The geotechnical properties of a Champlain clay deposit with saline pore water in Lachenaie, Quebec

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ABSTRACT
This paper summarises the results of an extensive geotechnical testing program for the Champlain clay deposit of Lachenaie, Quebec. Nine sites spread over a 50 km^2 area were sampled. The testing program included 80 œdometer tests, 80 pore water extractions and analyses, 70 Swedish fall cone tests and 50 grain size distributions. Details on the tools used to manage and compare the large amount of generated test data are given in the paper. Typical values and vertical profiles for relevant geotechnical properties are presented. The occurrence of two distinct grey silty clay layers is discussed. The high clay stiffness is shown to be in agreement with the occurrence of an erosion event and with the maximum clay elevation of a nearby terrace. Finally, the presence of quick clay lenses in this otherwise saline and relatively insensitive clay body is discussed.

RÉSUMÉ
Cet article présente les résultats d'un vaste programme de caractérisation géotechnique du dépôt d'argile Champlain de Lachenaie, au Québec. Neuf sites répartis sur 50 km^2 ont été échantillonnés. Le programme de caractérisation comprend 80 essais oedométriques, 80 analyses et extractions d'eau interstitielle, 70 essais au cône suédois et 50 distributions granulométriques. Certains détails quant aux outils utilisés pour gérer et comparer la grande quantité de résultats obtenus sont présentés. Des valeurs typiques et des profils des propriétés géotechniques pertinentes sont donnés. La présence de deux couches distinctes d'argile grise est rapportée. On montre que la grande rigidité de l'argile est en accord avec l'hypothèse d'un épisode d'érosion et avec l'élévation maximale de l'argile sur une terrasse avoisinante. Finalement, malgré la salinité élevée et la faible sensibilité du dépôt en général, on note la présence de lentilles d'argile très sensible.

1 INTRODUCTION

This paper summarises a large geotechnical testing program conducted on the Lachenaie clay body, located near Montreal, Quebec. During the testing program, 9 sites spread over a 50 km^2 area bisected by highway 640 were sampled and characterised (Figure 1).

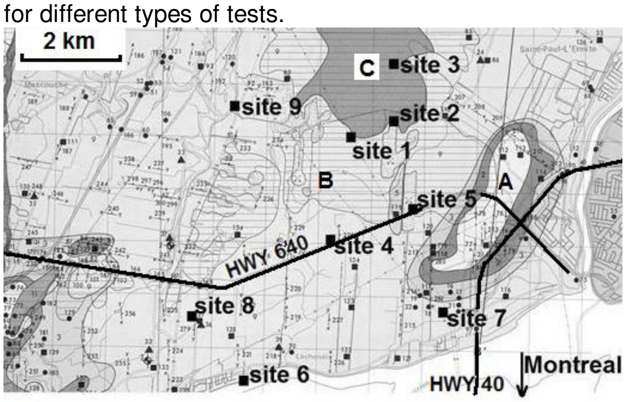
The main objectives of the testing program were to explain and to model the relatively high pore water salinity found in the soil profile and in the shale bedrock of the Lachenaie area (Réginensi 2009; Benabdallah 2010). The testing program was not limited to pore water extraction and analysis. X-ray diffraction measurements were also employed to evaluate the clay mineralogy. Most of the geotechnical properties commonly considered when dealing with Champlain clays were evaluated. Consolidation tests, Swedish cone measurements, permeability tests and grain size analyses were conducted. Some results were found in previous geotechnical reports covering the same area. For example, shear strength (c_u) from vane shear tests were found in a report by GSI Environnement (2001). In due course, the large quantity of test data raised interesting questions which prompted the redaction of this article.

The first issue considered in this paper pertains to the occurrence of two distinct grey silty clay layers in the Lachenaie area. Often seen as homogeneous bodies, Champlain clay deposits may show interesting discontinuities when looked at in detail. This paper describes the characteristics of the two layers observed in Lachenaie. Comparisons are made with the Champlain clay deposits found in other localities.

The second issue regards the stiffness of the clay body in Lachenaie where c_u and σ'_p can respectively reach 125 and 580 kPa (GSI Environnement 2001). In this paper, we show that this relative stiffness can be explained by involving an erosion scenario. By using the same approach as Bouchard et al. (1983), we show that a maximum surface elevation slightly lower than the current maximum clay elevation on a nearby terrace would suffice to explain the high σ'_p and c_u values found in Lachenaie.

Owing to its high pore water salinity, the Lachenaie clay deposit has a relatively low sensitivity when compared with other clays of the Champlain Sea basin. Nevertheless, some sensitive clay lenses were observed. Their distribution is explained in the paper. The array of geotechnical and geochemical properties measured during the Lachenaie testing program is well suited to study clay sensitivity as this property often reflects the intricate links between geochemistry, mineralogy, grain size distribution and mechanical properties in clay bodies. Comparisons are made with the trends observed during previous efforts to map and to predict the occurrence of sensitive clays in the Champlain Sea basin (Lefebvre and Grondin 1978; Lebuis et al. 1983).

As a large amount of data was generated during this testing program, this paper also exposes a simple and inexpensive way to compare databases in Excel format for different types of tests.



A ( ): till
B ( ): clay sometimes overlain by a thin layer of sand
C (■): clay overlain by peat

Figure 1: The Lachenaie test sites superposed on the geotechnical map of Dion (1978) (Modified from Benabdallah 2010).

2 CHAMPLAIN CLAY GEOLOGY, GEOCHEMISTRY, AND GEOTECHNICAL PROPERTIES: A BRIEF OVERVIEW

Champlain clays were deposited during the Champlain Sea episode which followed the last North American glaciation (Wisconsinian glaciation). This episode lasted roughly from 12 000 to 10 000 years BP (before present). Around Montreal, the Champlain Sea episode was preceded by Lake Chambly and followed by Lake Lampsilis, two fresh water lakes. In some areas around Montreal, notably a few kilometres north of Lachenaie, varved clays were deposited during the Lake Chambly episode (Dion 1978).

The silty clays deposited during the Champlain Sea episode are mainly composed of rock flour, primary minerals ground by the glaciers. Around Montreal, the minerals that predominate are feldspars, quartz and amphiboles (Foscal-Mella 1976). The clay size fraction varies throughout the basin and on each vertical profile. It can be as low as 20% at the outskirts of the basin while it can reach 85 % near its center (Leroueil et al. 1983).

As the load of the glacier on the continental crust was removed, the Champlain Sea basin gradually emerged from the water. Since then, variable thicknesses of clay have been eroded. At the center of the basin, overconsolidation ratios (*OCR*) are often low (between 1.2 and 2.5), indicating that little erosion has occurred since deposition. Elsewhere, major erosion events can sometimes be inferred from high preconsolidation pressures (σ'_p) or from vane shear test profiles. For example, in the Saguenay River valley, σ'_p and *OCR* can reach values of 1000 kPa and 25 respectively (Demers and Leroueil 2002). When important, the extent of the erosion can be evaluated using the methodology proposed by Bouchard et al. (1983). The intercept of the linear relationship between elevation and c_u or σ'_p is thought to provide a good estimate of the original ground surface elevation.

Champlain clays are thought to have been deposited in water where the salinity was highly variable in time and space. However, at the bottom of the Champlain Sea, the salinity was probably close to the actual average sea water salinity of 35 g/L (Hillaire-Marcel 1988; Wassenaar et al. 1988).

Since the retreat of the Champlain Sea, salts have been partially leached from the clay pore water. The leaching process is known to result in clay sensitivity. Sensitivity (S_t) is the ratio of the intact and remoulded shear strengths (c_u/c_{ur}). For the Champlain Sea basin, several studies have looked at the link between geochemistry, mineralogy, grain size distribution and S_t (Lefebvre and Grondin 1978; Lebuis et al. 1983). The main objective of these two groups of authors was to map the areas prone to the massive earth flows associated with very sensitive (quick) clays (S_t>50). Consequently, their work was focused on leached clays. In this paper, we look instead at a clay deposit where little leaching has occurred.

The development of very sensitive clays has been found to require two geochemical conditions: a low salinity and a low divalent cations / total cations ratio (Andersson-Sköld et al. 2005 and references therein). The link between salinity and sensitivity is not linear. Torrance (1974) observed that salinity must be lower than a threshold value of 2 g/L for sensitivity to increase during leaching. However, leaching is not a sufficient condition for the development of sensitivity. Söderblom (1969) noted that if the leaching process leads the pore water from a Na^+ system to a Ca^{2+} and Mg^{2+} system, as it is often the case, sensitivity will remain low. Dispersant agents must be present to ensure that the pore water remains in a Na^+ system after the leaching. From a more geotechnical standpoint, sensitive clays are often associated with the siltier parts of clay deposits, and thus to materials with low liquid limits (w_L) (Lebuis et al. 1983). The link between sensitivity and low w_L values is two-fold as for a given material, the salt leaching process itself will lower w_L.

3 SITE DESCIPTION AND TESTING PROGRAM

The 9 Lachenaie test sites are located just north of the island of Montreal, west of highway 40, on both sides of highway 640 (Figure 1). The sites are located on a plain which is gently sloping toward the Mille-Îles River. The ground surface elevation at the 9 sites varies between 11 and 22 m. A terrace with an elevation of 50 to 60 m can be found 5 km west of site 9. The bluff which delimits the terrace is thought to be the remnant of an abandoned estuarine channel (Brown-Macpherson 1967).

A similar stratigraphy is observed at each of the 9 sites. A thin (less than 5 m) veneer of sand or brown oxidised clay is found on top of 10 to 25 m of grey silty clay. Underneath the clay layer, there is between 2 and 7 m of till. The till sits on the shale bedrock which is highly fractured on top.

On each site, 3 monitoring wells were installed: one in the upper part of the grey silty clay layer, one close to the bottom of this layer and one in the fractured shale bedrock. During the drilling operations preceding the installation of the bedrock monitoring well, the silty clay layer was sampled continuously with 3-inch thin-walled samplers. The geochemical and hydraulic data gathered using the 27 monitoring wells were used to model the migration of saline water since the end of the Champlain Sea episode (Réginensi 2009; Benabdallah 2010). This paper will focus on the geotechnical data obtained from the large number of intact clay samples recovered.

Most of the geotechnical properties commonly evaluated when working with Champlain clays were measured. Table 1 lists the various tests that were conducted and the reference or standard on which the procedures were based. Depending on the thickness of the clay layer and on the variability of the property being evaluated, different numbers of tests per site were decided upon. For example, only 3 or 4 specific gravity (G_s) measurements per site were deemed necessary, whereas 10 to 20 w_L values were obtained for most sites.

The w_L values were obtained using the Swedish fall cone method. A few samples were tested using the Casagrande apparatus to verify that both methods were equivalent (Lefebvre and Grondin 1978; Claveau-Mallet et al. 2010). The Swedish fall cone has the advantage of allowing the evaluation of S_t and c_u. Grain size analysis and G_s measurements were done using the standard procedures. Triaxial cells and in situ variable-head tests were used to evaluate the clay hydraulic conductivity (K). Œdometers tests allowed evaluating K and σ'_p. An incremental loading procedure with $\Delta p/p \approx 0.5$ was used.

For each site several tests and analyses were conducted to obtain information pertaining to the clay geochemistry and mineralogy. Mineralogy and organic matter content were investigated with the X-ray diffraction technique (XRD) and loss-on-ignition tests (LOI) (Réginensi 2009). Details on the testing methods are especially important for pore water extraction. Pore water salinity has been shown in the past to depend on extraction methods. The leaching method used in early studies regarding the leaching hypothesis — the idea that sensitivity originated from salt leaching (e.g. Bjerrum 1954) — has been shown to be more erratic and to give higher salinity values than methods based on clay consolidation (Torrance 1974; Söderblom 1969). For this study, a modified triaxial cell was used to extract pore water by consolidating the clay sample. Several tests were done to validate this extraction method (Benabdallah et al. 2008). More details on the extraction and analysis protocols are given in Benabdallah (2010).

For each test, results were compiled in an Excel Database. To compare the different databases, an Excel VBA subroutine was written (Figure 2). For each entry of the destination database, the subroutine finds the closest entry (elevation-wise) in the source database. This allows comparing two databases with different numbers of tests per borehole. For example, by using the G_s database (lower number of tests) as the destination file and the grain size analysis database (higher number of tests) as the source file, we can verify if there is a link between G_s values (or mineralogy) and the percentage of grains finer than 2 μm.

```
Sub CompareDB()
'This subroutine compares two databases. For each entry of the destination file, the subroutine finds the closest entry
'(elevation-wise) in the source file. For each database, the first four columns contain respectively the borehole number,
'the site number, the sample depth and its elevation. All databases have their first entry on line 3.

'Variables
Dim DestinationFile As String, SourceFile As String, Distance As Double, BestEntry As Long, SourceCell As Range
Dim DestinationCell As Range, ColumnInDestination As Long, SourceSheet As String, DestinationSheet As String
'Source and destination files
DestinationFile = "BD_LIMITES.xlsm" 'Type-in the name of your sheets and files
SourceFile = "BD_THIXOTROPIE.xlsm" 'Type-in the name of your sheets and files
SourceSheet = "BD_THIXOTROPIE" 'Type-in the name of your sheets and files
DestinationSheet = "BD_LIMITES_COMPARED" 'Type-in the name of your sheets and files
Set DestinationCell = Workbooks(DestinationFile).Worksheets(DestinationSheet).Range("A3")
ColumnInDestination = Workbooks(DestinationFile).Worksheets(DestinationSheet).Range("A1").End(xlToRight).Column
'Loop
While Not IsEmpty(DestinationCell)
    Distance = 999
    BestEntry = 3
    Set SourceCell = Workbooks(SourceFile).Worksheets(SourceSheet).Range("A3")
    While Not IsEmpty(SourceCell)
        If SourceCell.Cells(1, 2) = DestinationCell.Cells(1, 2) Then 'If entries are from same site
            If Abs(Distance) > Abs(SourceCell.Cells(1, 4) - DestinationCell.Cells(1, 4)) Then 'Compares the entries' elevation
                Distance = SourceCell.Cells(1, 4) - DestinationCell.Cells(1, 4)
                BestEntry = SourceCell.Row
            End If
        End If
        Set SourceCell = SourceCell.Offset(1, 0)
    Wend
    DestinationCell.Cells(1, ColumnInDestination + 1) = Distance
    Workbooks(SourceFile).Worksheets(SourceSheet).Range("E" & BestEntry & ":CV" & BestEntry).Copy _
        Destination:=DestinationCell.Cells(1, ColumnInDestination + 2)
    Set DestinationCell = DestinationCell.Offset(1, 0)
Wend
End Sub
```

Figure 2: VBA Subroutine used for databases comparison.

Table 1: Test and method references

Test	Standard or reference
Atterberg limits	CAN/BNQ 2501-092 and 2501-090
Sensitivity	CAN/BNQ 2501-110
Grain size analysis	ASTM D422
Specific gravity	ASTM D854
Pore water extraction	Benabdallah et al. (2008)
LOI and XRD	Réginensi (2009)
Triaxial permeability tests	ASTM D5084
Consolidation tests	ASTM D2435

Figure 3 shows the geotechnical profile of site 8, a site with a relatively thin clay body and relatively low maximum salinity (1.5 g/L) whereas Figure 4 presents the profile for site 2, a site with a high maximum salinity (16 g/L) and relatively thick clay sequence.

4 TWO DISTINCT GREY SILTY CLAY LAYERS

On top of the clay layer, a thin layer of brown oxidised clay is found on some sites (Figures 3 and 4). This layer generally has S_t<10 and w_L ≈70 %. Underneath the brown oxidised clay, two layers of grey silty clay can be observed for all sites, except for site 8 where only the lower layer is present. The property that best shows the difference between the two clays is w_L (Figure 5). In the top layer, w_L exceeds 60 %. In the lower one, w_L decreases gradually to 40 %. The lower w_L values in this layer are associated with smaller clay size fraction percentages. For all sites except site 8, the top of the lower layer is found at an elevation of 5 m. For site 8, the westernmost site, the lower layer is observed at an elevation of 10 m (Figure 5).

During sample extrusion from the thin-walled samplers, very little difference was observed visually between the two clay layers. The slightly higher organic matter content in the top layer (2.5 % vs. 1.5 % in the lower layer) did not reflect on sample colour.

Mineralogy profiles were obtained for sites 2 and 6. For site 2, the mineral proportions were found to be constant throughout the two grey silty clay layers. For site 6, the percentage of phyllosilicates (illite, muscovite and chlorite) decreases with depth from 30 % at the surface to 18 % near the clay-till interface. The average mineralogy for sites 2 and 6 (71% feldspars, quartz and amphiboles, 10% illite/muscovite/sericite, 15% chlorite and 4% carbonates) is in agreement with results obtained by Foscal-Mella (1976) for Champlain clay samples from the eastern part of the Island of Montreal.

Permeability tests results also showed little difference between the two layers. The *K* value is relatively constant throughout the profiles, with an average value of 1 X 10^{-9} m/s.

For most sites, clay stiffness (σ'_p and c_u) increases abruptly at the base of the top layer at an elevation of 5 to 8 m (Figure 4). In the lower layer, σ'_p and c_u are more variable. On average, they seem to remain constant as we progress downward in this layer. Several reasons could be invoked to explain this pattern. First, it could be

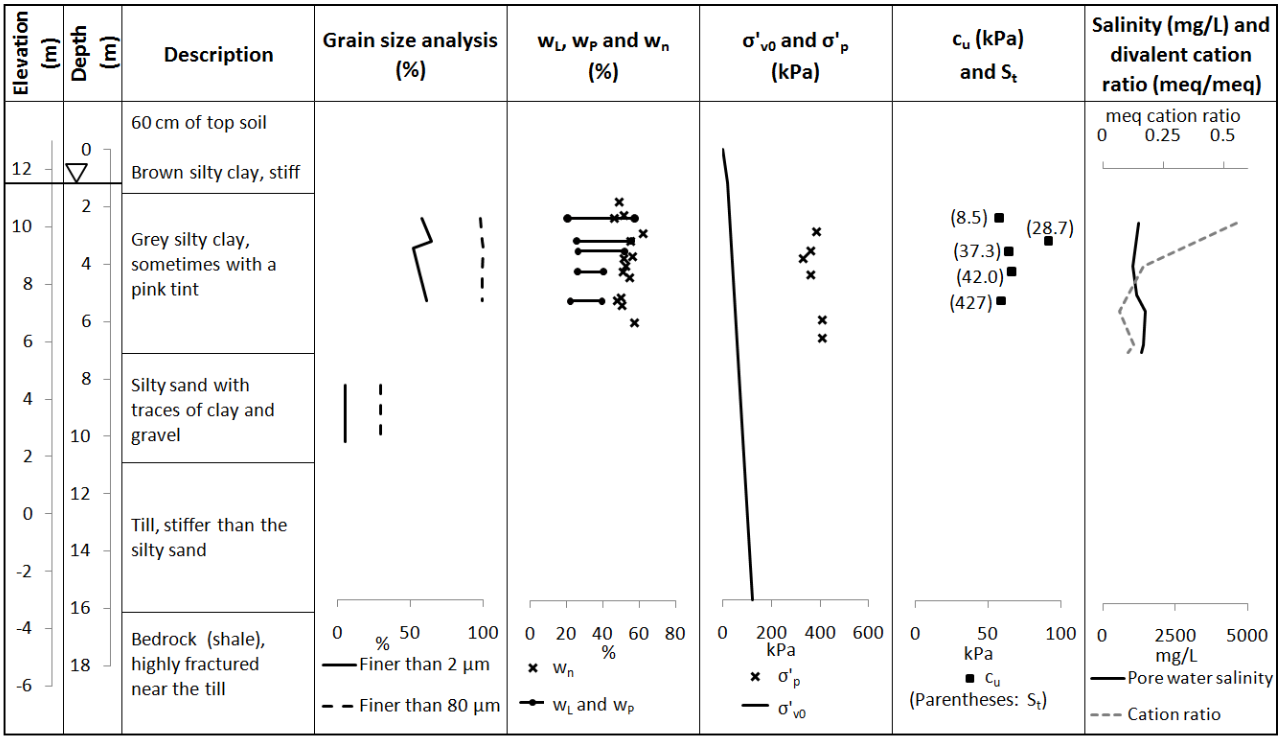


Figure 3. Geotechnical profile for site 8 (low salinity).

suggested that the abrupt stiffening of the clay corresponds to an erosion surface and that the lower clay layer has sustained a higher vertical load before erosion. However, this explanation appears unlikely because the relative sea level changes which have resulted from isostatic rebound and global eustatic sea level change are thought to have induced a steady emergence of the Champlain Sea basin since the last glaciation. The geological record does not suggest any rapid fluctuation of the relative sea level since the last glaciation (Kenney 1964). The different stiffness could also be due to the nature of the materials found in the upper and lower clay layers. We can reasonably expect the volume changes due to secondary consolidation and physicochemical processes to be different in the two layers. The gradual decline of σ'_p observed in the lower layer for some sites could then be linked to the gradual decline of w_L in this layer (Figure 4).

As suggested by Leahy (1980), the occurrence of the two grey silty clay layers can probably be explained by a progressive change in sedimentation regime at the beginning of the Champlain Sea episode. It is unlikely for the bottom layer to be the result of clay deposition in a fresh water environment as the void ratio would have to be lower. The presence of the lower layer at higher elevations in the westernmost site could reflect the topography when this change of deposition conditions occurred. However, the elevation of this transition does not vary much between the sites. This change in deposition conditions seems to have occurred elsewhere as the same layering can be observed on the south shore of the Saint-Lawrence River between Nicolet and Yamaska (Kenney 1964).

5 PRECONSOLIDATION PRESSURES

As mentioned in the previous section, for most sites, we do not observe a linear increase of σ'_p or c_u with depth as observed by Bouchard et al. (1983) for clay in the Saguenay River valley. These properties' values generally increase in the upper grey silty clay layer, reach a maximum at the transition between the two layers, and then stay approximately constant in the lower layer.

Figure 5 shows values of σ'_p and c_u with respect to elevation for sites 1, 2 and 3. Values of σ'_p for these sites are presented with field vane tests results and σ'_p values from a geotechnical report written before the construction of a new landfill cell in this area (GSI Environnement 2001). As was observed by Bouchard et al. (1983), results for the field vane test lead to a clearer linear relationship with elevation data. This is especially apparent for the upper clay layer. In this layer, the average intercept for some 17 vane profiles is 37 m.

Since the linear relationship between σ'_p and elevation is unclear, a range of maximum ground elevations corresponding to a range of hypothetical hydraulic gradients is the best that can be obtained from the σ'_p values. A range of elevation can be obtained by assuming that σ'_p corresponds to the previous maximum vertical effective stress (σ'_v). σ'_v can be evaluated from an average clay volumetric weight and by using a range of likely vertical hydraulic gradients. For the upper clay layer of site 2, the average of w_n is 61 %. Using this value and assuming that the clay is saturated and that the G_s value is 2.75, we obtain a volumetric weight of 16.2 kN/m^3. For an upward vertical hydraulic gradient of modulus

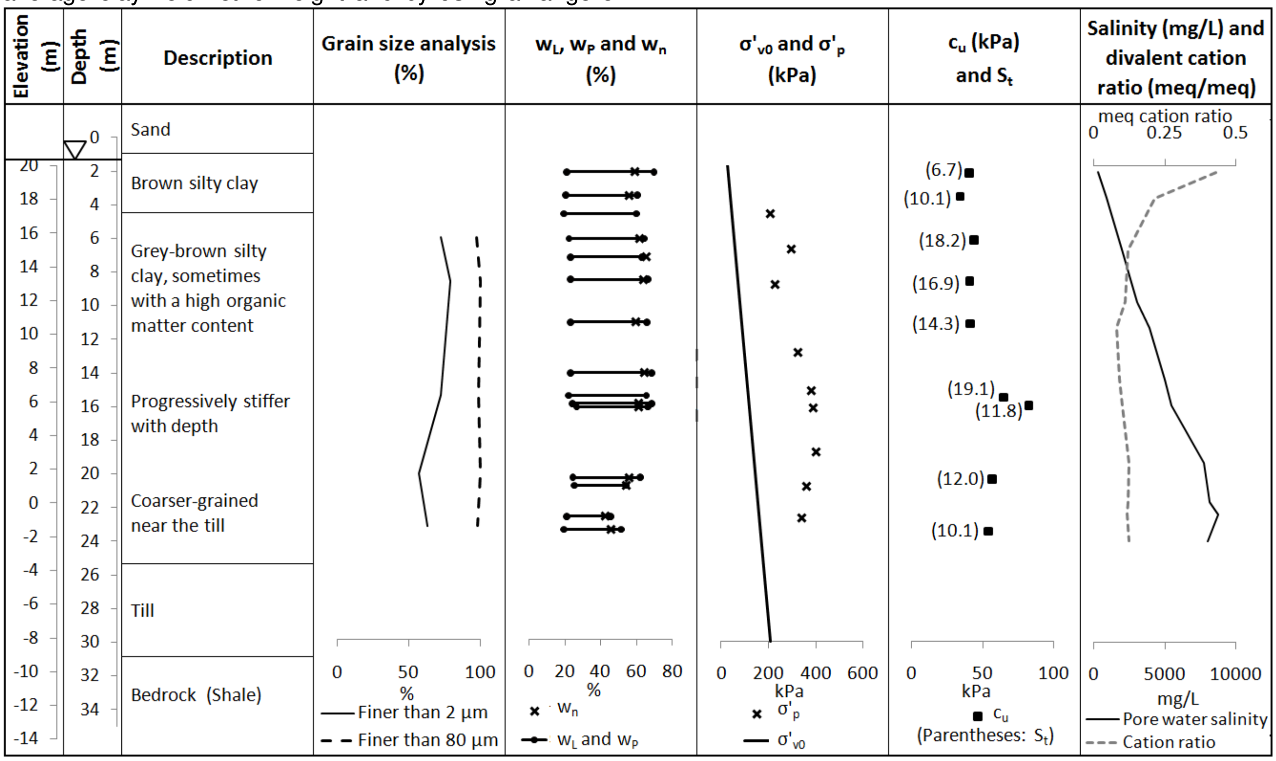


Figure 4: Geotechnical profile for site 2 (high salinity)

between 0 and 1, the rate of change of σ'_v with elevation will be somewhere between 16.2 and 9.8 kPa/m. Using these rates and the σ'_p values measured in the upper clay layer of site 2, the maximum ground elevation can be estimated between 30 and 50 m.

The range of maximum ground elevations obtained from the σ'_p and c_u values compares well with the elevation of the terrace found at the western limit of Figure 1, 5 km west of site 9. The cross section of Dion (1978) indicates that on top of the terrace, the upper surface of the clay body has an elevation of around 50-60 m. The lower ground elevation (30-50 m) over sites 1, 2 and 3 would indicate a ground surface dipping eastward. This is in agreement with the fact that the highest values of σ'_p were observed for site 9, one of the westernmost sites, where the ground surface would have been at higher elevations. The erosion scenario also confirms the interpretation of Brown-Macpherson (1967) who described the bluff which delimits the terrace as resulting from erosion by former estuarine channels.

Since pore water salinity is high, it could be suggested that physicochemical processes account for part of the preconsolidation in Lachenaie. These processes are thought to be responsible for the stiffness of some eastern Canadian clays (e.g. Loiselle et al. 1971). However, some examples of normally consolidated clay bodies with saline pore water can be found in the profiles of Lefebvre and Grondin (1978), for example in Yamaska and Louiseville. Figure 3 also shows that σ'_p values are relatively high on site 8, even if it is the site with the lowest pore water salinity. Thus there is no clear link between clay salinity and cementation.

6 SENSITIVE CLAY OCCURRENCE

Even if the pore water salinity of the Lachenaie clay is relatively high, some lenses of very sensitive clay (S_t>50) can be found in this area. By inspecting the different databases and by referring to the trends reported in the literature (section 2), the occurrence of those lenses can be explained, and eventually predicted.

Figure 7 shows the relationship between salinity and sensitivity for clay of the Lachenaie area ("x" symbols) and from other localities in the Champlain and Laflamme Sea basins (circles). It can be observed that a low salinity is necessary to develop high sensitivity. For salinities of more than 1.5 g/L, almost all data points are found below an envelope defined by Equation 1.

$$S_t < 6\times10^{10}\left[Salinity\ (mg/L)\right]^{-2.5} + 20 \qquad [1]$$

However, Figure 7 also shows that a low salinity is not a sufficient condition to guarantee high sensitivity. Some data points have low salinities and low sensitivities. Two other conditions must be verified to get high sensitivities.

First, the clay must be relatively silty to become very sensitive after salt leaching. This is also the case elsewhere in the Champlain and Laflamme Sea basins where sensitive clays are always associated with silty clay having lower I_P values. In the data presented by Lefebvre and Grondin (1978), samples with I_p > 30 always have S_t<30. When data points respecting this condition are plotted on a graph like Figure 7, sensitivity is more-or-less independent of salinity. As mentioned in the previous section, in Lachenaie, clay is siltier in the second layer, at the bottom of the clay profile. As a result, sensitive clay lenses are found where this layer has been at least partially leached. As noted in section 2, the siltier grain size distribution is not the sole cause of the low I_p of sensitive clays. For a given material, salt leaching will lower w_L, and, accordingly, will lower the I_p.

As mentioned in section 2, the second condition necessary to develop very sensitive clays regards the presence of divalent cations in the pore water. For sensitivity to be high, the ratio of divalent cations (Ca + Mg) to total cations (Na + K + Mg + Ca) must be low. In this paper, ratios were calculated using concentrations in milliequivalent (MEQ) per liter (Figures 3 and 4). For the Champlain Sea basin, a ratio inferior to 15% appears to be needed to develop very high sensitivities (S_t > 100).

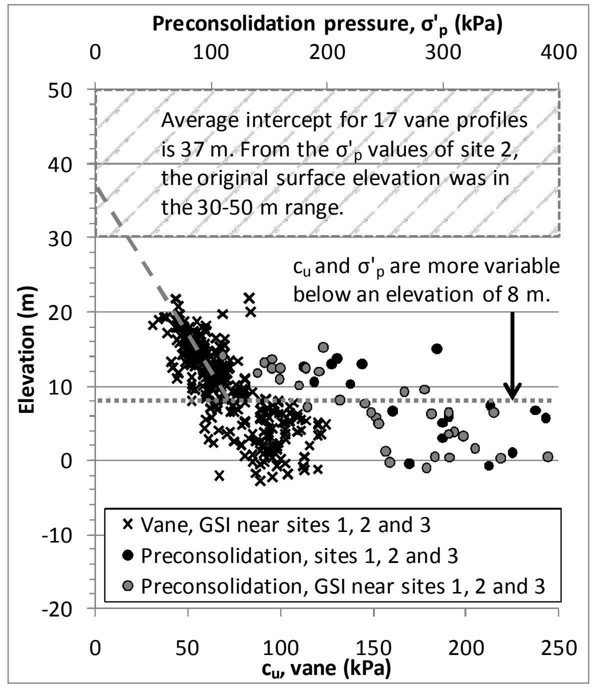


Figure 6. Maximum surface elevation for sites 1, 2 and 3 as estimated from vane profiles and preconsolidation pressures.

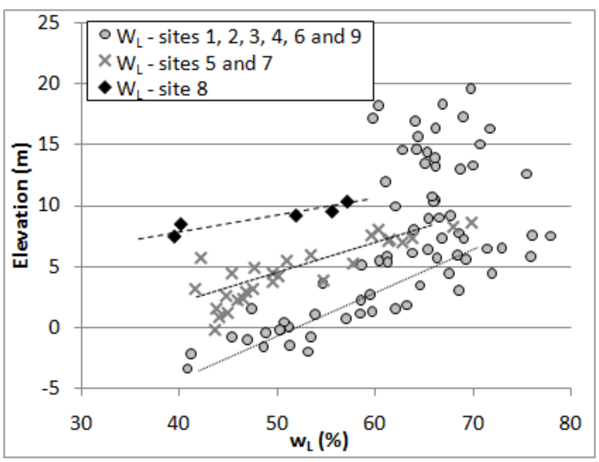


Figure 5. Liquid limit with respect to elevation.

In Figure 7, grey symbols where used for clay respecting both the $I_p \leq 30$ and divalent cation ratio ≤ 15% conditions. Data points for which at least one of those two conditions was not verified are shown in black. When salinity is low it can be seen that sensitivity is consistently higher for data points respecting both conditions. This seems to be true everywhere in the Champlain Sea basin.

In Lachenaie, the divalent cation ratio generally decreases with depth. It is often close to 50 % in the oxidized crust and closer to 10 % at the bottom of the profile (Figures 3 and 4). The influence of the cation ratio on sensitivity can be understood by looking at the geotechnical profile for Site 8 (Figure 3). Even if salinity is roughly constant throughout the profile, and even if I_p falls below 30 at a depth of 3.5 m, very sensitive clay was only observed around a depth 5.5 m, were the cation ratio reached a local minimum of 7%.

Low pore water salinities are associated with thinner clay layers in Lachenaie (Réginensi 2009). Since high sensitivities are associated with low salinities, the former are also associated with thinner clay layers (Figure 8). If the hydraulic gradient is kept constant, both advection and diffusion will proceed faster for thin clay bodies. The actual leaching process is however relatively complex as both advection and diffusion play a role, and as the hydraulic gradient varies between sites (Benabdallah 2010). Consequently, the relationship between sensitivity and clay thickness does not always hold. For example, the clay at sites 5 and 6 has the same thickness; however, its maximum salinity is respectively 4.8 and 11.3 g/L. This is probably due to a smaller upward hydraulic gradient at site 6. At this site, the surface elevation is relatively low, close to the hydraulic head value in the bedrock. Nevertheless, assuming that the lower silty layer that is more prone to sensitivity is present everywhere, in Lachenaie, sensitive clays are more likely to be encountered where the clay layer is thin.

7 CONCLUSION

The data gathered during the extensive geotechnical testing program allowed two interesting questions regarding the geological history of the Lachenaie clay deposit to be investigated.

First, the liquidity limit w_L profiles indicated that two different layers representing different sedimentation conditions exist in Lachenaie. Secondly, preconsolidation pressures and vane shear test profiles validated the theory that clay stiffness in Lachenaie is due to an erosion event and that this event is related to the formation of the terrace located 5 km west of site 9.

However, the geotechnical tools used in this paper have limits and many questions remain regarding the two geological problems studied in this paper. They would

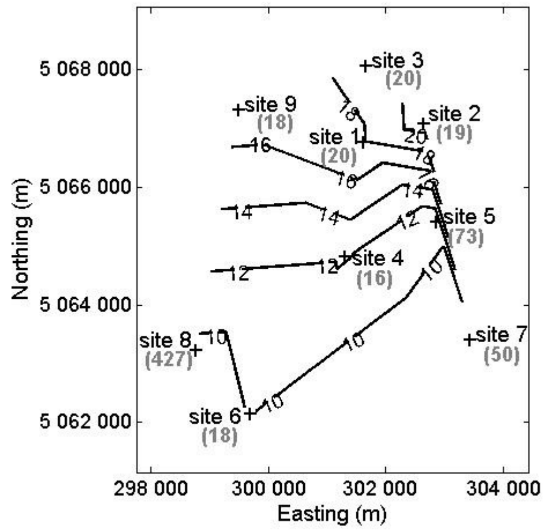


Figure 8. Contours of total thickness of grey silty clay (excluding the oxidised crust). The maximum sensitivity for each site is given between parentheses.

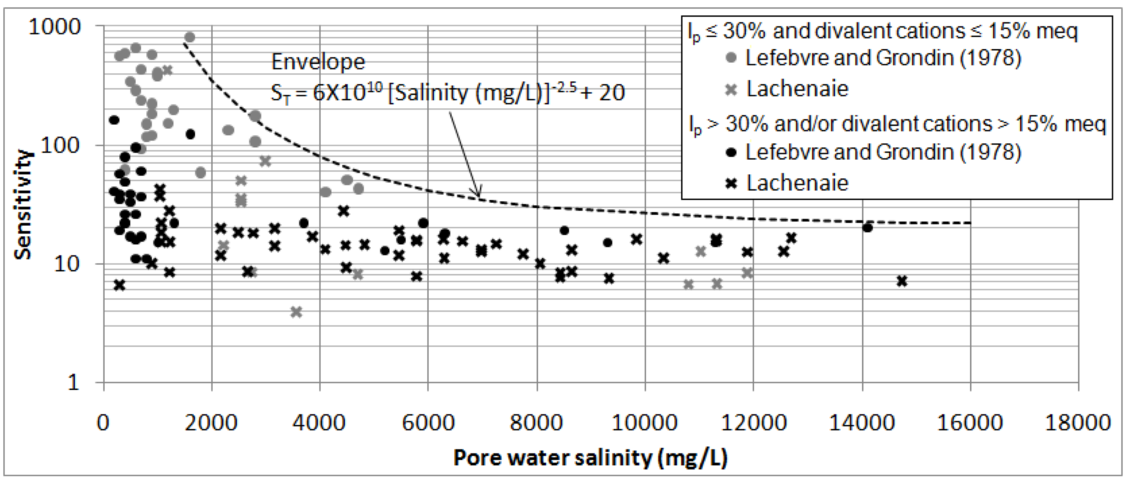


Figure 7. Sensitivity for low I_p and low divalent cation percentages. The results of Lefebvre and Grondin (1978) cover 12 localities spread over the former Champlain and Laflamme sea basins.

benefit from a better understanding of the geological context and a combined use of geological and geotechnical tools. A better knowledge of the geological context could also help locating the zones where the deposit is thin and where the siltier layer is present. It is in these areas that the three conditions for the development of a high sensitivity, namely low salinity, low divalent cation ratio and low I_p, are reunited.

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