, near Eardley, Quebec

Location	Sample name/ number	Geographical coordinates	Laboratory number	C-14 age (yr BP)	2σ calibrated age range (cal yr BP)	Collector ^a	Comments	References
Eardley west landslide, near Eardley, Quebec	MTQ-EARD02-01 (wood)	N45.551299° W76.140578°	UCIAMS-171459 (ULA-5944) ^b	220±15	1-303	PL	Data derived from wood sampled at 0.5 m depth under the clay bed of a creek incised into the western side of the debris lobe. Date probably represents an indirect, minimum age for the landslide.	Unpublished data, Ministère des Transports du Québec
Eardley west landslide, near Eardley, Quebec	MTQ-EARD02-03 (wood)	N45.552334° W76.140437°	UCIAMS-171459 (ULA-5945) ^b	185±20	1-289	PL	Data derived from wood sampled at 0.5 m depth under the clay bed of a creek incised into the western side of the debris lobe. Date probably represents an indirect, minimum age for the landslide.	Unpublished data, Ministère des Transports du Québec

^a PL – Pascal Locat, Ministère des Transports du Québec.

^b The second laboratory number is from Laval University (ULA) who pretreated the sample prior to radiocarbon analysis by the University of California Irvine Keck-CCAMS facility.

Quyón Valley landslide, Quyón, Québec

A large landslide source area, covering 28 km², extends along the lower ~11 km of Quyón Valley (Fig. 7). Geomorphic and chronological evidence presented by Brooks (2013a) and Brooks and Crow (2020) indicates that the scar is the site of a massive landslide, about 600 Mm³, which occurred at ~1020 cal BP. Brooks (2013a) correlated the age of the Quyón Valley landslide to nine other landslides in the Ottawa-Pontiac region (see Tables 9, 11, 12, 13, 17 and 18), and hypothesized that they represent evidence of a paleoearthquake at ~1020 cal BP. Table 16 lists 19 radiocarbon dates collected from within the landslide source and depositional areas; 17 of these are relevant to the age of the failure. Two additional dates are included that were collected from within the landslide scar, but interpreted by Brooks (2013a) to be substantially older and unrelated to the age of the massive landslide. The dates are organized by general location of collection area: lower scar zone, upper scar zone, depositional area, and wetland coring sites. The sample collection sites of all 19 dates are shown on Fig. 7.

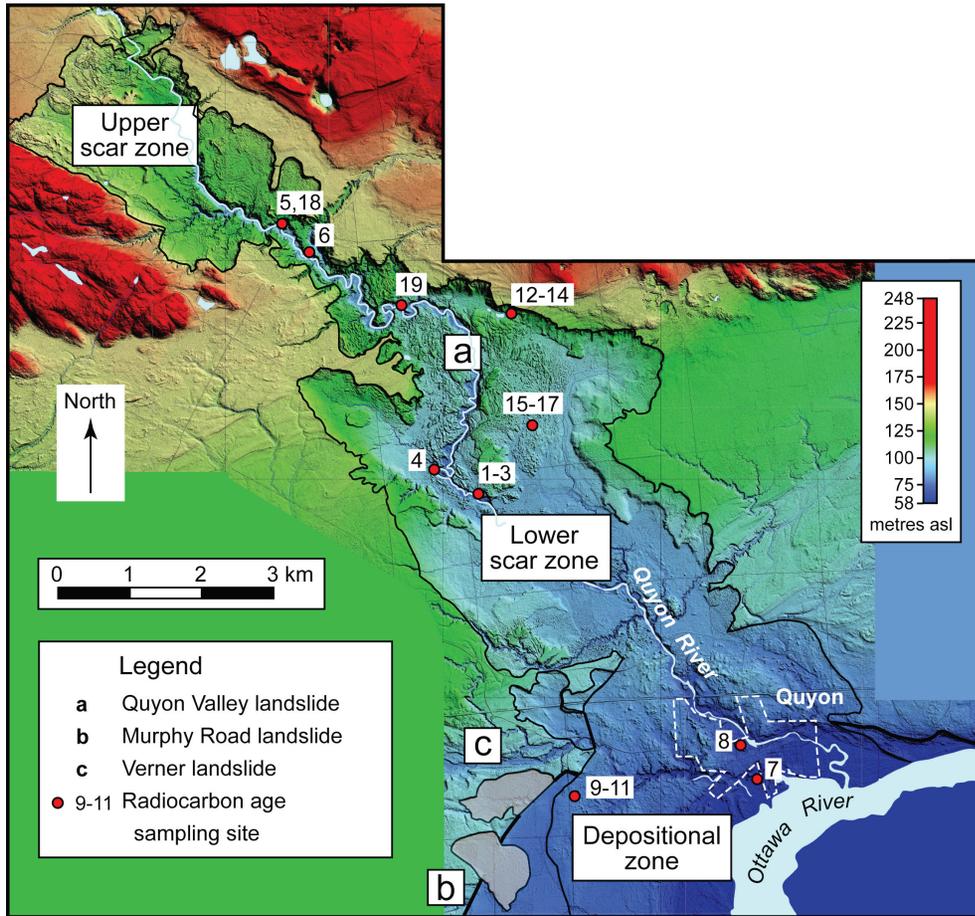


Fig. 7 Shaded relief map showing the sample locations within the upper and lower landslide scar zones, and depositional area of the Quyon Valley landslide (modified from Brooks, 2013). The radiocarbon age sampling site numbers are keyed to numbers listed under ‘Sample name/number’ column in Table 16. Also shown are the Murphy ‘b’ and Verner ‘c’ landslides for which dates are listed in tables 18 and 19.

Table 16 List of radiocarbon dates collected from the lower Quyon River valley, Quebec. Numbers listed under ‘Sample name/number’ are keyed to sample site locations shown on Fig. 7.

Location	Sample number/ name	Geographical coordinates	Laboratory number	Radiocarbon age (yr BP)	2 σ calibrated age range (cal yr BP)	Collector ^a	Comment	References
Lower scar zone, Quyon Valley landslide	1; QUY-AC-01	N 45.5519° W 76.2863°	UCIAMS-106587	1180 ± 20	1018-1173	GRB	Date derived from outer rings of log buried within a bank exposure along the Quyon River. Sampled portion of log covered by preserved bark that was freshly exposed by excavating into the bank. Log encapsulated by sand and associated with a buried, disoriented, paleosol layer located ~10 m below the top of ~16 m high bank. Date represents maximum age for Quyon Valley landslide.	Brooks (2013a).
Lower scar zone, Quyon Valley landslide	2; QUY-AC-02	As above.	UCIAMS-106645	1135 ± 15	979-1067	GRB	Date derived from outer rings of a second buried log at same location as above. Date represents maximum age for Quyon Valley landslide.	Brooks (2013a).
Lower scar zone, Quyon Valley landslide	3; QUY-AC-04	As above.	UCIAMS-106646	1130 ± 15	79-1064	GRB	Date derived from outer rings of buried root, ~5 cm diameter and with preserved bark, at same location as above. Date represents maximum age for Quyon Valley landslide.	Brooks (2013a).
Lower scar zone, Quyon Valley landslide	4; QUY-AL-01	N 45.5549° W 76.2941°	UCIAMS-106648	1350 ± 20	1264-1303	GRB	Date derived from outer rings of log buried ~2.5 m below top of ~20 m high bank exposure along Quyon River. Log encapsulated by sand and associated with a buried, disoriented, paleosol layer that dips across exposure surface. Modern roots picked from the sample prior to submission. Date represents maximum age for Quyon Valley landslide.	Brooks (2013a).

Upper scar zone, Quyon Valley landslide	5; QUY-BB-03	N 45.5848° W 76.3212°	UCIAMS-112434	1145 ± 20	977-1167	GRB	Date derived from outer rings of log, ~50 cm diameter, protruding from clay-rich deposit along Quyon River. Log buried ~29 m beneath top of ~30 m high bank. Sampled portion of log covered by preserved bark and was freshly exposed by excavating into the bank. Log stratigraphically overlies sample 18 (UCIAMS-112433; this table) which is located ~25 m downstream within same exposure. Date represents maximum age for Quyon Valley landslide.	Brooks (2013a).
Upper scar zone, Quyon Valley landslide	6; QUY-BD-01	N 45.5815° W 76.3161°	UCIAMS-112435	1185 ± 20	1059-1173	GRB	Date derived from outer rings of log, ~25 cm diameter, protruding from clay-rich deposit along Quyon River. Log buried ~22.5 m beneath top of ~23.5 m high bank. Sampled portion of log covered by preserved bark and was freshly exposed by excavating into the bank. Date represents maximum age for Quyon Valley landslide.	Brooks (2013a).
Depositional zone, Quyon Valley landslide	7; Vuori Log	N 45.5165° W 76.2373°	UCIAMS-106649	1215 ± 15	1069-1223	HV	Date derived from inner 35-40 rings of log, 13 cm diameter, recovered during winter of 1997 or 1998 from ditch excavated into wetland located within village of Quyon, at approximate level of modern Ottawa River floodplain. Log was one of several encountered in ditch, ~2 m below surface of wetland buried within clay-rich deposit. Date represents maximum age for Quyon Valley landslide.	Unpublished sketch by Hank Vuori; Brooks (2013a).

Depositional zone, Quyon Valley landslide	8; QUY-AA-01	N 45.5209° W 76.2407°	Beta-90879 ^b	1180 ± 60	967-1261	DG	Date derived from “carbonized wood fragments plus other unidentified plant matter”, ~ 1cm thick, from litter layer developed on cross-bedded, oxidized sand unit and overlain by internally-deformed, sand-clay mudflow bed, 2-3 m thick. Sampling site is a sand-clay pit within the village of Quyon. Underlying sand unit interpreted to be upper deposit of large block of intact Champlain Sea sediments rafted downvalley in Quyon Valley landslide that was capped by a thin mudflow deposit during transport. Date interpreted to represent maximum age for Quyon Valley landslide.	Aylsworth et al (1997); Brooks (2013a).
Depositional zone, Quyon Valley landslide	9; QuyDrill-AE-1	N 45.5145° W 76.2697°	UCIAMS-106653	1120 ± 15	976-1060	GRB	Date derived from wood fragment sampled between 3.20-3.25 m depth in 4.27 m long core sample recovered from western edge of depositional zone, just off Chemin Bronson-Bryant, near village of Quyon. Sample contained within clay-rich landslide debris and was situated 0.13 m above the upper of two wood/organic-rich layers, which are interpreted to represent the ground surface buried and presumably deformed beneath landslide debris. Date represents maximum age for Quyon Valley landslide.	Brooks(2013a).
Depositional zone, Quyon Valley landslide	10; QuyDrill-AE-1	As above.	UCIAMS-106654	1220 ± 20	1067-1237	GRB	Date derived from wood fragment sampled between 3.51-3.56 m depth in same core sample as above. Sample contained with the lower of two wood/organic-rich layers contained within core sample that represent surface buried and presumably deformed beneath landslide debris. Date represents maximum age for Quyon Valley landslide.	Brooks(2013a).

Depositional zone, Quyon Valley landslide	11; QuyDrill-AE-1	As above.	UCIAMS-106655	1160 ± 15	1000-1170	GRB	Date derived from wood fragment sampled between 3.63-3.66 m depth in same core sample as above. Wood contained within lower of two wood/organic-rich layers, as above. Date represents maximum age for Quyon Valley landslide.	Brooks(2013a).
Wetland 1, lower scar zone, Quyon Valley landslide	12; QuyCore-AB-1	N 45.5742° W 76.2803°	UCIAMS-106572	880 ± 20	733-901	GRB	Date derived from isolated wood fragment sampled between 0.73-0.75 m depth in 2.27 m long core sample recovered from wetland situated in depression between landslide deposits and side scarp, near Cain Lake. Sample encapsulated by sand and situated ~0.40 m below organic-rich sediment/sand interface. Date represents minimum age for Quyon Valley landslide.	Brooks(2013a).
Wetland 1, lower scar zone, Quyon Valley landslide	13; QuyCore-AB-2	N 45.5742° W 76.2802°	UCIAMS-106573	1005 ± 20	833-962	GRB	Date derived from conifer needles (larch, fir and pine) ^b sampled between 0.41-0.43 m depth in 1.56 m long core sample from same wetland as above. Sample encapsulated by sand and situated 0.12 m below organic-rich sediment/sand interface. Date represents minimum age for Quyon Valley landslide.	Brooks(2013a).
Wetland 1, lower scar zone, Quyon Valley landslide	14; QuyCore-AB-2	As above.	UCIAMS-106574	830 ± 20	692-779	GRB	Date derived from bark fragment sampled between 0.27-0.30 m depth in same core sample as above. Sample situated within lower 0.03 m of organic-rich sediment. Date represents minimum age for Quyon Valley landslide.	Brooks(2013a).

Wetland2, lower scar zone, Quyon Valley landslide	15; QuyCore-AF-1	N 45.5585° W 76.2777°	UCIAMS-106578	705 ± 15	656-679	GRB	Date derived from cedar leaves ^b sampled between 0.33-0.38 m depth in 1.48 m long core sample from wetland on landslide surface. Sample situated within lower 0.05 m of peat deposits that overlie soft, massive, clay deposit. Date represents minimum age for Quyon Valley landslide.	Brooks (2013a).
Wetland2, lower scar zone, Quyon Valley landslide	16; QuyCore-AF-1	As above.	UCIAMS-106579	630 ± 20	556-660	GRB	Date derived from five pine needles ^b sampled between 0.33-0.38 m depth in same core sample as above. Date represents minimum age for Quyon Valley landslide.	Brooks (2013a).
Wetland2, lower scar zone, Quyon Valley landslide	17; QuyCore-AF-1	As above.	UCIAMS-106580	600 ± 15	548-646	GRB	Date derived from bur marigold seeds ^b sampled between 0.33-0.38 m depth in same core as above. Date represents minimum age for Quyon Valley landslide.	Brooks (2013a).
Unrelated older age from Upper Scar Zone of Quyon Valley landslide.	18; QUY-BB-01	N 45.5848° W 76.3212°	UCIAMS-112433	3920 ± 20	4260-4423	GRB	Date derived from outer rings of log, 0.1 m diameter, buried ~28.5 m below top of ~30 m high bank exposed along Quyon River. Log encapsulated by deformed sand bed, 0.3-0.4 m thick, which contained other woody materials and logs. Sand bed overlain by thick clay-rich deposit. Sampled wood covered by preserved bark and was freshly exposed by excavating into the bank. Log stratigraphically underlies sample QUY-BB-03 (UCIAMS-112434) which is located ~25 m upstream within the same bank exposure. Date is substantially older than, and is interpreted to be unrelated to, the age of large Quyon Valley landslide.	Brooks (2013a).

Unrelated older age from Lower Scar Zone of Quyon Valley landslide.	19; QUY-AJ-01	N 45.5752° W 76.30°	UCIAMS- 106647	8630 ± 30	9534-9665	GRB	Date derived from <i>Abies</i> needles ^b (some charred) sampled from deformed organic-rich layer contained within sand dike injected into lower ~1 m of clay-rich block. Sampling site situated at head of gully ~9 m below top of 25 m high bank. Date is substantially older than, and interpreted to be unrelated to, the age of large Quyon Valley landslide.	Brooks (2013a).
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^a GRB – Greg Brooks, DG – Doug Grant; BEM – Barbara Medioli; HV – Hank Vuori
^b Identified by A. Telka, Paleotec Services.

Upper Quyon River landslide, ~10.3 km east-northeast of Shawville, Quebec

The upper Quyon River landslide is located along the Quyon River just north of the 8th Line between Smith and Thorne Lake roads, Municipality of Bristol, ~10.3 km east-northeast of Shawville, Quebec (Fig. 1). The failure resulted in a large ‘flake’ slide that translated to the northeast across the Quyon River valley (Fig. 8). Most of this block remained intact after transport; fractured blocks of debris are present between the intact slide block and the head scarp. Listed in Table 17 are three dates obtained from organic materials contained in core samples recovered from a wetland that formed between the intact slide block and head scarp (Fig. 8). Each date represents a minimum age for the failure. This landslide is distinctly separate and not to be confused with the massive Quyon Valley landslide, the scar of which is located ~1 km downstream (see Table 16). Brooks (2013a) correlated the age of the upper Quyon River landslide to nine other landslides in the Ottawa-Pontiac region (see Tables 9, 11, 12, 13, 16 and 18) and hypothesized that they represent evidence of a paleoearthquake at ~1020 cal BP.

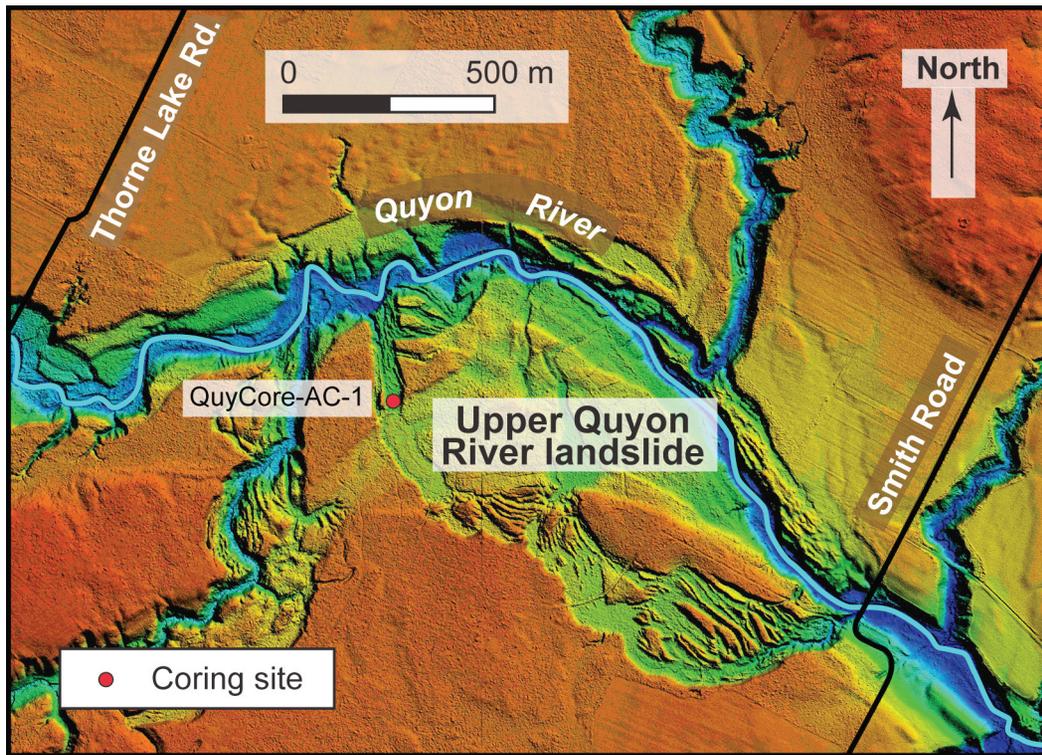


Fig. 8 Shaded relief map showing the coring site on the Upper Quyon River landslide.

Table 17 List of radiocarbon dates collected from the upper Quyon River landslide, Quebec.

Location	Sample name/ number	Geographical coordinates	Laboratory number	Radiocarbon age (yr BP)	2 σ calibrated age range (cal yr BP)	Collector ^a	Comment	References
Upper Quyon River landslide	QuyCore-AC-1, 0.61-0.63 m depth	N45.6192° W76.3719°	UCIAMS-106575	955 ± 15	797-926	GRB	Date derived from five needle pine needles ^b sampled between 0.61-0.63 m depth in 2.26 m long core recovered from wetland situated in zone between large, translated slide block and head scarp. Sample situated within lower 0.02 m of peaty deposits that overlie sand bed, ~0.1 m thick, and clay-rich sediment. Date represents minimum age for upper Quyon River landslide.	Brooks (2013a).
Upper Quyon River landslide	QuyCore-AC-1, 0.59-0.61 m depth	As above.	UCIAMS-106576	955 ± 15	797-926	GRB	Date derived from birch bracts and nutlets ^b sampled from 0.59-0.61 m depth in same core sample as above. Sample situated within peaty deposits, 0.02 to 0.04 m above interface with underlying sand bed, ~0.1 m thick, and clay-rich sediment. Date represents minimum age for upper Quyon River landslide.	Brooks (2013a).
Upper Quyon River landslide	QuyCore-AC-1, 0.59-0.61 m depth	As above.	UCIAMS-106577	970 ± 15	799-930	GRB	Date derived from fragments of five needle pine needles ^b sampled from 0.59-0.61 m depth in same core sample as above. Date represents minimum age for upper Quyon River landslide.	Brooks (2013a).

^a GRB – Greg Brooks

^b Identified by A. Telka, Paleotec Services.

Murphy Road landslide, near Quyon, Quebec

The Murphy Road landslide is located ~4 km west-southwest of the village of Quyon, Quebec, and just west of the margin of the Quyon Valley earthflow (Fig. 1). The landslide is crossed by the northern portion of Murphy Road and part of the 3rd Concession (Fig. 9). The landslide retrogressed into a steep-sided slope that forms a scarp along a broad terrace of the Ottawa River. The landslide debris splayed onto this terrace forming a large debris lobe, sometime after abandonment of the terrace surface by the Ottawa River. The three dates listed in Table 18 were obtained from organic materials buried beneath landslide debris that were recovered at two coring sites (Fig. 9). Brooks (2013a) correlated the age of the Murphy Road landslide to nine other landslides in the Ottawa-Pontiac region (see Tables 9, 11, 12, 13, 16 and 17) and hypothesized that they represent evidence of a paleoearthquake at ~1020 cal BP. The Verner landslide is located nearby (Table 19; Fig. 9).

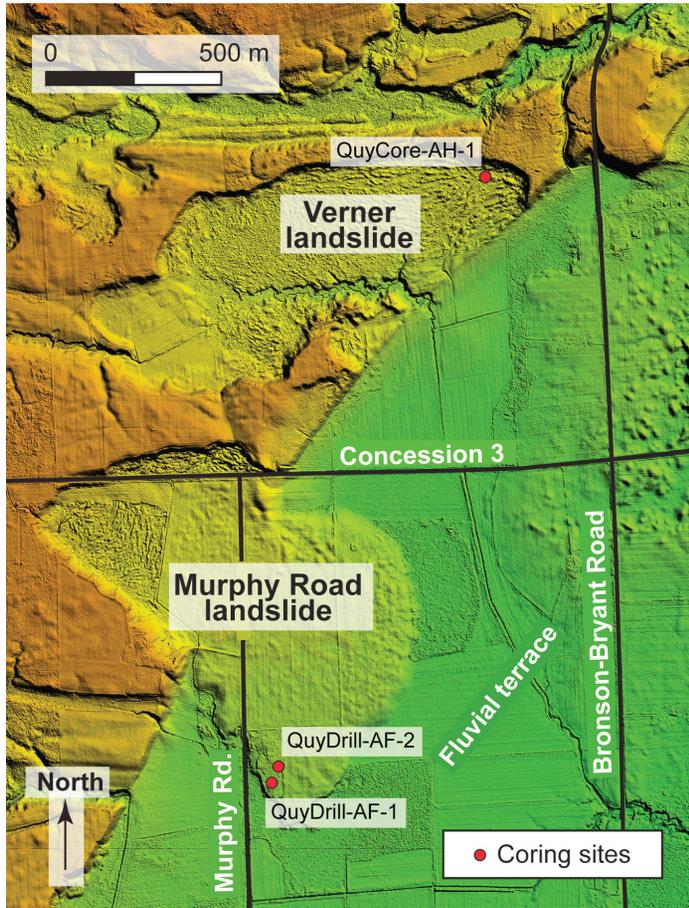


Fig. 9 Shaded relief map showing the coring locations on the Murphy Road and Verner landslides, near Quyon, Quebec. The hummocky area in the right-centre of the map is a portion of the debris field from the Quyon Valley landslide (see Fig. 9).

Table 18 List of radiocarbon dates collected from the Murphy Road landslide, near Quyon, Quebec.

Location	Sample name/ number	Geographical coordinates	Laboratory number	Radiocarbon age (yr BP)	2 σ calibrated age range (cal yr BP)	Collector ^a	Comment	References
Murphy Road landslide, near Quyon, Quebec	QuyDrill-AF-1, 4.17-4.27 m depth	N45.5014° W76.2826°	UCIAMS-106650	1145 ± 20	977-1167	GRB	Date derived from branch/twig fragment sampled from buried organic-rich layer situated between 4.17-4.27 m depth in 4.88 m long core sample recovered near edge of landslide debris splayed onto terrace of Ottawa River. Organic-rich layer overlain by clay-rich landslide debris. Date represents maximum age for Murphy Road landslide.	Brooks (2013a); Brooks and Crow, (2020)
Murphy Road landslide, near Quyon, Quebec	QuyDrill-AF-1, 4.17-4.27 m depth	As above.	UCIAMS-106651	1140 ± 15	978-1077	GRB	Date derived from bark fragment sampled from same buried organic-rich layer, as above. Date represents maximum age for Murphy Road landslide.	Brooks (2013a); Brooks and Crow, (2020)
Murphy Road landslide, near Quyon, Quebec	QuyDrill-AF-2, 4.83-4.88 m depth	N45.5018° W76.2823°	UCIAMS-106652	1145 ± 20	977-1167	GRB	Date derived from wood fragment sampled from the upper of two organic layers buried between 4.83-4.88 m and 5.0-5.05 m depth in 5.49 m long core sample, recovered from edge of landslide, near same site mentioned above. Organic-rich layers overlain by sand and clay-rich landslide debris. Date represents maximum age for Murphy Road landslide.	Brooks (2013a); Brooks and Crow, (2020)

^a GRB – Greg Brooks

Verner landslide, near Quyon, Quebec

The Verner landslide is located ~3 km west-southwest of the village of Quyon, Quebec (Fig. 1). The failure retrogressed into a steep-sided scarp forming the margin of a broad terrace of the Ottawa River (Fig. 9). Landslide debris flowing from the scar undoubtedly splayed onto the adjacent terrace surface, but debris is truncated across the base of the scarp by erosion from the Ottawa River (Fig. 9). Table 19 lists three dates obtained from organic materials collected in core samples recovered from a post-failure wetland that developed between ridges on the scar (Fig. 9). All three dates represent minimum ages for the Verner landslide. The Murphy Road landslide is located nearby (Table 18; Fig. 9).

Table 19 List of radiocarbon dates collected from the Verner landslide, near Quyon, Quebec.

Location	Sample name/ number	Geographical coordinates	Laboratory number	Radiocarbon age (yr BP)	2 σ calibrated age range (cal yr BP)	Collector ^a	Comment	References
Verner landslide, near Quyon, Quebec	Quycore- AH-1, 0.42-0.47 m depth	N 45.5170° W 76.2747°	UCIAMS- 106581	5830 ± 20	6563-6727	GRB	Date derived from 'aged' root fragment ^b sampled between 0.42-0.47 m depth in 1.65 m long core sample recovered from elongated wetland located between ridges within landslide source area. Sample situated within the lower 0.05 m of peaty wetland deposits that overlie organic-stained clay, and clay and sand landslide debris. Date represents minimum age for the Verner landslide.	Brooks and Crow, (2020)
Verner landslide, near Quyon, Quebec	Quycore- AH-1, 0.47 m depth	As above.	UCIAMS- 106582	5790 ± 25	6503-6659	GRB	Date derived from wood fragment sampled at 0.47 m depth within same core sample as above. Date represents minimum age for the Verner landslide.	Brooks and Crow, (2020)

Verner landslide, near Quyon, Quebec	Quycore-AH-1, 0.42-0.50 m depth	As above.	UCIAMS-106583	5740 ± 20	6473-6632	GRB	Date derived from birch(?) twig ^b sampled between 0.47-0.50 m depth in same core sample as above. Sample situated within organic-stained clay sediment several cm above landslide debris. Date represents minimum age for the Verner landslide.	Brooks and Crow, (2020)
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^a GRB – Greg Brooks
^b Identified by A. Telka, Paleotec Services.

Heath Road landslide, Quebec

The Heath Road landslide is located 5.5 km south of Shawville, Quebec, along the southern most section of Heath Road (Fig. 10). The landslide source area is situated along a creek valley immediately upstream of the scarp slope that extends along the north side of the Ottawa River, into which numerous landslides have retrogressed (e.g., Murphy Road and Verner landslides). The failure retrogressed into the western side of the valley, forming a source area 1100 m wide, 440 m deep, and about 0.5 km² in area. Just beyond the mouth of the incised creek valley, a debris field is splayed onto a terrace of the Ottawa River below the level of the mapped terrace II surface (Fig. 10). This debris field is inferred to have originated from the Heath Road landslide source area. It is not clear from the topography if the debris field is completely or partly preserved.

Table 20 lists three dates collected from the debris field area that represent maximum ages for the Heath Road landslide. Two of the dates (UCIAMS-122453 and UCIAMS-122454) are from the outer rings of two adjacent tree trunks that are protruding through a creek bed (Fig. 10). The tree trunks are interpreted to be part of a forest growing on the terrace of the Ottawa River that was buried by landslide debris. The trees were later exhumed by incision of the creek course into the landslide debris. The third date (UCIAMS-122466) is from wood recovered in the cuttings on auger blades from the coring site shown on Fig. 10. This sample is inferred to originate 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 event.

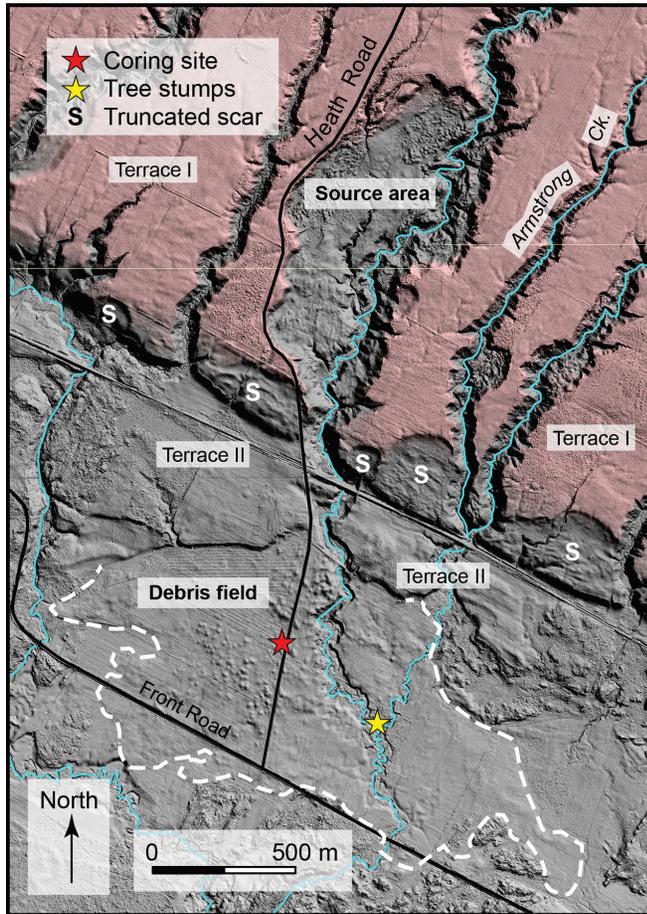


Fig. 10 Shaded relief map of the source area and debris field of the Heath Road landslide, and the locations of the tree trunk protruding through the incised creek course and a coring site. Note, the five truncated scars of older, undated landslides that retrogressed into scarp slope at the edge of terrace I.

Table 20 List of radiocarbon ages from Heath Road landslide, Quebec.

Location	Sample name/ number	Geographical coordinates	Laboratory number	Radiocarbon age (yr BP)	2 σ calibrated age range (cal yr BP)	Collector ^a	Comments	Reference
Heath Road landslide, near Shawville, Quebec	HeathAE-01	N 45.54619° W 76.52599°	UCIAMS-122453	5745±20	6484-6633	GRB	Date derived from outer rings of a tree trunk, ~27 cm diameter, protruding through bed of Heath Creek. Sampling site on tree trunk was situated ~5 cm above observed water surface. Sampled wood was exposed subaerially, but sound, well preserved, and without visible contamination. Sampled tree is one of two tree trunks located ~1 m apart. Date represents maximum age for the Heath Road landslide.	Brooks and Crow (2020)
Heath Road landslide, near Shawville, Quebec	HeathAE-02	As above.	UCIAMS-122454	5700±20	6412-6539	GRB	Date derived from outer rings of tree trunk, ~45 cm diameter, protruding through bed of Heath Creek. Sampling site on tree trunk was situated ~40 cm below channel bed, covered by bark, and buried in clay. Sampled tree is second of two tree trunks located ~1 m apart. Date represents maximum age for the Heath Road landslide.	Brooks and Crow, (2020)
Heath Road landslide, near Shawville, Quebec	Core HeathAF-01, Auger sample B	N 45.54853° W 76.53015°	UCIAMS-122466	5760±20	6496-6634	GRB	Date derived from wood fragment subsampled from buried organic material recovered in cuttings on auger blades of drill rig. Organic layer situated between 6.43-6.48 m deep, and buried beneath clay landslide debris. Date represents maximum age for the Heath Road landslide.	Brooks and Crow, (2020)

^a GRB – Greg Brooks

Daly Creek landslide complex, near Farrellton, Quebec

Daly Creek drains westerly from the east side of the Gatineau Valley; its confluence with the Gatineau River is located about 1.3 km south of the bridge crossing at Farrellton, Quebec (Fig. 11). The Daly Creek landslide complex (2.4 km²) consists of two landslide zones (labeled debris fields 'A' and 'B' in Fig. 11) that are separated by a bedrock constriction in the valley bottom. Debris field A is the larger zone, covering 1.5 km² relative to the 0.9 km² area of the 'T'-shaped, upvalley, debris field B. Four elongated sub-source areas extend off the southern side of the debris field A, while an elongated sub-source area extends about 1 km southward in zone B. All of the radiocarbon ages are from sampling sites located within debris field A (Fig. 11).

Daly-AE sampling site Table 21 lists four samples of organic materials collected from the Daly-AE sampling site (Fig. 11), where three mass movement deposits are exposed (referred to as the lower, middle, and upper mass movement units). Three samples were collected from a buried, continuous, paleosol-woody layer situated about 5.0 m below the top of the 13.1 m high valley side, and yielded ages ranging between 5050-5440 cal BP (UCIAMS-137113, -137114, and -137115). These dates represent maximum ages for the directly overlying middle mass movement unit that forms much of the upper part of the valley-side exposure, and indirect minimum ages for the underlying, lower mass movement unit. A charcoal fragment sampled from a charcoal layer, which underlies the upper mass movement unit forming the upper ~2.1 m of the valley side, yielded a fourth radiocarbon age of 5320-5460 cal BP (UCIAMS-137116; Table 21). This age represents a maximum age for the upper unit. The slightly older age of the charcoal sample, compared to the three stratigraphically lower ages, is consistent with the intermediate and upper mass movement units being approximately the same age.

Daly-AB sampling site Two of the dated organic samples collected at the Daly-AB sample site are from a disoriented, organic layer buried within a mass movement deposit near the base of the 13.9 m high, valley side (Fig. 11). The layer presumably represents a paleosol on an intact clay sediment clast (or block) contained within the mass movement deposit that forms the lower 9.2 m of valley side. The dates, ranging between 5040-5430 cal BP (UCIAMS-137108 and -137109; Table 21), represent maximum ages for the encapsulating (lower) mass movement deposit at this site. A third date (5300-5450 cal BP; UCIAMS-137110) is from a buried charcoal layer, located 4.7 m below the top of the valley side, that is overlain by a second mass movement deposit. This date represents a maximum age for the second mass movement deposits at this location. The slightly older age of the charcoal sample than the two stratigraphically lower ages is consistent with the two mass movement deposits at the Daly-AB site being approximately the same age.

The youngest of the two lower dates from Daly-AB (UCIAMS-137109) is close in age to the youngest of the three ages (UCIAMS-137113) from the lower paleosol layer at Daly-AE (Table 21), which may indicate that the middle Daly-AE and lower Daly-AB mass movement beds are extensions of the same deposit. The upper mass movement deposits at both sampling sites may also be extensions of a common deposit, but this is not well supported by ages derived from charcoal samples (UCIAMS-137110 and -137116) that are slightly older than stratigraphically lower ages at each sampling site. The dates from Daly-AE and -AB, however, are consistent with the broad surface of debris field A being the product of a major failure between 5040-5310 cal BP.

Daly-AC sampling site The Daly-AC sampling site is located along an aggradational terrace situated within the stream-cut valley incised by Daly Creek into debris field A (Fig. 11). Table 21 lists three dated organic samples collected from a woody debris layer exposed at the base of a cut bank, and directly overlain by a mass movement deposit. Each date represents a maximum age for the mass movement deposit. The three samples yielded similar radiocarbon ages, ranging between 730-890 cal BP (UCIAMS-137110, -137111, and -137121; Table 21), indicating that the overlying mass movement deposit is late Holocene in age. The apparent source of the mudflow deposit is the middle of three well-defined, elongated scars along the southern side of the debris field A. The landslide debris lobe extends from the middle scar to the stream-cut river valley and downstream across the location of the Daly-AC sampling site.

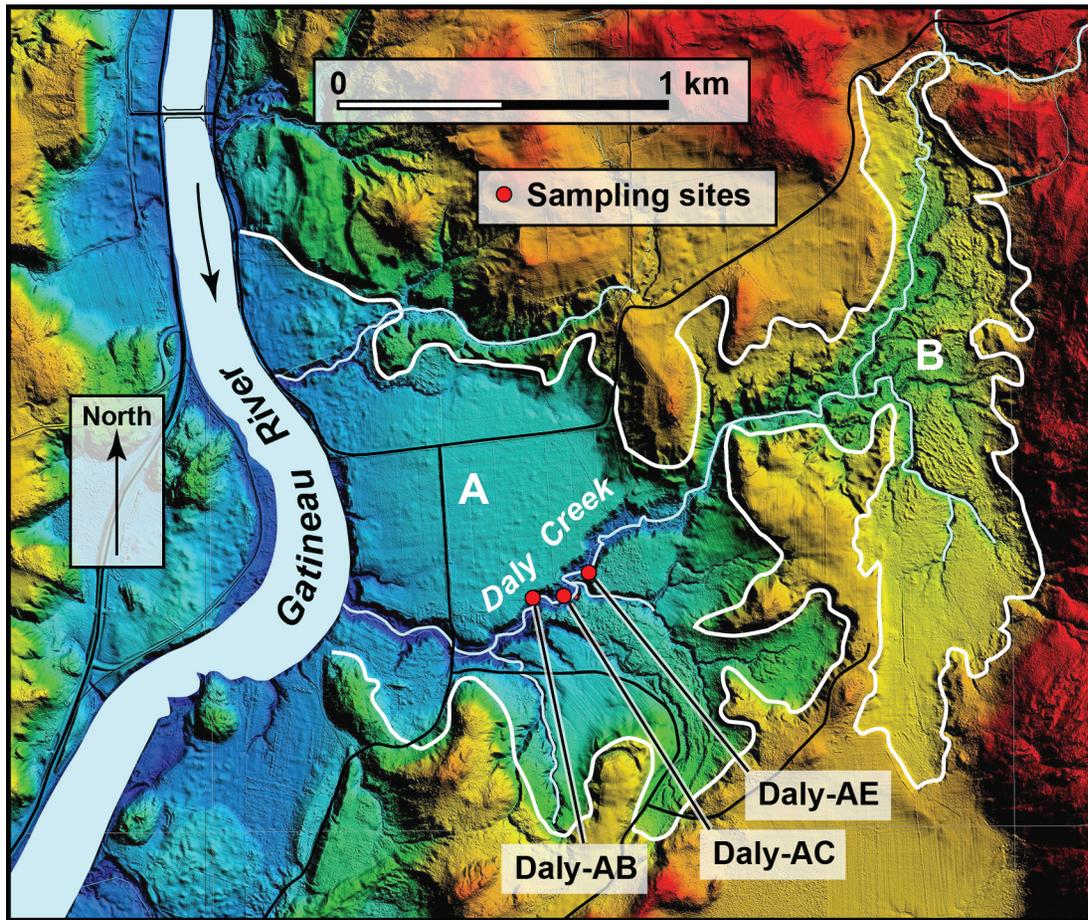


Fig. 11 Shaded relief map of the Daly Creek landslide complex along the Gatineau Valley, Quebec, showing the locations of the Daly-AB, -AC and -AE sampling sites. The landslide debris occurs in two zones (labeled “A” and “B” that are separated by a narrow bedrock constriction.

Table 21 List of radiocarbon ages from the Daly Creek landslide complex, near Farrellton, Gatineau River valley, Quebec.

Location	Sample name/ number	Geographical coordinates	Laboratory number	Radiocarbon age (yr BP)	2 σ calibrated age range (cal yr BP)	Collector ^a	Comments	Reference
Sample site Daly-AE, Daly Creek landslide complex, near Farrellton, Quebec	Daly- AE-a01	N45.72574° W75.89151°	UCIAMS- 137113	4525±20	5053-5305	GRB	Date derived from a well-preserved twig, several centimetres long and 0.2-0.3 cm diameter, sampled from buried paleosol-organic layer, 2-3 cm thick, situated ~5.0 m below top of the 13.1 m high valley side. The paleosol underlies a middle mass movement deposit forming the upper part of the bank, and in turn overlies a lower mass movement deposit. Date represents maximum age for the overlying, middle, mass movement deposit at the sampling site, and a minimum age for the underlying (lower) one.	Unpublished GSC data.
Sample site Daly-AE, Daly Creek landslide complex, near Farrellton, Quebec	Daly- AE-a02	As above	UCIAMS- 137114	4565±25	5066-5436	GRB	Date derived from wood of bark-covered branch, 1-2 cm thick and ~20 cm long, sampled from same paleosol-organic layer and same approximate location as Daly-AE-a01 sample. Date represents maximum age for the overlying, middle, mass movement deposit at the sampling site, and a minimum age for the underlying (lower) one.	Unpublished GSC data.

Sample site Daly-AE, Daly Creek landslide complex, near Farrellton, Quebec	Daly- AE-a04	As above	UCIAMS- 137115	4575±25	5075-5441	GRB	Date derived from well-preserved, bark-covered twig, 0.5 cm diameter and 8 cm long, sample from same paleosol-organic layer as samples Daly-AE-a01 and -a02, but about 0.5 m away laterally. Date represents maximum age for the overlying, middle, mass movement deposit at the sampling site, and a minimum age for the underlying (lower) one.	Unpublished GSC data.
Sample site Daly-AE, Daly Creek landslide complex, near Farrellton, Quebec	Daly- AE-b07	As above	UCIAMS- 137116	4660±20	5317-5464	GRB	Date derived from charcoal fragment sampled from charcoal-rich layer situated ~2.1 m below top of valley side. Charcoal layer only observed across ~5 m long length of bank. Date represents maximum age for the upper mass movement deposit at the sampling site.	Unpublished GSC data.
Sample site Daly-AB, Daly Creek landslide complex, near Farrellton, Quebec	Daly- AB-a02	N45.72506° W75.89370°	UCIAMS- 137108	4570±20	5077-5432	GRB	Date derived from well-preserved twig, 7 cm long and 0.5 cm diameter situated at top of compressed, 3-4 cm thick, organic layer present within 0.1 m of observed water surface at base of 13.9 m high valley side exposure along Daly Creek. Layer was oriented vertically and presumably is part of rip-up clast within the mass movement deposit forming at least the lower 9.2 of valley side. Date represents maximum age for encapsulating mass movement deposit.	Unpublished GSC data.

Sample site Daly-AB, Daly Creek landslide complex, near Farrellton, Quebec	Daly- AB-a03	As above	UCIAMS- 137109	4485±20	5043-5286	GRB	Date derived from well-preserved, cedar (<i>Thuja occidentalis</i> ^b) cone scales from one cone sampled from upper 1 cm of same compressed, 3-4 cm thick, organic layer, as above. Date represents maximum age for encapsulating mass movement deposit.	Unpublished GSC data.
Sample site Daly-AB, Daly Creek landslide complex, near Farrellton, Quebec	Daly- AB-b01	As above	UCIAMS- 137110	4605±25	5295-5447	GRB	Date derived from charcoal fragment sampled from charcoal layer, up to 1 cm thick and situated 4.7 m below the top of the valley side. The layer extends at least 20 m laterally across exposure at sampling site. Date represents maximum age for overlying mass movement deposit.	Unpublished GSC data.
Sample site Daly-AC, Daly Creek landslide complex, near Farrellton, Quebec	Daly- AC-01	N45.72511° W75.89251°	UCIAMS- 137111	875±20	731-900	GRB	Date derived from well-preserved, bark-covered branch, 7 cm long and 0.5 cm diameter, sampled from top of a woody debris layer (several logs and abundant branches, twigs and wood fragments) contained in top of sand and gravel deposit located at base of cut bank along Daly Creek. Woody debris and, sand and gravel deposit extends across ~8 m of bank and forms lower ~0.2 m of 3.3 m high terrace; an overlying mass movement deposit forms the remaining height of the terrace. Date represents a maximum age for the overlying mass movement unit.	Unpublished GSC data.

Sample site Daly-AC, Daly Creek landslide complex, near Farrellton, Quebec	Daly- AC-02	As above	UCIAMS- 137121	875±20	731-900	GRB	Date derived from well-preserved, bark- less, branch, 6 cm long and 1.5 cm diameter, sampled from top of the same woody debris layer as above. Date represents a maximum age for the overlying mass movement deposit.	Unpublished GSC data.
Sample site Daly-AC, Daly Creek landslide complex, near Farrellton, Quebec	Daly- AC-03	As above	UCIAMS- 137112	860±20	726-892	GRB	Date derived from well-preserved, bark- less, branch, 5 cm long and 2 cm diameter, sampled from the top of same woody debris layer as above. Date represents a maximum age for the overlying mass movement deposit.	Unpublished GSC data.

^a GRB – Greg Brooks
^b Identified by Paleotec Services.

Mullin Creek landslide area, Quebec

Mullin Creek is a westerly-flowing tributary of the Gatineau River; their confluence is located ~6.5 km upstream of the Highway 366 (Chemin Edelweiss) bridge at Wakefield, Quebec (Fig. 1). A large landslide area, about 4.5 km long, up to 2 km wide, and about 4.5 km² in area, extends along the lower portion of the creek (Fig. 12). It is unclear if the majority of the landslide area is the product of one or possibly several large-scale failures. There is an approximately 8 m high step in the downvalley profile of the debris field (marked by a dashed line in Fig. 12), located 0.9 to 1.2 km from the Gatineau River. The areas above and below the step are designated debris fields 'A' and 'B', respectively in Fig. 12, but it is not known if these are similar or distinctly different in age. Six elongated sub-scars have retrogressed from the main landslide area along the north and south-sides of the landslide area. A lobe of landslide debris originating from a northern sub-scar is mapped as debris field 'C' in Fig. 12. This deposit is inferred to be superimposed on debris field B. A well-defined, secondary failure along Mullin Creek, which retrogressed up to 175 m across a distance of about 840 m wide, is inset into the surfaces of the debris fields B and C (see area 'D' in Fig. 12).

Table 22 lists two sets of radiocarbon-dated organic materials that are relevant to the ages of debris field C and landslide D. Relating to debris field C, four dated samples are from a core sample recovered from a wetland located on the surface of the debris field (MulCore-AB, Fig. 12). The yielded ages range between 500-1180 cal BP (UCIAMS-137104 to -137107). All four represent minimum ages for the underlying debris field C. Situated at an approximately similar depth in the core sample, the two deepest and oldest dates best represent the age of debris field C (UCIAMS-137104 and UCIAMS-137105), which was deposited at or before 960-1180 cal BP. This age range is also an indirect minimum age for the much larger debris field B that underlies debris field C.

Three wood samples collected from a buried paleosol-organic layer exposed within landslide area D each yielded ages up to 281 cal BP (UCIAMS-137101 to -137103; Table 22). All represent maximum ages for the landslide, and indicate that the landslide of area D happened in the very late Holocene, and possibly historically.

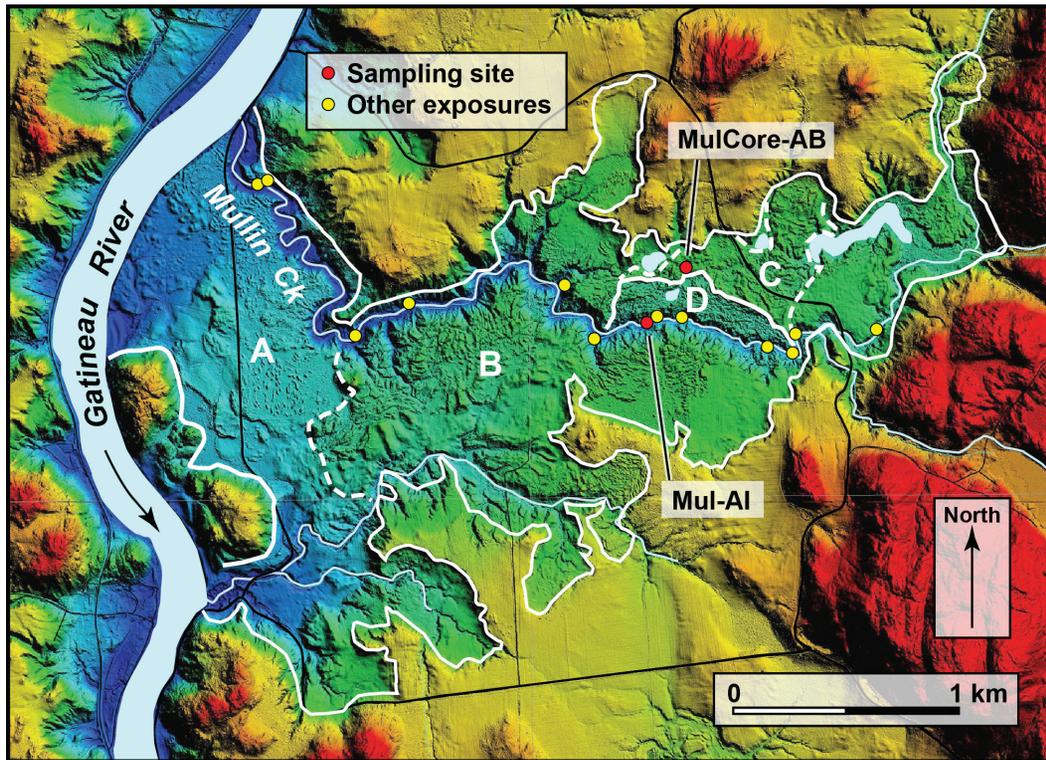


Fig. 12 Shaded relief map of the Mullin Creek landslide area along the Gatineau Valley, Quebec, showing the Mul-AI and MulCore-AB sampling locations. Two major zones of the landslide debris field are labeled ‘A’ and ‘B’, and separated by a dashed line. A smaller portion of the debris field is thought to have originated from an arcuate scar on the north side of the landslide area, and is labeled ‘C’. A secondary landslide that is inset into debris fields B and C is labeled as ‘D’.

Table 22 List of radiocarbon ages from the Mullin Creek landslide area, Gatineau Valley, Quebec.

Location	Sample name/ number	Geographical coordinates	Laboratory number	Radiocarbon age (yr BP)	2 σ calibrated age range (cal yr BP)	Collector ^a	Comments	Reference
Landslide area D, Mullin Creek Valley, Quebec	Mul-AI-03	N45.69436° W75.89958°	UCIAMS-137101	90±20	31-256	GRB	Date derived from well-preserved, bark-less, branch fragment, 5 cm long and ~1 cm diameter, sampled from a buried paleosol-organic layer, situated 4.5 m above observed surface of Mullin Creek and approximately 10 m below top of incised valley side. Paleosol-organic layer is buried by clay deposits inferred to be directly associated with landslide area D, as the overlying slope of valley side is steep and lacks evidence of major secondary slumping. Sampled within about 20 cm of samples -04 and -05. Date represents a maximum age for landslide D.	Unpublished GSC data.
Landslide area D, Mullin Creek Valley, Quebec	Mul-AI-04	As above	UCIAMS-137102	100±20	27-259	GRB	Date derived from outer several rings of well-preserved, bark-covered, branch fragment, 3 cm long, sampled from same buried paleosol-organic layer as above. Sampled within about 20 cm of samples -03 and -05. Date represents a maximum age for landslide area D.	Unpublished GSC data.
Landslide area D, Mullin Creek Valley, Quebec	Mul-AI-05	As above	UCIAMS-137103	145±25	5-281	GRB	Date derived from well-preserved fragment of tree branch, 4 cm long and 1.5 cm diameter, encapsulated in clay and situated several centimetres above same buried paleosol-organic layer as above. Sampled within about 20 cm of samples -03 and -04. Date represents a maximum age for landslide area D.	Unpublished GSC data.

Landslide area C, Mullin Creek Valley, Quebec	MulCore-AB-70-72cm	N45.69655° W75.89730°	UCIAMS-137107	475±20	503-533	GRB	Date derived from outer rings of wood situated between 0.70-0.72 m depth in 1.24 m long core sample recovered from wetland on debris field C. The wetland is located in a depression on surface of debris field C. Date represents minimum age for debris field C.	Unpublished GSC data.
Landslide area C, Mullin Creek Valley, Quebec	MulCore-AB-100cm	As above	UCIAMS-137106	400±20	334-508	GRB	Date derived from wood fragment (root?), 8 cm long, encapsulated within stiff clay at 1.0 m depth in same 1.24 m long core sample as above. Date represents minimum age for debris field C.	Unpublished GSC data.
Landslide area C, Mullin Creek Valley, Quebec	MulCore-AB-106cm	As above	UCIAMS-137105	1185±20	1060-1177	GRB	Date derived from wood fragment situated within humic organic layer ~1 cm thick at 1.06 m depth in same 1.24 m long core sample as above. Date represents minimum age for debris field C.	Unpublished GSC data.
Landslide area C, Mullin Creek Valley, Quebec	MulCore-AB-108cm	As above	UCIAMS-137104	1105±20	964-1057	GRB	Date derived from aged root, 4 cm long and ~0.3 cm thick, situated within stiff clay at 1.08m depth in same 1.24 m long core sample as above. Date represents minimum age for debris field C.	Unpublished GSC data.

^a GRB – Greg Brooks

Stag Creek landslide complex. Low, Quebec

Stag Creek is an easterly-flowing tributary of the Gatineau River that passes through the village of Low, Quebec (Fig. 13). A major landslide complex, ~10.1 km long, up to 1.6 km wide, and covering ~11.6 km², extends along the lower course of Stag Creek and into the Gatineau River valley (Fig. 13). The scale and characteristics of the debris field within the landslide complex are consistent with a large-scale failure(s) occurring within the upper and central portion of the valley. However, there are a number of elongated scar features extending from the margins of the landslide area, as well as, the localized occurrences of levees and debris lobes within the debris field. Collectively, these are suggestive of multiple, separate, smaller-scale failures also occurring, particularly in the lower portion of the complex. Fifteen samples of organic materials collected from three sampling sites yielded radiocarbon ages that provide insights into the chronology of three mass movement deposits within the Stag Creek landslide complex.

Low12/Low13-AA sampling site The Low12/Low13-AA sampling site is located 200 m downstream of the Chemin Fieldville bridge crossing of Stag Creek, about 2.5 km above the Stag-Gatineau confluence (Fig. 13). Within the head scarp of a recent slump, minor excavating revealed a buried, well-preserved, organic layer forming the top of a paleosol, 10-12 m below the top of the valley-side. Four samples from the organic layer yielded radiocarbon ages ranging between 800-960 cal BP that provide maximum ages for the overlying mass movement deposit (Table 23; UCIAMS-122455, -122456, -137099, and -137099). This deposit is inferred to have originated from the north-side of Stag Creek valley, where two elongated landslide scars are present (Fig. 13). Clasts of clay suspended within a clay matrix underlie the paleosol layer represent an older mass movement deposit of unknown age. Deformed and tilted laminated clay deposits are present along the bed of Stag Creek in the area of the slump that may be an extension of this lower deposit.

Low12/Low13-AB sampling site The Low12/Low13-AB sampling site is located immediately downstream of the confluence with Creek 'B', about 5.8 km above the Stag-Gatineau confluence (Fig. 13). Mass movement deposits forming two stratigraphic units of markedly different age are present in the ~12 m high cut-bank exposure (units II and IV; Fig. 14). The lower mass movement deposit (unit II) varies in character across the 30 m wide exposure. On the upstream (left) portion of the exposure, the deposit is at least 3 m thick and extends beneath the observed Stag Creek water surface. In 2012 and 2013, abundant woody debris was contained within the lower 0.5 m of mass movement clay. On the downstream (right) portion of the exposure, the deposit is ~1.5 m thick and directly overlies a buried paleosol and associated organic layer (layer 'A'; Fig. 14). The paleosol is developed on fluvial sediments of unit I, both of which are present only in this part of the bank (undoubtedly it is truncated erosively). Two samples of the woody debris of unit II and three wood samples from organic layer A

yielded similar radiocarbon ages, ranging between 5070 to 5300 cal BP (UCIAMS-122457; -122458, -122460, -122461 and-122462; Table 23). All of the dates represent maximum ages for the unit II mass movement deposit, and confirm an age congruency of unit II across the exposure. The age of unit II is best represented by the three youngest radiocarbon ages (UCIAMS-122457; -122458 and-122462). Unit II is overlain by stratified fluvial deposits (unit III) interpreted to represent restored fluvial sedimentation in the valley bottom following the deposition of the unit II mass movement. The surface of unit III eventually stabilized, allowing an organic layer and paleosol (layer 'B') to form (Fig. 12).

The unit IV mass movement deposit forms the upper portion of the bank, is 8-10 m thick, and directly overlies a buried paleosol and associated organic layer developed on unit III (layer B in Fig. 14). Three samples from organic layer B yielded radiocarbon ages ranging between 980-1170 cal BP (UCIAMS- 122459, -137097 and -137098; Table 23) that represent maximum ages for the unit IV mass movement deposit. These ages are close to, but significantly older than those from Low12/13-AA (800-960 cal BP), and indicate these two late Holocene mass movement deposits are the product of failures of different ages.

The origin of the unit IV deposit is unclear, but presumably is from a local source, as it has only been identified at the Low12/Low13-AB sampling site. The debris possibly originated from the elongated landslide scar immediately to the west of the sampling site, or from the Creek B watershed to the north (Fig. 13).

Low12-AE sampling site Situated at a recent bank slump, the Low12-AE sampling site is located about 800 m west of the Low12/Low13-AB site, and about 6.6 km above the Stag-Gatineau confluence (Fig. 13). In 2012, the upper 9 m of the 21 m high valley side was exposed, consisting of massive and deformed clay, and several blocks of tilted, laminated clay deposits. A high-angle shear plane with buried organic materials separated two clay blocks in the upper 7 m of the exposure. Three wood samples were collected from the upper part of the exposure; two from within the shear zone and a third from within a deformed, buried, organic layer located about 10 m away. These samples yielded radiocarbon ages ranging between 5050 to 5570 cal BP (UCIAMS-122463, -122464 and -122465; Table 23), and represent maximum ages for the encapsulating mass movement deposits.

The mass movement deposit containing the three Low12/13-AE dates underlie an extension of the highest level of a major debris field surface within the middle and upper areas of the Stag Creek landslide complex. The youngest of these dates (UCIAMS-122464) indicates that this mass movement occurred roughly between 5053 to 5299 cal BP. This age range is essentially identical to

the two youngest ages from the unit II mass movement deposit at Low12/13-AB (UCIAMS-122457 and -122458; Table 23). It is inferred that extensions of the same mass movement deposit are present at both sites, and this deposit originated from a major failure within the Stag Creek landslide complex, occurring between 5070-5300 cal BP. This hypothesis needs confirmation from additional chronological and stratigraphic evidence.

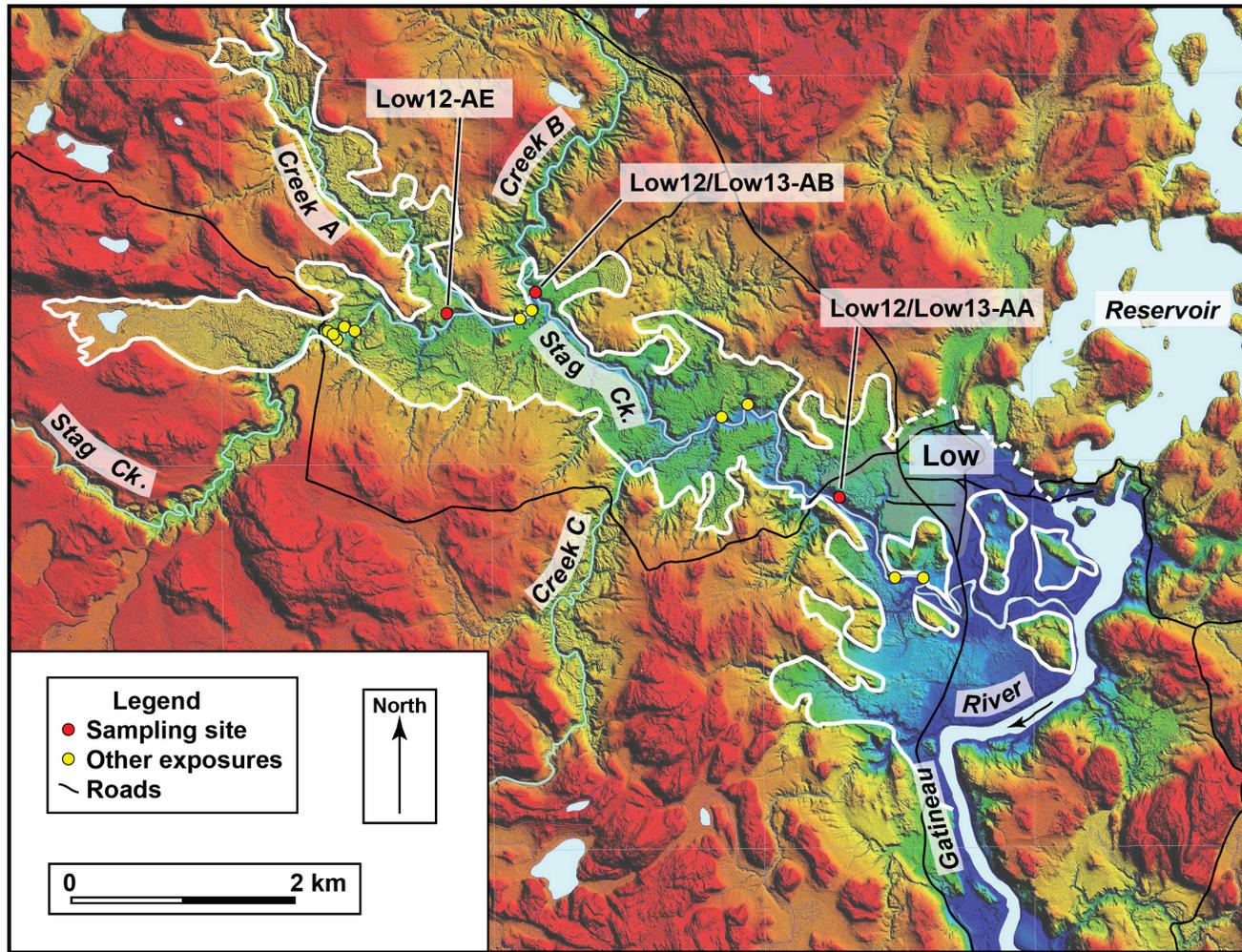


Fig. 13 Map of the Stag Creek landslide complex at Low, Quebec, showing the location of the three sampling sites. Also shown are other exposures that lacked buried organic materials relevant to the age of the landslide complex.

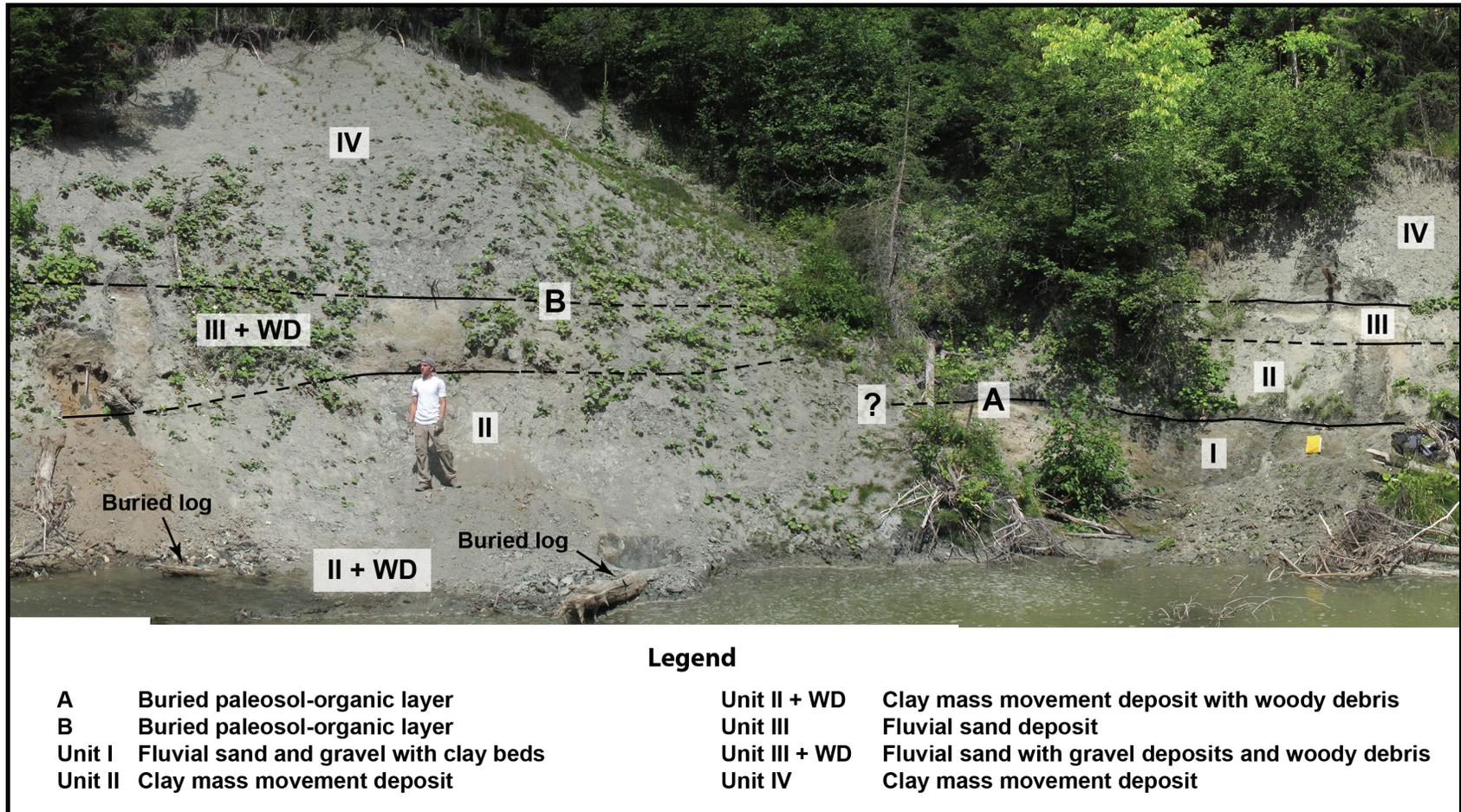


Fig. 14 Photomosaic of the Low12/Low13-AB bank exposure showing the four stratigraphic units and two buried paleosol-organic layers; Stag Creek flows from left to right and a person provides scale. Units II and IV are mass movement deposits. Note, the two logs protruding from the unit II deposits at the base of the bank. Photograph by G.R. Brooks. NRCan photo 2020-846

Table 23 List of radiocarbon ages from the Stag Creek valley landslide complex, near Low, Quebec.

Location	Sample name/ number	Geographical coordinates	Laboratory number	C-14 age (yr BP)	2 σ calibrated age range (cal yr BP)	Collector ^a	Comments	References
Exposure at site of recent slump along Stag Creek, ~200 m downstream of the Chemin Fieldville bridge, Low, Quebec	Low12-AA-01	N45.80960° W75.95983°	UCIAMS-122455	940±15	795-919f	GRB	Date derived from fragments of charred and uncharred red pine needles (<i>Pinus resinosa</i>) ^b subsampled from a buried, slightly-defined, paleosol-organic layer exposed within headscarp area of recent slump along the incised course of Stag Creek. Paleosol developed on older mass movement deposit. Sampling location situated 11.8 m below top of bank and 8.3 m above observed water surface of Stag Creek. Paleosol is overlain by intact, back-tilted block of glaciomarine sediments associated with a mass movement within Stag Creek valley thought to have originated from an elongated landslide scar(s) north of the sampling site. Date represents a maximum age for the overlying mass movement deposit, and indirect minimum age for underlying mass movement deposit.	Unpublished GSC data.
Exposure at site of recent slump along Stag Creek, ~200 m downstream of the Chemin Fieldville bridge, Low, Quebec	Low12-AA-03	As above.	UCIAMS-122456	940±15	795-919	GRB	Date derived from well-preserved branch, 0.5-1.5 cm diameter with discontinuous bark cover, sampled from the same buried paleosol-organic layer as above. Date represents a maximum age for the overlying mass movement deposit, and indirect minimum age for underlying mass movement deposit.	Unpublished GSC data.

Exposure at site of recent slump along Stag Creek, ~200 m downstream of the Chemin Fieldville bridge, Low, Quebec	Low13-AA-02	As above	UCIAMS-137099	995±20	803-958	GRB	Date derived from well-preserved, small branch, ~5 cm long and 0.3 cm diameter, sampled from the same buried paleosol-organic layer as above. Date represents a maximum age for the overlying mass movement deposit, and indirect minimum age for underlying mass movement deposit.	Unpublished GSC data.
Exposure at site of recent slump along Stag Creek, ~200 m downstream of the Chemin Fieldville bridge, Low, Quebec	Low13-AA-03	As above	UCIAMS-137100	965±20	798-930	GRB	Date derived from well-preserved, small branch, ~6 cm long and 0.25 cm diameter with bark cover, sampled from same buried paleosol-organic layer as above. Date represents a maximum age for the overlying mass movement deposit, and indirect minimum age for underlying mass movement deposit.	Unpublished GSC data.
Valley-side exposure along Stag Creek at confluence with Creek B	Low12-ABc-02	N45.82627° W75.99484°	UCIAMS-122459	1155±20	983-1170	GRB	Date derived from branch, ~1 cm diameter, sampled from paleosol-organic layer contained within a bank exposure (layer 'B' on Fig. 12). Buried organic layer extends continuously and quasi-horizontally across the bank and includes an <i>in situ</i> stump, woody and humic organic matter. Layer is situated 3.8 m above observed water surface of Stag Creek, and overlain by unit IV mass movement deposit that forms the upper 8-10 m of the bank (Fig. 12). Date represents maximum age for the overlying unit IV mass movement deposit.	Unpublished GSC data.

Valley-side exposure along Stag Creek at confluence with Creek B	Low13-ABc-10	As above.	UCIAMS-137097	1175±25	1004-1178	GRB	Date derived from well-preserved, aged-root, ~1.5 cm diameter, partially covered with bark. Occasional modern roots in sample removed or avoided during sample preparation. Sampled from same buried organic layer 'B' as above, but from site located ~10 m upstream. Date represents maximum age for the overlying unit IV mass movement deposit.	Unpublished GSC data.
Valley-side exposure along Stag Creek at confluence with Creek B	Low13-ABc-12	As above.	UCIAMS-137098	1145±25	976-1173	GRB	Date derived from well-preserved, aged root, ~2 cm diameter and covered with bark, sampled from same buried paleosol-organic layer 'B' and location as immediately above. Date represents maximum age for the overlying unit IV mass movement deposit.	Unpublished GSC data.
Valley-side exposure along Stag Creek at confluence with Creek B	Low12-ABa-01	As above.	UCIAMS-122457	4560±20	5070-5317	GRB	Date derived from branch fragment, ~1 cm diameter with preserved bark, sampled from unit II clay deposit at base of bank exposure along Stag Creek (see Fig. 12). Sample is part of zone of concentrated detrital organic material (large and small logs, wood fragments, branches, and leaves) suspended in unit II mass movement clay deposit. Detrital organic zone situated 1.5-12 m below top of bank at approximately the observed water surface of Stag Creek. Date represents maximum age for the encapsulating unit II mass movement deposit.	Unpublished GSC data.
Valley-side exposure along Stag Creek at confluence with Creek B	Low12-ABa-02	As above.	UCIAMS-122458	4540±20	5057-5312	GRB	Date derived from branch fragment, ~1 cm diameter with discontinuous preserved bark, sampled from same concentrated detrital organic material suspended in unit II mass movement clay deposit as above (see Fig. 12). Date represents maximum age for encapsulating unit II mass movement deposit.	Unpublished GSC data.

Valley-side exposure along Stag Creek at confluence with Creek B	Low12-ABd-02	As above.	UCIAMS-122460	4685±20	5322-5570	GRB	Date derived from well-preserved, aged-root ^a , ~0.3 cm diameter, situated at the top of paleosol-organic layer 'A', developed on unit I fluvial sediments along right (downstream) portion of bank exposure (Fig. 12). The organic layer A is situated approximately 10-11 m below top of bank and ~2 m above the observed Stag Creek water surface. The layer is overlain by the unit II clay mass movement deposit, ~1.5 m thick. Date represents a maximum age for the overlying unit II mass movement deposit.	Unpublished GSC data.
Valley-side exposure along Stag Creek at confluence with Creek	Low12-ABd-03	As above.	UCIAMS-122461	4685±20	5322-5570	GRB	Date derived from well-preserved, aged-root ^b , ~1 cm diameter, contained within the same buried paleosol-organic layer 'A' as above. Date represents a maximum age for the overlying unit II mass movement deposit.	Unpublished GSC data.
Valley-side exposure along Stag Creek at confluence with Creek B	Low12-ABd-05	As above.	UCIAMS-122462	4562±20	5072-5430	GRB	Date derived from outer portion of well-preserved, bark-covered, tree trunk, ~10 cm diameter, associated with same buried paleosol-organic layer 'A' as above. Date represents a maximum age for the overlying unit II mass movement deposit.	Unpublished GSC data.
Exposure at site of recent valley-side slump along Stag Creek	Low12-AE-03	N 45.82450° W 76.00497°	UCIAMS-122463	4685±20	5322-5570	GRB	Date derived from well-preserved, aged-root ^b , 1.5 cm diameter, contained within discontinuous, deformed, and tilted paleosol-organic layer buried within mass movement debris. Layer situated ~4 m below top of bank and 17 m above observed Stag Creek water surface. Date represents a maximum age for the encapsulating mass movement deposit.	Unpublished GSC data.

Exposure at site of recent valley-side slump along Stag Creek	Low12-AE-04	As above.	UCIAMS-122464	4515±20	5053-5299	GRB	Date derived from branch, ~1.5 cm diameter and partly covered with bark, situated within shear zone between intact blocks within mass movement debris. Sample was part of woody and humic material that occurs sporadically along shear zone. Sample location ~6 m below top of bank and 15 m above Stag Creek water surface. Date represents a maximum age for the encapsulating mass movement deposits.	Unpublished GSC data.
Exposure at site of recent valley-side slump along Stag Creek	Low12-AE-06	As above.	UCIAMS-122465	4660±20	5317-5465	GRB	Date derived from well-preserved twig, ~0.5 cm diameter and encapsulated with organic detritus, from same shear zone and approximate depth as above. Date represents a maximum age for the encapsulating mass movement deposits.	Unpublished GSC data.

^a GRB – Greg Brooks
^b Identified by Paleotec Services.

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