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EARTHQUAKE-INDUCED LIQUEFACTION IN FERLAND, QUEBEC

by

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A report by M. Tuttle and L. Seeber under contract to the Atomic Energy Control Board.

ABSTRACT

Detailed geological investigations are under way at a number of liquefaction sites in the Ferland-Boilleau valley, Quebec, where sand boils, ground cracks and liquefaction-related damages to homes were documented immediately following the Ms=6.0, Mblg=6.5 Saguenay earthquake of November 25, 1988. To date, results obtained from these subsurface investigations of sand boils at two sites in Ferland, located about 26 km from the epicentre, indicate that (1) the Saguenay earthquake induced liquefaction in late-Pleistocene and Holocene sediments which was recorded as sand dikes, sills and vents in near-surface sediments and soils, (2) earthquake-induced liquefaction and ground failure have occurred in this area at least three times in the past 10,000 years, and (3) the size and morphology of liquefaction features and the liquefaction susceptibility of source layers of the features may be indicative of the intensity of ground shaking. These preliminary results are very promising and suggest that with continued research liquefaction features will become a useful tool in glaciated terrains, such as northeastern North America, for determining not only the timing and location but also the size of past earthquakes.

RÉSUMÉ

Des études géologiques détaillées sont en cours sur certains sites de liquéfaction dans la vallée de Ferland-Boilleau, au Québec, où des cratères de renard, des fissures du sol et des dommages aux maisons liés à la liquéfaction ont été documentés immédiatement après le séisme du Saguenay, le 25 novembre 1988 (Ms=6,0; Mblg=6,5). Jusqu'à maintenant, les résultats obtenus à partir de ces reconnaissances de cratères de renard en profondeur sur deux sites à Ferland, situés à quelque 26 km de l'épicentre, indiquent que : (1) le séisme du Saguenay a liquéfié certains sédiments du pléistocène et de l'holocène en créant des dykes de sable, des filons-couches et des cheminées dans des sédiments et des sols peu profonds; (2) la liquéfaction et les défaillances du sol provoquées par le séisme se sont déjà produites au moins trois fois dans cette région depuis 10 000 ans, et (3) la taille et la morphologie des caractéristiques de liquéfaction et la propension des couches de source de ces caractéristiques à se liquéfier pourraient être un indice de l'intensité des secousses du sol. Ces résultats préliminaires sont des plus prometteurs et laissent supposer, pourvu que la recherche se poursuive sur la liquéfaction, qu'ils pourraient s'avérer très utiles dans les terrains glaciaires, comme c'est le cas dans le nord-est de l'Amérique du Nord, pour déterminer le moment, l'endroit et l'importance de séismes antérieurs.

A. Introduction

The Saguenay earthquake of November 25, 1988 earthquake occurred ~ 150 km north of Quebec City, 70 km northwest of the Charlevoix seismic zone and 40 km south of Chicoutimi (Figure 1). Located at 48.121° N and 71.186° W, the Mblg=6.5 and Ms=6.0 earthquake occurred at a focal depth of ~29 km (North et al., 1989) and triggered liquefaction and related ground failures in the Ferland-Boilleau valley located 25 to 30 km east of the epicenter (Tuttle et al., 1989 and 1990). The rupturing fault can be resolved from aftershock data combined with constraints on the mainshock from the regional network (North et al., 1989) and from teleseimic waveforms (e.g., Carabajal and Barker, 1989) as northwest striking, dipping steeply to the northeast and experiencing oblique slip combining reverse and left-lateral motion (Seeber et al., 1989). The rupture is probably confined to a depth between 25 and 30 km and appears to be 5 to 10 km in length. Aftershocks originated from at least two faults other than the one that ruptured in the main shock.

Except for a series of moderate earthquakes recorded in 1939 and 1940 (Smith, 1966), the Saguenay region is believed to have experienced few earthquakes during the historic period and is characterized by low seismic hazard (e.g., Basham et al., 1985). Thus, the Saguenay earthquake was unexpected and demonstrates the inadequacy of the historic record alone for accurate assessment of seismic hazards. Similarly, the Saguenay event illustrates how the seismic hazard of other intraplate regions of historically low seismicity may be higher than currently estimated.

Geologic methods have been developed to determine the approximate location, size and recurrence intervals of moderate to large, prehistoric earthquakes. In California, paleoseismicity studies have focused on characteristics of active faults. In eastern North America, where surface ruptures are rare (none have been recognized in historic time), alternative approaches are being developed to identify earthquakes in the geologic record. Subsurface investigations in the meizoseismal areas of the 1811-12 New Madrid, Missouri earthquakes (Russ, 1979), the 1886 Charleston, South Carolina earthquake (e.g. Obermeier et al., 1986 and Weems et al., 1986), the 1925 St. Lawrence Valley earthquake (Chagnon and Locat, 1988) and the 1727 Newbury, Massachusetts earthquake (Tuttle and Seeber, 1989) have yielded data on the morphology of liquefaction features and on the types of sediments in which they form. In addition, large historic earthquakes have been correlated with large-scale silting and slumping events recorded in Holocene lake sediments in seismically active areas of southeastern Canada (Adams, 1982; Doig, 1986; Shilts, 1989). These various investigations of structures resulting from historical earthquakes have provided the basis for identifying past earthquakes in the geologic record.

In northeastern North America, paleoseismic studies utilizing liquefaction features are complicated by the prevalence of deformation structures related to glacial processes. Processes leading to prominent deformation structures in glacial sediments include syn-depositional slumps and dewatering of subaqueous deposits characterized by high sedimentation rates, ice-tectonics, collapse due to ice-melt, and other phenomena related to freezing and thawing. An investigation in the meizoseismal area of the 1727 Newbury, Massachusetts earthquake differentiated earthquake-induced sand dikes and sills from other deformation structures in glacial deposits (Tuttle and Seeber, 1989). The Saguenay earthquake, which triggered liquefaction and related ground failures, presents a timely opportunity to further advance liquefaction features as paleo-earthquake indicators in glaciated portions of North America. Constraints on the timing, location and size of moderate to large earthquakes may be developed from the study of earthquake-induced liquefaction features in sediments. These investigations improve and expand the record of damaging earthquakes, thus contributing to seismic hazard assessment..This report presents detailed descriptions of subsurface structures resulting from liquefaction triggered by the 1988 Saguenay earthquake.

B. Geographical and Geological Setting

The Ferland-Boilleau valley is located in the Laurentide Mountains of the Grenville Province which are bordered on the south by the St. Lawrence River and on the north by the Saguenay River. The Ferland-Boilleau valley is approximately 30 km in length and extends from Lac Ha! Ha! northward to Baie des Ha! Ha! on the Saguenay River. The surficial geology of the valley is dominated by glacial sediments including till, glaciofluvial and glaciolacustrine deposits (Raymond, 1969). The Riviere des Ha! Ha! and its tributaries dissect the valley sediments in some places forming series of alluvial terraces. Holocene fluvial deposits occur along modern stream channels.

The continental ice sheet retreated from this area about 10,000 to 9,500 years ago (LaSalle, 1968). During retreat of the ice front from the Laurentides, meltwater may have flowed southward through a number of large valleys (including the Ferland-Boilleau valley) forming proglacial lakes and depositing sediments. When sufficiently free of ice, the Saguenay River region experienced a marine incursion, known as the Laflamme Sea, which lasted from 9,500 to 8,500 years BP. During this episode, marine sediments over 100 m thick were deposited. However, marine sediments are not known to occur above elevations of 600 ft.. Due to isostatic rebound following deglaciation, base-level was lowered and the sea retreated from the region. Today, the Saguenay region is drained by the tidal Saguenay River.

C. Earthquake Effects

During a two-week survey of ground failure following the Saguenay earthquake, sand boils, ground cracks and differential settlement of house foundations were observed in Ferland. These as well as other ground failures including various types of mass movements are reported in Tuttle et al., 1989 and summarized in the following paragraphs.

The post-earthquake survey was hampered by winter weather. Snow fell the day following the earthquake and snow flurries occurred almost every day thereafter for two weeks. As a result, ground effects of the earthquake were covered by snow, and forest roads into the meizoseismal area were closed. Liquefaction failures were located by interviewing local residents who had observed sand boils and cracks before they were covered by snow. Most of these observations were made close to homes. For these reasons, the survey was incomplete and strongly biased towards populated areas.

Sand boils in the Ferland-Boilleau valley that had been described during the initial survey were revisited in June 1989. Although vegetation had overgrown their edges, most sand boils were still clearly visible. Several new sand boils were discovered in the areas immediately surrounding the sand boils that had been documented during the initial survey. In addition, a house-to-house survey, that was coordinated by Reynald Du Berger of the University of Quebec in Chicoutimi and conducted during the second half of 1989, turned up new cases of ground cracking, sand venting and differential settlement of house foundations in the Ferland-Boilleau valley.

At Site 1, located 26 km northeast of the 1988 epicenter, a sand boil (A) with a conical apron 0.5 to 1 m in diameter and 7.5 cm thick, formed 6 m west of the house #1 (Figure 2 and 3). In addition, a large quantity of gray sand clogged the bed of a creek that traverses the property. A small crack, 1 cm wide, at least 0.6 m long, and trending N33°E was observed within 3 m of the house. Along the same trend and only 0.6 m away, a pre-existing crack in the sidewalk widened by upward buckling. Damage to the cinder-block house was greatest in the basement apartment where almost every wall was cracked. Displacements on these cracks indicated that the outside walls had moved down relative to the inside walls by about 1 cm (Figure 4). The western wall, closest to the crack and sand boil, was bulging into the basement. Near the center of the basement, wooden floorboards were buckled up by about 1 cm. On the east side of the house, the floor was separated from the baseboard by about 1 cm through which sand and water had entered the basement during the earthquake. Water and sand also had entered through the drain into the bathtub and shot out of the toilet. The tenant had removed a 22 cm thick layer of gray, fine sand from the bathtub. Few cracks were visible in the walls of the upstairs apartment. However, the floor in the upstairs kitchen had a noticeable bulge that apparently resulted from the earthquake. On the exterior of the house, every cinder-block wall was cracked and the chimney was tilted.

During a visit to Site 1 in June 1989, a large sand boil (B), 8 m in diameter and up to 22 cm thick, was observed in the creek bed 46 m west of the house. In addition, several small sand boils, about 10 cm in diameter, were also discovered along the banks of the creek. The water well, which had filled with gray, fine sand during the earthquake, went dry in July 1989. During the topographic survey of the area in August 1989, another sand boil (C) 30 cm in diameter was discovered south of Rue Paquet. House #3 located within 10 m of that sand boil had suffered damage during the earthquake including an apparent elevation of the center portion of the basement floor and cracking of the concrete foundation. In addition, the water well for this house also had filled with sand during the earthquake. It is interesting to note that house #2, which is located about 1.5 m above house #1 and 1 m above house #3, did not suffer similar damage to the basement.

The intrusion of water and sand into house #1 and the spatial distribution of sand boils and failed wells suggest that a subsurface layer of very fine, gray sand had liquefied over an area of at least 60 m^2 during the earthquake. The relative shear between the exterior and interior walls of the house at Site 1 indicates a bearing-capacity failure of the footing in the liquefied material. Buoyant forces of liquefied sand or sediments displaced by foundering footings may have pushed up the unattached basement floor. The formation of the crack west of the house, the bulging of the western wall, and the buckling of both the basement and upper-story floors suggest a small amount of lateral movement towards the east.

At Site 2, located 26.3 km from the 1988 epicenter and about 1.5 km north of Site 1, two sand boils and three cracks formed within 30 m of house #4 that was also damaged during the earthquake (Figures 2 and 5). One sand boil (E) was about 3 m in diameter and formed 7.6 m from a creek that defines the eastern boundary of the site. Another sand boil (F) was about 1 m in diameter and formed 3 m from the western edge of an artificial pond. Three parallel cracks formed within 20 m of the house and exhibited separations of 0.5 to 1 cm. Sand and water also entered the basement of this house during the earthquake. Water had briefly covered the basement floor before draining away. A 20 to 30 cm thick layer of gray, fine sand was deposited on the basement floor and injected between the studs along the western, northern and southern walls. A few cracks formed in the walls of the first floor. These cracks exhibited small displacements indicating that the exterior walls had moved down relative to the interior walls by about 1 cm. The foundation of the northwestern corner of the house had separated from the garage floor by 1 cm. According to the home owner, the excavation for the foundation had been in coarse sand and gravel. Gray, fine sand, similar to that which had entered the basement during the earthquake, had been observed in the northwest corner of the excavation.

The formation of two sand boils and the intrusion of large quantities of sand and water into the basement indicate that subsurface material at this site liquefied during the earthquake. The shear between the interior and exterior walls of the house suggests that the footings foundered in the liquefied material that may underlie the foundation. The formation of cracks and the separation of the house foundation from the garage floor suggest a small amount of lateral movement downslope towards the creek.

D. Detailed Site Investigations

In August 1989, detailed investigations were carried out at the two sites in Ferland, Quebec described above. The two sites were surveyed using a "total station" comprised of a Zeiss Elta 4 tachometer and a Hewlett Packard 41 CX/Co-op 41 data collector equipped with a surveyor's module. Errors in survey closures were typically less than 3 cm. Based on the survey data, topographic maps of the sites were constructed at 2-foot contour intervals. Two sand boils were trenched at Site 1 and one sand boil was trenched at Site 2. Structures exposed by trenching were logged with the total station and photographed. A third trench at Site 1 excavated to install a new water-pump for the house was also logged. Because of problems with flooding, the trench of sand boil B was not logged with the total station.

The three sand boils were composed of aprons deposited on the ground surface and of dikes, sills and vents intruded within sediments and modern soils. In addition to these 1988 liquefaction features, other structures were revealed in the excavations that are suggestive of two earlier liquefaction events. Grain-size analyses of samples of the three generations of sand dikes and of subsurface layers were conducted at the Civil Engineering Department of the City College of New York (Appendix 1). Radiocarbon analyses (liquid scintillation counting technique) of organic samples associated with older liquefaction features are being performed by the Radiocarbon Laboratory of the University of Illinois in Champaign-Urbana (Table 1). Several small organic samples are being analyzed by the accelerator mass spectrometry technique at the University of Zurich. Results are not expected back until the end of 1990.

1. 1988 liquefaction features

At Site 1, sand boil A, located close to the damaged house, was about 0.5 to 1 m in diameter, 7.5 cm thick and composed of very fine, sandy silt (Figure 3). In the excavation of the sand boil, a well-developed system of subsurface dikes and faults was exposed (Figure 6). These dikes could be followed along a northeast-trending, linear zone just below the modern soil for a distance of 4 m. At a depth of 1 m below the sand boil, a prominent planar and subvertical dike could be clearly identified as the main structure. Above this depth, the dike split into a family of thin and discontinuous dikes. The passageway of the sand through the soil to the surface was marked by a very small sand vent not more than 1 cm in diameter. Several subsidiary dikes branched upward from the main dike, occurring along faults exhibiting centimeters of displacement. Where dikes encountered pebbles or stones, sand had accumulated below the obstacles. Dikes injected along normal faults terminated at the contact between silty, very fine sand below and medium sand above. Flow characteristics within the dikes varied with depth. Below 1.5 m, the dikes exhibited vertical grading and were finer-grained near their edges; above this depth, dikes exhibited horizontal grading.

In order to identify the layer that liquefied, sediment samples were collected from the main dike below sand boil A and below the bottom of the trench by hand-auger at depths of about 2 m, 3 m, 3.5 m, 4.25 m, 5.5 m, and 6.25 m. The grain-size distribution curve of the dike sand sampled in the trench is very similar to the distribution curves for auger samples taken at 3.5 m, 4.25 m, 5.5 m and 6.5 m and most closely matches the curve for the sand sampled at 4.25 m (Appendix 1). The color descriptions of the samples would suggest that the brownish-gray dike sand may actually be a mixture of the brownish sand sampled at 3.5 m and the gray sand sampled at 4.25 m. During hand-augering, it was noted that the material at 4.25 m was the weakest encountered between 2 m and 6.25 m depth. Geotechnical testing to a depth of 11 m was conducted adjacent to sand boil A by Tim Law of the National Research Council of Canada. Results of the tests indicated that a 0.3 m-thick sandy layer between 4.4 to 4.7 m depth was the most likely source of the liquefied sand (Figure 7; Tuttle et al., 1990). Based on these findings, we suggest that the layer identified by geotechnical testing was indeed the layer that liquefied in 1988. Liquefied sand from this layer, contaminated with material slightly higher in the section, formed the youngest dikes exposed in the trench and was vented to the surface.

Normal faults and a reverse fault, comprised of several splays, were exposed in an excavation about 5 m north of sand boil A (Figure 8). The normal faults exposed in this excavation trended from N35°W to N47°E and dipped steeply from 70°W to 54°E. The two westward dipping faults were roughly parallel to the main dike and normal faults observed in the trench below sand boil A. The westward dipping normal fault exposed towards the northwest end of the excavation was on-line with and probable extension of normal faults exposed in the trench. This normal fault was cut by the reverse fault, which trended S70°E and dipped on the average 82°S, roughly perpendicular to the normal fault and parallel to reverse faults noted in the nearby trench. Both faults extended into the 1962 fill layer indicating fault movement within the past 27 years. Very fine, silty sand, similar to that of sand boil A, was injected along the reverse fault and related normal fault probably during the Saguenay earthquake. Both these faults exhibited greater offsets of marker beds within the glacial sediments than of the overlying and younger fill suggesting at least two faulting events, the most recent being in 1988.

Sand boil B at Site 1 was about 10 m in diameter and up to 22 cm in thickness (Figure 3). It was the largest boil observed and was comprised of at least 4 coalesced aprons. The fans of the aprons were composed of several beds of graded, gray, fine sand and silty, very fine sand. The vents through the aprons were characterized by steep truncation of the subhorizontal laminae of the fans. Sand within the vent was normally graded, with coarse sand at the base and silty, very fine sand at the surface (Figure 9). Rip-up clasts of soil occurred within both the fan and vent deposits. The sand boil was fed from below via 4 vents through the organic-rich surface horizon and at least 1 feeder dike through a subsurface layer of medium-grained sand. The vents ranged from 5 to 15 cm in width and were widest near the surface. The observed feeder dike was about 30 cm in width and dipped 70° to the northeast. The trend of the dike was subparallel to the creek bed in which the sand boil formed. Sills up to 10 cm wide were intruded below the organic-rich surface horizon.

At Site 2, sand boil E, located 8 m west of the creek, Bras Hamel, was about 3 m in diameter and composed of very fine to coarse sand (Figure 5). Like sand boil B, the fan deposit was comprised of laminated and normally graded, gray, fine sand and silty, very fine sand. The vent deposit truncated the subhorizontal laminae of the fan and was composed of normally graded, fine to coarse sand (Figure 10). The boil was fed from below by a dike striking N25-50°W and dipping 25-40°NE that could be traced below boulders to a depth of 1 m. Sand had accumulated below these boulders as well as smaller stones that were in the pathway of the dike. The trend of this dike as observed near the surface is perpendicular to the topographic contour. This is opposite to observations at Site 1 where dikes were oriented roughly parallel to the local topographic contour. In this case, the large boulders may have played a large role in the near surface emplacement of the dike.

At the two sites in Ferland, dikes were the primary pathway for liquefied sand as it moved towards the ground surface from its source. The textural and structural characteristics of 1988 dikes suggest that the pore pressure of escaping liquefied sand was affected by the permeability of host sediments. Therefore, the permeability of near-surface sediments may play an important role in determining the types of structures formed during liquefaction events. If the permeability of the near-surface sediments is high, then the pore pressure of the liquefied sand may be reduced and structures either terminate or are only weakly developed (e.g., Figure 6). If the permeability of the host sediments is low, which is the case for thick soil or organic-rich layers, then sills and vents may form and sand is more likely to be vented at the surface (e.g., Figure 9). Furthermore, boulders or other impermeable objects can obstruct the movement of liquefied sand resulting in accumulations of sand below these obstacles and possible deflection of the course of dikes (e.g., Figure 10).

The occurrence of several 1988 sand boils near slope breaks suggest that topography may influence the localization of ground failure. Furthermore, the occurrence of sand dikes below the sand boils and the orientation of most sand dikes and related faults parallel to the topographic contour suggest that a small amount (cm) of lateral movement in the downslope direction resulted from liquefaction. The relationship of normal faults to a well-developed system of 1988 sand dikes supports this hypothesis. Hypothetically, once a subsurface layer liquefies, overlying material may begin to move downslope. Tension fractures form in the upslope portion of the slide block. Downslope or lateral movement of surficial materials creates an unstable boundary condition along the tension fractures leading to normal faulting of adjacent sediments into the fracture. Liquefied sand forcefully fills the fractures, possibly driving fracture propagation towards the surface. Alternatively, buoyancy forces in the liquefied subsurface layer may lead to diapirism. The liquefied sand would rise through weak zones in overlying material leading to normal faulting in sediments above the diapir and to reverse faulting in the surrounding sediments. At this locality, a combination of these two mechanism could explain the observed effects.

2. Pre-1988 liquefaction features

The 1988 liquefaction features exposed in the excavations in Ferland are superimposed on at least two older generations of liquefaction structures. The younger pre-1988 generation (generation 2) is characterized by weathered dikes and sills similar to 1988 (generation 3) structures in texture and morphology. The oldest generation (generation 1) is strikingly different from the more recent dikes and sills in size and morphology. The oldest structures exhibit a high degree of weathering, primarily iron-staining and iron-cementation and are cross-cut by generation 2 as well as 1988 dikes and sills.

Several weathered dikes and sills (generation 2) were exposed in the excavation of sand boil A at Site I (Figure 5) and are suggestive of a pre-1988 liquefaction event. Some of the weathered dikes were associated with normal and reverse faults, as mentioned above, and appear to have been intruded by 1988 dikes, including the main dike. In addition, a much larger structure was exposed that was comprised of a 10 cm wide, weathered sand dike at depths of 1.5 to 2 m merging upward into a 2 m wide, iron-stained and -cemented sand crater. Organic material lined the base of the crater and clasts of host sediment were contained within the crater. Several reverse faults with up to 20 cm of displacement all occurred within 0.5 m of the crater and rooted into the associated sand dike. This structure is different from 1988 liquefaction features, but exhibits many of the characteristics of sand-blows in Charleston, South Carolina (Obermeier et al., 1986), suggesting that it also resulted from liquefaction. The relationship of the reverse faults to the sand dike is not clear. However, the reverse faults do not cut the dike and therefore may have formed prior to or concurrently with the dike. The iron-stained sand crater and the proposed feeder dike are the oldest (generation 1) structures recognized so far because they are cut by 1988 as well as the weathered (generation 2) sand dikes.

Grain-size analysis was performed on samples taken from all three generations of dikes (Appendix 1). The grain-size distribution curve for the sample taken from a second generation dike was very similar to the curve for the sample taken from the 1988 feeder dike, suggesting that the same source layer at a present depth of 4.4 to 4.7 m liquefied during the two events. In contrast, the first generation dike is finer-grained than either the second or third generation dike. The curve of the sample from the first generation dike closely matches the curve for a sample taken at about 3 m depth with a hand-auger. Geotechnical testing indicated that a 0.75 m-thick sand layer between 2.25 to 3 m-depth may also be susceptible to liquefaction when subjected to slightly higher ground shaking than was experienced at the site in 1988 (Figure 7). This may suggest that either ground shaking during the event that liquefied this layer was greater than in 1988 or that liquefaction of this layer in the past resulted in densification of the layer and effectively reduced its liquefaction potential. In considering prehistoric liquefaction events, it must be kept in mind that ground water conditions and overburden pressure that affect the liquefaction potential of sediments have probably changed over time as streams have incised and eroded sediments in the Ferland-Boilleau valley.

Pre-1988 liquefaction features including dikes, sills and vents were observed in the excavation of sand boil B. At a depth of 1m, the 1988 feeder dike mentioned above was associated with a weathered dike (generation 2?) having the same strike and dip. It would appear that the 1988 dike had been intruded along the older dike. Weathered sills (generation 2) typically occurred within the organic-rich soil (Figure 9). A soil sample was taken from below such a sill (#1; see table 1) and dated by radiocarbon analysis yielding an age of 2,640 ± 80 years BP (1950). Based on calibration of the radiocarbon time-scale (Stuiver et al., 1986), this radiocarbon age translates into a calibrated age of about 2,330 years BP. Because soils contain residual carbon, the age of the soil is likely to be much greater than the age of the intruding sand dikes and sills, and therefore, the liquefaction event that produced them. The soil date indicates a maximum age of the weathered dikes and sills. Near the surface, coarse-grained and iron-stained sand occurring within the organic-rich soil and immediately adjacent to one of the 1988 vents is interpreted as an old sand vent. No cross-cutting relationships were observed to help establish the relative age of this feature; however, its weathering characteristics suggest that it is a first generation structure similar in age to the sand crater exposed in the excavation of sand boil A.

TABLE 1: RESULTS OF RADIOCARBON ANALYSIS

SAMPLE	SITE	BOIL	MATERIAL	C-14 AGE*	METHOD
1	1	B	SOIL/WOOD	2,640 ± 80	LSCT
2	2	E	WOOD	1,910 + 70	LSCT

*Years before 1950

Two generations of pre-1988 features were also observed at Site 2 in the excavation of sand boil E (Figure 6). Again, 1988 and generation 2 structures were similar in size and morphology. Grain-size analyses were performed on samples taken from both a second generation dike and a 1988 dike. The results indicate that the second generation dike is finer-grained than the 1988 dike, and therefore, that liquefied material was probably derived from different source layers during the two events. The older dikes cross-cut a charcoal layer at a depth of 0.75 m. The charcoal layer was sampled (#2; see table 1) and wood within the layer yielded a radiocarbon age of 1,910 ± 70 years. This radiocarbon age translates into a calibrated age of about 1,868 years BP (Stuiver and Pearson, 1986). The wood date provides a maximum age of the weathered dikes and sills; however, unlike the soil date mentioned above, the wood date will not be biased by residual carbon. The second generation dikes also cross-cut deformation structures (generation 1) including sand lenses located below boulders and 30 cm wide dikes and diapirs that may also have resulted from liquefaction. Overlying organic-rich sediment and soil are deformed by these older structures. A post-depositional bearing-strength failure due to liquefaction is one plausible mechanism for the formation of these structures. The degree of iron-staining of the sand in these structures is similar to that of the sand filling the crater at Site 1, suggesting that the oldest deformation event at both sites may be contemporaneous.

Evidence for an earlier (generation 2) liquefaction event including liquefaction features resembling the 1988 (generation 3) features suggests that the Ferland area has been subjected to moderate ground shaking at least three times in the past 2,000 years. The size and morphology of the oldest (generation 1) structures suggest that pore pressures and possibly ground shaking were higher during this liquefaction event and that the causative earthquake may have been either larger than the 1988 earthquake or closer to Ferland. The degree of weathering of these structures suggest that they are significantly older than the generation 2 structures. Additional radiocarbon analysis of samples associated with these liquefaction events will hopefully help constrain the age of their formation.

E. Other Paleo-Earthquake Indicators

Several earthquake-induced landslides were also documented during the post-earthquake survey, including a failure of a 10° slope in St. Thècle about 180 km southwest of the epicenter (Tuttle et al., 1990). The St. Thècle slide was about 88 m across from one side of the scarp to the other, extended 150 m from the main scarp across the valley and had the morphology of a slump-flow failure (Figure 11). The creek at the bottom of the slope was buried by about 10 m of slide debris which covered the entire span of the valley. Rock slides triggered by the 1988 event were prevalent in the high relief areas of the Laurentide Mountains. The largest slide observed was south of Lac Ha! Ha!, about 25 km from the epicenter. The slide was about 100 m in height and 50 m in width and composed of blocks with dimensions as large as 10 m. At the base of this and other rock slides, there was clear evidence of past landslide activity including large blocks exhibiting weathered surfaces (some lichen) and previously damaged trees. The prevalence of landslides triggered by the Saguenay earthquake, combined with the presence of pre-1988 liquefaction features observed in the excavations in Ferland, suggest that many of the older rock slides may also be earthquake-induced. The study of the timing and distribution of landslides in the Laurentide Mountains could serve to cross-check other results pertaining to paleoseismic activity in the region.

Another paleo-earthquake method that has been developed by Ronald Doig at McGill University may also be fruitfully applied in the Laurentide Mountains. The technique involves identifying seismic silting events in cores of lake sediments (Doig, 1986). During the post-earthquake (Saguenay) survey, it was observed that cracks in ice on many of lakes in the epicentral area were lined by dark material, possibly silt re-suspended and brought to the surface in lake water during ground shaking. In addition, landslides were observed along the margins of lakes and along streams feeding into lakes. Whether by the mechanism of re-suspension of lake-bottom sediments or by landsliding, it is likely that the 1988 Saguenay is recorded as a silting event in lakes in the Laurentide Mountains. If so, the Saguenay event, for which the location, magnitude and level of ground shaking are fairly well-constrained, could serve to calibrate past earthquake-induced silting events identified by this method.

F. Conclusions

The Ms=6 Saguenay earthquake occurred in a region of Quebec that was believed to be relatively aseismic, based on the historic record of earthquakes. This earthquake illustrates the inadequacy of the historic record alone for hazard assessment. The Saguenay earthquake triggered liquefaction and slope failures in glacial sediments, suggesting that moderate to large, historic and pre-historic earthquakes are likely to be recorded in glacial and post-glacial sediments. Therefore, paleoseismic techniques may be useful in improving seismic hazard estimates not only in the Saguenay region but elsewhere in eastern North America.

Sand boils, ground cracks and liquefaction-related damages to homes and to water wells were documented in Ferland, Quebec, following the Saguenay earthquake. Several sand boils were excavated and physical and sedimentological characteristics described. Sand boils ranged in size up to 10 m in diameter and up to 22 cm in thickness. At the surface, the sand boils were comprised of aprons and vent deposits. The fan deposits were composed of laminated and graded, fine sand and silty, very fine sand and were truncated laterally by vent deposits composed of medium to coarse sand. The largest sand boil was composed of at least 4 coalesced aprons. Below the surface, sand boils were fed by sand vents, dikes and sills. The vents were typically 5 to 15 cm in diameter and the dikes and sills ranged from 1 to 30 cm in width. Sills had formed below and within laterally continuous horizons of low permeability, such as organic-rich soils, and sand vents occurred within the soil horizons. Sills and vents were best developed where the soil was at least 0.3 m thick. Dikes were wider and more continuous at depths greater than 1 m and several dikes were injected along faults.

Weathered dikes and sills similar in size, texture and morphology to 1988 structures were exposed in the excavations of the sand boils. These structures (generation 2) are likely to have formed within the past 2,000 years in response to ground shaking similar in intensity to shaking caused by the 1988 Saguenay earthquake. In addition, even older (generation 1) sand dikes, craters, diapirs and lenses have been recognized from cross-cutting relationships and advanced weathering characteristics. These older structures are much larger than the 1988 and the weathered dikes and sills and may be indicative of more elevated pore pressures and/or ground shaking during the causative earthquake than was achieved during the 1988 event. The physical characteristics, cross-cutting relationships and degree of weathering of both generations of pre-1988 structures are consistent between excavations supporting the hypothesis that they formed during two separate events.

The three generations of liquefaction features, exposed by the excavations of sand boils induced by the 1988 Saguenay earthquake, suggest that the Ferland area has been subjected to at least three moderate to large earthquakes since the deposition of the sediments about 10,000 years ago. This would suggest as an upper limit a 3,300 year recurrence interval for moderate to large earthquakes in this region. Actual recurrence times could be much shorter as indicated by a maximum age of 1,868 years BP for generation 2 liquefaction features. These results are preliminary but suggest that with further study liquefaction features will become a useful tool, perhaps in combination with other approaches, for determining not only the timing and location but also the size of past earthquakes in glaciated regions such as northeastern North America.

In the future, a broader-based paleoliquefaction survey would help to test these preliminary findings and may constrain the location of pre-historic earthquakes. In addition, a comparison of 1988 liquefaction features that formed at different distances from the epicenter and under different site conditions may help to develop a scaling relationship for estimating the size of past earthquakes. Analysis of the physical characteristics of deposits as a function of their environment of deposition will be useful in the development of such a scaling relationships as well as in the identification of indicator deposits for future paleo-earthquake investigations. In addition, geotechnical testing of the source layers of paleoliquefaction features may help to quantify ground shaking during past events.

G. Acknowledgements

Supported by Atomic Control Board of Canada and National Center for Earthquake Engineering Research contracts 88-1303 and 88-1508. Many thanks to John Adams of the Geological Survey of Canada for his encouragement to conduct a post-earthquake ground failure survey in Quebec and to many people of the Saguenay region for their generous assistance, particularly Françoise Lange and Professors Du Berger and Roy at l'Université du Québec à Chicoutimi, Roland Veilleux at the Ministere de l'Energie et des Ressources, and Sylvie Gagnon at the Ferland-Boilleau municipal office. Thanks to the many property owners of Ferland especially Josée Simard and Michele Simard for permission to work on their land. Caroline Moseley and Claude Otis provided valuable assistance in the field.

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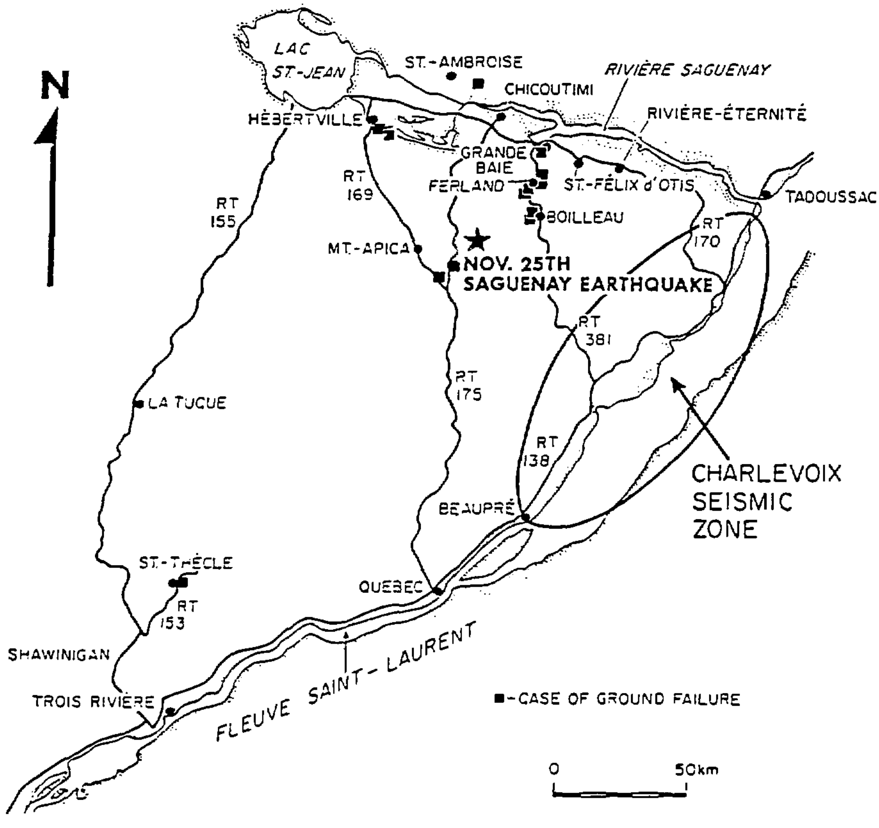


Figure 1. The November 25, 1988 Saguenay earthquake occurred in the Laurentide Mountains of Quebec Province between the Saguenay and St. Lawrence Rivers. Ground failures were triggered by the earthquake as far away as St. Thècle, 180 km southwest of the epicenter. Liquefaction occurred in the Ferland-Boilleau valley located about 25 to 30 km northeast of the epicenter. In sharp contrast to the active Charlevoix Seismic zone located between 60 and 120 km southeast of the Saguenay earthquake, the Laurentide-Saguenay region was thought to have experienced few historic earthquakes and therefore to be relatively aseismic. The Saguenay event brings into question the presumed locations of historic events as well as the accuracy of hazard assessments based on historic seismicity alone.

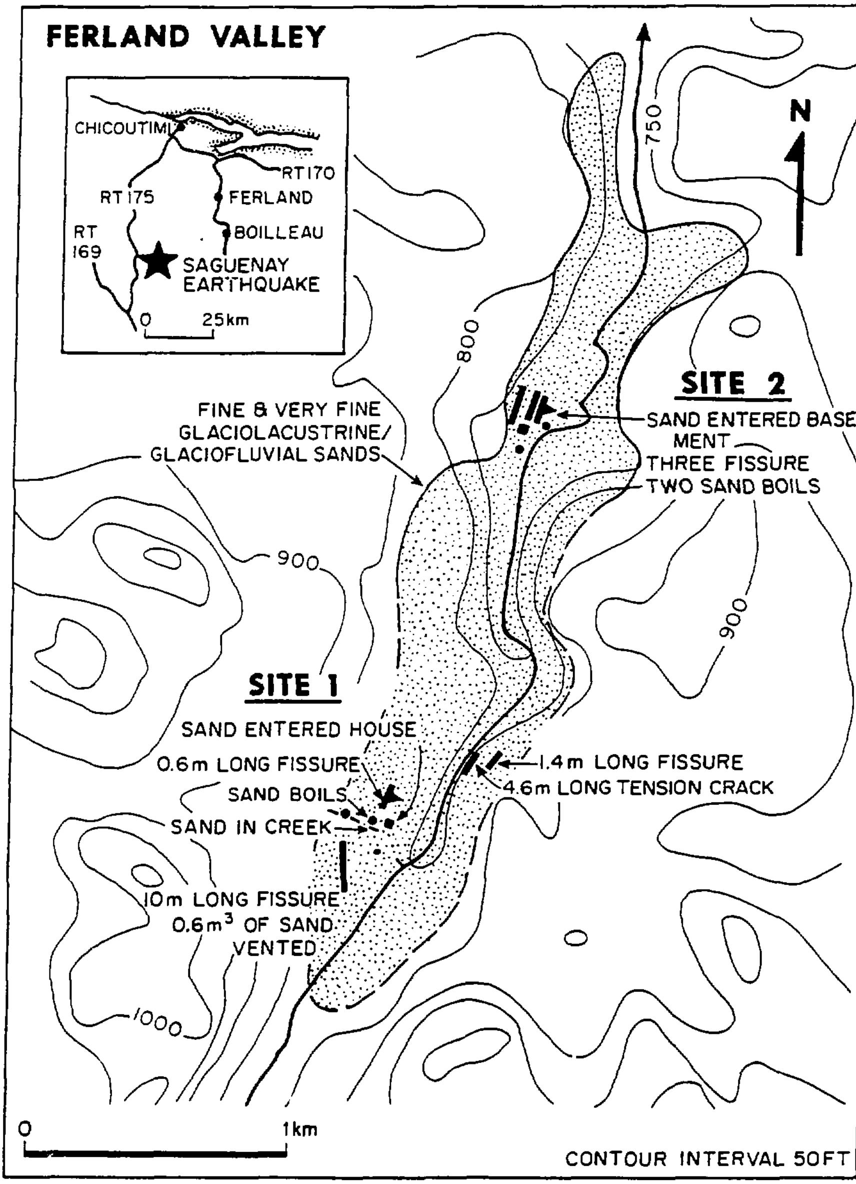


Figure 2. In Ferland, located about 26 km northeast of the epicenter of the Saguenay earthquake, liquefaction of glaciofluvial and glaciolacustrine sediment was manifested by the formation of sand boils and sand fissures, and the intrusion of sand and water into and differential settlement of two homes at Sites 1 and 2. Ground cracks with 0.1 to 1 cm separations formed parallel to the contour of the topography and were the result of downslope movement (1 to 10 cm) of course-grained sediment over the liquefied sand. Teeth on lines (not drawn to scale) delineating cracks indicate the direction of movement.

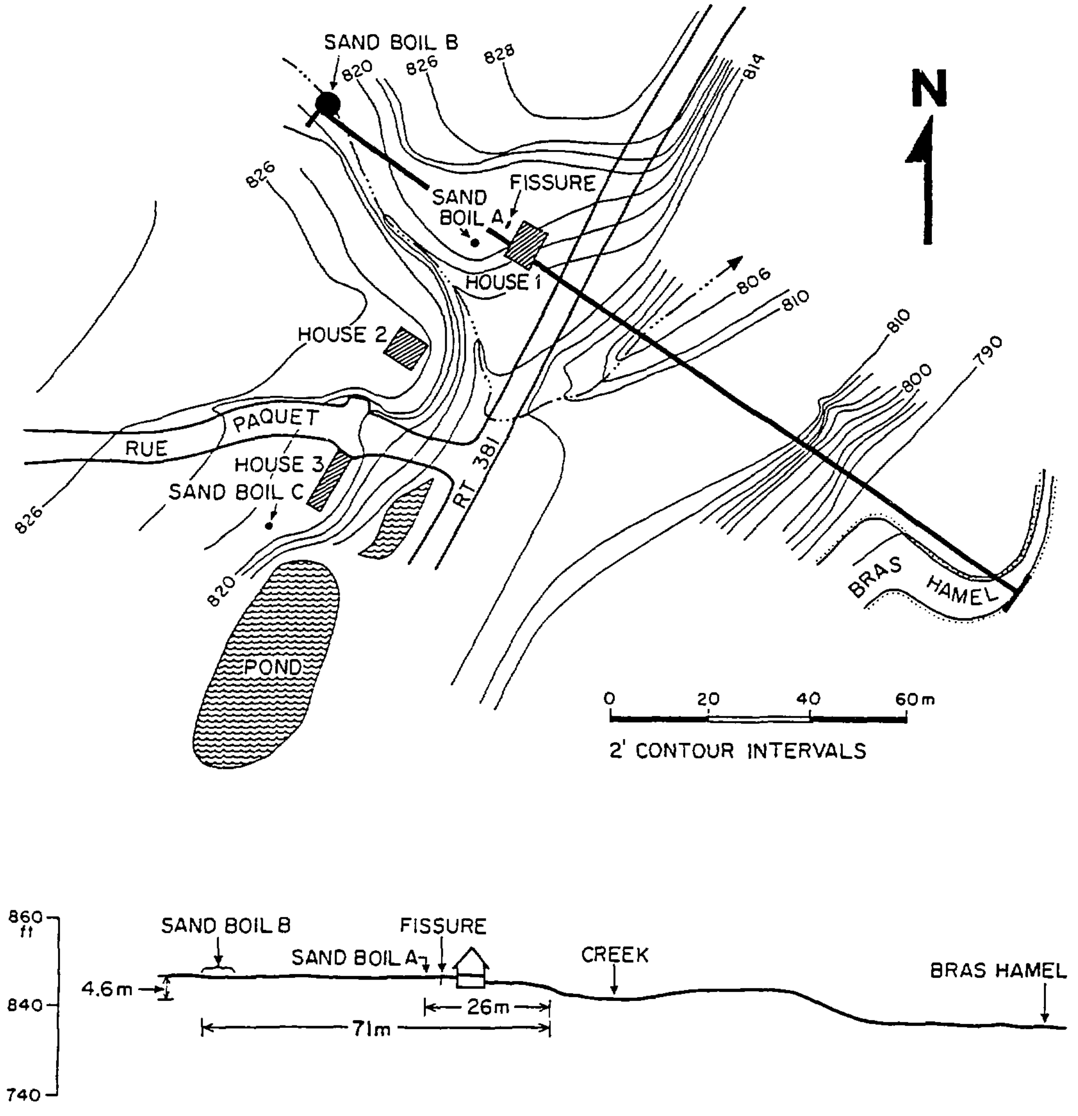


Figure 3. Topographic map and profile of Site 1 in Ferland with locations of sand boils and ground cracks induced by the Saguenay earthquake. The house along the line of section suffered damage due to the earthquake (see Figure 4).

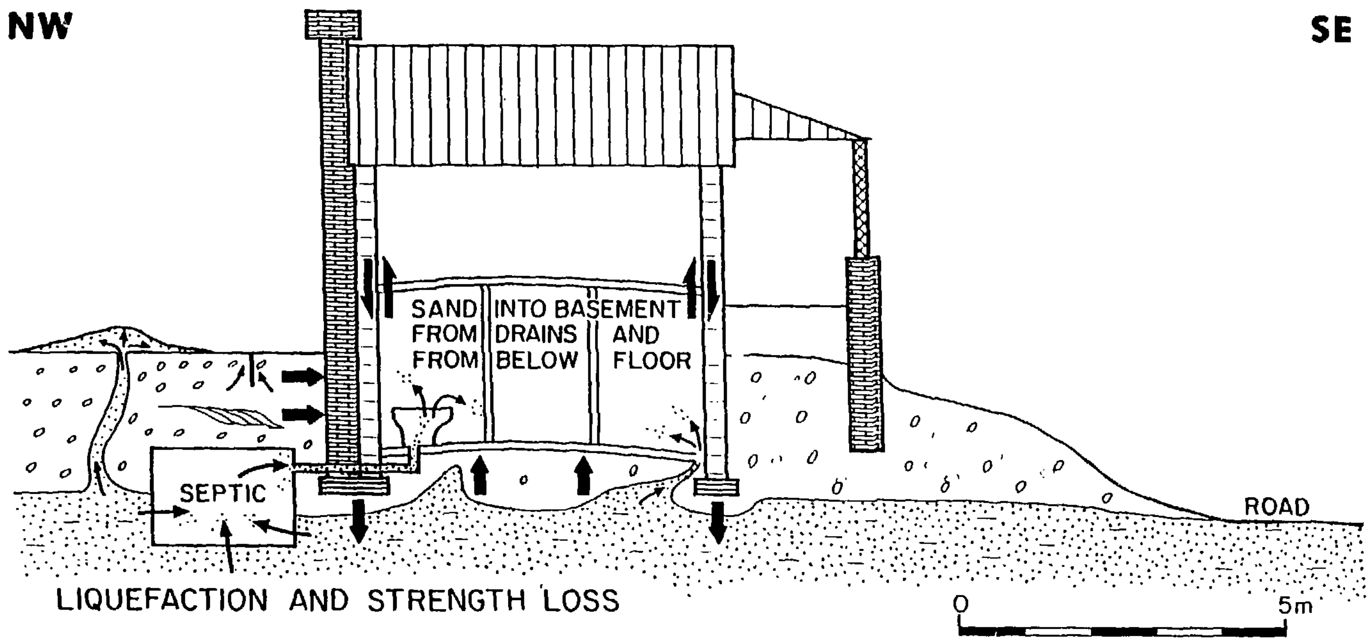


Figure 4. Sketch of damage caused by liquefaction to a house at Site 1 in Ferland. The floors buckled upward and the interior walls were sheared upward relative to the outside bearing walls by about 1 cm. Very fine, gray sand and water entered the cellar via the drains and a 1 cm gap that formed between the floor and the foundation. A ground crack and sand boil formed a few meters from the house and a nearby stream was choked with vented sand. Liquefaction of a subsurface layer may have caused lateral spreading and foundering of the house footings. In addition, the cement-block walls cracked in many places, substantially weakening the building. Very similar kinds of damage were observed at the cement-block home at Site 2.

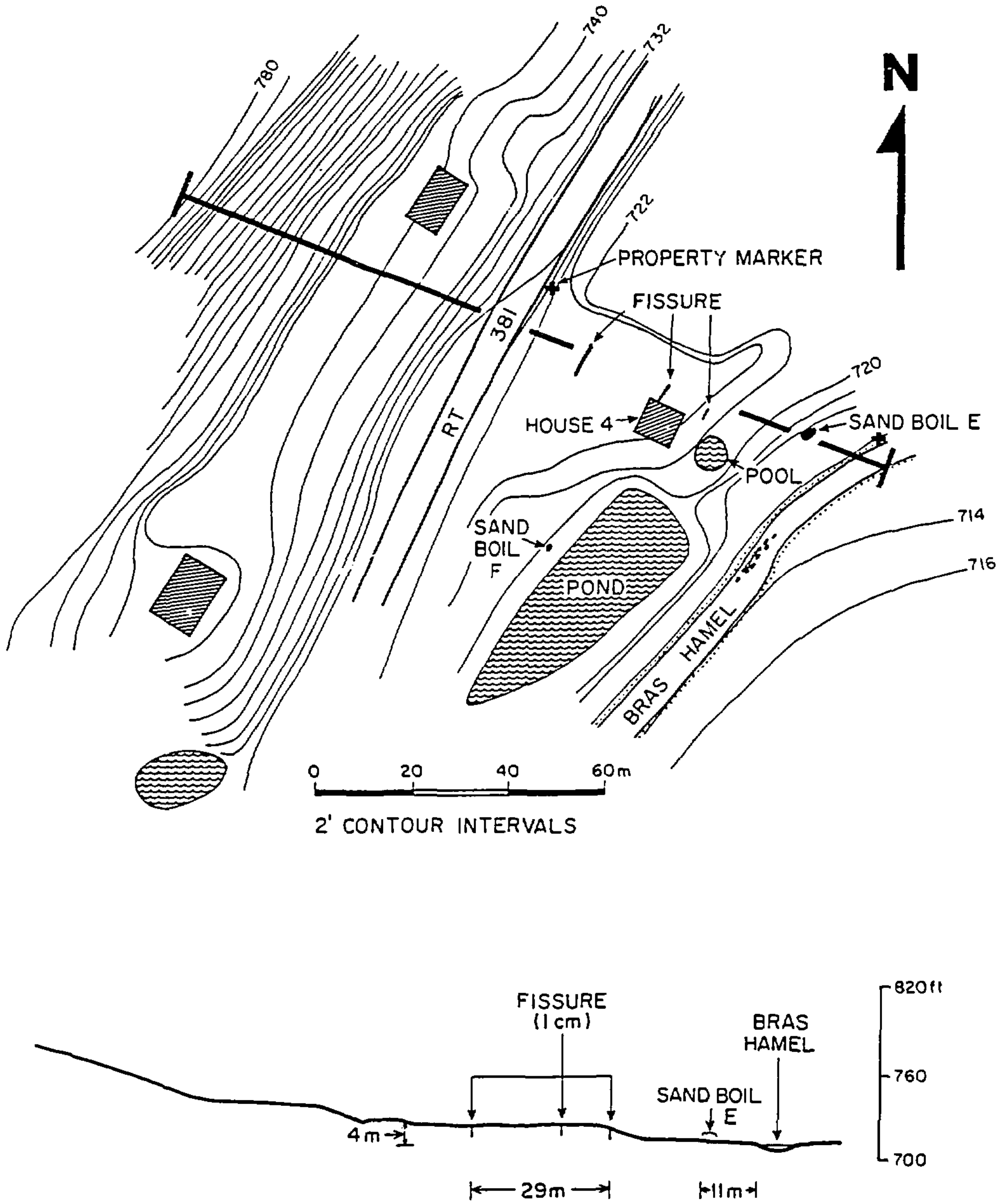


Figure 5. Topographic map and profile of Site 2 in Ferland with locations of sand boils and ground cracks induced by the Saguenay earthquake. The house east of Rt. 381 located along the line of section sustained damages similar to those of the house at Site 1.

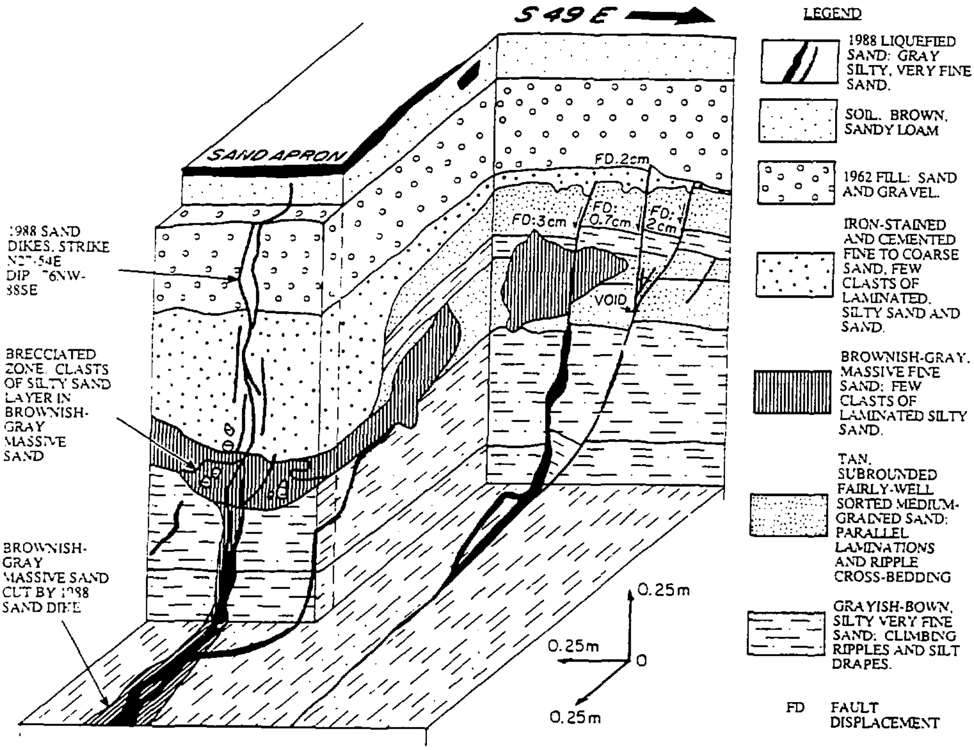


Figure 6. Block diagram of an excavation of the sand boil A at Site 1. Sand liquefied during the 1988 earthquake was intruded along a steeply dipping dike directly below the sand boil and also along several subsidiary dikes that are associated with normal faults. The subsidiary dikes are subparallel to the main dike. The system of 1988 dikes is subparallel to the topographic contour and occurs upslope from a topographic break. The emplacement of the dikes may be linked to the formation of tension cracks in unconsolidated sediments during downslope movement over a liquefied layer. Older liquefaction structures include weathered sand dikes and sills and a crater filled with iron-stained sand.

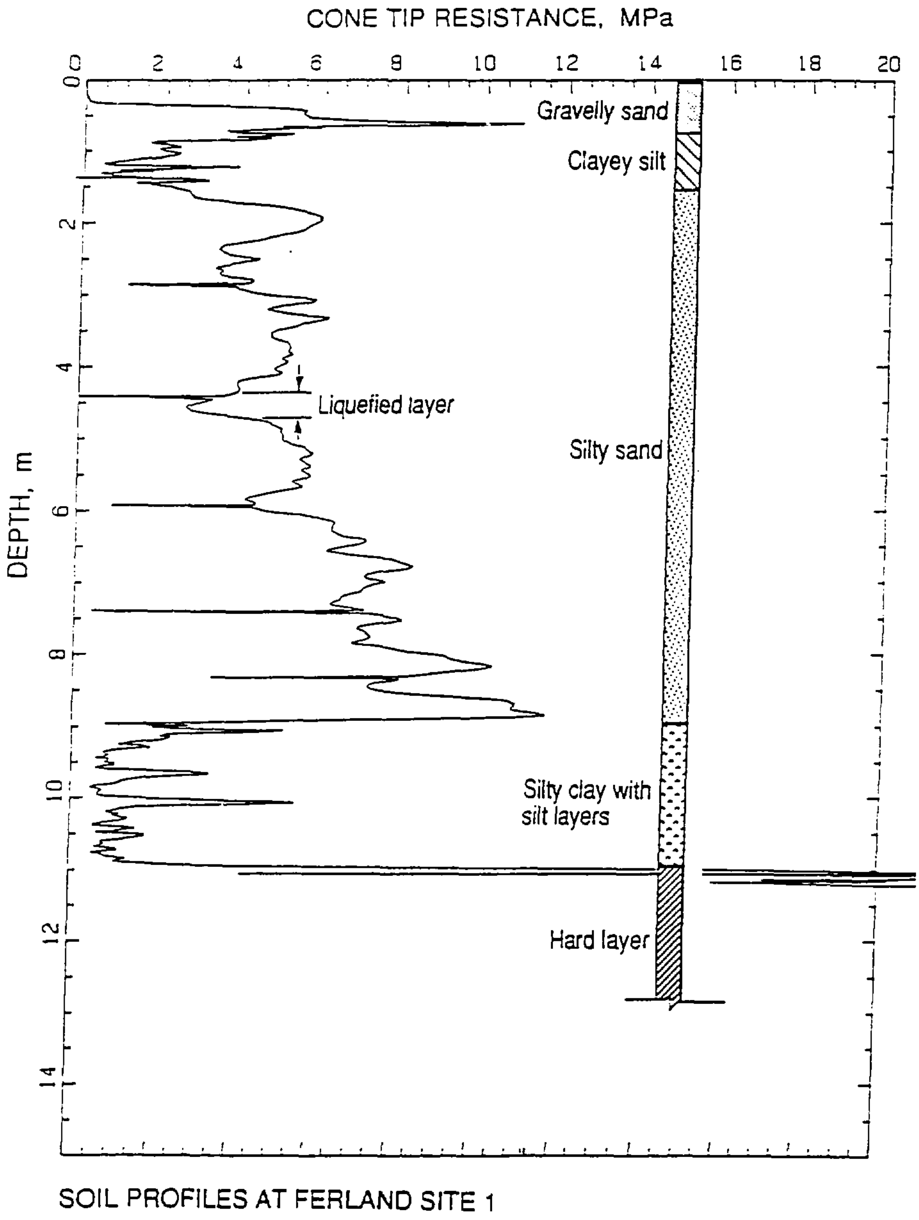


Figure 7. Soil profile determined with piezocone penetrometer adjacent to sand boil A at Site 1 by Tim Law of the National Research Council of Canada. A 0.3 m-thick sandy layer between 4.4 to 4.7 m depth was identified as the most likely source of the 1988 liquefied sand. A 0.75 m-thick sand layer between 2.25 to 3 m-depth appears to be susceptible to liquefaction and may have liquefied during past earthquakes.

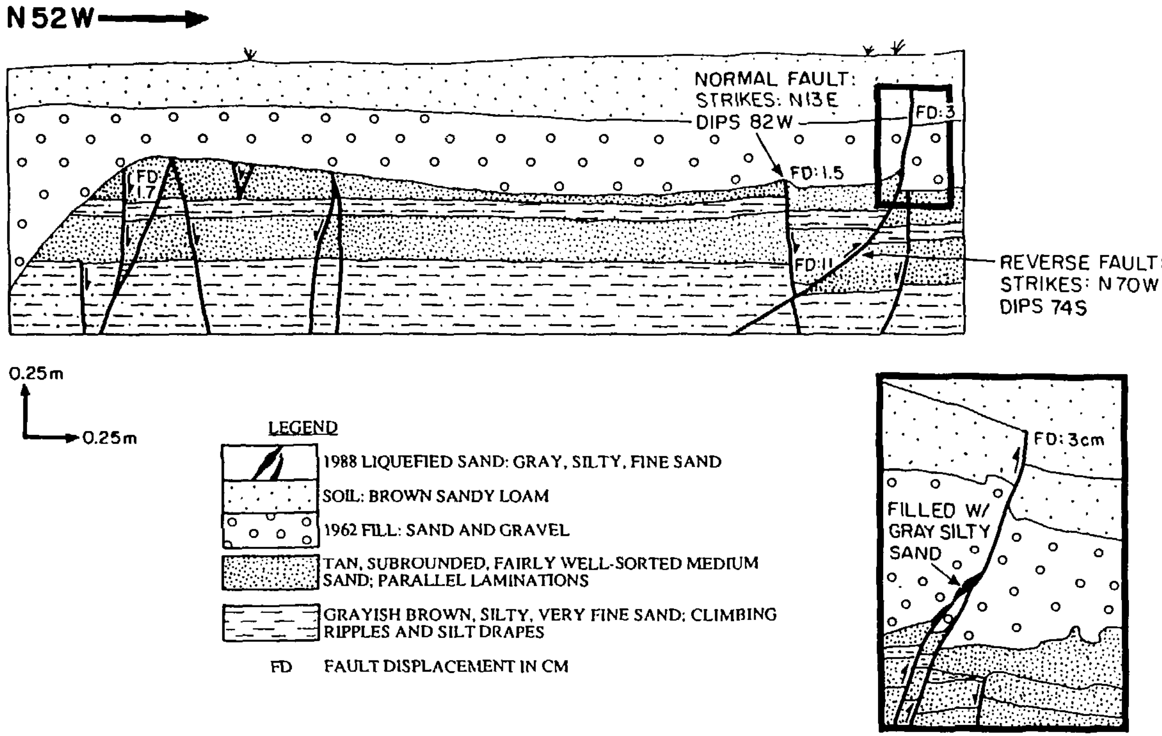


Figure 8. Trench log of southwestern wall of an excavation located about 5 m north of sand boil A. Normal faults on the southeast end (left) of the trench do not offset overlying fill that was placed in 1962. Normal and reverse faults on the northwest (right) end of the trench do offset the overlying fill and have been intruded by gray, silty sand (see blowup). Both these faults displace marker beds within the glacial sediments more than they offset the overlying fill suggesting at least two faulting events, the most recent being during the earthquake-induced liquefaction event in 1988.

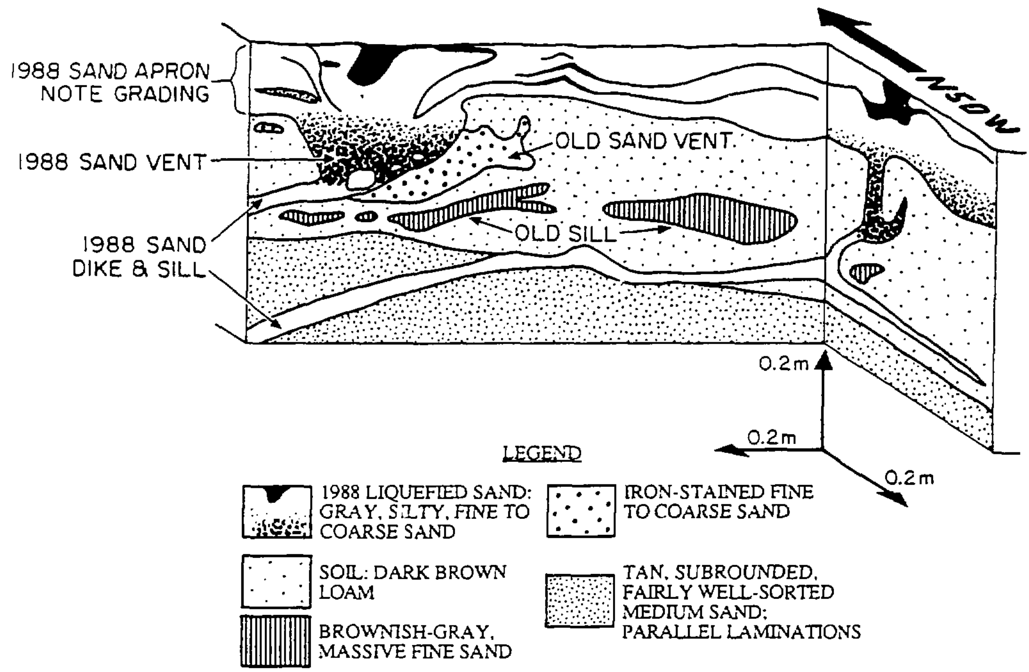


Figure 9. Block diagram of an excavation of sand boil B at Site 1 interpreted from photographs. The large apron of sand was about 10 m in diameter and up to 22 cm in thickness and had been fed from below through dikes, sills and vents. Sand was normally graded in both the vent and apron deposits. Pre-1988 sand dikes, sills and vents can be differentiated from 1988 features by the degree of weathering and the presence of roots. A soil sample taken below a weathered sill (generation 2) yielded a calibrated radiocarbon age of 2,330 years BP. This soil date indicates a very maximum age of the second generation dikes and sills exposed in this trench.

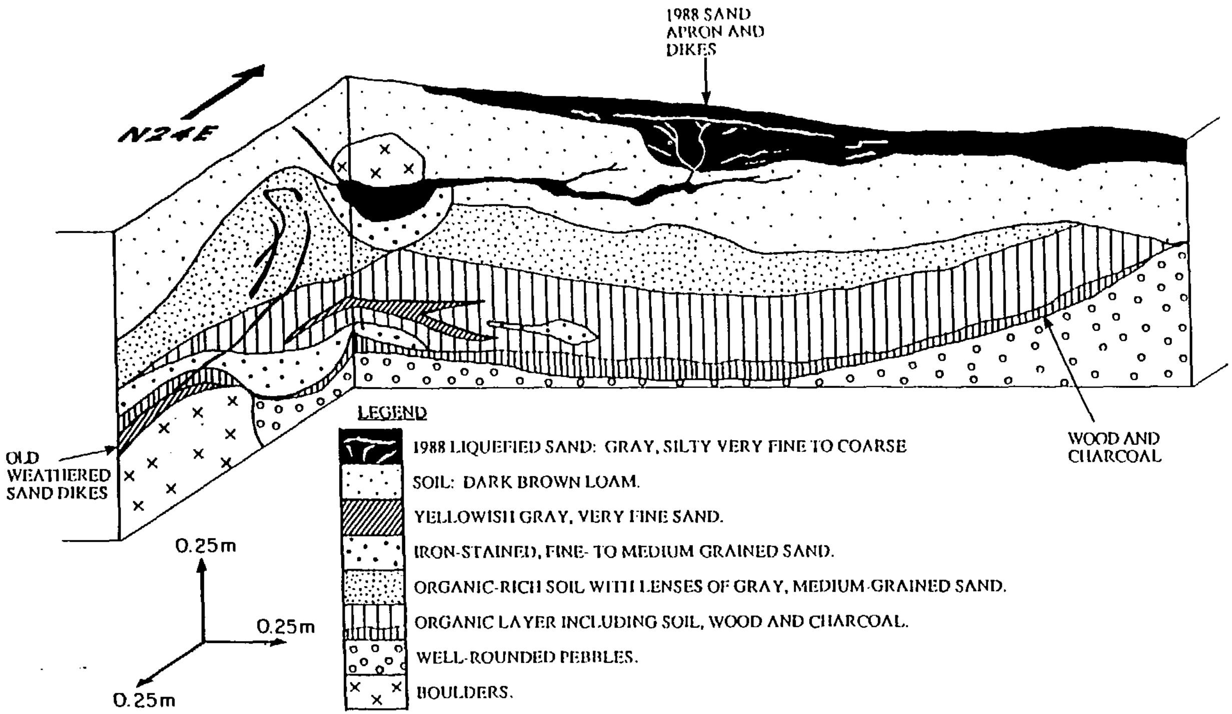


Figure 10. Block diagram of an excavation of sand boil E next to the creek, Bras Hamel, at Site 2 (Figure 5). Sand liquefied during the 1988 earthquake was intruded along a moderately dipping dike. The dike is roughly perpendicular to the topographic contour and occurs downslope from a topographic break. The formation of the dike may be linked to compression in the toe of a lateral spread or may reflect the influence of boulders on the emplacements of dikes. An older dike cross-cuts a charcoal layer that dates back to 1,868 years BP. Other old structures that may be related to liquefaction include dikes, diapirs and lenses of iron-stained sand.

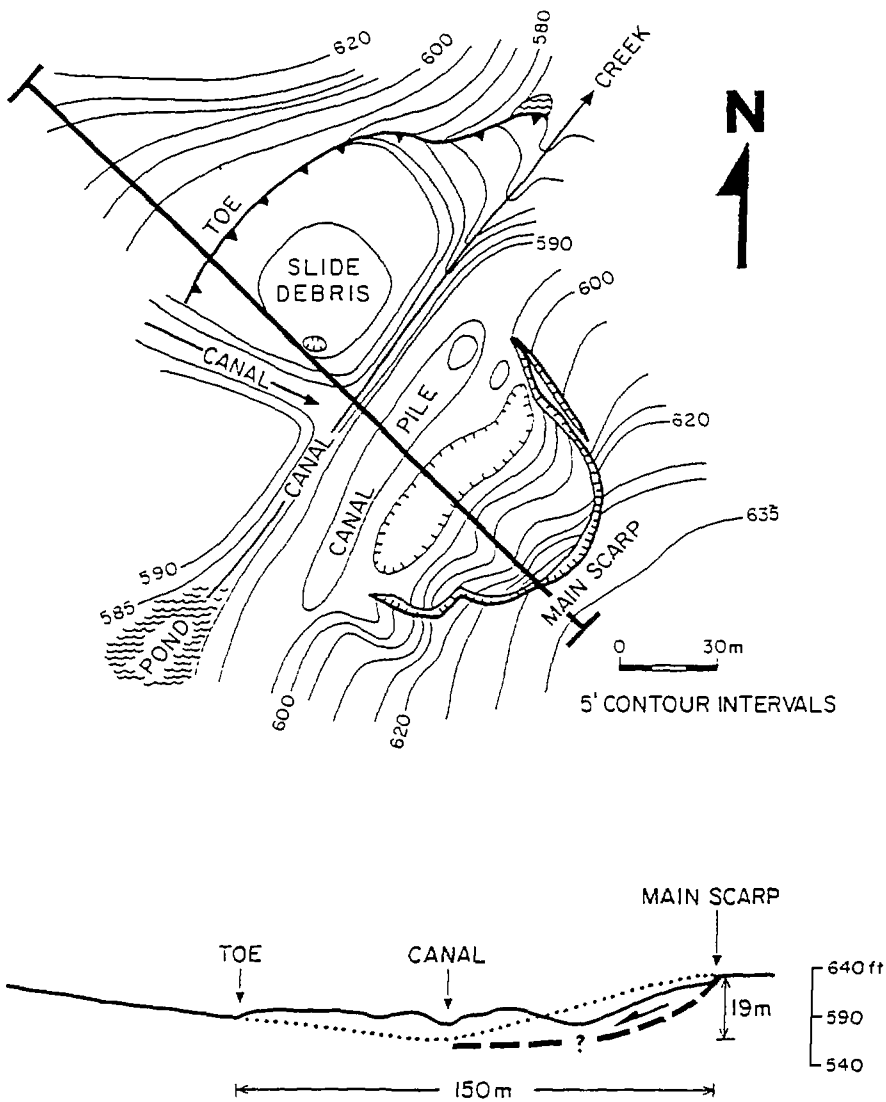


Figure 11. Topographic map and profile of St. Thècle landslide induced by the Saguenay earthquake. The slide is about 88 m across and extends 150 m across the valley. Before channelization of the creek, it was buried by about 10 m of slide debris. The mechanism of the failure is currently under investigation (Lefebvre, personal communication, 1989).

APPENDIX 1: Grain-Size Analyses

CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

PROJECT: QUEBEC JOB NO.: LOCATION: TRENCH SITE #2 IN
BORING: SAMPLE: 3 FERLAND, QEUBEC.
DATE: 2/16/1990 COMMENTS: .

MECHANICAL SIEVE ANALYSIS

SIEVE NO.	SIEVE SIZE (MM)	SIEVE WGT. (GR)	SIEVE +SOIL (GR)	SOIL WGT. (GR)	PERCENT RETAIN.	PERCENT CUMULAT.	PERCENT FINER
NO. 4	4.760	595.00	595.00	.00	.00	.00	100.00
NO. 8	2.360	647.40	650.00	2.60	.21	.21	99.79
NO. 20	.840	600.40	608.30	7.90	.64	.85	99.15
NO. 40	.425	506.70	527.50	20.80	1.68	2.53	97.47
NO. 80	.180	472.20	605.40	133.20	10.77	13.30	86.70
NO.100	.149	456.20	481.00	24.80	2.01	15.30	84.70
NO.200	.074	335.20	1051.80	716.60	57.94	73.24	26.76
PAN		373.00	704.00	331.00	26.76	100.00	.00

CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

PROJECT: QUEBEC JOB NO.: LOCATION: TRENCH SITE #2 IN
BORING: SAMPLE: 3 FERLAND, QEUBEC.
DATE: 2/16/1990 COMMENTS:.

HYDROMETER ANALYSIS

IDENTIFYING CAN NO. = 34 SPECIFIC GRAVITY = 2.65
WGT. OF SAMPLE (GR) = 50.00 % FINER, TOTAL SAMPLE= 26.76
HYDRO. A FACTOR = 1.00 MENISCUS CORRECTION = -3.00

ELAPSED TIME (MIN)	TEMP (C)	ACTUAL HYDRO. READ. (RA)	ZERO HYDRO. READ. (RO)	CORR. HYDRO. READ. (RC)	MENIS. CORR. READ. (RD)	EFFECT. LENGTH (CM)	EFFECT. PARTICLE DIAM. (MM)	PERCENT FINER
.25	28.00	27.00	-3.00	30.00	24.00	12.38	.0875	16.03
.50	28.00	22.00	-3.00	25.00	19.00	13.20	.0639	13.36
1.00	28.00	14.00	-3.00	17.00	11.00	14.50	.0474	9.08
2.00	28.00	7.00	-3.00	10.00	4.00	15.65	.0348	5.34
4.00	28.00	2.50	-3.00	5.50	-.50	16.38	.0252	2.94
8.00	28.00	.00	-3.00	3.00	-3.00	16.79	.0180	1.60
16.00	28.00	-1.00	-3.00	2.00	-4.00	16.95	.0128	1.07
30.00	28.00	-2.00	-3.00	1.00	-5.00	17.12	.0094	.53
60.00	27.00	-2.00	-3.00	1.00	-5.00	17.12	.0067	.53
120.00	27.00	-3.00	-3.00	.00	-6.00	17.28	.0048	.00

CRITICAL SIZES:

D85 SIZE = .153 MM
D60 SIZE = .111 MM
D30 SIZE = .077 MM
D10 SIZE = .051 MM
UNIFORMITY COEFFICIIENT CU = 2.176
CONCAVITY COEFFICIIENT CC = 1.047

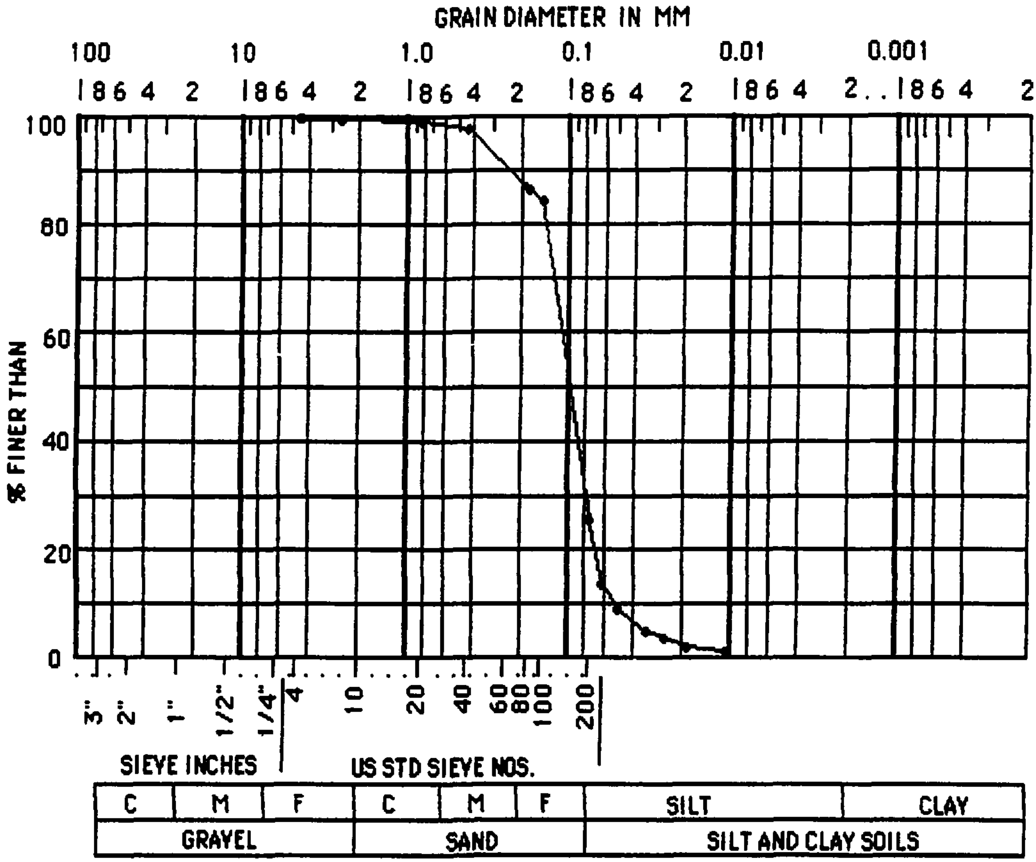
CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

GRAIN SIZE DISTRIBUTION

PROJECT: QUEBEC
BORING:
DATE: 2/16/1990

JOB NO.:
SAMPLE: 3
COMMENTS:

LOCATION: TRENCH SITE *2 IN FERLAND, QUEBEC.



DESCRIPTION " Dark grey Medium to Fine ($M - F^{+}$) SAND, some Silt. "

CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

PROJECT: QUEBEC JOB NO.: LOCATION: TRENCH SITE #3 IN
BORING: SAMPLE: 4 FERLAND, QUEBEC.
DATE: 2/16/1990 COMMENTS: .

MECHANICAL SIEVE ANALYSIS

SIEVE NO.	SIEVE SIZE (MM)	SIEVE WGT. (GR)	SIEVE +SOIL (GR)	SOIL WGT. (GR)	PERCENT RETAIN.	PERCENT CUMULAT.	PERCENT FINER
NO. 40	.425	506.70	506.70	.00	.00	.00	100.00
NO. 80	.180	472.20	491.90	19.70	5.62	5.62	94.38
NO.100	.149	456.20	499.30	43.10	12.30	17.92	82.08
NO.200	.074	335.20	544.10	208.90	59.62	77.54	22.46
PAN		373.00	451.70	78.70	22.46	100.00	.00

CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

PROJECT: QUEBEC   JOB NO.:   LOCATION: TRENCH SITE #3 IN
BORING: SAMPLE: 4   FERLAND, QUEBEC.
DATE: 2/16/1990   COMMENTS:.

HYDROMETER ANALYSIS

IDENTIFYING CAN NO. = 66   SPECIFIC GRAVITY = 2.65
WGT. OF SAMPLE (GR) = 50.00   % FINER, TOTAL SAMPLE= 22.46
HYDRO. A FACTOR = 1.00   MENISCUS CORRECTION = 1.00

ELAPSED TIME (MIN)	TEMP (C)	ACTUAL HYDRO. READ. (RA)	ZERO HYDRO. READ. (RO)	CORR. HYDRO. READ. (RC)	MENIS. CORR. READ. (RD)	EFFECT. LENGTH (CM)	EFFECT. PARTICLE DIAM. (MM)	PERCENT FINER
.25	26.00	19.00	-2.00	21.00	20.00	13.03	.0917	9.42
.50	26.00	13.00	-2.00	15.00	14.00	14.01	.0672	6.73
1.00	26.00	7.00	-2.00	9.00	8.00	14.99	.0492	4.04
2.00	26.00	3.00	-2.00	5.00	4.00	15.65	.0355	2.24
4.00	26.00	.00	-2.00	2.00	1.00	16.14	.0255	.90
8.00	26.00	-1.00	-2.00	1.00	.00	16.30	.0181	.45
16.00	26.00	-1.50	-2.00	.50	-.50	16.38	.0128	.22
30.00	26.00	-2.00	-2.00	.00	-1.00	16.46	.0094	.00
60.00	26.00	-2.00	-2.00	.00	-1.00	16.46	.0066	.00
120.00	26.00	-2.00	-2.00	.00	-1.00	16.46	.0047	.00

CRITICAL SIZES:

D85 SIZE = .156 MM
D60 SIZE = .115 MM
D30 SIZE = .081 MM
D10 SIZE = .069 MM
UNIFORMITY COEFFICIENT CU = 1.667
CONCAVITY COEFFICIENT CC = .827

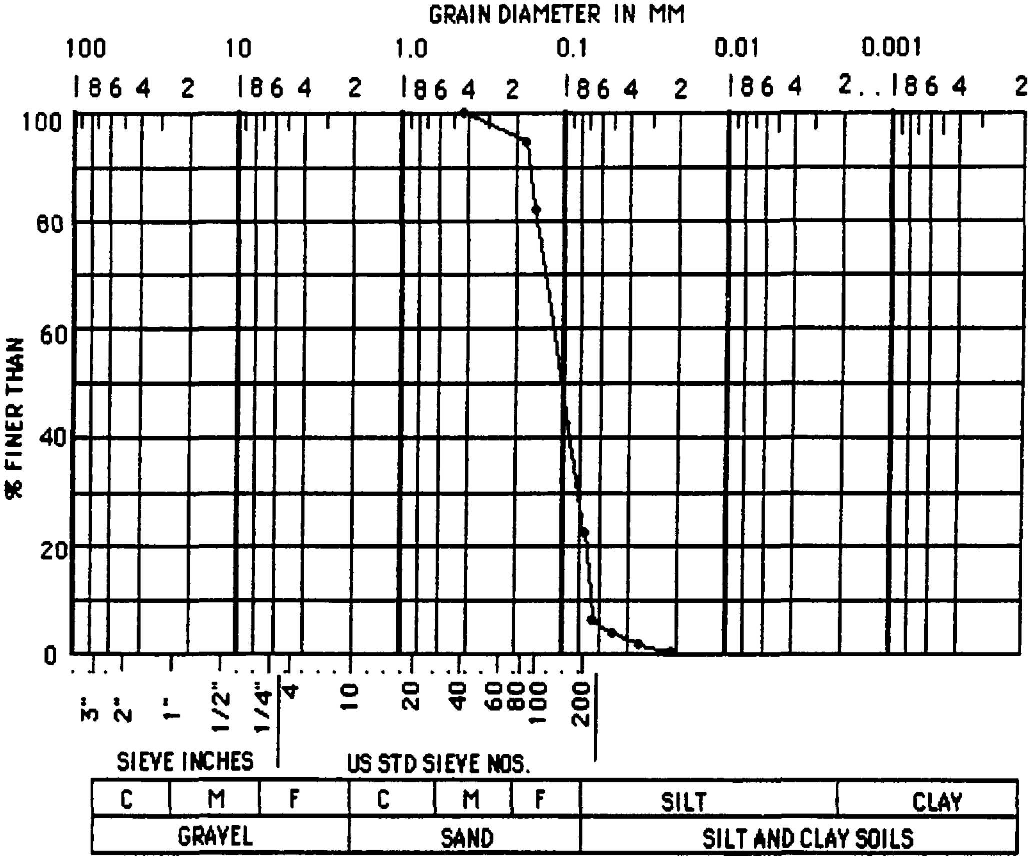
CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

GRAIN SIZE DISTRIBUTION

PROJECT: QUEBEC
BORING:
DATE: 2/16/1990

JOB NO.:
SAMPLE: 4
COMMENTS:

LOCATION: TRENCH SITE #3 IN FERLAND, QUEBEC.



DESCRIPTION " Brownish grey Fine (F^{+}) SAND, some (-) Silt. "

CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

PROJECT: QUEBEC JOB NO.: LOCATION: CONDUIT AT 7' DEPTH
BORING: SAMPLE: 5 CUT BY 1988 DICK.
DATE: 2/16/1990 COMMENTS:

MECHANICAL SIEVE ANALYSIS

SIEVE NO.	SIEVE SIZE (MM)	SIEVE WGT. (GR)	SIEVE +SOIL (GR)	SOIL WGT. (GR)	PERCENT RETAIN.	PERCENT CUMULAT.	PERCENT FINER
NO. 40	.425	506.40	506.40	.00	.00	.00	100.00
NO. 80	.180	472.20	474.50	2.30	.49	.49	99.51
NO. 100	.149	456.20	463.30	7.10	1.52	2.01	97.99
NO. 200	.074	335.20	563.20	228.00	48.67	50.67	49.33
PAN		373.00	604.10	231.10	49.33	100.00	.00

CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

PROJECT: QUEBEC JOB NO.: LOCATION: CONDUIT AT 7' DEPTH
BORING: SAMPLE: 5 CUT BY 1988 DICK.
DATE: 2/16/1990 COMMENTS:.

HYDROMETER ANALYSIS

IDENTIFYING CAN NO. = 44 SPECIFIC GRAVITY = 2.65
WGT. OF SAMPLE (GR) = 50.00 % FINER, TOTAL SAMPLE= 49.33
HYDRO. A FACTOR = 1.00 MENISCUS CORRECTION = 1.00

ELAPSED TIME (MIN)	TEMP (C)	ACTUAL HYDRO. READ. (RA)	ZERO HYDRO. READ. (RO)	CORR. HYDRO. READ. (RC)	MENIS. CORR. READ. (RD)	EFFECT. LENGTH (CM)	EFFECT. PARTICLE DIAM. (MM)	PERCENT FINER
.25	26.00	26.00	-2.00	28.00	27.00	11.89	.0875	27.57
.50	26.00	19.00	-2.00	21.00	20.00	13.03	.0648	20.68
1.00	26.00	10.00	-2.00	12.00	11.00	14.50	.0483	11.82
2.00	26.00	4.50	-2.00	6.50	5.50	15.40	.0352	6.40
4.00	26.00	2.00	-2.00	4.00	3.00	15.81	.0252	3.94
8.00	26.00	1.00	-2.00	3.00	2.00	15.97	.0179	2.95
16.00	26.00	.00	-2.00	2.00	1.00	16.14	.0127	1.97
30.00	26.00	.00	-2.00	2.00	1.00	16.14	.0093	1.97
60.00	26.00	.00	-2.00	2.00	1.00	16.14	.0066	1.97
120.00	26.00	.00	-2.00	2.00	1.00	16.14	.0047	1.97

CRITICAL SIZES:

D85 SIZE = .124 MM
D60 SIZE = .086 MM
D30 SIZE = .068 MM
D10 SIZE = .044 MM
UNIFORMITY COEFFICIENT CU = 1.955
CONCAVITY COEFFICIENT CC = 1.222

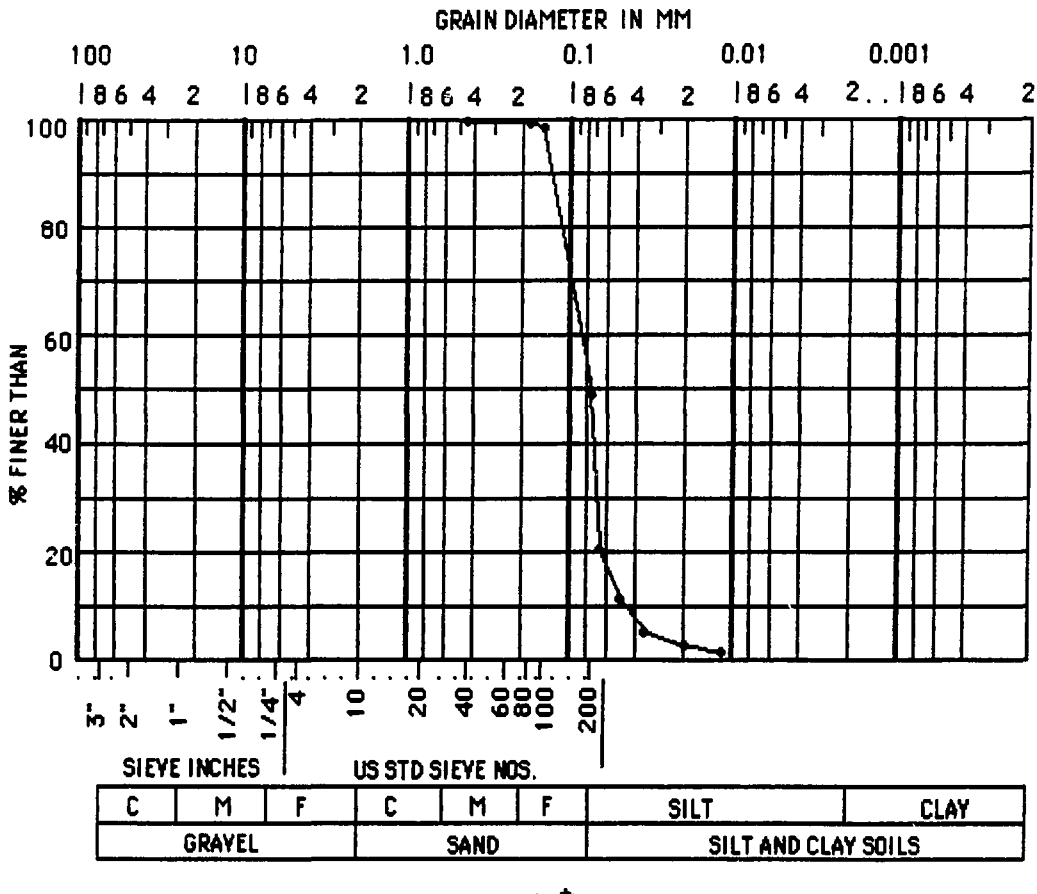
CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

GRAIN SIZE DISTRIBUTION

PROJECT: QUEBEC
BORING:
DATE: 2/16/1990

JOB NO.:
SAMPLE: 5
COMMENTS:

LOCATION: CONDUIT AT 7' DEPTH CUT BY 1988 DICK.



DESCRIPTION " Greyish brown Fine (F⁺) SAND, and (+) Silt. "

CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

PROJECT: QUEBEC JOB NO.: LOCATION: NW CORNER OF TRENCH #3
BORING: SAMPLE: 6 IN FERLAND, QUEBEC.
DATE: 2/16/1990 COMMENTS:.

MECHANICAL SIEVE ANALYSIS

SIEVE NO.	SIEVE SIZE (MM)	SIEVE WGT. (GR)	SIEVE +SOIL (GR)	SOIL WGT. (GR)	PERCENT RETAIN.	PERCENT CUMULAT.	PERCENT FINER
NO. 8	2.360	647.40	647.40	.00	.00	.00	100.00
NO. 20	.840	600.40	600.60	.20	.05	.05	99.95
NO. 40	.425	506.70	509.70	3.00	.80	.85	99.15
NO. 80	.180	472.20	524.80	52.60	14.04	14.89	85.11
NO.100	.149	456.20	492.00	35.80	9.55	24.45	75.55
NO.200	.074	335.20	502.40	167.20	44.62	69.07	30.93
PAN		373.00	488.90	115.90	30.93	100.00	.00

CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

PROJECT: QUEBEC   JOB NO.:   LOCATION: NW CORNER OF TRENCH #3
BORING: SAMPLE: 6   IN FERLAND, QUEBEC.
DATE: 2/16/1990   COMMENTS:

HYDROMETER ANALYSIS

IDENTIFYING CAN NO. = 85   SPECIFIC GRAVITY = 2.65
WGT. OF SAMPLE (GR) = 50.00   % FINER, TOTAL SAMPLE= 30.93
HYDRO. A FACTOR = 1.00   MENISCUS CORRECTION = 1.00

ELAPSED TIME (MIN)	TEMP (C)	ACTUAL HYDRO. READ. (RA)	ZERO HYDRO. READ. (RO)	CORR. HYDRO. READ. (RC)	MENIS. CORR. READ. (RD)	EFFECT. LENGTH (CM)	EFFECT. PARTICLE DIAM. (MM)	PERCENT FINER
.25	26.00	21.00	-2.00	23.00	22.00	12.71	.0905	14.20
.50	26.00	15.00	-2.00	17.00	16.00	13.69	.0664	10.50
1.00	26.00	7.00	-2.00	9.00	8.00	14.99	.0492	5.56
2.00	26.00	2.00	-2.00	4.00	3.00	15.81	.0357	2.47
4.00	26.00	.00	-2.00	2.00	1.00	16.14	.0255	1.24
8.00	26.00	-1.00	-2.00	1.00	.00	16.30	.0181	.62
16.00	26.00	-1.50	-2.00	.50	-.50	16.38	.0128	.31
30.00	26.00	-2.00	-2.00	.00	-1.00	16.46	.0094	.00
60.00	26.00	-2.00	-2.00	.00	-1.00	16.46	.0066	.00
120.00	26.00	-2.00	-2.00	.00	-1.00	16.46	.0047	.00

CRITICAL SIZES:

D85 SIZE = .180 MM
D60 SIZE = .117 MM
D30 SIZE = .074 MM
D10 SIZE = .065 MM
UNIFORMITY COEFFICIENT CU = 1.80
CONCAVITY COEFFICIENT CC = .72

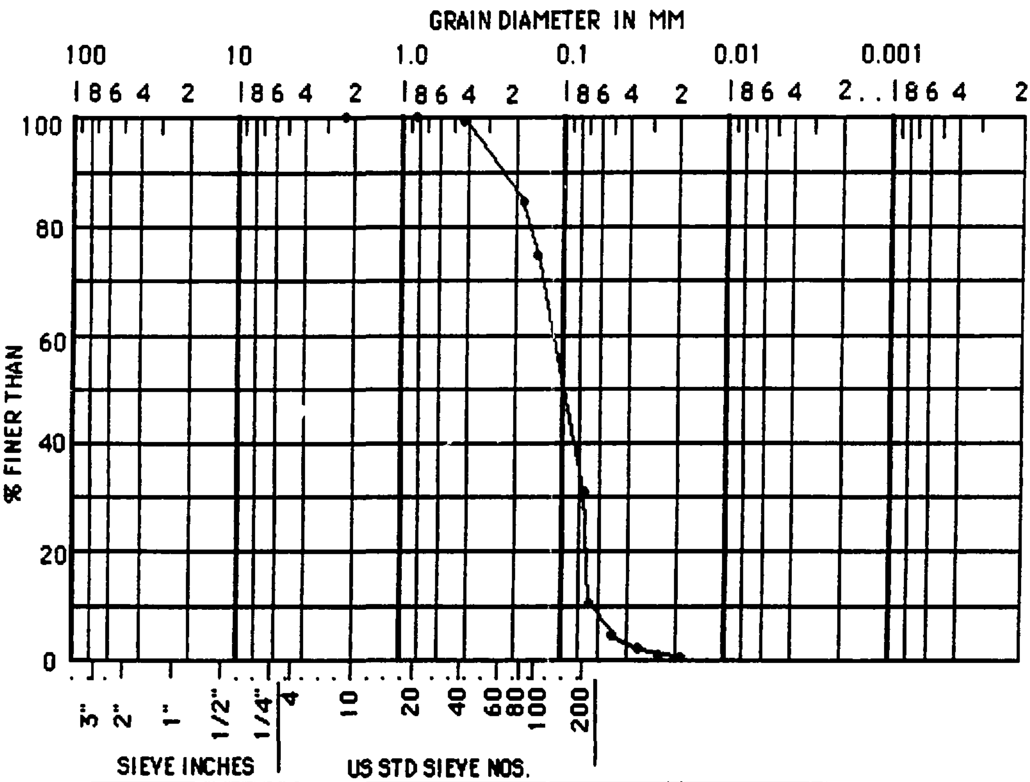
CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

GRAIN SIZE DISTRIBUTION

PROJECT: QUEBEC
BORING:
DATE: 2/16/1990

JOB NO.:
SAMPLE: 6
COMMENTS:

LOCATION: NW CORNER OF TRENCH #3 IN FERLAND, QUEBEC.



C	M	F	C	M	F	SILT	CLAY
GRAVEL			SAND			SILT AND CLAY SOILS	

DESCRIPTION " Brownish Medium to Fine (M-F+) SAND, some Silt. "

CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

PROJECT: QUEBEC   JOB NO.:   LOCATION: BOTTOM OF TRENCH #3
BORING: SAMPLE: 7   IN FERLAND, QUEBEC.
DATE: 2/20/1990   DEPTH: 9-10'

MECHANICAL SIEVE ANALYSIS

SIEVE NO.	SIEVE SIZE (MM)	SIEVE WGT. (GR)	SIEVE +SOIL (GR)	SOIL WGT. (GR)	PERCENT RETAIN.	PERCENT CUMULAT.	PERCENT FINER
NO. 40	.425	506.70	506.70	.00	.00	.00	100.00
NO. 80	.180	472.20	473.20	1.00	.11	.11	99.89
NO. 100	.149	456.20	460.00	3.80	.41	.52	99.48
NO. 200	.074	335.20	841.80	506.60	54.92	55.44	44.56
PAN		373.00	784.00	411.00	44.56	100.00	.00

CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

PROJECT: QUEBEC JOB NO.: LOCATION: BOTTOM OF TRENCH #3
BORING: SAMPLE: 7 IN FERLAND, QUEBEC.
DATE: 2/20/1990 DEPTH: 9-10'

HYDROMETER ANALYSIS

IDENTIFYING CAN NO. = 47 SPECIFIC GRAVITY = 2.65
WGT. OF SAMPLE (GR) = 50.00 % FINER, TOTAL SAMPLE= 44.56
HYDRO. A FACTOR = 1.00 MENISCUS CORRECTION = 1.00

ELAPSED TIME (MIN)	TEMP (C)	ACTUAL HYDRO. READ. (RA)	ZERO HYDRO. READ. (RO)	CORR. HYDRO. READ. (RC)	MENIS. CORR. READ. (RD)	EFFECT. LENGTH (CM)	EFFECT. PARTICLE DIAM. (MM)	PERCENT FINER
.25	25.00	37.00	-2.00	39.00	38.00	10.09	.0815	34.69
.50	25.00	31.00	-2.00	33.00	32.00	11.07	.0604	29.36
1.00	25.00	22.00	-2.00	24.00	23.00	12.54	.0455	21.35
2.00	25.00	11.00	-2.00	13.00	12.00	14.34	.0344	11.56
4.00	25.00	4.00	-2.00	6.00	5.00	15.48	.0252	5.34
8.00	25.00	2.00	-2.00	4.00	3.00	15.81	.0180	3.56
16.00	25.00	.00	-2.00	2.00	1.00	16.14	.0129	1.78
30.00	25.00	-1.00	-2.00	1.00	.00	16.30	.0095	.89
60.00	25.00	-1.00	-2.00	1.00	.00	16.30	.0067	.89
120.00	25.00	-2.00	-2.00	.00	-1.00	16.46	.0048	.00

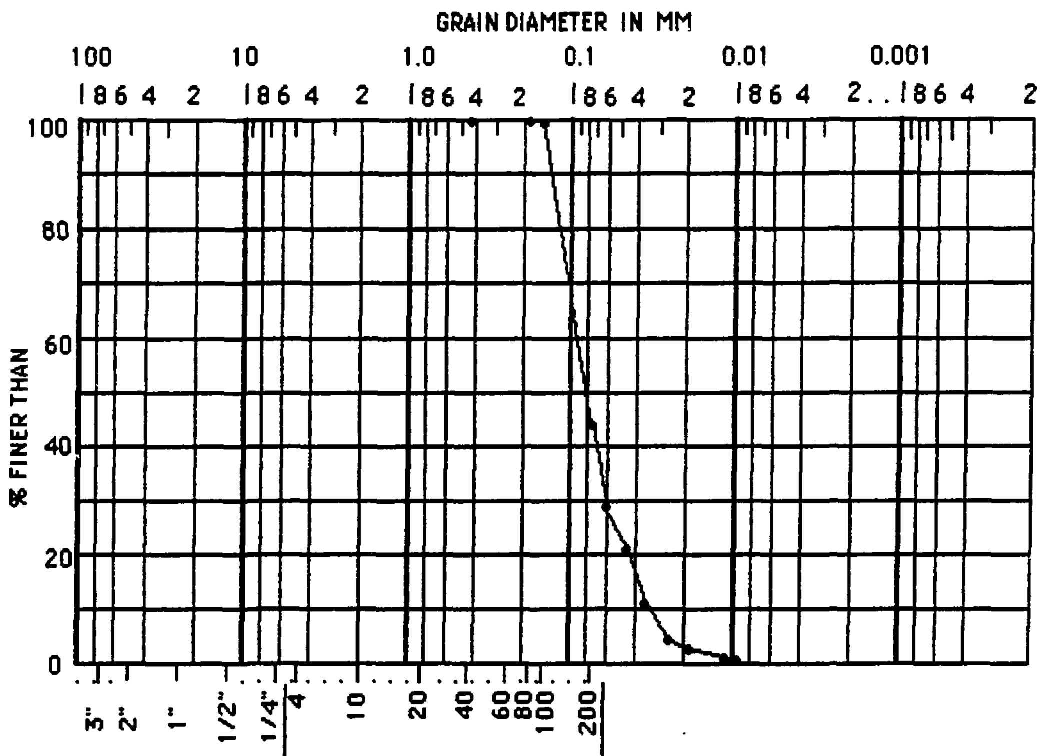
CRITICAL SIZES:

D85 SIZE = .124 MM
D60 SIZE = .090 MM
D30 SIZE = .061 MM
D10 SIZE = .032 MM
UNIFORMITY COEFFICIENT CU = 2.813
CONCAVITY COEFFICIENT CC = 1.292

CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

GRAIN SIZE DISTRIBUTION

PROJECT: QUEBEC　　JOB NO.:　　LOCATION: BOTTOM OF TRENCH #3 IN FERLAND, QUEBEC.
BORING:　　SAMPLE: 7
DATE: 2/20/1990　　DEPTH: 9-10'



GRAVEL			SAND			SILT AND CLAY SOILS	
C	M	F	C	M	F	SILT	CLAY

DESCRIPTION " Brownish grey Fine (F) SAND, and Silt. "

CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

PROJECT: QUEBEC JOB NO.: LOCATION: BOTTOM OF TRENCH #3
BORING: SAMPLE: 8 IN FERLAND, QUEBEC.
DATE: 1/30/1990 DEPTH: 11-11.5'

MECHANICAL SIEVE ANALYSIS

SIEVE NO.	SIEVE SIZE (MM)	SIEVE WGT. (GR)	SIEVE +SOIL (GR)	SOIL WGT. (GR)	PERCENT RETAIN.	PERCENT CUMULAT.	PERCENT FINER
NO. 40	.425	455.10	455.10	.00	.00	.00	100.00
NO. 80	.180	467.00	516.70	49.70	5.01	5.01	94.99
NO. 100	.149	455.70	561.40	105.70	10.65	15.66	84.34
NO. 200	.074	415.30	944.80	529.50	53.36	69.02	30.98
PAN		382.60	690.00	307.40	30.98	100.00	.00

CRITICAL SIZES:

D85 SIZE = .151 MM
D60 SIZE = .108 MM

CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

PROJECT: QUEBEC   JOB NO.:   LOCATION: BOTTOM OF TRENCH #3
BORING: SAMPLE: 8   IN FERLAND, QUEBEC.
DATE: 2/20/1990   DEPTH: 11-11.5'

HYDROMETER ANALYSIS

IDENTIFYING CAN NO. = 39   SPECIFIC GRAVITY = 2.65
WGT. OF SAMPLE (GR) = 50.00   % FINER, TOTAL SAMPLE= 19.14
HYDRO. A FACTOR = 1.00   MENISCUS CORRECTION = 1.00

ELAPSED TIME (MIN)	TEMP (C)	ACTUAL HYDRO. READ. (RA)	ZERO HYDRO. READ. (RO)	CORR. HYDRO. READ. (RC)	MENIS. CORR. READ. (RD)	EFFECT. LENGTH (CM)	EFFECT. PARTICLE DIAM. (MM)	PERCENT FINER
.25	25.00	37.00	-2.00	39.00	38.00	10.09	.0815	14.90
.50	25.00	30.00	-2.00	32.00	31.00	11.24	.0608	12.23
1.00	25.00	20.00	-2.00	22.00	21.00	12.87	.0460	8.41
2.00	25.00	11.00	-2.00	13.00	12.00	14.34	.0344	4.97
4.00	25.00	5.00	-2.00	7.00	6.00	15.32	.0251	2.67
8.00	25.00	3.00	-2.00	5.00	4.00	15.65	.0179	1.91
16.00	25.00	.00	-2.00	2.00	1.00	16.14	.0129	.76
30.00	25.00	.00	-2.00	2.00	1.00	16.14	.0094	.76
60.00	26.00	-1.00	-2.00	1.00	.00	16.30	.0066	.38
120.00	27.00	-1.50	-2.00	.50	-.50	16.38	.0046	.19

CRITICAL SIZES:

D85 SIZE = .173 MM
D60 SIZE = .119 MM
D30 SIZE = .084 MM
D10 SIZE = .052 MM
UNIFORMITY COEFFICIENT CU = 2.288
CONCAVITY COEFFICIENT CC = 1.140

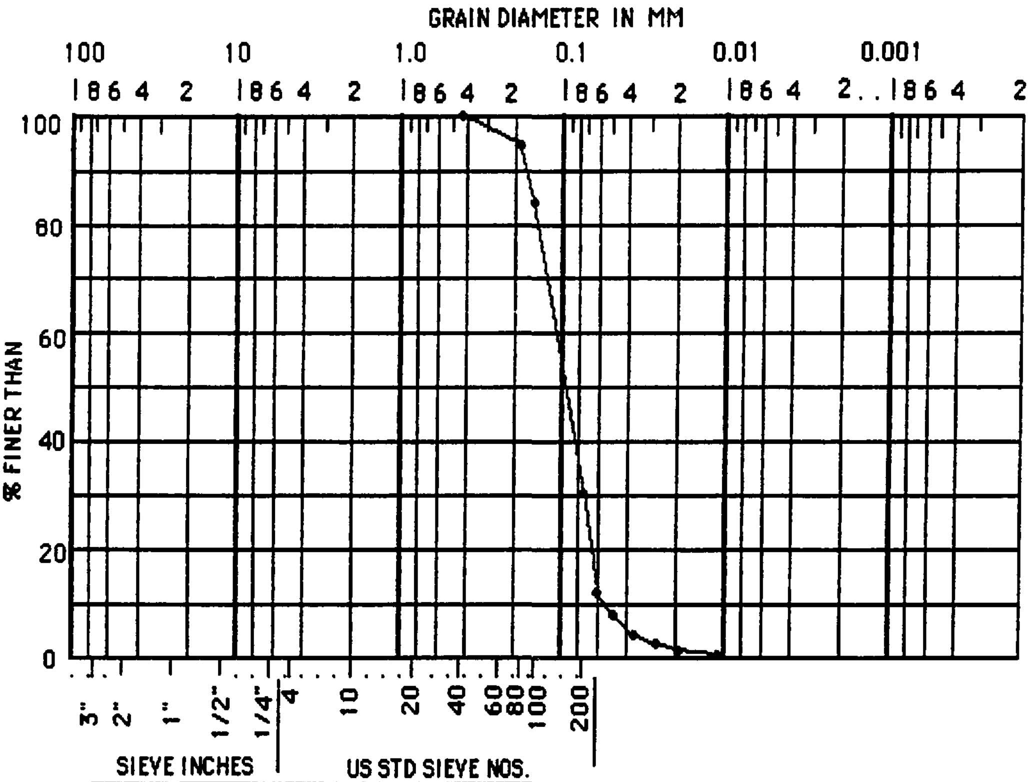
CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

GRAIN SIZE DISTRIBUTION

PROJECT: QUEBEC
BORING:
DATE: 2/20/1990

JOB NO.:
SAMPLE: 8
DEPTH: 11-11.5'

LOCATION: BOTTOM OF TRENCH #3 IN FERLAND, QUEBEC.



C	M	F	C	M	F	SILT	CLAY
GRAVEL			SAND			SILT AND CLAY SOILS	

DESCRIPTION " Brownish Fine (F) SAND, some Silt. "

CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

PROJECT: QUEBEC JOB NO.: LOCATION: BOTTOM OF TRENCH #3
BORING: SAMPLE: 9 IN FERLAND, QUEBEC.
DATE: 2/20/1990 DEPTH: 14'

MECHANICAL SIEVE ANALYSIS

SIEVE NO.	SIEVE SIZE (MM)	SIEVE WGT. (GR)	SIEVE +SOIL (GR)	SOIL WGT. (GR)	PERCENT RETAIN.	PERCENT CUMULAT.	PERCENT FINER
NO. 40	.425	506.70	506.70	.00	.00	.00	100.00
NO. 80	.180	472.20	488.90	16.70	2.24	2.24	97.76
NO. 100	.149	456.20	509.60	53.40	7.16	9.40	90.60
NO. 200	.074	335.20	847.10	511.90	68.62	78.02	21.98
PAN		373.00	537.00	164.00	21.98	100.00	.00

CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

PROJECT: QUEBEC JOB NO.: LOCATION: BOTTOM OF TRENCH #3
BORING: SAMPLE: 9 IN FERLAND, QUEBEC.
DATE: 2/20/1990 DEPTH: 14'

HYDROMETER ANALYSIS

IDENTIFYING CAN NO. = 20 SPECIFIC GRAVITY = 2.65
WGT. OF SAMPLE (GR) = 50.00 % FINER, TOTAL SAMPLE= 21.98
HYDRO. A FACTOR = 1.00 MENISCUS CORRECTION = 1.00

ELAPSED TIME (MIN)	TEMP (C)	ACTUAL HYDRO. READ. (RA)	ZERO HYDRO. READ. (RO)	CORR. HYDRO. READ. (RC)	MENIS. CORR. READ. (RD)	EFFECT. LENGTH (CM)	EFFECT. PARTICLE DIAM. (MM)	PERCENT FINER
.25	26.00	32.00	-2.00	34.00	33.00	10.91	.0839	14.92
.50	26.00	23.00	-2.00	25.00	24.00	12.38	.0632	10.97
1.00	26.00	13.00	-2.00	15.00	14.00	14.01	.0475	6.58
2.00	26.00	7.00	-2.00	9.00	8.00	14.99	.0348	3.95
4.00	26.00	4.00	-2.00	6.00	5.00	15.48	.0250	2.63
8.00	26.00	2.00	-2.00	4.00	3.00	15.81	.0178	1.76
16.00	26.00	.00	-2.00	2.00	1.00	16.14	.0127	.88
30.00	26.00	-1.00	-2.00	1.00	.00	16.30	.0094	.44
60.00	27.00	-1.00	-2.00	1.00	.00	16.30	.0065	.44
120.00	27.00	-2.00	-2.00	.00	-1.00	16.46	.0047	.00

CRITICAL SIZES:

D85 SIZE = .141 MM
D60 SIZE = .109 MM
D30 SIZE = .080 MM
D10 SIZE = .060 MM
UNIFORMITY COEFFICIENT CU = 1.817
CONCAVITY COEFFICIENT CC = .979

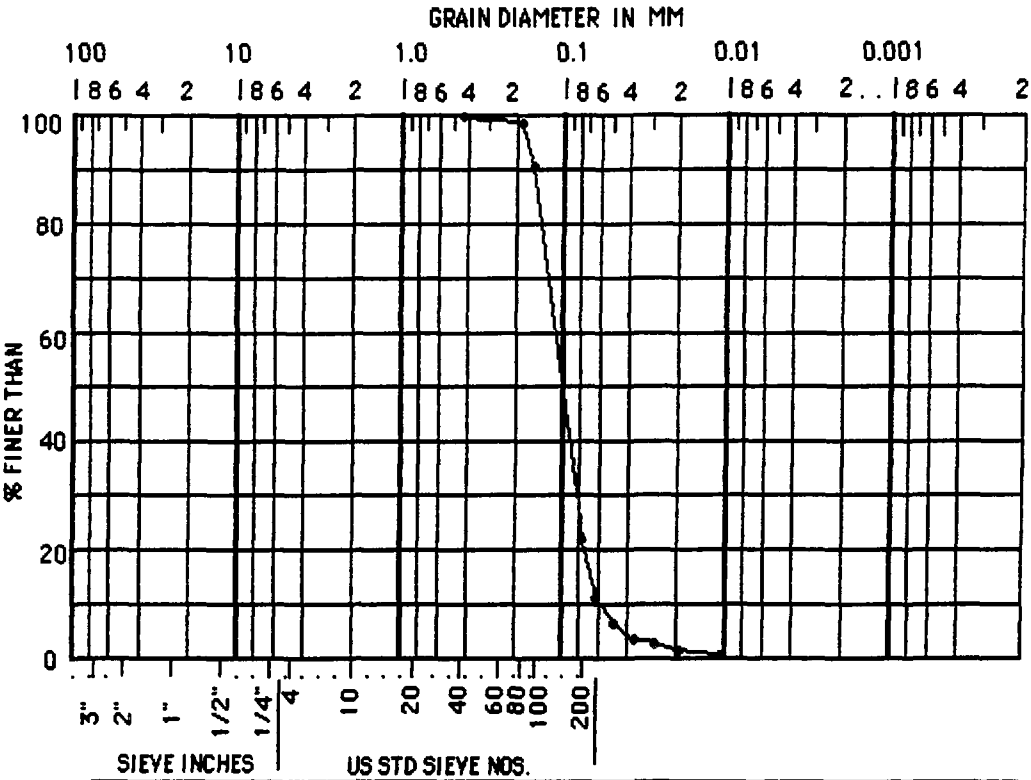
CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

GRAIN SIZE DISTRIBUTION

PROJECT: QUEBEC
BORING:
DATE: 2/20/1990

JOB NO.:
SAMPLE: 9
DEPTH: 14'

LOCATION: BOTTOM OF TRENCH #3 IN FEALAND, QUEBEC.



C	M	F	C	M	F	SILT	CLAY
GRAVEL			SAND			SILT AND CLAY SOILS	

DESCRIPTION "Grey Fine (F) SAND, some (-) Silt."

CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

PROJECT: QUEBEC JOB NO.: LOCATION: BOTTOM OF TRENCH #3 IN FERLAND, QUEBEC.
BORING: SAMPLE: 10
DATE: 2/20/1990 DEPTH: 18'

MECHANICAL SIEVE ANALYSIS

SIEVE NO.	SIEVE SIZE (MM)	SIEVE WGT. (GR)	SIEVE +SOIL (GR)	SOIL WGT. (GR)	PERCENT RETAIN.	PERCENT CUMULAT.	PERCENT FINER
NO. 40	.425	506.70	506.70	.00	.00	.00	100.00
NO. 80	.180	472.20	503.00	30.80	3.51	3.51	96.49
NO. 100	.149	456.20	543.30	87.10	9.91	13.42	86.58
NO. 200	.074	335.20	938.50	603.30	68.67	82.09	17.91
PAN		373.00	530.40	157.40	17.91	100.00	.00

CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

PROJECT: QUEBEC JOB NO.: LOCATION: BOTTOM OF TRENCH #3
BORING: SAMPLE: 10 IN FERLAND, QUEBEC.
DATE: 2/20/1990 DEPTH: 18'

HYDROMETER ANALYSIS

IDENTIFYING CAN NO. = 67 SPECIFIC GRAVITY = 2.65
WGT. OF SAMPLE (GR) = 50.00 % FINER, TOTAL SAMPLE= 17.91
HYDRO. A FACTOR = 1.00 MENISCUS CORRECTION = 1.00

ELAPSED TIME (MIN)	TEMP (C)	ACTUAL HYDRO. READ. (RA)	ZERO HYDRO. READ. (RO)	CORR. HYDRO. READ. (RC)	MENIS. CORR. READ. (RD)	EFFECT. LENGTH (CM)	EFFECT. PARTICLE DIAM. (MM)	PERCENT FINER
.25	27.00	36.00	-2.50	38.50	37.00	10.26	.0805	13.77
.50	27.00	23.00	-2.50	25.50	24.00	12.38	.0625	9.12
1.00	27.00	14.00	-2.50	16.50	15.00	13.85	.0468	5.90
2.00	27.00	8.00	-2.50	10.50	9.00	14.83	.0342	3.76
4.00	27.00	4.50	-2.50	7.00	5.50	15.40	.0247	2.50
8.00	27.00	3.00	-2.50	5.50	4.00	15.65	.0176	1.97
16.00	27.00	.00	-2.50	2.50	1.00	16.14	.0126	.89
30.00	27.00	-1.00	-2.50	1.50	.00	16.30	.0093	.54
60.00	28.00	-2.00	-2.50	.50	-1.00	16.46	.0065	.18
120.00	28.00	-2.00	-2.50	.50	-1.00	16.46	.0046	.18

CRITICAL SIZES:

D85 SIZE = .147 MM
D60 SIZE = .114 MM
D30 SIZE = .084 MM
D10 SIZE = .064 MM
UNIFORMITY COEFFICIENT CU = 1.781
CONCAVITY COEFFICIENT CC = .967

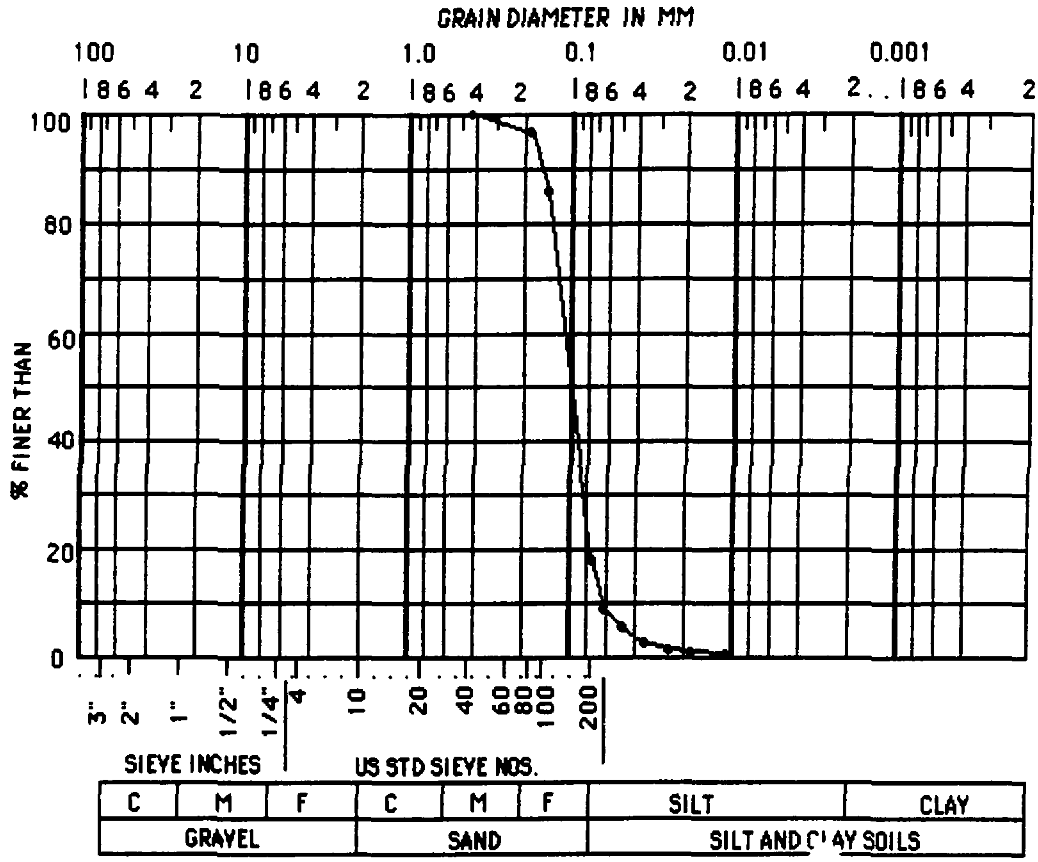
CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

GRAIN SIZE DISTRIBUTION

PROJECT: QUEBEC
BORING:
DATE: 2/20/1990

JOB NO.:
SAMPLE: 10
DEPTH: 18'

LOCATION: BOTTOM OF TRENCH #3 IN FERLAND, QUEBEC.



DESCRIPTION " Grey Fine (F) SAND, little Silt. "

CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

PROJECT: QUEBEC JOB NO.: LOCATION: BOTTOM OF TRENCH #3
BORING: SAMPLE: 11 IN FERLAND, QUEBEC.
DATE: 2/20/1990 DEPTH: 20.5'

MECHANICAL SIEVE ANALYSIS

SIEVE NO.	SIEVE SIZE (MM)	SIEVE WGT. (GR)	SIEVE +SOIL (GR)	SOIL WGT. (GR)	PERCENT RETAIN.	PERCENT CUMULAT.	PERCENT FINER
NO. 20	.840	600.40	600.40	.00	.00	.00	100.00
NO. 40	.425	506.70	507.70	1.00	.11	.11	99.89
NO. 80	.180	472.20	528.60	56.40	6.43	6.55	93.45
NO. 100	.149	456.20	540.00	83.80	9.56	16.11	83.89
NO. 200	.074	335.20	875.60	540.40	61.64	77.75	22.25
PAN		373.00	568.10	195.10	22.25	100.00	.00

CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

PROJECT:	QUEBEC	JOB NO.:		LOCATION:	BOTTOM OF TRENCH #3
BORING:		SAMPLE:	11		IN FERLAND, QUEBEC.
DATE:	2/20/1990	DEPTH:	20.5'		

HYDROMETER ANALYSIS

IDENTIFYING CAN NO. =	90		SPECIFIC GRAVITY =	2.65
WGT. OF SAMPLE (GR) =	50.00		% FINER, TOTAL SAMPLE=	22.25
HYDRO. A FACTOR =	1.00		MENISCUS CORRECTION =	1.00

ELAPSED TIME (MIN)	TEMP (C)	ACTUAL HYDRO. READ. (RA)	ZERO HYDRO. READ. (RO)	CORR. HYDRO. READ. (RC)	MENIS. CORR. READ. (RD)	EFFECT. LENGTH (CM)	EFFECT. PARTICLE DIAM. (MM)	PERCENT FINER
.25	27.00	34.00	-3.00	37.00	35.00	10.58	.0817	16.44
.50	27.00	27.00	-3.00	30.00	28.00	11.73	.0608	13.33
1.00	27.00	19.00	-3.00	22.00	20.00	13.03	.0454	9.77
2.00	27.00	12.00	-3.00	15.00	13.00	14.18	.0334	6.66
4.00	27.00	8.00	-3.00	11.00	9.00	14.83	.0242	4.89
8.00	27.00	4.50	-3.00	7.50	5.50	15.40	.0174	3.33
16.00	28.00	3.00	-3.00	6.00	4.00	15.65	.0123	2.67
30.00	28.00	2.00	-3.00	5.00	3.00	15.81	.0090	2.22
60.00	28.00	1.00	-3.00	4.00	2.00	15.97	.0064	1.78
120.00	28.00	.00	-3.00	3.00	1.00	16.14	.0046	1.33

CRITICAL SIZES:

D85 SIZE = .152 MM
D60 SIZE = .114 MM
D30 SIZE = .081 MM
D10 SIZE = .046 MM
UNIFORMITY COEFFICIENT CU = 2.478
CONCAVITY COEFFICIENT CC = 1.251

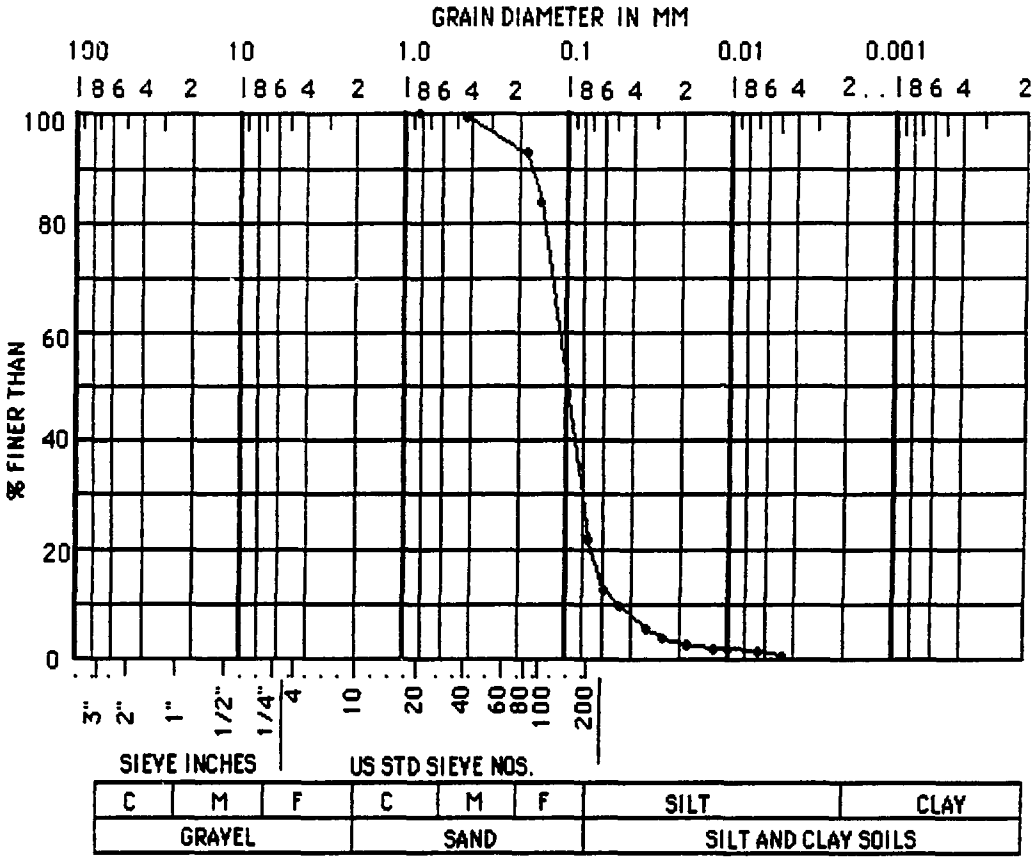
CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

GRAIN SIZE DISTRIBUTION

PROJECT: QUEBEC
BORING:
DATE: 2/20/1990

JOB NO.:
SAMPLE: 11
DEPTH: 20.5'

LOCATION: BOTTOM OF TRENCH #3 IN FERLAND, QUEBEC.



DESCRIPTION " Grey Fine (F) SAND, some (-) Silt. "

CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

PROJECT: QUEBEC JOB NO.: LOCATION: SECTION A OF TRENCH
BORING: SAMPLE: 12 #4, FERLAND, QUEBEC
DATE: 2/20/1990 COMMENTS:

MECHANICAL SIEVE ANALYSIS

SIEVE NO.	SIEVE SIZE (MM)	SIEVE WGT. (GR)	SIEVE +SOIL (GR)	SOIL WGT. (GR)	PERCENT RETAIN.	PERCENT CUMULAT.	PERCENT FINER
NO. 8	2.360	647.40	647.40	.00	.00	.00	100.00
NO. 20	.840	600.40	601.70	1.30	.14	.14	99.86
NO. 40	.425	506.70	517.10	10.40	1.14	1.28	98.72
NO. 80	.180	472.20	560.70	88.50	9.70	10.98	89.02
NO. 100	.149	456.20	501.50	45.30	4.96	15.94	84.06
NO. 200	.074	335.20	861.30	526.10	57.65	73.59	26.41
PAN		373.00	614.00	241.00	26.41	100.00	0.00

CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

PROJECT: QUEBEC   JOB NO.:   LOCATION: SECTION A OF TRENCH
BORING: SAMPLE: 12   #4, FERLAND, QUEBEC
DATE: 2/20/1990   COMMENTS:

HYDROMETER ANALYSIS

IDENTIFYING CAN NO. = 23   SPECIFIC GRAVITY = 2.65
WGT. OF SAMPLE (GR) = 50.00   % FINER, TOTAL SAMPLE= 26.41
HYDRO. A FACTOR = 1.00   MENISCUS CORRECTION = 1.00

ELAPSED TIME (MIN)	TEMP (C)	ACTUAL HYDRO. READ. (RA)	ZERO HYDRO. READ. (RO)	CORR. HYDRO. READ. (RC)	MENIS. CORR. READ. (RD)	EFFECT. LENGTH (CM)	EFFECT. PARTICLE DIAM. (MM)	PERCENT FINER
.25	28.00	31.00	-3.00	34.00	32.00	11.07	.0828	17.93
.50	28.00	21.00	-3.00	24.00	22.00	12.71	.0627	12.65
1.00	28.00	10.00	-3.00	13.00	11.00	14.50	.0474	6.85
2.00	28.00	3.50	-3.00	6.50	4.50	15.57	.0347	3.43
4.00	28.00	2.50	-3.00	5.50	3.50	15.73	.0247	2.90
8.00	28.00	-.50	-3.00	2.50	.50	16.22	.0177	1.32
16.00	28.00	-1.00	-3.00	2.00	.00	16.30	.0126	1.05
30.00	28.00	-1.50	-3.00	1.50	-.50	16.38	.0092	.79
60.00	28.00	-2.00	-3.00	1.00	-1.00	16.46	.0065	.53
120.00	28.00	-2.00	-3.00	1.00	-1.00	16.46	.0046	.53

CRITICAL SIZES:

D85 SIZE = .154 MM
D60 SIZE = .111 MM
D30 SIZE = .077 MM
D10 SIZE = .056 MM
UNIFORMITY COEFFICIENT CU = 1.982
CONCAVITY COEFFICIENT CC = .954

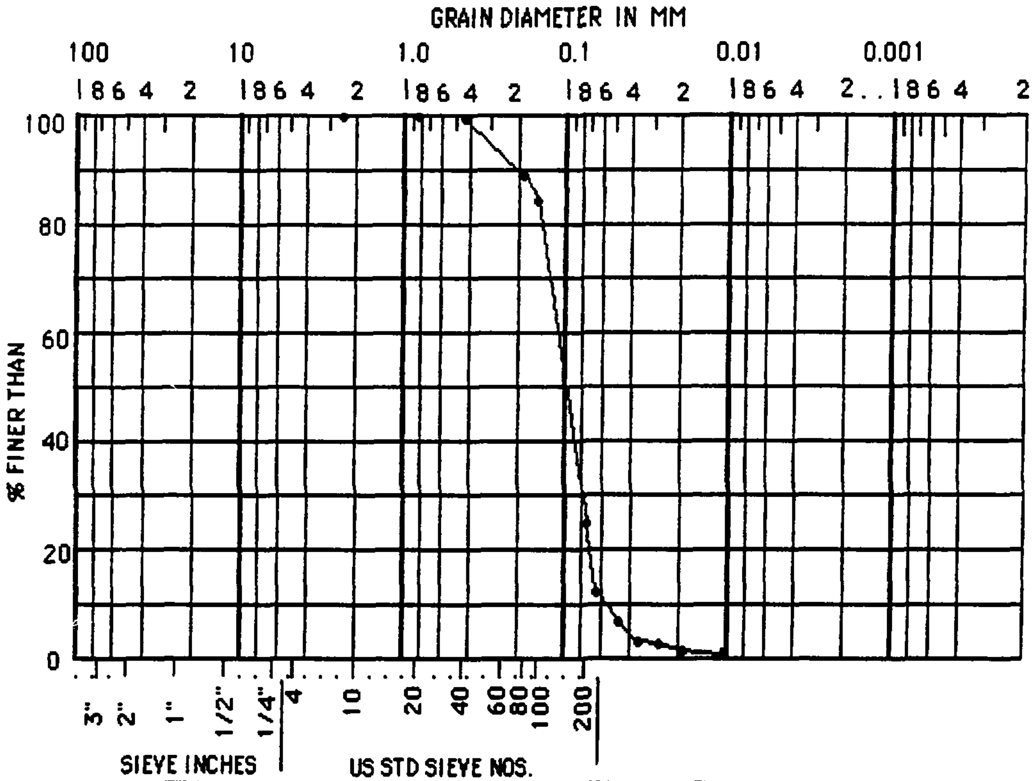
CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

GRAIN SIZE DISTRIBUTION

PROJECT: QUEBEC
BORING:
DATE: 2/20/1990

JOB NO.:
SAMPLE: 12
COMMENTS:

LOCATION: SECTION A OF TRENCH #4, FERLAND, QUEBEC



C	M	F	C	M	F	SILT	CLAY
GRAVEL			SAND			SILT AND CLAY SOILS	

DESCRIPTION " Light grey Medium to Fine (M-F+) SAND, some Silt. "

CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

PROJECT: QUEBEC JOB NO.: LOCATION: SECTION D OF TRENCH
BORING: SAMPLE: 13 #4, FERLAND, QUEBEC
DATE: 2/20/1990 COMMENTS:

MECHANICAL SIEVE ANALYSIS

SIEVE NO.	SIEVE SIZE (MM)	SIEVE WGT. (GR)	SIEVE +SOIL (GR)	SOIL WGT. (GR)	PERCENT RETAIN.	PERCENT CUMULAT.	PERCENT FINER
NO. 8	2.360	647.40	647.40	.00	.00	.00	100.00
NO. 20	.840	600.40	600.70	.30	.10	.10	99.90
NO. 40	.425	506.70	507.70	1.00	.32	.42	99.58
NO. 80	.180	472.20	480.70	8.50	2.72	3.13	96.87
NO.100	.149	456.20	462.40	6.20	1.98	5.12	94.88
NO.200	.074	335.20	451.40	116.20	37.15	42.26	57.74
PAN		373.00	553.60	180.60	57.74	100.00	.00

CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

PROJECT: QUEBEC   JOB NO.:   LOCATION: SECTION D OF TRENCH
BORING: SAMPLE: 13   #4, FERLAND, QUEBEC
DATE: 2/20/1990   COMMENTS:.

HYDROMETER ANALYSIS

IDENTIFYING CAN NO. = 55   SPECIFIC GRAVITY = 2.65
WGT. OF SAMPLE (GR) = 50.00   % FINER, TOTAL SAMPLE= 57.74
HYDRO. A FACTOR = 1.00   MENISCUS CORRECTION = 1.00

ELAPSED TIME (MIN)	TEMP (C)	ACTUAL HYDRO. READ. (RA)	ZERO HYDRO. READ. (RO)	CORR. HYDRO. READ. (RC)	MENIS. CORR. READ. (RD)	EFFECT. LENGTH (CM)	EFFECT. PARTICLE DIAM. (MM)	PERCENT FINER
.25	28.00	29.00	-3.00	32.00	30.00	11.40	.0840	36.89
.50	28.00	17.00	-3.00	20.00	18.00	13.36	.0643	23.05
1.00	28.00	8.00	-3.00	11.00	9.00	14.83	.0479	12.68
2.00	28.00	3.00	-3.00	6.00	4.00	15.65	.0348	6.92
4.00	28.00	1.00	-3.00	4.00	2.00	15.97	.0249	4.61
8.00	28.00	.00	-3.00	3.00	1.00	16.14	.0177	3.46
16.00	28.00	-1.00	-3.00	2.00	.00	16.30	.0126	2.31
30.00	28.00	-1.50	-3.00	1.50	-.50	16.38	.0092	1.73
60.00	27.00	-2.00	-3.00	1.00	-1.00	16.46	.0066	1.15
120.00	27.00	-2.00	-3.00	1.00	-1.00	16.46	.0047	1.15

CRITICAL SIZES:

D85 SIZE = .124 MM
D60 SIZE = .077 MM
D30 SIZE = .066 MM
D10 SIZE = .042 MM
UNIFORMITY COEFFICIENT CU = 1.833
CONCAVITY COEFFICIENT CC = 1.347

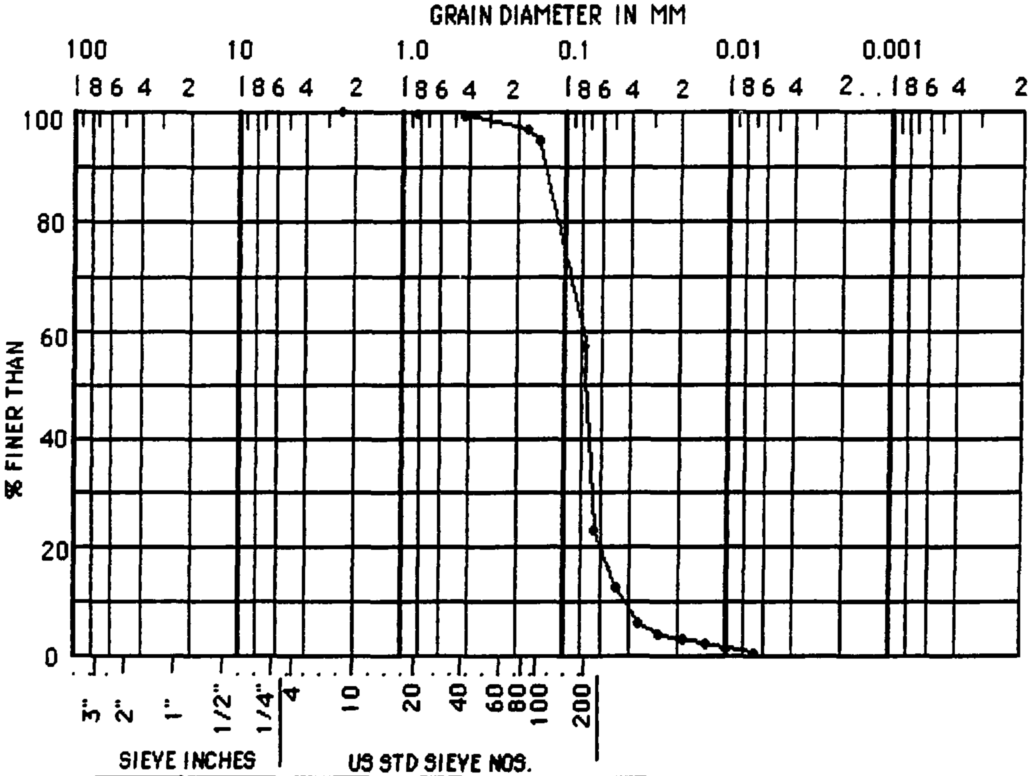
CITY COLLEGE OF NEW YORK
CIVIL ENGINEERING DEPARTMENT
SOIL MECHANICS LABORATORY

GRAIN SIZE DISTRIBUTION

PROJECT: QUEBEC
BORING:
DATE: 2/20/1990

JOB NO.:
SAMPLE: 13
COMMENTS:

LOCATION: SECTION D OF TRENCH #4, FERLAND, QUEBEC



C	M	F	C	M	F	SILT	CLAY
GRAVEL			SAND			SILT AND CLAY SOILS	

DESCRIPTION " Brownish grey SILT, and Fine (F) Sand. "