Trip A-3

THE 1993 LEMIEUX LANDSLIDE AND MER BLEUE BOG, SOUTHEASTERN ONTARIO, CANADA

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SECTION 1. THE LEMIEUX LANDSLIDE

Marine silts and clays were deposited through much of the St. Lawrence and Ottawa Valleys during the incursion of the Champlain Sea. These clays, known in Canada as Leda clay and in the U.S. as Massena clay, are sensitive to disturbance and prone to low-angle slope failure despite the muted topography of the area. Landslides have been occurring in the Ottawa Valley (Figure 1) since the recession of the Champlain Sea at about 10 ka (Aylsworth *et al.*, 2000). Several of these landslides have resulted in significant loss of life and property damage. Geotechnical testing for slope stability and landslide potential led to the abandonment of the 28 homes making up the community of Lemieux in 1991. Only 2 years later, on June 20, 1993, a large (17 ha) retrogressive landslide occurred near the former townsite. The landslide occurred within the scar of an earlier rotational failure, and widened through lateral spreading and subsidence, translation, and rotation of blocks separated from the side walls. About 2.8 million cubic meters of debris flowed into the South Nation River valley, extending for several kilometers up and downstream. Since the landslide, the site has changed considerably owing to erosion of the sides of the crater, erosion and revegetation of spoil piles, and the incision of the river into the debris. This field trip (Figure 2) visits the landslide scar and will discuss the conditions that led to these low-angled failures. An additional stop will be made at Mer Bleue, one of the largest ombrotrophic peatlands in southern Canada. This bog has developed in a former channel of the Ottawa River, and in places is underlain by Champlain Sea sediments.

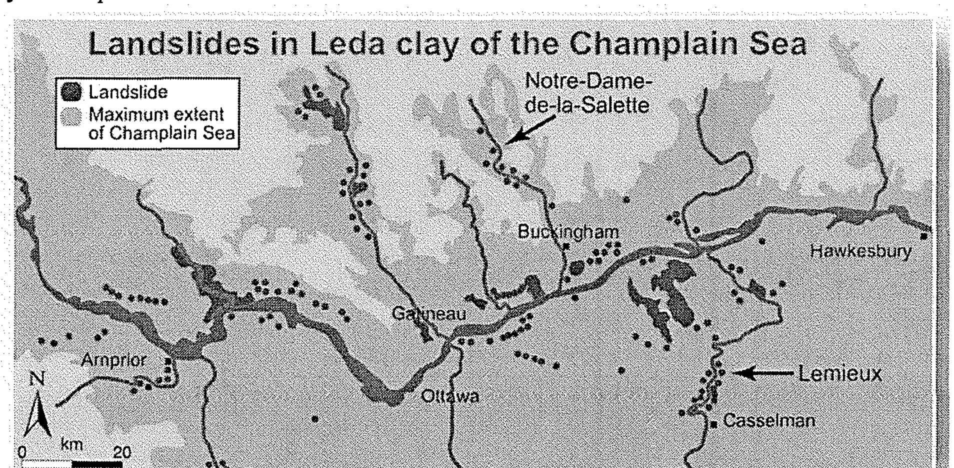

Figure 1. The maximum extent of the Champlain sea and the distribution of landslides in Leda clay. More than 250 landslides, historical and ancient, have been identified within 60 km of Ottawa. Figure from Natural Resources Canada.

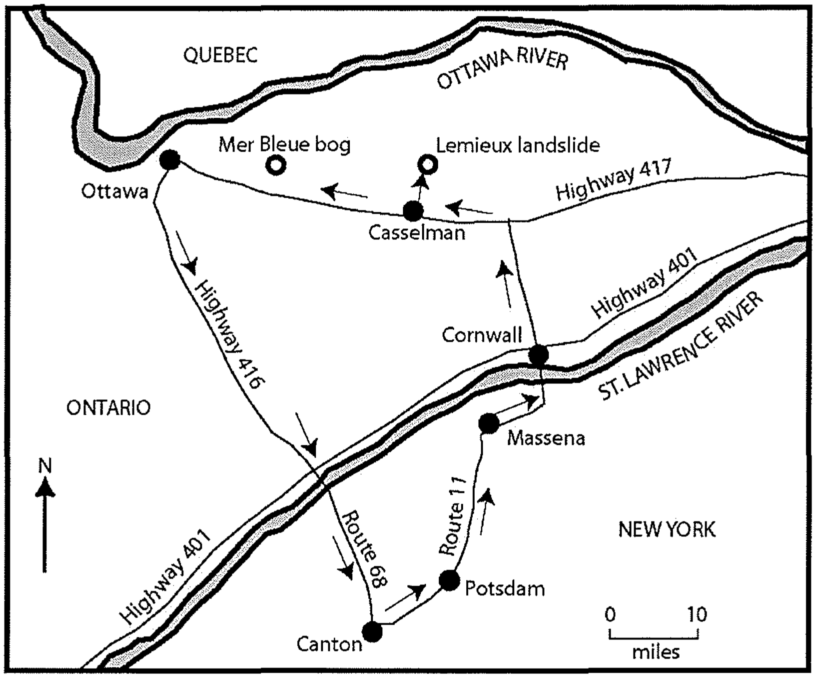

Figure 2. Field trip route to the Lemieux landslide and Mer Bleue, Ontario.

SURFICIAL GEOLOGY OF THE OTTAWA VALLEY

The Ottawa Valley is largely underlain by Paleozoic sedimentary rock that lie in a northwest-trending graben with uplifted Precambrian bedrock to the north in Quebec, and to the south in Ontario. Quaternary infilling consists primarily of a thin till overlain in places by glaciofluvial deposits of silt, sand, and gravel (stratigraphic unit A in Figure 3). Overlying the glaciofluvial sediments is a thin layer of freshwater, commonly varved, fine-grained sediments.

Depression of the Ottawa and St. Lawrence vallies by up to 200 m was caused by ice loading during the last glaciation. The retreating ice margin to the north resulted in the brief impoundment of a freshwater glacial lake and the deposition of a rhythmite series overlying glaciofluvial sediments. A marine inlet called the Champlain Sea occupied this depressed area starting at about 11.4 ka BP (Rodrigues, 1988) (Figure 4). Gadd (1986), and Fransham and Gadd (1977) indicate that the lowest depositional unit of this marine incursion consisted of weakly stratified clay and silty marine clays. Subsequent regressive deposition resulted in a coarsening-upwards sequence grading from marine to estuarine to freshwater sediments (Unit B in Figure 3). The freshwater sediments are overlain by interbedded silt and fine-grained sand deltaic sands (Unit C). The Champlain Sea had retreated from the Ottawa valley by about 10 ka owing to ongoing isostatic rebound. Many low-lying areas, especially those in former channels of the proto-Ottawa River, were subsequently filled with organics. Mer Bleue bog is one of the largest of these ombrotrophic peatlands.

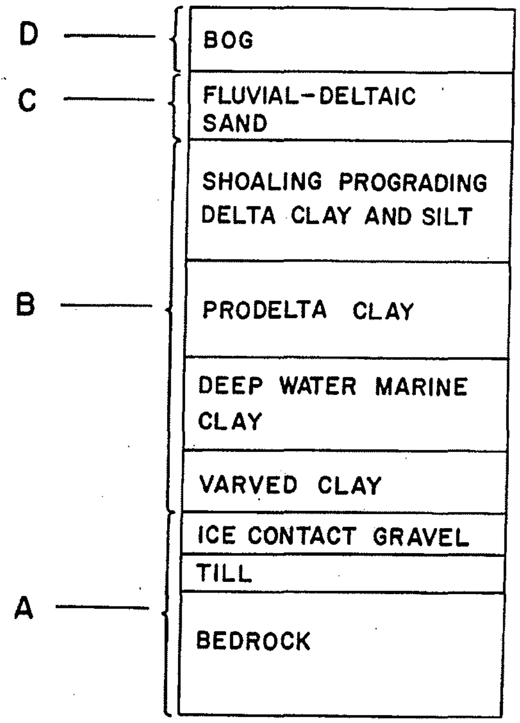

Figure 3. Generalized Quaternary stratigraphic units in the Ottawa Valley. Note that not all units are present at all sites. Figure from Fransham and Gadd (1977).

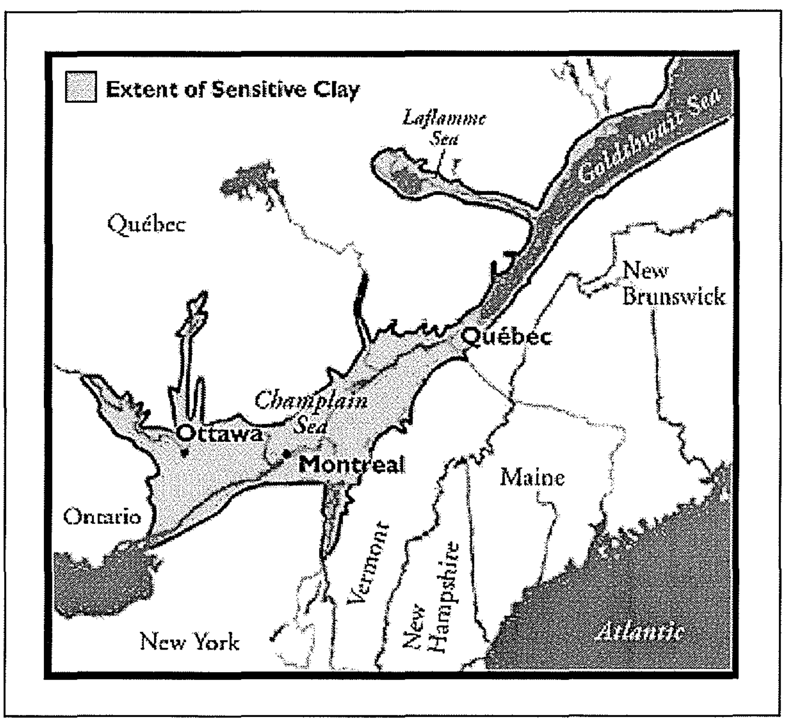

Figure 4. The extent of the Champlain Sea in the Ottawa and St. Lawrence River lowlands. Sensitive marine clays and silts are found throughout this area. Figure from the Canada Mortgage and Housing Corporation web site (www.cmhc-schl.gc.ca)

Broad channels were cut into the Quaternary sediments by the anastomosing paleo-Ottawa River. The current Ottawa River occupies the northernmost channel, with the Mer Bleue bog developing in an abandoned channel. Ongoing downcutting by local rivers (*e.g.* the South Nation River) has exposed sections of deltaic sediments underlain by the sensitive marine clays. Landslide development has been most significant along the immediate banks of these Ottawa River tributaries.

SENSITIVE CLAYS AND LANDSLIDES

The fine-grained sediments deposited in the marine to brackish waters of the Champlain Sea are composed primarily of quartz, feldspar, amphibole, illite, and chlorite, derived from Canadian Shield bedrock to the north ground into a rock flour by the action of the waning continental glacier to the north. True clay minerals make up only a small portion of the sensitive soils. As such, these fine-grained deposits lack the strong interparticle attractive forces commonly found in soils of true clay mineralogy. Clay-sized particles deposited in salt water often form aggregates with individual particles that are ramdomly aligned. These factors, combined with their deposition in waters with significant salt ions, resulted in an unstable, "house-of-cards" structure of material (Figure 5) accumulated to an average thickness of 30-50 m (Aylsworth *et al.,* 1997) in a relatively short time span (maximum 2,000 years).

Following the retreat of the Champlain Sea, meteoric water percolation through the sediments during the Holocene has resulted in a loss of salt ions and an overall decrease in the cohesive strength of the soils. Upon disturbance, the loss of strength transforms these clays into a mud-like consistency, with the remolded strength being only a fraction of the *in situ* strength. In many cases, the natural moisture content of the soils actually exceeds the liquid limit of the material (Aylsworth *et al.*, 1997)(Table 1).

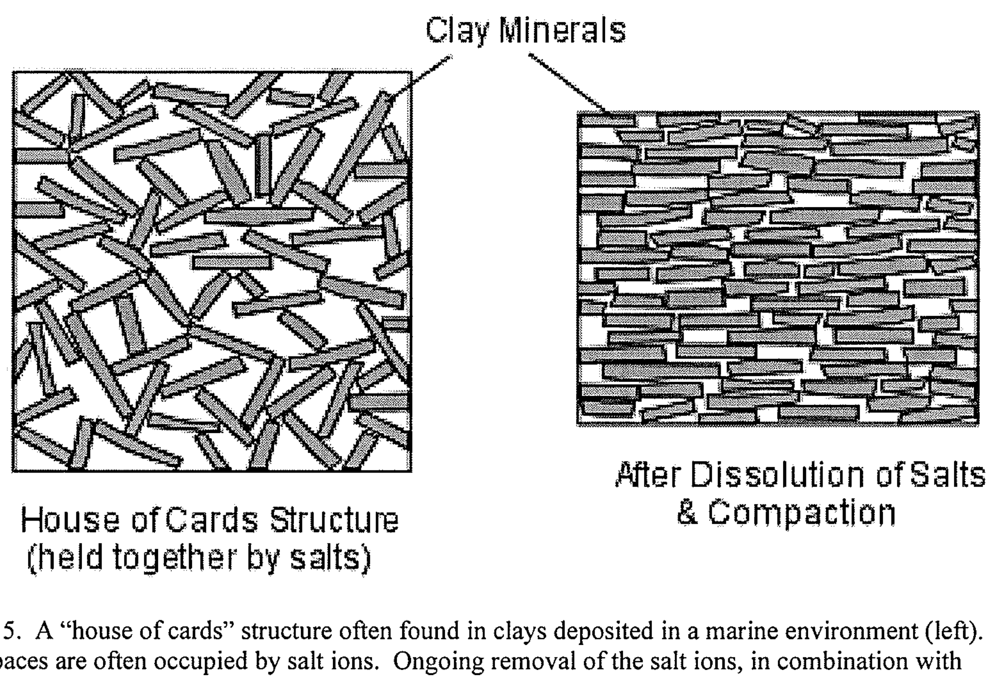

Figure 5. A "house of cards" structure often found in clays deposited in a marine environment (left). The pore spaces are often occupied by salt ions. Ongoing removal of the salt ions, in combination with disturbance can result in sudden liquification and compaction of the sediments (right). Structural failure often results, even on low-angled slopes such as those found in the Ottawa Valley.

The loss of strength in these soils has resulted in many landslides in the Ottawa Valley (Figure 1). Aylsworth *et al.* (2000) indicate that several massive landslides may have been triggered by earthquakes in the early Holocene. More recent landslides have likely been triggered by fluvial erosion and high water tables.

These landslides (technically earthflows) are retrogressive in nature. Initial failure commonly occurs at a riverbank where the slope is greatest. The failure of the initial block then triggers the collapse of another section, with ongoing failure proceeding in a retrogressive manner. The majority of failures in Leda clay are small, but some retrogress as much as 1 km, often in less than one hour.

In many cases it is fairly deep-seated sediments that fail, transporting a relatively intact sediment cap in blocks into the failure bowl (Figure 6).

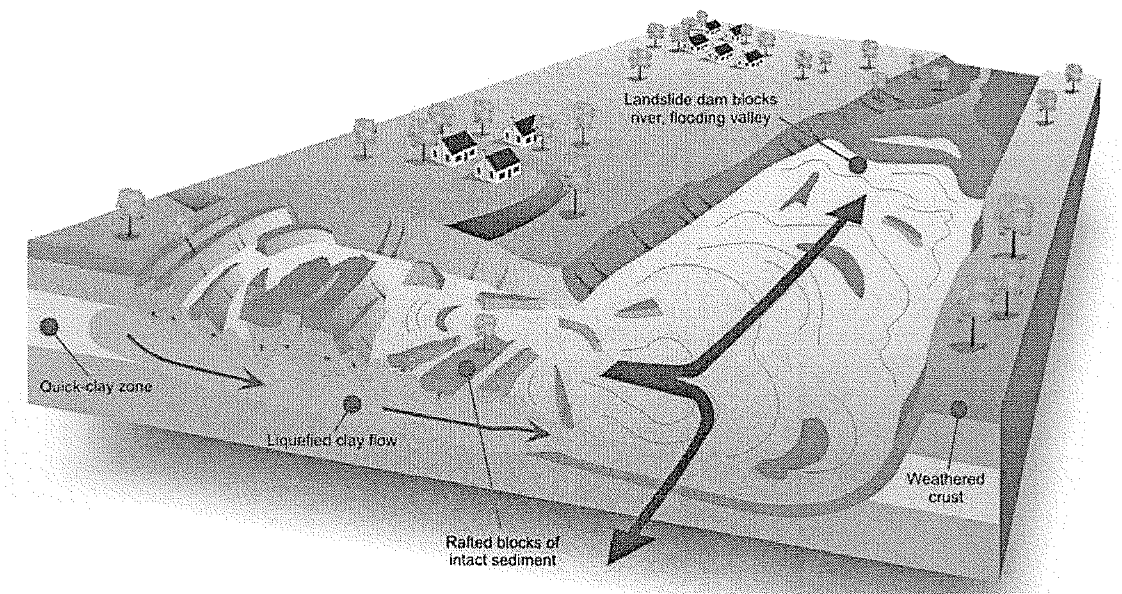

Figure 6. A typical sensitive clay landslide, showing a zone of liquified clay and relatively intact capping sediments. Figure from Natural Resources Canada.

FIELD TRIP STOPS

Start	Junction of Highway 417 and Regional Road 7 in Casselman, Ontario. This is exit 66 on Highway 417. Drive north towards Casselman, and turn right on Regional Road 3 (the sign says to Ste. Isadore).
5.0 km	Turn left at the T-junction onto Regional Road 8.
8.0 km (13 km cum)	Turn right onto Regional Road 16 just before the bridge. The remains of the village (cemetery) are 400 m ahead on the left. Park at the monument in front of the cemetery.

STOP 1. The Lemieux Townsite

The small village of Lemieux (28 homes, 50 km east of Ottawa) was a predominantly French-speaking farming community started in the 1850's as a mill town to service the local lumber industry. The Roman Catholic church was the focal point of the small community that became known as La Paroisse Saint Joseph de Lemieux. The villagers had always known about the local landslides, as a significant failure occurred nearby in 1895 and there are numerous older landslide scars in the area.

Engineering studies were conducted in the area following the large landslide on the South Nation River in 1971 (Eden *et al.*, 1971) (Figure 7). In 1989, the South Nation Conservation Authority (SNCA) engineers discovered that soil conditions underlying the community were unstable. Mindful of the landslide that had killed 33 people under similar conditions in Notre-Dame-de-la-Salette, and the loss of 31 lives in 1971 at St. Jean Vianny, Quebec, government authorities decided that the community of Lemieux would have to be abandoned. Homes were purchased by the SNCA as part of a landslide mitigation program.

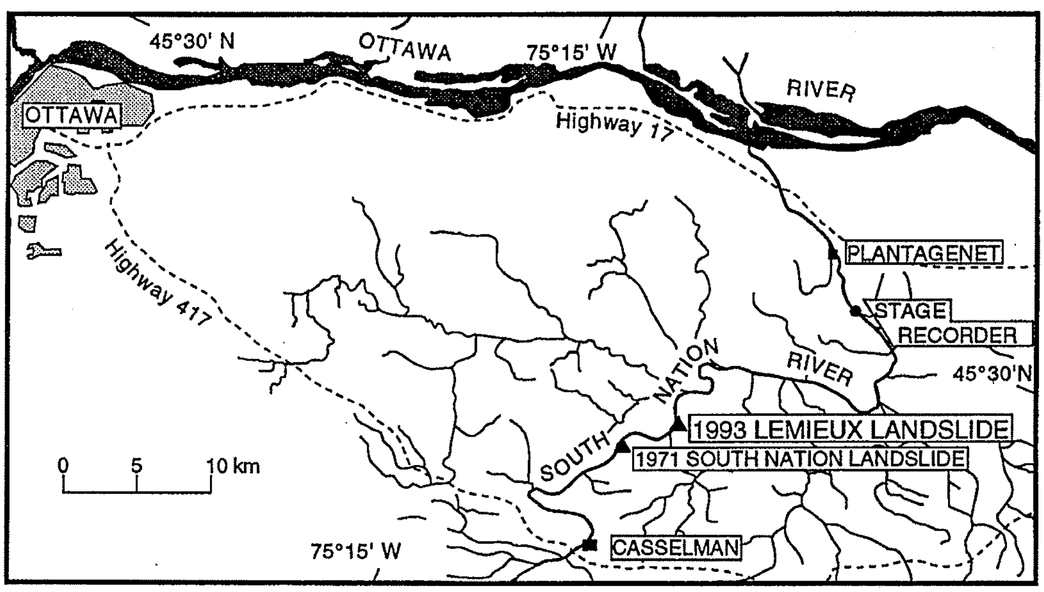

Figure 7. Recent landslides in the South Nation River valley. Figure from Evans and Brooks, 1994.

Some homes were moved and others were bulldozed. All that remains of the community is the cemetery and a plaque reading

"...The village was located over an area of sensitive clay soils, known as the Champlain Sea clays or Leda clays. These soils are unique to eastern Ontario and western Quebec and exhibit the characteristic that, when disturbed, they can liquefy. River banks and slopes composed of Leda clay, when left unprotected, have a tendency to fail and can cause large and small scale landslides.

After consultation with residents, the South Nation Conservation Authority, in conjunction with the Ministry of Natural Resources and the Township of South Plantagenet, purchased the residences in 1989 to eliminate the possible threat to life and property. Some houses were relocated while others were destroyed. With the closing of the church, the parish of Lemieux ceased to exist on August 4, 1991."

Several homesites are still easily seen as small clearings in the forest with obviously recent vegetation, and several sections of driveway tarmac.

Continue along Regional Road 16 for 2.85 km, turning left along a small access lane (very sharp turn doubling back on itself...see also Figure 9). This small lane leads to the landslide headwall about 200 m off the main road. The lane is passable except following severe rains.

STOP 2. The Lemieux Landslide

Late on the afternoon of June 20, 1993, a 17 ha area of sensitive marine silt and clay close to the Lemieux townsite failed with flow proceeding rapidly into the South Nation River (Figure 8). The first eyewitnesses noted a water displacement of up to 2 m high moving along the river both up- and downstream. Trees and spoil accumulation were soon noted at the bridge crossing Regional Road 8. It took over half an hour for the retrogressive failure to reach and sever Regional Road 16, with portions of the road surface being rafted up to 200 m down into the crater. One motorist on Regional Road 16 ended up in the crater, and was rescued by a Canadian Forces helicopter. In all, Brooks *et al.* (1994) estimate that the entire failure event probably lasted less than one hour. The debris from the landslide eventually buried 3.3 km of valley bottom and caused flooding 18 km upstream. Costs relating to the failure event have been estimated at $12.5 million Canadian dollars.

Figure 9 shows the extent of the failure area. The bowl of the landslide is about 10-12 m below the unfailed sediments. The failure retrogressed between 680 m from the river (Evans and Brooks, 1994), and involved between 2.5 and 3.5 million m^3 of sediment. Evans and Brooks (1994) suggest that the failure was constrained at the margins by gullies (Figure 9).

Figure 8. The Lemieux landslide several days after failure. Note the large intact rafted sections, and the severing of Regional Road 16. Some of the rafted blocks show rotation while the bedding in other blocks remains horizontal suggestive of lateral translation. The blocked South Nation River, flowing from right to left, is at the bottom of the picture. Photograph from the Geological Survey of Canada.

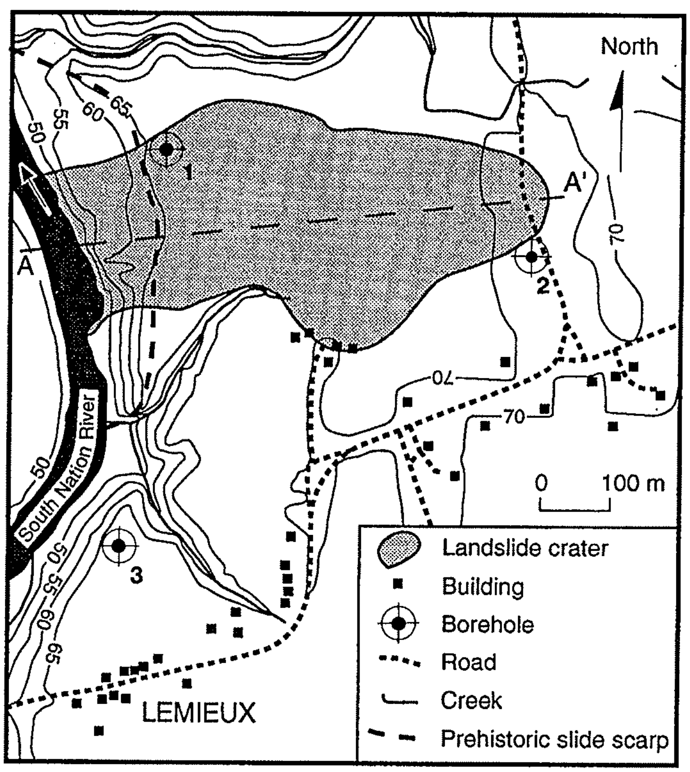

Figure 9. Map showing the extent of the Lemieux landslide, including the area affected during a prehistoric failure event. From Evans and Brooks, 1994.

Three boreholes had been drilled in 1986 and 1987 as a part of the geotechnical investigation. Three coarse units are delineated from these boreholes by Evans and Brooks (1994) (Figure 10; Table 1). An upper cap of loose brown silty sand forms the upper 3-7 m. The middle unit is composed of laminated interbedded silts and sands ranging in thickness from 5 to 10 m and depth below the pre-failure surface of 3 to 17 m. These are the sediments that make up the majority of the blocks and sharp crests in the landslide crater. One of the boreholes indicated that the strength of this unit decreased with depth.

The lowest unit is composed of marine clay below about 8 to 17 m depth (Figure 10). During drilling the auger rods of the drill decended into the hole under their own weight (Evans and Brooks, 1994); a testament to the low strength inherent in this layer. Below 19 m the liquidity index (a measure of the sensitivity to remolding and failure, with values greater than 1.0 indicating extreme sensitivity) is measured to be up to 1.6, and shear strength testing also indicate low strengths when remoulded (Figure 10; Table 1). This lower layer of soft marine clay is thought to be the failure plane that caused the failure owing to liquefaction, with the overlying sediments remaining somewhat intact but transported into the crater (Evans and Brooks, 1994).

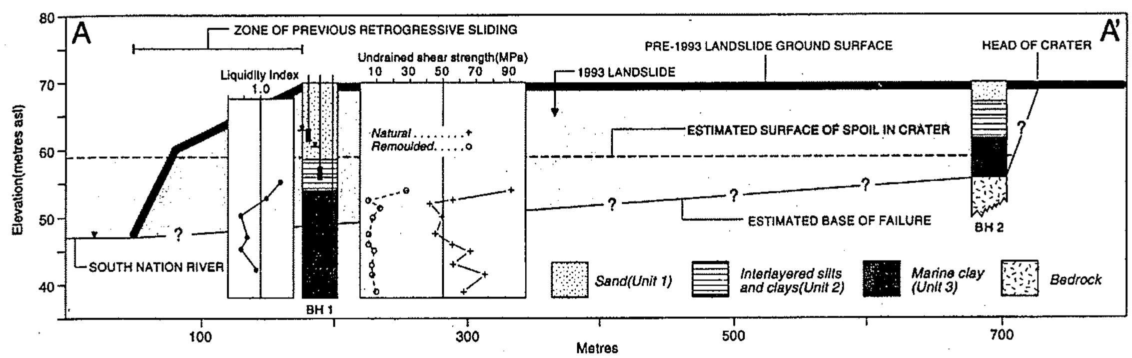

Figure 10. An approximate cross section of the Lemieux landslide based upon drilling conducted in 1986 and 1987. Failure occurred in the upper marine clay sediments with high indices of liquidity and low remoulded undrained shear strengths. Figure from Evans and Brooks, 1994.

Unit	Lithology	Depth range (m)	Index properties W_P (%)	W_L (%)	W (%)	I_L	Undrained strength C_u (MPa)[a] Natural	Remoulded	Sensitivity
1	Silty fine sand	0–7	—	—	—	—	—	—	—
2	Interlayered silty clay	3–17	25	52.5	36.7	0.4	68.7–91.7	23.8–28	2.19–3.18
3	Silty clay	8–32	19.9–27.8	31.4–56.2	36.4–59	0.8–1.6	41.7–76.7	3.7–10.9	4.3–11.4

[a]Field vane tests.

Table 1. Summary of geotechnical data for boreholes near the Lemieux landslide. From Evans and Brooks, 1994.

There was no obvious trigger for the landslide (Evans and Brooks, 1994), although an elevated water table appears to have been an important factor (Aylsworth *et al.*, 1997). The first 6 months of 1993 were the wettest on record for the first half of the year since 1947 (Brooks *et al.*, 1994). The region had above average snowfall, a rapid spring melt and heavy spring rainfall, resulting in a water table that was at or near the ground surface in many areas. Ongoing erosion from the South Nation River played an important role in providing an initial scarp for failure along its banks.

The field trip vans park along a road that represents the original path of Regional Road 16. From here the headwall and landslide crater are easily visible. Failure of the landslide occurred in blocks, and intact tilted blocks of the original stiffer surface cap are visible. Several trees survived the rafting into the crater and have continued to grow on the ridge and furrow topography. It is unclear why the landslide terminated at this point, although the bedrock rise noted towards the headwall (Figure 10) may have contributed to stabilization. Sections of the headwall have been regraded and flattened to prevent further retrogressive retreat.

In walking thorough the bowl eleven years after the event, it is obvious that previously sharp-edged blocks and topography have been muted through ongoing erosion (Figure 11). Several of the ridges contain trees that survived the rafting event, while the general vegetation is of more recent succession. Several sections of impounded drainage contain cattails.

The failure occurred at depths of greater than 10 m (Evans and Brooks, 1994), so the majority of the surficial material in the failure bowl is reworked sand that provided the stiff cap sediments. Transported Leda clay is not noticed until the banks of the South Nation River are reached (Figure 12). Tilted rythmitic bedding is noticed on both banks of the river. Groundwater piping at the edge of the crater, noted shortly after failure (Aylsworth *et al.*, 1997), is no longer visible. The river has entrenched 5-6 m into the spoil pile and river flow has essentially been restored (Aylsworth *et al.*, 1997), with striated limestone bedrock exposed to the north of the failure.

Figure 11. The Lemieux landslide crater in 2004, 11 years after the failure. Total crater depth is approximately 10-12 m. Notice the muting of the previously sharp-edged blocks of cap material. Revegetation of the crater is also well underway.

Figure 12. Rythmitic bedding of silt and clay on the banks of the South Nation River.

Retrace your steps back to Regional Road 8, and turn right (north) towards the bridge. Park on the north side of the bridge. Walk onto the bridge for a view of the Lemieux landslide debris in the river valley.

Stop 3. The South Nation Bridge.

Landslide spoil up to 12 m deep is visible at this site upstream of the landslide (Aylesworth *et al.*, 1997). The debris at this location consisted of the liquefied clay and silt, intact silt and sand blocks, and rafts of sod with some intact trees (Evans and Brooks, 1994). Several of the trees hit the bridge, although no damage was reported. Fishermen near the bridge report running for their lives to avoid an "8ft. high wall of water" (Ottawa Citizen, June 21, 1993 reported in Evans and Brooks, 1994). The landslide dam was overtopped by the South Nation River late on June 22, two days after the failure, with a strong current flowing over the debris by June 23. Incision into the spoil pile has been ongoing since then, with bedrock reached in several areas.

A Water Survey of Canada hydrographic station at Plantagenet Springs, 28.4 km downstream, recorded the abrupt increase in water level in response to the displacement wave (Figure 13), followed by a dramatic drop in stage as upstream flow was disrupted by the dam at the failure site.

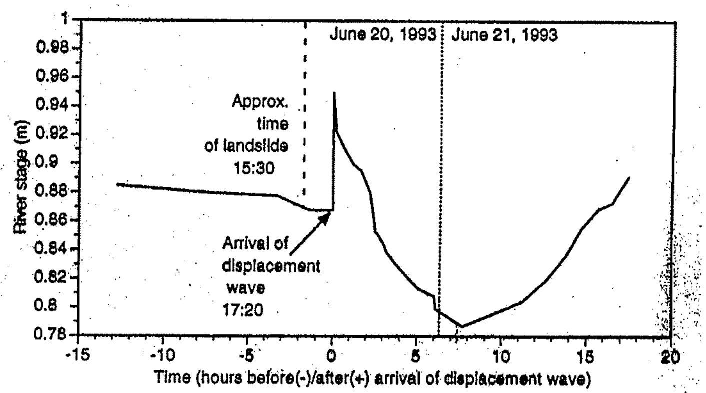

Figure 13. Hydrograph from the South Nation River at Plantagenet Springs, 28 km downstream from the landslide. The displacement wave arrived at the site just over an hour after the landslide. Impoundment of the river caused a drop in water level. Recovery of water levels starting 8 hours after the displacement wave was caused by rainfall in the basin. From Evans and Brooks (1994) with data from Environment Canada.

Recross the bridge and drive south on Regional Road 8 for 1.0 km. On the right (west) side of the road just past a dairy farm is the headwall of the 1895 landslide.

Stop 4. The 1895 Landslide.

This brief stop is at the headwall of the 1895 landslide (Figure 14) that covered 24.4 ha and retrogressed a total of 600 m from the South Nation River. Notice that the landslide scar is now well vegetated and is used by the owner as a pasture.

Figure 14. The headwall scar of the 1895 landslide.

From the 1895 landslide scar, retrace your steps to Casselman and get onto Highway 417 westbound towards Ottawa. Exit the Highway at Anderson Road (exit 104), 38 km west of Casselman. Take Anderson Road north to Ridge Road, and turn right. Four km along Ridge Road is a parking lot for the Mer Bleue nature trail. Park in this lot and follow the nature trail signs.

SECTION 2. MER BLEUE BOG

Mer Bleue Bog is a Provincial Conservation Area in the eastern portion of the National Capital Region, and less than 10 km from the city of Ottawa. The bog covers approximately 3500 hectares (Figure 15), and has formed in an abandoned channel of the Ottawa River. The western section of the bog has three distinct arms, separated by sand ridges that were formed by the anastomosing river channel.

Figure 15. A satellite image of Mer Bleue surrounded by farmland. Sand ridges formed by the paleo Ottawa River produce a digitate nature to the western portion of the wetland.

The majority of the central portions (Figure 16) of the bog are composed of a raised carpet of *Sphagnum* mosses, representing an ecological community usually found further north in the boreal forest of Canada. Other vegetation dominating the raised central portions includes Labrador tea (*Ledum groenlandicum*), bog laurel (*Kalmia polifolia*), Leatherleaf (*Chamaedaphne calyculata*), and various sedges. The majority of trees in the central portions are tamarack (*Larix laricina*), with some black spruce (*Picea mariana*) in more acidic areas. The dominance of Sphagnum species and a lack of contact with mineralized groundwater leads to acidic conditions within the bog.

Figure 16. The raised, central portion of Mer Bleue.

Raised bogs such as Mer Bleue obtain all of their nutrients through rainwater, and are termed ombrotrophic peatlands. Drainage from the raised portions flows laterally to the marginal channels. These channels, or lagg areas, provide the slow continual lateral drainage for the central portions of the peatland. Marginal areas of the bog are actually marsh (Figure 17), composed of open water lagg and vegetated primarily by cattails (*Typha sp.*), *Salix sp.*, and various sedges. Drainage of the wetland downwards is impeded by the presence of fine-grained material, including Leda clay. Lagg areas generally have greater contact with mineralized groundwater and their less acidic waters are able to support more luxurious vegetation.

Peat deposits in Mer Bleue are up to 6 m thick, but are most commonly about 3 m in thickness, and are underlain by up to 40 m of Champlain Sea sediments (Fraser et al., 2001). This peatland has been forming for approximately 8,500 years. The ecosystem here is unique as the vegetation assemblages are more typical of northern boreal forest, found over 1000 km to the north.

Figure 17. The marginal areas of Mer Bleue act as drainage for the central portions, and are dominated by open water and marsh vegetation, predominantly cattails.

The return to Potsdam, New York can be conducted by retracing your steps to Casselman and crossing the border at Cornwall. Alternatively continue west along Highway 417 through Ottawa to Highway 416 south. This route crosses the border at Ogdensburg, from which you can take Route 68 south to Canton and Route 11 east to Potsdam.

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