

## THE ST. JEAN VIANNEY QUICKCLAY

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### ABSTRACT

Extremely sensitive clay soil (quickclay) from the site of the 1971 landslide at St. Jean Vianney (Quebec) has been investigated by thermogravimetry, x-ray diffraction and x-ray fluorescence spectroscopy. TG indicated four major thermal events between room temperature and 1000°C: the 750° event is caused by a carbonate mineral, possibly dolomite, the 580° event is due to clay-mineral material, identified as illite, the 350° event is due to organic material, and the 100° event is caused by adsorbed water associated with the clay-mineral materials. The bulk of the mineral particles appears to be quartz or plagioclase. The most significant observation is probably the very small amount of clay-mineral material present, estimated at 9% or less. The carbonate mineral is dolomite that is concentrated totally in the >2 $\mu$ m fraction; the estimated dolomite content is ~4%. The mode size of quartz particles is larger than that of feldspar.

### RÉSUMÉ

De l'argile extrêmement sensible (argile boullant) du site du glissement de 1971 à Saint-Jean Vianney (Québec) a été étudié à l'aide de la thermogravimétrie, de la diffraction par rayons-X et de la spectroscopie par fluorescence X. La thermogravimétrie a indiqué quatre événements thermiques majeurs entre une température de pièce et 1000°C: l'événement produit à 750° est dû à un minéral carbonaté, possiblement la dolomite; l'événement produit à 580° est dû à du matériel de minéral argileux identifié comme étant de l'illite; l'événement produit à 350° est dû au matériel organique et l'événement produit à 100° est causé par de l'eau absorbée associée aux matériaux de minéral argileux. La plus grande partie des particules minérales semble être du quartz ou du plagioclase. Le fait le plus important observé est probablement la présence du très petit nombre de matériel de minéral argileux évalué à 9% ou moins. Le minéral carbonaté est la dolomite qui est concentré entièrement dans la fraction >2 $\mu$ m; le contenu de dolomite est évalué à ~4%. La taille modale des particules de quartz est plus grande que celle du feldspath.

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### INTRODUCTION

There have been many landslides in the so-called Leda or Champlain clay of Eastern Canada (Mitchell & Markell 1974) and one of the most destructive of recent times was the 1971 slide at St. Jean Vianney in Quebec (Tavenas *et al.* 1971; La Rochelle 1974). According to Gillott (1971) the Leda clay is a predominantly marine deposit of post-glacial age which accumulated in an arm of the ocean known as the Champlain Sea. Some of the upper layers of sediment may have been redeposited under fresh-water conditions (Gadd 1963). The Leda clay, which often contains considerable quantities of silt and sand-sized particles, is of variable thickness and exceeds 60 m in places. Some investigators prefer to call it Champlain clay (Gadd 1960; La Rochelle *et al.* 1970), but the name Leda clay is very persistent.

The St. Jean Vianney area is 2.4 km north of the Saguenay River and about 10 km west of Chicoutimi. The region was flooded some 9000 years ago by an extension of the Champlain Sea, sometimes called the Laflamme Sea, in which deep layers of marine clay were deposited. Chagnon (1968) has shown that 14 landslides can be identified in the region of Chicoutimi, and the largest slide known to have occurred in the Leda/Champlain clay was described by La Salle & Chagnon (1968) in the immediate vicinity of St. Jean Vianney. The town of St. Jean Vianney is in the crater of this ancient landslide which appears to have taken place about 500 years ago.

The mineralogy of the Leda clay has been comprehensively studied by Gillott (1971); earlier studies were made by Brady & Dean (1966a,b), Soderman & Quigley (1965), Brydon & Patry (1961) and Allen & Johns (1960). Gillott concluded that five samples of Leda clay he studied had a complex mineralogy, and that the clay-size fraction (< 2 $\mu$ m) contained a significant proportion of primary minerals. This affects the engineering properties of clay soils because primary minerals have a smaller speci-

fic surface area and weaker colloid chemical properties than clay minerals. There appears to be a direct connection between the mineralogy of the Leda clay and its extraordinary geotechnical properties, in particular its very high sensitivity. Sensitivity is the ratio of the undisturbed strength of soil to its remoulded strength at the natural moisture content. Penner (1963) has measured Leda clay sensitivities of 1500. The high sensitivity is directly responsible for the landslide problem, and the name 'quickclay'.

Gillott examined clay samples from four sites; this paper is an attempt to supplement our knowledge of Leda clay mineralogy by investigating another material (St. Jean Vianney clay) and using another technique — thermogravimetric analysis (TG).

### SAMPLES AND TECHNIQUES

Samples of clay soil from the site of the 1971 St. Jean Vianney landslides were supplied by the Division of Building Research of the National Research Council of Canada at Ottawa. Samples were disaggregated, dispersed ultrasonically and separated by gravity sedimentation into two fractions: greater than 2  $\mu\text{m}$  and less than 2  $\mu\text{m}$ . Tests were carried out on the whole-soil samples and the two fractions. Some TG tests were carried out on "as received" samples but the usual practice was to dry at 105°C before storage.

The major technique used was thermogravimetric analysis with a Stanton-Redcroft TR-02 thermobalance. The samples were heated, in air in 'Vitreosil' crucibles, at a rate of just over 4°/minute. The standard test used a 1g sample, but in some cases it was found that the reaction intervals were better-defined with a 2g sample. The TR-02 beam-type thermobalance was preferred to the electrobalance because of this

capacity to examine a fairly large, representative sample. The TG tests were supplemented by x-ray diffraction and x-ray fluorescence spectroscopy (XRF). The XRF analyses gave essentially similar chemical compositions to those obtained by Gillott (1971) with wet-chemical analyses; typical analyses are shown in Table 1.

The TG results are presented as derivative curves in the form recommended by the International Confederation for Thermal Analysis (see Blažek 1973, p. 271). The DTG presentation allows the thermal events to be identified more clearly. Weight-loss results for quantitative estimations of mineral content are taken from the direct TG curve. In all the DTG Figures (1-8) the temperature scale departs from linear below 100°C: the histogram intervals relate to weight loss over a 5 minute period as the thermobalance timer makes this a convenient interval. The system was calibrated at intervals during the test program by use of potassium hydrogen phthalate as a standard (reactions at 245°, 370°, and 565°; see Blazek 1973, p. 169 for details of calibration substances). Standard TG mineral data were obtained from the Atlas of Thermoanalytical Curves edited by Liptay (1971-1974).

### THERMOGRAVIMETRY

The whole-soil samples reveal four distinct thermal events; these have been labelled A-D for convenience, and are discussed separately. Temperatures of occurrence are A, 100°; B, 350°; C, 580°; D, 750°; these represent the mid-points of the reaction intervals in each case. Figures 1 and 2 are of whole-soil samples, Figures 3 and 4 are size fractions, Figures 5-7 are treated samples, and Figure 8 is a comparative standard.

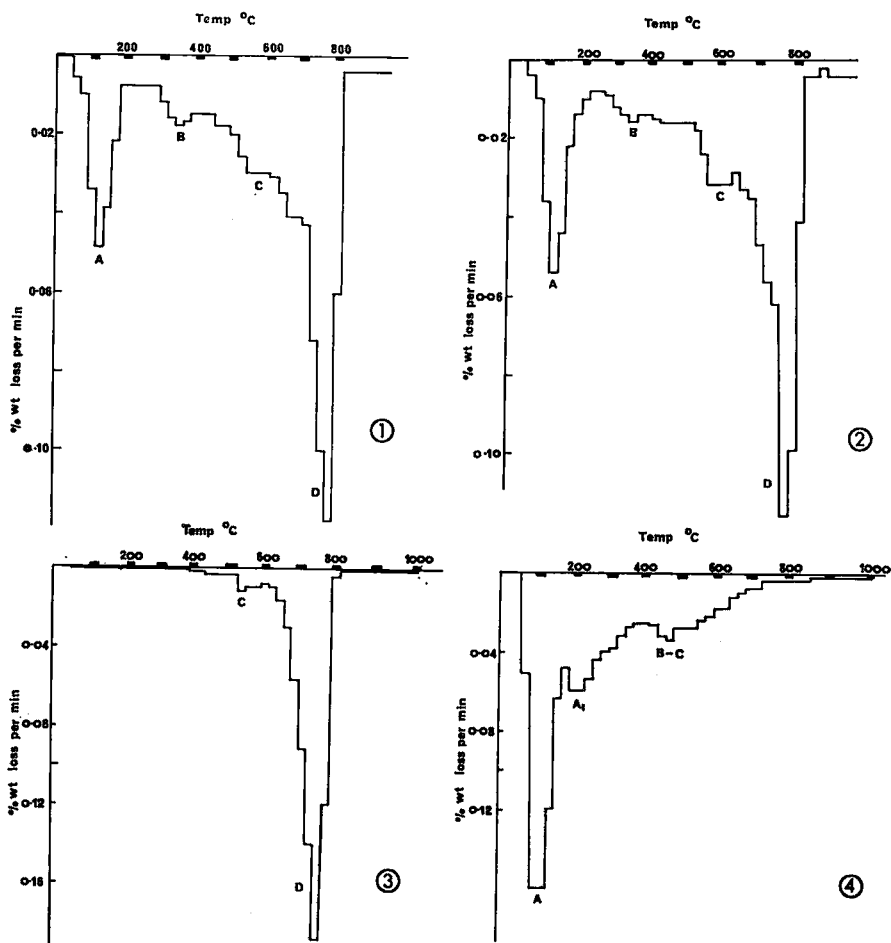
#### A peak

This appears in each case to be due to uncombined (adsorbed) water and has a simple symmetrical form, although in Figure 4 a subsidiary peak ( $A_1$ ) appears. Figure 4 shows the behaviour of the <2 $\mu\text{m}$  material and it may be that the enhanced proportion of clay minerals has allowed another clay mineral peak to be observed. Gaudette *et al.* (1966), considering the DTA investigation of illite, listed reaction peaks at 100-200°, 500-600° and 800-900° and it is possible that  $A_1$  is an aspect of the low-temperature illite response, or it might be some minor clay mineral constituent such as vermiculite. The A peak is completely missing from the >2 $\mu\text{m}$  material (Fig. 3). This had been

TABLE 1. XRF DATA FOR ST. JEAN VIANNEY CLAY\*

Element as oxide	wt. % (a)	wt. % (b)
SiO <sub>2</sub>	54.93	54.22
TiO <sub>2</sub>	0.75	0.75
Al <sub>2</sub> O <sub>3</sub>	16.21	15.78
Fe <sub>2</sub> O <sub>3</sub>	6.51	6.49
MnO <sub>2</sub>	0.10	0.10
MgO	3.54	3.38
CaO	6.75	6.71
K <sub>2</sub> O	3.11	3.04
P <sub>2</sub> O <sub>5</sub>	0.25	0.26
Na <sub>2</sub> O	not obtained	3.47
Total	92.15	94.20

\* Analyses were carried out using two different fluxes (a & b). The borate flux (b) allows Na<sub>2</sub>O to be determined.



FIGS. 1-4.: 1. SJV whole soil 2g sample. DTG result showing well-defined B peak. 2. SJV whole soil; 2g sample. DTG result showing well-defined C peak. 3. SJV  $>2\mu\text{m}$ ; 1g sample. DTG result showing elimination of A peak and concentration of carbonate material among the larger particles. 4. SJV  $<2\mu\text{m}$ ; 1g sample. DTG result showing elimination of D peak.

dried at  $105^\circ$  and the relatively non-adsorbent larger material had not reabsorbed a significant amount of water between drying and testing. The adsorbent materials in the  $<2\mu\text{m}$  fraction retained and reabsorbed sufficient water to make an obvious A peak (Fig. 4).

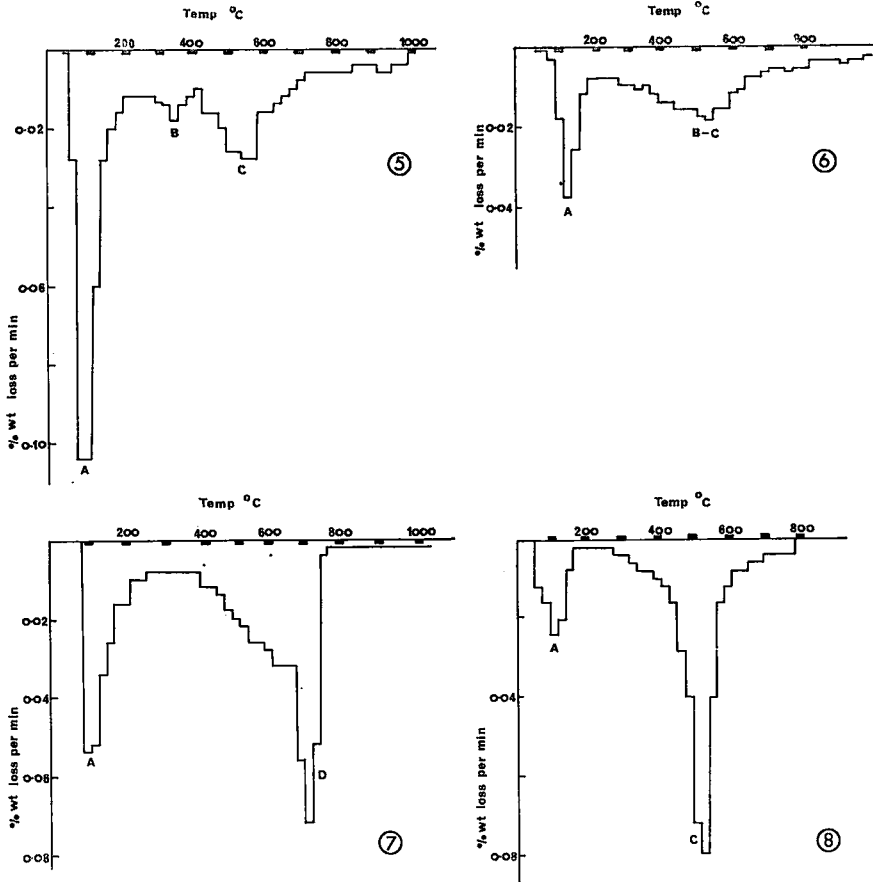
#### *B peak*

The B peak is not very large in the SJV material but it is undoubtedly present; in Figure 1 particularly it is well-defined and has the shape of a classic DTG peak. The DTA investigation by Gillott showed that when an untreated Leda clay was analyzed in an air atmosphere, thermograms displayed a broad exotherm in the  $200$  to  $400^\circ$  range; this was at-

tributed to organic material. It is difficult to relate the neat, well-defined B peak to the broad exotherm of Gillott, but at present organic material appears to be the best possibility for peak B. Some experiments to clarify this were carried out; samples were treated with  $\text{H}_2\text{O}_2$  and tested by TG and by differential scanning calorimeter (DSC). The DTG result is shown in Figure 7, with B peak removed. A similar result was obtained in the DSC tests.

#### *C peak*

This appears to be an illite response. The  $>2\mu\text{m}$  fraction shows only the smallest trace of a C peak, which is what would be expected if it were caused by clay-mineral material. Some



FIGS. 5-8: 5. SJV treated with 20% acetic acid; lg sample. DTG result showing elimination of D peak. 6. SJV treated with 5N HCl; lg sample. DTG result showing elimination of D peak; B and C peaks appear to merge. 7. SJV treated with  $H_2O_2$ ; lg sample. DTG result showing elimination of B peak. 8. Moon (1975) model soil, 75% quartz + 25% illite; lg sample. DTG result showing prominent C peak.

tests were carried out on a model soil devised by Moon (1975) to simulate certain quickclay properties. This consisted of 75% quartz and 25% illite, with a size distribution similar to the SJV clay. This artificial material was made for rheological experiments but also provides a useful TG standard. The DTG result is shown in Figure 8; the 25% illite provides a large C peak, and gives an indication of the small amount of illite in the SJV clay.

#### D peak

The abrupt drop in the rate of weight loss at the end of the reaction interval is characteristic of carbonate minerals. The temperature at which the D peak is observed in the SJV clay suggests that the carbonate might be dolomite

rather than calcite, although under certain conditions calcite can react at lower temperatures (Liptay 1971, p. 20). Under ideal conditions dolomite should show a double peak but at low partial pressures of  $CO_2$  the peaks merge (Liptay 1971, p. 35); these conditions may reasonably be expected to exist inside the thermobalance furnace. Gillott (1971) detected a DTA peak system at 750-800° consisting of an endotherm followed by an exotherm which he attributed to the decomposition of chlorite; if this response is present in the SJV whole-soil results it is apparently totally obscured by the carbonate.

To establish more firmly that the D peak is due to a carbonate mineral, some acid-treated specimens were tested. Figure 6 shows the result after treatment by 5N HCl; Figure 5 shows

the result after treatment by 20% acetic acid. This latter result gives a clear indication that the D peak is caused by a carbonate mineral. The carbonate peak obtained in the  $>2\mu\text{m}$  material shows clearly the single-peak nature of the carbonate response; there appears to be no possibility of a lower-temperature peak being obscured by the clay-mineral response.

#### X-RAY DIFFRACTION

Diffraction traces for the whole soil,  $>2\mu\text{m}$  and  $<2\mu\text{m}$  samples were obtained. The most obvious features were two peaks at  $d = \sim 3.20\text{\AA}$  and  $\sim 3.34\text{\AA}$ . The  $3.34\text{\AA}$  peak is the major quartz peak and its presence and form suggest that the SJV material has a considerable quartz content. The  $3.20\text{\AA}$  peak is apparently due to a group of feldspar minerals. Albite, anorthite, orthoclase and combinations as plagioclase all have their major diffraction peaks at about  $3.2\text{\AA}$ . There is appreciable quartz in the  $<2\mu\text{m}$  fraction but the proportion is diminished. Plagioclase is probably the major constituent of this fraction. Some traces of illite and other minerals were detected but they appear to be of minor importance.

#### DISCUSSION

The acid treatments appear to establish conclusively that the SJV clay contains a carbonate mineral. The D peak temperature suggests that this is dolomite. If the amount is calculated on this basis the result is of the order of 4% dolomite. The problem of clay-mineral nature and content is more difficult. The C peak is apparently due to illite, and by comparison with the Moon (1975) model soil the SJV clay appears to contain about 9% illite. However the XRF results show that the SJV clay contains 3%  $\text{K}_2\text{O}$ , and if all this is attributed to illite, a content of much more than 9% is indicated. It seems reasonable to assign most of the  $\text{K}_2\text{O}$  to orthoclase. In the acetic acid-treated sample (Fig. 5) the interference by the carbonate is removed and the C peak can be seen more clearly.

If it is assumed that the B peak is due to organic material which disappears completely on oxidation, a content of about 0.1% is indicated. The major minerals do not make a showing on the DTG results; they are quartz and assorted feldspars. It appears that more quartz than feldspar is found in the  $>2\mu\text{m}$  fraction and the reverse is true for the  $<2\mu\text{m}$  fraction. All the carbonate mineral is found in the  $>2\mu\text{m}$  fraction and is presumably attached

to the quartz particles as a cementation deposit.

Some preliminary investigations by high-voltage electron microscopy have been carried out on the SJV clay (Hammond *et al.* 1973) and it appears that the majority of particles are highly-deformed rock fragments, presumably produced by glacial action. It was observed that many of the quartz particles had a platy habit, similar to those of the more massive clay minerals (Krinsley & Smalley 1973), and it was suggested that some size-controlled cleavage mechanism operated. However it now seems more likely that the platy shape of small quartz particles is caused by stresses encountered while the quartz is still within the original igneous rock (Moss *et al.* 1973; Smalley 1974). In the SJV clay the size distribution of the primary minerals also suggests a glacial origin; both quartz and feldspars are finely ground but the somewhat harder quartz has suffered slightly less size reduction than the feldspars.

The iron appears to be concentrated in the  $<2\mu\text{m}$  fraction. This was indicated by the colour of the samples after heating to  $1000^\circ$  in the thermobalance furnace. The  $<2\mu\text{m}$  sample is a deep, dark maroon with white specks, the  $>2\mu\text{m}$  sample is a pale buff colour, and the whole-soil sample has an intermediate brick-red colour.

#### CONCLUSIONS

In his investigation of the mineralogy of Leda clay, Gillott (1971) concluded that the clay-size fractions contain a significant proportion of primary minerals. This is certainly true for the SJV clay, and, in fact, a much more general statement can be made. The SJV clay consists essentially of primary mineral particles; the clay-mineral content is 9% or less; the carbonate mineral (possibly dolomite) content is of the order of 4%; there is a small amount of organic material present (the TG investigations indicate about 0.1%). The primary mineral particles consist of quartz and feldspars. The mode feldspar particle size is lower than that of the quartz. The carbonate mineral is associated with the larger-size fraction and the iron-containing material with the smaller.

Comparisons were made with the Leda clay results of Gillott on the assumption that there was enough similarity to allow these comparisons to be made. Nothing has been discovered during these investigations which suggests that the SJV clay is not very similar, in mineralogical terms, to the Leda clays from the main part of the Champlain Sea.

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