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Stop 6. Townsite of Lemieux

Geotechnical testing for slope stability and potential landslide retrogression assessment led to the identification of the 28 homes comprising the townsite of Lemieux as lying within a zone of potential highly retrogressive failure (Lawrence *et al*. 1996). Lemieux was subsequently abandoned. All that remains today are the graveyard and a monument marking the former townsite. The plaque on the monument reads "After consultation with the residents, the South Nation River 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 homes were relocated while others were destroyed. With the closing of the church, the parish of Lemieux ceased to exist on August 4, 1991."

The conclusion that this area could be subject to highly retrogressive failure was validated on June 20, 1993 when a large earthflow occurred immediately north of the former townsite. The Lemieux Landslide retrogressed 680 m, the highest retrogressive distance recorded in the South Nation area.

Stop 7. The 1993 Lemieux Landslide

On June 20, 1993, a 17 ha area of sensitive marine silts and clays failed and rapidly flowed into and along the valley of the South Nation River. The debris buried 3.3 km of valley bottom, impounded the South Nation River, and caused flooding for 18 km upstream (Fig. 13; Evans and Brooks 1994; Brooks *et al*. 1994; and a popular account of the event by Lankin 1996). Like the nearby 1895 landslide, this landslide has a narrow, elongated shape (maximum dimensions 680 m by 320 m). The flow, consisting of rafted blocks of relatively intact material within a matrix of liquefied clay and silt, involved about 2.8 million cubic metres of sand, silt and clay, much of which flowed into the valley of the South Nation River, extending about 1.6 km upstream and 1.7 km downstream of the crater mouth. The local township estimates that direct costs of this event are $4 million; if indirect costs are included, the estimate is $12.9 million (Gore and Storrie Ltd. 1994).

First notice of the failure occurred shortly after 15:30 when eyewitnesses at several locations both upstream and downstream of the landslide crater observed a displacement wave about 2 m high moving up the river and another large displacement wave 2 to 3 m high, which traveled at "great speed" down the river, followed by trees and spoil moving both upstream and downstream along South Nation Valley. As observed from the Regional Road 8 bridge, the movement of spoil within the river valley occurred over a period of about 30 minutes. Shortly before 16:00, headward regression of the crater reached and severed Regional Road 16. Eyewitnesses reported that at about 16:30, a last pulse of movement from the headwall rafted parts of the road from 20 to 200m down the crater. Major movement within the crater seems to have ceased by about 16:30. The duration of the event probably was less than one hour (Brooks *et al*. 1994).

There was no obvious trigger for the June 1993 failure, although an elevated water table seems to have been an important factor. The winter of 1993 had an above normal snowfall with heavy snowfall occurring in March and early April. This fact, combined with a rapid spring melt and heavy spring rainfall resulted in water tables near or at the ground surface (Brooks *et al*. 1994). Initial failure occurred within the scar of a pre-existing rotational slide which, although laterally extensive, had only retrogressed 150 m. One witness reported seeing a small slump of the river bank in the vicinity of the June 20th failure one week prior to the main event.

Near-surface stratigraphy, consisting of sand overlying interbedded fine sand, silt and silty clay, is visible in the sidewalls. Deeper stratigraphy, is derived from 3 pre-slide cores and 5 post-slide cores drilled by the Geological Survey of Canada (Fig. 10, 14, 15). Local stratigraphy consists of 2-7 m of fine sand overlying 5 to 10 m of interbedded fine sand and silt with occasional silty clay layers. This unit generally fines downward in the core. This overlies 3 to 20 m of rhythmites of soft gray and red clayey silt or silty clay with narrow silt partings, some thixotropic, which is underlain by till. In places a thin unit of dark gray fossiliferous silty clay may occur immediately above the till.

The results of pre-slide geotechnical tests from a nearby borehole core, summarized in Evans and Brooks (1994), revealed that plastic limits in the main silty clay unit varied from 19.9 to 27.8 and liquid limits varied from 31.4 to 56.2. Below 19 m natural moisture contents exceeded the liquid limit and in this zone the liquidity index varied from 1.6 at 19.8m, 1.4 at 23 m, 1.6 at 24.8 m, and 1.1 at 27.8m. Field vane tests indicated natural values of undrained shear strength between 40 and 77 kPa, showing a general trend of an increase with depth down to below 30 m where, beneath a compact silty sand layer, a decrease in strength was indicated (Fig. 14). In the zone between 19 m and 23 m, the range of C_u was 41 to 56 kPa with an average of 50 kPa. Remolded C_u values were generally less than 10 kPa yielding a range of sensitivities between 4.3 and 11.2. Between depths of 23.8 m and 28.5 m sensitivities of 8.2 to 11.2 were measured, suggesting a zone of highly sensitive clay. In this zone the value of the liquidity index varied between 1.1 to 1.6.

Liquidity index values in excess of 1 indicate that the mid- to lower part of the rhythmically bedded silty clay unit is very sensitive to remolding. Field vane tests measured high sensitivities (>4) in the lower part of the unit at a location which corresponds to the base of the landslide. Based on this evidence, Evans and Brooks (1994) suggested that the 1993 Lemieux Landslide occurred as a result of strength loss in a sensitive clay zone located between 8 and 23 m beneath the surface and that the liquefaction of most of the slide mass beneath the stiffer cap was due to the its high liquidity index (> 1).

The initial fluidization also caused most of the overlying silt and clay to liquefy and flow, thereby fracturing and carrying the stiffer surface sediments as rafted blocks within the mass of remolded clay. The failure began at the river, probably as a reactivation of the older landslide. Through consecutive failures at the headwall, the landslide eroded retrogressively headward for 680 m into the surrounding plain. The landslide widened through lateral spreading and the subsidence, translation, and rotation of blocks separated from the sidewalls, creating embayments into both the north and south sidewalls. The lateral extent of the failure seems to have been restricted by the presence of nearby deep ravines lying to the north and south of the landslide. These ravines probably allowed sufficient drainage of their immediate area to prevent failure. The crater widens where no longer confined by the southern gully.

Bedrock lies at a depth of over 55 m on the north side of the slide, but rises to a depth of about 15 m on the south side, indicating that failure was probably along the clay/bedrock interface at least in the headward portion of the failure. This suggests that bedrock had some role in controlling the extent of the failure. Bedrock is exposed at river level along the valley immediately south of the crater mouth.

Sharp-crested ridges and prism-shaped blocks of intact sediments are prominent features of the spoil particularly within the southern embayment. However, with time, these features have become more subdued. The ridges are composed of horizontal interbeds of clay, silt and sand which suggests that these ridges were formed by the lateral translation and differential subsidence of the blocks of the stiffer surface sediments (Fig. 16; Evans and Brooks 1994). Between the sharp-crested ridges, the spoil generally consists of remolded sediments and disturbed blocks with the more disrupted and tilted blocks showing evidence of sliding along the interbeds. The final stages of failure along the embayment on the north side of the crater occurred as rotational failures rather than translation and subsidence as on the south side.

After the failure, groundwater seeped from the crater sides with horizontal pipes being eroded at locations of concentrated flow, mainly at the base of the sand cap. Small alluvial fans lined the base of the scarp. For months after the landslide, water seeped from the coarser sediment laminations in the crater walls.

Since June 20, 1993, the site has changed considerably due to erosion of the crater sides, erosion and revegetation of the spoil, incision of the South Nation River and tributary gullies into the spoil, and construction of the highway detour. Although the back scarp has been re-profiled, graded and smoothed as part of construction for the highway relocation, water is still running from this vicinity, depositing fans behind the row of trees which marks the last movement in the failure. Frost action, precipitation, and revegetation has eroded and subdued the blocks in the spoil. The South Nation River has entrenched 5-6 m into the landslide debris in the valley and a deep gully extends back into the crater. After the overtopping of the landslide dam, the restored flow of South Nation River occurred initially as a broad sheet interrupted by intact sediment blocks. The river gradually incised the spoil, reducing the level of impoundment, and created a relatively narrow, sinuous channel (Fig. 17). The rotational blocks remaining from the earlier landslide may be seen along the valley wall north of the crater mouth.