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Lithostratigraphy And Geochronology Of The Quaternary Deposits Of The Pierreville And St-pierre Les Becquets Areas, Quebec

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LITHOSTRATIGRAPHY AND GEOCHRONOLOGY OF THE QUATERNARY DEPOSITS OF THE PIERREVILLE AND ST-PIERRE LES BECQUETS AREAS, QUEBEC

by

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ABSTRACT

For three decades, a Traditional Concept of stratigraphy involving one glaciation with two major ice advances separated by one brief interstade has been invoked to explain the distribution of Pleistocene deposits in the St-Lawrence Lowland. The Bécancour Till (early Wisconsinan ?), the St-Pierre Sediments (early to middle Wisconsinan) and the Gentilly Till with associated Deschaillons Varves (middle to late Wisconsinan) are the key lithostratigraphic units of this framework.

In this thesis, field work and sedimentologic analyses document the lithostratigraphic units in the Pierreville and St-Pierre les Becquets areas. Eight sections and two geologic cross-sections are presented. A new stratigraphic nomenclature is proposed.

Isotopic studies of calcareous concretions found *in situ* in glaciolacustrine sediments and as striated clasts in tills provide evidence that those carbonates are the product of an early diagenetic process. The concretions show a minute radiocarbon activity but most are found or derived from sediments undoubtedly older than 60 ka. Contamination by a second generation of carbonate is likely.

Stadial and interstadial sediments as well as modern silt collected in the St-Lawrence River have been dated by thermoluminescence (TL) using R-Gamma method. The major problems encountered were only partly solved: (a) anomalous fading of the polymineralic fraction, (2) estimation of

the TL growth curve, (3) determination of the past water content and (4) laboratory overbleaching of the inherited TL in recent sediments.

The data reported, herein, provide evidence that the succession of geologic events may be as follows:

1) an Illinoian glacial event: the St-Lawrence Stadial, represented by the Odanak Formation, older than 135 ka;

2) an early Wisconsinan glacial event the Nicolet Stadial, represented by glaciolacustrine sediments and tills (Rivière aux Vaches Formation; Lévrard Formation), dated at 70 to 86 ka by TL;

3) A middle Wisconsinan nonglacial event: the St-Pierre Interstadial, represented by organic-rich sediments (St-François du Lac Formation), dated at 60 to 75 ka (Pierreville) and 28 to 65 ka (St-Pierre les Becquets) by TL and ^{14}C; and

4) a late (?) Wisconsinan glacial event: the Trois-Rivières Stadial, represented by the Gentilly Formation; the timing of the onset of this glacial advance is problematic and ranges from 66 to 30 ka.

Three formations, Les Becquets, Deschaillons and Pierreville, have an *equivocal* stratigraphic position.

This framework can be summarized as a three-stadial model, spanning the last 135,000 years. It is presented as an alternative to the Traditional Concept of earlier workers. Recommendations for future work are proposed in order to confirm either model.

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The substance of this thesis is my own but the form is due to the drafting skill of Michèle Laithier , the competent typing of Elisabeth Giami and the dark room work of Pierre Bédard. I have a deep feeling of indebtedness to Michèle and will never thank her enough.

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A Sophie, ma fille

A Paul, mon père.

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CHAPTER 1

INTRODUCTION

1.1 Objectives

During the last decade, the isotopic deep ocean floor stratigraphy has disclosed the complex nature of the late Cenozoic Ice Age. It suggests indeed that at least seventeen events of full glacial severity pulse the Quaternary time scale. Traces of each of those drastic climatic changes have yet to be found on the land. This may be achieved only by means of correlations with the continental Quaternary stratigraphy. However, land deposits are discontinuous and chronological control on continental reference sections is poor. Correlations between these two types of stratigraphy are consequently difficult to demonstrate.

Among important North American continental sections, the St-Pierre interstadial site (Gadd, 1955) found in the Central St-Lawrence Lowland has become a classical reference for the Early Wisconsin in northeastern North America (Dreimanis and Karrow, 1972). Although the St-Pierre interstadial deposits and bounding sediments are of great stratigraphical significance, their chronostratigraphy has been based on ^{14}C dates at the maximum limit of this method. This Interstadial displays a complex sequence of sediment facies and chronology. Consequently, most of the suggested correlations with the oxygen isotopic stages are speculative.

This thesis presents a study of the stratigraphy of the Quaternary deposits of the Central St-Lawrence Lowland in which the St-Pierre sediments are found. Lithologic and geochronologic analyses are the most specific objectives of this investigation. They are presented in Chapters 2, 3 and 4. The stratigraphic framework derived from these data is described in Chapter 5. Regional and land-ocean correlations shall be discussed in Chapter 6.

1.2 Location of the study area

The investigated stratigraphic sections lie within the central part of the St-Lawrence River Lowland (*sensu lato*), between Montreal and Quebec City (Fig. 1-1). Particular attention was paid to the sections found on the south shore of the St-Lawrence River and along the banks of its tributaries. This area is delimited by latitude $46^{0}00'$, longitude $72^{0}00'$ and by the south shore of the St-Lawrence River.

From earlier work (see next section), and the preliminary investigations of this study, it became clear that a complete stratigraphic framework can be built through a comprehensive examination of selected sections from two distinct sub-areas outlined on Figure 1-1 (i.e. Pierreville and St-Pierre-les-Becquets).

1.3 Previous Work

1.3.1 The first hundred years of investigations

A general acceptance of the Glacial Theory followed one of the most raging disputes in the history of geology. Among the opponents

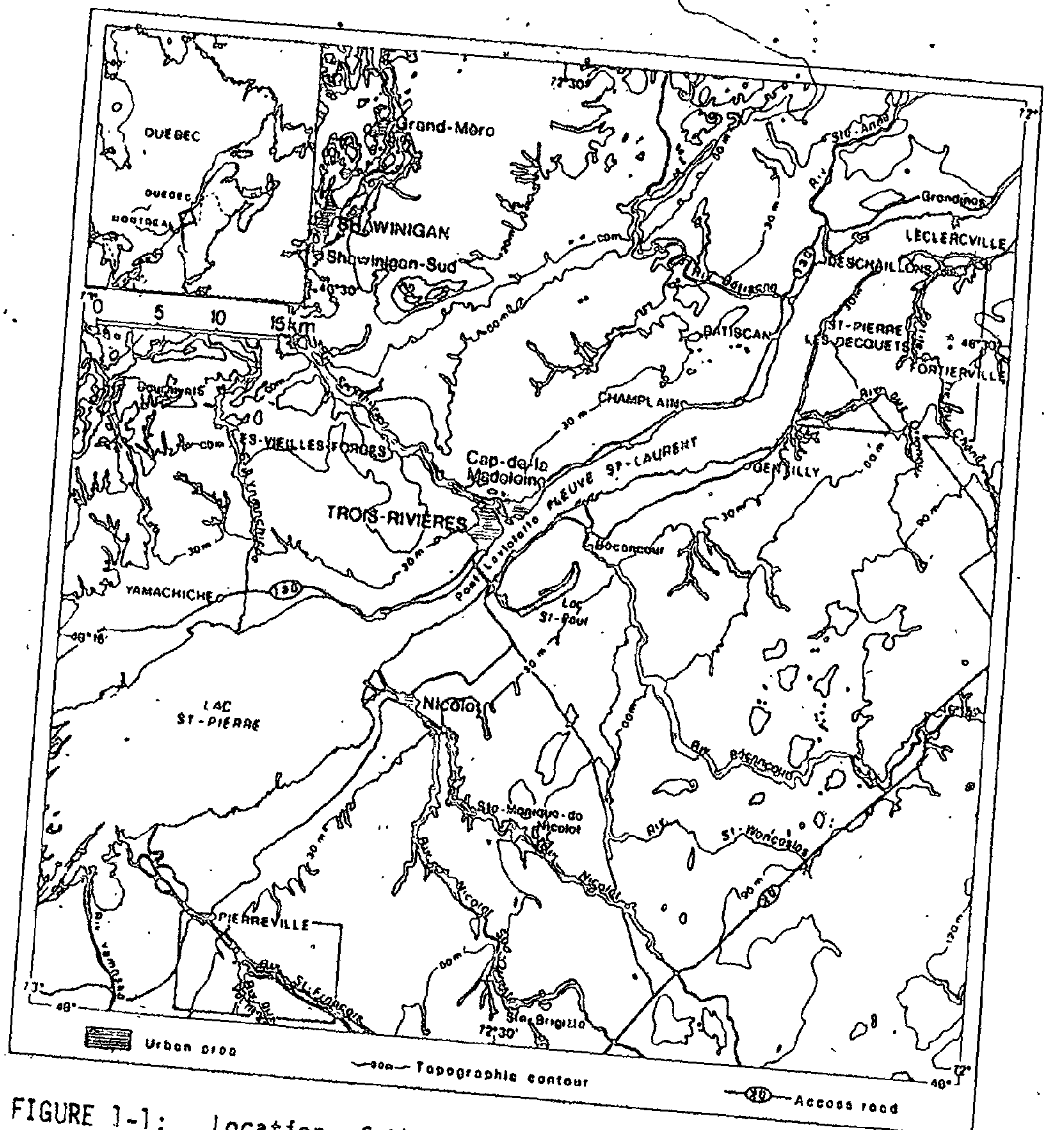


FIGURE 1-1: Location of the Pierreville and St-Pierre les Becquets area (outlined on the map).

to the Continental Glaciation concepts was Sir J. William Dawson (1893) to whom modern Quaternary geologists are nevertheless mostly indebted. Dawson's work, inaccurately reported by Logan (1863), contained the first comprehensive study of the unconsolidated deposits found in the St-Lawrence Valley. Stratigraphic classifications proposed by Dawson and Logan were based on a single "glacial or marine-drift event" followed by a marine episode. Evidences of multiple glaciations in Southern Quebec were reported by Chalmers (1899) who probably yielded the most stimulating contributions in the history of Pleistocene Geology in Eastern Canada.

The concept of two till sheets in the present study area has originated from Keele (1915) who described an older "red boulder clay" (with incorporated "red Medina shale") and a younger "dark grey boulder clay" in the sections found along the St-François River (ibid, pp. 81-82). He also reported stratified clays containing concretions and a buried peat layer.

1.3.2 1950-1960 A decade of formal stratigraphical work

During the next forty years, not much was added to the above concepts. Dresser and Denis (1944) summarized the prevailing ideas on the matter.

In 1955, N.R. Gadd presented a PhD dissertation at the University of Illinois on the "Pleistocene Geology of the Bécancour-Map-Area, Québec" (Gadd, 1955). He recognized two glaciations separated by a major "Interglacial interval". The basal red till was defined as the Bécancour till of probable pre-Wisconsin age. The interglacial(?) deposits, mainly sand and peat, were named the St-Pierre sediments, and the youngest grey till, the Gentilly till. All these terms were later formalized in Gadd (1960). "Gray" varves were thought to have been deposited during the advance of Gentilly ice. Some of Gadd's findings were supported by field work pursued in the Yamaska area, along the St-François River. As a member of the Geological Survey of Canada, he mapped the Aston (1953), Yamaska (1954) and Upton (1955) sheets and collaborated with Karrow to map the Trois-Rivières sheet (Gadd and Karrow, 1959).

During 1955 and 1956, the Grondines sheet was mapped by P.F. Karrow whose PhD thesis at the University of Illinois was entitled: "Pleistocene Geology of the Grondines Map-Area, Quebec" (Karrow, 1957). Gadd's work was extended in the Grondines area and sections outside the map area were also described (e.g., the Vieilles Forges section). Karrow defined the "Gray" varves as the Deschaillons Formation. He proposed the name of Hochelaga Formation, following Woodworth (1905), for the deep water facies of the Champlain Sea but this name was soon forgotten.

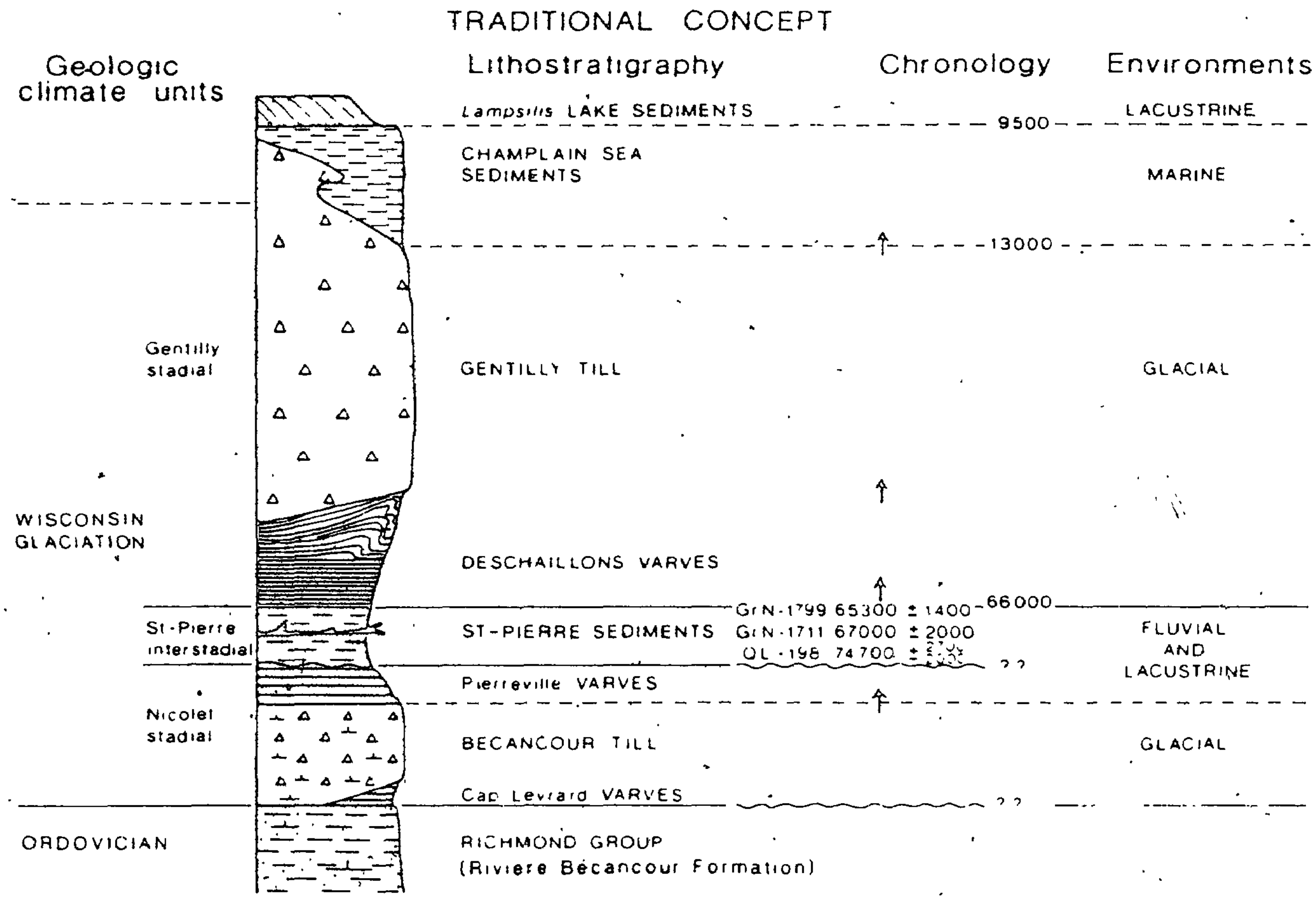
Terasmae (1958) shed some light on the paleoclimate of the St-Pierre Interval through his "Contributions to Canadian Palynology". He revealed the boreal nature of the pollen spectra (that is, cooler than today) built from these non-glacial peat and organic-rich layers found in the St-Lawrence Lowland.

In terms of chronology, the first finite radiocarbon dates were performed by De Vries and reported by Dreimanis (1960) at the International Geological Congress (Norden). They gave an approximate age of 65,000 ^{14}C years BP for both Pierreville and St-Pierre les Becquets peat sites. Discussion of these ^{14}C results together with the recent radiocarbon data are found in Chapter 3.

Gadd (1971) later synthesized the data for the six map-areas. The original manuscript was submitted to the Geological Survey of Canada in 1963 and accepted in its final form in 1966. Publication of the Memoir 359 was delayed until 1971. The "Pleistocene Geology of the Central St-Lawrence Lowland" is therefore based mainly on field and laboratory data acquired during the fifties. The present writer feels that this point is relevant for further discussion.

The Quaternary stratigraphy established through these years is illustrated in Figure 1-2 and will be referred herein to as the "Traditional Concept". For the sake of clarity, the writer prefers to quote Gadd (1976) who summarized this concept in the following words:

> "St. Lawrence Lowland Region
>
> Important stratigraphic relationships between lithologic units establish their sequence and continuity:
>
> 1. Bécancour Till rests on bedrock or on thin deposits of varved clay and is overlain in a number of places by varved clay. No older lithologic unit of Pleistocene age is known in the areas of the St. Lawrence Lowland studied.
>
> 2. An erosional discontinuity exists between Bécancour glacial deposits and overlying St. Pierre fluvial beds. These latter beds are nonglacial and have both a wide distribution and a consistency in their nature; this suggests that the fluvial system in which they were formed was of magnitude similar to that of modern St. Lawrence River system. Therefore they represent a major nonglacial interval.



From GADD, 1955, 1971 and 1976 and KARROW, 1957

FIGURE 1-2: The Traditional Concept of Quaternary stratigraphy in the St-Lawrence Lowland according to earlier workers.

(comment: of 5 to 6 000 years duration, Terasmae, 1958)

3. Peat and wood in compressed beds up to 1 m thick are in excess of 50,000 14C years (GSC-1927) and have finite dates of the order of 66,000 14C years (GrN-1799). This is the approximate age of open drainage to the sea of the central part of the St. Lawrence Valley. Because the radiocarbon dates are at or beyond the test limit of most radiocarbon laboratories, St. Pierre beds and the older Bécancour Till, therefore, should be designated as being early Wisconsin or older.

(comment: The Pierreville peat has been recently dated at 74 700 -2000,+2700 BP, by Stuiver et al., 1978)

4. There is no evidence of marine submergence of the St. Lawrence Lowland during the St. Pierre Interval.

5. Ripple marks on the surface of St. Pierre sand at the Deschaillons brickyard section are preserved by conformable beds of varved clay of glacial Lake Deschaillons (Karrow, 1957). In addition Terasmae's (1955) study of pollen in the St. Pierre beds and superjacent varved sediments shows a climatic cycle represented by tundra vegetation, ameliorating to boreal forest conditions, and then reverting to tundra; evidence of the younger tundra sequence is found in pollen extracted from the lower strata of Deschaillons glacial lake sediments. According to these data, the St. Pierre Interval was closed by an advance of ice (presumed to be Laurentide) that blocked the St. Lawrence Valley below Quebec city to produce glacial Lake Deschaillons shortly after 66,000 BP (or earlier). Interstratification of the indicator pollen with sediments of the glacial lake, which represents the beginning of Gentilly Glaciation, shows that there was no time break between the nonglacial St. Pierre Interval and Gentilly Glaciation.

6. In the brickyard section at Deschaillons the upper layers of Deschaillons varved sediments are disturbed and broken to a depth of several feet and are overlain by sandy, grey Gentilly Till. The base of the till incorporates numerous pebbles and cobbles of rhythmically banded silt, derived from the underlying varves. Laurentide ice, therefore, depo-

sited Gentilly Till as it advanced southward through glacial Lake Deschaillons.

(comment: Karrow (1957) estimated 500 varves, at the Deschaillons brickyard).

7. In several sections varved clay, or varve-like rhythmites, are superposed on Gentilly Till and grade upwards into fossiliferous marine clay of the Champlain Sea. Coupled with Deschaillons' varves these represent a normal sequence of ponded glacial sediments preceding and following emplacement of Gentilly Till. There is no evidence of any subaerial erosional break in the sequence. The varves that predate Gentilly Till are in conformable contact with St. Pierre sediments. The post-Gentilly Till varves, or rhythmites, are in gradational contact with deep-water sediments of Champlain Sea.

The foregoing evidence is the basis for the interpretation that Gentilly Till, and the glaciation it represents, span all the Wisconsin between at least 66,000 years BP and approximately 13,000 years BP. Support of this hypothesis comes from the fact that none of the studies carried out in the central St. Lawrence Lowland region over the past twenty-five years has provided intermediate dates. Two groups of radiocarbon dates for nonglacial events have emerged: those greater than or near the laboratory limit for C^{14} dating, and those ≤ 13,000 years BP. This fact also supports the concept of a single glaciation of the 'central Lowland' region during most of the Wisconsin (Gadd, 1971)".

(Gadd, 1976 pp. 41-43)

Data in brackets are the writer's comments.

This concept is based on a short and almost continuous chronology characterized by a single non-glacial interval.

1.3.3 Recent conflicting data and the specific objectives of this investigation

In his work on the sediments and fauna of the Champlain Sea, Hillaire-Marcel (1979) included a geochemical study of older litho-stratigraphic units from the St-Lawrence River Valley. In a paper presented with Pagé in 1979 (published as Hillaire-Marcel and Pagé, 1981) a new interpretation was given to Lake Deschaillons through stable isotope analyses and radiocarbon dating of calcareous concretions previously ascribed by Gadd (1971) to a secondary concentration of salts through groundwater activity. The Hillaire-Marcel and Pagé (1981) geochemical model tends to support a syngenetic origin for these carbonates. The carbon is of organic origin and, therefore, the activity of its radioactive isotope is significant. The ^{14}C ages ($\simeq$ 35,000 years BP) equate more or less with the age of the lake. Total duration of the lake was also extented to 3,600 years by varve counting i.e. about an order of magnitude higher than Karrow's (1957) and Gadd's (1971) estimates.

In another PhD dissertation, Occhietti (1979) mapped the Shawinigan sheet and parts of the Mattawin and Montauban sheets. The Gentilly till was divided into sub-units and the Bécancour till was described for the first time up-river from the Vieilles Forges section. At this section, a 15 m silty sand unit conformably overlying the Deschaillons varves and truncated by the Gentilly till, was formally described as the "Sables des Vieilles-Forges", a member of the Deschaillons Formation (Occhietti, 1977).

Both Occhietti (1979) and Hillaire-Marcel (1979) stressed that assigning absolute ages to most of the units found in the St-Lawrence Lowland is problematic. Nevertheless, they both felt that Nicolet stadial (Bécancour till) should be correlated with marine isotope stage 4 as defined by Shackleton and Opdyke (1973).

Dreimanis and Karrow (1972) tentatively proposed an early Wisconsin age for the Nicolet stadial and the St-Pierre Interstadial. However, Dreimanis and Raukas (1975) correlated the St-Pierre Interstadial and the Nicolet Stadial with the events of the latest part of marine stage 5 and Dreimanis has adhered to this correlation in his subsequent papers. Stuiver et al. (1978) placed the St-Pierre Interstadial at the boundary of marine stages 4 and 5 on the basis of a ^{14}C date of 74 700 $^{+2700}_{-2000}$ years BP (QL-198).

From these studies, it became clear that a reliable geochronological technique that could overlap the radiocarbon range was needed. Partly from discussions with Drs Maurice Morency and Claude Hillaire-Marcel from Université du Québec à Montréal and Aleksis Dreimanis from University of Western Ontario, it appeared that application of the thermoluminescence technique could be worthwhile, even as a relative dating tool. However, during the first field season, it became apparent that the lithostratigraphic framework was more complex than expected. The use of lithological criteria for correlation purposes became compulsory. The thesis then gradually evolved to this final form.

Consequently, this thesis is divided into three parts. First, the lithostratigraphy of the Pierreville and St-Pierre les Becquets areas is presented in the next chapter. Key sections and stratigraphic logs are described and a general discussion on lithological indicators is presented. For both areas, tentative fence diagrams are proposed. The third chapter presents the ^{14}C dates obtained on organic matter, shells and concretions and discusses the chronological significance of the radiocarbon data. Chapter 4 describes an exhaustive thermoluminescence dating program in which 19 samples have been analyzed in an attempt to build an absolute time scale. Chapter 5 summarizes the stratigraphical framework derived from this study and the Chapter 6 is concerned with continental and land-ocean correlations.

1.4 Bedrock geology and its relation to Quaternary events

The Central part of the St-Lawrence Lowland is underlain by an Early to Middle Ordovician shelf composed of (1) a series of mainly limestones (Black River and Trenton groups) overlain by (2) shales and sandstones (Utica, Lorraine and Richmond groups). This sequence is gently folded into a large synclinorium (Fig. 1-3).

North of the area, paragneiss, marbles and quartzites of the Grenville SuperGroup are unconformably superimposed on Archean gneiss, migmatites, metavolcanics and amphibolites. Large bodies of anorthositic and granitic rocks intrude the series.

In the southeastern part of the area, the Ordovician sequence was affected by the Appalachian orogen (Taconic phase). Shales, slates and sandstones are divided into a thrust-imbricated para-autochtonous belt and an allochtonous belt of gravity nappes, both parts of the External domain as defined by St-Julien and Hubert (1975).

The lithology and structure of the bedrock exerted a strong control on the configuration of the sedimentary basins during the Quaternary (Fig. 1-3 and 1-4).

(1) The "preglacial" landscape affected the iceflow at least during the retreating stages. The Lower Paleozoic shelf and parts of the External domain were periodically inundated by large bodies of marine

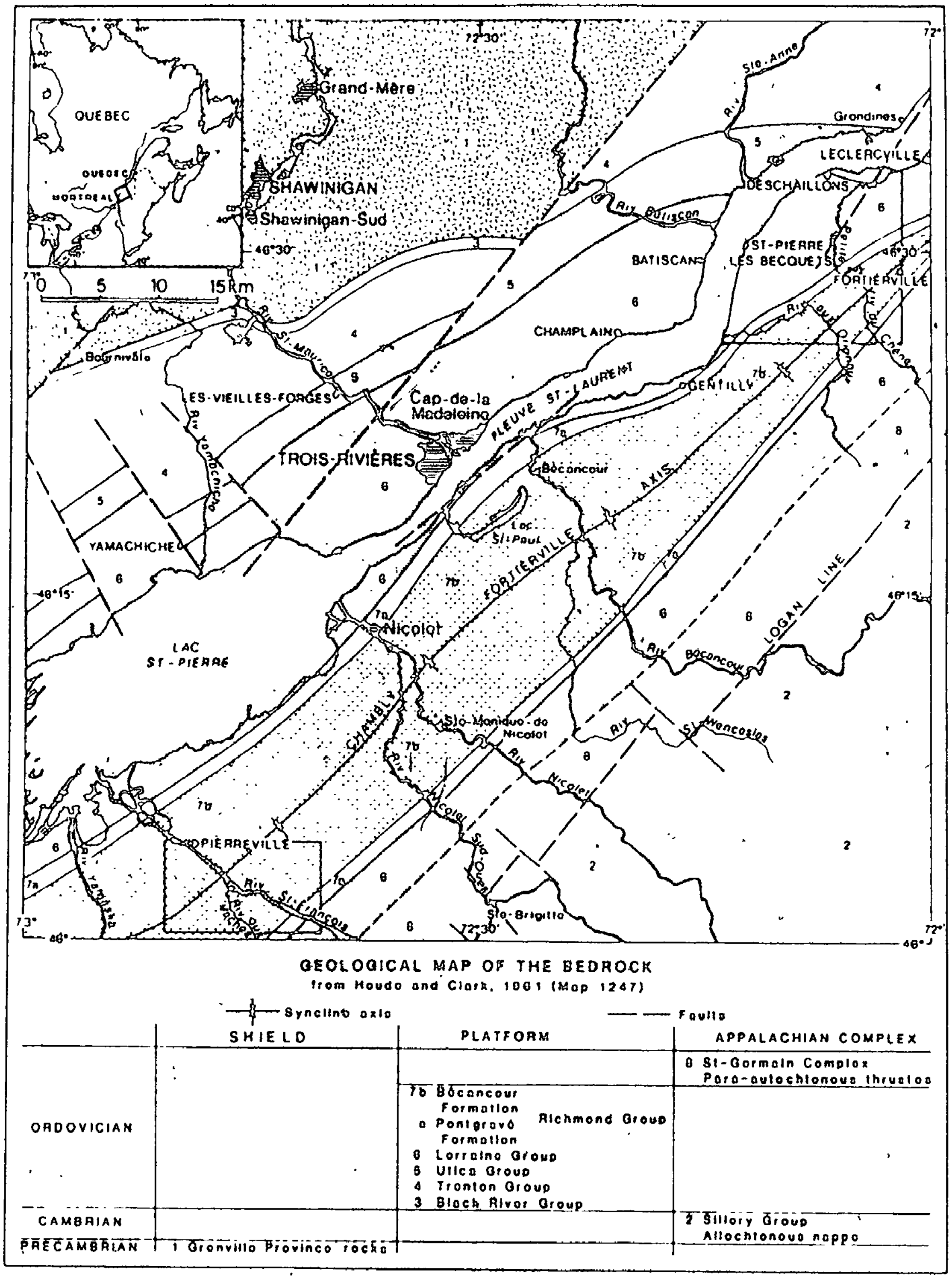


FIGURE 1-3: Geologic map of the bedrock. Becancour Formation is also known as Riviere Becancour Formation.

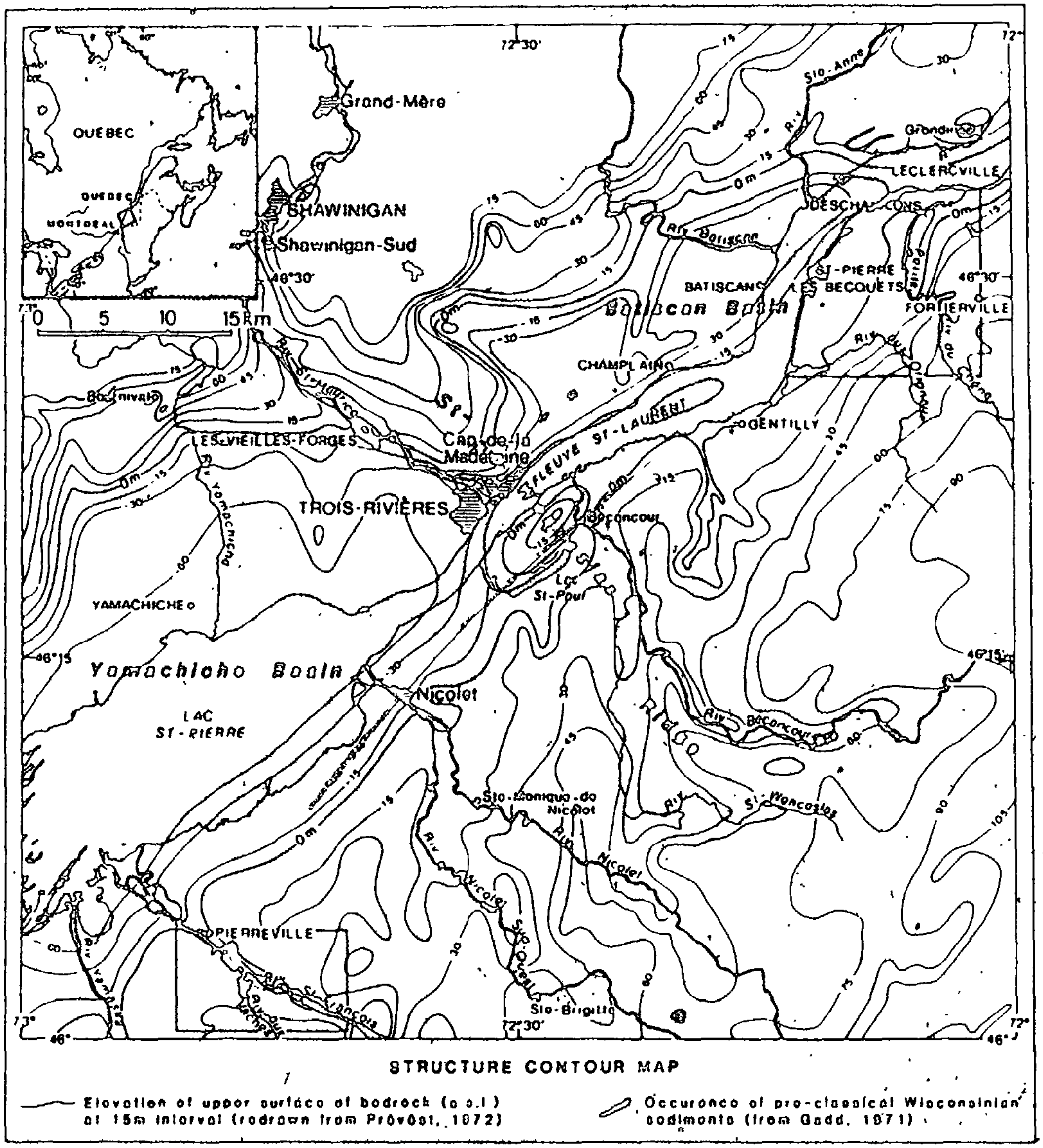


FIGURE 1-4: Structure countour map of the pre-Quaternary formations.

and/or lacustrine waters during most of the Pleistocene. Moreover, the structure countour map (Fig. 1-4) clearly shows two deep negative structures separated by a smooth positive feature. These are herein named Yamachiche and Batiscan Basins and St-Wenceslas Ridge. These depressions are partly structural due to the presence of the Chambly-Fortierville axis and partly lithological in origin since erosion has been more pronounced in the Lorraine Group. Their eastern flanks were favourable sites for the glacio-lacustrine sedimentation prior to the last glacial advance.

(2) The stratigraphic indicators mainly reflect "provenance" of some key lithological elements. For glacial sediments, as already noted by Keele (1915) and Gadd (1955), the local imprint to tills was a reddish colour due to comminution of the Rivière Bécancour red shales. The distal indicators are the Precambrian "crystalline" rocks. In the next chapter, other provenance indicators will be added.

The influence of Appalachian rocks is believed to be less pronounced since no evidence for strong ice flow from the east has ever been documented in the study of these tills. Nevertheless, these rocks were lying inside the drainage basin and must have contributed to the detrital influx brought into the former glacial lakes.

CHAPTER 2

LITHOSTRATIGRAPHY

The traditional lithostratigraphic framework proposed by earlier workers is based on field criteria such as texture, colour or relative stratigraphic position of the lithologic units. In this chapter, the description of the sections from the two sub-areas as defined in Chapter 1 includes new field observations and measurements as well as laboratory analyses. Correlation of units may be demonstrated through the use of specific lithologic criteria such as carbonate content or clay mineralogy. However, where possible, lateral lithologic continuity is considered to be the prevailing criterion.

The original description of the following sections by Gadd (1955, 1971) and Karrow (1957) may be found in Appendix I.

The methods of investigation are described in Appendix II.

2.1 Pierreville

The Pierreville area is located at 40 km NE of Montreal, along the St-François River, some 10 km before it reaches Lake St-Pierre (Fig. 2-1). The sections are found on both sides of the river, inside a 30 m high (a.s.l.) terrace that is most probably related to the Montréal phase of the proto-St-Lawrence River (MacPherson, 1967). Gadd's section numbers were used. As previously noted, the sediments described here have been laid down in the eastern sector of the Yamachiche Basin (Fig. 1-4).

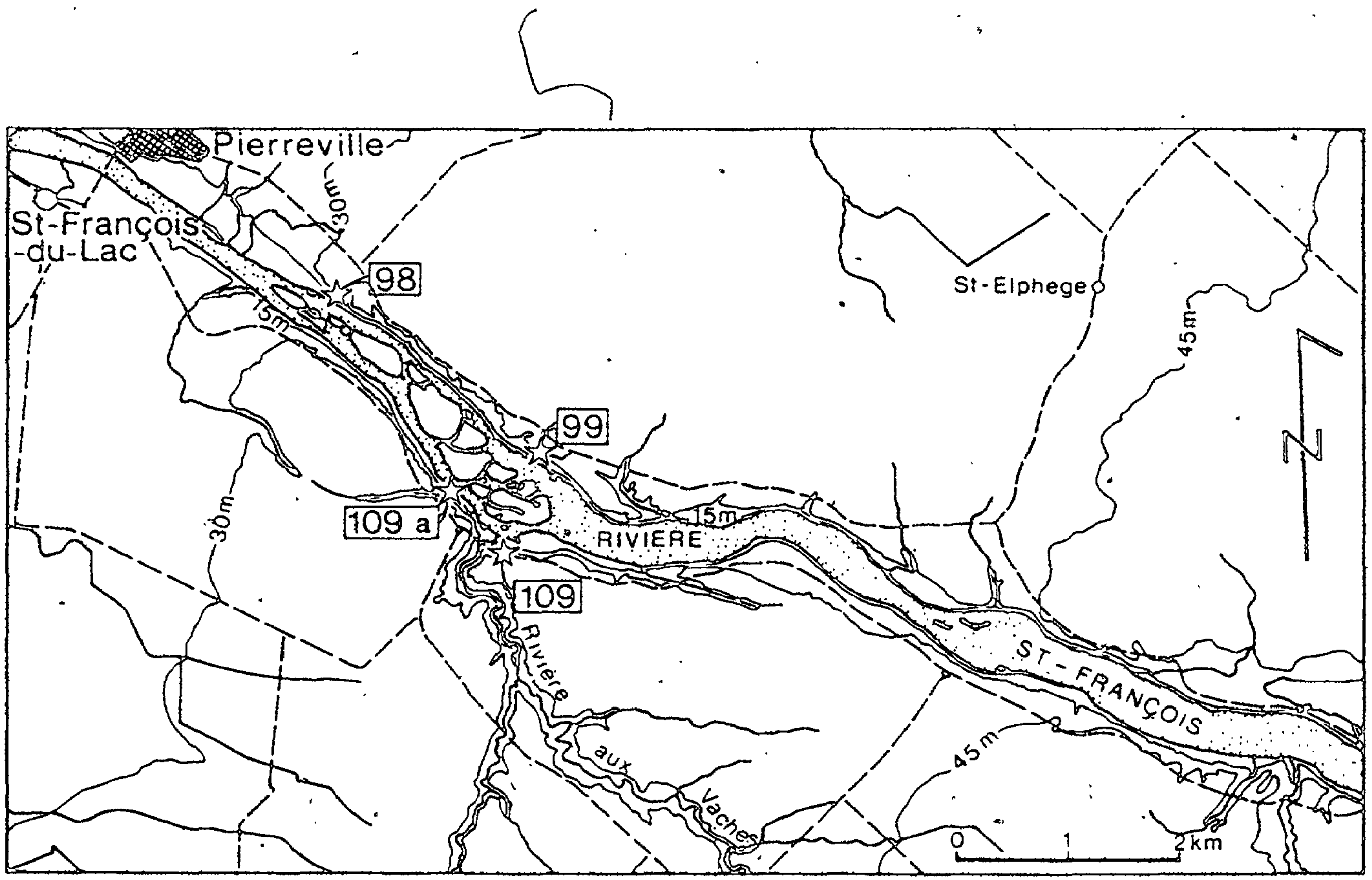


FIGURE 2-1: Location of the Pierreville sections.

2.1.1 The Pierreville section (98).

The section is located 2 km southeast of Pierreville Village, on the northeastern bank of the St-François River (Plate 2-1a). It was described by Keele (1915), Gadd (1955, 1971) and Terasmae (1958). Six units are found (from the base to the top; Fig. 2-2):

Unit A: 10 m of laminated grey (5 Y 4/1) to greenish (5 Y 5/2) clayey silt. The laminations consist of distinct clayey layers that appear rhythmically in the unit alternating with silt layers 3 to 5 cm thick (Plate 2-1b). They show parallel stratification and rare cross-bedding. The silt is relatively rich in carbonates (≈10%). Clay layers are 1 cm thick and have less carbonates (7 %, 1 sample). They are dark grey (5 YR 4/1) although some layers have a reddish (7.5 YR 6/2) or greenish (5 Y 5/2) tint. Such rhythmites in which the silt layers are consistently thicker than the clay layers belong to the Group III varves of Ashley (1975) sedimented typically in proximal position relative to the source. In this unit 235 couplets were counted. In the first hundred couplets, nine definite levels of silt layers were found to contain elliptical calcareous concretions (≈50% carbonates) (Plate 3-1b). No dropstones were found. The top couplets are leached and truncated by an erosional discontinuity (Plate 2-1c).

Unit B: 3 m of well-sorted non-calcareous yellowish grey (10 YR 7/2) sand beginning with a gravelly sand lens overlying unit A. At the base, the sand shows graded bedding and parallel stratification. Upward, the silt content increases and ripple-drift

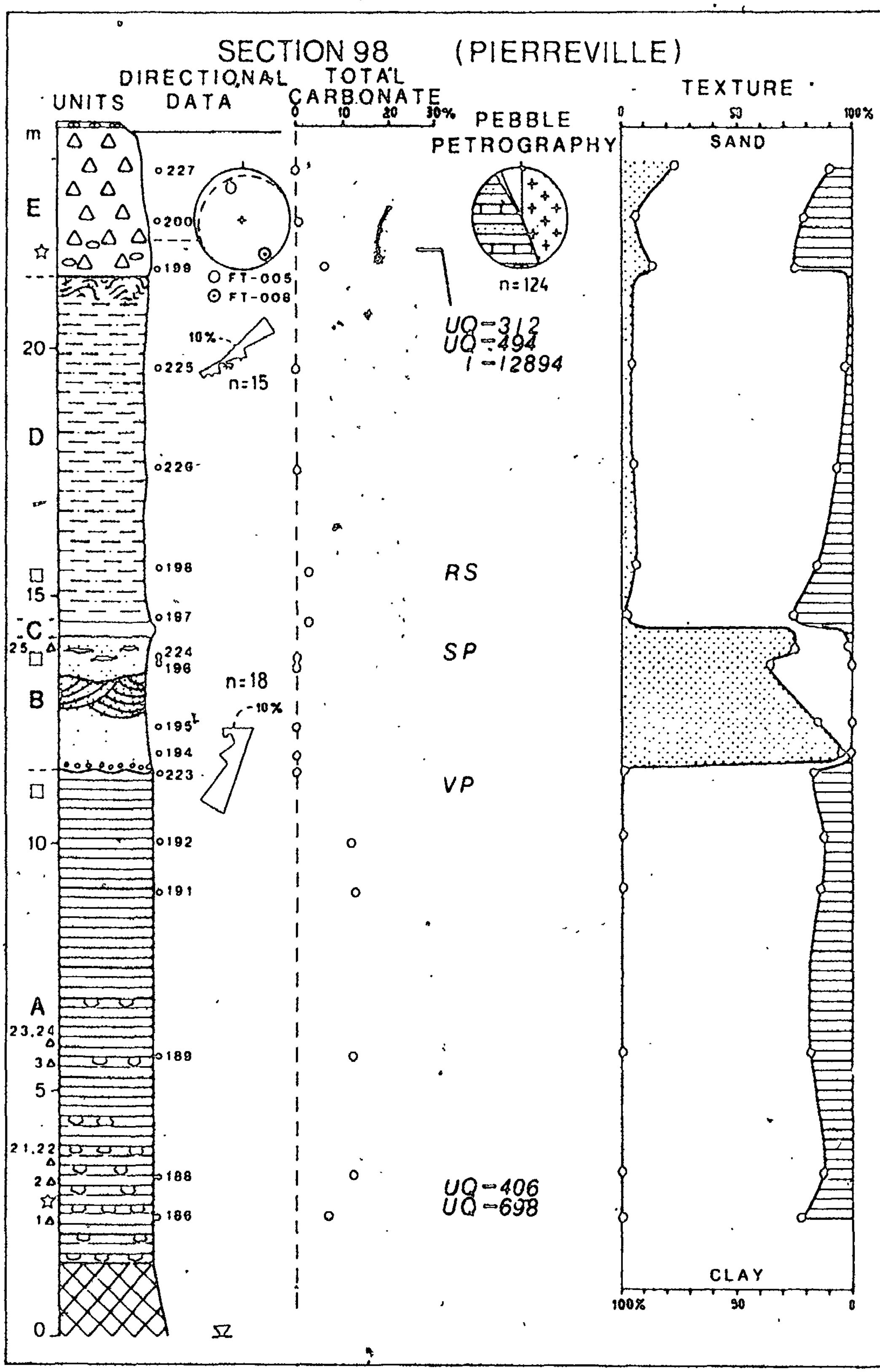


FIGURE 2-2: Stratigraphic log for section 98. See Appendix V for legend.

PLATE 2-1

a: The Pierreville section; man stands on the top of unit 98-A and points to the peat layer; view looking west.

b: Type III rhytmites in unit 98-A; knife is 25 cm.

c: Unconformable contact between units 98-A and 98-B.

d: Organic-rich sand below the peat layer (shown by triangle)

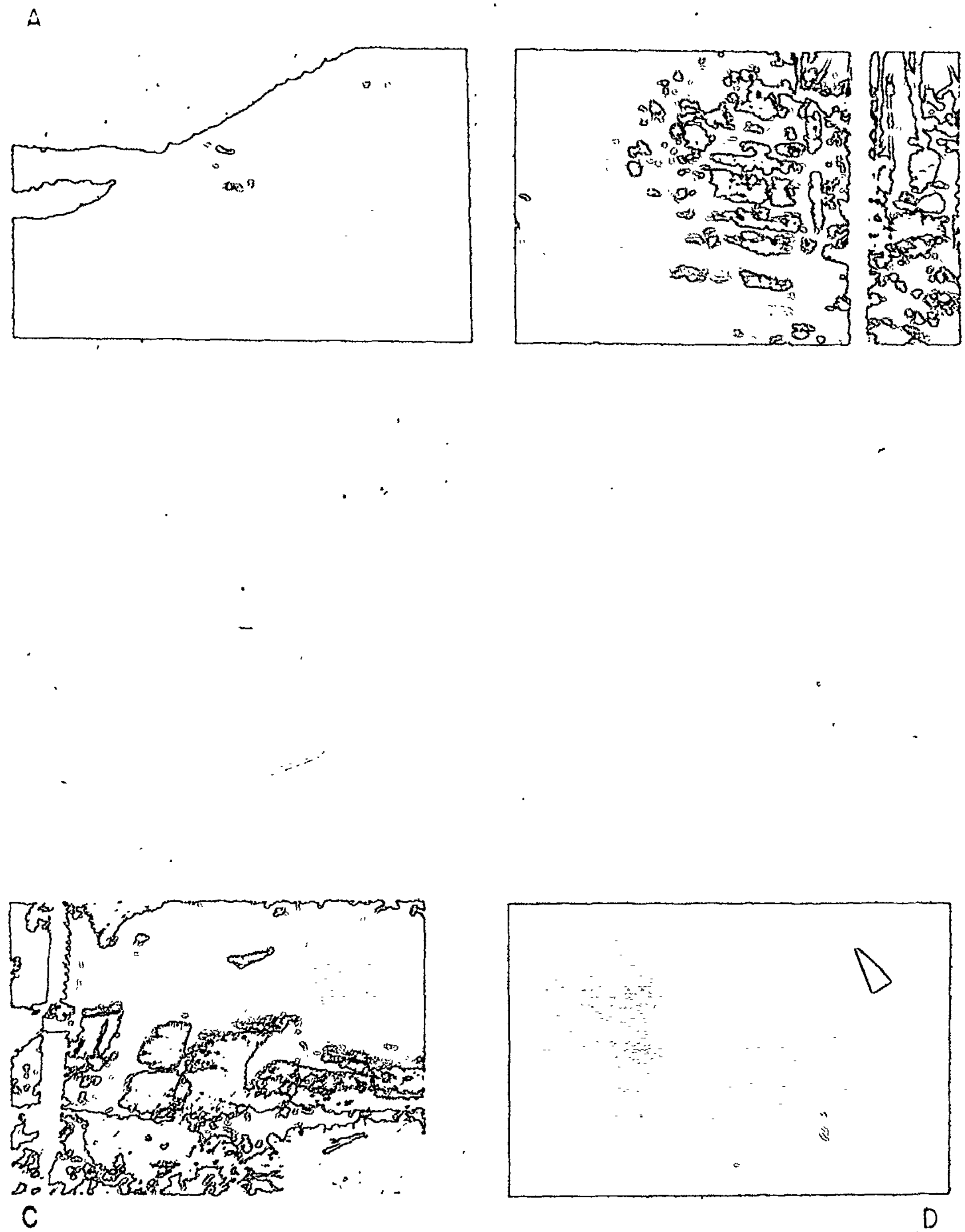


PLATE 2-1

cross-lamination (type B) appears together with some deformation and peat balls (Plate 2-1d). The sedimentary structures suggest a paleocurrent direction from NNE towards SSW. These sediments are indicative of a shallow lacustrine environment.

Unit C: 30cm of highly compressed dark brown (10 YR 3/2) peat. Large stems and branches of wood extend out from the section. From this peat, Terasmae (1958) described a cold climate pollen assemblage dominated by Picae and Pinus. Fossil Sphagnum and beetles are also very abundant.

Unit D: 4 m of silt resting conformably on the peat (Plate 2-2a). In the lowermost 2 m, the silt is clayey, grey (10 YR 5/1), weakly calcareous (2%) and shows a faint rythmicity. They nevertheless do not exhibit a distinct clay laminae and are devoid of dropstones. In the uppermost 2 m, sand lenses become important and they show ripple-drift cross-lamination, load structures and flaser bedding (Plate 2-2b). Sedimentary structures have a preferential dip towards the NE. This coarsening-upward unit is interpreted as a slowly shoaling non-glacial lacustrine environment.

Unit E: 3 m of weakly calcareous oxydized brownish-grey (7.5 YR 7/4) diamicton disconformably overlying the preceeding unit. The diamicton is moderately compact. It is rich in silt, with approximately 15% of particles greater than 2 mm. These are mainly Precambrian (40%). The pebble fabric and shear planes suggest emplacement from NNW towards SSE (Fig. 2-10).

PLATE 2-2

a: Conformable contact between the peat layer (dark) and the overlying unit 98-D; camera protector is 5 cm wide.

b: Flaser bedding and load structures at the top of unit 98-D; rule is 15 cm.

c: Striated concretion embedded in the upper diamictic unit 98-E.

d: Lower bouldery brick-red till at section 109 seen locally overlying massive silt; contact is shown by triangle; west bank of Riviere aux Vaches.

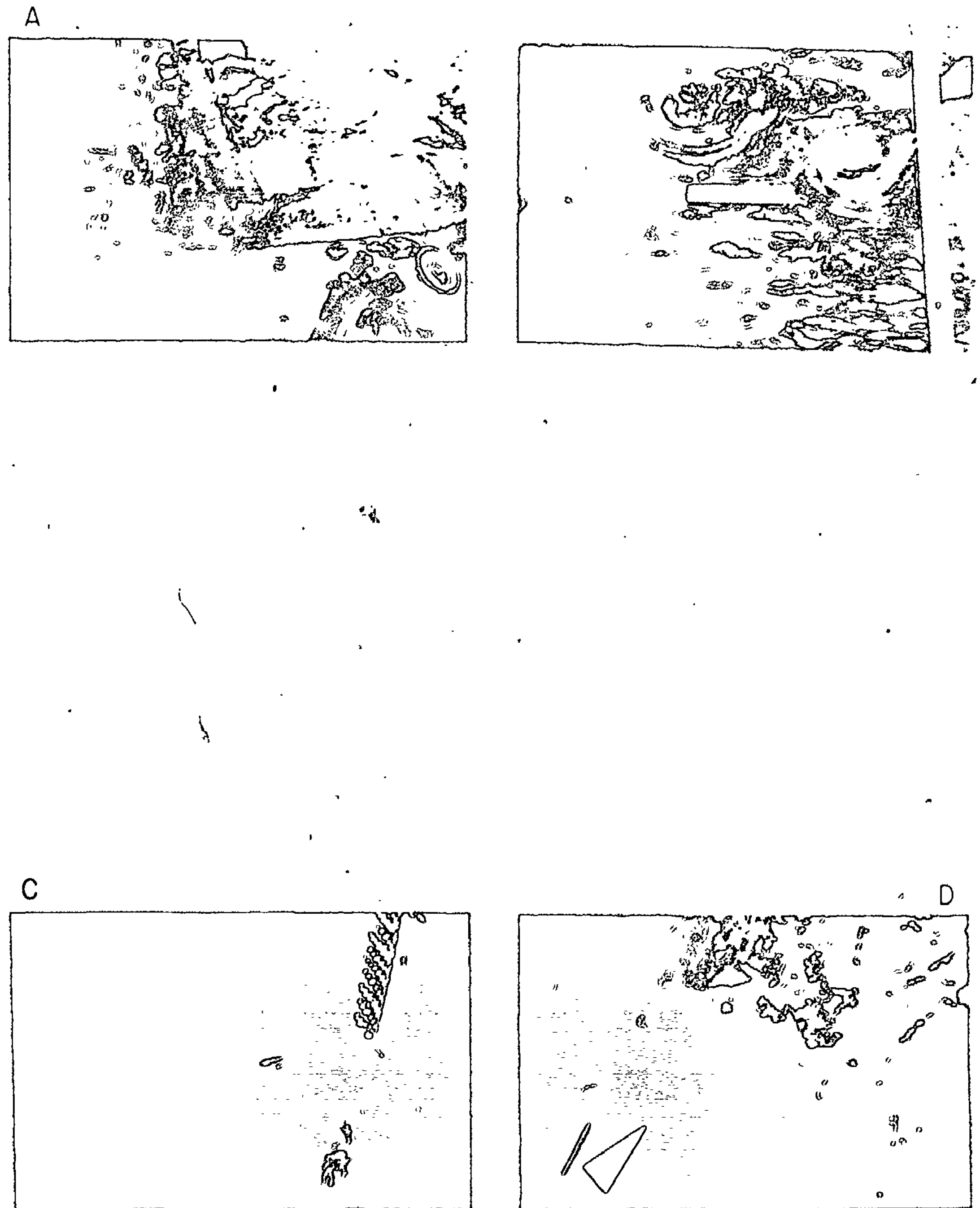


PLATE 2-2

Smudges of brick-red (5 YR 6/4) clay lenses are abundant. This diamicton is interpreted as a till and it has probably been emplaced by lodgement at the base of the ice. The basal 30 cm are dark grey (5 YR 4/1), clayey and more calcareous (5 %) and contain numerous elliptical striated concretions (Plate 2-2c) with about 50% carbonates (Fig. 2-9), which suggests that the base of this diamicton is composed of the underlying unit A.

Unit F: 60 cm of weathered brownish grey (7.5 YR 7/4) vertically jointed silt.

2.1.2 The Rivière St-François section (99)

This section is located 5 km up-river from Pierreville Village, on the northeastern bank of the river. It is described in Gadd (1971). From base to top, the section consists of seven units (Fig. 2-3):

Unit A: Red (5 YR 5/4) to greenish (5 Y 5/2) calcareous (9 % carbonates) siltstone of the Ordovician Rivière Bécancour Formation outcropping at low-river level.

Unit B: 4 m of brick-red (5 YR 6/2) sandy and silty diamicton. The diamicton has approximately 10% of carbonates, shows a few shear planes and is very compact. Most probably, it has been emplaced by glacial lodgement. Towards the base, 30 cm of this unit is slightly greenish (5 Y 5/2).

Unit C: 7 m of weakly calcareous, dark grey (5YR 7/1) thinly laminated clay. The contact with the underlying till is sharp (Plate 2-3b); basal couplets are not calcareous and show equally

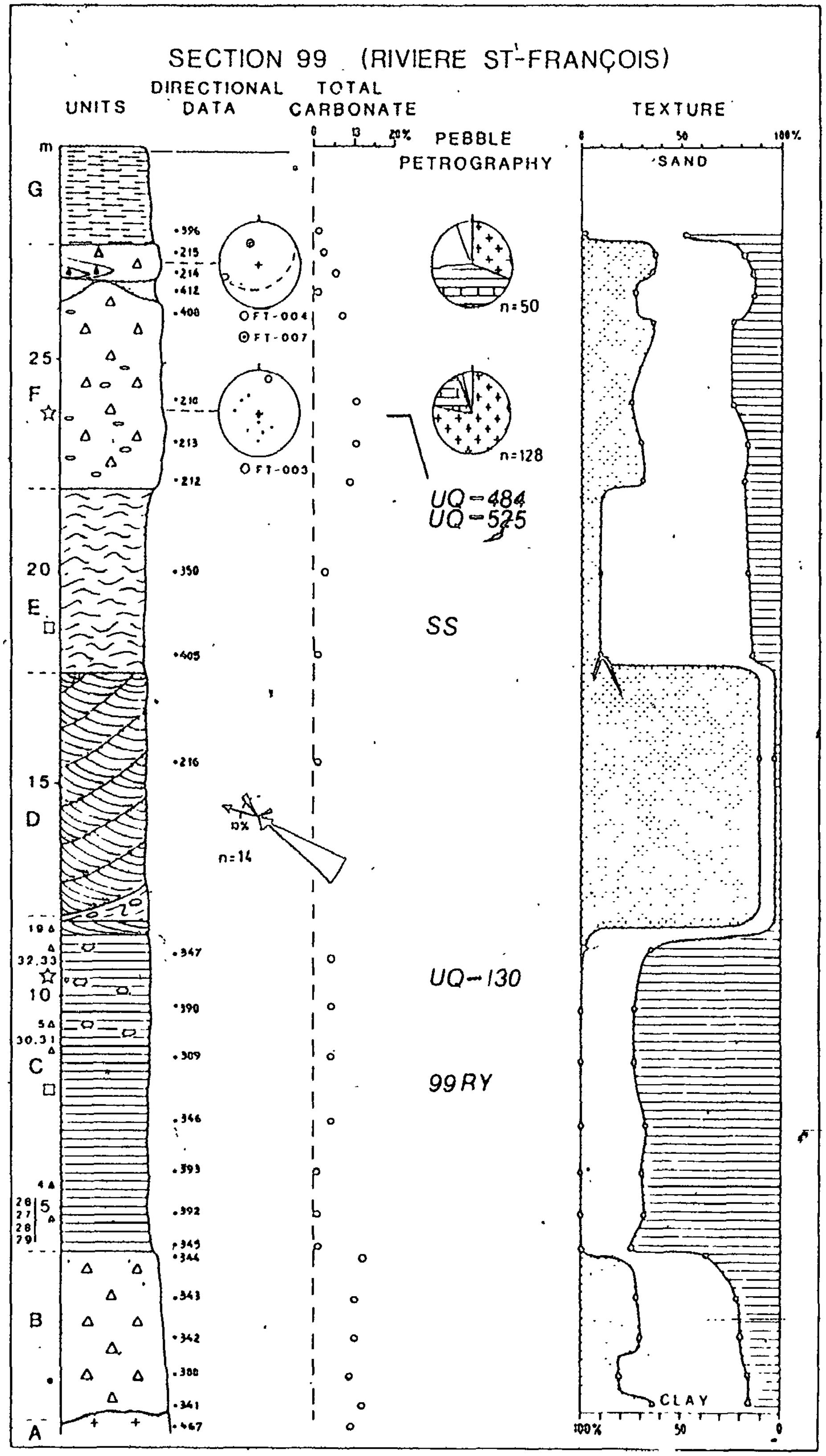


FIGURE 2-3: Stratigraphic log for section 99.

PLATE 2-3

a: Boulder pavement in diamictic unit 109-A; west bank of St-Francois River; view looking down river.

b: N-S fluting at the top of unit 99-B (base of pen) in sharp contact with the overlying unit 99-C; view looking northwest.

c: Calcareous crust (base of knife) and dropstone in unit 109-C.

d: Micro laminations in basal part of unit 99-C; bar is 1 cm.

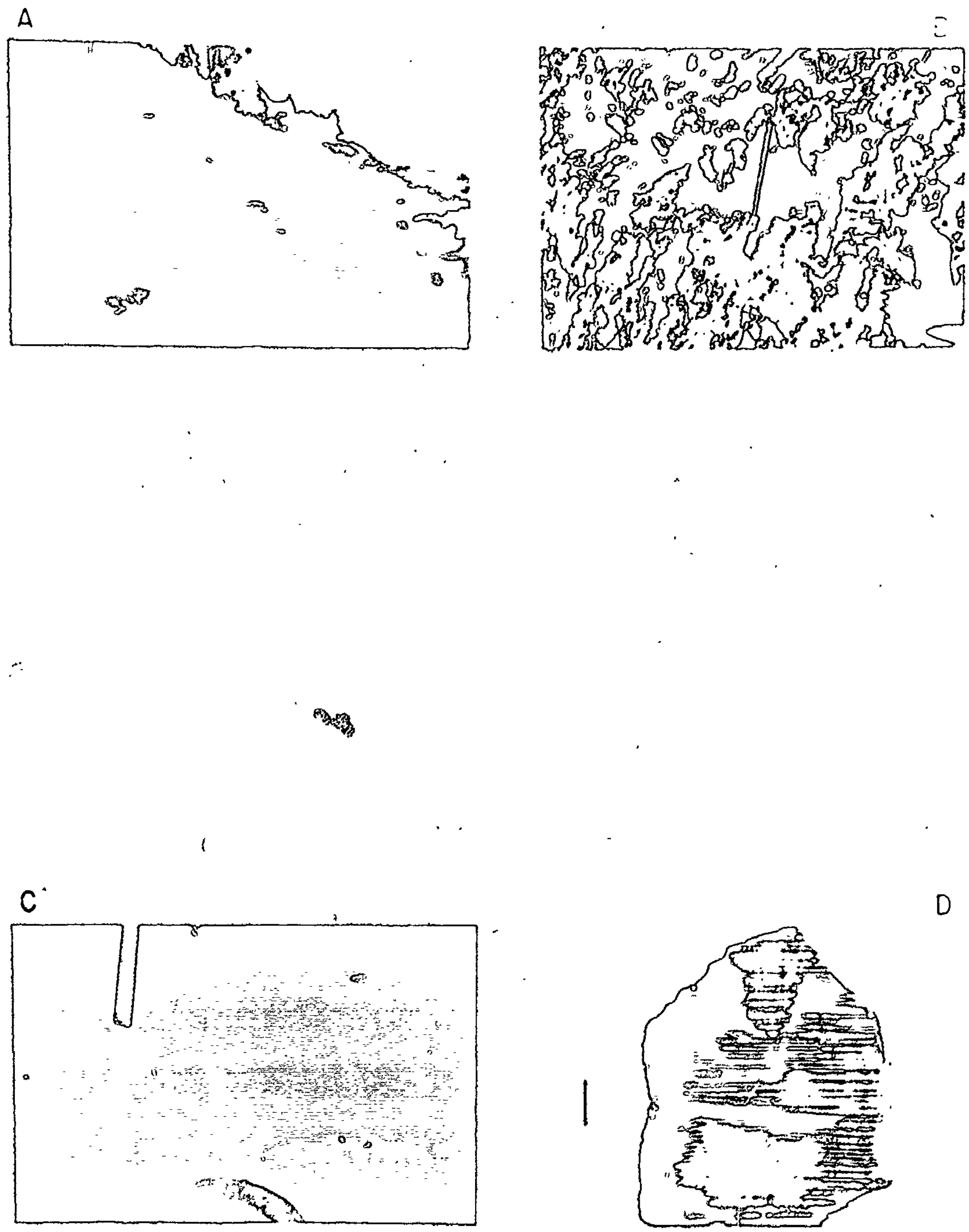


PLATE 2-3

thin silty and clayey laminae (Group II varves of Ashley, 1975) with an average thickness of 0.13 cm/couplet (Plate 2-3d) Upward, the silty laminae tend to disappear (tendency to group I varves), except for some sand parting. The average thickness increase to 0.75 cm/couplet and the carbonate content reaches 4 %. Towards the top, there appear a few red (5 YR 6/2) laminae. The top layers are slightly sheared although the uppermost ones are not. There is a minimum of 2 000 couplets. Disc-shaped concretions (60% carbonates) are found towards the top (Plate 3-1c). Dropstones are common (Plate 2-3c). This unit is interpreted as being sedimented in a distal glaciolacustrine environment.

Unit D: 5 m of yellow stained (10 YR 5/5) well-sorted sand with some gravel at the base. They show major tabular cross-bedding dipping towards the NW, shown on the log. However, directional current data measured on the minor laminae are oriented towards SE.

Unit E: 3 m of brown stained (10 YR 5/2) sandy and clayey silt with faint rhythmicity slightly deformed towards the top.

Unit F: a) 5 m of calcareous brownish grey (10 YR 6/2) silty diamicton with 20 % of particles greater than 2 mm. The orientation of their long axes is aligned along a N-S trend. A pebble count revealed a high amount of Precambrian rocks (80%). This unit is very compact and contains numerous striated concretions. It is interpreted as a lodgement till.

b) 2 m consisting of 2 layers of weakly calcareous reddish (5 YR 5/4) and brownish grey (5 YR 6/1) silty diamictons interstratified with discontinuous lenses of silty and gravelly sand. The top diamicton shows a large hook fold with a NW shallow dipping axial plane. The fabric of the diamicton is diffuse and has a preferred orientation toward the NW (Fig. 2-10). The unit is loosely compacted. It has been deposited probably by supraglacial or ice-marginal flowage.

Unit G: 2 m of dark grey brownish (10 YR 6/2) clayey silt, weathered and vertically jointed. The silt is massive and weakly calcareous.

2.1.3 The Rivière aux Vaches sections (109)

The junction of the Rivière aux Vaches with Rivière St-François has exposed a number of sections shown in Figure 2-4. Section 109 as originally described by Gadd (1971) is located at the junction of the two rivers. Because of poor exposure, Figure 2-5 is a composite section built from sub-sections b, c and d. It shows essentially the same stratigraphic succession as section 99. However,

(1)the basal brick-red (5 YR 6/2) till exhibits a strong NNW-SSE fabric (Fig.2-10). The lower metre is a brick-red silt with few stones (Plate 2-2d).

(2)the top of unit C shows a fold with an axial plane dipping towards the northwest.

(3)Pieces of wood have been collected at the base of unit D.

(4)The lodgment facies of the upper grey till is absent.

(5)The uppermost brownish grey till exhibits a moderately strong fabric towards the NW (Fig 2-10). The fabric was measured at

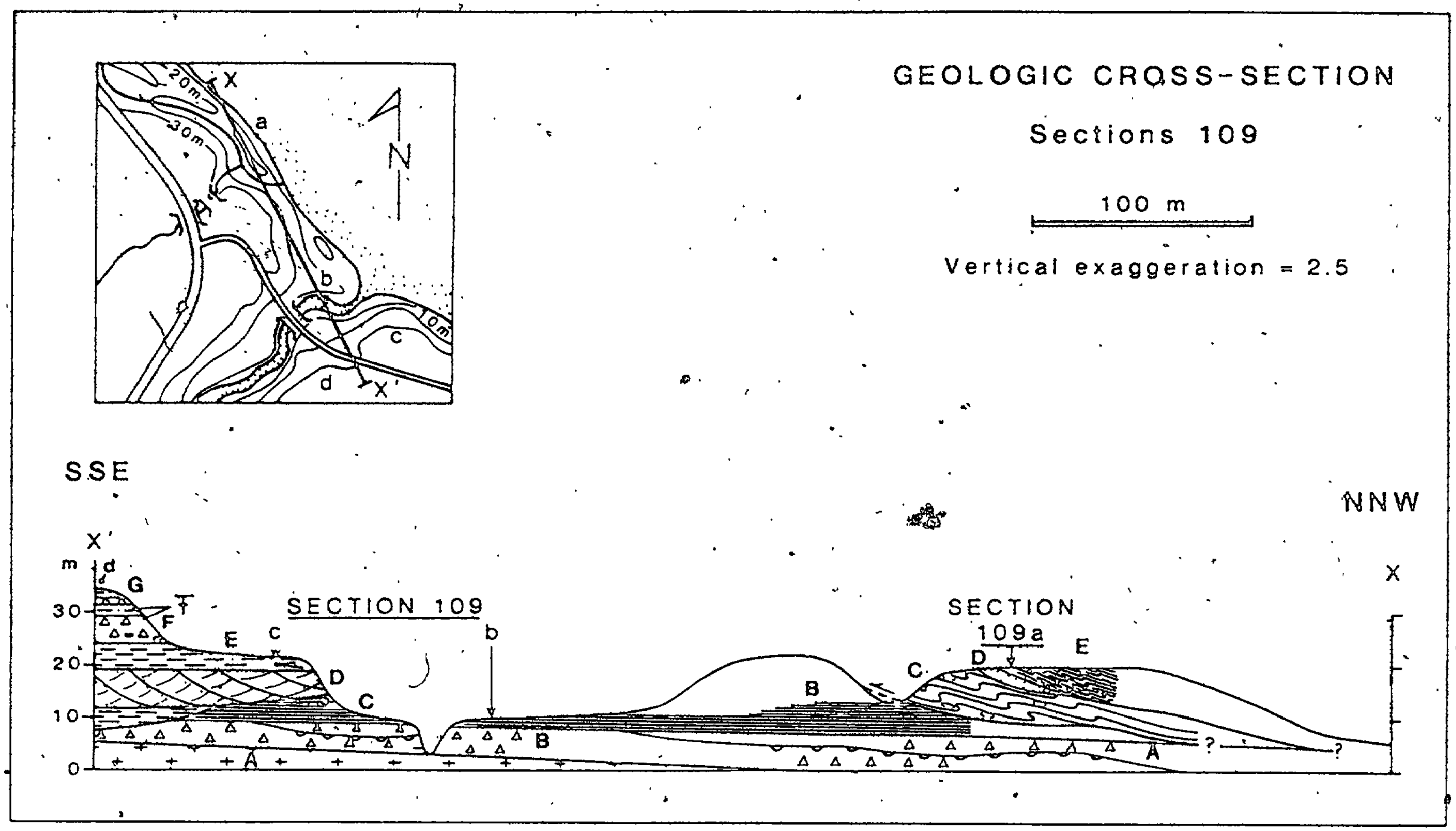


FIGURE 2-4: Geologic cross-section at Rivière aux Vaches.

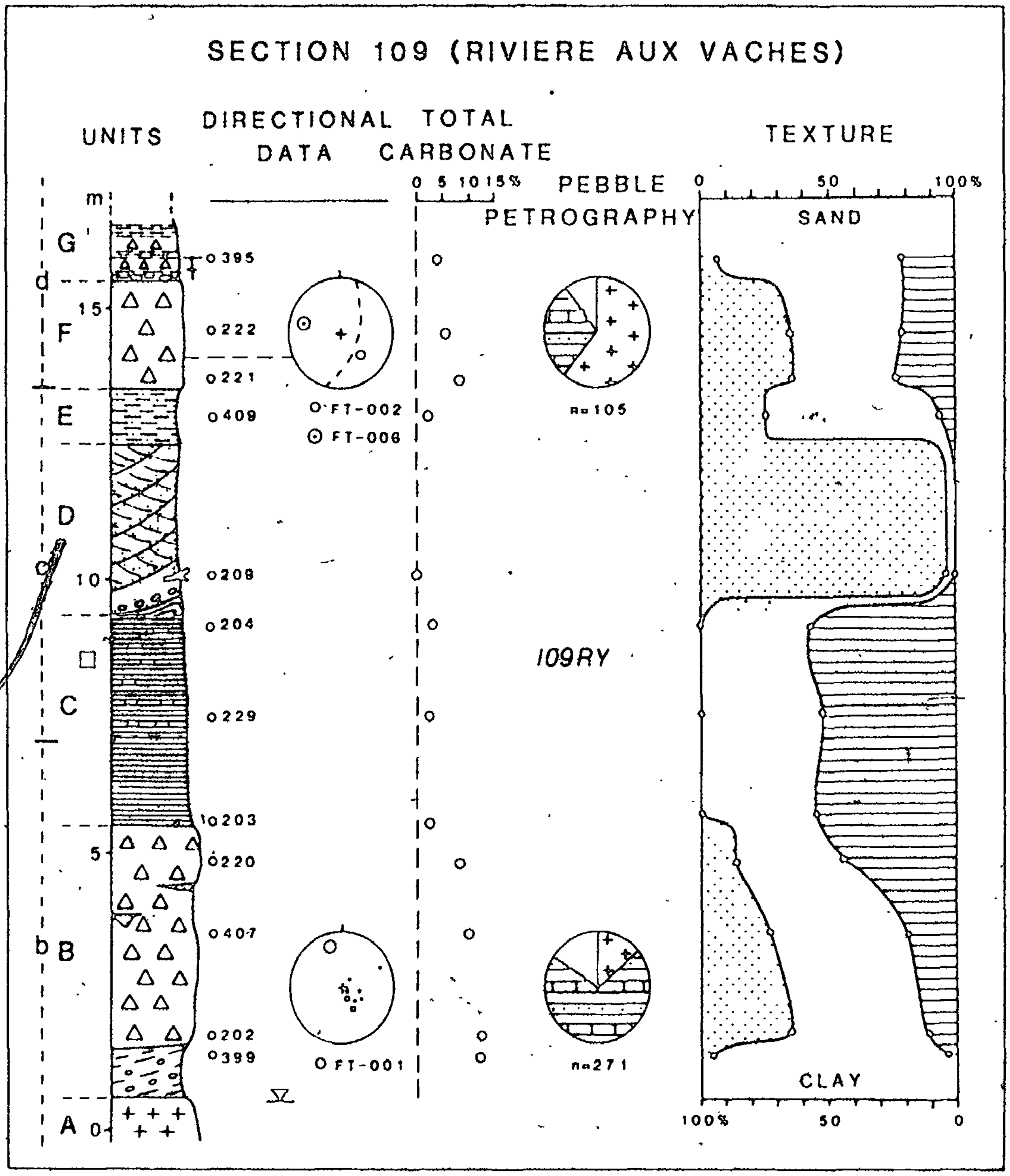


FIGURE 2-5: Stratigraphic log for section 109.

site d. It is interpreted, herein, as a flow till. Shells of *Portlandia arctica* are scattered through this till which is interbedded with marine clay at the top.

The geological cross-section shown on Figure 2-4 reveals further information:

(1) A boulder pavement on which one set of striations have been measured (N22W), divides the red till into a lower brick-red unit and an upper reddish brown (5 YR 5/4) unit (Plate 2-3a). In the lower most part of this unit, discontinuous gravel and sand lenses are abundant.

(2) 50 m eastwards from 109a, a 3 m thick unit can be found under the sand unit 99-D. It consists of grey (10 YR 5/1) clayey silt and brownish-grey (10 YR 5/2) fine sand.

(3) An isolated hill can be seen approximately 100 m downriver from 109 . This section, labelled 109a, is described, herein, for the first time. The description begins at the top of the lower till (fig. 2-6):

Unit A: 1 m of reddish-brown (5 YR 5/4) to grey (10 YR 5/2) diamicton in lithological continuity with 109-B.

Unit B: 20 cm of dark grey (5 YR 4/1) to brownish red (5 YR 6/2) weakly calcareous (4 % carbonates), laminated silty clay with disc-shaped concretions (≈60% carbonates). The unit is massive close to the upper contact.

Unit C: 4 m of calcareous laminated clayey silts (10% carbonates) consisting of 5 to 6 cm thick light grey (5 Y 4/1) silt laminae

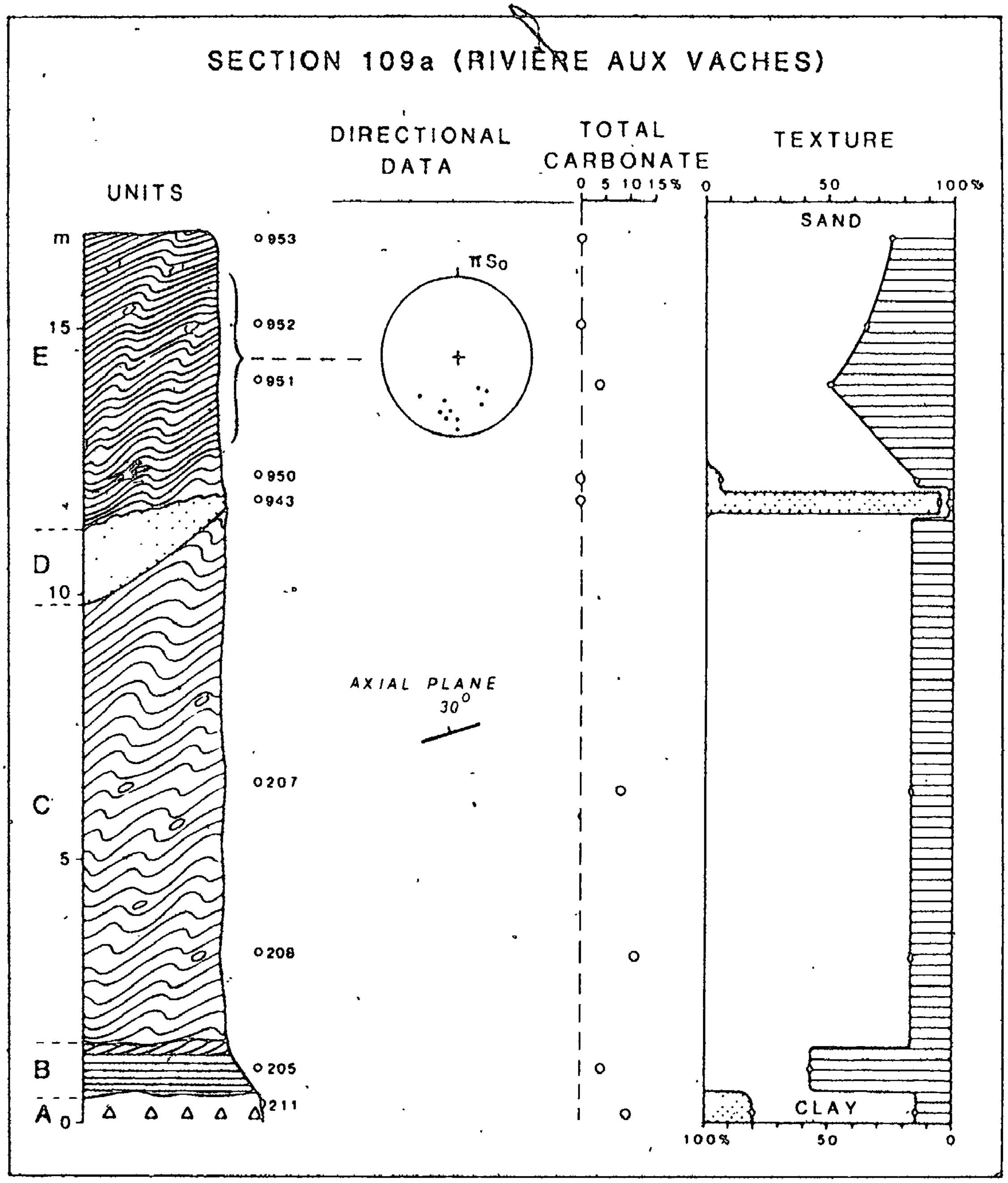


FIGURE 2-6: Stratigraphic log for section 109a.

with 1 cm thick dark grey (5 YR 4/1) clay laminae. This unit is gently folded with axial plane striking ENE-WSW and dipping to the NNW. The unit is rich in elliptical concretions (≈50% carbonates).

Unit D: 1 m of deformed non-calcareous yellow (10 YR 5/5) medium sand, with some clasts of lacustrine silt.

Unit E: 5 m of grey and brick-red laminated very clayey silt. The couplet thickness is 0.8 cm. This unit is weakly calcareous and contains blade-shaped concretions (66% carbonates, one sample). It is highly deformed and sheared towards the south. The sediment is compact and shows some flowage of probably glaciotectonic origin.

2.1.4 Discussion: Lithostratigraphy of the Southern Area

As already mentioned in the first chapter, Keele (1915) described two tills in this area. They are exposed at section 99 which apparently displays a complete glacial to non-glacial to glacial cycle. However, a major unit is missing: the peat layer. Consequently, to illustrate the complete lithostratigraphic framework of this area, it is necessary to correlate sections 98 and 99. The latter is a more or less complete image of the Rivière aux Vaches sections.

According to Gadd (1971), sections 98 and 99 can be simply correlated by drawing tie lines at the boundary of most of the lithostratigraphic units as shown in Figure 2-7. Although not explicitly discussed by Gadd but hinted at through his lithological descriptions, lateral facies variations must account for such correlation.

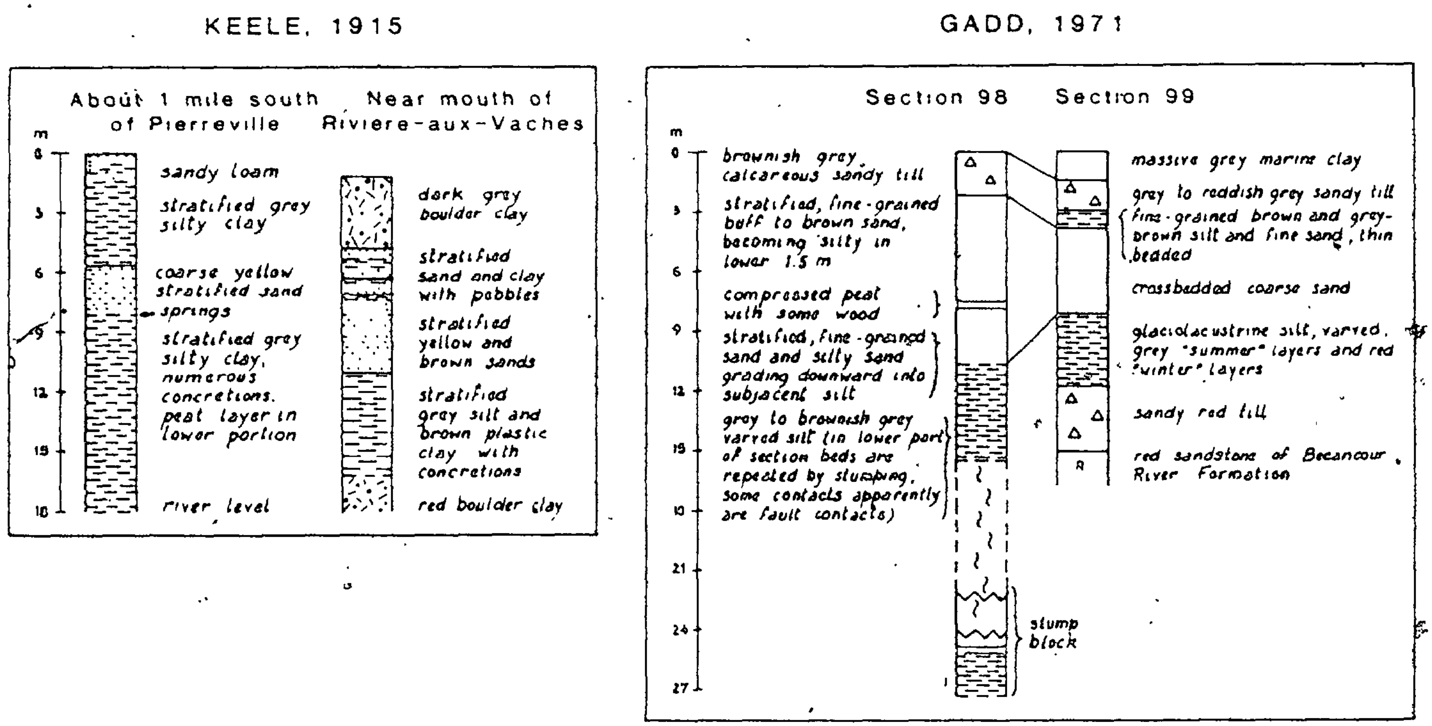


FIGURE 2-7: Correlations of sections 98 and 99, according to earlier workers.

The upper grey till thickens from 98 to 99. In this section, subglacial and supraglacial facies represent the last glacial advance.

The lower till is only found in section 99. It is interpreted as a lodgement till. This unit disappears under the river level at mid-distance towards section 98. Both upper and lower tills seem to have been deposited by ice flowing southward.

Non-glacial sediments are exposed in both sections but, in the Rivière aux Vaches area, the only organic remains are pieces of wood in the sand unit D of section 109. Units 98-B and D are therefore correlated with 99-D and E.

However, since the early part of our work, it was proposed (Lamothe, 1982) that lateral facies variation cannot alone account for the differences found in the pre-St-Pierre laminated units formaly defined by Terasmae (1958) and Gadd (1971) as the Pierreville Varves. The following discussion is therefore concerned with the relative stratigraphic position of units 98-A and 99-C.

Both units are composed of varved sediments. Even though the annual nature of the rythmicity is hard to demonstrate, it is generally believed that the rythmicity by itself, the constant thickness and extensive lateral continuity in the unit of the clay laminae and the lithological discontinuities found at the base and at the top of the clay laminae and some other criteria such a bioturbation and pollen fragments being found only in the silty laminae (Banerjee, 1973; Terasmae, 1963) suggest an annual rythmicity. The number of couplets (2000 - 2500 in 99-C; 235 in 98-A), the average thickness of the couplets (0.4 cm in 99-C; 4 cm in 98-A) and the thickness ratio of the summer to the winter laminae suggest that these two units were formed in two different glacio-lacustrine environments.

Grain size analysis of 99-C and 98-A samples submitted to the Pleistocene Laboratory of the University of Western Ontario have been displayed on Figure 2-8. The 99-C samples are very rich in clay, a consequence of their probable distal provenance whereas 98-A samples are much richer in silt-size particles.

Differences in overall mineralogy between these types of sediments are probably not significant and may be the result of different textures. It is therefore convenient and actually a routine procedure in stratigraphy to select some specific mineralogic criteria if they are found to be constant inside a particular unit. Herein, the total carbonate content of the sediment and the concretions are relatively constant inside each unit but differ between units.

The carbonate analysis of the sediments in this study revealed that, as a general rule, the carbonate content of the Quaternary sediments found in the St-Lawrence Lowland is low. There seems to be a general background value of 2 to 4% (99-C is an example) with higher carbonate contents in tills and glacio-lacustrine sediments of the proximal type e.g. unit 98-A. The carbonate contents have been obtained by the technique described by Dreimanis (1962) in which individual values of calcite and dolomite are measured (Appendix II). Figure 2-9 presents the results for the samples collected in the Pierreville area. Also shown are the carbonate analyses for the Rivière Bécancour shale, Black

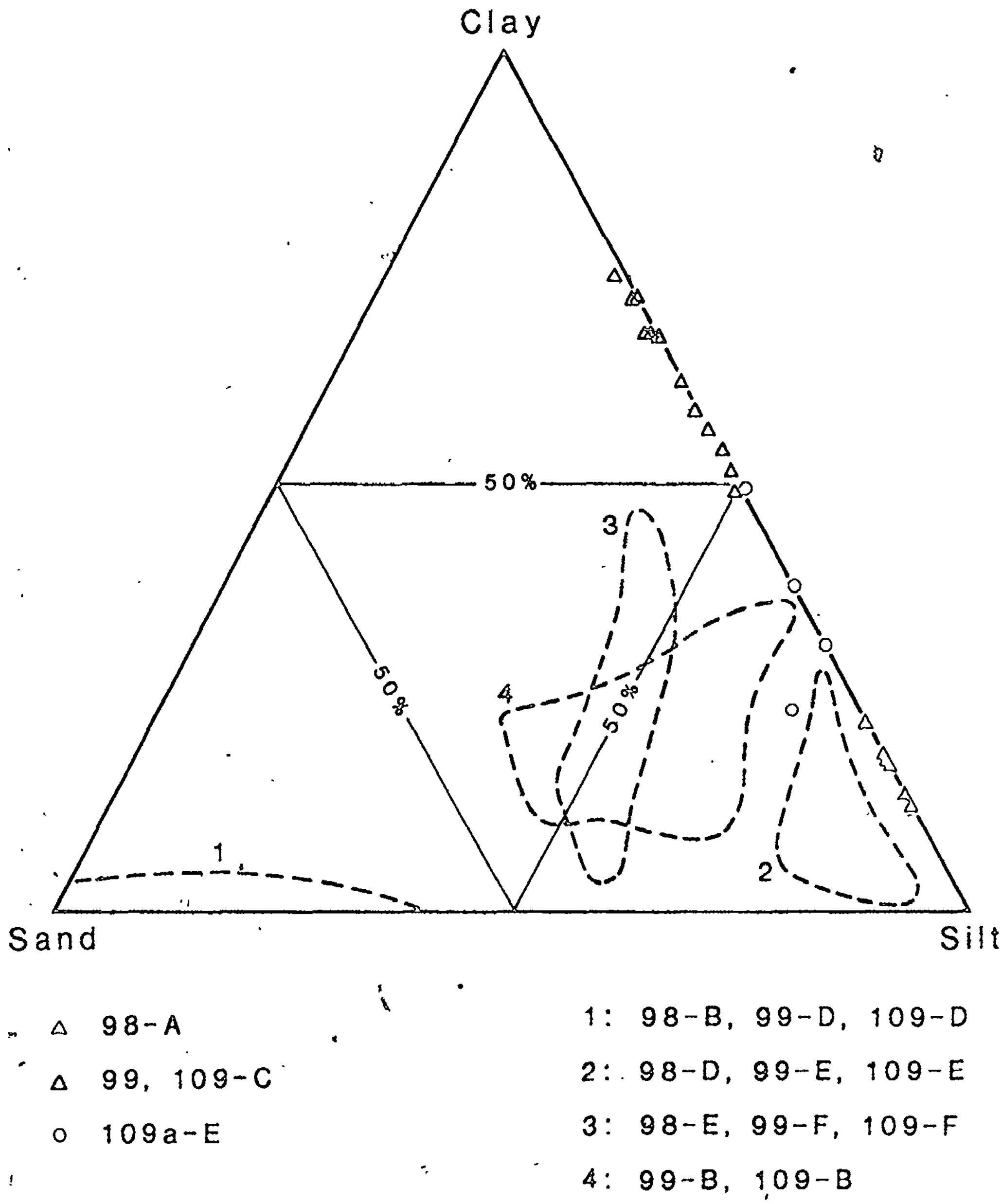


FIGURE 2-8: Textural ternary diagram, Pierreville area.

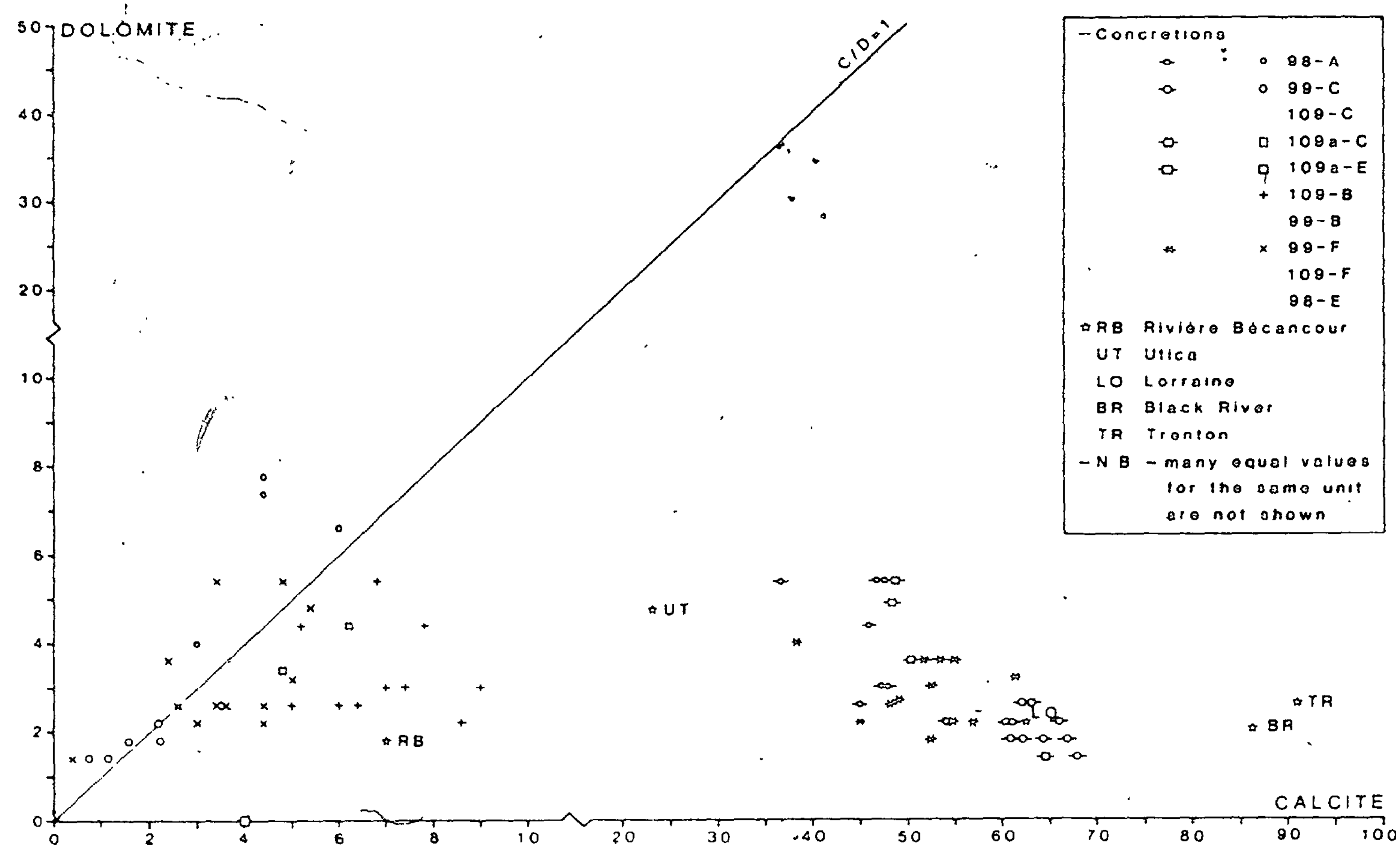


FIGURE 2-9: Calcite and dolomite contents, Pierreville area.

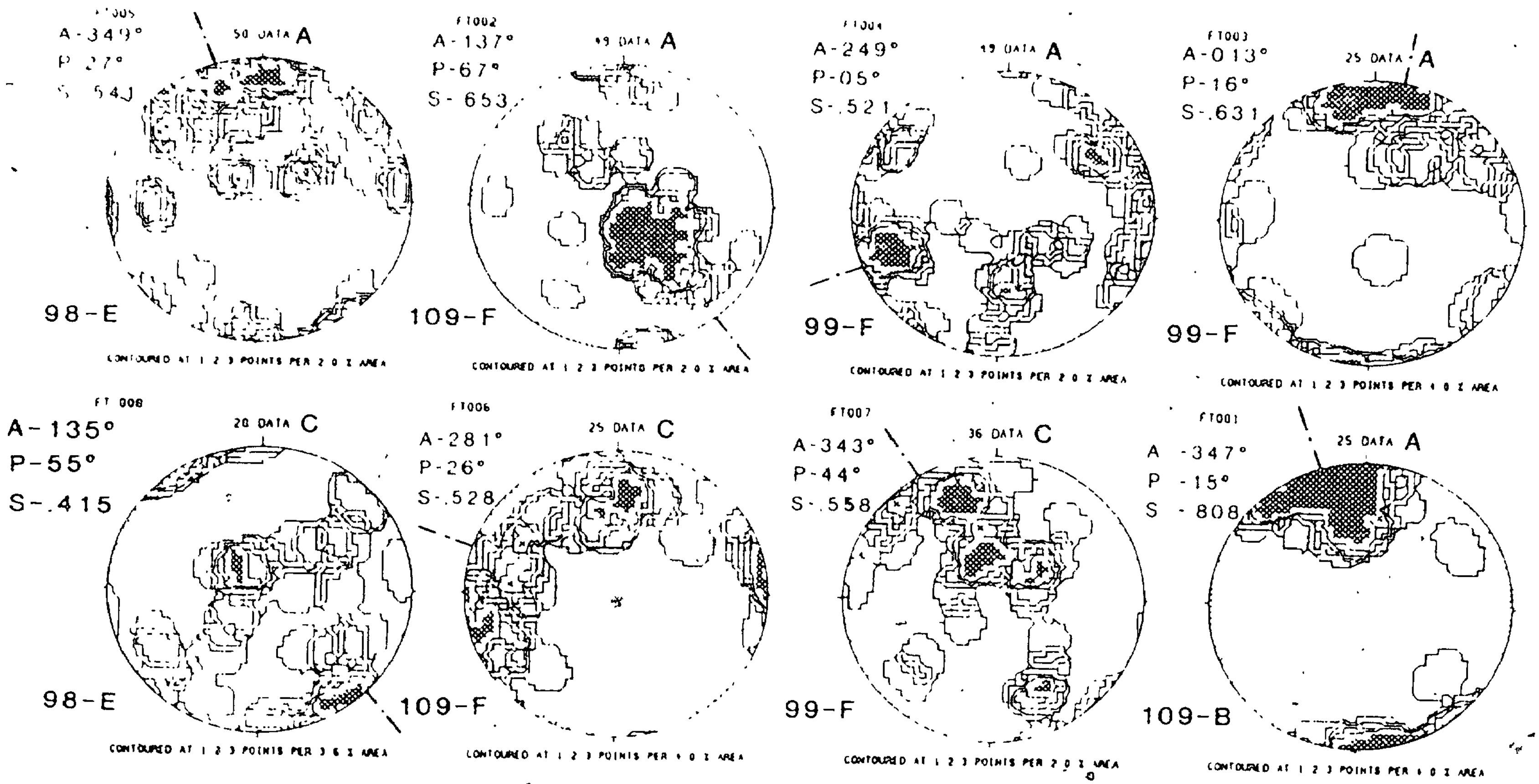


FIGURE 2-10: Contour diagrams of till fabrics data, Pierreville area; azimuth (A), plunge (P) and strength (S) of eigenvector V_1 are given on the left of diagrams.

River, Trenton and Lorraine limestones and Utica shale. The lower red till (109-B; 99-B) plots very close to the Riviere Becancour shale. Samples collected in unit 98-A are not far apart from this lower till. The carbonate content of the concretions found in unit 98-A (50%) is lower than the ones that are found in 99-C (60%).

Based on the above lithologic data, it is therefore proposed that 98-A and 99-C represent two distinct glaciolacustrine units. However, their relative stratigraphic position is not clear.

The only contact between these two units can be observed at section 109a. In this section, units 109a-C, D and E are thrusted over units A and B. Unit B is in lithologic continuity with 109-C and 99-C. The texture, structure and the carbonate contents of the sediment and concretions clearly demonstrate that units 109a-C and 98-A are the same (Fig. 2-6, 2-8 and 2-9). If the thrusting is local, then 98-A (i.e. 109a-C) is younger than 99-C (i.e. 109a-B). However, unit 109a-E could be correlated with 99-C on the basis of the carbonate contents of the sediment and concretions (Fig. 2-9) although it is richer in silt (Fig. 2-8). If 109a-E and 109a-B (i.e. 99-C) are part of the same unit, the thrusting is of greater extent and the result is a repetition of strata. In this case, 99-C (and 109a-B) is younger than 98-A (and 109a-C).

The two following arguments would support this last hypothesis: (1) Unit 98-A is lithologically much closer to the lower red till mainly because of (a) its proximal facies; (b) its texture,

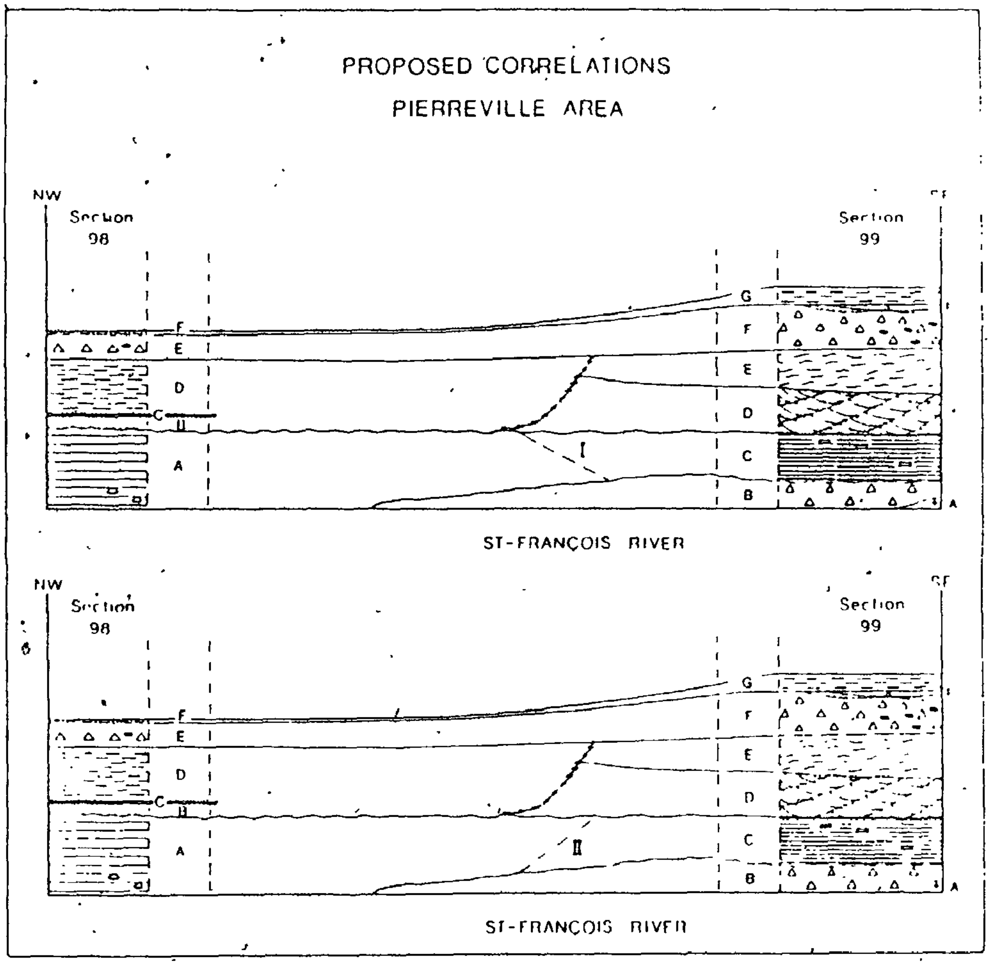


FIGURE 2-11: Suggested correlations of sections 98 and 99. In the first case (hypothesis I), 99-C is younger than 98-A. In the second case (hypothesis II), 99-C is older than 98-A. Zig-zag line means facies change; dotted line represents lithostratigraphic boundaries.

and (c) its sediment total carbonate content. According to Terasmae (1958), this unit is underlain at section 98 by red silt which are believed to grade into the lower red till.

(2) There is most probably a lithologic discontinuity at the contact between the red till and the overlying varves at section 99. There is a clear break in terms of texture and carbonate content (Fig. 2-3). In one site, unit 99-C can be seen as draping the fluted surface of the red till (Plate 2-3b). Therefore, two different correlations are possible. They are shown on Figure 2-11.

2.2 St-Pierre Les Becquets

From Gentilly to Leclercville, a 30 m (a.s.l.) terrace displays a very complex stratigraphy which has retained the attention of geologists since Logan's time (1863) (Figure 2-12). This stratigraphy was worked out by Gadd (1955) and Karrow (1957) in their Ph.D. studies and synthetized in Gadd's memoir (1971). More recently, Hillaire-Marcel and Pagé (1981) proposed a reinterpretation of the Deschaillons section.

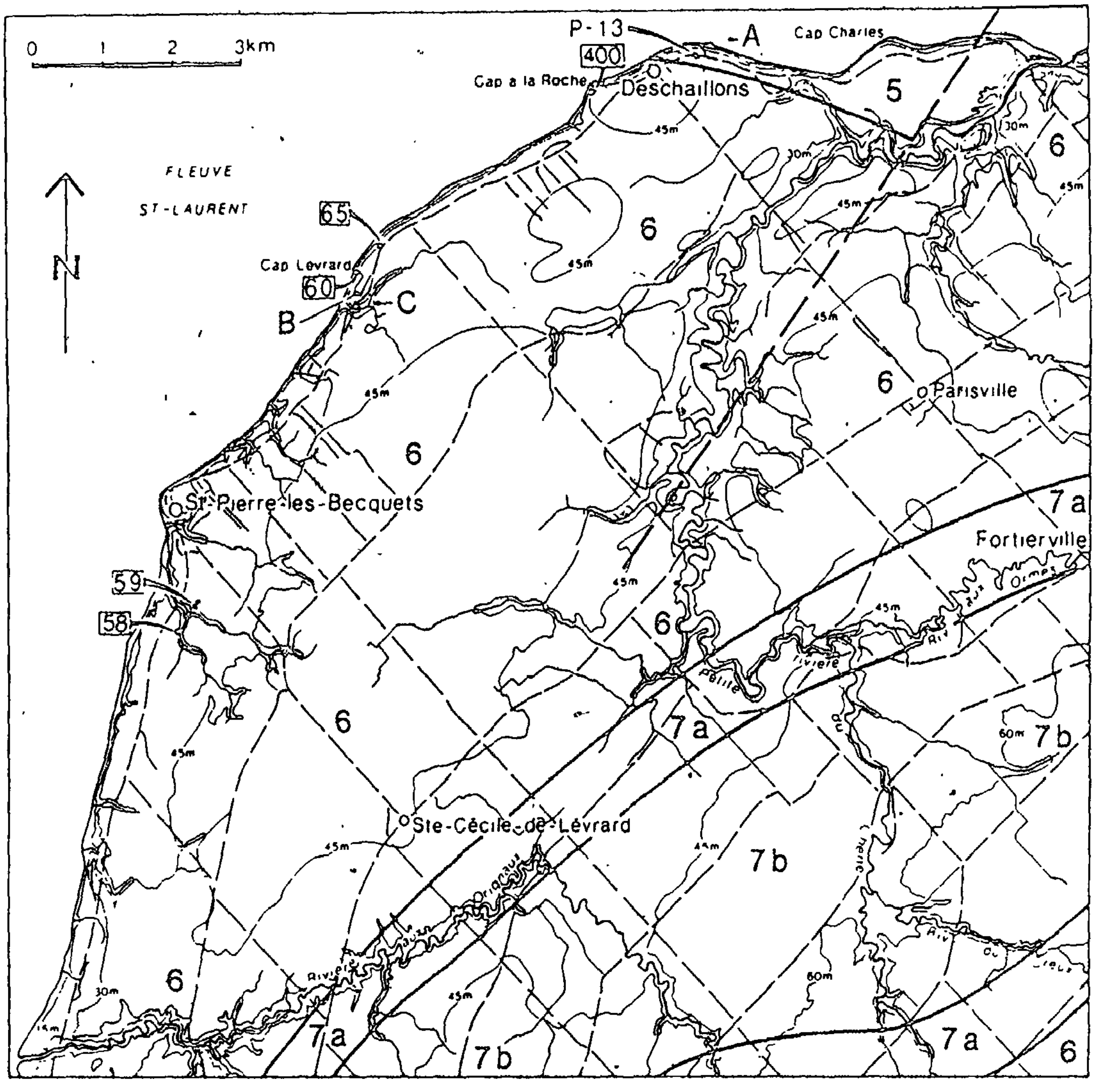


FIGURE 2-12: Location of the St-Pierre les Becquets sections (in squares); numbers refer to the bedrock units (see Fig. 1-3).

According to them, the major stratigraphic units in the northern area can be described from the following sections: the St-Pierre sections (58-59), the Cap Lévrard sections (60 and 65) and the Deschaillons section (400). These sections are located in the north-eastern sector of the Batiscan Basin.

2.2.1 The St-Pierre Sections (58 - 59)

Section 58 is located 500 m upstream from its intersection with highway 132, along a small brook. This is the type-section for the St-Pierre sediments. At 160 m downstream, a sub-section (59) exposes sediments underlying the peat-bearing silt (Fig. 2-13):

Section 59:

Unit A: 1.5 m of dark grey (5YR 4/1) and reddish clayey (7.5 YR 6/2) silt laminated for the first metre and then slightly deformed with concretions (Plate 3-2 b). The silt and clay laminae of the rhythmites are of equal thickness, totalling 1 cm (Plate 2-4a). One sample showed that little carbonate is present (2 %).

Section 58:

At this section, unit A is unconformably overlain by 2 m of sand with one peat layer and then by a sequence of laminated silt. The other units have been described at section 58.

Unit B: 2.25 m of well-sorted sediments (from the base):

10 cm: light grey (5Y 4/1) massive clay

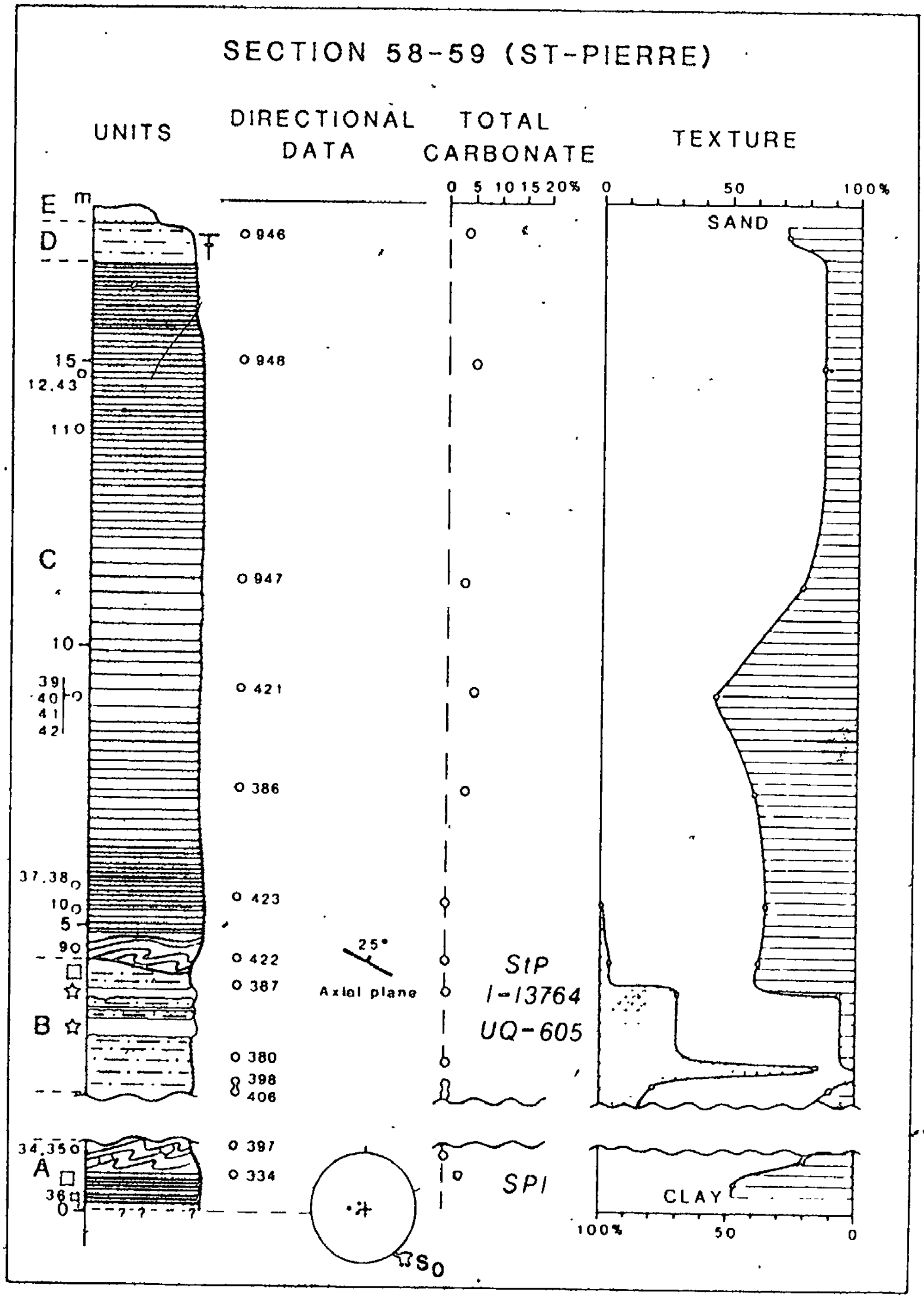


FIGURE 2-13: Stratigraphic log for sections 58-59.

PLATE 2-4

a: Microlaminations in unit 59-A; bar is 1 cm.

b: Silty laminations in basal part of unit 58-C.

c: The Cap Levrard section 60; top of unit 60-A (1), unit 60-B (2) and base of marine deltaic sand (3) are shown by triangle; section is oriented NE (left) to SW (right); the St-Lawrence River can be seen in the foreground.

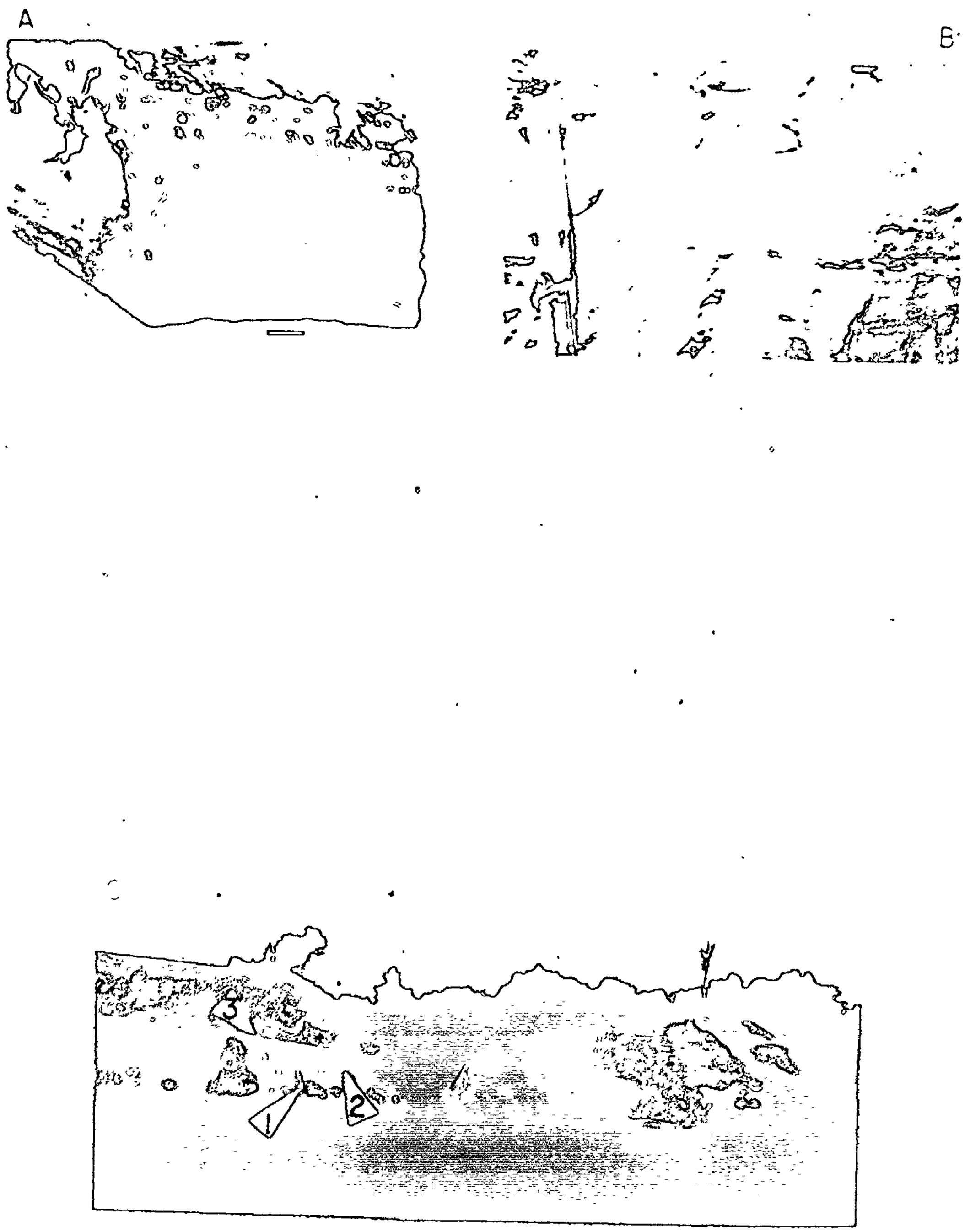


PLATE 2-4

1 m: brown to black (10 YR 3/2) silt rich in organic matter, becoming more clayey to the top. A 10 cm discontinuous sand zone occurs at 20 cm.

30 cm: woody peat rich in mineral grains

10 cm: light brown silty clay

5 cm: peat

10 cm: clayey sand and silt

30 cm: dark compact peat (Plate 3-3)

30 cm: massive grey clayey silt.

These sediments show large lateral variations so that it may be more convenient to describe this unit B as being composed of clayey silt interbedded with peat layers and sand.

Unit C: 16.5 m of rhythmites: the couplets are dark grey (5 YR 4/1) clay and light grey (5Y 4/1) silt; the basal couplets have a small amount of sand (Plate 2-4b); from the base to the top, although the thickness ratio of the clay layer remains at approximately 25%, the thickness of the couplets increases from 2.5 cm to a maximum of 15 cm and then slightly decreases (Fig. 2-21); the rhythmites are not calcareous in the first 5 m although eight Fe-rich calcareous lenses were counted (41 % total carbonate) upward, the silt laminae become calcareous when thicker and show parallel stratification. Some of these laminae are rich in biogenic tracks; at the base, those rhythmites unconformably overly the St-Pierre unit, they exhibit numerous penecontemporaneous deformations cemented by the same Fe - rich carbonate; some lenses of the underlying silts are found interstratified in the basal rhythmites ; 1100 couplets were counted.

Unit D: 1 m of massive yellowish brown (10 YR 5/2) silt; Staplin (in Gadd, 1955) described a foraminiferal assemblage in this unit; where observed, the contact with the underlying rhythmites seems gradational; i.e. some rhythmites can be found inside the massive silt layer.

Unit E: 1 m of cross-bedded yellow (10 YR 5/5) gravelly sand.

2.2.2 The Cap Lévrard sections (60 - 65)

These sections are located mid-way between the St-Pierre type-section and the Deschaillons brickyard (Figure 2-12). The first of them, section 60, has a large exposure due to the presence of a small post-glacial marine delta incised in the glacial deposits. This section is found at the confluence of a small brook with the St-Lawrence River. A generalized section can be seen on Plate 2-4c. Diamictons dominate the northeastern part of the section. They gradually thin southwestward and are reduced to a two-diamicton complex with rhythmites underlying each diamicton.

The description is restricted to the sub-section shown in Figure 2-14:

Section 60

Unit A: 3.5 m of thin-bedded weakly calcareous, light grey (5Y 4/1) clayey silt; the first 1.5 m is laminated; the clay laminae thickness is approximately 25 % of the total couplet which makes 0.3 cm; in the upper 2 m, the same rhythmites are contorted probably because of glacial overriding; discontinuous sand lenses can be seen at the top; one calcareous concretion was found in this sand.

Unit B: 5 m of silty and clayey diamicton, slightly pinkish grey (10 R 5/1), compact, with 20 % clasts; some of these are striated concretions; the fabric of this diamicton suggests compressive ice flow toward southwest since the C axes are concentrated in this quadrant (Fig. 2-25); in the diamicton, the red Rivière Becancour shale fragments are absent whereas the limestones and crystalline rocks are abundant; they both outcrop northward,a generally southward ice flow direction is indicated; a second fabric measured in the same till at section 65 (FT-108-109) shows the C axes are concentrated in the northwest quadrant; these fabrics may be locally influenced by the subglacial topography; the top of the underlying units 60-A and 65-B is dipping toward south; differential melt-out (Lawson, 1979) may have shifted the C axes in their actual position; the top of the till is discontinuously covered by laminated silt; the upper surface is oxydized as is the base of the overlying unit, suggesting that

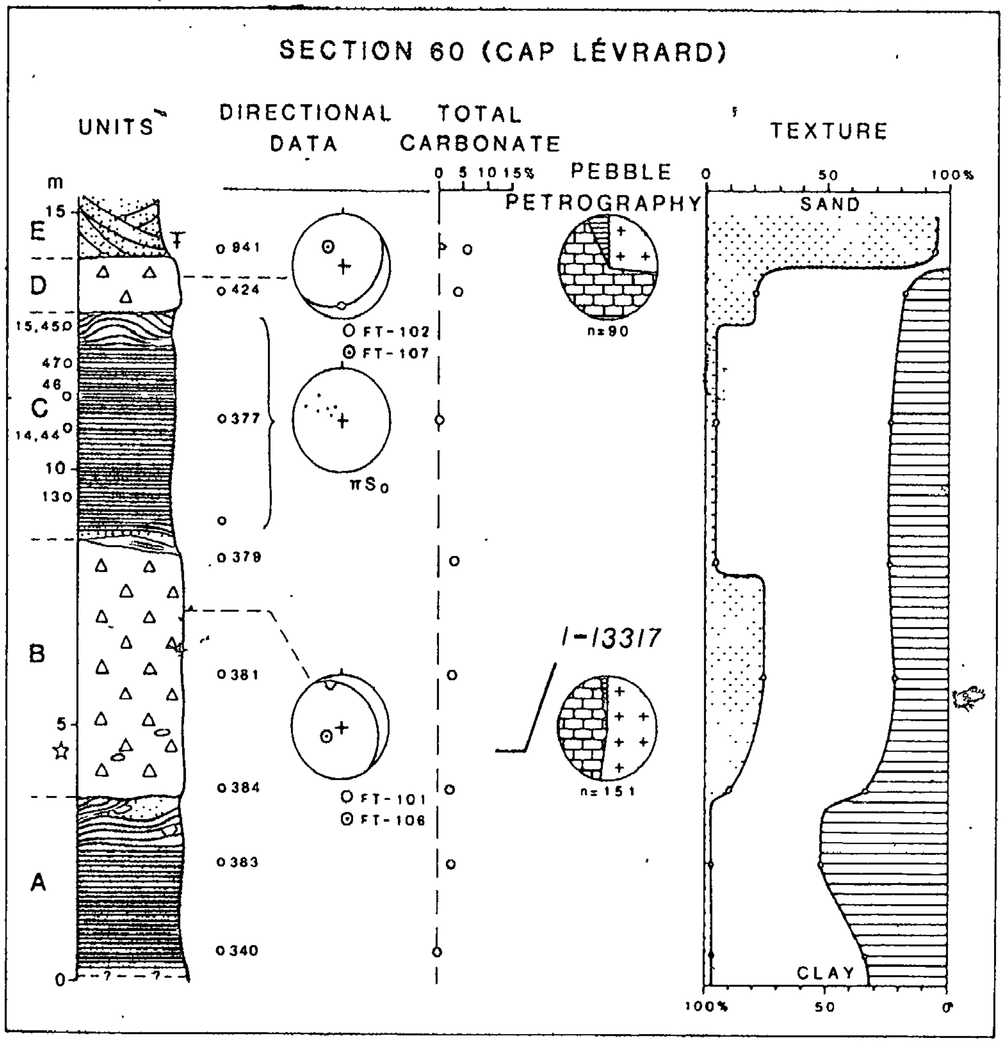


FIGURE 2-14: Stratigraphic log for section 60.

at least part of this is due to recent groundwater activity.

Unit C: 4.5 m of thin-bedded light grey (5Y 4/1) clayey silt (greenish (5Y 5/2) when wet); thickly bedded towards the southwest, this unit is draped over unit B (Plate 2-5a); clay laminae form 25% of the couplets; at the southwest of the section, a large block of the rhythmites is slumped and contorted; elsewhere they show deformations towards the north-northwest which could be attributed to either slumping or glacial overriding (Plate 2-5c); a small (3 cm) piece of broken peat was found in the lowermost laminae (Plate 2-5b); 850 couplets were counted.

Unit D: 1 m of light grey (5Y 4/1) clayey and silty diamicton oxydized at the top; the sediment is massive and has 15% clasts ; the fabric is weak (Fig. 2-25); therefore, this diamicton may have been emplaced by a supra-glacial process or more likely could be the result of reworking of the underlying diamicton.

This unit is overlain by a thick sequence of deltaic sands, rich in fossil fragments (Macoma baltica).

A second section of interest in the area is section 65, located 500 m down river from section 60. The basal units of section 60 (60-A and B) can be traced . The lower pinkish grey

PLATE 2-5

a: Draping of unit 60-C over 60-B along the beach at Cap Levrard; view looking south.

b: Peat fragment (triangle) at the base of unit 60-C; fragment is 3 cm wide.

c: Contact between units 60-C and 60-D; rhythmites in 60-C are slightly folded.

d: Disc-shaped pebble in pinkish diamictic unit 65-B; C axis plunges toward northwest; view looking southwest.

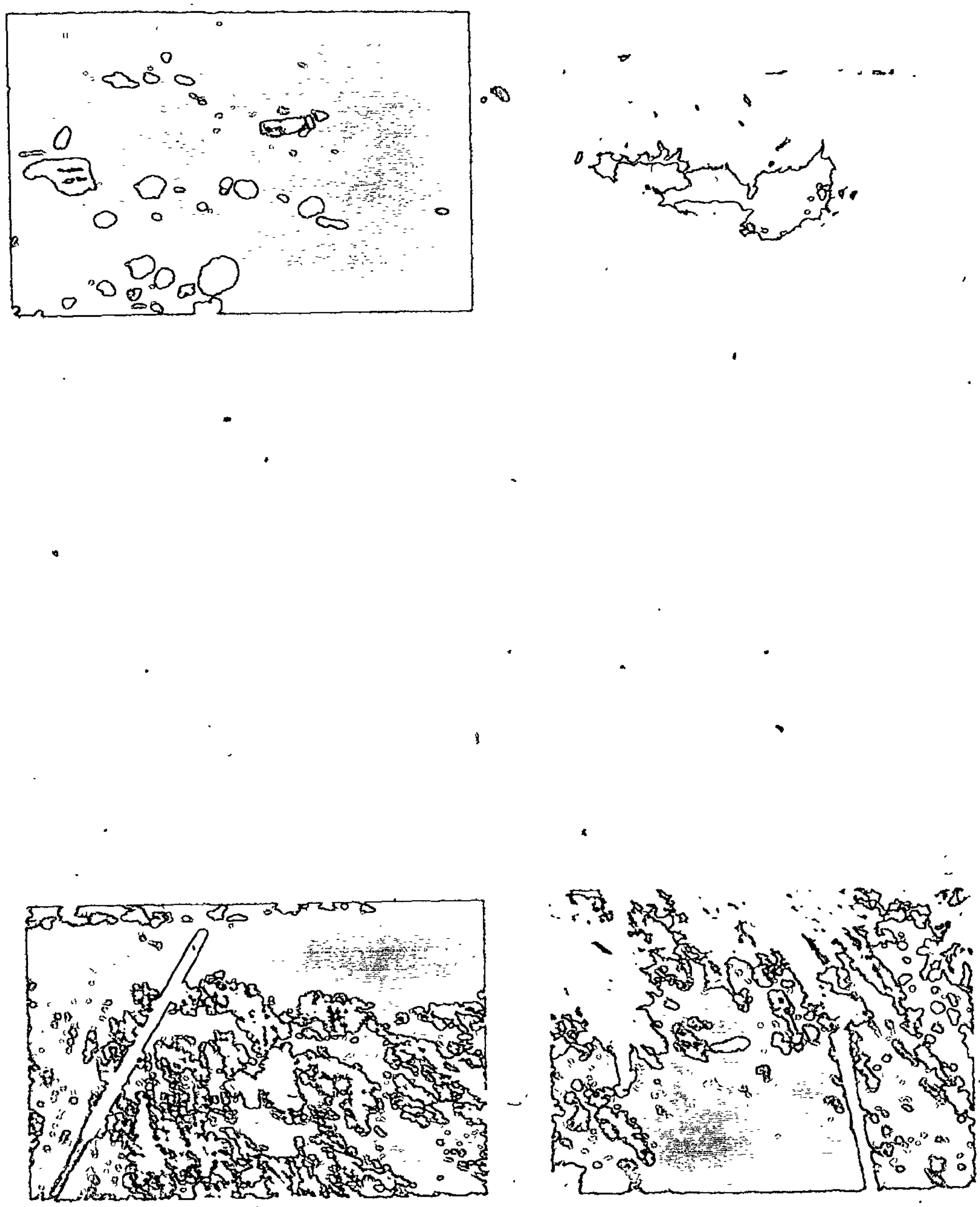


PLATE 2-5

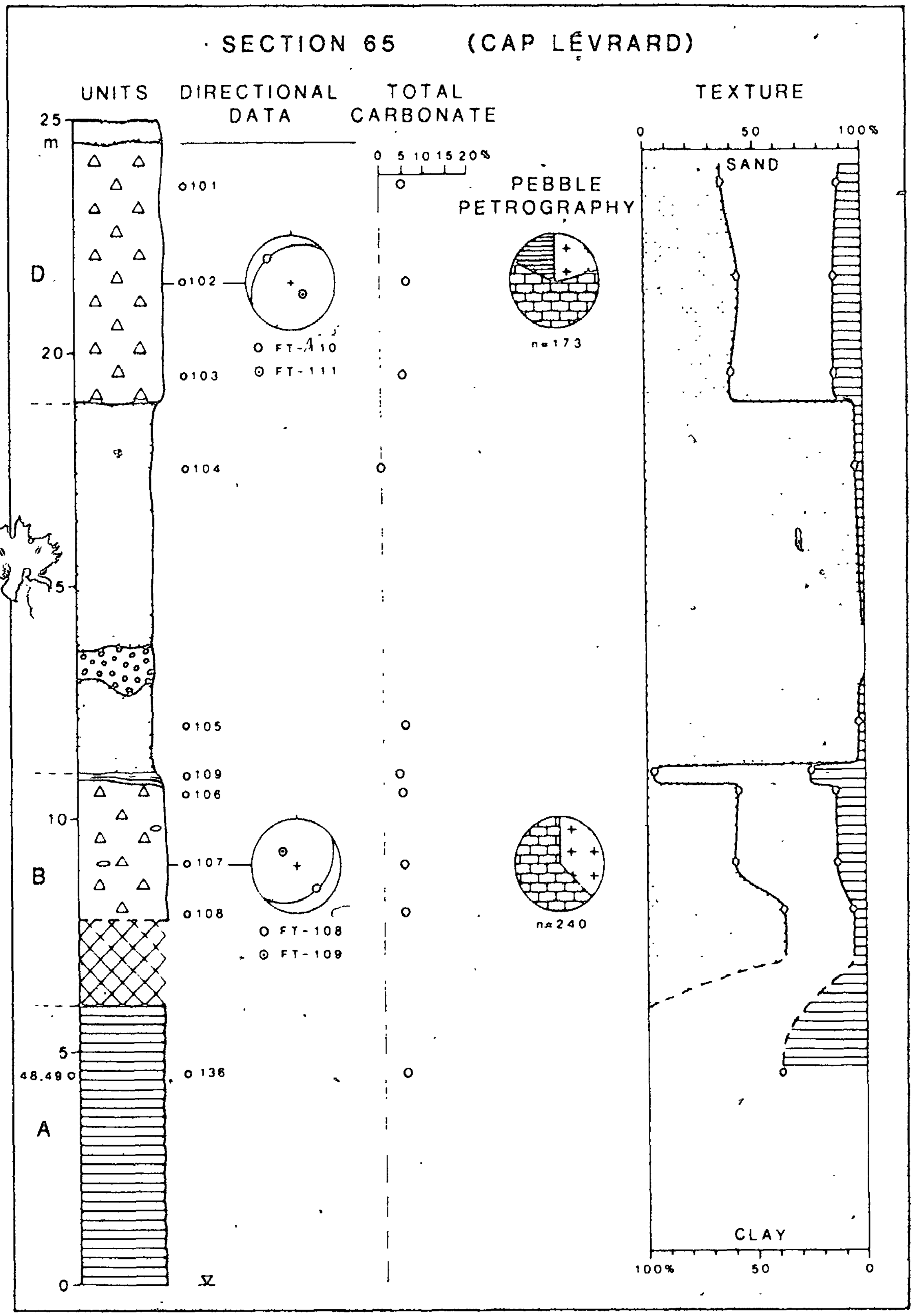


FIGURE 2-15: Stratigraphic log for section 65.

till (Plate 2-5d) exhibits a north-northwestward fabric and is discontinuously covered by a clayey silt layer as is 60-A. Two new units can be observed.

Unit C: 8 m of yellowish grey (10 YR 7/2) sand with parallel stratification and some slight deformation; a discontinuous layer of gravel is present towards the base; under the gravel the sand is slightly calcareous (5 % total carbonate).

Unit D: 5 m of grey (10 YR 6/1) sandy and silty diamicton with 20% of clasts most of which are limestone and shale (79%) this diamicton may have been emplaced by subglacial melt-out or lodgement; the outcrop did not revealed shear structures but exposure was very poor; whatever the origin, the fabric is southeastward.

2.2.3 The Deschaillons Brickyard section (400)

This section has been described by Karrow (1957) and Hillaire-Marcel and Pagé (1981). Their description can be found in Appendix I. The section is shown in Figure 2-15.

Unit A: 5 m of slightly oxydized yellow (10 YR 5/5) sand with parallel stratification and small scale ripples at the top (λ = 10cm): sedimentary structures are oriented toward the northeast. Some silty layers appear towards the top of this unit; pieces of wood have been found in this sand by Gadd (1955).

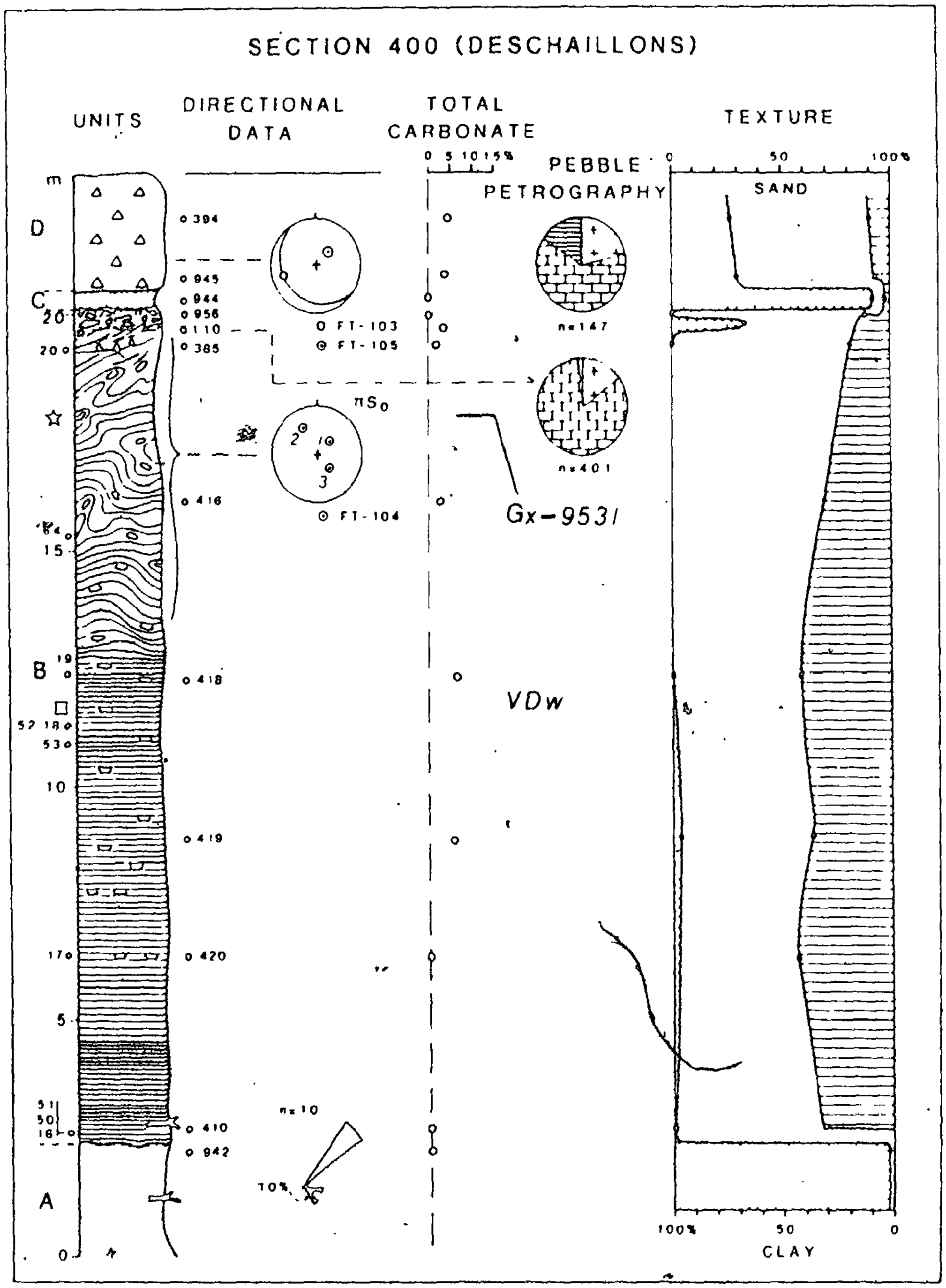


FIGURE 2-16: Stratigraphic log for section 400.

Unit B: 17 m of very clayey laminated silt; the contact with the underlying sand is marked by a slightly asymmetrical undulating surface (Plate 2-6a);at the base, these couplets have a thickness of 0.25 cm; the clay laminae form 25% of the total thickness; towards the middle part of the unit, the thickness increases to a maximum of 4 cm, the clay laminae making 50% of the total (Fig. 2-21) (varves II of Ashley, 1975); the silt laminae are light grey (5 Y 4/1); they show at the base some disseminated organic matter and vivianite (Plate 2-6b); a piece of wood was discovered by M. Parent during a field trip with the writer (Plate 2-6c); from the middle part of the section, the rhythmites are frequently reddish-brown (5 YR 5/4) and may contain 5% carbonate as well as numerous calcareous concretions (Plate 3-2a);at the top, some of the rhythmites are definitely pinkish (10 R 4/1); some silt laminae are bioturbated; the upper 11 m are deformed (Plate 2-6d, 2-7 a, b, c); according to Hillaire-Marcel and Pagé (1981) in the undeformed part of the section, 1800 couplets can be counted; they therefore suggest the deformed part contains at least the same number of laminations; this point will be discussed later; the pattern of deformations in the folded and fractured beds is complex (Fig. 2-25b); poles to shear planes are oriented toward northeast and northwest; the intensity of the deformations suggests that the agent responsible for the

PLATE 2-6

a: Slightly asymmetrical rippled surface between sandy unit 400-A and rhythmic unit 400-B; view looking east.

b: Specks of vivianite in basal part of unit 400-B; spherule shown by triangle has a diameter of 2 mm.

c: Compressed wood fragment in basal part of unit 400-B; mean thickness of couplets is 0.2 cm; view looking east.

d: Decollement plane in the middle part of unit 400-B; view looking southeast.

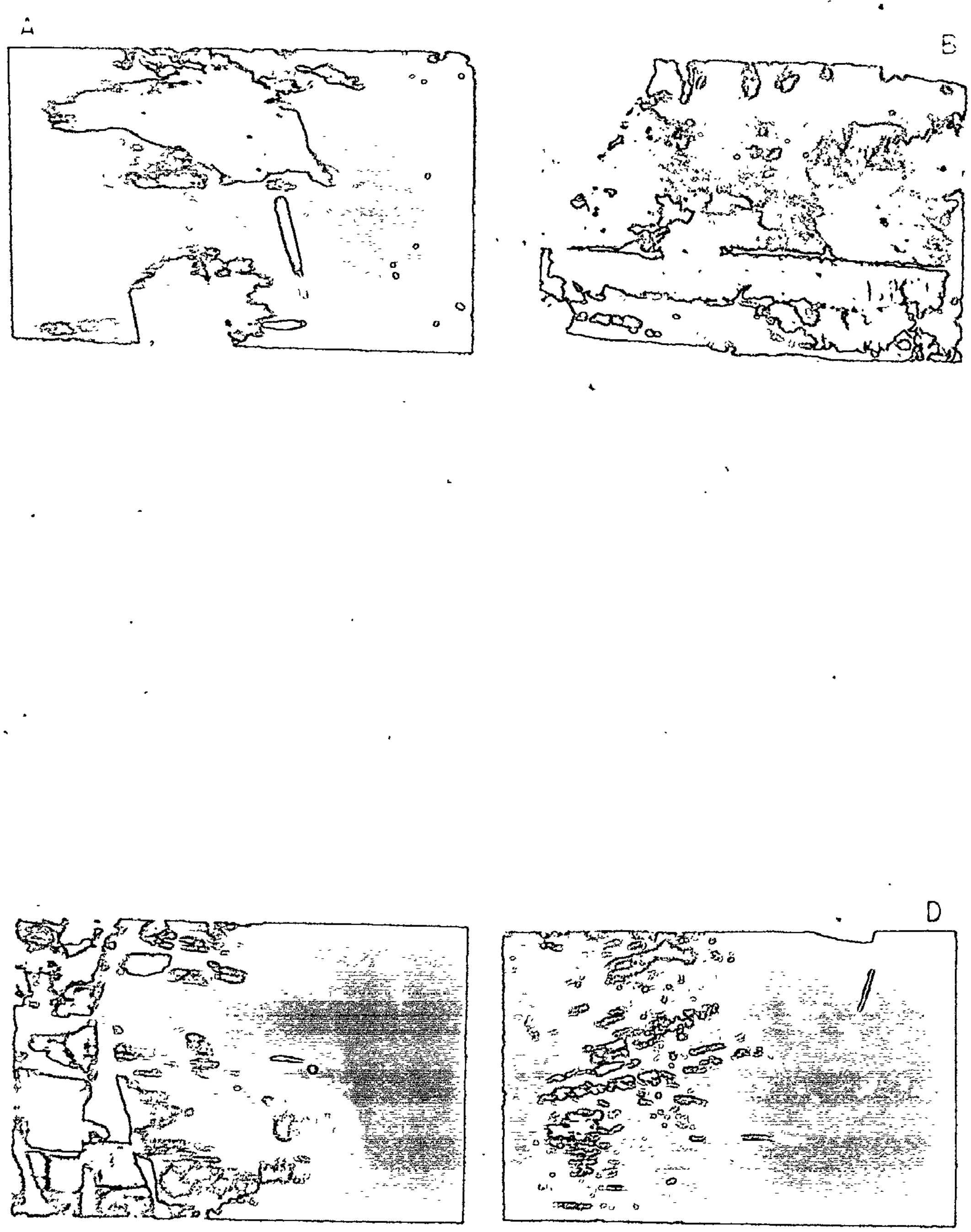


PLATE 2-6

PLATE 2-7

a: Upper section of the Deschaillons section at the brickyard; highly deformed rhythmites of the unit 400-B; locations of a waterlain diamicton (1) and of the overlying unit 400-D (1),shown by triangles; view looking south.

b: Drag fold in unit 400-B; couplets thickness is 2cm; folding is southward.

c: Highly deformed rhythmites in unit 400-B; couplets thickness is 3 cm; view looking east.

d: Contact between sandy unit 400-C and diamictic unit 400-D, shown by a triangle; view looking southwest.

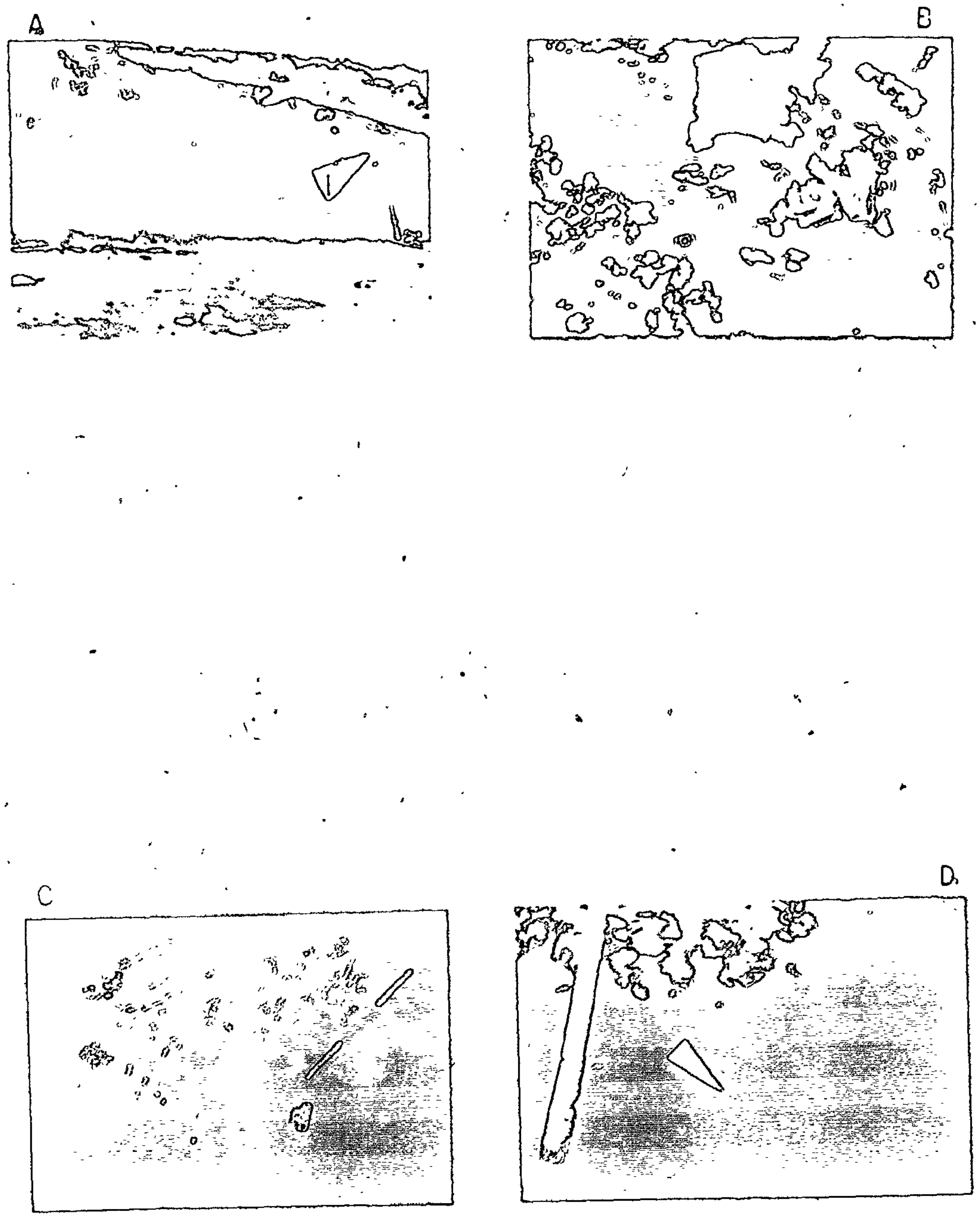


PLATE 2-7

deformation was probably glacier ice flowing toward east or north ; at the very top, appears discontinuously a thin (5-10 cm) layer of a sandy diamicton (sample 11Q) very rich in limestone clasts (84%) followed by 1 m of massive pinkish grey silt with brecciated fragments of the underlying rhythmites.

Unit C: 20 cm of oxydized greenish (5 YR 5/2) and brownish yellow (10 YR 6/6) sand that is slightly deformed.

Unit D: 1.5 m of brownish grey (7.5 YR 7/4) silty diamicton with 20% of clasts, most of which are limestone and shale (79%) (Plate 2-7d): this diamicton is sheared and show a strong fabric towards the northeast. It is interpreted as a lodgement till.

2.2.4 Discussion: Lithostratigraphy of the Northern Area

Most of the Traditional Concept as defined in the first chapter was developed from the sections just described. The modern stratigraphic nomenclature derives from type-localities such as Deschaillons, Cap Lévrard, St-Pierre, Bécancour and Gentilly which are all located in the northern area.

The sections exposed along the St-Lawrence River were correlated by Gadd (1955, 1971) and Karrow (1957) using the following logic (Fig. 2-17).

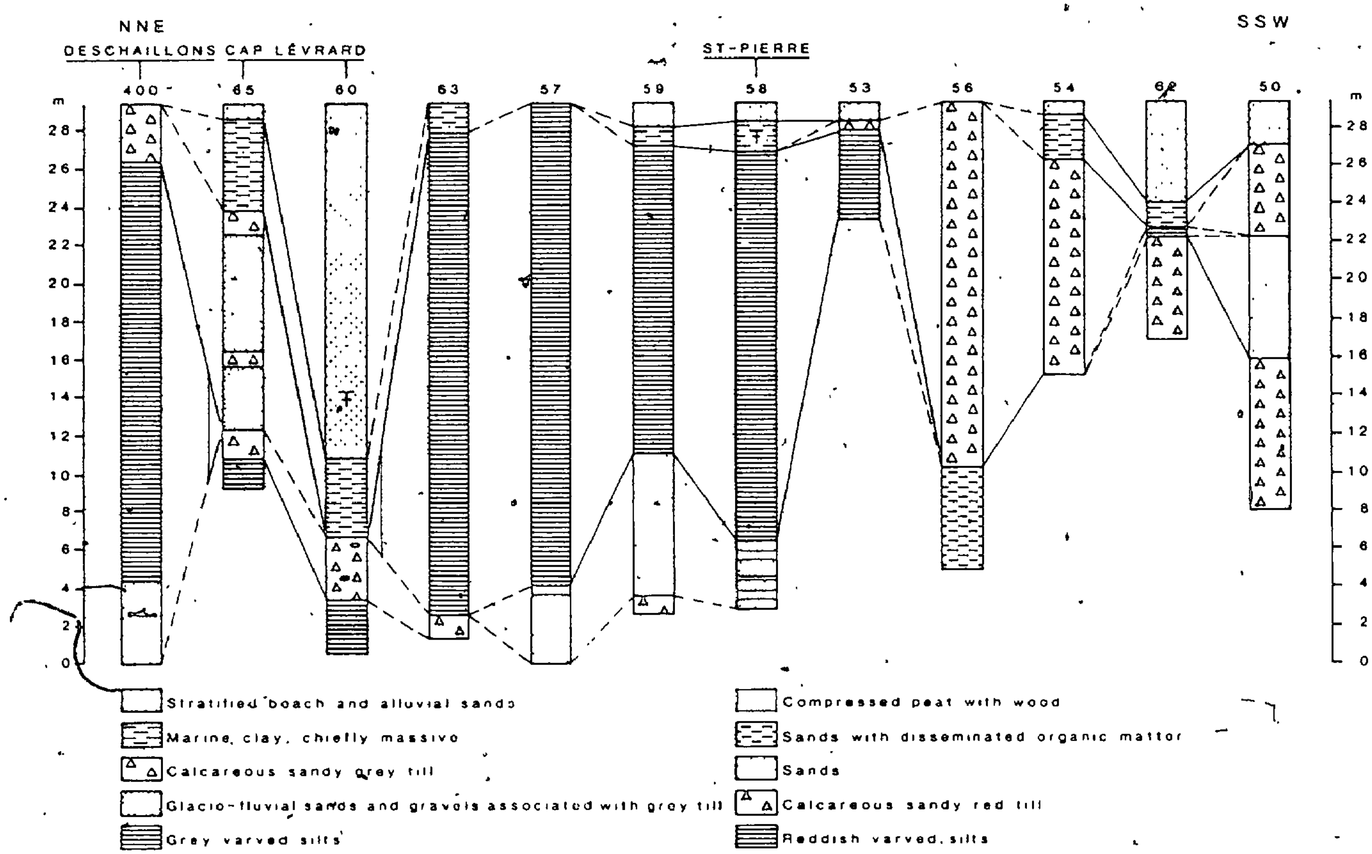


FIGURE 2-17: Correlation of the St-Lawrence River sections according to Gadd (1971), figure 8, slightly modified: section 400, the black pinch-outs and concretions in till of section 60 (reported by Karrow, 1957) are added.

1) non-glacial sediments radiocarbon dated at 65 ka are exposed at section 58;

2) these St-Pierre sediments are underlain by a reddish to red till at sections 63, 59 and 50; this till is correlated with the Bécancour Till;

3) the lower reddish till at Cap Lévrard sections 60 and 65 is also correlated with the Bécancour Till;

4) varves underlying this till are called the Cap Lévrard Varves; they are believed to represent the oldest Quaternary deposits in the area;

5) a grey till is found directly overlying the St-Pierre sediments at sections 56, 50 and 65 and this "grey till - non glacial sand" relationship is very common in the area south of Rivière aux Orignaux; for these reasons, the upper grey till of these 3 sections is correlated with the surficial till of the area, the Gentilly Till, with its type-section defined in the excavations for Théatre Genty and fire-protection reservoirs in the village of Gentilly;

6) varves overlying the St-Pierre sediments at section 58 are called the Gray Varves and since these varves are covered by a thin (60 cm) layer of grey till at section 53, they are believed to represent a glacial lake dammed by the glacier that has eventually deposited the grey till;

7) these Gray Varves are then correlated with the Deschaillons

Varves because

a) the varves at the brickyard are capped by a grey till, the Gentilly Till;

b) the varves at the brickyard are underlain by sand in which pieces of wood were found; this unit is therefore correlated with the St-Pierre sediments;

c) "varves occupy the entire escarpment below the Roman Catholic Church at St-Pierre les Becquets, about 75 feet are exposed; these are in continuous outcrop with an eighty-foot vertical section of varves in the brickyard at Deschaillons". (Gadd, 1955, p. 106)

However, it can be clearly seen from Figure 2-17 (a slightly modified version of Figure 8 of Gadd, 1971 in which the Deschaillons section is added) that this last argument cannot hold since, midway between sections 400 and 58, are the Cap Lévrard sections in which no pre-Gentilly and post-Bécancour varves can be observed. The dark triangles in Figure 2-17 are the location of the expected pinch-outs. Moreover, no thick accumulation of till can be observed over the Gray Varves (i.e. Unit 58-C) wherever they can be traced. This point is also addressed by Gadd (1955) in the following terms:

> "In the vicinity of the St-Pierre Section a concentration of large boulders attests to the former existence of glacial till above the varves" (Gadd, 1955, p. 71)

The writer walked the entire 20 km distance between Rivière aux Orignaux and Deschaillons Village. A general geologic cross-section is shown on Figure 2-18. Most of the original work by Gadd and Karrow has been confirmed. Figures 2-17 and 2-18 are not much different indeed. The depth to the bedrock in the Rivière aux Orignaux is deduced from the preliminary geophysical work of Gagné (1984). In the Deschaillons area, a hydrogeological survey carried by Babineau (1976) for the Quebec goverment identified the bedrock surface in numerous locations in the village (example is drill hole P-13). This surface is, in many places, covered by "very gravelly sand" , underneath 400-A. It is impossible to ascertain from these exclusively textural descriptions if this is till. However, where there was no exposure, the original description of these authors was used in the cross-section, such as sections 63 and 50. In the vicinity of the St-Pierre sections, no lower reddish till was observed. However a new and major stratigraphic relationship was found. The Deschaillons Varves and the underlying sand can be traced over most of the distance from the brickyard as far as Cap Lévrard, under the lower pinkish till. In other words, the Deschaillons and Cap Lévrard varves are in *almost* lithologic continuity. This was expected since concretions can be found in units 65-A and 60-A as well as in the overlying till. Karrow (1957) himself described "lime concretions" in this till.

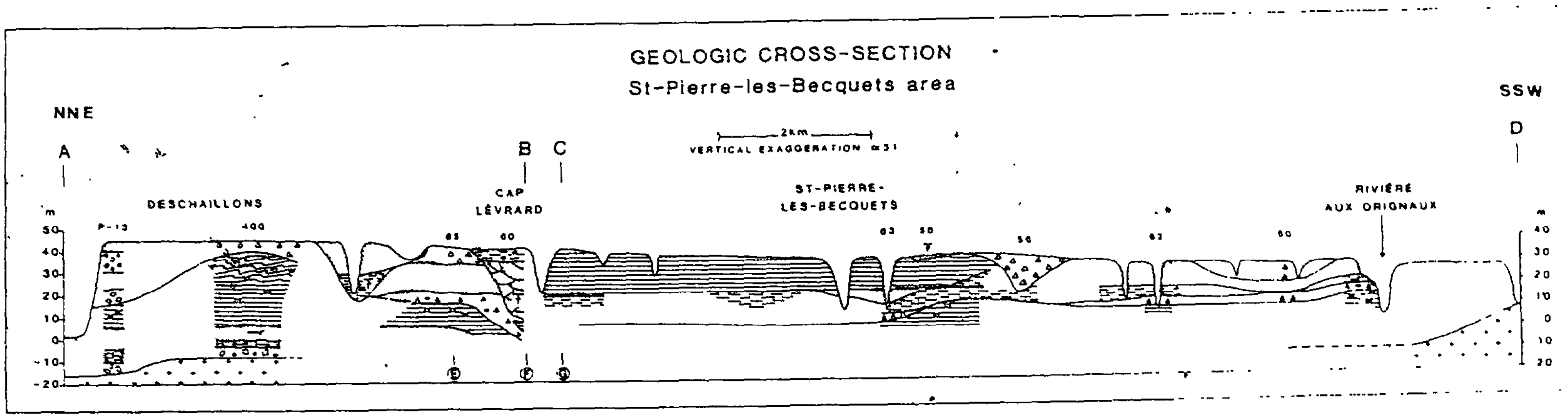


FIGURE 2-18: Geologic cross-section along the St-Lawrence River; point D is located 1 km southward from Riviere aux Orignaux; note the vertical exaggeration.

The consequence of this stratigraphic relationship is major. In the stratigraphic Traditional Concept, the Deschaillons Varves are post-St-Pierre, the Cap Lévrard Varves are pre-St-Pierre. Being correlated, their true stratigraphic relationship with the St-Pierre sediments has to be found.

The lithosome geometry may in itself give part of the answer since the Deschaillons Varves (from now on referred as 400-B) and the Cap Lévrard Varves (referred as 60-A) are found at river level at Cap Lévrard while the base of the Gray Varves (referred as 58-C) are found approximately 15 m higher up. However, the vertical exaggeration (X31) of Figure 2-18, distorts the true geologic cross-section. Figure 2-19 (x5) gives a better image. The precise question is two-fold: a) does unit 400-B (65-A, 60-A) correlate with 58-C or 59-A? b) does unit 60-C correlate with 58-C, 59-A or is it of limited extent?

The correlation of these units is hampered by their lithological similarities.

These sediments may for instance be all described as clayey silt (Fig. 2-20). None of the samples analyzed contained more than 5% of sand-size particles.

In terms of structures, they are all rhythmites. Whatever these rhythmites represent, it is suggested that those laminations do reflect a particular environment of sedimentation.

However, as can be seen from Figure 2-21, the number of these laminations are largely different. Unit 58-C has 1100 couplets. Unit 60-C has 850 couplets. Unit 400-B, according to Hillaire-Marcel and

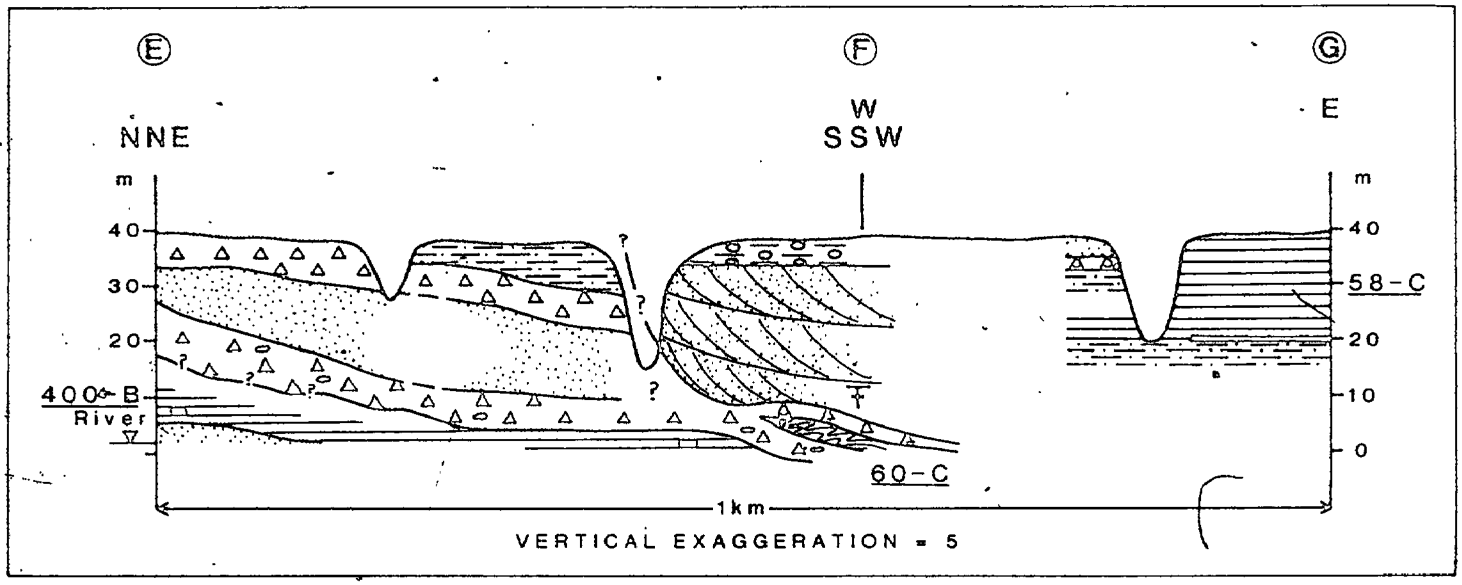


FIGURE 2-19: Geologic cross-section at Cap Lévrard.

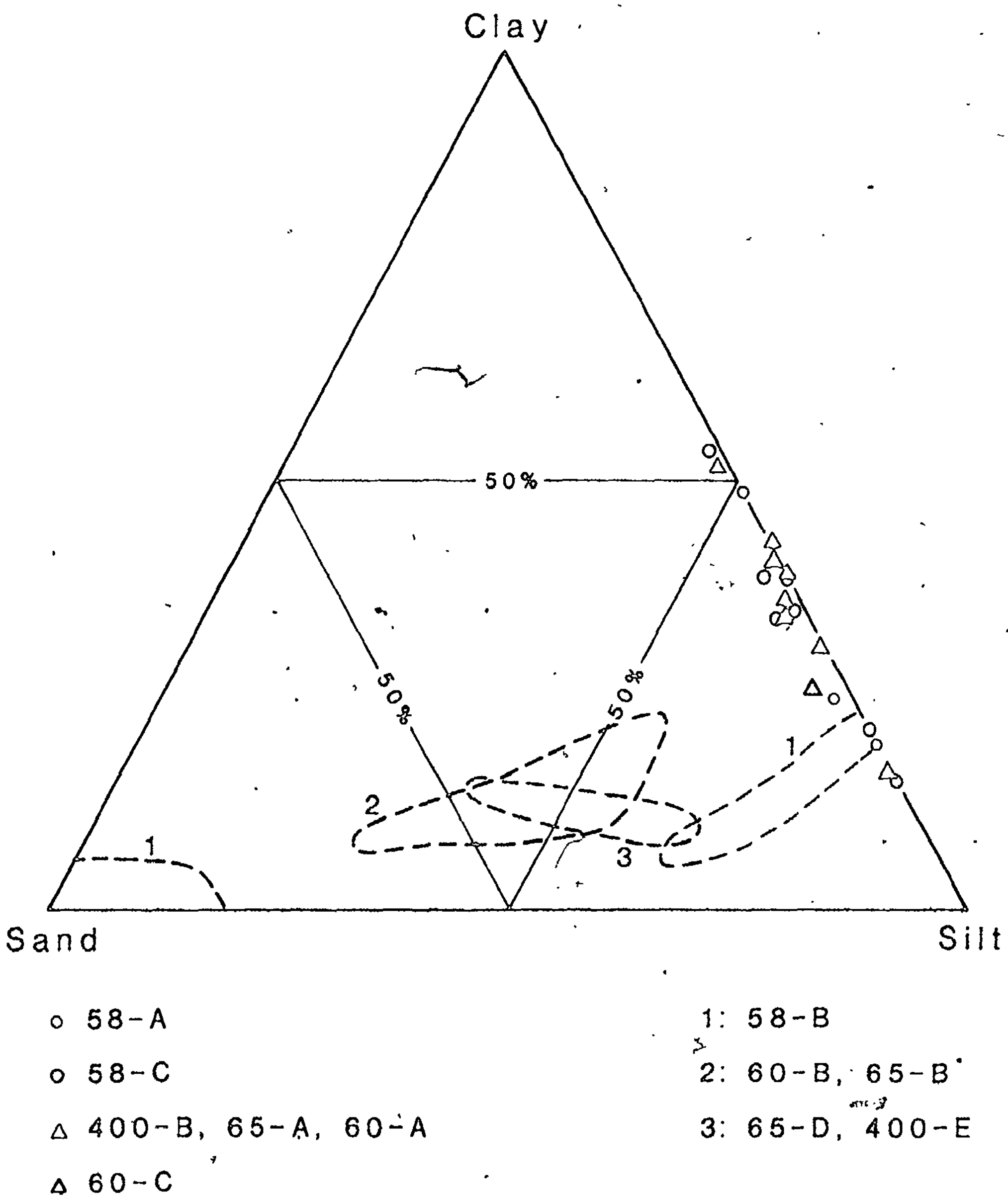


FIGURE 2-20: Textural ternary diagram, St-Pierre les Becquets area.

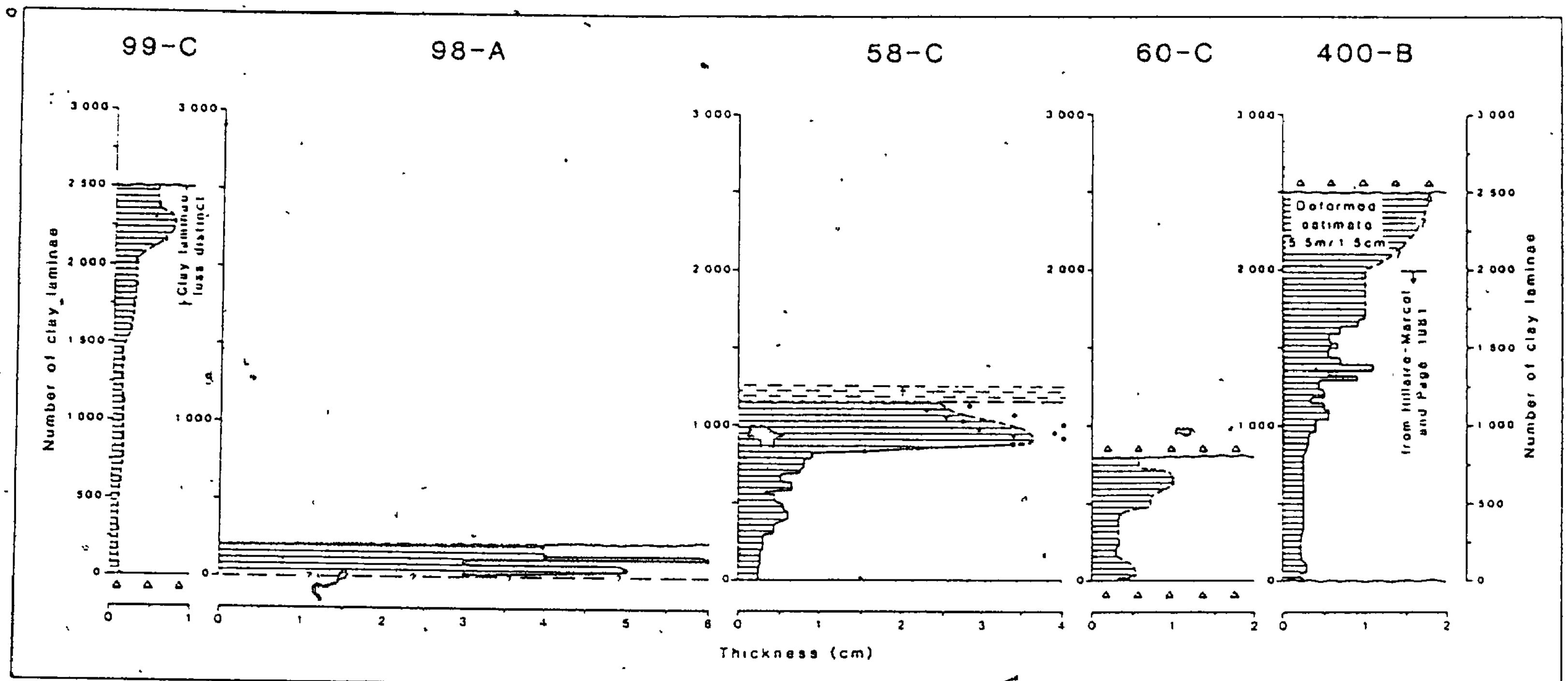


FIGURE 2-21: Couplet thicknesses of the glaciolacustrine sediments in the Lowland.

Pagé (1981) exhibits 1800 couplets in the undeformed part of this unit (7.5 m). They suggest that the upper 12.5 m contain at least as many couplets. However, the stratigraphic thickness may have to be reduced by half if the average dip due to folding is 45° (Fig. 2-25) and there are no micro-varves such as the ones found at the base of the unit, in the deformed member. Using an average thickness of 1.5 cm and a stratigraphic thickness of 5.5 m, a total of 500 couplets is indicated. Since most of the deformations have been measured at the top of the varves, it can be argued that the average dip may be lower. Consequently, it is proposed herein that the total number of couplets cannot exceed 2500. This number still exceeds greatly the 1100 couplets of 58-C. Exiguity of the outcrop impedes any counting for 59-A. However, along the St-Lawrence River, when the same varves are exposed, a *tentative* estimation of at least 500 couplets has been done. Concerning the structural pattern of these units, it may be pointed out once again that unit 58-C is *not* deformed whereas unit 400-B is strongly folded.

In terms of mineralogy, these units have never more than 5% total carbonates (Fig. 2-22). An important difference however lies in the fact that units 400-B and 59-A have authigenic concretions and 60-C and 58-C are devoid of concretions. In the next chapter, the genesis and significance of these concretions are discussed but it may already be reported herein that they are a primary feature of the sediment and therefore characterize it.

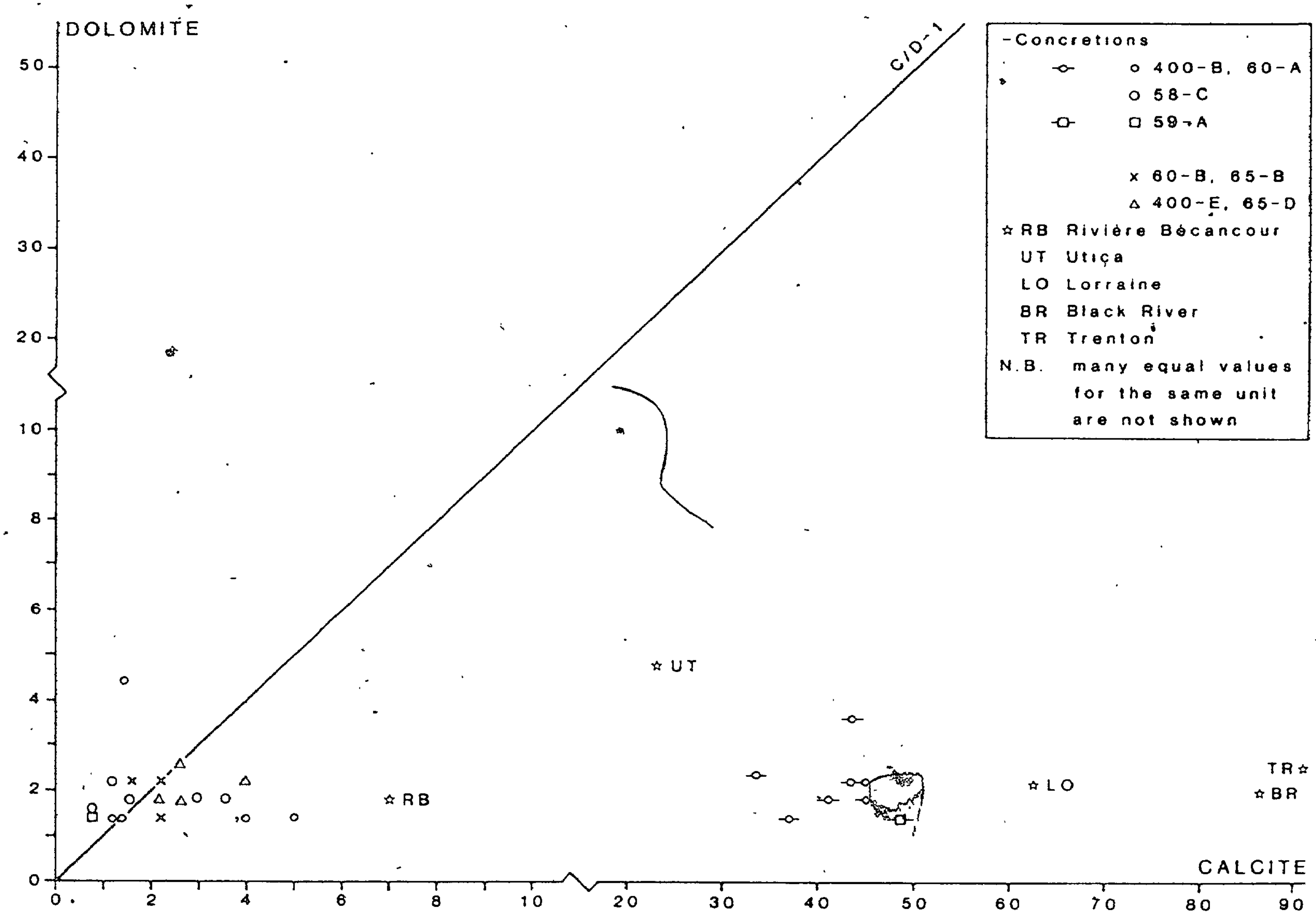


FIGURE 2-22: Calcite and dolomite contents, St-Pierre les Beçquets area.

The clay minerals were also investigated. Illite and chlorite are the major clay minerals to be found in the Quaternary deposits of the Lowland (Fig. 2-23). They are mainly derived from the bedrock and therefore detrital. Chlorite is identified by its first-order 14Å and second-order 7Å reflections. The 10Å peak is due to the reflection of the first-order peak of illite (Grim, 1968). Since a warm HCl treatment led to eradication of the 14 and 7Å peaks, it is believed that no kaolinite is present. The chlorite to illite peaks height ratios (7/10Å and 14/10Å) and the illite "crystallinity" (L/10Å) have been measured by a technique described in Appendix II. Results are presented on Figure 2-24. No clear difference is revealed. It is suggested that this reflects the heterogeneity of grain-size as this has been commonly observed elsewhere (Carson and Arcaro, 1983).

Finally, in terms of stratigraphic relationship, unit 400-B is covered by a grey till at the brickyard and by two tills at the Cap Lévrard sections. The pinkish color of the lower till is due to incorporation of pinkish rhythmites that are relatively common towards the top of unit 400-B. It should be remembered that the till does not contain any red shale fragments. This means that the ice that deposited the lower till in the vicinity of Cap Lévrard-Deschaillons was probably an ice stream originating from the Laurentide area. The upper tills 400-D and 65-D have exactly the same amount of ecambrian pebbles (21%, Fig. 2-15 and 16), they have fabrics toward northeast and southeast and should be correlated. The number of till fabrics is unfortunately still too small to draw definite conclusions.

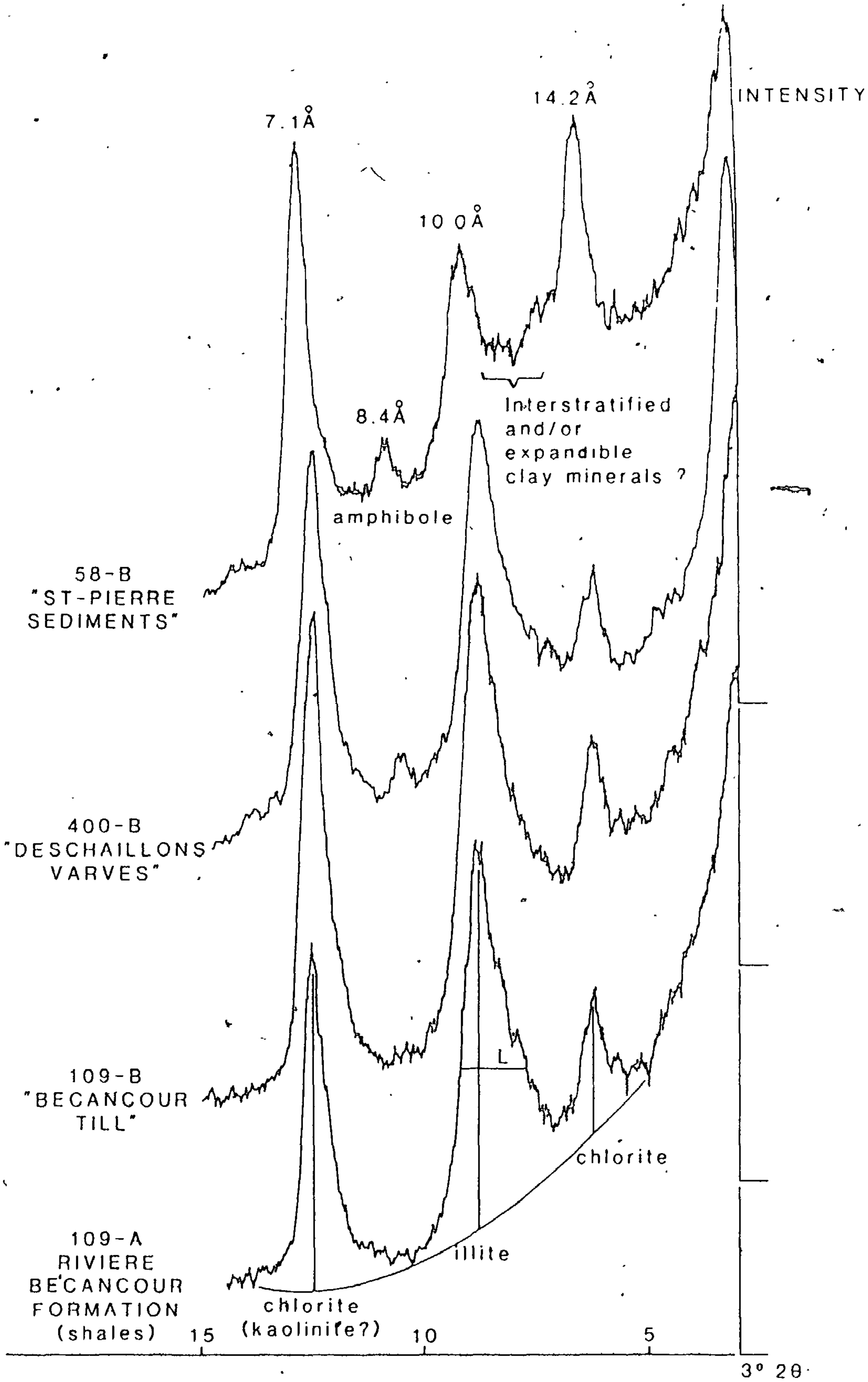


FIGURE 2-23: X-Ray diffractograms of the clay fraction for selected lithostratigraphic units.

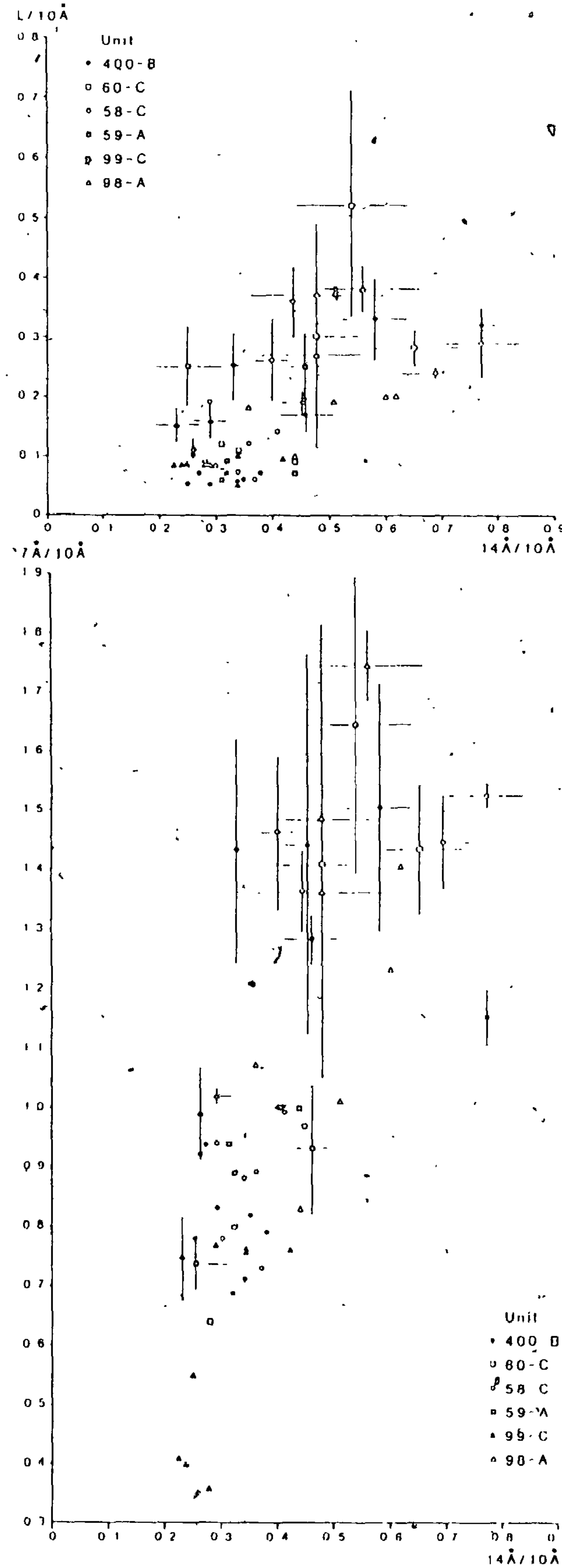


FIGURE 2-24: Peak-heights and peak-width ratios.

This supposes that the Deschaillons Varves are covered by two different till sheets. Unit 59-A is, according to Gadd (1955, 1971), overlain by red till (sections 59-63) which should correlate with units 60-B and 65-B. A similar pinkish grey till was observed at Rivière aux Orignaux (Fig. 2-18) but the upper grey till is absent. In this section, the pinkish grey till includes calcareous concretions and overlies pinkish varves with concretions (Plate 3-2d). Unit 58-C is not covered by a thick lodgement till. It is instead overlain by a massive silt in which foraminifera were described by Staplin (in Gadd, 1955). Rhythmites at the top of unit 58-C are, some places, interbedded with this massive silt. However, the writer did not find any marine fossils.

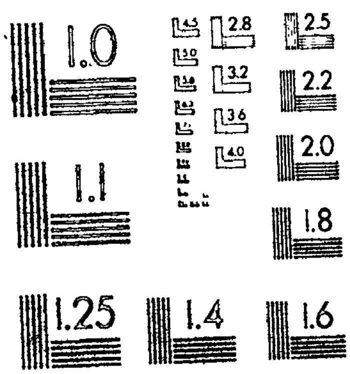
Therefore, three hypotheses of correlation are possible (Fig. 2-26). In the first and least likely hypothesis, unit 400-B (65-A, 60-A) would correlate with 58-C. In the second case, Unit 60-C would be a slumped equivalent of 58-C and 400-B would be older than the St-Pierre peat. In the third case, the whole 400-B (60-A), 60-B-C and D would be older than the St-Pierre peat and would correlate in terms of stratigraphic position with 59-A. The second and third hypotheses are favoured by the writer because of

1). lithosome geometry

2) presence of multiple-till sheets over 400-B (60-A - 65-A) and none over 58-C:

3) presence of concretions in 400-B and 59-A and their absence in 58-C.

2



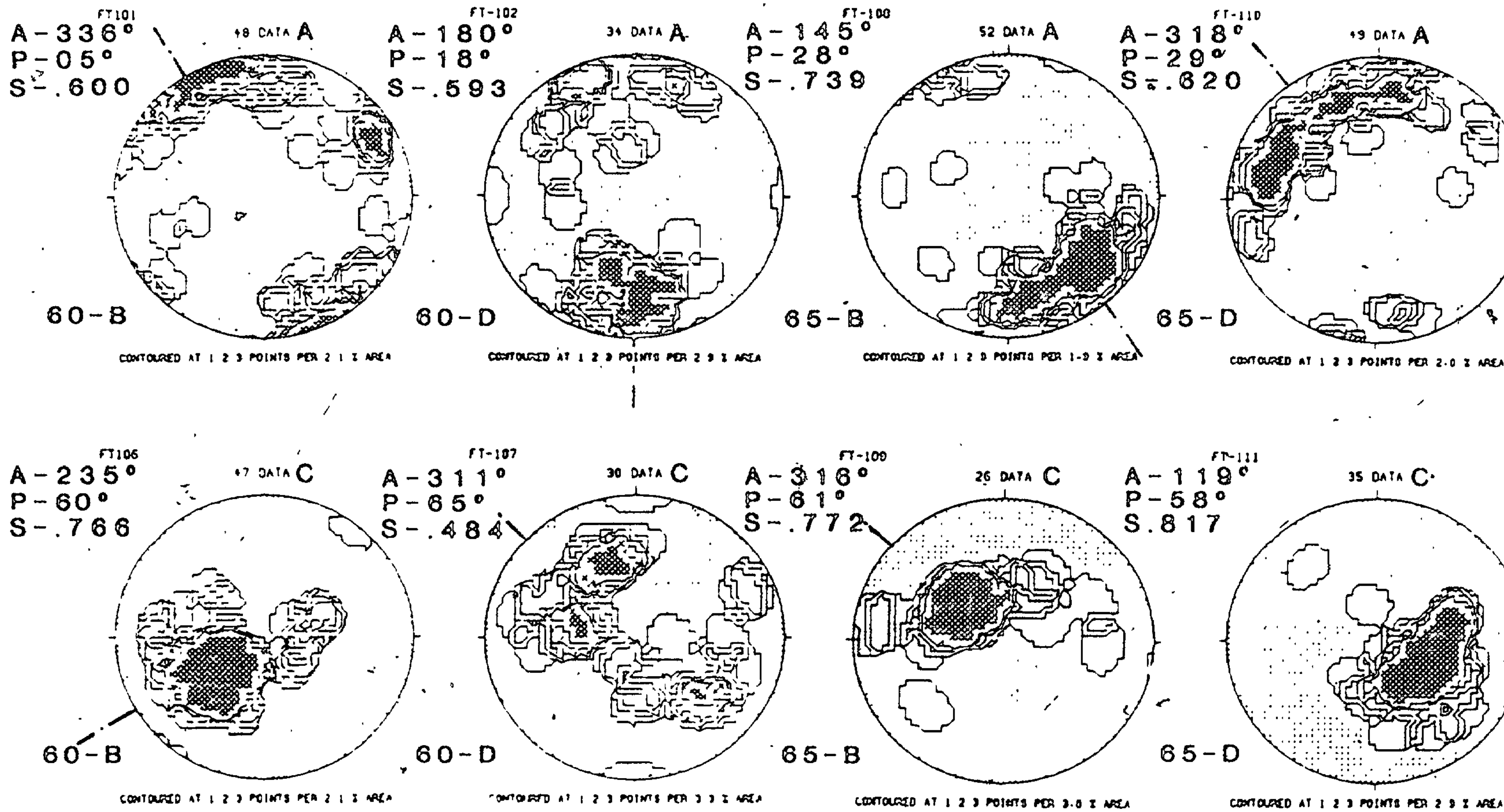


FIGURE 2-25: a) Contour diagrams of till fabric data, Cap Layrard.

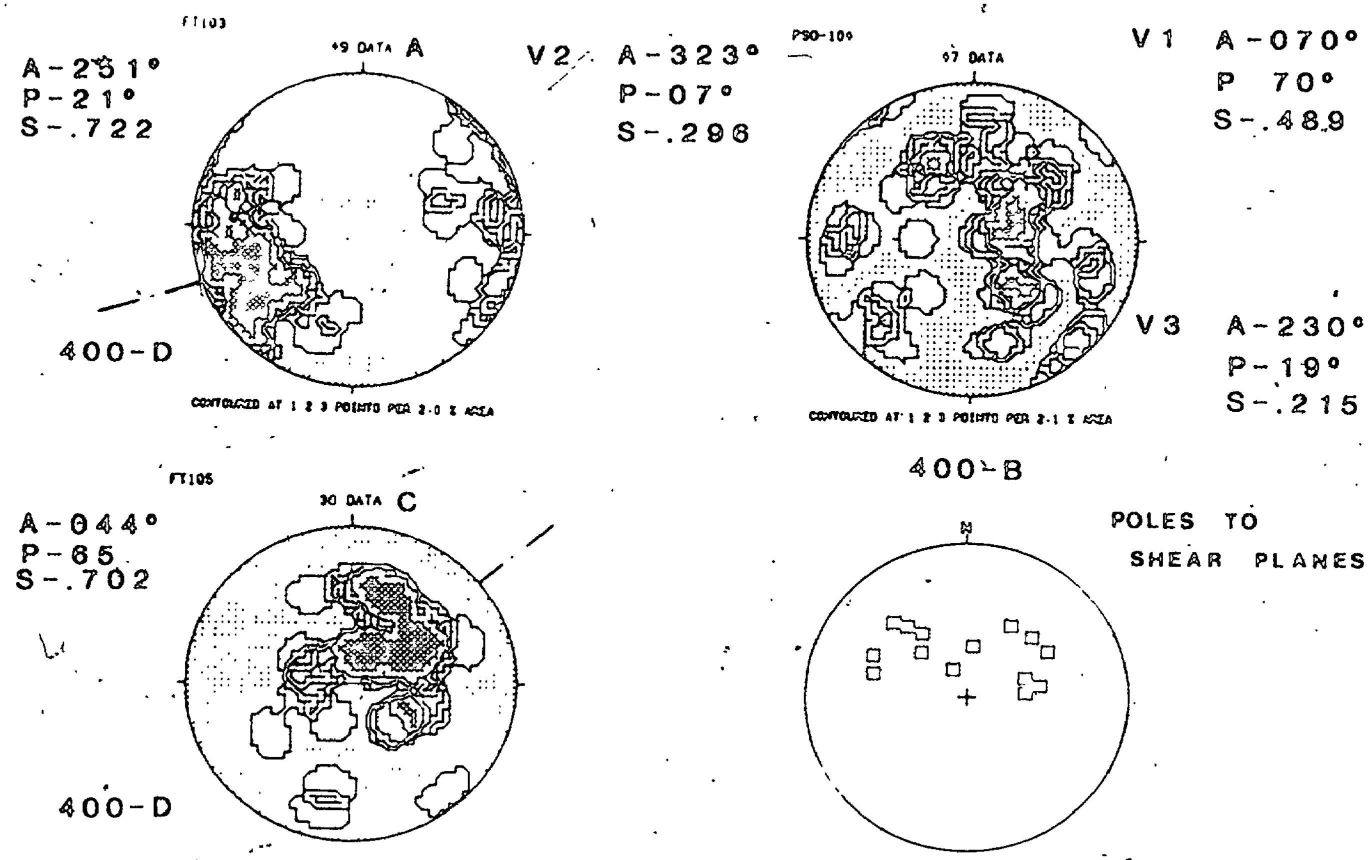


FIGURE 2-25: b) Contour diagrams of directional data, Deschaillons.

V1, 2 and 3 are eigenvectors of PSO-104.

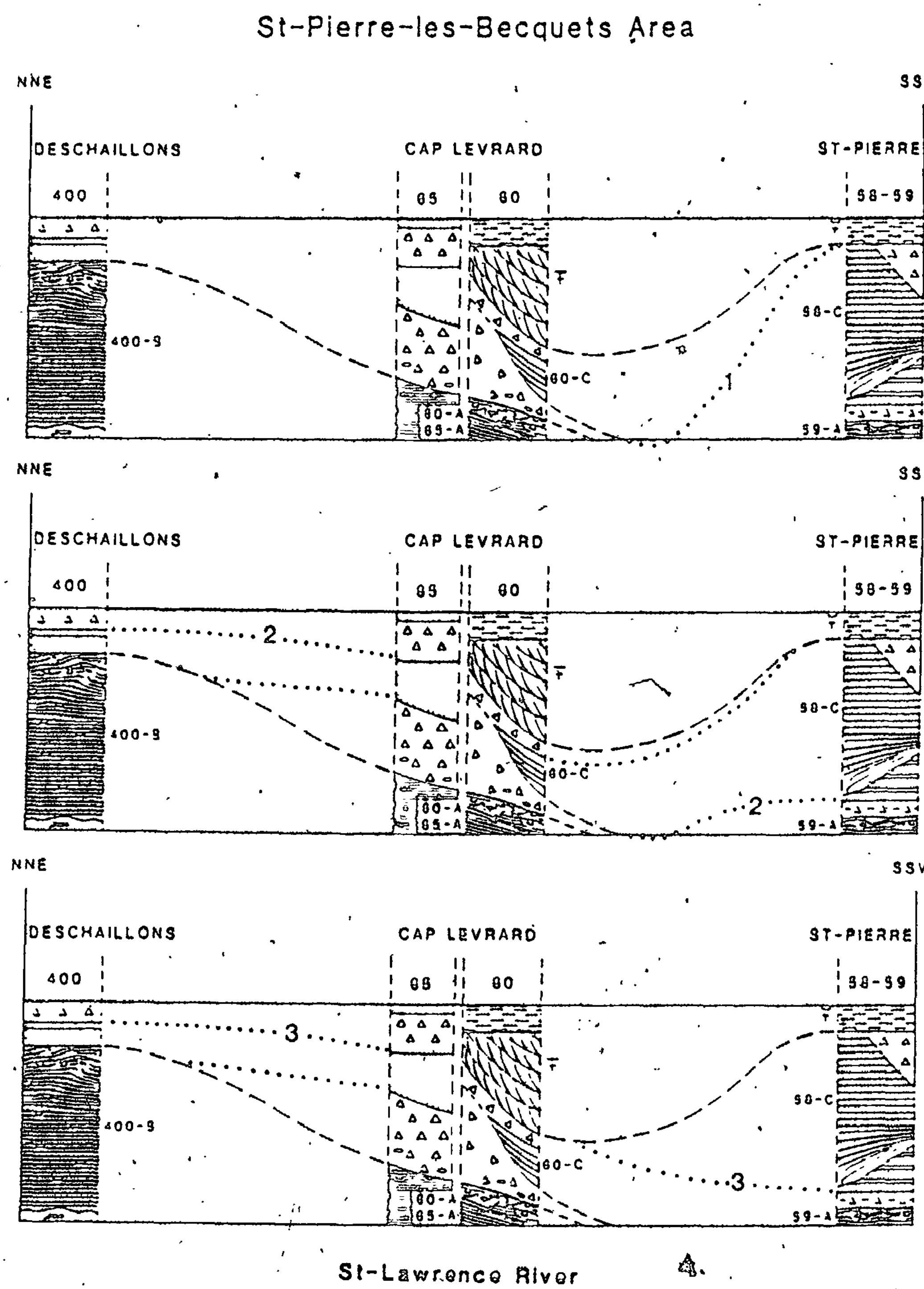


FIGURE 2-26: Suggested correlations, St-Pierre les Becquets area.

However, in these hypotheses, the Deschaillons Varves are older than the St-Pierre Sediments and are overlain by what has been traditionnally considered as the Bécancour Till. Moreover, the wood-bearing sand unit 400-A could represent an older Interstade than the St-Pierre. These conclusions, if adopted, would lead to a major revision of the St-Lawrence Lowland Quaternary stratigraphic framework. Arguments on which these hypotheses are built have obviously to be improved. For instance, geochronologic data are needed. They are presented in the next chapter.

CHAPTER 3

RADIOCARBON DATING

Until the second half of this century, age estimates of lithostratigraphic units relied on relationships such as the depth of leaching at the top of tills. Radiocarbon dating later provided Quaternarists with finite numbers from which most of the current chronostratigraphy evolved. Nevertheless, the time range of this dating technique only spans the very last part of the Quaternary Period. Consequently, the last decade has been a period of major developments in alternative techniques, the most promising being amino-acid racemization, thermoluminescence (TL) and uranium-thorium dating.

These techniques have been recently applied to various materials from the St-Lawrence Lowland. For instance, in this study, the results of a thermoluminescence dating program are reported in the next Chapter. New radiocarbon dates obtained on organic matter, shells and calcareous concretions are found below.

3.1 Introduction

The St-Pierre peat was among the first materials dated by the radiocarbon dating technique (Gadd, 1955). The "evolution" of the ^{14}C age of this peat, first reported as 11,000 years BP, to the most recent result of 75,000 years BP, belongs to the history of the development of dating techniques in Quaternary geology.

Most of the ^{14}C dates that will be discussed herein are higher than 25,000 years BP. Indeed, Stuiver et al. (1978) reported a ^{14}C age of $74{,}700 \pm ^{2700}_{2000}$ years BP (QL-198) for a piece of wood collected from the

Pierreville peat unit. To the author's knowledge, this is the oldest finite ^{14}C date ever published. Strong doubts have been cast on these dates. However, the early and middle Wisconsinan chronostratigraphy is largely based on such data (Dreimanis and Karrow, 1972). Consequently, a brief comment on some of the theoretical and practical aspects of the technique is given.

Upon death of biogenic carbon, or from the time of precipitation for carbonates, the radioactive isotope of carbon decays with a half-life of 5730 years. Therefore, a 35,000 year-old wood has an age of 6 half-lives (i.e. the ^{14}C activity of this sample is only $(\frac{1}{2})^6$ of the original activity of the organic matter grown in equilibrium with normal pre-nuclear atmosphere). This activity would produce 0.2 counts per minute (cpm) per gram of carbon. In liquid scintillation counting, the environmental background may yield as much as 4 cpm. A very long counting time is needed in order to statistically discriminate this minute activity. At the GEOTOP[1] laboratory, the background count is commonly around 3.9 cpm and the counting time is between 1400 and 2000 minutes. Table 3-1 compares activities and age calculations of a finite and infinite ^{14}C age obtained from a concretion and from a piece of wood collected at the St-Pierre type-section. As the reader may note, pre-treated sample UQ-312, which was the first striated concretion dated (Lamothe et al., 1983), shows

(1) GEOTOP: Laboratoire de Géochimie Isotopique de l'Université du Québec à Montréal. Seven dates on calcareous concretions were measured in this laboratory.

TABLE 3-1 ^{14}C AGE CALCULATIONS

AGE EQUATION: AGE (^{14}C years)= 8033 ln sample activity (/95% NBS)

SAMPLE	UQ-605: wood collected from the St-Pierre section	UQ-312: striated concretion in unit 98-E
counts	14X100 mn	14X100 mn
sample	385.0 ± 4.3	426.6 ± 7.2
background	374.9 ± 4.4	381.0 ± 7.1
net sample	11.1 ± 6.2	45.6 ± 10.2
ncps/mn/g carbon	.048 ± 0.028	.116 ± 0.026
sample activity (%) (/95% NBS)	0.57 ± 0.32	1.45 ± 0.33
AGE (^{14}C years)	>41 500 (infinite)	34 000 $^{+1880}_{-1470}$ (finite)

a measurable activity, whereas the ^{14}C activity of the piece of wood, if it has any, is less than two standard deviations. The ^{14}C age in this latter case is considered as a minimum, a common practice in radiocarbon dating.

The upper age limit in liquid scintillation counting is 40,000 ^{14}C years (4 g of carbon). The use of the proportional carbon dioxide counter has extended this limit to the 60,000 year range and isotopic enrichment of ^{14}C through thermal diffusion has lowered the detection limit to 0.1 per mil of the original activity for wood, therefore extending the age limit to 75,000 years BP (Grootes, 1978; Stuiver et al., 1978). Consequently, even though dates obtained by scintillation are criticized , in most cases they show a measurable radiocarbon activity. Other variables affecting the reliability of ^{14}C dates, such as sample contamination, reservoir effect and variation of the original atmospheric ^{14}C, are discussed in the next section.

3.2 Organic matter

In the study area, marine fossils have been found only in late-glacial sediments. Early radiocarbon dating of units older than the classical Wisconsin was therefore restricted to wood and peat fragments imbedded in the sediments. Table 3-2 presents a list of ^{14}C dates obtained on organic matter in the area up to 1984.

The first sample of wood submitted by N.R. Gadd to the Lamont Geological Observatory yielded an age of 11,050 years BP (L-190A) suggesting a Two Creekan age for the St-Pierre type-section peat (Gadd, 1953). This result has not been published and is believed to be due to modern contamination. Sample Y-242, collected from the same middle

TABLE 3-2
^{14}C DATES ON ORGANIC MATTER

Sample	Date (years BP)	Material	Location	References
L-1900A	11 050 ± 400	WOOD	St-Pierre les Becquets	Gadd, 1953
"	> 40 000	"	"	Broecker and Kulp, 1957
Y-242	> 20 300	"	"	Preston <u>et al.</u>, 1955
"	> 30 840	"	"	"
"	> 29 360	"	"	"
W-189	> 40 000	"	"	Rubin and Suess, 1955
L-369A	> 44 000	"	"	Olsen and Broecker, 1959
Sn-93	> 35 000	"	"	Heikkinen, 1971
Sn-94	> 40 000	ORGANIC MATTER	"	"
GrN-1713	> 47 000	PEAT	"	Vogel and Waterbolk, 1972
GrO-1766	64 000 ±2 000	WOOD	"	Dreimanis, 1960
GrN-1799	65 700 ±1 300	"	"	Muller, 1964 Vogel and Waterbolk, 1972
UQ-605	> 41 500	"	"	This study
I-13764	> 40 000	"	"	"
Y-256	> 29 630	WOOD AND PEAT	Pierreville	Preston <u>et al.</u>, 1955
GrN-1807	> 48 000	PEAT	"	Vogel and Waterbolk, 1972
GrO-1711	67 000 ±1 000	WOOD	"	Dreimanis, 1960
GrN-1711	66 500 ±1 600	"	"	Vogel and Waterbolk, 1972
QL-198	74 700 $^{+2\,700}_{-2\,000}$		"	Stuiver <u>et al.</u>, 1978

peat layer unit at the type section showed an apparent finite age of 20,300 years BP, but it was considered at that time, quite reasonably, that all radiocarbon dates over 10,000 years be reported as infinite since the "black carbon" technique was very sensitive to contamination (see discussion in Gadd, 1955). Most of the other samples failed to show any detectable activity. A piece of wood from the basal layer was recently studied at the GEOTOP laboratory to detect contamination or the presence of a laboratory artifact such as memory effect. The age obtained (UQ-605: >41500) is infinite.

Only three finite dates have been published. The first two were performed by H. de Vries in Groningen and variously reported as Gro 1711, Gro 1766 (Dreimanis, 1960) and GrN-1711, GrN-1799 (Muller, 1964). Following the discussion in Gadd et al. (1972), only the dates abbreviated GrN will be considered. Updated results are published in Vogel and Waterbolk (1972). The third date (QL-198) was obtained through thermal diffusion isotopic enrichments (Stuiver et al., 1978).

In order for ^{14}C ages to correspond with calendar years, some restraining conditions should be met. Obviously, no contamination should be added during laboratory treatment. In the cases of GrN, such contamination might have occurred since, according to Grootes (1978), a slight and specific laboratory contamination was present in the Groningen laboratory at the time de Vries was working.

No in situ contamination is also required . For a 60,000 year-old sample, the addition of 0.1 per mil of modern carbon would yield an age of one Libby period younger (i.e. 5,568 years). This type of contamination may be detected when the leached humic acids and other organic constituents obtained during a pre-treatment with a hot alkali solution shows a greater activity than the remaining sample. According to this test, the Pierreville wood (QL-198) was found to be uncontaminated.

Reservoir effects can be easily corrected with the help of ^{13}C measurements. In any case, they are rather systematic and may be disregarded.

Another assumption is that the original ^{14}C concentration in the atmosphere was equal to the one that would have been measured before the first nuclear tests in the 1950's. Grootes (1978), following a discussion held at the 12th Nobel symposium, suggests that the original ^{14}C concentration should not have fluctuated by more than a factor of two during the last 100,000 years. If so, in the 50,000 years range, the discrepancy between a ^{14}C age and the calendar years would not exceed 10% (i.e. one Libby period).

Because of this last assumption, it is considered that the above three finite dates are not geologically different and that the ^{14}C age of these organic layers is most probably 70,000 ± 10,000 years BP.

3.3 Carbonates

3.3.1. Shells

For purposes of comparison with a TL date performed on the sediment, labelled MC-Des, a population of Balanus hameri was dated at 11,130 ± 180 years BP (UQ-651). This sample is from a massive marine clay located 2 km south from the Deschaillons brickyard.

3.3.2 Calcareous concretions

Keele (1915) was apparently the first to report the presence of calcareous concretions in the St-Lawrence Lowland from the Pierreville sections. Terasmae (1958) also noted numerous concretions in the Pierreville varves, at section 98. In the St-Pierre les Becquets area, Gadd (1955, 1971) and Karrow (1957) described calcareous concretions from the Deschaillons varves. This last author also noted the presence of "lime" concretions in the Bécancour till of the Cap Lévrard section. As demonstrated in Chapter 2, these concretions are derived from the Deschaillons varves. Gadd (1955, 1971) believed these were the result of groundwater activity. Recently, Hillaire-Marcel and Pagé (1981) analyzed a suite of concretions collected at the Deschaillons brickyard, for their ^{18}O, ^{13}C and ^{14}C contents. They proposed an authigenic origin for these carbonates and suggested that the ^{14}C activities may date the period of glacial lake Deschaillons. Finally, in the course of this study, concretions of the same age were found as striated clasts in the Gentilly Till and it was proposed, considering the radiocarbon dates of these striated concretions, that the inception of the classical Wisconsin glaciation was an event younger than what was generally assumed (Lamothe et al., 1983).

Description of the concretions

The different types of concretions are shown in Plates 3-1 and 3-2. Most concretions are circular to elliptical in shape. In situ concretions are found in discrete layers where they crop out from the

PLATE 3-1

a: Wood and remains of aquatic plants in uppermost peat layer layer of unit 58-B, from the St-Pierre type-section; wood fragment is 30 cm.

b: Calcareous concretions from unit 98-A, Pierreville section; grid is 1 cm square .

c: Calcareous concretions from unit 99-C, Riviere St-Francois section.

d: Striated calcareous concretion collected from unit 98-E, Pierreville section; this concretion was dated at $34\ 000\ ^{+1800}_{-1470}$ years BP (UQ-312).

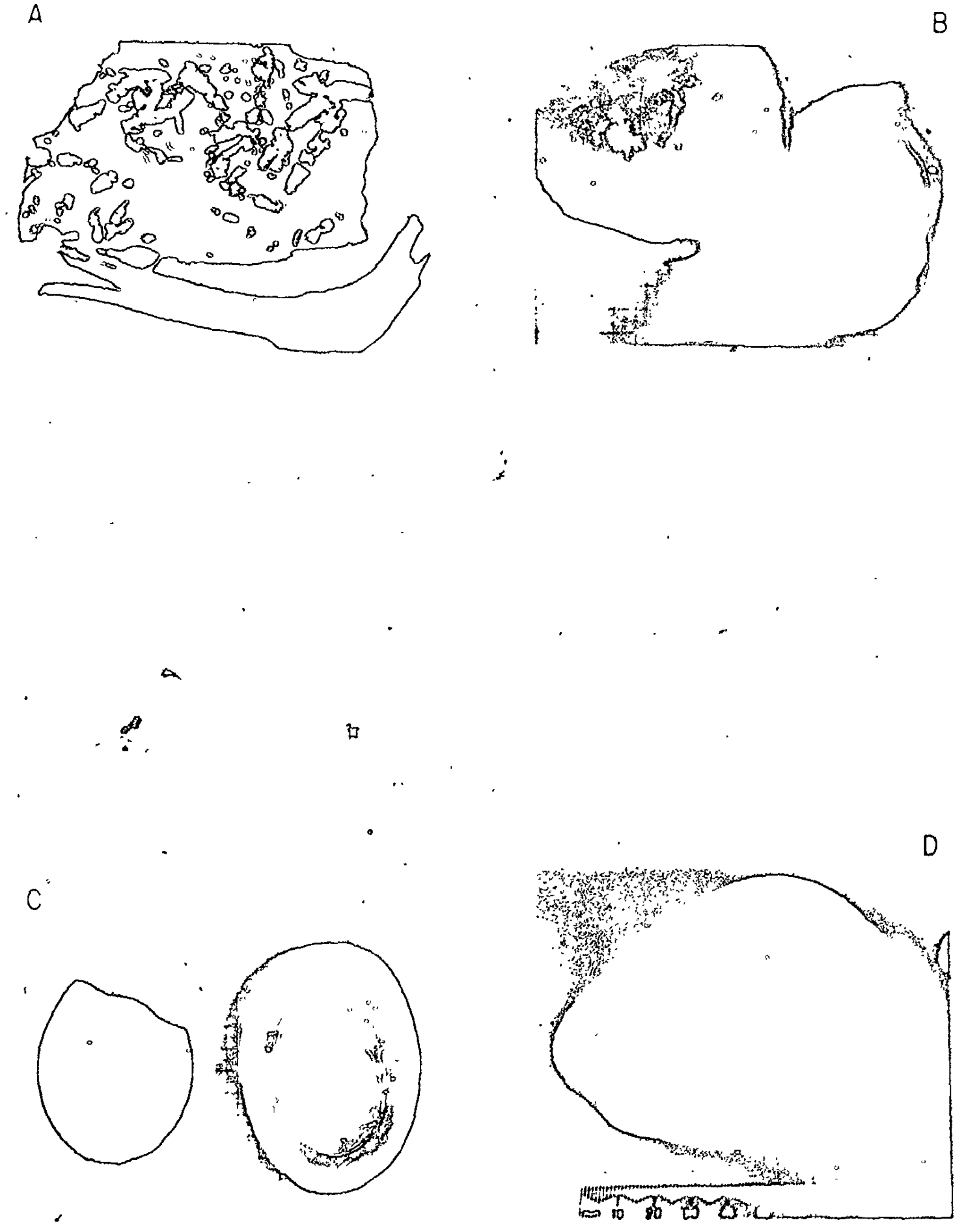


PLATE 3-1

PLATE 3-2

a: Calcareous concretions collected in unit 400-B, Deschaillons brickyard.

b: Calcareous concretions collected in unit 59-A, along the St-Lawrence River.

c: Striated calcareous concretion collected in unit 60-B, at Cap Levrard; this concretion was dated at >41 000 years BP (I-13 317).

d: Calcareous concretions collected in a pinkish rhythmic unit at section 50a, Riviere aux Orignaux.

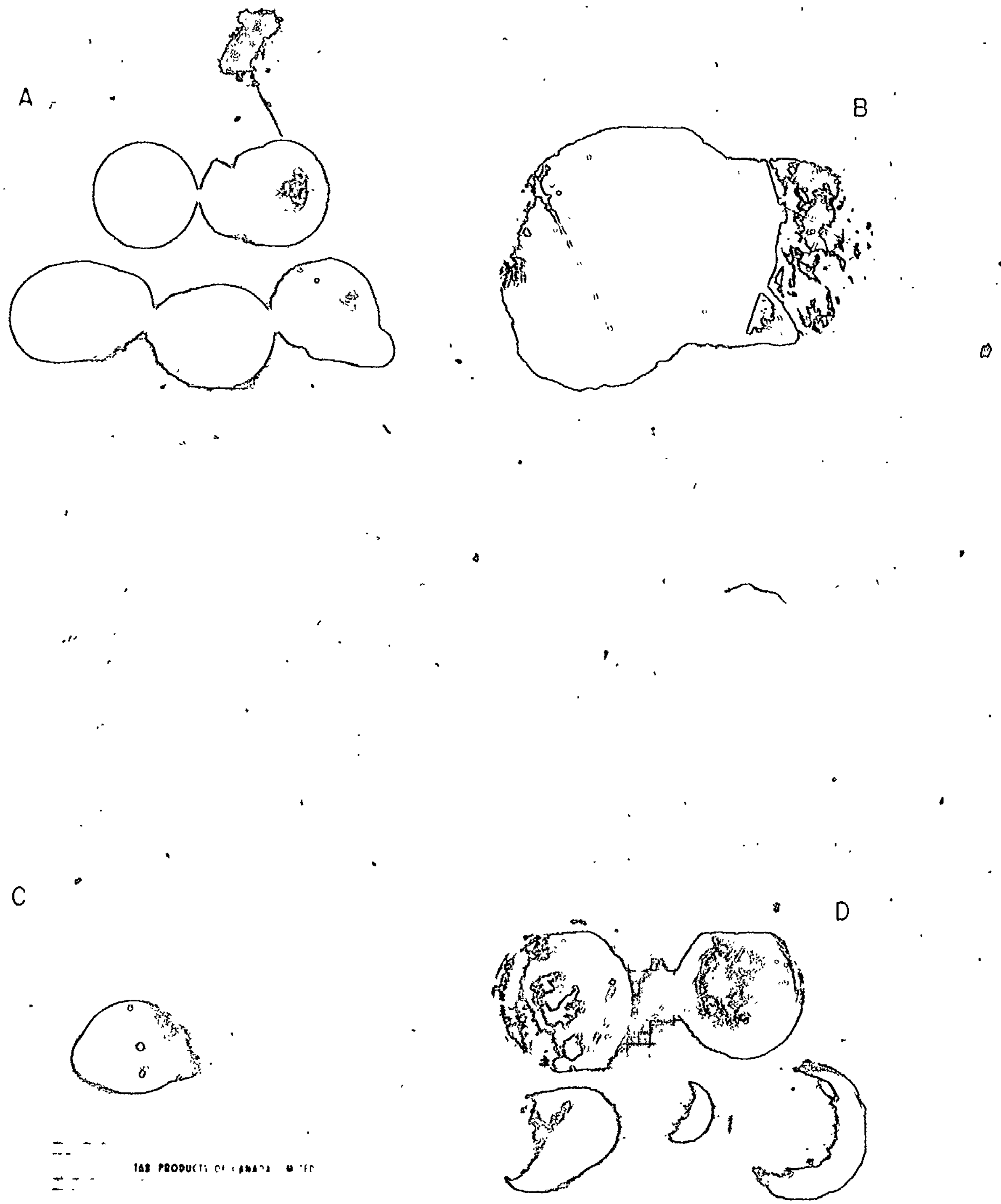


PLATE 3-2

surface of the sections. The host sediment laminae can be seen in the concretions in hand specimens as well as in thin-sections (Plate 3-3) Indeed, microscopic examination of these concretions provides useful lithologic information about the host sediment since they actually preserved the original fine-scale sedimentary structures. However, the individual calcite crystals can not be observed. This calcite is micritic. Septarian fractures are seen in thin-section (Plate 3-3). They do not extend to the outside of the concretion. Carbonate contents are consistantly 50% for concretions of unit 98-A and 60 % for those of unit 99-C. The Deschaillons concretions have a carbonate content averaging 50%, but values range from 35 to 60%. Their calcite to dolomite ratio is high (10 to 25). This carbonate is therefore a low-Mg calcite, which is typical of fresh water.

The concretions shown on Plate 3-2b have a carbonate content of 50 %. They were collected in unit 59-A. Other concretions collected in the same unit yielded a carbonate content of 60% . However, chemical analysis reported by Cloutier (1983) revealed that this carbonate is siderite, with 38 to 40% total iron. This mineral is indicative of reducing conditions.

The carbon and oxygen isotopic ratios measured on the carbonate of these concretions are listed in Appendix III and presented in Figure 3-1. They focus around -20‰ for $^{13}C_{PDB}$ and -12‰ for $^{18}O_{PDB}$.

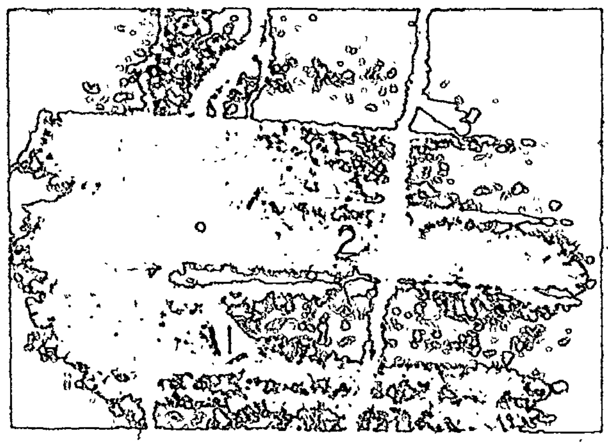
It should be noted that vivianite is very common in the host sediment. Some specks of this mineral have been found covering the external surface of one of the concretions found under the St-Pierre peats at the type-section.

PLATE 3-3

a: Photomicrograph of a concretion collected in unit 400-B; scouring (1), graded bedding (2) and septarian fractures (3) are shown by triangles; plane of view is 1 cm wide.

b: Photomicrograph of a siderite rich carbonated crust collected in unit 58-C; triangle shows sand size grain; plane of view is 1 cm.

A



B

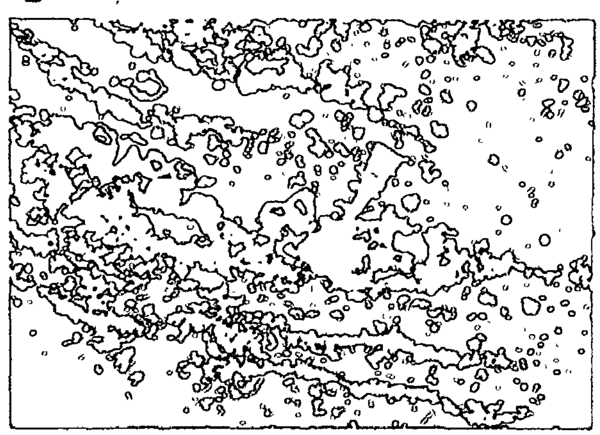


PLATE 3-3

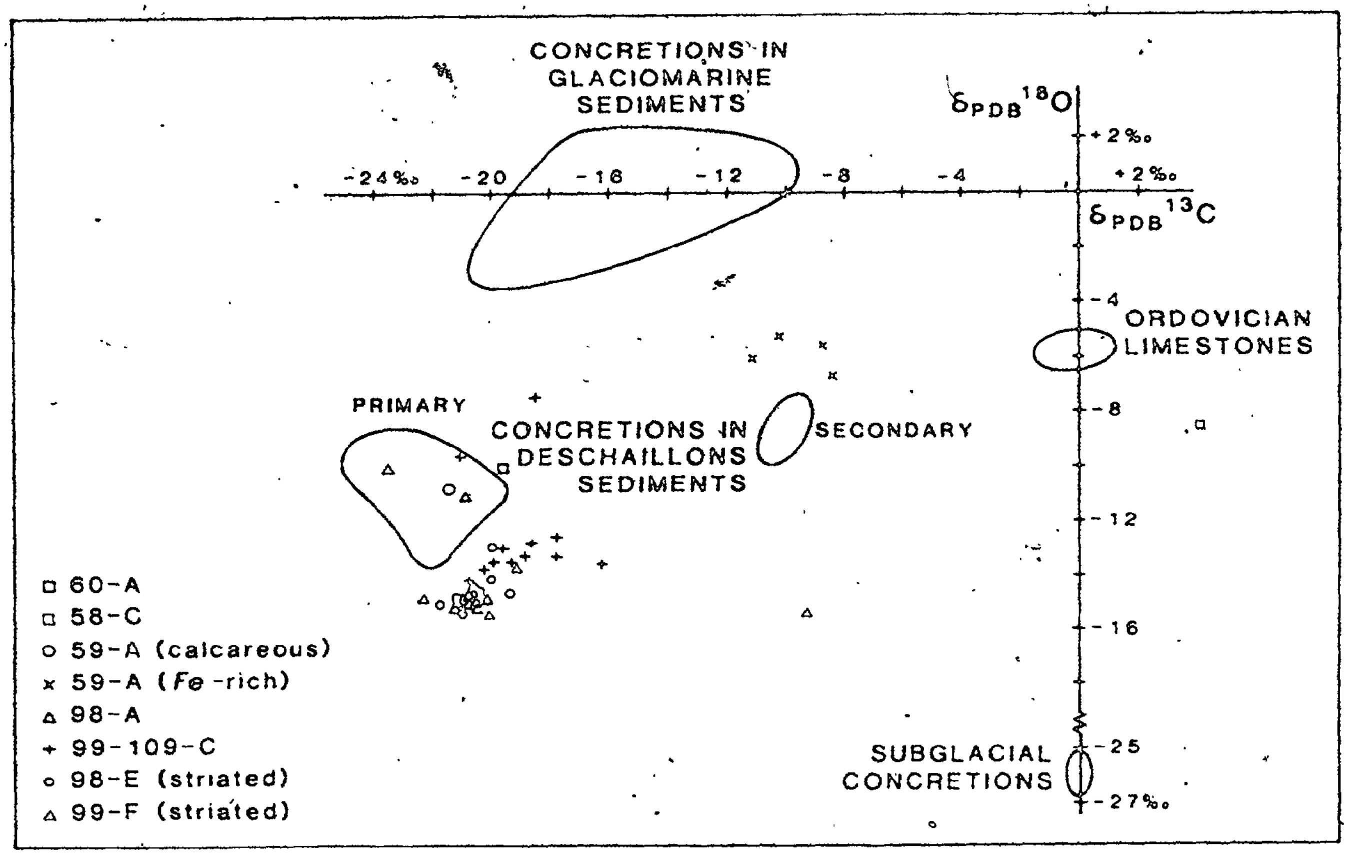


FIGURE 3-1: Carbon and oxygen isotopic ratios of the carbonate extracted from sediment , concretion and limestone samples; areas outlined are taken from Hillaire-Marcel, 1979.

Stratigraphic positions and ^{14}C ages of the concretions

The radiocarbon dates obtained on the concretions are listed in Table 3-3. Of a total of 13 dates, 5 were collected in the Gentilly Till as striated clasts (UQ-312, UQ-494, I-12894, section 98 ; UQ-484, UQ-525 section 99), 5 from the Deschaillons Formation (Qu-279, QC-559, QC-357, GX-9531, section 400), 2 from the Pierreville Varves (UQ-406, UQ-698, section 98), 1 from the 99-C unit (UQ-130, section 99), and 1 from the lower diamicton at Cap Lévrard also as a striated clast (I-13317, section 65).

Samples abbreviated QC(Queen's College, New York), Gx (Krüger Enterprises Inc., Cambridge, Mass.) and I (Teledyne Isotopes, New Jersey) were measured in a proportional counter whereas the other samples were counted by liquid scintillation.

Except for I-13317, the ^{14}C dates are finite and strongly focus in the 30-35,000 years range. QC-353 (Hillaire-Marcel and Pagé, 1981) is a secondary concretion, occurring as molds in fractures and folds of the Deschaillons rhythmites.

Discussion

As shown in a preceding section, the concretions have a minute radiocarbon activity. However, the question must be asked if this activity is geologically significant.

Some of these concretions dated at 35,000 BP have been collected in undoubtedly older sediments, such as those found under the

TABLE 3-3

^{14}C DATES ON CALCAREOUS CONCRETIONS

Sample	Date (years BP)	Material	Unit		Location	References
QU-279	$36\,280 \pm 2\,410$	in situ concretion	Deschaillons Varves	400-B	Deschaillons	Hillaire-Marcel, 1979 and Page, 1981
QC-558	$34\,900 \pm ^{1\,625}_{1\,350}$	"	"		"	Barrette et al. 1981
QC-357	$37\,580 \pm ^{2\,300}_{1\,800}$	"	"		"	"
Gx-9531	$35\,100 \pm ^{3\,070}_{2\,420}$	"	"		"	This study
UQ-406	$34\,000 \pm 1\,050$	"	Pierreville Varves	98-A	Pierreville	"
UQ-688	33 600 - 2 300	"	"	"	"	"
UQ-312	$34\,000 \pm ^{1\,800}_{1\,470}$	striated concretion	Gentilly Till	98-E	"	Lamothe et al. 1983
UQ-494	$36\,400 \pm ^{3\,000}_{2\,400}$	"	"		"	"
I-12894	$37\,200 \pm 2\,500$	"	"		"	This study
UQ-484	$26\,000 \pm 2\,300$	"	"	99-F	Riviere aux Vaches	"
UQ-525	$32\,500 \pm 900$	"	"		"	"
UQ-130	$28\,030 \pm 760$	in situ concretion	Riviere aux Vaches Fm.	99-C	"	Lamothe et al. 1982
QC-353	$8\,670 \pm 460$	secondary concretion	Deschaillons Varves	400-B	Deschaillons	Hillaire-Marcel and Page, 1981
I-13317	> 40 000	striated concretion	Becancour Till	60-B	Cap Levrard	This study

Pierreville peat layer. This raises the question of their origin.

A conclusive mode of genesis for these concretions, has not yet been demonstrated.

Gadd (1971, 1980) strongly favours a recent precipitation event related to ground water activity mainly on the basis of the shape of some calcareous "concretions" observed in the upper rhythmites of the St-Pierre type-section, and because of their higher degree of consolidation when found at the face of the exposure. Based on the present observations, these "concretions" are secondary calcareous "lenses" such as the ones found overlying the St-Pierre Sediments at the type-section.

Hillaire-Marcel and Pagé (1981) and Pagé et al., (1982) proposed a synsedimentary or early diagenetic origin for these carbonates on the basis of the following arguments: (1) ^{13}C and ^{18}O are highly depleted in heavy isotopes (Fig. 3-1) suggesting the carbon is biogenic and was precipitated in glacial waters; (2) most of their structural relationships with the host sediments suggest a synsedimentary precipitation event. Moreover, in the deformed upper Deschaillons rhythmites, a second event of precipitation molded the folds and fractures of the host sediment as well as the early concretions. These concretions are clearly secondary and yielded, as expected, a much younger radiocarbon age, i.e., 8,670 $\pm$ 460 years BP (QC-353); (3) the mineralogical association of this calcite with authigenic vivianite in glacio-lacustrine sediments and with sulfides in marine sediments indicates precipitation in a slightly reducing environment. The present writer favours a pene-contemporaneous origin for this carbonate. It may be the result of an early diagenetic process which has occured during the early compaction of the enclosing sediment. The isotopic composition of these carbonates suggests that precipitation must have been in cold water and the carbon is biogenic.

The concretions cannot be precipitated by groundwater since this aggressive water tend to dissolve the Paleozoic limestones. Their $^{13}C_{PDB}$ rarely exceeds -11 °/₀₀. Also, a spherical shape would not be expected since this carbonate would have precipitated in porous silty laminations behaving as an anisotropic medium (three last sentences : P. Pagé, 1984, personal communication). The carbonate content should reflect the initial porosity of the sediment. For example, concretions in unit 109-C have a carbonate content of 60-70% and an actual porosity of 54% (measured by a water content) ; for concretions in unit 98-A, numbers are 50% total carbonate versus 37% porosity ; for concretions in unit 400-B, carbonate content range from 35 to 50% whereas sediment porosity if 33%. Because of the large range in carbonate content, more data on porosity are needed. However, it is felt that the precipitation took place early after deposition but before compaction since the host sediments have a smaller average modern porosity. If precipitation is recent, two unlikely processes would have to be invoked : (a) replacement of silicates by carbonates or (b) displacive precipitation.

However, the precipitation cannot be truly synsedimentary since concretions cement numerous sedimentary laminations and even post-depositional structures such as pseudo-nodules (Plate 3-3). Following Pettijohn (1975), the septarian fractures necessitate case hardening of the exterior part of the original "nodule" and dehydration of the interior in order to generate the shrinkage-crack pattern. Raiswell (1971) considers these are characteristic of highly porous water-saturated sediments. The original nodule must therefore be anterior to compaction.

For all the above reasons, it is suggested that the late Quaternary concretions found in the St-Lawrence Lowland are early diagenetic and were precipitated in equilibrium with glaciolacustrine water trapped in pores of the host sediment. Ionic activities of this formation water may have increased through salt-sieving. In this process, concentration of ions increases under semi-impervious laminae during expulsion of water (White, 1965). Upon saturation with $CaCO_3$, a low-Mg calcite is able to precipitate. According to P. Pagé (1984, personal communication), the solubility of calcite may be lowered with increase of pH due to production of NH_3 during an early stage of decomposition of organic matter. Authigenesis of vivianite supports this concept of slight decomposition since any more severe decomposition of organic matter would have released sulfur. Pyrite would then have been the stable form of ferrous iron instead of vivianite. Therefore, (1) field evidence demonstrates the concretions are older than the last glacial advance ; (2) the high carbonate contents together with the stable isotope geochemistry require the concretionary event to be early with respect to the host sediment. It may herein be noted that both the TL data for the Deschaillons rythmites and preliminary U-Th measurements for one of the in situ concretion (C. Causse, 1984, personal communication) suggest ages in the 80-100 ka range.

The minute radiocarbon activity of these carbonates can be explained by the following two hypotheses :

(1) If the activity is true, there must have been some contamination. Contamination by recent carbon seems unlikely because of the complete absence of any permeability in both in situ and striated concretions. Furthermore, whatever the intensity of the pre-treatment (20 to 60%) and

whatever the type of sediment in which they are found, they consistently yield the same small activity, i.e. 1.5% of the oxalic acid standard. If recent random contamination had occurred, a large distribution of ages ranging from 15,000 years to infinite, for example, should be found. Contamination under phreatic conditions could have occurred in late Wisconsinan time. In this case, a primary permeability in the concretions would have been present. This would have permitted a second event of cementation. However, this second generation of carbonate cement should have left some traces. This fact remains unexplained. In order to yield a 1.5% activity today for the total carbonate, the second generation would have to be almost as important in volume when compared to the first generation of ("dead") carbonate, if this event occurred 30,000 years ago. In thin-sections, this micritic calcite is, however, homogeneous, except for the septarian fractures. This second cement generation, if present, might only be detected by more sensitive techniques such as cathodoluminescence. The second phase of cementation may also have involved some dissolution of the first generation followed by diffuse reprecipitation. This event would not have occurred after late Wisconsinan time since the concretions must have been indurated before being imbedded in the Gentilly Till. It should be noted that whatever the apparent age of this ground water and whatever the amount of detrital (mainly Ordovician) carbonates, they would in all cases give a higher apparent age to the secondary contamination event and, therefore, to the inception of the following glacial event. Moreover, the infinite age (>40,000 ; I-13317) measured on a striated concretion collected from the lower till at the Cap Levrard section (Bécancour Till ?), which is believed to be older than the St-Pierre peat of the type-section, supports this latter hypothesis since contamination in this weakly permeable unit must have been less severe than in the underlying rhythmites.

(2) The activity is the result of an artifact : this would have been found in the 5 radiocarbon laboratories from which 12 concretions were dated at 35,000 years BP.

An interesting hypothesis has been proposed by L. Dever (1983, personal communication) who suggested that the chemical attack on the carbonate during benzene synthesis releases radon which decays with the same spectrum of energy as the ^{14}C beta decay. However, even if the time elapsed between benzene synthesis and beta counting is not documented in the radiocarbon dating data, it is proposed by the writer that this type of artifact should have produced random results in terms of ^{14}C ages. It is also a standard ^{14}C laboratory procedure to allow a few days between preparation and counting. The half -life of radon-222 is 3.83 days. The hypothesis cannot, at the moment, be carried further.

In summary, the geochemical, mineralogical, textural and structural features described above advocate for a penecontemporaneous origin for this carbonate. Therefore, it is tentatively proposed that its radiocarbon activity is true and might be the result of some poorly understood secondary contamination which would have occurred before the last glacial advance.

CHAPTER 4

THERMOLUMINESCENCE DATING

Light emitted by a crystal when heated is termed thermoluminescence (TL). This thermally stimulated process has been used for dating archaeological objects for two decades. Its application in geochronology is more recent and still under development.

The TL dating technique is part of a group of methods based on solid state physics, which include Electron Spin Resonance (ESR), Thermally Stimulated Current (TSC), etc... They are measures of trapped electrons in minerals, a fact which is largely a consequence of radioactive decay.

Randall and Wilkins (1945) demonstrated that the release of electrons trapped in crystalline defects was responsible for thermoluminescence and long-period phosphorescence. A few years later, Daniels et al. (1953) proposed many potential uses of the TL process including correlation and dating. Research was then directed towards carbonates, and partly for this reason, it met with many difficulties. In fact, in 1966, at the "Thermoluminescence of Geological Materials" Conference (McDougall, 1968), the technique was still bound with many set-backs. One major problem was the occurrence of "spurious" non-radiation-induced TL. A technical suggestion by Aitken et al. (1963) to perform heating in an oxygen-free atmosphere of an inert gas (nitrogen or argon), led to an eradication of this problem. The technique then evolved quite rapidly. Today the TL dating method is used on a routine basis in archaeology as research is now directed towards refinements of various aspects within the technique.

Unfortunately, applications to geochronology of sediments is not straight forward. The pioneering work of Shelkoplyas (1971, 1974) kept alive the interest in the technique in spite of methodological misconceptions. Recently, new hopes have been generated by a series of papers (Huntley and Johnson, 1976; Hütt and Raukas, 1977; Wintle and Huntley, 1980 and Wintle, 1981) which proposed solutions to specific problems of geological dating. An exhaustive review of the published TL work on sediment dating up to 1981 will be found in Wintle and Huntley (1982).

The results of the present TL dating program are presented below. However, since most Quaternary geologists are unfamiliar with this technique, the general principles of the thermoluminescence process are outlined and the age equation is given. Most of the next two sections is taken from Lamothe et al. (1984).

4.1 The TL Process

An exhaustive treatment of this subject can be found in Levy (1974), Aitken (1974) and Fleming (1979).

Most minerals previously subjected to ionizing radiation will emit light when heated. Since this is an irreversible phenomenon, the mineral will not emit light when heated again unless it is irradiated. At moderate doses, the intensity of the light is directly related to the irradiation dose (Fig. 4-1). Therefore, TL can reflect the total radiation a material has received.

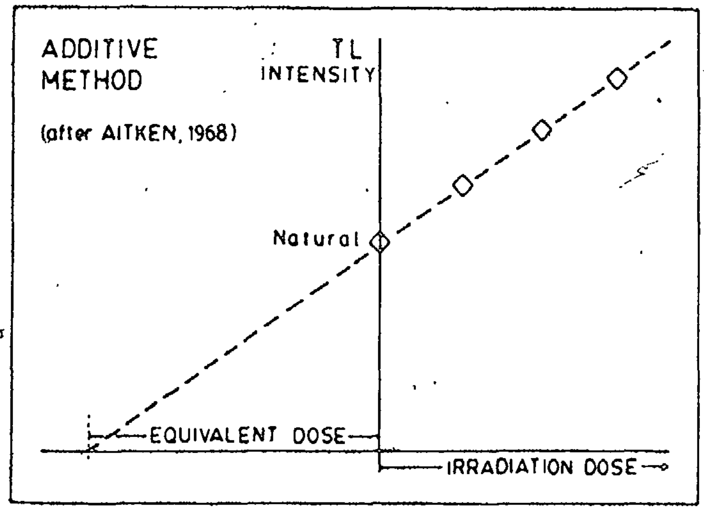


FIGURE 4-1: The additive method in thermoluminescence dating.

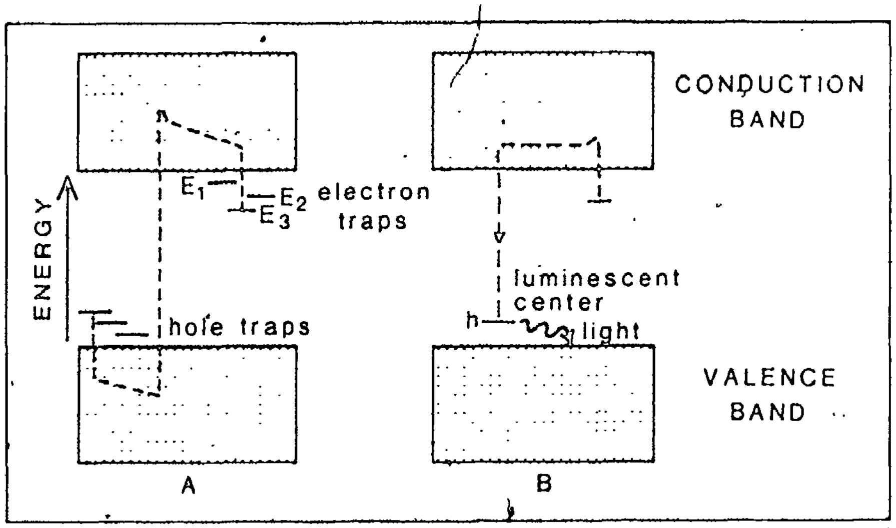


FIGURE 4-2: The Band model, modified from Aitken, 1974.

Radiation

In the natural environment, radiation derives mainly from litho-spheric decay to which may be added a minute contribution from cosmic rays. Alpha (α) and beta (β) rays are particle-like radiations whereas the gamma-rays are part of the electromagnetic spectrum. Entering a crystal , those three types of radiation will differ largely in terms of electron-hole pairs production efficiency. For example, the alpha contribution, because of its small range($\approx$22 μm), is restricted to the surface of quartz grains, because they are frequently free of internal radioactivity. The beta and gamma rays penetrate completely the fine silt and clay sized particles.

Storage of Energy

All minerals (quartz, feldspars , calcite) in sediments absorb the incoming radiation. Ionizing radiation can expell an electron from its normal orbit. This electron may become trapped at a lattice charge disequilibrium site, thereby called an electron-trap. Energy is stored. Alternatively, by mutual exchanges of peripheral electrons between atoms, an "absence of electron" (a "hole") will travel in the lattice and will eventually be also trapped. Immediate recombination of the electron with a trapped hole is,nevertheless, by far a more frequent process (99%, according to Levy, 1974). The traps are vacancies, impurities, interstitial atoms, etc... (Marfunin, 1979); for example, it has been suggested that aluminium impurities act as hole traps in quartz, with lithium, sodium and sometimes germanium as charge compensators while oxygen vacancies act as electron traps (McMorris, 1971).

Release of the Energy

When an irradiated crystal is heated, the electrons gain enough energy to escape from the traps. The electron release rate is temperature dependent and is expressed by the Randall-Wilkins equation

$$\frac{dn}{dt} = -nse^{-E/kT}$$

Where n : trap charge concentration at time t

s : "attempt to escape" frequency

k : Boltzman constant

E : Activation energy for thermal charge release

T : temperature

The band model is an energy representation of this process (Fig. 4-2). Having gained freedom, the electron wanders in the conduction band. If the electron recombines at a luminescent center, usually a hole trap, energy may then be released in the form of light. This conduction band charge transfer is not the only possible route for the electron. There are processes in which no light is emitted e.g., radiationless recombination may occur at "killer" centres.

In a simplified way, minerals receive ionizing radiation. They behave as natural dosimeters if they can store part of this energy over geological time and release it when heated.

4.2 The Age Equation

From the preceeding section it follows that if the radiation dose-rate and the number of traps are constant, the light emitted upon heating may be a measure of time. Therefore, if one can find the dose that can reproduce the natural TL level (equivalent dose) and compute the annual dose from the radio-active elements found in the sample, an age can be calculated from:

$$\text{AGE (years)} = \frac{\text{EQUIVALENT DOSE (grays)}}{\text{DOSE-RATE (grays/year)}}$$

Equivalent Dose

The equivalent dose (ED) is defined as the artificial dose that can simulate the natural TL level. It is expressed in grays (1 gray = 1J/Kg = 100 rads).

In the case of pottery or any fired material, the calculation of the ED is achieved by the additive method in which the artificial dose is gradually added to the natural sample; the ED is found at the interception of the TL growth curve with the abcissa (Fig. 4-1).

As a function of temperature, the ED normally increases and reaches a stable value. A plateau identifies the stable part of the glow curve where leakage of electrons should not have occurred during archaeological time. A sample which fails to exhibit such a plateau will be rejected for TL dating. However, it may show a plateau and yet, have suffered leakage of electrons from traps of any depth by wave-mechanical "tunnelling". This phenomenon is termed anomalous fading and has been a major obstacle in TL dating (Wintle, 1973). An anomalous fading test compares the TL emitted by two sets of the same sample which were irradiated at different times before measurements. There will be no anomalous fading if the TL emitted by the two sets is the same. This is not always the case.

Another problem linked with the determination of the equivalent dose is the shape of the TL growth curve. At moderate doses (100 grays) the growth curve is fairly linear. However, it has a tendency to flatten at high doses and might even saturate (Troitsky et al., 1980).

Dose-Rate

The Dose-Rate is the lower term in the TL age equation and it is defined as the rate at which energy is deposited in the material. It is expressed in grays-year^{-1} where 1 gray (Gy) equals 1 J/kg. In continental deposits, this energy comes from the radioactive decay of potassium 40, thorium 232, uranium 238 and 235. Part of this energy is also delivered by the cosmic rays.
The K-40 content is easily determined by atomic absorption. The others may be found by gamma-ray spectrometry, neutron activation analysis or, more commonly, by alpha-counting. Bell (1979) computed the most recent values of dose-rate contributions for unit quantity of each element. Typical dose-rate values in sediments are in the order of a few mgrays per year.

Thus, the dose-rate value is easily computed. The possibility remains, however, that this dose-rate could have fluctuated during geological time because of various factors, the two most critical being the water content of the sediment and radon escape.

Water acts as a barrier for all three types of radiation to various degrees. It decreases the effective dose-rate by a factor of:

$$\frac{1}{1 + H\Delta}$$

where H : ratio related to the stopping power of water to dry sediment (different for α , β and γ ; see Table 4-1)

Δ : water to solid weight ratio in the sample

For unsaturated sediments, the evaluation of the average water content can be fairly speculative.

Radon 222 is a gaseous product highly mobile in dry soil. Its depletion is important because 98% of the γ contribution in the uranium series is produced beyond radon. However, water enhances radon escape from minerals but greatly prevents its mobility. Radon escape from a dry sample can be detected in the laboratory by comparing alpha-counts of sealed and unsealed aliquots of the same sample. There is yet no way to correct for such depletion.

Disequilibrium of the radioactive chains, removal of radioactive elements by the ground water and even inhomogeneity of the radiation field (Sutton, 1979), are also possible.

Analytical Techniques

Due to different microdosimetries, two techniques have been developed.

a) The Quartz Inclusion Technique (Fleming, 1970)

This method makes use of quartz grains ($\approx 100\,\mu m$) isolated from the matrix by heavy liquids and/or magnetic separation. By etching the sample in HF, the other light minerals (mainly calcite and feldspars) are removed and moreover, the outer surface of the quartz grains is dissolved, thereby eliminating the alpha dose contribution. The age. equation is then:

$$AGE = \frac{ED_i}{D_\beta + D_\gamma + Dc}$$

Where ED_i : equivalent dose for inclusion dating

D_β, D_γ, Dc: dose-rate from the β, γ and cosmic rays respectively

b) The Fine-Grain Technique (Zimmerman, 1971)

This technique has been used in the present test program. It involves very fine grains (4-11 μm) sedimented on 1cm diameter aluminium disks. In this fashion, as compared to loose sand grains, samples are found to be more homogeneous and easier to handle (particularly for irradiation purposes). For this particle size, the alpha dosage attenuation is negligible and the gamma and beta contribution importance is reduced. An efficiency factor, k, is introduced in the age equation and defined as:

$$k = \frac{\text{TL per gray of } \alpha \text{ radiation}}{\text{TL per gray of } \beta \text{ radiation}}$$

so that the dose-rate is expressed in beta equivalents. For sediments, the alpha radiation is generally 1/10 as efficient in inducing TL as compared to beta radiation. The age equation in fine-grain dating is then:

$$AGE = \frac{ED_{fg}}{kD_{\alpha} + D_{\beta} + D_{\gamma} + Dc}$$

Where ED_{fg} : equivalent dose for fine-grain dating

D_{α}, D_{β}, D_{γ}, Dc : dose-rate from the α, β, γ and cosmic rays

The TL per gray of irradiation varies with the energy. However, the TL per unit of alpha particle track length is not. Therefore, the k-value has been replaced by the a-value defined as:

$$a = X / 13\,S$$

where X: number of grays of gamma radiation that produces the same TL as 1 mn of alpha irradiation from a source of strength S $\mu m^{-2} mn^{-1}$.

A more complete discussion on this "track length system" is given by Aitken and Bowman (1975) and Bowman and Huntley (1984).

4.3 Application to Quaternary Geology: the R-Gamma method

Specific problems related to the application of the technique to sediments are discussed in Dreimanis et al. (1978) and Wintle and Huntley (1982). The most critical problem is the TL zeroing of the sediments.

Archaeological dating assumes complete drainage of the previously acquired TL due to firing of the ceramic. For secondary detrital deposits, this thermal event has not occurred. Nevertheless, some zeroing mechanism must have taken place since (1) traps in Quaternary detrital minerals are not saturated and (2) their TL commonly increases with depth. Morozov (1969), Shelkoplyas (1971) and Vlasov et al. (1978b) suggested that sunlight bleaches part of the initial TL signal. This may be attributed to photon interaction with trapped electrons (D.J. Huntley, personal communication, 1980). Vlasov et al. (1978a) measured total TL for sediments naturally exposed to sunlight from river bars and terraces which yield apparent TL ages of up to 9400 years, without any correlation with the geological ages of these units. Thus, an initial level of thermoluminescence is inherited at the time of sedimentation. From that time on, in a continuous manner, the environmental radiation supplies electrons to trapping centers until the sediment is remobilized in the sedimentary cycle (Fig. 4-3).

Therefore, this residual contribution (Io) must be subtracted from the natural glow curve in order to date the last sedimentation event. Wintle and Huntley (1980) suggested that traps in detrital minerals can be subdivided into light sensitive and light insensitive traps. Consequently, the TL glow curve is the sum of two components: I= Id + Io, Io being the presumably inherited TL at time of sedimentation and Id, the TL acquired since sedimentation. In their paper, they proposed three methods to determine Io. In laboratory, Io was measured through bleaching experiences using a 275W Sylvania sunlamp. This provides a standard and uniform illumination for the different sets of natural and

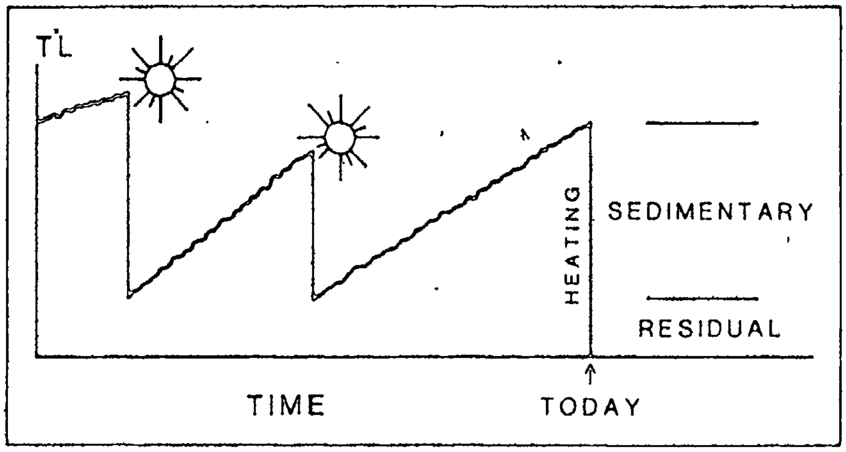


FIGURE 4-3: Hypothetical resetting of the TL clock in sediments.

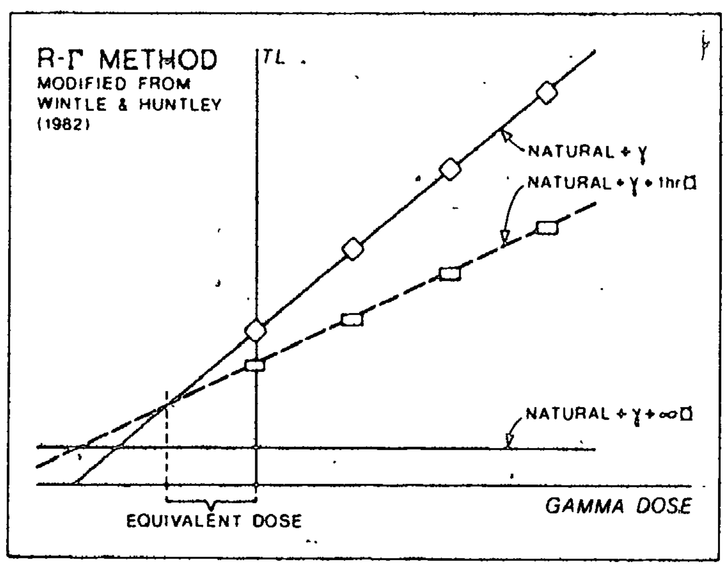


FIGURE 4-4: The R-Gamma method.

irradiated samples. The basic assumption is that the event being dated is the last exposure to sunlight.

A very lengthy exposure to either direct sun or to the sunlamp could cause ejection of electrons from defects which were already trapped at time of sedimentation (Fig. 4-4). The sunlamp exposure should therefore be small. In method a (now known as the regeneration method), the irradiation dose (G) necessary to regenerate the natural TL level after the samples have been exposed under the sunlamp for a standard time (say 40 mn) should be measured first. The ED is then =G/(1-f) where f is the fraction of the TL left after (1) bleaching the sample under the sunlamp enough to reduce the TL to a negligible value, (2) giving the sample a large irradiation dose and (3) bleaching the same sample under the sunlamp for 40 minutes. TL dates obtained on oceanic sediments (Wintle and Huntley, 1980) and loess (Wintle, 1981) by method 'a' were found to be in good agreement with stratigraphic evidences. However, changes in the TL sensitivity of the samples after they have been bleached shed some doubts on the EDs obtained by this method 'a' (D.J. Huntley, 1982, personal communication). A second method ($G-\gamma$) was used in which those sensitivity changes could be eliminated but the procedure implies lengthy and tedious measurements. Therefore, a method based on the reduction (R) of the TL caused by a standard sunlamp exposure was developed. This is the R-Gamma method (method 'c' of Wintle and Huntley, 1980). The equivalent dose is taken at the intersection of the unbleached TL growth curve ($N+\gamma$) with the bleached growth curve constructed from natural and irradiated discs which have been exposed to a short sunlamp exposure ($N+\gamma$ + Sunlamp ; Fig. 4-4). This should be considered as the sedimentary dose. Furthermore, in order to cut off the undesirable UV portion of the sunlamp, it is common practice at the

SFU-TL laboratory to introduce an optical filter between the mercury sunlamp and the discs.

From the above introduction, it is clear that the TL dating technique, when applied to sediments, is more complex than the common routine used in dating archeological material. In their review paper of 1982, Wintle and Huntley conclude that most TL dates published in the literature were unacceptable since very few methodological details were given on how the TL dates were obtained and which event was actually dated. They therefore suggested a set of criteria that would have to be met before giving any credibility to a suite of TL dates. These criteria are listed in Table 4-5. They later added, "simple publication of dates alone is quite inadequate". This is clearly demonstrated by what has been discussed above and by what will be presented below.

4.4 The TL dating program

In the course of this study, 14 samples were collected for TL dating from which 19 TL dates were obtained. All TL measurements were performed at the Physics Department of Simon Fraser University (Burnaby, BC). The fine-grain technique (4-11 μm) was used and the ED was measured using the R-Gamma method. Experimental details are given in Appendix IV. The age equation that was used is shown in Table 4-1.

4.4.1 Nature and stratigraphic position of the selected samples

The samples collected for TL dating are shown on figure 4-5. They can be classified into four categories, according to their presumed age:

TABLE 4-1

AGE EQUATION

$$\text{AGE (years)} = \text{ED (grays)} \Big/ W_{K_2O}\left[\frac{d\beta K}{1+H\beta\Delta}+\frac{d\gamma K}{1+H\gamma\Delta}\right] + \lambda U\left[\frac{1.80a}{1+H\alpha\Delta}+\frac{d\beta U}{1+H\beta\Delta}+\frac{d\gamma U}{1+H\gamma\Delta}\right] + \lambda Th\left[\frac{1.74a}{1+H\alpha\Delta}+\frac{d\beta Th}{1+H\beta\Delta}+\frac{d\gamma Th}{1+H\gamma\Delta}\right] + \frac{Dc}{1+H\gamma\Delta}\ (\text{grays-year}^{-1})$$

$H\alpha = 1.49$, $H\beta = 1.25$, $H\gamma = 1.00$

Dose rates (rad/year) for the decay of K-40, U-238, U-235, Th-230, and Pa-231

A. Dose rate for K-40 per 1% K_2O

K-40	$d_{\beta K} = 0.0682$	$d_{\gamma K} = 0.0205$

B. Dose rates for an alpha count rate of 1.00 $cm^{-2}\ ks^{-1}$

	d_α	d_β	d_γ
U-238 / U-235	$d_{\alpha U} = 2.330$	$d_{\beta U} = 0.1226$	$d_{\gamma U} = 0.0983$
Th-232	$d_{\alpha Th} = 2.093$	$d_{\beta Th} = 0.0819$	$d_{\gamma Th} = 0.1414$

(1 gray = 100 rads)

(WINTLE & HUNTLEY, 1980)

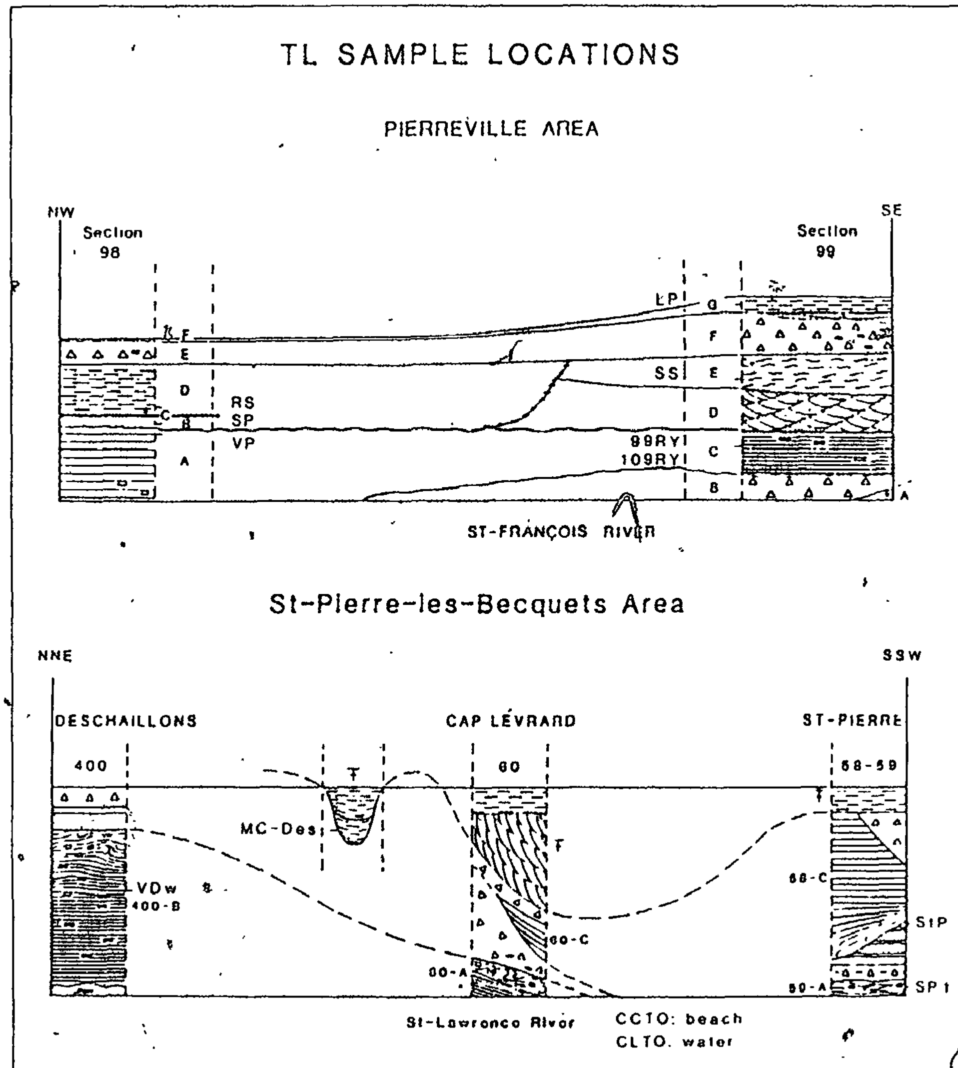


FIGURE 4-5: Location of the samples selected for TL dating.

Precise sampling is shown on individual logs.

Modern sediments:

CLTO: silt collected in the water of the St-Lawrence River, at Cap Lévrard, 20 cm under the surface of water.

CCTO: gravelly sand collected on the Cap Charles beach, 5 cm from the surface; beach sand.

Late-glacial sediments: Those sediments were laid down in the Champlain Sea basin (9,500 - 12,500 BP).

LP: clayey silt; collected 30 cm over the Gentilly till at section 99; apparently non fossiliferous; *Portlandia arctica* bearing silts are found on the top of the same till at section 109; shallow water marine clay (unit 99-G).

Mc-Des: massive silty and sandy clay collected in a St-Lawrence River section found approximately 2 km upstream from the Deschaillons brickyard (Fig. 2-12); *Balanus hameri* collected in these silts yielded a ^{14}C date of 11,130 ±180 years BP (UQ-651); deep water marine clay .

Interstadial sediments: These samples were collected in lithostratigraphic units related to the St-Pierre Interstadial. These sediments are presumably 70,000 ± 10,000 years old.

SP: silty sand collected 30 cm below the peat, section 98; beach sand (unit 98-B).

RS: clayey silt collected 30 cm above the same peat, section 98 (Plate 2-2a); shallow lacustrine silt ; (unit 98-D).

SS: clayey and sandy silt collected in a unit correlated with RS, section 99; (unit 99-E).

StP: sandy silt collected 30 cm above the uppermost peat layer at the St-Pierre type section (58); alluvial silt; (unit 58-).

Stadial sediments: The following set of sediments is older than the St-Pierre peat layers and younger than the brickred sandy basal till of the Rivière aux Vaches sections which can not be reasonably older than the Illinoian; their presumed age is therefore 70,000 - 130,000 years old.

RY: silty clay of 99 or 109C.

99RY; 2m above the brickred till, section 99; (unit 99-C).

109RY; same unit, section 109 ; 1m below the overlying St-Pierre (?) sand.; (unit 109-C).

These sediments are interpreted as distal glacio-lacustrine clay .

VP: clayey silt , of the Pierreville varves , section 98; 30cm under the base of the St-Pierre sand ; (unit 98-A).

VPw: winter laminae of an equivalent sample; proximal glaciolacustrine sediments.

SPl: clayey silt collected 30 cm below the St-Pierre sand , section 59; glaciolacustrine sediments; (unit 59-A).

VDw: clayey silt from the Deschaillons Formation; section 400; winter laminae of a sample collected 2m under the first deformations, in the middle part of the unit; (unit 400-B).

The presumed age of this last sample is younger than 70 ka if unit 400-B overlies true St-Pierre Sediments or older if unit 400-B is correlated with 59-A.

4.4.2 TL characteristics of the samples

This program used the fine-grain technique in which was separated the 4-11 μm fraction of the samples. The carbonates were removed by a dilute HCl treatment. The resulting samples were composed of quartz and feldspars, mainly, with minor amount of amphibole, chlorite and illite. Typical glow curves are shown in Figure 4-6. It shows two natural peaks centered at 240^{0}C and 320^{0}C (heating rate: 3^{0}C/s). A hydrofluosilicic treatment, described in Berger and Huntley (1982), isolated the quartz fraction in sample RS. This fraction yields a single peak at 320-330^{0}C, with low light intensity (Fig. 4-6). Feldspars are therefore the chief source of the TL. This has important consequence since this mineral may show anomalous fading (see next section).

A growth curve generated on the LP sample (≈10ka; Fig. 4-7) showed that the growth of the TL in these sediments is best approximated by an exponential or a quadratic best-fit curve; the TL accumulates in traps in an almost linear fashion at low doses and gradually flattens at high doses. Apparently, traps of the polymineralic fraction of this sample were not saturated even after addition of an artificial irradiation of 1500 grays. Therefore, assuming a dose-rate of 4 grays/ka and providing a precise knowledge of the growth curve, apparent TL dates of over 400,000 years should be possible in this particular geological context.

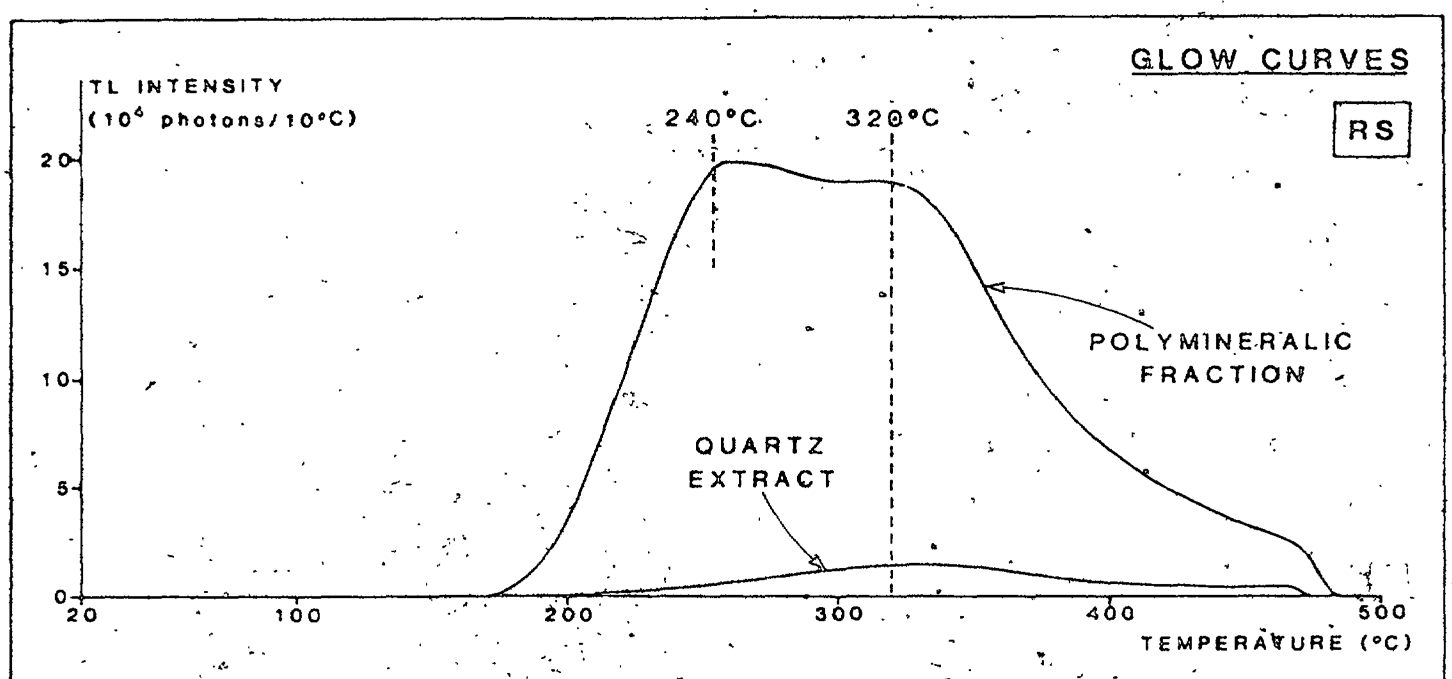


FIGURE 4-6: Typical glow curves for the 4-11 μm fraction.

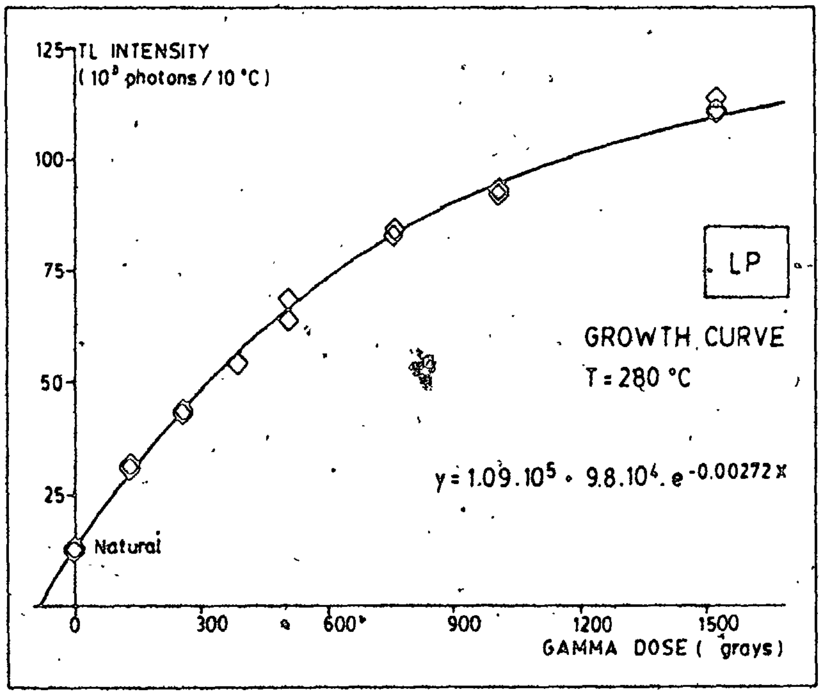


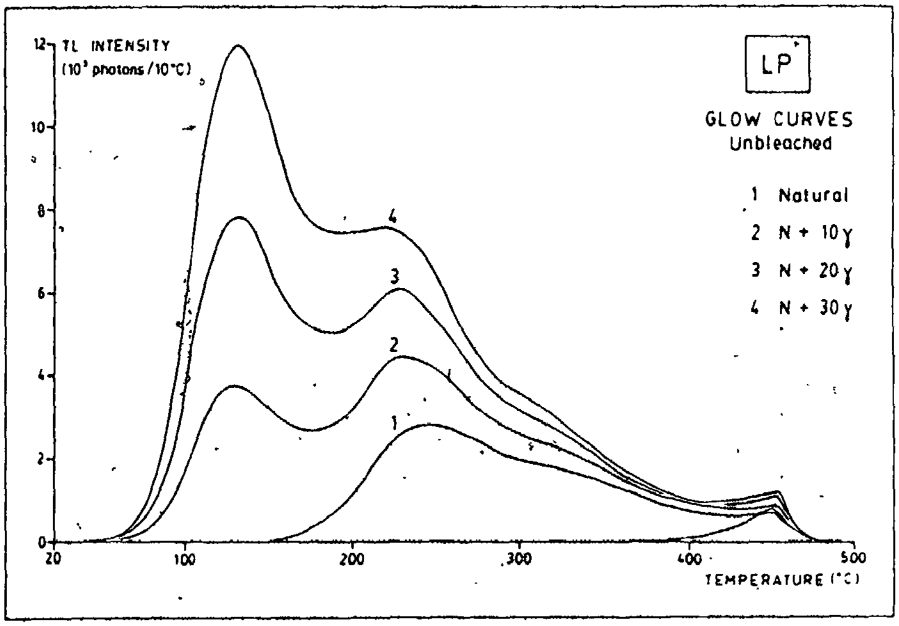
FIGURE 4-7: Representative growth curve generated on the LP sample.

4.4.3 Determination of the equivalent dose: the problem of anomalous fading.

The equivalent dose was obtained using the R-Gamma method. Backward extrapolation of the unbleached growth curve was achieved through an exponential best-fit program devised at the laboratory (Fig. 4-8 and 4-9). However, because of processing limitations, the quadratic best-fit had to be used for sample VP. It was found that both types of extrapolation gave the same result within one standard-deviation. The bleached growth curve was approximated by a linear best-fit.

All the samples measured in this test program yielded good plateaus (Fig. 4-10). The condition of thermal stability of the electrons in the traps is consequently met. Nevertheless, anomalous fading tests carried over 6 to 8 weeks showed a decrease of the TL signal during storage (Table 4-3 and 4-4). Unfortunately, this problem became apparent after most of the samples had been glowed since anomalous fading tests are routinely ran after the ED measurements. The ED of such a sample is therefore lower than the true equivalent dose. A delayed measurement approach was sought to solve this problem.

An anomalous fading test (AF) compares TL emitted by two sets of the same sample which were irradiated at different times before measurements (Fig. 4-11). There is no anomalous fading if the TL emitted by the two sets is the same. It was shown by Wintle (1977) that part of the curve of anomalous TL loss in feldspars is logarithmic. Visocekas (1979), by graphically compiling fading data for various minerals, showed that the TL losses for these minerals are directly proportional to the logarithm of the time elapsed since irradiation. These studies were carried on individual minerals. Wintle (1978) suggested that since TL in fine-grains derives from a number of minerals, it is to be expected



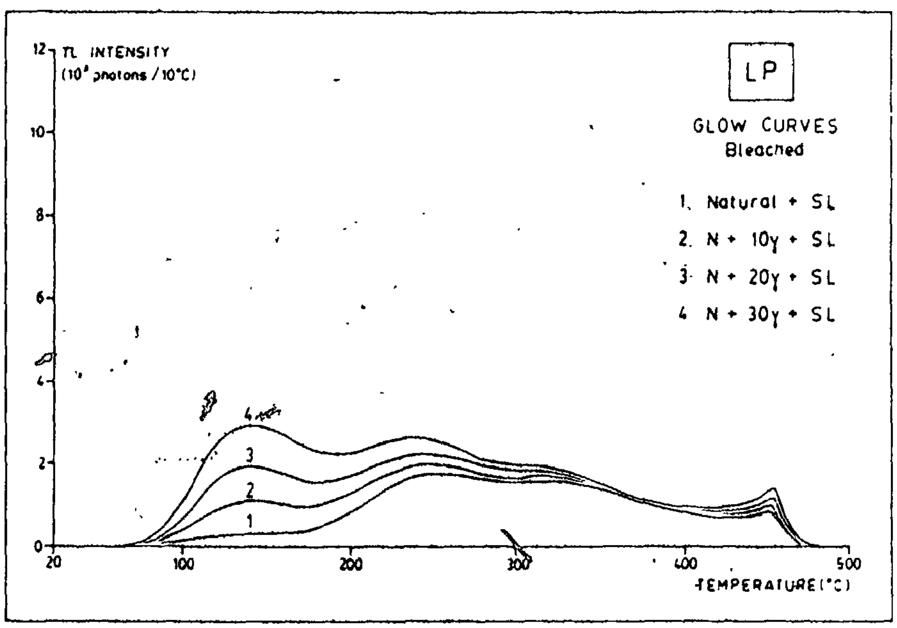


FIGURE 4-8: Unbleached and bleached growth curves for natural and irradiated samples.

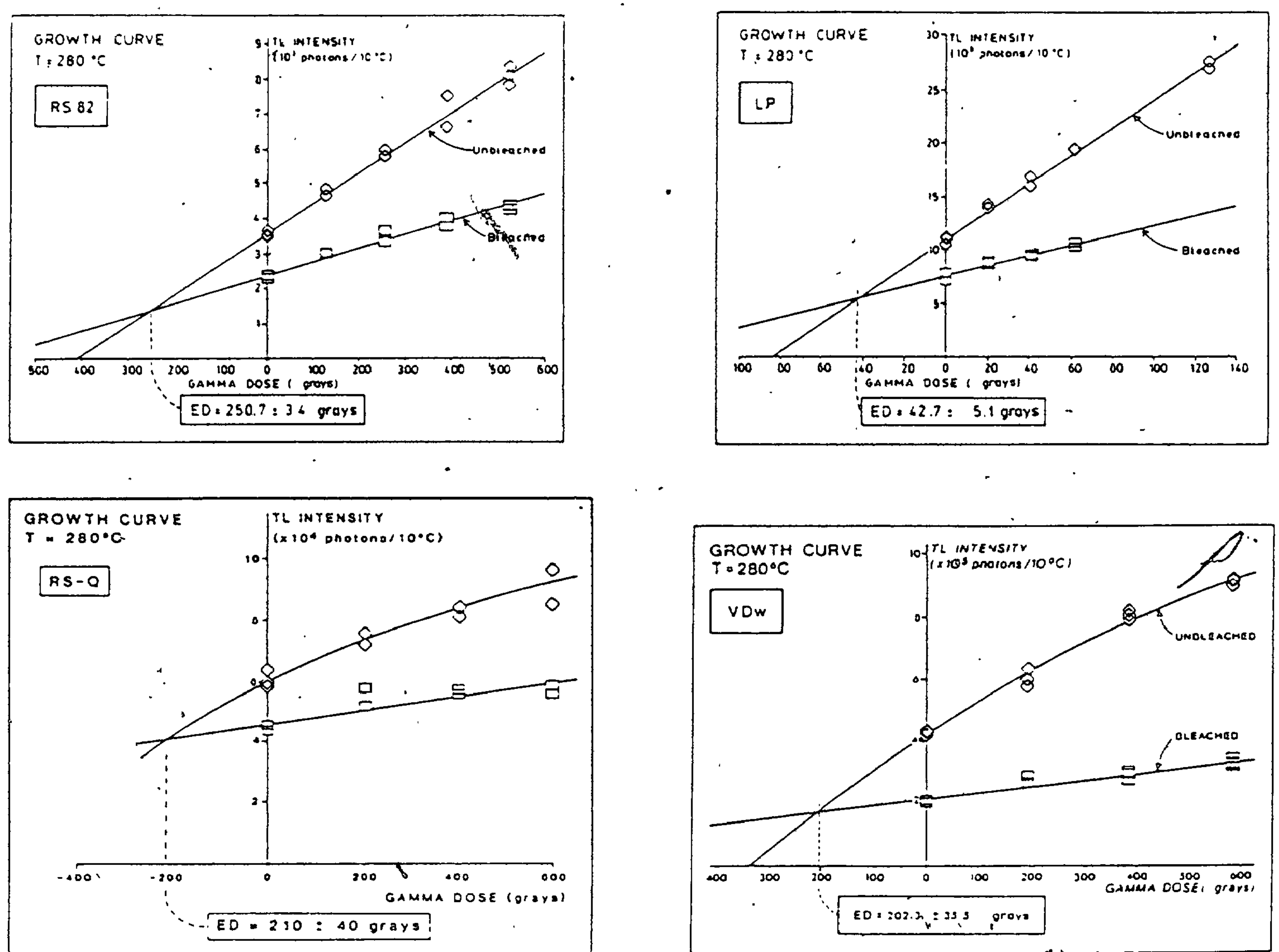


FIGURE 4-9: Suite of growth curves, at 280^{0}C.

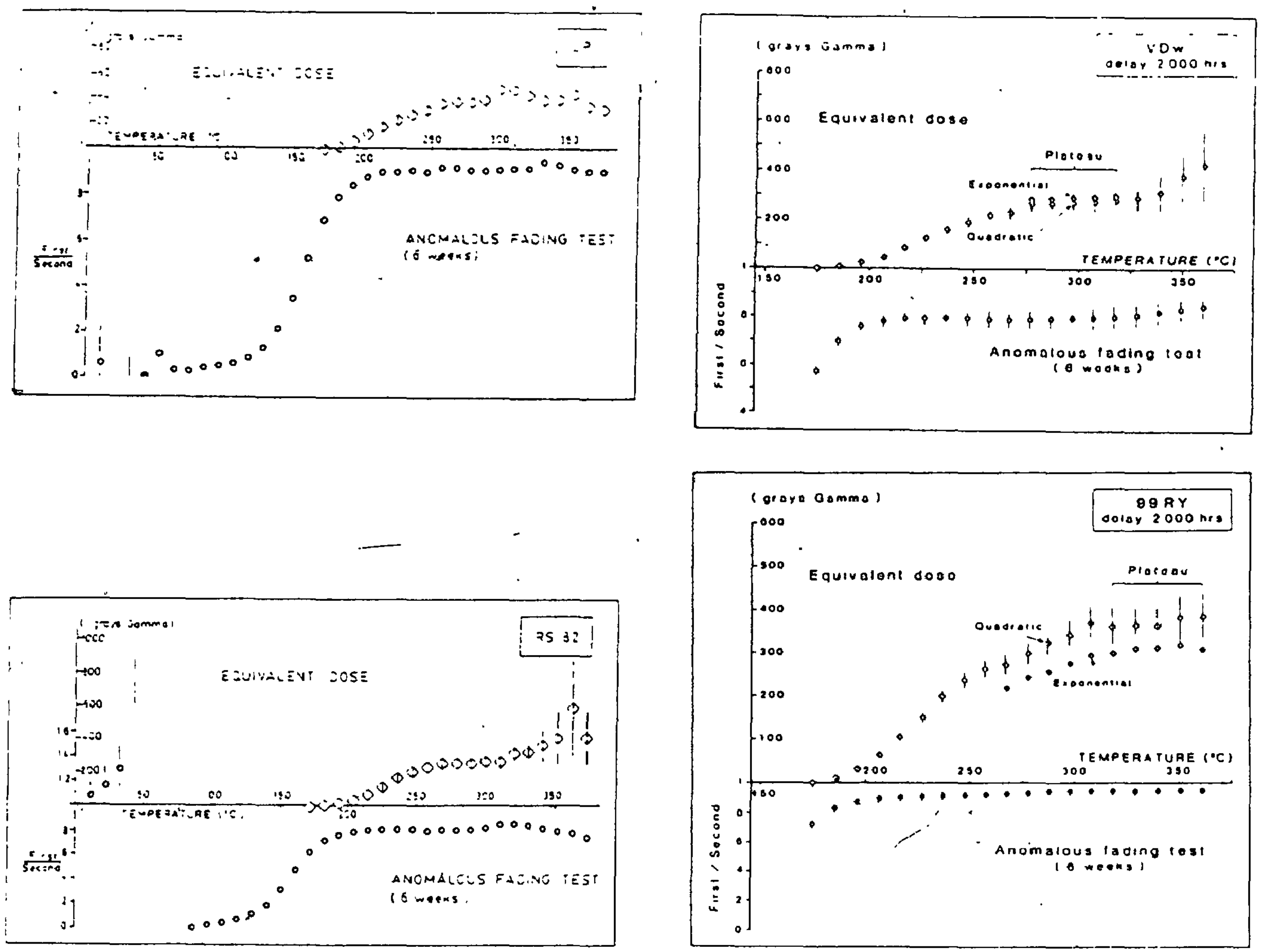


FIGURE 4-10: Equivalent doses and plateaus of selected samples.

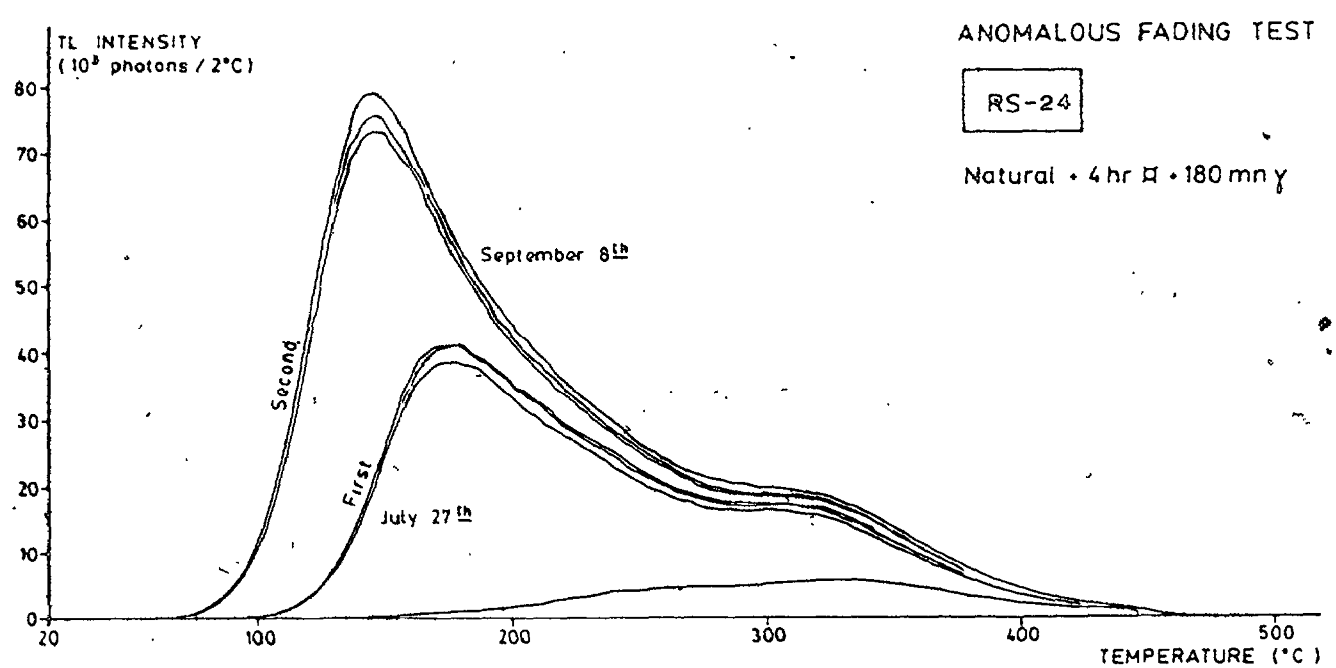


FIGURE 4-11: Glow curves used for the anomalous fading test.

that the anomalous fading may be caused by only a very small fraction of the grains which fades badly. With this in mind, some of the units were resampled and the measurement of their equivalent dose was delayed for three months after irradiation. The purpose was to store the samples until cessation of fading and then obtain an apparent TL age on the non-fading component of the polymineralic assemblage. Results obtained on the suite of interstadial sediments from the Pierreville area are described below.

A total of 6 apparent TL ages was obtained on the 4 to 11 μm fraction of these samples which had been stored for different periods of time. Samples RS-2, RS-Q, and SP-2 were glowed approximately 2 hours after irradiation. This delay is an average since the glowing of unbleached irradiated discs takes about one hour. Samples RS-24 and SS-24 were glowed one day after irradiation. Sample RS-2000 was glowed twelve weeks after irradiation. Sample RS-Q is the quartz extract of RS.

The apparent TL ages obtained are listed in Table 4-3 and shown on Figure 4-12.

Anomalous fading tests were carried out for periods of 2, 71, 163, 1000, and 2000 hours for sample RS. Because of practical limitations, TL losses have to be compared to an initial "first glow set of discs" which was measured approximately 20 minutes after irradiation.

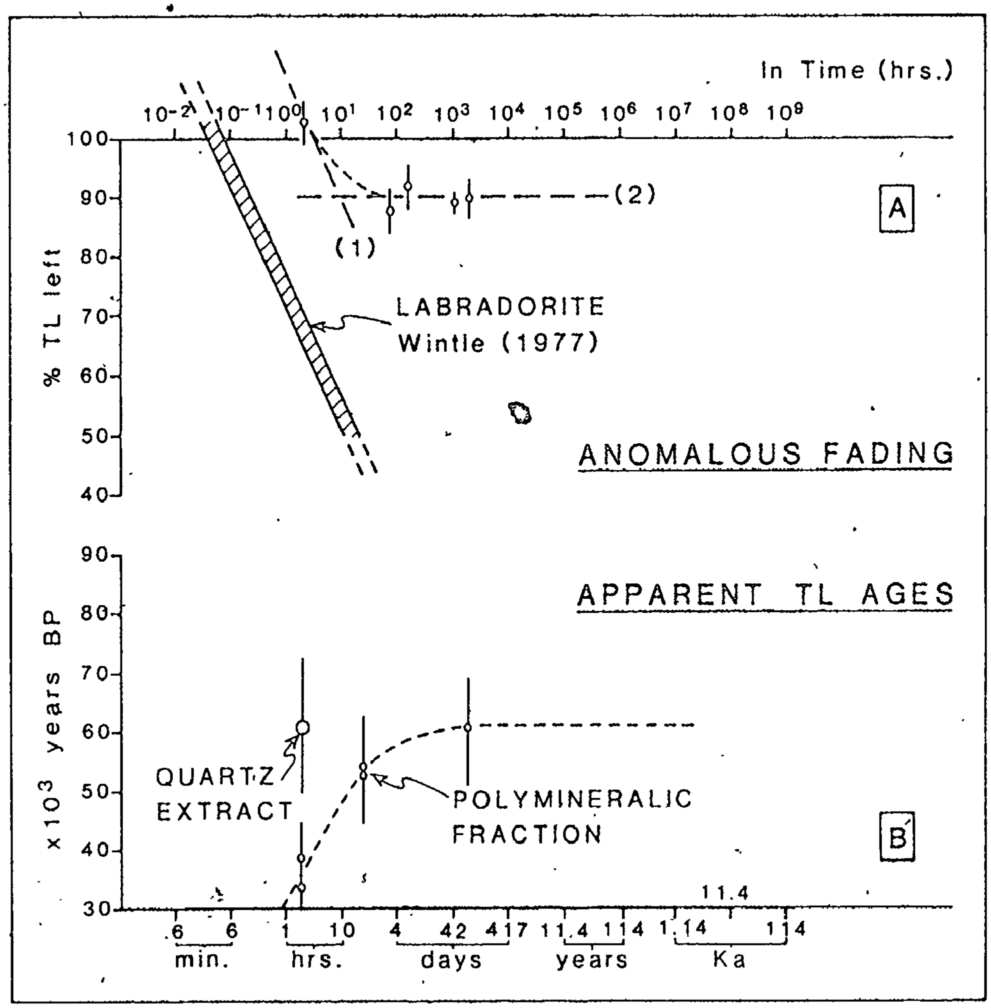


FIGURE 4-12: Anomalous fading and apparent TL ages for the suite of interstadial sediments , Pierreville area (Lamothe, 1984).

As expected, apparent TL ages increase with storage time. However, the age increment is greater than the TL losses monitored by the anomalous fading test performed on the RS sample. This is probably due to the fact that the TL ages were obtained on different samples which showed slightly different fading. Correcting for the anomalous fading values observed on RS-24 (17% ± 4%; 6 weeks/24 hrs) and SS-24 (16% ± 3%; 6 weeks/24 hrs) would have yielded TL ages in the lower 60 ka range. Although the fading corrected ages agree closely with the RS-2000 apparent TL age, these should not be reported in the literature as finite ages. The polymineralic fraction of sample RS-2000 yielded an apparent TL age of 61.2 ± 9.2 ka when stored for 12 weeks after irradiation. A TL age of 61.1 ± 11.1 ka was obtained for RS-Q. It is generally observed that quartz does not fade (Wintle, 1978; Berger and Huntley, 1982; Divigalpitiya, 1982). The agreement between the ages obtained on quartz and on the delayed polymineralic fraction suggests cessation of fading for this sample. In this study, the emitted TL is dominated by feldspars in all samples whatever the delay, suggesting that some of these feldspars fade badly or that most of them suffer a small short-term TL loss. The first case is believed to be more likely since Wintle (1978) reported that in most case studies, "volcanic" feldspars seem to exhibit this fading behaviour and the "non-volcanic" do not. In Figure 4-12, the fading curve has flattened after approximately three days. This fading curve may be interpreted as a two-component curve, one of which has a slope typical of fading minerals (line 1 on Fig. 4-12). This component is, herein, compared with TL losses measured by Wintle (1977) on a strongly fading laboradorite.

A similar agreement between equivalent doses measured on polymineralic (feldspar dominated) grains and on the quartz extracted from the same sample was also reported by Wintle (1982) during a dating study of loesses. According to her, this agreement confirmed that these feldspars were not subject to anomalous fading. Very recently, delayed measurements were used by Templer (1984) in order to remove anomalous fading in zircon.

Alternative procedures for circumventing anomalous fading in sediments have been proposed where the non-fading components of the original samples were isolated through mineralogical separations (Berger and Huntley, 1982; Mulhern et al., 1981). Quartz and the magnetically susceptible minerals were used to measure the ED. However, these mineral extractions have the following disadvantages: (1) it is believed that the required chemical treatment (e.g., use of $H_2Si_2F_6$ to isolate quartz) may affect the quartz grain surfaces and thus lead to unpredictable TL characteristics; (2) their light output is very low; (3) the TL of quartz saturates at much lower laboratory doses than feldspars (Wintle, 1977, 1982; Berger and Huntley, 1982; Divigalpitiya, 1982) giving rise to non-linear growth curves with error-prone extrapolation to original ED; (4) their extraction is time consuming. This point is important if TL becomes a routine dating technique .

Storage of samples for at least a short period after irradiation has been suggested in the past (Fleming, 1979). However, the introduction of a long delay between irradiation and measurement in this study permitted reporting the first agreement of apparent TL ages between a polymineralic and a quartz extract fraction of a sample which exhibited anomalous fading (Lamothe, 1984).

Since sediments contain a wide variety of minerals, it should be expected that, in most cases, they will show at least short term fading.

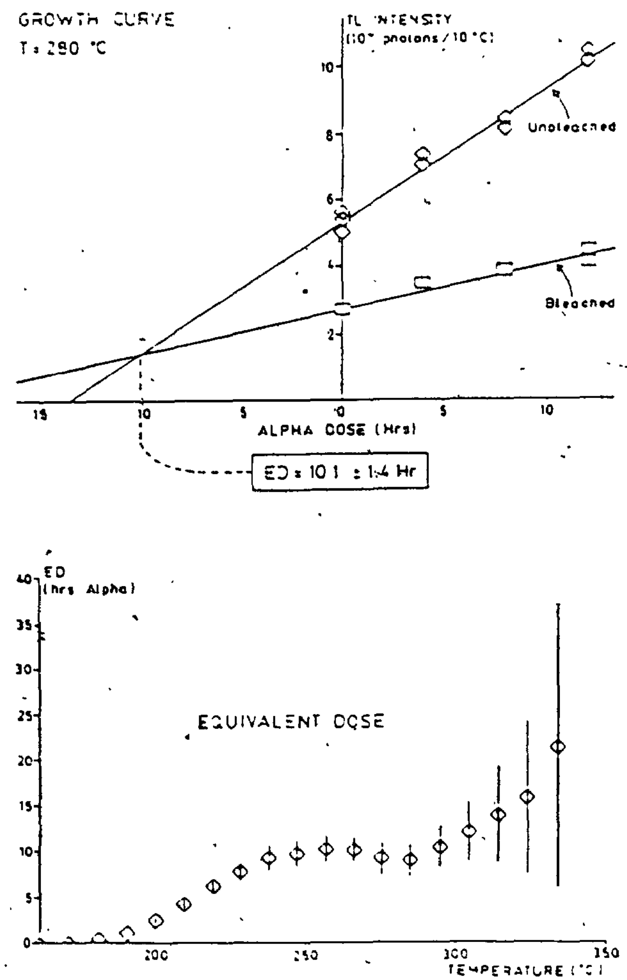
The above case study demonstrates that the TL dates obtained after a 2 hrs delay are too young: they are labelled as "greater than". Dates obtained after a 24 hrs delay are also reported as "greater than" even if, for weakly fading sediments, they may be close to the finite apparent TL age. TL dates obtained after a 12 weeks delay are considered as finite. In the case of VDw, fading exceeded 20% (6 weeks/24 hrs); consequently, the age is reported as "greater than or equal to" (≥).

4.4.4 Determination of the dose-rate: the problem of the water content

Dose-rates are listed on Table 4-2. (1) They range between 3 and 4 grays per/ka with extremes as low as 2.8 and as high as 4.7. In this study, the natural annual dose is largely dominated by potassium. It is fortunate that the determination of this element which contributes to 50% of the total dose-rate is very precise (±.05%). (2) The alpha efficiency factor was measured for 5 samples (using R-α) (Fig. 4-13). The a-value was close to 0.1 and this value was used as an approximation for the other samples. (3) The cosmic dose rate was estimated at 0.14 grays per ka in post-glacial sediments (Wintle, 1981, Prescott and Stephan, 1982) and to half of this value for those sediments which have been under a thick ice-cover for part of their geological history. (4) Radon escape was encountered in many samples.

TABLE 4-2
DOSE-RATES

Sample	K_2O (% ±0.5)	U (per Ks-cm^2)	Th (per Ks-cm^2)	Water content ±25%	a ±10%	Rn escape (%)	Dc	Dose-rate ±10% (mgrays-y^{-1})
LP	2.94	.437 ± .044	.178 ± .042	.41	.143	15 ± 5	.14	3.67
MC-Des	3.86	.395 ± .040	.133 ± .037	.30	.980	7 ± 4	.14	4 05
SP-2	2.58	.310 ± .039	.101 ± .036	.21	.087	-	07	3.06
RS-2	2.91	.342 ± .060	.209 ± .057	.25	.084	-	07	3.55
RS-24	3 07	.253 ± .047	.298 ± .045	.25	.084	no	.07	3.65
SS-24	2.74	.214 ± .045	.269 ± .043	.21	.100	10 ± 5	.07	3.47
RS-2000	3.07	.268 ± .086	.284 ± .082	.25	.084	no	.07	3.61
StP	2.66	.263 ± .040	.168 ± .038	.22	.100	22 ± 4	07	3.17
109RY	3.98	.414 ± .057	.150 ± .053	.44	.114	13 ± 4	.07	3.91
99RY	3.91	.241 ± .033	.277 ± .035	.44	.114	no	.07	3.69
VP	2.70	.238 ± .052	.219 ± .049	.31	.100	-	.07	3.06
VPw	2 34	.167 ± .022	.170 ± .021	.31	.100	-	07	2 53
SP1	3.44	.318 ± .086	.340 ± .082	.34	.100	14 ± 6	07	4 01
VDw	3.98	.259 ± .048	.318 ± .046	.33	.100	13 ± 3	.07	4.27
	(3 52)							



CALCULATION OF THE a VALUE

SAMPLE RS-24 T=280°C

$$a = \frac{\frac{ED\ (\gamma) min}{ED\ (\alpha) min} \times \gamma \text{ dose-rate (grays/min)}}{1300 \times \text{strength } \alpha\text{-source}}$$

$$a = \frac{\frac{119 min}{606 min} \times 2.11 grays/min}{1300 \times 0.38\ \mu m^{-2}\ min^{-1}}$$

$a = 0.084$

FIGURE 4-13: An example of the calculation of the a-value

It is impossible to correct for this. It is tentatively assumed that this waste is counterbalanced by incoming radon from the underlying strata.

When discussing dose-rate evaluations, most authors stress the very limiting aspect of the water content in the samples. This problem can be easily exemplified as following: the apparent TL age of sample 99 RY is 86 ka, given a water content of 44% (average value of the in situ and saturation) as compared to 70 ka for a water content of 33% (in situ value). The estimation of the saturation value is not straightforward in sediments because of the lack of cohesiveness in unconsolidated deposits.

If care is not taken during laboratory saturation of the samples, the sediment may be disturbed. The saturation value is then overestimated. The following procedure was taken to minimize this effect: (1) the samples were collected with a plastic tube gently pushed into the sediment at the section site; (2) they were slowly dried in the oven (75^{o}C during 3 to 4 days; 100^{o}C during a few hours), to obtain the in situ value; (3) samples were, then, stabilized in the tube with corks into which was drilled a 5mm hole; (4) the tube was immersed in water for 3 to 4 days; (5) the cork was removed and the outer part of the sample which could be slightly disturbed was scrapped; (6) the saturated sediment was slowly dried to obtain the saturation value. The resulting in situ and saturation values were then averaged and used in the age equation, since it is expected that these sediments were under ice and therefore saturated during at least half of their geological history.

4.4.5 Apparent TL ages: results and discussion

The apparent TL ages measured on samples from the Central St-Lawrence Lowland are listed in Tables 4-3 and 4-4. They range from 4 to 135 ka. They have been tabled according (1) to the sampling area and (2) to the unit in which they were found. Apart from the modern samples, it should be mentioned that among 17 TL ages, 5 finite apparent TL ages were obtained. The TL dates presented herein carry large uncertainties which are mainly due to the estimation of the past water content (±25%).

Wintly and Huntley (1982) proposed criteria to be met before giving a geological significance to TL dates on sediments. They are listed in Table 4-5. Plateaus, anomalous fading, a value and non-linearity of the TL growth curve (herein, at high doses) have been discussed in preceding sections. Zeroing of modern and older sediments is discussed below.

Criterion 1: *modern:* CCTO: this silt, collected from the actual beach, gave an apparent TL age of 7 ka. CLTO: these were collected in the St-Lawrence River water; they yielded a slightly younger age of 4-5 ka. Theoretically, these samples should give a zero age. However, it seems that whether some of the grains may not have been zeroed or that the sunlamp may have overbleached the grains. Jungner (1983) and Huntley (1984) have proposed that, in some cases, the central part of these silts aggregates would not be exposed to sunlight and would therefore give a discrete "sedimentary" TL signal. Sample CCTO was collected on a sandy and gravelly beach. These silt grains were probably transported in water and sedimented with the sand grains as lumps. In this sample, the lumps can be observed under the binocular.

TABLE 4-3

APPARENT THERMOLUMINESCENCE AGES
PIERREVILLE

Sample (unit)	Sunlamp (hrs) (filter 052)	Fading (% TL left)	Delay (hrs)	ED (grays)	Dose-rate (mgrays-y^{-1}) (±10%)	Apparent TL age (ka)
late-glacial						
LP (99-G)	2.0	.93 ± .04	24	38.0 ± 4.0	3.67	> 10.3 ± 1.7
interstadial						
SP-2 (98-B)	2.0	.95 ± .03	2	105.0 ± 13.0	3.06	> 34.3 ± 5.5
RS-2 (98-D)	4.0	.90 ± .04	2	137.0 ± 14.0	3.55	> 38.6 ± 5.4
RS-24 (")	1.0	.83 ± .04	24	196.0 ± 22.0	3.65	≥ 53.7 ± 8.1
SS-24 (99-E)	1.0	.84 ± .03	24	184.0 ± 20.0	3.47	≥ 52.9 ± 7.9
RS-Q (98-D)	1.5	–	2	217.0 ± 33.0	3.55	61.2 ± 11.0
RS-2000 (")	2.0	no	2000	220.0 ± 24.0	3.61	61.1 ± 9.2
stadial						
99RY (99-C)	2.0	.92 ± .04	24	267.0 ± 37.0	3.69	≥ 72.3 ± 12.3
99RYdel. (")	2.0	no	2000	318.0 ± 54.0	3.69	86.3 ± 17.0
109RY (109-C)	1.0	.95 ± .03	2	300.0 ± 51.0	3.91	≥ 76.7 ± 15.0
VP (98-A)	1.0	.92 ± .03	2	251.0 ± 38.0	3.06	> 82.0 ± 15.0
VPw (")	4.0	no	48	341.0 ± 64.0	2.53	135.0 ± 26.0

TABLE 4-4

APPARENT THERMOLUMINESCENCE AGES

ST-PIERRE

Sample (unit)	Sunlamp (hrs) (filter 052)	Fading (% TL left)	Delay (hrs)	ED (grays)	Dose-rate (mgrays-y^{-1}) (± 10%)	Apparent TL age (ka)
modern						
CLTO	2.0	-	-	18.9 ± 4.4	≃ 4.00	4.7 ± 0.9
	0.5	-	-	15.2 ± 3.4	≃ 4.00	3.8 ± 0.8
CCTO	2.0	-	-	27.7 ± 10.0	≃ 4.00	6.9 ± 2.6
late-glacial						
MC-Des	2.0	still 5% ?	48	63.5 ± 7.6	4.05	⩾ 15.7 ± 3.0
interstadial						
StP (58-B)	2.0	no	2000	87.8 ± 10.6	3.17	27.7 ± 4.3
stadial						
VDw (400-B)	4.0	.79 ± .05	24	192.0 ± 24.0	4.27	> 45.0 ± 8.0
VDwdel. (")	2.0	still 10% ?	2000	297.0 ± 34.0	4.27	⩾ 69.5 ± 10.5
SP1 (59-A)	2.0	.80 ± .02	24	240.0 ± 27.4	4.01	> 59.8 ± 9.0

TABLE 4-5

PROPOSED CRITERIA FOR JUDGING TL DATES OF SEDIMENT
(from Wintle and Huntley, 1982)

1) For each type of material and method used on it, the method should have been shown to yield zero age for recently deposited material.

2) For the type of material and the method used, the method should have been shown to give correct ages for at least three suites of samples for which reliable ages have been determined independently. These should cover the time span in question.

3) The results of a number of tests which have been found necessary should be reported. These include, but are not limited to, in order of importance:
   a) plateau test,
   b) anomalous fading test,
   c) alpha-effectiveness value and
   d) test for non-linearity at low doses.

During the initial preparation of the bulk sample, prior to settling on the aluminum discs, the grain-size segregation frees these inner silts which are then exposed to the sunlamp. The CLTO, sampled in the river itself, at a water depth of 1 m, yielded a smaller ED suggesting that recycling of these grains may lower the ED progressively. The length of sunlamp exposure affects also the ED value since a 30 minutes exposure decreases this malign ED by 20% when compared to the standard 2 hours exposure (see Table 4-3). As suggested by G. Berger (1984, personal communication), the use of the 052 filter may lead to a slight "overbleach". These two samples were originally derived from sediments exposed in the Cap Lévrard and Cap Charles cliffs, that are 70 ka old or more.

It is believed that these data do not disprove the other results for the following reasons: 1) in the other samples, the silt grains were probably all deflocculated at the time of sedimentation since most of them are of marine or lacustrine origin; 2) this inherited TL is barely significant for old samples; and 3) most of the other samples showed a good agreement between the TL age and the expected age.

Criterion 2:*Late-glacial:* LP: this sample comes from a marine unit with very few fossils, suggesting a ^{14}C age range of 12500 to 9500 years BP. The most probable age of this unit is ≃11 ka. The apparent TL age of >10.3 ±1.7ka is therefore geologically reasonable and demonstrates that, in the case of weakly fading sediments, the TL age may be close to the true age.

MC-Des: the apparent TL age of ≥15.7 ka ± 3.0 is 4 ka older than the ^{14}C age obtained on the *Balanus* (UQ-651: 11 130 ± 180 years BP), a value comparing with the apparent TL age of the modern river silt CLTO, suggesting that "overbleaching" may be responsible for the inherited TL. It should be noted here that considering this ^{14}C age, this body of massive clay has been sedimented under a water depth of at least 150 m which should have prevented these grains from being exposed to sunlight. They nevertheless, have been. However, the delay of 48 hrs may not have been sufficient since a faint fading (≈5%) has been measured on the 2000 hrs/48 hrs AF test. This complicates the interpretation.

Interstadial: The apparent TL ages obtained on the St-Pierre suite (SS, RS, and SP), exposed at Pierreville, have been discussed briefly before, in the section 4.4.3.

The lacustrine member of the St-Pierre Sediments (RS) is dated by thermoluminescence at 61.1 ± 9.2 ka. This result has to be compared with the radiocarbon ages obtained on pieces of wood collected from the peat layer. This TL date agrees with the finite ^{14}C date measured by DeVries (66.5 ± 1.6 ka; GrN-1711; Vogel and Waterbolk, 1972). However, dates obtained before 1967 may have to be disregarded since, according to Grootes, contamination was present in the Groningen laboratory during these first years. The ^{14}C date of 74,700 $^{+2700}_{-2000}$ years BP (QL-198) and the TL date are believed to be coherent since (1) ^{14}C years do not necessarily equate calendar years because of possible fluctuations in the original ^{14}C concentration in the atmosphere; (2) the peat layer may well represent 3 to 5,000 years of sedimentation (Terasmae, 1958); and (3) the large uncertainties still carried by the TL dates may themselves account for the difference.

In the St-Pierre area, sample StP, collected in unit 5B-B, yielded a TL age of 27.7 ± 4.3 ka. This age is considered as possible even if it is much younger than the underlying peat layers. Their ^{14}C age should be in the 60 ka range. So far, only one finite ^{14}C date has been reported (67.7 ± 1.3 ka; GrN-1799; Vogel and Waterbolk, 1972). The TL sample was collected in silts overlying the uppermost peat layer. A lacuna betweenthe peat and these silts cannot be demonstrated but may exist.

The possibility exists that these silts may have been zeroed at the end of the interstadial whose age is still a matter of controversy. The apparent TL age of this sample can be explained by this hypothesis: If the TL age and the ^{14}C dates are significant, the St-Pierre peat bearing sediments of the type-section would represent 30 to 40 ka The upper part of the sequence would be 30 ka old or would have been zeroed at that moment by exposure to sunlight or by pedogenesis. This process is responsible for the bleaching of TL in the upper horizons of modern soils (Huntley et al.,1983).

From the above discussion, it can be concluded that the apparent TL dates reported for modern, late-glacial and interstadial sediments are in relatively good agreement with the stratigraphic evidence . The "zeroing error" of 4 ka could hardly be applied to older sediments since it is geologically not significant.

This TL dating program meets most of the criteria listed by Wintle and Huntley (1982). It is therefore suggested that the apparent TL ages measured on the stadial sediments, which are pre-St-Pierre, should be geologically significant, particularly if one takes into consideration the large uncertainties attached to these numbers.

Samples 99RY, SP1 and VDw yielded apparent TL ages in the order of 70 to 85 ka, that is early Wisconsinan. Since these TL ages are close to but still slightly higher than the TL ages obtained on St-Pierre sediments, zeroing before sedimentation must have taken place.

Unit 59-A seems therefore to correlate with the Deschaillons Formation , as suggested in the Chapter 2, not only in terms of TL age but also in terms of TL behaviour since they also show equal values of anomalous fading and radon escape. This last point deserves attention. If TL is not yet an undisputable absolute chronological method, it may prove, in the future, to be a strong correlation tool.

Samples VP yielded two apparent TL ages, one of which is finite and in the order of 135 ka, that is late Illinoian. Following the discussion in Chapter 2, the lithostratigraphic relationship of 98-A to 99-C and of 98-A to the lower red till cannot be clearly observed. It was proposed that because of their lithological affinity (carbonate content and proximal facies of 98-A), unit 98-A should be related to the retreat of the ice that laid down the red till. The finite apparent TL age of 135 ± 26 ka supports this hypothesis. However, two points need to be mentioned : 1) only one finite date is available; 2) this unit is composed of proximal rhythmites which deposition is commonly quick and follows grains transportation by turbidity currents. Zeroing may have been incomplete.

In conclusion, thermoluminescence dating is promising since it gives, for the first time, preliminary absolute ages for sediments older than the upper limit of the radiocarbon method. It can be performed on detrital grains that are ubiquitous and is not dependent on the presence of fossils or organic matter. However, TL ages reported herein are "apparent". They cannot be compared to calendar years at the present state of knowledge. They are "strictly analytical products" (Odin, 1982) which are believed to date a sedimentation event.

CHAPTER 5

QUATERNARY STRATIGRAPHY IN THE ST-LAWRENCE LOWLAND

The lithostratigraphy and geochronology of the two sub-areas under study have been presented in Chapters 2, 3 and 4. In this chapter, these data are compiled in order to present a complete stratigraphic framework for both areas. As superposition of glacial and non-glacial lithostratigraphic units suggests changes in geologic environments, the correlation between the two areas has to be based on geologic-events referred to as stadials and interstadials.

This section also proposes a new stratigraphic nomenclature which tries (1) to preserve the existing formal names; (2) to restrict the use of genetic names and (3) to eliminate the lithostratigraphic units which, at this point, have equivocal stratigraphic positions. In terms of stratigraphic terminology, the use of genetic terms in naming lithostratigraphic units should be avoided because these units are defined on the basis of objective lithologic characteristics. It is proposed to remove from the nomenclature terms such as Tills and Varves and use Formation throughout. This nomenclature is actually a working hypothesis. Indeed, its formalization will have to be done through a scientific medium and it is hoped that the arguments on which it is based are improved during further work.

A striking feature of the St-Lawrence Lowland stratigraphy is the importance, in terms of lithosomes of glaciolacustrine sediments, particularly in the St-Pierre Les Becquets area. In consequence, a brief review of their geologic characteristics precedes the stratigraphic discussion.

5.1 Glaciolacustrine sediments in the St-Lawrence Lowland

Gadd (1971) suggested that 4 distinct glaciolacustrine episodes are recorded in the Lowland; they are based on the existence of (1) Pre-Becancour Till silt ; (2) Post-Becancour Till silt ; (3) Pre-Gentilly Deschaillons varved sediments and (4) Post-Gentilly Till silt . In this scheme, group (1) is represented by the Cap Levrard varves e.g. unit 60-C; group (2) by the Pierreville Varves e.g. units 98-A and 99-C; group (3) by the Deschaillons Varves e.g. unit 400-B; they are correlated to the "Gray Varves" of Gadd (1955) e.g. unit 58-C; group (4) includes varved sediments grading into Champlain Sea sediments; these were not considered in this investigation.

Table 5-1 lists all the available data for the glaciolacustrine units investigated . Some important aspects are stressed below:

(1) The stratigraphic position of the following units is unequivocal with respect to St-Pierre: 98-A, 99-C and 59-A are older, 58-C is younger. Unit 400-B overlies sand in which pieces of wood were found.

(2) The number of couplets differs largely but 99-C and 400-B have comparable number of approximately 2,500 couplets.

(3) Concretions dated at 35 ka are found in 99-C, 98-A, 59-A, 400-B and 60-A

(4) In terms of facies, type III varves (Ashley, 1975) are common in units 58-C and 98-A.

TABLE 5-1 SELECTED CHARACTERISTICS OF THE GLACIOLACUSTRINE UNITS

UNIT	99 C	98 A	58 C	59-A	400-B
TEXTURE (clay/ clay and silt)	> 50%	< 50%	< 50%	< 50%	< 50%
CLAY LAMINAE	2000 2500	235	1100	500 (?)	2000-3000
COUPLET THICKNESS (cm)	1 - 1	3 - 6	3 - 30	2 - 1	.3 - 2
CARBONATE (%)	0 - 4	7 - 12	0 5	0 - 2	0 - 6
CLASSIFICATION (Ashley, 1975)	I II	III	II III	II	II
CONCRETION	present	present	none	present	present
APPARENT TL AGE (ka)	86	135	< 28	> 60	≥ 70
STRATIGRAPHIC RELATION TO ST-PIERRE	under	under	over	under	?

(5) Except for 98-A, the carbonate content is low.

(6) Apparent TL ages of 59-A, 99-C and 400-B are in the range of 60 to 86 ka. 58-C is younger than 78 ka. 98-A is tentatively dated at 135 ka.

(7) At section 60, unit 400-B is overlain by a pinkish till that was correlated with the Bécancour Till. The same is true for 59-A. At the type-section, unit 400-B is overlain by a layer of sand and a grey till. 58-C is mostly covered by marine deposits. Unit 98-A overlies a local sandy brick-red till as well as 99-C.

From this, it is proposed that a major early Wisconsinan glaciolacustrine *event* is recorded in the Lowland. It would be represented by the concretion-bearing units 99-C, 59-A and 400-B.

Units 400-B and 99-C show indeed many common characteristics and should be correlated However, unit 400-B, the Deschaillons Varves, has been traditionally considered as younger than the St-Pierre Sediments. This is based on the correlation of the underlying sand (Unit 400-A) from which pieces of wood were excavated by Gadd (1955), with the St-Pierre Sediments exposed at the type-section (e.g. section 58). This study however reveals that a pre-St-Pierre assignation for 400-A and 400-B is more probable. However, the arguments presented in this investigation are not yet conclusive. Consequently, the stratigraphic position of the Deschaillons Varves is considered *equivocal* and the name should be removed from the current stratigraphic nomenclature. This discussion will be carried further in section 5.3.

5.2 Stratigraphy of the Pierreville area

The superposition and geochronology of the lithostratigraphic units of this area is compiled in Figure 5.1.

The lower red till was originally defined as the Bécancour Till by Gadd (1960; 1971) since it is the oldest glacial sediment of this area. However, the type-section of the Bécancour Till (section 21 of Gadd, 1955, 1960, 1971) is located 40km northeastward from Pierreville. This section is not dated and correlation can only be tentative. Therefore, a local name for this brick red till at Rivière aux Vaches is proposed : *Odanak Formation*. This name comes from an indian village located 2 km west of Pierreville. This till is at least older than 86 ka (±17) and possibly 135 ka (±26). Where observed, its upper surface is erosional and in sharp contact with the overlying varves. It is also highly compacted. Therefore, it is believed that this till is most probably Illinoian.

Overlying the Odanak Formation, varved silt and clay formerly referred as the Pierreville Varves by Gadd (1971) are divided in two different units. Unit 98-A should be known as the *Pierreville Formation* because they were first described by Terasmae (1958) at the Pierreville section 98. The age of these glaciolacustrine sediments is at least early Wisconsinan (>82 ka± 5) and possibly late Illinoian (135 ka ±26), in which case they would be associated to the underlying till. Unit 99-C should be differentiated from the Pierreville Formation for reasons discussed in Chapter 2. The name *Rivière aux Vaches*

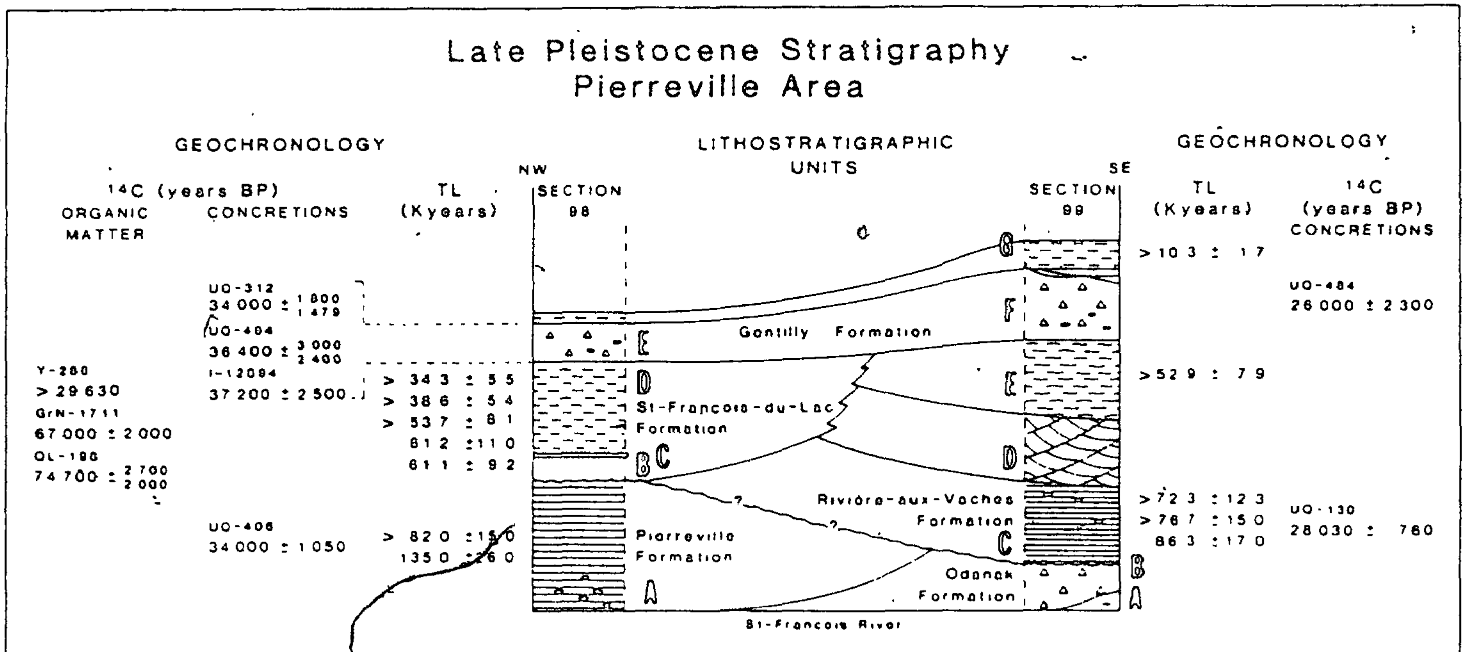


FIGURE 5-1: Late Pleistocene stratigraphy of the Pierreville area.

Formation is proposed because they are well exposed at the junction of this river with the St-François River. This formation is early Wisconsinan.

Non-glacial units 98-B, C and D and 99-D and E were named St-Pierre Sediments by Gadd (1971). St-Pierre should not be used as a formal lithostratigraphic name since it has been used as a geologic-climate unit for now more than three decades (Dreimanis and Karrow, 1972; Terasmae, 1958; Karrow, 1984b). The formal name proposed, herein, is *St-François du Lac Formation*. The age of these sediments is approximately 60 ka, that is early to middle Wisconsinan. The reader is referred to section 5.4 for a more complete discussion on the age of the corresponding geologic event.

Finally, the upper grey and reddish brown tills (units 98-E, 99-F) are younger than the underlying sediment dated at 60 ka and probably younger than the incorporated striated concretions dated at 35 ka. These tills are probably late Wisconsinan . They are included in the *Gentilly Formation*.

At least three and possibly four geologic events are recorded in this area. They are numbered from top to base in order to be easier to compare with the oceanic stratigraphy (Fig. 5-3).

The Gentilly Formation has been deposited during the *Trois-Rivières Stadial* (Occhietti, 1980), that is Stade I. The St-François du Lac Formation was sedimented during the *St-Pierre Interstadial* (Gadd, 1955), that is Interstade A. The Rivières aux Vaches Formation are glaciolacustrine sediments deposited during an Early Wisconsinan ice advance, Stade II that is herein considered as the *Nicolet*

Stadial (Dreimanis and Karrow, 1972). The Odanak Formation has been deposited during an ice advance that may be much older than the subsequent one. It is proposed to name this glacial event, Stade III, the *St-Lawrence Stadial*. Depending on the importance of the hiatus between the Odanak and Rivières aux Vaches formations, the two stadials may represent two different ice advances or Stade II could reflect a minor fluctuation of the ice that deposited the lower till (99-B). In other words, Stade III may represent a full glacial event and Stade II a late-glacial event. If the Pierreville Formation is indeed related to the lower till and was deposited during the St-Lawrence Stadial, an important hiatus separates these two stadials. If the Pierreville Formation is related to the Nicolet Stadial, the finite apparent TL age of 135 ka would be disproved and the true age of the lower red till would remain unknown. The stratigraphic position of the Pierreville Formation is *equivocal*.

5.3 Stratigraphy of the St-Pierre Les Becquets area

The proposed stratigraphic succession and the geochronology of the Quaternary sediments exposed in this area are presented on Figure 5-2.

Following the discussion in section 5.1, the stratigraphic position of unit 400-B, e.g. the Deschaillons Formation, is *equivocal*. Consequently, it is proposed that, in a first step, only the superposition exposed in the vicinity of the St-Pierre type-section

LATE PLEISTOCENE STRATIGRAPHY

St-Pierre-les-Becquets Area

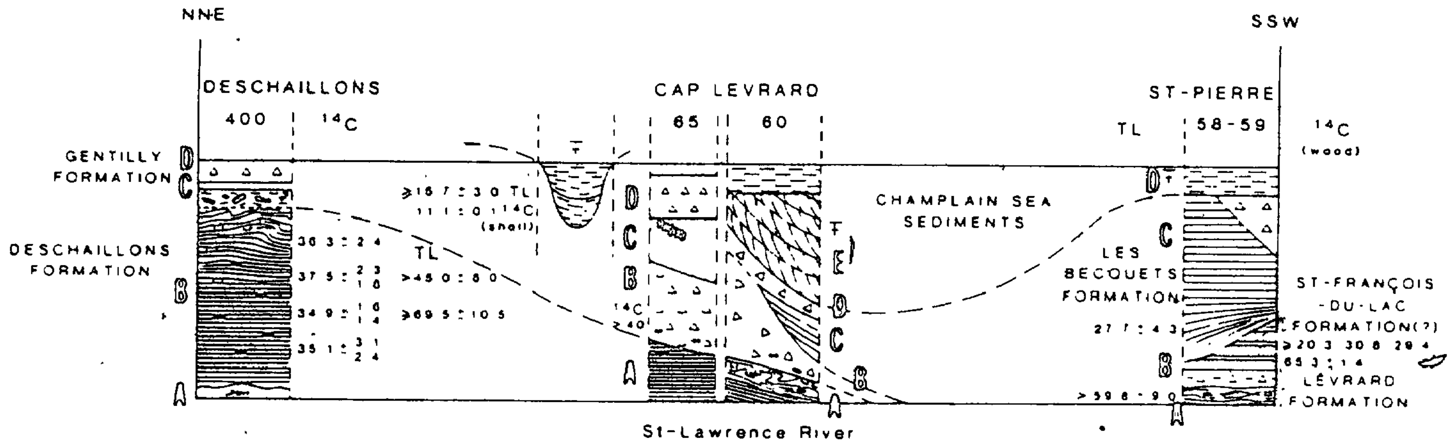


FIGURE 5-2: Late Pleistocene stratigraphy of the St-Pierre les Becquets area.

should be considered.

The lower sediments are glaciolacustrine sediments (59-A) capped by a red till that was described by Gadd (1955, 1971), but not observed during this investigation. It is strongly believed by this writer that the correlation of unit 59-A and the associated till with the units exposed at the bottom of the Cap Levrard sections (60 A-B ; 64 A-B) is highly probable. This correlation was proposed by Gadd (1955, 1971), who also demonstrated that the reddish varves--red till superposition is common in the Lowland. However, the best exposed sample is at Cap Levrard. It is therefore proposed to name this assemblage, the *Levrard Formation*. The age of this formation is early Wisconsinan. Correlation of this pinkish till with Bécancour till cannot be demonstrated.

The peat-bearing silt and sand of the type-section (unit 58-B) have been known as the St-Pierre Sands (Gadd, 1955) and St-Pierre Sediments (Gadd, 1971). Following the discussion in 5.2, it is felt that another name should be given to these sediments. Since (1) the correlation with the St-François du Lac Formation is undoubtful (see next section) and (2) proliferation of new names should be avoided as far as possible (Hedberg, 1976), it is tentatively proposed that the unit 58-B should also be part of this formation.

The upper grey till, not present at the type-section but intensively exposed in the area as the surficial till, is the *Gentilly Till*.

Unit 58-C has been traditionally considered by most workers in Quaternary stratigraphy as the Deschaillons Varves or the

Deschaillons Formation. However:

(1) the Deschaillons Formation *sensu stricto* is defined as glaciolacustrine sediments exposed at the Deschaillons brickyard.

(2) Correlation of these sediments with the glaciolacustrine sediments overlying the peat-bearing sediments at the St-Pierre type-section ("Gray Varves" of Gadd, 1955) was based on (a) the assumption that these units were in lithologic continuity or could be "walked out" in the sense of Krumbein and Sloss (1963; p. 339); as demonstrated in section 2.2.4, this assumption is not valid; and (b) the correlation of the lower *wood-bearing* sand at the brickyard (unit 400-A) with unit 58-B; these pieces of wood cannot be dated at the moment and may have been the witnesses of a much older non-glacial episode.

(3) Over much of the distance along which they can be traced, the "Gray Varves" are *not* capped by a true lodgment till which would suggest full glaciation. Therefore, a new name has to be given to this unit in order to remove confusion. *Les Becquets Formation* is proposed. It may be younger than 28 ka and may even be late-glacial.

Geologic-events recorded in this area are: (1) Stade I, the Trois-Rivières Stadial represented by the Gentilly Formation and possibly by Les Becquets Formation; (2) Interstade A, the St-Pierre Interstadial represented by the St-François du Lac Formation; (3) Stade II, the Nicolet Stadial represented by the Lévrard Formation.

5.4 Correlation across the St-Wenceslas Ridge

The sediments described above have been deposited in two negative areas, in terms of structure countour e.g. the Batiscan and Yamachiche Basins (Fig. 1-4). There is no possibility of tracing any of the lithostratigraphic units across the St-Wenceslas Ridge.

Therefore, the proposed correlation shown on Figure 5-3 is based solely on geologic-events and geochronology.

The correlation is straightforward for the St-Pierre Interstadial as well as the Trois-Rivières Stadial. The ^{14}C dates obtained on the peat layers of both areas are strong evidence for these correlations. An early Wisconsinan glaciolacustrine event is recorded in both areas and is represented by the Rivière aux Vaches and Levrard formation.

The existence of a distinct and older glacial event depends largely on the age of the Deschaillons Formation. Would these sediments be definitely older than the St-Pierre Interstadial sediments, then, the existence of an older non-glacial episode would be recorded by the organic remains found in the basal sand of the Deschaillons Formation. Following the discussion in Section 2.2.4, the presence of a sub-surface till directly superposed on the bedrock is possible and would then represent an Illinoian ice advance to which could correspond the Odanak Formation. This correlation depends on the existence of this sub-surface till. It is felt that such a stratigraphic discussion cannot be carried very far since it now deals with something that was not observed.

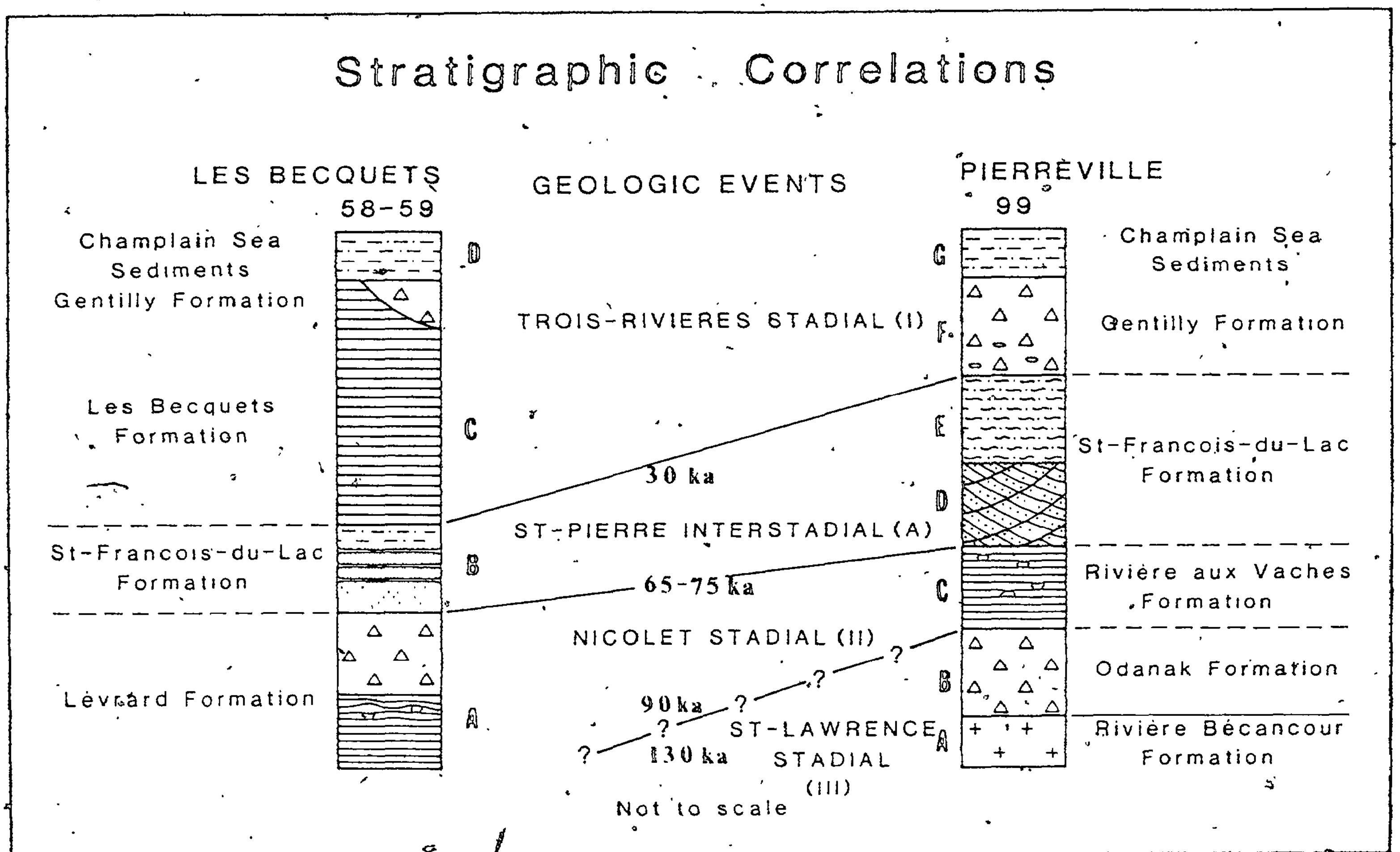


FIGURE 5-3: Suggested correlation between the Pierreville and St-Pierre les Becquets area. Time boundaries are also proposed.

5.5 Chronology of the geologic events

The lower and upper boundaries of the geologic events described above are difficult to ascertain since they are chronostratigraphic units which are imperfectly represented by lithostratigraphic units. It is generally agreed that hiatuses exist in continental sequences but the importance in terms of length of time is disputed.

In this investigation, the radiocarbon and thermoluminescence dating methods yielded a relatively large number of dates with which the geologic events can be bracketted.

(1) 130 ka should be taken as the age of the upper boundary for the St-Lawrence Stadial in the case it represents a truly distinct glacial episode. The possibility of the TL date of 135 ka being an artifact has however to be considered.

(2) the following period, from which apparently no sediments have been described, is probably the last interglacial; its lower limit would be set at 130 ka, its upper limit at approximately 90 ka; the wood fragments found at the base of the Deschaillons Formation may have been the witnesses of the end of the last Interglacial.

(3) the Nicolet Stadial is a geologic event which could be bracketted by the apparent TL age of unit 99-C (86 ka ± 17) and the ^{14}C and apparent TL ages obtained on the St-François du Lac Formation, discussed below.

(4) the oldest date obtained on the St-Pierre woods is the ^{14}C date

of 75 ka (Stuiver et al., 1978). However, the reliability of the ^{14}C dating technique may be questioned, in this range; how close these ^{14}C years are to the calendar years is unknown. Since the apparent TL ages obtained on the St-François du Lac Formation at Pierreville agree closely with the two 65 ka ^{14}C dates already reported by Dreimanis (1960; see also Vogel and Waterbolk, 1972), it is proposed that the lower age of the St-Pierre Interstadial should be between 65 and 75 ka.

The age of the upper limit of this interstadial has become the subject of large disagreement amongst Quaternary stratigraphers in northeastern America, basically because it has important implications in the estimation of the extent of the last ice sheet in middle Wisconsinan time over Eastern Canada.

In the Traditional Concept, the St-Lawrence Valley has been occupied by ice from 66 ka (BP) to 13 ka (BP). This is still based on (1) the assumption that, at the Deschaillons brickyard, the underlying sand is part of the St-Pierre sequence and grades conformably into superjacent varves that suggest the inception of the Gentilly "glaciation" and (2) the absence of finite radiocarbon dates in the range 66-13 ka (Gadd, 1976).

Hillaire-Marcel and Page (1981) were the first to report ^{14}C dates in the 35 ka range. They were obtained on calcareous concretions found in situ in the Deschaillons Formation.

Since these concretions are found in the Gentilly Formation (Lamothe et al., 1983), as striated clasts, the inception of the last ice advance in the Lowland is younger than 35 ka unless (1) the second generation of carbonates which should be responsible for the measured ^{14}C activity has originated sub-glacially and (2) the tills themselves are deposited towards the end of the glaciation. In other words, the age of the whole Gentilly glacial sequence (see Chapter 3) would be late-glacial. That is unlikely. However, since tills cannot be dated directly, the question of their age remains unanswered.

Those ^{14}C dates are close to the apparent TL age of 28 ka measured at the top of the peat-bearing silt of the St-Pierre type-section. Herein, 30 ka BP is proposed as the upper limit of the St-Pierre Interstadial.

(5) the Trois-Rivières Stadial is bracketted between 30 and 13 ka BP, because late-glacial marine invasion in the Lowland did not occur before 12,700 ± 100 BP years (GSC-1859; ^{14}C date on marine shells, near Ottawa, Romanelli, 1975).

5.6 Note on the paleoenvironments

A stratigraphic framework based on geologic events implies drastic changes in the Quaternary paleoenvironments. However, in the Lowland, these are poorly known. Analysis of paleoenvironmental factors has to be based on detailed sedimentology which was outside the scope of this investigation. Consequently, only a brief discussion is given below.

A full discussion on ice flows during the glacial episode is not possible at the moment, because (1) till fabrics are too scarce, and

(2) good lithologic indicators and outcrops of striated bedrock are lacking. However, full glaciation characterized the St-Lawrence and Trois-Rivières Stadial, with a generally southward to eastward ice flow. Gadd (1971) reported S8^{o}W to S28^{o}W striations from a bedrock outcrop immediately south from Rivières aux Orignaux, along highway 132. The Nicolet Stadial, is typically represented by glaciolacustrine sediments. In the past, Antevs (1957) did demonstrate that rhythmites may be annual. If their rhythmicity is annual and if the Deschaillons and Rivières aux Vaches are correlated, a major glacial lake has covered the St-Lawrence Lowland during 3 000 years with the ice margin being located probably in the Quebec vicinity until it reached the St-Pierre les Becquets area. This implies a less extensive ice advance in the Lowland, in early Wisconsinan time.

During the St-Pierre Interstadial, elevated lacustrine sediments (≈25 m a.s.l.; section 98) needed the St Wenceslas Ridge or some other positive feature down the St-Lawrence River be relatively higher than today relative to these silts. These sediments can not be considered as glacigenic. This suggests that isostatic rebound after the Nicolet Stadial may have been different than generally assumed. It is generally believed that the peat-bearing silty sediments of the St-Pierre type-section were probably deposited in an abandonned channel of the St-Lawrence River. A modern analog could be Lac St-Paul, located a few km south of Bécancour (Fig. 1-1) It is also well known that the climate was probably 2^{o}C colder than today, at least when the organic sediments were deposited (Terasmae, 1958). A discussion on the Quaternary paleoenvironmental conditions having existed in the Lowland may be found in Occhietti (1979, 1982).

CHAPTER 6

CORRELATION OF THE STUDY AREA WITH SELECTED CONTINENTAL AND DEEP-SEA SITES

For the past 25 years, the Traditional Concept of a two-stadial stratigraphy of Gadd (1955, 1971) has been considered as the only stratigraphic model in the Lowland and has been correlated as such with other areas in the St-Lawrence River drainage basin. In the preceding chapter, a revised scheme of stratigraphic nomenclature in the central part of the St-Lawrence Lowland was described and it is suggested on the basis of absolute dating techniques that the inferred geologic events may be time-bracketted as shown in Figure 5-3. This investigation demonstrates that, at least, hiatuses, which were not identified before, are common in the St-Lawrence Lowland. It is indeed proposed they may isolate an Illinoian glacial event from the two already known Wisconsinan glacial events. This Alternative Concept needs much further investigation but since it is ambitious and may stimulate discussions, this model of stratigraphy is favoured in the following text.

6.1 Correlations in the St-Lawrence River drainage system

Since most other Quaternary reference sites found in this drainage system lack chronological control, correlations must be based on geologic events and on some other indirect arguments. The following four Quaternary sequences are of interest in these regional correlations.

6.1.1 The Toronto area

The metropolitan area of Toronto is underlain by a thick Quaternary sequence displaying a complex stratigraphy well exposed at three main sites: the Woodbridge Cut, the Don Valley brickyard and the impressive Scarborough Bluffs. The stratigraphy is summarized as follows (Karrow, 1967, 1984b). The lowermost unit is represented by the York Till. It is overlain by the Don Beds. This formation consists of fluvial and lacustrine sand, silt and clay deposited up to 20 m above the present Lake Ontario level. According to palynological evidence (Terasmae, 1960), the Don Beds must have been sedimented at a time when the climate was warmer than today by possibly 2°C. Since no other warm assemblages have been found in the overlying strata, this unit is referred to the last interglacial. Amino-acid data on wood fragments and freshwater shells tend to support this age (Karrow, 1984b). Consequently, the underlying York Till is assigned to the Illinoian Glaciation. The top of the Don Beds is weathered (Gray, 1949). Overlying the interglacial sediments, a thick sequence of silty clay and sandy silt, the Scarborough Formation, occurs up to an altitude of 45 m above the present level of the lake and it contains plant remains and invertebrate fossils typical of a climate colder by 6°C than today (Terasmae, 1960; Williams et al., 1981). This formation is in some places cut by valleys up to 50 m deep filled with fluvial sediments described as the Pottery Road Formation (Karrow, 1974). It is unconformably overlain by the Sunnybrook Till (Terasmae, 1960). This unit has been re-interpreted by Eyles and Eyles (1983) as glaciolacustrine

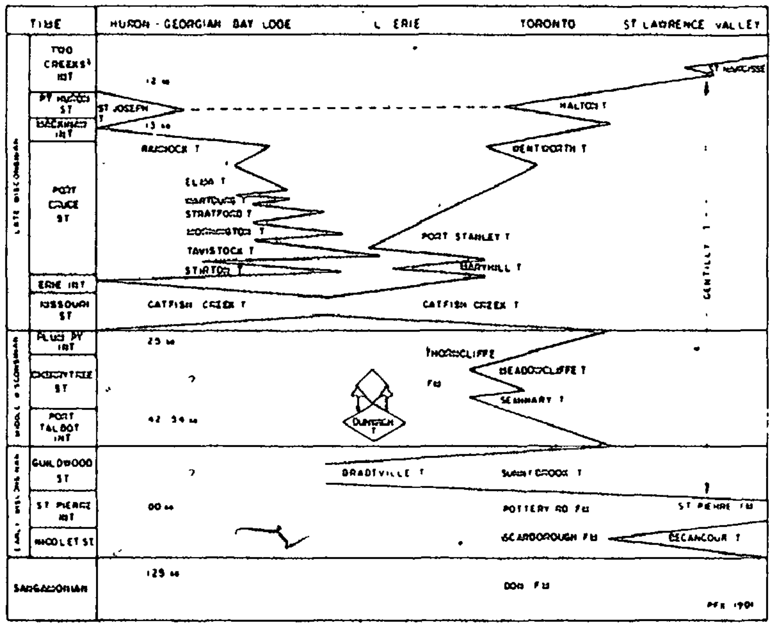


FIGURE 6-1: Time-space diagram for Ontario, Erie and Huron basins and St-Lawrence Lowland (modified after Karrow, 1984b: Dunwich is in Cherry Tree Stadial).

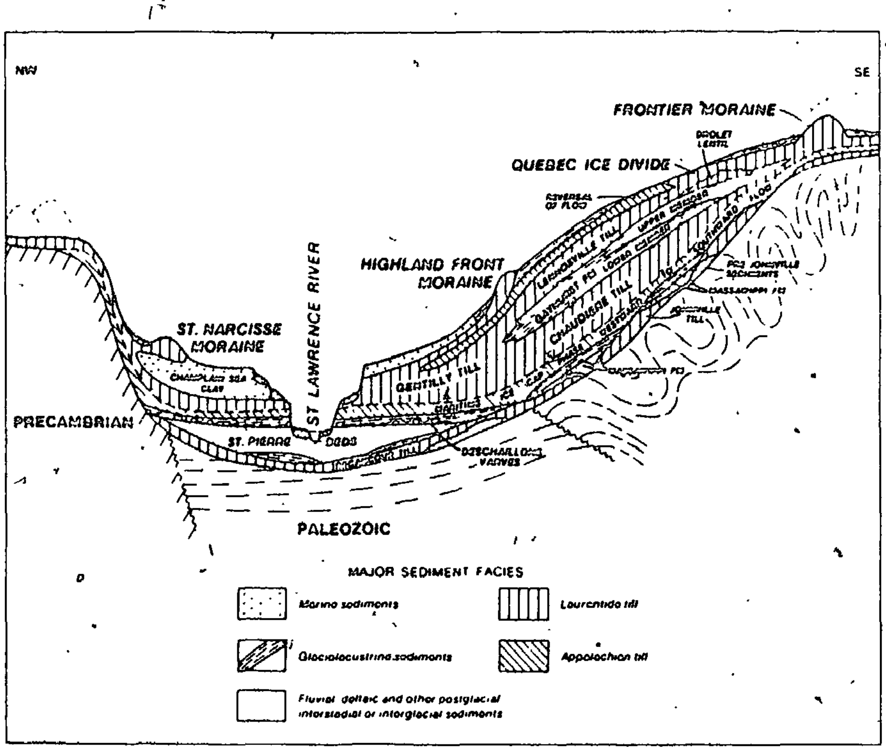


FIGURE 6-2: Schematic geologic cross-section for the Appalachians and the St-Lawrence Lowland, from Shilts (1981).

diamicts deposited under a floating ice which does not need to be attached to an ice sheet, thereby casting some doubts on the true stadial character of this diamicton. It is argued, however, by Karrow (1984a), Dreimanis (1984) and Sharpe (1984) that there are many sites where the Sunnybrook Till shows multiple evidence of the presence of a glacier in the Lake Ontario basin during its deposition. Overlying the Sunnybrook Drift, a complex lithostratigraphic assemblage has been described as consisting of members of the Thorncliffe Formation separated by the Seminary and Meadowcliffe Tills, The discussion on the true glacial origin of the Sunnybrook Till by Eyles and Eyles (1982) has been extended to the Seminary and Meadowcliffe whereas the interstadial character of the Thorncliffe sediments has been demonstrated by Berti (1975). At the top of the Toronto sequence, the Halton Till (Karrow, 1974) has been described as the Late Wisconsinan glacial deposit. The unit is overlain by the late-glacial Lake Iroquois lacustrine sediments.

Correlation of the St-Lawrence Lowland sequence with the Toronto area is hampered by the lack of a good chronological control in the latter beyond 45 ka and by the continuing dispute over the genesis of some of these units. Figure 6-1 shows the correlations proposed by earlier workers as summarized by Karrow (1984b). This correlation depends on the two-fold stadial character of the Traditional Concept of Gadd (1971), on the length of the "Gentilly Stadial" (ibid.) and on the elevation of the Scarborough sediments. Since no true interglacial deposits are found in the St-Lawrence Lowland, and, as the elevation of the Scarborough Formation is up to 45 m above the present lake level, it was proposed that the ice responsible for deposition of the Becancour Till raised the Lake Ontario water level permitting the development of the Scarborough delta. The St-Pierre sediments are then correlated with the Pottery Road Formation which suggests a return to normal drainage conditions due to the opening of the St-Lawrence Lowland. All the overlying units are correlated with the Gentilly Till because (1) Gadd (1971, 1976) proposed that this till spans a large part of the Wisconsinan i.e. from 66 ka to 13 ka BP, and (2) Karrow (1967) suggested that during the Port Talbot interstadial, the drainage to the Lowland was blocked.

A three stadial sequence in the St-Lawrence Lowland could be correlated with the Toronto sequence as follows (Fig. 6-4):

(1) the York Till is correlated with the Odanak Formation, being both assumed to be Illinoian.

(2) The Don Beds have no stratigraphic equivalent in the St-Lawrence Lowland.

(3) Since the Scarborough Formation is bounded by unconformities and bears a cold fossil biota, it may represent the very end of the Sangamonian or an earliest Wisconsinan interstade which apparently would have no equivalent in the Lowland; it is proposed that its elevation (25 m higher than the top of the Don Beds) is not a sufficient argument to command the presence of an ice sheet in the St-Lawrence Lowland; it may be due partly to differential rebound of the crust during the last 100 ka or even to local subsidence in the Don River Valley due to the weight of its own sediments (Eyles and Eyles, 1983); it should be kept in mind that the Sangomonian *may* have lasted for 50 ka,

a time interval sufficient to allow the Frontenac Axis to have upwarped much more than generally assumed:

(4) The genesis of the Pottery Road Formation is still obscure (Karrow, 1984b). Those sediments and the channelling structures are interpreted as evidence for a sudden lowering of the lake level It is believed herein that the Pottery Road Formation may as well be part of a proglacial delta Nevertheless, a Lowland equivalent is lacking.

Guildwood Stadial is correlated with the Nicolet Stadial, the former being represented by the Sunnybrook Drift. Even though its true glacial origin may be questionned. there is a general agreement that glacier ice was close to the Toronto area. Therefore this unit may represent a less extensive glacier expansion than the Illinoian and the late Wisconsinan glacial maximum. This may be compared with the smaller ice development in the Lowland evidenced by the Nicolet Stadial deposits. Very recently, an apparent TL age of 66.5 ± 6.8 ka has been reported by Berger (1984) for the non-fading component of the Sunnybrook Till collected at the Woodbridge Cut by P. Karrow. In the same paper, apparent TL ages of 36.9 ± 5.4 ka and > 140 ka are reported for the Upper Thorncliffe sediments and the Halton Till. Exposure to sunlight is likely for the Sunnybrook Till, a fact which supports, partly, the "pelagic rain-out" process of Eyles and Eyles (1983).

> "However, for samples WC-HT and WC-ST an unknown water loss occurred between collection and analysis, so the assumed Δ values for these two samples are lower than would otherwise be the case, though the assigned uncertainties are large enough to accommodate this effect".
> (Berger, 1984, p. 1394).

It is therefore believed by the present writer that the age of the Sunnybrook Till (sample WC-ST) is probably in the 80 ka range since a higher water content would lower the dose-rate and raise the final age. The apparent TL ages measured on the Nicolet Stadial deposits are in the range of 70 to 85 ka.

(6) Dreimanis and Raukas (1975) concluded from regional comparison that the middle Wisconsinan of the Eastern Great Lakes area lasted from 65 to 24 ka. The whole middle Wisconsinan of this area may then be correlated with the St-Pierre Interstadial if the latter is bracketted between 65-75 and 30 ka BP. In other words, Port Talbot I and II and Plum Point interstadials would be equivalent in time with the St-Pierre geologic event. In the Toronto area and in the Lowland, radiocarbon dates are insufficient and, in the case of St-Pierre, the dates are at the limit of the method. However, the ^{14}C dates obtained on organic material from Lake Erie interstadial sites have consistently clustered in the 25-28 and 40-48 ka ranges. Therefore, the middle Wisconsinan may be considered as a long interstadial interval during which nonglacial sediments were deposited in the St-Lawrence River basin. They need not be synchronous.

(7) The Halton and Gentilly tills represent the classical late Wisconsinan advance.

6.1.2 The Upper St-Lawrence River and the Montreal area

The stratigraphy in this area has been described by MacClintock and Stewart (1965) and Prest and Hode-Keyser (1977). Until recently, not much has been added to their work since most of the sections used in developing the stratigraphic record were exposed only during the construction of the St-Lawrence Seaway and are not accessible today. There are no significant ^{14}C dates available in this area. The following discussion is, therefore, brief, and is not included in Figure 6-4.

Two major glacial advances are recorded in this area, separated by glaciolacustrine sediments. No true interstadial or interglacial sediments have been described from this area. The stratigraphy can be summarized as follows: (1) at the base, the Malone Till is overlain by (2) a sequence of varved sediments and waterlain tills defined as the Middle Till Complex which are believed to be associated with the retreat of the Malone ice; (3) At the top, the Fort Covington Till represents the last major glacial advance in the area. Clarke and Karrow (1983) proposed recently that the surficial diamicton exposed at Malone should be correlated with the upper till described in the Seaway. They propose the term Malone should be removed from the lithostratigraphic nomenclature. This is disputed by Dreimanis (1985).

It is proposed that (1) the Fort Covington correlates with the Gentilly Formation (2) the Malone Till and the Middle Till Complex may then be correlated with the Nicolet Stadial drift, in which case an unconformity should exist at the bottom of the Fort Covington Till.

6.1.3 The Appalachian area

This sequence, represented at two major sites, the Ascot River section and the Gayhurst Dam site, has been studied in detail by MacDonald (1967) and Shilts (1970, 1981). They reported the following sequence of events (McDonald and Shilts, 1971):

(1) an early Laurentide ice advance deposited the Johnville Till; this till is underlain by oxydized gravel;

(2) the overlying Massawippi Formation registers interstadial conditions during which organic matter-rich lacustrine silt was deposited; it yielded an infinite radiocarbon date of >54 000 years BP (Y-1683);

(3) a second ice advance deposited the Chaudière Till which, at the base, exhibits a westward trending fabric gradually shifting to a southward fabric at the top;

(4) glaciolacustrine conditions were prevalent after the retreat of the Chaudière ice and before the advance of the Lennoxville ice, particularly in the Chaudière River Valley where the Gayhurst Formation consists of 4 000 varves; a radiocarbon date of >22 000 years BP (GSC-1137) has been obtained on the organic matter disseminated in the sediment.

(5) the classical Wisconsinan advance deposited the Lennoxville Till

These units have been correlated with the St-Lawrence Lowland as follows (Fig. 6-2).

(1) Johnville with Bécancour

(2) Massawippi with St-Pierre

(3) Chaudière-Gayhurst-Lennoxville assemblage with Deschaillons and Gentilly.

Shilts (1981) suggested that conformable relationship exists between the Chaudière Till, the Gayhurst Varves and the Lennoxville Till and stressed the regional importance of this stratigraphic relationship in these terms:

> " The sediments exposed in this vicinity provide the critical key for interpreting the relationship of Chaudière Till to Lennoxville Till in the Appalachians and to Gentilly Till in the St-Lawrence Lowland. In fact, they provide, along with the St-Pierre beds, the "peg" on which all modern interpretations of the Quaternary history of southern Quebec are hung. (p. 41)
>
> The lack of an erosional break within the period of Gayhurst sedimentation explains the presence of only one post-St-Pierre till, the Gentilly, in the St-Lawrence Lowland. Only one till was deposited in the St-Lawrence Lowland because ice cover was continuous from the onset of Chaudière glaciation to the end of Lennoxville glaciation; in other words, the Gentilly Till is stratigraphically equivalent to the Chaudière Till, Gayhurst Formation and Lennoxville Till of the Appalachian Mountains. " (p. 42)

However, this study strongly suggests the Gentilly Till spans only the very last part of the Wisconsinan. During the Nicolet Stadial, glacier ice does not seem to be extensive in the Lowland. Moreover, Parent (1984 a,b) found no evidence for a Laurentide provenance in

Pierreville peat unit. To the author's knowledge, this is the oldest finite ^{14}C date ever published. Strong doubts have been cast on these dates. However, the early and middle Wisconsinan chronostratigraphy is largely based on such data (Dreimanis and Karrow, 1972). Consequently, a brief comment on some of the theoretical and practical aspects of the technique is given.

Upon death of biogenic carbon, or from the time of precipitation for carbonates, the radioactive isotope of carbon decays with a half-life of 5730 years. Therefore, a 35,000 year-old wood has an age of 6 half-lives (i.e. the ^{14}C activity of this sample is only $(\frac{1}{2})^6$ of the original activity of the organic matter grown in equilibrium with normal pre-nuclear atmosphere). This activity would produce 0.2 counts per minute (cpm) per gram of carbon. In liquid scintillation counting, the environmental background may yield as much as 4 cpm. A very long counting time is needed in order to statistically discriminate this minute activity. At the GEOTOP(1) laboratory, the background count is commonly around 3.9 cpm and the counting time is between 1400 and 2000 minutes. Table 3-1 compares activities and age calculations of a finite and infinite ^{14}C age obtained from a concretion and from a piece of wood collected at the St-Pierre type-section. As the reader may note, pre-treated sample UQ-312, which was the first striated concretion dated (Lamothe et al., 1983), shows

(1) GEOTOP: Laboratoire de Géochimie Isotopique de l'Université du Québec à Montréal. Seven dates on calcareous concretions were measured in this laboratory.

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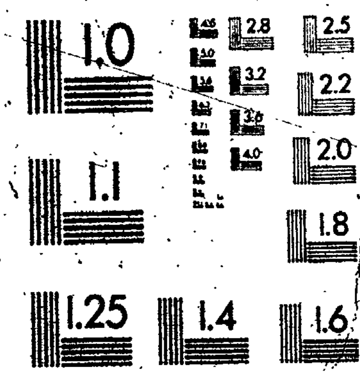


the whole Chaudière Till. With the use of numerous till fabrics and a careful study of glaciotectonic structures, he believes that the overall deformation pattern in the Chaudière Till could be explained by a migrating ice flow center of an autonomous Appalachian ice. The Nicolet Stadial deposits which suggest minor Laurentide ice expansion may then correlate with the Chaudière *event* (Fig. 6-4).

The Johnville Till would correlate with the Odanak Formation and the Lennoxville Till with the Gentilly Formation.

In this scheme, the Massawippi does not have a lateral equivalent in the Lowland unless it can be demonstrated that the wood-bearing sand at the base of the Deschaillons Formation is older than the Nicolet Stadial drift. The Gayhurst Varves have to be related to either the retreat of Chaudière ice or to the advance of Lennoxville ice but not to both. The 4 000 years duration they suggest, if they are true varves, is not explained.

6.1.4 The Northern Shore of the St-Lawrence Lowland.

Two sections are worthy of mention:

(a) Vieilles-Forges Section (Gadd and Karrow, 1959 ; Occhietti (1979))
At the base, Occhietti (1979) described a lateral equivalent of the Bécancour Till. It is overlain by organic rich silts in which two peat layers are found. Radiocarbon dates performed so far have yielded infinite ages except a recent ^{14}C date of 32,000 ± 2 800 BP (UQ-588: liquid benzene; S. Occhietti, personal communication, 1984) obtained on the uppermost peat layer. Over these peat layers a sequence of 800 varves were assigned by these workers to the Deschaillons Formation.

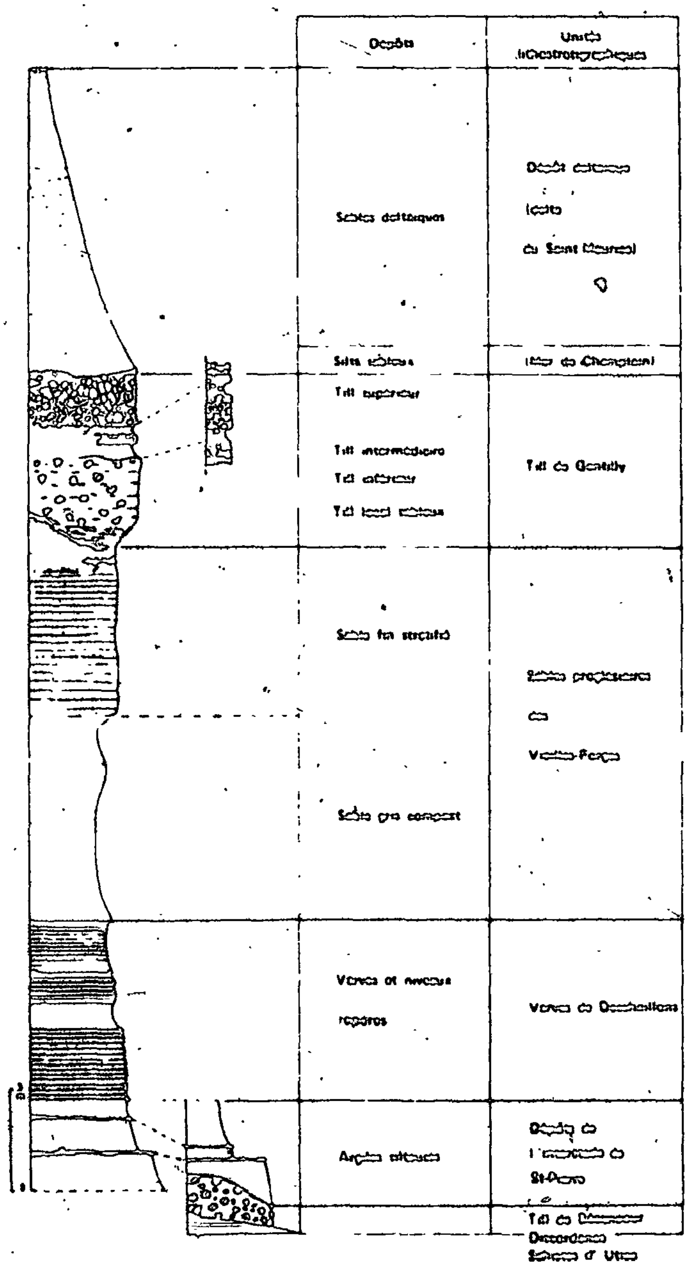


FIGURE 6-3: The Vieilles-Forges section,
according to Occhietti (1979).

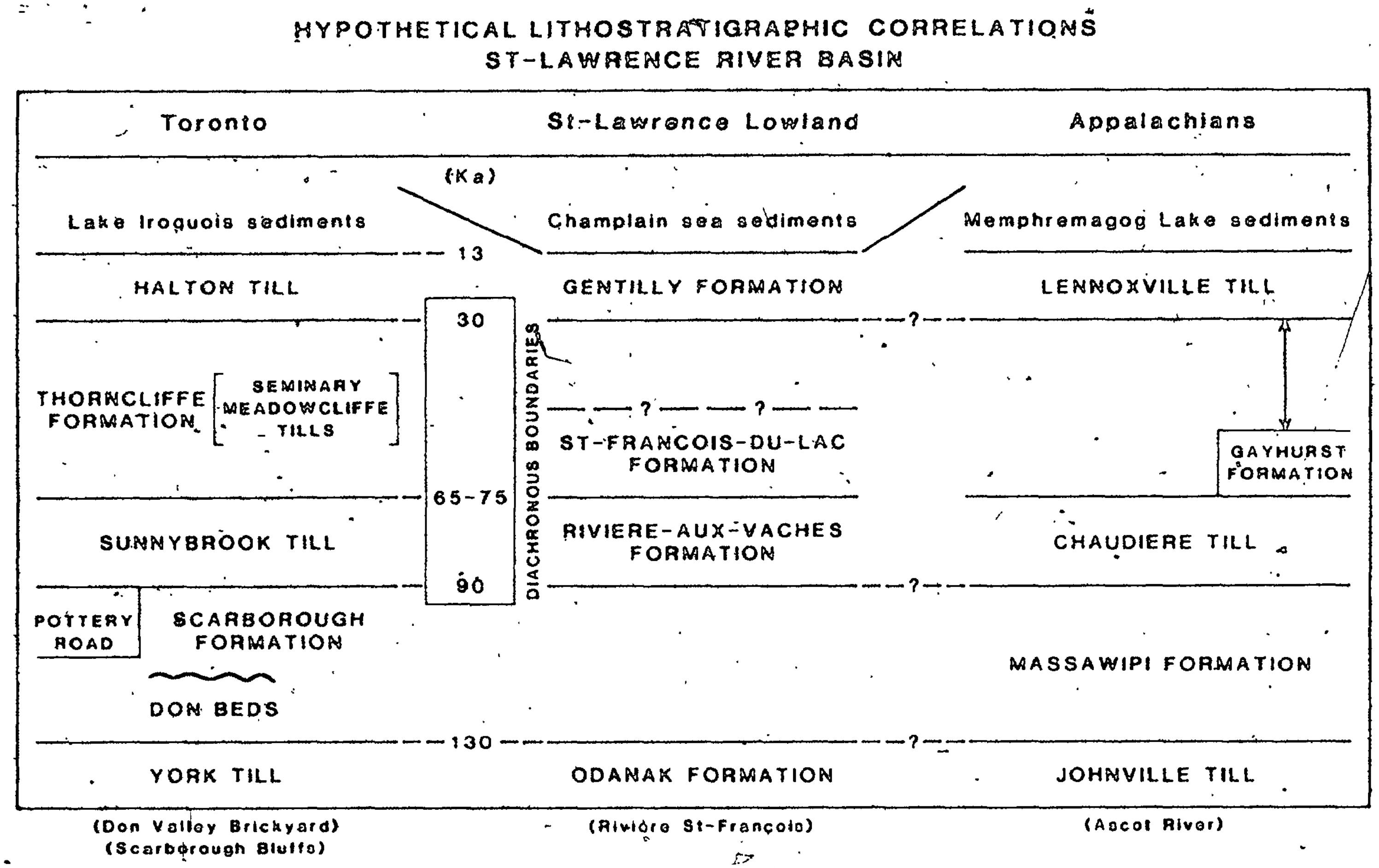


FIGURE 6-4: Hypothetical correlation chart in the St-Lawrence River drainage system.

They are separated from the overlying Gentilly Till by a sandy and silty unit described by Occhietti (1979) as a prograding delta in the Deschaillons glacial lake and formally defined as the Vieilles-Forges member of the Deschaillons Formation. It is herein proposed that the Deschaillons Varves are not present at this site since (1) no concretion have ever been found in the rhythmites and (2) the number of laminations differs by at least one order of magnitude. Consequently, the upper 800 "varves" may be correlated with Les Becquets Formation if ever they are pre-Gentilly, the lower till is probably a lateral equivalent of the Odanak Formation or the Levrard Formation.

(b) Grondines section (Karrow, 1957); this section shows two tills, an upper "highly calcareous gray till" and a lower "dark gray moderately calcareous silty till" in which irregular masses of "pink gray varved clay" are included (Karrow, 1957; p. 94). The occurence of these varved sediments in the lower till (assigned to Bécancour by Karrow, 1957 and Gadd, 1971) is strong evidence that the glaciolacustrine event of early Wisconsinan age was major and it is believed that its sediments probably covered a large area.

Other sites have been recently described in the St-Lawrence River area (Prichonnet, 1984; LaSalle, 1984) in which two distinct tills are exposed. Correlations with those sections are not discussed here mainly because of the lack of geochronologic data.

6.2 Land and deep-sea correlations through ice-volume synchronization

A general consensus exists today among Quaternary geologists in considering Emiliani's (1955) and Shackleton and Opdyke's (1973) foraminiferal assemblages as reference chronozones for most of the Quaternary system.

This stratigraphy is based on oxygen isotopic ratios of benthic foraminifera which should reflect global ice-volumes on land, the temperature of the bottom sea water being a minor factor in the isotopic ratio. In this scheme, $\delta^{18}O$ changes correlate with climatic changes which is the fundamental feature of the upper Cenozoic chronostratigraphy. Boundaries are set at inversions in $\delta^{18}O$ and they define isotopic stages in the sense of Emiliani (1955). Odd stage numbers are related to cold phases and even numbers to warm phases. The major time-boundaries are placed at the ends of the major cold phases, the glaciations, and are termed terminations (Broecker and van Donk, 1970). Since this study is concerned with the last glacial-interglacial-glacial cycle, the information which forms the basis of the discussion is restricted to the last 150 ka. On Figure 6-5, the deep-sea stratigraphic data are smoothed by an ice volume changes curve published in Imbrie and Imbrie (1981). The absolute chronology is based on sedimentation rates as well as on U-Th dates obtained on raised coral terraces found on the west coast of Barbados (Shackleton and Matthews, 1977) and in New Guinea (Bloom et al., 1974) The major features of the deep-sea stratigraphy are:

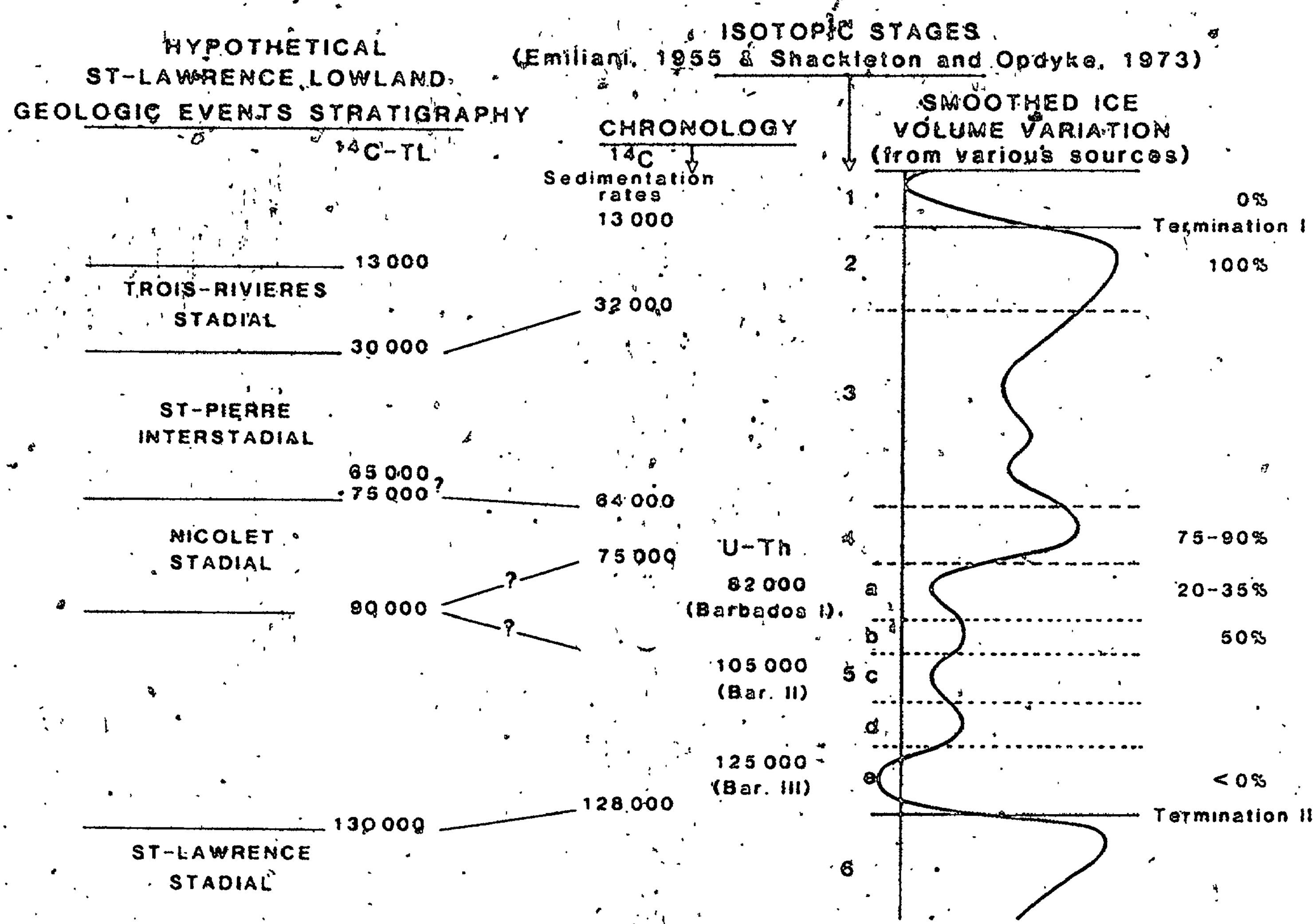


FIGURE 6-5: Hypothetical correlation of the St-Lawrence Lowland Quaternary geologic events with the deep-sea isotopic stratigraphy.

(1) Stage 6, the last cold phase of the penultimate glaciation ends at 128 ka; this defines termination II.

(2) Stage 5 defines the last major interglacial period and part of it is considered to represent a warmer episode than the Holocene; it ends at 82 ka and should have lasted for 45-50 ka; it was broken apart by two brief colder episodes and thereby split into substages 5e, d, c, b and a; there has been a long-lasting dispute as to whether or not the last interglacial period should be represented by 5e alone or by the entire stage 5; this discussion is mostly academic and restricted to the West European land stratigraphy which appears to be more easily divided into sub-stages because long and continuous pollen sequences can be found in former periglacial area (Woillard, 1978).

(3) the first major cold pulse of the last glaciation defines stage 4 and is represented by a short cooling with a supposed less extensive ice cover on land; according to Shackleton (cited as personal communication in Ruddiman <u>et al.</u>, 1980), if the ice volume in stage 2 is defined as 100%, the ice volume during stage 4 would have attained 75-90%. However, this is an average estimate for the entire globe.

(4) a warmer episode, but still cooler than the Holocene, would then have taken place between 64 ka and 32 ka; this defines stage 3;

(5) the maximum of the last glaciation is represented by stage 2 in the deep-sea stratigraphy; it ends at 13 ka; this defines termination I.

The chrono-correlation of the St-Lawrence continental stratigraphy and the deep-sea stratigraphy seems straightforward. The major features are:

(1) the correlation of a glaciation event represented on land by the St-Lawrence Stadial of the Illinoian Glaciation with stage 6, both terminating at 130 ka;

(2) a warm episode well displayed in the deep-sea stratigraphy and sporadically on land (e.g. Don Beds) because of the discontinuous nature of the continental record;

(3) a short-lived and less extensive glacial advance represented by the stage 4 and by the Nicolet Stadial; the 82 ka U-Th date represents the very end of stage 4 (Bloom <u>et al.</u>, 1974), the difference in ages between the land and marine chronology is not significant and is, moreover, based on different dating techniques;

(4) stage 3, a cool episode in the deep-sea stratigraphy is represented on land by a series of discontinuous non-glacial sediments deposited during the St-Pierre Interstadial dated at 30 to 65-75 ka.

(5) the inception of the last glacial maximum is dated on land as well as in the isotopic stratigraphy at ≈30 ka;

(6) the disintegration of the last major ice sheets on land correlates closely with termination I, i.e. at 13 ka.

CHAPTER 7

CONCLUSIONS AND FUTURE WORK

7.1 Conclusions

For three decades, a Traditional Concept of stratigraphy involving one glaciation with two major ice advances separated by one brief interstade has been invoked to explain the distribution of glacial and non-glacial deposits in the St-Lawrence Lowland. The Bécancour Till, the St-Pierre Sediments and the Gentilly Till with the associated Deschaillons Varves are the key lithostratigraphic units of this stratigraphic framework.

In this thesis, it is proposed that a new Alternative Concept of continental stratigraphy may equally or better explain the stratigraphic relationships observed in the Lowland. It can be summarized as a three-stadial model, spanning the last 130,000 years. Radiocarbon and thermoluminescence dating as well as sedimentologic and field work provide evidence that the succession of geologic events may be as follows:

1) an Illinoian glacial event: the St-Lawrence Stadial;
2) an early Wisconsinan glacial event: the Nicolet Stadial;
3) a mainly middle Wisconsinan nonglacial event: the St-Pierre Interstadial and
4) a late Wisconsinan glacial event: the Trois- Rivières Stadial.

The key lithostratigraphic units are: the Odanak, Rivière aux Vaches, Lévrard, St François du Lac and Gentilly Formations. The Les Becquets, Deschaillons and Pierreville formations have an equivoqual stratigraphic position.

This new stratigraphic framework raises numerous questions and needs to be tested. Consequently, a set of recommendations for future work is presented below.

7.2 Future work

Four different types of investigation should be carried out.

1. Field work

In order to confirm the three stadial model, the existence of an older glacial diamicton on the bedrock surface has to be confirmed in the St-Pierre les Becquets and Deschaillons area. This has to be done by drilling and coring the surficial deposits that are to be found under the St-Lawrence River level. A drill hole should also be planned in the Cap Lévrard vicinity, at point C (or G) of Figure 2-19 to confirm the expected presence of the Deschaillons and/or Lévrard Formation under the non glacial sediments. In the Pierreville area, an exploration program should confirm the true stratigraphic relationship of the Pierreville Formation with the Rivière aux Vaches and Odanak formations. If the latter is indeed Illinoian, sediments of Sangamonian age may exist in the Lowland and should be searched.

2. Sedimentology

A detailed sedimentologic analysis of every section, is still much needed. Sedimentary structures and till fabrics should be measured systematically. No clear paleogeographic picture can yet emerge because knowledge about the sedimentary environments and, in particular, about the direction of ice flows, is lacking.

3. Radiocarbon Dating

The radiocarbon activity measured on calcareous concretions which are, according to this study, found in glaciolacustrine sediments older than the limit of the radiocarbon method has to be understood. The two generations of carbonates have to be confirmed and distinguished. Future investigation should be based on geochemical and cathodoluminescence analysis. Finally, the U-Th and ESR dating techniques should be applied to these concretions. The timing of the last ice advance in the Lowland and the length of the St-Pierre Interstadial are based on the very small radiocarbon activity measured on carbonates that are sensitive to contamination.

4. Thermoluminescence Dating

It is not known, at this moment, if every mineralogic grain in every sedimentary unit have been equally exposed to sunlight. It is believed that this is probably not the case. In future work, a new approach suggested by Mejdahl (1984) in which artificial bleaching procedures are done on isolated minerals should be tested on sediments of known age from different environments, such as the ones that have been deposited in the late-glacial Champlain Sea. However, it should be remembered that the determination of the residual TL signal is not critical for old sediment.

Isolation of a non-fading component in the St-Lawrence Lowland sediments is already under way in order to confirm the delayed measurement procedure proposed in this investigation.

7.3 Concluding remarks

In conclusion, this study presents new ideas on the continental stratigraphy and geochronology that have to be tested. The hypothetical three-stadial stratigraphy discussed in this thesis is ambitious and much more work needs to be done before it reaches the status of a solid stratigraphic framework. However, the agreement between the major ice-volume changes suggested by the isotopic composition of deep sea foraminifera and the ones deducted from the St-Lawrence Lowland glacial stratigraphy is particularly gratifying for the chronostratigraphic correlation of the Nicolet Stadial with isotope stage 4. They both suggest a less extensive ice cover on land in Early Wisconsinan time, as compared to the last glacial maximum.

It is therefore believed that the concept of the oxygen isotopic ratios of benthic foraminifera as reflecting global ice-volumes and therefore global glacial events as put forward by Shackleton and Opdyke (1973) is well-founded. This study indeed presents a regional evidence of such timing between glacierized land environments, deep-sea sedimentation and climatic changes.

APPENDIX I: PUBLISHED DESCRIPTIONS OF THE SECTIONS INVESTIGATED

Sections are from Gadd (1971)

* Karrow (1957)

** Hillaire-Marcel and Pagé (1981)

Section 98

Location: 31 1/2 St-François River, northeast bank, 1.6 miles upstream from bridge on highway 3, the Pierreville section. 46°03 N, 72°47'20"W, elev 100 feet approx.

	GENTILLY STADE UNITS	
7.5	Brownish grey calcareous sandy till	7.5
	ST. PIERRE INTERVAL UNITS	
17.5	Stratified, fine-grained buff to brown sand, becoming silty in lower 5 feet	25
1	Compressed peat with some wood	26
9	Stratified fine-grained sand and silty sand grading downward into subjacent silt	35
	BÉCANCOUR STADE UNITS	
16.5	Grey to brownish grey varved silt (in lower part of section beds are repeated by slumping, some contacts apparently are fault contacts)	51.5
25.5	Section covered by slump debris	77

Section 99

Location 31 1/2 St-François River east bank, 3 miles upstream from highway 3 46°02'10"N, 72°46 W, elev 80 feet approx

	CHAMPLAIN SEA UNITS	
5	Massive grey marine clay	5
	GENTILLY STADE UNITS	
5	Grey to reddish grey sandy till	10
	ST PIERRE INTERVAL UNITS	
3	Fine-grained brown and grey-brown silt and fine sand, thin bedded	13
14	Crossbedded coarse sand	27
	BÉCANCOUR STADE UNITS	
12	Glaciolacustrine silt, varved, grey "summer" layers and red "winter" layers	39
10.5	Sandy red till	49.5
	BEDROCK	
?.5	Red sandstone of Bécancour River Formation	55

Section 109

Location 31 1/2 St-François River, west bank, at mouth of Rivière aux Vaches, 3 miles upstream from highway 3 46°01'45"N, 72°46 25"W, elev 100 feet approx

	POST-CHAMPLAIN SEA UNITS	
0.5	Medium-grained alluvial sand	0.5
	CHAMPLAIN SEA UNITS	
21	Light grey, stratified, calcareous and fossiliferous marine silt	21.5
2.5	Grey to brown-grey sandy silt, varve-like stratification, fossiliferous, grading upward into grey marine silt	24
	GENTILLY STADE UNITS	
1.5	Stratified, apparently varved red and grey silt, non-fossiliferous, grading upward into fossiliferous varve-like strata	25.5
8	Sandy reddish grey till	33.5
3	Stratified, crossbedded, buff medium-grained sand	36.5
	BÉCANCOUR STADE UNITS	
13.5	Regularly alternating varve-like thin strata of fine-grained sand and silt, grey, weathering buff, grade downward into grey silt varves	50
16	Grey varved silt, thin bedded near base and with red "winter" layers in lower 4 feet	66
16	Coarse, sandy brick-red till	82
	BEDROCK	
2	Red shale of Bécancour River Formation	84

Section 58

Location 31 I 8 St Lawrence River, south shore, ravine at 0.4 mile southwest of north margin of Bécancour map-area along highway 3, section 0.4 mile upstream (east and south) from highway on left bank of intermittent stream. Discovery and type section for St Pierre interstadial sediments 46°29'25"N, 72°12'W, elev 121 feet (bar.)

	Post-Champlain Sea Units	
3.5	Fine-grained buff alluvial sand	3.5
	Champlain Sea Units	
5	Massive, soft, light grey silt	8.5
	Gentilly Stade Units	
65.5	Approximately 500 varves of calcareous grey silt, thin-bedded at top and bottom of section	[illegible]
	St Pierre Interval Units	
1.5	Fine- to medium-grained sand heavily charged with disseminated fragments of organic matter, brown	76.5
1.75	Compressed peat with abundant wood as flattened stems, branches, twigs	78.25
3	Stratified medium- to fine-grained sand, some silt, alluvial	81.25
0.5	Compressed peat, some wood	81.75
1.5	Medium- and fine-grained sand, a few pebbles, alluvial	83.25
1.25	Compressed peat, beetle remains most common in this bed	84.5
3	Fine- to medium-grained sand and silty sand, alluvial	87.5

Section 60

Location 31 I/8 St Lawrence River, south shore, ravine 0.4 mile southwest of north margin of Bécancour map-area along highway 3, section 0.1 mile west of highway on right bank of ravine 46°29'45"N, 72°12'20"W, elev 100 feet approx.

	Champlain Sea Units	
60	Fine- to medium-grained buff sands, crossbedded and having a structure like delta fore-sets dipping towards the St. Lawrence; a few valves of *Macoma* present	60
15	Fossiliferous (*Portlandia*) blue-grey soft marine clay silt with black patches of disseminated organic matter, sulphurous odour	75
	Bécancour Stade Units	
10	Calcareous, brownish to reddish grey silty till	85
10	Brownish to reddish grey varved silt (lower 30 feet of section obtained by hand auger boring)	95

note: in Gadd, 1955: 2.4 mi east of the parish church at St-Pierre les Becquets, at the St-Lawrence River escarpment.

Section 65

Location 31 I/9 St Lawrence River, south shore, Cap Lévrard, 2.4 miles downstream from Roman Catholic church at St-Pierre-les-Becquets 46°32'N, 72°10'W, elev 100 feet approx.

	Post-Champlain Sea Units	
3	Alluvial sand	3
	Champlain Sea Units	
12	Stratified silts, marine	15
	Gentilly Stade Units	
1	Medium gravel	16
2	Buff sand	18
4	Calcareous grey sandy till	22
20	Stratified crossbedded medium sand	42
3	Calcareous grey sandy till	45
10	Stratified crossbedded medium sand	55
	Bécancour Stade Units	
5	Very sandy brick-red till	60
5	Reddish grey and red varved silts	65

SECTION 402

location: south shore of St-Lawrence River, 2.4 mi northeast of St-Pierre Church.

70': stratified, yellow sand; gray silt bands near bottom

5': gray silty sand with marine fossils

8': dark pinkish gray, weakly calcareous, silty till

10': red, weakly calcareous, varved silt and clay.

* SECTION 400

location Brickyard at Deschaillons

15': buff till

70': gray, thin-bedded, varved silt and clay

15': stratified, yellow, cross-bedded sand; wood has been found in this layer.

**

Coupe 1- Coupe principale de la Briqueterie de Deschaillons, entre l'usine et la route principale (route 3).

du sommet:

Éch. no.	Description lithologique	Épaisseur moyenne des varves	Épaisseur cum. (cm)		Calcimétrie %
	- début d'exploitation				
VD-2715e VD-1655e VD-1612e VD-1580e VD-1540e VD-1535e VD-1515e VD-1465e VD-1432e VD-1470e VD-1255e VD-1260e VD-1115e VD-1070e VD-1050e VD-1005e VD- 840e	. silt argileux déformé: les varves sont tronquées par de petites failles et plissotées. Les déformations ont modifié la structure originelle (rythmicité) pour développer une microstructure secondaire: le déplacement de matériel a rempli les interstices causés par le jeu des compartiments et a rendu la rythmicité plus diffuse. concrétions disposées parallèles dans les silts déformés; concrétions secondaires cimentant les déformations surface de décollement		100	1035	65.2 60.6 57.6 55.0 60.0 55.0 47.0 51.3 47.0 53.0 50.5 62.0 50.2 40.8 57.5
VD- 735e	. lit carbonaté avec concrétions		10	735	
	. silt argileux déformé affecté de plissements amples et de microfailles.				
VD- 726e	. lit carbonaté avec concrétions		100	725	69.4
VD- 626e	. niveau à concrétions		00	626	59.2
VD- 535e	. lit carbonaté avec concrétions surface de décollement: début de faibles déformations		63	535	55.0
VD- 491e	. lit carbonaté avec concrétions				60.0
	. vingt-huit (28) complète	10.0 cm	23	491	
	. trente-cinq (35) complète	9.16	32	663	
VD- 431e	. lit carbonaté avec concrétions				62.2
	. soixante-trois (63) complète	7.00	66	431	
VD- 335e	. niveau à concrétions				61.6
	. cinquante-et-un (51) complète	5.09	30	337	
VD- 357e	. niveau à concrétions				
	. dix-sept (17) complète	5.09	20	397	
VD- 317e	. niveau à concrétions				
	. vingt-deux (22) complète	6.02	15	317	
VD- 332e	. lit carbonaté avec dimensions concrétions				55.9
	. soixante-sept (67) complète	5.52	37	352	
VD- 295e	. lit carbonaté contenant de petites concrétions				67.3
	. trente-huit (38) complète	7.21	27	295	
VD- 260e	. lit faiblement carbonaté				
	. vingt-huit (28) complète	11.07	31	268	
VD- 237e	. lit carbonaté				24.1
	. cinquante-cinq (55) complète	5.65	30	237	
VD- 207e	. lit faiblement carbonaté				
	. onze (11) complète	9.09	10	207	
	. petit lit très faiblement carbonaté				

Coupe 2- Coupe située à environ 750m à l'aval de la Briqueterie, montrant le contact entre les sables deltaïques et les varves de Deschaillons

du sommet:

Éch. no.	Description lithologique	Épaisseur moyenne des varves	Épaisseur cum. (cm)		Calcimétrie %
	- début d'exploitation				
	. dix-neuf (19) complète	0.95 cm	17	675	
VD- 659e	. lit carbonaté avec concrétions				49.0
	. soixante-deux (62) complète	5.32	33	659	
VD- 626e	. lit carbonaté contenant de petites concrétions				50.6
	. quatre-vingt-un (81) complète	7.01	57	626	
VD- 559e	. lit carbonaté				23.7
	. quarante-huit (48) complète	5.63	27	559	
	- lacune: début d'exploitation; la coupe reprend en plus haut et 10m latéralement			552	
	. trente-huit (38) complète	2.63	10	121	
	. trente (30) complète	2.67	0	111	
	. trente-neuf (39) complète	2.05	0	103	
	. quarante-huit (48) complète	3.12	15	95	
	. quatre-vingt-quatre (84) complète	2.50	21	80	
	. trente-six (36) complète	2.77	10	59	
	. soixante-deux (62) complète	2.25	14	49	
	. soixante-dix-huit (78) complète	2.95	23	35	
	. dix-huit (18) complète: alternance de silts et sables fins de couleur rouille, avec des silts argileux grisâtres	2.22	4	12	
	. quinze (15) complète	2.00 cm	3	0	
	. lit mince de sables cimentés par des oxydes de fer				
	. dix-huit (18) complète marquée d'une alternance de silts et sables fins jaunâtres et de silts argileux grisâtres	2.77	5	5	
				0	
	. sables à stratifications entrecroisées avec des laminations de minéraux lourds, tournées au sommet par des rides de courant: amplitude : 1 à 2.5 cm longueur d'onde: 17 cm direction: N170-350°		23	209	
	. sables cimentés par des oxydes de fer; stratifications entrecroisées soulignées par des minéraux lourds; strates très irrégulières de silts argileux vers le sommet; quelques graviers dispersés vers le sommet.		26	101	
	. sables avec stratifications entrecroisées plus diffuses, marquées par des minéraux lourds		11	167	
	. sables alternant irrégulièrement avec des silts faiblement argileux (allure feuilletée vaguement rythmée)		17	146	
	. sables à stratifications subparallèles soulignées par d'abondantes laminations de minéraux lourds		15	129	
	. sables à entrecroisements très marqués, soulignés par des laminations épaisses, avec alternance de laminations de silts argileux (à allure rythmée) à la base et au sommet		10	114	
	. sables non-stratifiés		3	55	
	. silts argileux alternant irrégulièrement avec des poches de sables: lab.		3	52	

APPENDIX II METHODS: FIELD WORK AND SEDIMENTOLOGIC ANALYSES.

Methods used in Chapter 2 are briefly described below and the original data for granulometric, carbonate, pebble petrography, directional data and clay mineralogy analyses are tabulated.

II-A Field Work

Field work was carried out intermittently during the summers of 1980 through 1984. Stratigraphic sections were described following the classical methods of sedimentology. A Jacob's staff and metre stick was used for section measurements. Colors were assigned using the Munsell soil color Charts (1975 edition), samples being in the wet state.

II-B Granulometric and carbonate analysis

Samples collected during the field work were sent to the Pleistocene Laboratory of the University of Western Ontario where they have been analyzed.

The silt and clay contents of the <2mm grain-size fraction were determined by the hydrometer method (ASTM, 1964) followed by wet sieving of the sand fraction. Sand, silt and clay percentages were then calculated by computer. The weight of the original sample was 50g except for clay-rich samples for which 25 g aliquot were used. Results are shown on Table A-1.

Calcite and dolomite contents of the silt and clay fraction of each sample on which granulometric analysis had been performed, were measured using the Chittick apparatus (Dreimanis, 1962). Concretions discussed in Chapter 3 were also analyzed for their carbonate contents. Results are shown on Table A-1. Duplicate analyses were made using 0.85 g samples. For carbonate-rich samples, 0.425 g were also analyzed to check for abnormal dolomite which was detected in some samples (Dreimanis, 1962). In Chapter 2, the first measurement (0.85 g) was used for all samples, in the stratigraphic logs as well as on Figures 2-9 and 2-22.

In Table A-1, the analytical results are listed as reported, to the nearest 0.1 percent for granulometric data and to 0.2 percent for carbonate content. The accuracy of the analytical data is probably not better than to the nearest full percent, and therefore, full percentage data only are used in the text.

TABLE A-1

		GRANULOMETRIC ANALYSES			CARBONATE ANALYSES				
SAMPLE	UNIT	SAND	SILT	CLAY	DOLOMITE	CALCITE	C/D	TOTAL	LITHOLOGY
186	98-A	0.0	77.7	22.3	4.0	3.0	0.7	7.0	rhythmite
187	98-A		-	-	5.4	46.8	8.7	52.2	concretion
188	98-A	0.0	83.4	16.6	6.6	6.0	0.9	12.6	rhythmite(silt laminae)
189	98-A	0.0	81.8	18.2	7.8	4.4	0.5	12.2	rhythmite
190	98-A	-	-	-	3.0	3.6	1.2	6.6	rhythmite(clay laminae)
191	98-A	0.1	85.1	14.1	7.8	4.4	0.5	12.2	rhythmite
192	98-A	0.3	87.2	12.5	7.4	4.4	0.6	11.8	rhythmite
193	98-A	-	-	-	4.4	45.8	10.4	50.2	concretion
194	98-B	95.7	2.9	1.4	0.0	0.8	-	0.8	sand
195	98-B	85.0	15.0	0.0	0.0	0.4	-	0.4	sand
196	98-B	63.9	36.1	0.0	0.0	0.4	-	0.4	sand
197	98-D	1.8	72.2	26.0	1.4	0.8	0.5	2.2	silt
198	98-D	6.0	79.1	14.9	1.4	0.8	0.5	2.2	silt
199	98-E	13.2	61.3	25.5	3.6	2.4	0.7	6.0	diamicton
200	98-E	5.9	72.6	21.5	1.4	0.4	0.3	1.8	diamicton
201	109-C	-	-	-	2.2	61.2	27.8	63.4	concretion
202	109-B	36.6	57.9	5.5	5.4	6.8	1.2	12.2	diamicton
203	109-C	0.4	44.0	55.6	1.4	0.8	0.5	2.2	rhythmite
204	109-C	0.2	42.4	57.4	1.8	1.6	0.9	3.4	rhythmite
205	109a-B	0.2	42.4	57.4	2.2	2.2	1.0	4.4	rhythmite
206	109a-C	0.0	83.3	16.7	6.2	4.4	0.7	10.6	rhythmite
207	109a-C	0.0	83.4	16.6	4.8	3.4	0.7	8.2	rhythmite
208	109a-C	-	-	-	5.4	48.4	9.0	53.8	concretion
209	109-D	97.3	2.7	0.0	0.0	0.4	-	0.4	sand
210	109-F	34.8	49.8	15.4	2.6	3.4	1.3	6.0	diamicton
211	109-B	19.5	65.1	15.4	4.4	5.2	1.2	9.6	diamicton
212	99-F	32.3	50.3	17.4	5.4	3.4	0.6	8.8	diamicton
213	99-F	31.2	53.8	15.0	5.4	4.8	0.9	10.2	diamicton
214	99-F	38.1	49.4	12.5	2.2	3.0	1.3	5.2	diamicton
215	99-F	37.9	45.1	17.0	1.4	0.8	0.6	2.2	diamicton
216	99-D	92.4	5.6	2.0	0.0	0.8	-	0.8	sand
217	109-F	32.0	50.8	17.2	2.6	3.6	1.4	6.2	diamicton
218	99-F	26.4	50.5	23.1	4.8	5.4	1.1	10.2	diamicton
219	109-F	36.1	43.8	20.1	2.2	4.4	2.0	6.6	diamicton
220	109-B	14.1	41.4	44.5	2.6	6.0	2.3	8.6	diamicton

SAMPLE	UNIT	SAND	SILT	CLAY	DOLOMITE	CALCITE	C/D	TOTAL	LITHOLOGY
221	109-F	36.1	40.7	23.2	3.2	5.0	1.5	8.2	diamicton
222	109-F	35.2	44.7	20.1	2.2	3.6	1.6	5.8	diamicton
223	98-A	0.9	81.4	17.7	0.0	0.8	-	0.8	rhythmite
224	98-B	75.3	22.7	2.0	0.0	0.8	-	0.8	sand
225	98-D	4.8	92.5	2.7	0.0	0.8	-	0.8	silt
226	98-D	5.2	87.9	6.9	0.0	0.8	-	0.8	silt
227	98-E	23.2	66.5	10.3	0.0	0.8	-	0.8	diamicton
228	109-C	0.7	68.4	30.9	1.4	0.8	0.6	2.2	rhythmite
229	109-C	0.4	47.7	51.9	1.4	1.2	0.8	2.6	rhythmite
334	58-A	0.6	52.3	47.1	1.4	0.8	0.6	2.2	rhythmite
337	58-C	3.7	62.0	34.3	1.4	0.8	0.6	2.2	rhythmite
338	58-C	-	-	-	1.8	3.0	1.7	4.8	rhythmite(silt laminae)
339	58-C	-	-	-	0.0	0.4	-	0.4	rhythmite(clay laminae)
340	60-A	2.8	63.0	34.2	0.0	0.4	-	0.4	rhythmite
341	99-B	36.9	48.4	14.7	3.0	9.0	3.0	12.0	diamicton
342	99-B	30.6	49.7	19.7	3.0	7.0	2.3	10.0	diamicton
343	99-B	26.1	49.6	21.3	3.0	7.0	2.3	10.0	diamicton
344	99-B	15.5	48.2	36.3	2.2	8.6	3.9	10.8	diamicton
345	99-C	1.3	24.2	74.5	0.0	0.6	-	0.8	rhythmite
346	99-C	0.2	33.4	66.4	1.8	2.2	1.2	4.0	rhythmite
347	99-C	0.2	37.8	62.0	2.2	2.2	1.0	4.4	rhythmite
350	99-E	5.9	85.5	8.6	1.8	0.8	0.4	2.6	silt
377	60-C	4.0	70.3	25.8	0.0	0.8	-	0.8	rhythmite
379	60-B	3.3	74.1	22.6	1.4	2.2	1.6	3.6	rhythmite
380	58-B	83.8	14.8	1.4	0.0	0.8	-	0.8	sand
381	60-B	24.3	54.2	21.5	1.4	1.6	1.1	3.0	diamicton
382	58-C	0.0	62.2	37.8	0.0	0.8	-	0.8	rhythmite(clay laminae)
383	60-A	1.4	46.9	51.7	1.4	1.6	1.1	3.0	rhythmite(clay laminae)
384	60-B	10.5	55.3	34.2	1.4	1.2	0.8	2.6	diamicton
385	400-B	1.4	82.5	16.1	1.4	1.2	0.8	2.6	rhythmite(silt laminae)
386	58-C	0.4	60.7	38.9	1.8	1.6	0.9	3.4	rhythmite(silt laminae)
387	58-B	29.3	65.1	5.6	0.0	0.8	-	0.8	silt
388	99-B	20.5	64.0	15.5	2.6	6.4	2.5	9.0	diamicton
389	99-C	0.0	27.9	72.1	1.5	2.2	1.2	4.0	rhythmite
390	99-C	0.6	27.3	72.1	1.8	2.2	1.2	4.0	rhythmite

SAMPLE	UNIT	SAND	SILT	CLAY	DOLOMITE	CALCITE	C/D	TOTAL	LITHOLOGY
392	99-C	1.2	31.8	67.8	0.0	0.4	-	0.4	rhythmite
393	99-C	1.2	30.7	68.1	0.0	0.8	-	0.8	rhythmite
394	400-E	27.3	63.2	9.5	1.8	2.6	1.4	4.4	diamicton
395	109	7.1	71.1	21.8	1.8	2.6	1.4	4.4	rhythmite
396	99-G	2.8	50.4	46.8	0.0	0.8	-	0.8	silt
397	58-A	0.0	80.2	19.8	0.0	0.8	-	0.8	rhythmite
398	58-B	20.5	70.5	9.0	0.0	0.8	-	0.8	silt
399	109-B	5.7	90.7	3.6	4.4	7.8	1.8	12.2	silt
405	99-E	10.1	76.8	13.1	0.0	0.8	-	0.8	silt
406	58-B	1.1	78.4	20.5	0.0	0.8	-	0.8	silt
407	109-B	26.9	54.4	18.7	3.0	7.4	2.5	10.4	diamicton
408	99-F	37.8	39.4	22.8	2.6	4.4	1.7	7.0	diamicton
409	109-E	15.7	77.5	6.8	1.4	0.8	0.6	2.2	silt
410	400-B	0.7	68.4	30.9	0.0	0.8	-	0.8	rhythmite
411	98-E	18.5	53.7	27.8	2.6	2.6	1.0	5.2	diamicton
412	99-F	28.0	59.5	12.5	0.0	0.8	-	0.8	silt
416	400-B	0.0	61.3	38.7	1.4	1.2	1.2	2.6	rhythmite
418	600-B	1.2	57.9	40.9	1.4	5.0	3.6	6.4	rhythmite
419	400-B	2.2	62.1	35.7	1.4	4.0	2.8	5.4	rhythmite
420	400-B	0.0	56.6	43.4	0.0	0.8	-	0.8	rhythmite
421	58-C	0.8	45.4	53.8	1.8	3.6	2.0	5.4	rhythmite
422	58-C	3.4	58.3	38.3	0.0	0.8	-	0.8	rhythmite
423	58-C	1.4	63.5	35.1	0.0	0.8	-	0.8	rhythmite
424	60-D	18.9	62.5	18.6	1.4	2.6	1.8	4.0	diamicton
426	98-A	-	-	-	0.0	0.8	-	0.8	rhythmite
429	400-B	-	-	-	0.0	0.8	-	0.8	rhythmite (clay laminae)
430	400-B	-	-	-	0.0	0.8	-	0.8	rhythmite (clay laminae)
431	400-B	-	-	-	1.4	33.6	24	35	concretion
432	99-F	-	-	-	3.0	52.6	17.5	55.6	striated concretion
435	98-A	-	-	-	3.0	47.4	15.8	50.4	concretion
436	60-B	-	-	-	2.2	45.4	20.6	47.6	striated concretion
437	109a-C	-	-	-	4.8	48.4	10.1	53.2	concretion
439	99-C	-	-	-	2.2	54.0	24.5	56.2	concretion

SAMPLE	UNIT	SAND	SILT	CLAY	DOLOMITE	CALCITE	C/D	TOTAL	LITHOLOGY
440	58-A	-	-	-	NA	NA	NA	71.8	concretion
441	58-A	-	-	-	NA	NA	NA	73.4	concretion
442	109a-C	-	-	-	3.6	50.2	13.9	53.8	concretion
443	109-C	-	-	-	2.2	61.4	27.9	63.6	concretion
446	400-B	-	-	-	2.8	32.4	11.6	35.2	concretion (.425 g)
446	400-B	-	-	-	2.4	31.8	13.2	34.2	concretion (.85 g)
450	-	-	-	-	3.6	86.4	24.0	90.0	Black River limestone (.425 g)
450	-	-	-	-	2.0	86.0	43.0	88.0	Black River limestone (.85 g)
453	400-B	-	-	-	8.0	36.0	4.5	44.0	Secondary concretion (.425 g)
454	60-A	-	-	-	3.6	43.6	12.1	47.2	concretion (.425 g)
454	60-A	-	-	-	1.8	45.0	25.0	46.8	concretion (.85 g)
455	98-A	-	-	-	4.4	48.0	10.9	52.4	concretion (.425 g)
455	98-A	-	-	-	3.0	47.8	15.9	50.8	concretion (.85 g)
456	98-A	-	-	-	5.2	46.0	8.8	51.2	concretion (.425 g)
456	98-A	-	-	-	3.0	47.8	15.9	50.8	concretion (.85 g)
457	98-A	-	-	-	3.6	45.2	12.5	48.8	concretion (.425 g)
457	98-A	-	-	-	2.6	45.0	17.3	47.3	concretion (.85 g)
458	98-A	-	-	-	4.4	35.6	8.1	40.0	concretion (.425 g)
458	98-A	-	-	-	5.4	36.4	6.7	41.8	concretion (.85 g)
459	98-A	-	-	-	8.0	44.0	5.5	52.0	concretion (.425 g)
459	98-A	-	-	-	5.4	47.4	8.8	52.8	concretion (.85 g)
460	98-E	-	-	-	3.6	54.0	15.0	57.6	Striated concretion (.425 g)
460	98-E	-	-	-	2.2	54.4	24.7	56.6	Striated concretion (.85 g)
461	98-E	-	-	-	4.4	38.4	8.7	42.8	Striated concretion (.425 g)
					4.0	38.2	9.5	42.2	Striated concretion (.85 g)
462	98-E	-	-	-	4.4	45.2	10.3	49.6	Striated concretion (.425 g)
					2.2	45.0	20.4	47.2	Striated concretion (.85 g)
463	98-E	-	-	-	4.4	48.0	10.9	52.4	Striated concretion (.425 g)
					2.6	48.8	18.8	51.4	Striated concretion (.85 g)
464	98-E	-	-	-	4.4	60.8	13.8	65.2	Striated concretion (.425 g)
					3.2	61.2	19.1	64.4	Striated concretion (.85 g)
465	98-E	-	-	-	4.4	50.0	11.4	54.4	Striated concretion (.425 g)
					3.6	52.2	14.5	55.8	Striated concretion (.425 g)
466	98-E	-	-	-	3.6	47.6	13.2	51.2	Striated concretion (.85 g)
467	-	-	-	-	2.8	7.2	2.6	10.0	Riv. Bécancour Shale (.425 g)
					1.8	7.0	3.9	8.8	Riv. Bécancour Shale (.85 g)

SAMPLE	UNIT	SAND	SILT	CLAY	DOLOMITE	CALCITE	C/D	TOTAL	LITHOLOGY
468	99-F	-	-	-	3.6	55.6	15.4	59.2	Striated concretion (.425 g)
					2.2	56.8	25.8	59.0	Striated concretion (.85 g)
469	99-F	-	-	-	2.8	52.0	18.6	54.8	Striated concretion (.425 g)
					1.8	52.6	29.2	54.4	Striated concretion (.85g)
470	99-F	-	-	-	6.0	52.0	8.7	58.0	Striated concretion (.425 g)
					3.6	54.8	15.2	58.4	Striated concretion (.85 g)
471	109-C	-	-	-	2.8	62.4	22.3	65.2	concretion (.425 g)
					1.8	62.4	34.7	64.2	concretion (.85 g)
472	109-C	-	-	-	2.8	61.2	21.8	64.0	concretion (.425 g)
					1.8	61.2	34.0	63.0	concretion (.85 g)
473	109-C	-	-	-	4.0	60.8	15.2	64.8	concretion (.425 g)
					2.6	62.2	23.9	64.8	concretion (.85 g)
474	109-C	-	-	-	3.2	66.4	20.7	69.6	concretion (.425 g)
					2.2	68.0	30.9	70.2	concretion (.85 g)
425	109-C	-	-	-	4.0	64.4	16.1	68.4	concretion (.425 g)
					2.2	66.0	30.0	68.2	concretion (.85 g)
476	109-C	-	-	-	4.4	61.6	14.0	66.0	concretion (.425 g)
					2.6	63.0	24.2	65.6	concretion (.85 g)
477	109-C	-	-	-	3.6	64.4	17.9	68.0	concretion (.425 g)
					1.8	64.4	35.8	66.2	concretion (.85 g)
478	109-F	-	-	-	4.4	52.8	12.0	57.2	Striated concretion (.425 g)
					3.6	53.6	14.9	57.2	Striated concretion (.85 g)
479	109a-B	-	-	-	2.8	67.2	24.0	70.0	concretion (.425 g)
					1.8	67.0	37.2	68.8	concretion (.85 g)
480	109a-B	-	-	-	1.4	68.0	48.6	69.4	concretion
481	400-B	-	-	-	3.6	44.4	12.3	48.0	concretion (.425 g)
					2.2	45.0	20.4	47.2	concretion (.85 g)
482	400-B	-	-	-	3.6	45.2	12.5	48.8	concretion (.425 g)
					2.2	43.6	19.8	45.8	concretion (.85 g)
483	60-A	-	-	-	1.8	41.0	22.8	42.8	concretion
937	59-A	-	-	-	0.0	44.0	-	44.0	concretion (side)
					1.4	48.6	35	50.0	concretion (center)
938	109a-E	-	-	-	1.4	64.4	46	65.8	concretion
939	58-C	0.2	58.7	41.1	1.4	0.8	0.6	2.2	rythmite (clay laminae)
940	58-C	-	-	-	NA	NA	NA	40.8	calcareous crust

SAMPLE	UNIT	SAND	SILT	CLAY	DOLOMITE	CALCITE	C/D	TOTAL	LITHOLOGY
941	60-E	94.2	5.8	0.0	2.2	3.0	1.4	5.2	sand
942	400-A	97.0	3.0	0.0	0	0	-	0	sand
943	109a-D	96.0	2.0	2.0	0	0	-	0	sand
944	400-D	90.6	7.4	2.0	0	0.4	-	0.4	sand
945	400-E	30.1	62.3	7.6	1.8	2.2	1.2	4.0	diamicton
946	58-D	0.0	72.4	27.6	1.8	1.6	1.0	3.4	silt
947	58-C	0.0	78.6	21.4	2.2	1.2	0.5	3.4	rhythmite
948	58-C	0.0	84.7	15.3	1.8	3.6	2.0	5.4	rhythmite
949	58-A	2.0	72.9	25.1	0.0	0.0	-	0.0	rhythmite
950	109a-E	7.2	77.3	15.5	0.0	0.0	-	0.0	rhythmite
951	109a-E	0.3	50.8	48.9	0.0	4.0	-	4.0	rhythmite
952	109a-E	0.5	64.5	35.0	0.0	0.0	-	0.0	rhythmite
953	109a-E	0.5	74.9	24.6	0.0	0.0	-	0.0	rhythmite
954	109a-A	13.9	70.8	15.3	2.6	5.0	2.0	7.6	diamicton
955	400-C	0.7	82.9	16.4	2.2	1.2	0.5	3.4	breccia
956	400-C	0.2	87.9	11.9	0.0	0.0	-	0.0	breccia
101	65-D	36.1	52.4	11.5	1.8	3.0	1.7	4.8	diamicton
102	65-D	43.3	43.2	13.5	2.2	4.0	1.8	6.2	diamicton
103	65-D	39.9	47.0	13.1	2.6	2.6	1	5.2	diamicton
104	65-C	98.5	0.0	1.5	0	0	-	0	sand
105	65-C	97.2	0.8	2.0	2.2	3	1.4	5.2	sand
106	65-B	41.1	45.4	13.5	1.8	2.2	1.2	4.0	diamicton
107	65-B	40.2	47.2	12.6	2.2	2.2	1.0	4.4	diamicton
108	65-B	61.9	31.3	6.8	2.2	2.2	1.0	4.4	diamicton
109	65-B	3.0	71.7	25.3	2.2	1.6	0.7	3.8	rhythmite
110	400-B	37.3	48.5	14.2	2.2	2.2	1.0	4.4	diamicton
111	58-B	95.2	0.8	4.0	1.4	0.0	0.0	1.4	sand
112	-	-	-	-	2.6	91.2	35.1	93.8	Trenton limestone
113	-	-	-	-	4.8	23.2	4.8	28.0	Utica shale
114	-	-	-	-	2.2	62.2	28.3	64.4	Lorraine limestone
135	65-A	0.0	61.0	39.0	4.4	1.4	0.3	5.8	rhythmite
136	60-C	4.0	73.0	23.0	0.0	0.8	0.0	0.8	rhythmite

N.B.: 1) sand, silt and clay totalize 100%
2) samples 186 to 956 correspond to laboratory number 9186 to 9956; 101 to 136 correspond to 10101 to 10136
3) sample 114 is from a thin bed of limestone interbedded with shale and sandstone.

TABLE A-2 PEBBLE COUNTS

UNIT	FABRIC NUMBER	N	CRYST. R	CONCR.	RED CLASTICS	Pierreville NOT RED SED.	St-Pierre LIMEST.	SHAL.
98-E	FT-005	124	50 40.3%	13 10.5%	5 4.0%	56 45.2%		
99-F	FT-003	128	100 78.1	4 3.1	4 3.1	20 15.6		
99-F	FT-004	50	15 30	3 6	10 20	22 44		
109-B	FT-001	271	36 13.3	0 0	46 17.0	189 69.7		
109-F	FT-002	105	65 61.9	1 0.9	9 8.6	30 28.6		
60-B	FT-101	151	78 51.7	1 0.7	0 0		69 45.7	3 2.0
60-D	FT-002	90	23 25.6	0 0	0 0		59 65.6	8 8.9
65-B	FT-108	240	95 39.6	2 0.8	0 0		143 59.6	0 0
65-D	FT-110	173	36 20.8	0 0	0 0		109 63.0	28 16.2
400-D	FT-103	147	31 21.1	2 1.4	0 0		90 61.2	24 16.3
400-B	Sample 110	401	60 15	3 0.7	0 0		338 84.3	0 0

(See appendix V for meaning of headings)

II-C Directional data

Till fabrics, shear planes and current directional data were measured using a Brunton compass and aluminium knitting needles.

Three-dimensional fabric used the long (A), intermediate (B) and short (C) axes of elongated pebbles (A/B > 1.5) and the A-B planes (i.e. C axes) of disc-shaped pebbles. Data have been processed using a computer program written by Starkey (1977) and eigenvectors calculated by the method discussed by Mark (1971, 1974). Results are shown on Table A-3 . Comparison of the vectorial data with the contoured diagrams (Fig. 2-10 and 2-25) reveals that, in some cases, eigenvectors , may be statistical artifacts. S values reflect clustering of the eigen vector whereas θ is a measure of dispersion around it. It should be noted that major eigenvector of the A-axis fabric may fall outside the A/B plane since this plane is related to the C-Axis fabric which is constructed from the A and B axis of elongated pebbles as well as the C axis of disc-shaped pebbles.

Directional data on non-glacial units were measured using the lee side of cross-bedded sedimentary structures. Rose diagrams were constructed by grouping measurements into 20^{o} intervals.

TABLE A-3 TILL FABRIC

STATISTICAL PARAMETERS

ECHANT.	N		Azimuth(°)	Dip (°)	S	θ (°)
FT-001	25	V_1	347	15	0.08797	26.0
		V_2	092	43	0.12499	69.3
		V_3	242	43	0.06703	75.0
FT-002	49	V_1	137	67	0.65317	36.1
		V_2	337	22	0.24637	60.2
		V_3	243	07	0.10045	71.5
FT-003	25	V_1	013	16	0.63131	37.4
		V_2	104	02	0.25685	59.4
		V_3	201	74	0.11184	70.5
FT-004	50	V_1	249	05	0.52086	43.8
		V_2	155	47	0.30563	56.4
		V_3	345	42	0.17351	65.4
FT-005	50	V_1	349	27	0.54073	42.7
		V_2	257	01	0.27632	58.3
		V_3	165	63	0.18294	64.7
FT-006	25	V_1	281	26	0.52821	43.4
		V_2	024	26	0.41479	49.9
		V_3	153	51	0.05700	76.2
FT-007	36	V_1	343	44	0.55766	41.7
		V_2	139	44	0.30223	56.6
		V_3	240	12	0.14010	68.0
FT-008	28	V_1	135	55	0.41483	49.9
		V_2	014	19	0.31739	55.7
		V_3	275	28	0.26777	58.8
FT-101	48	V_1	336	05	0.59963	39.3
		V_2	067	18	0.29795	56.9
		V_3	232	71	0.10242	71.3
FT-102	34	V_1	180	18	0.59316	39.6
		V_2	303	59	0.27978	58.1
		V_3	082	25	0.12706	69.1
FT-103	49	V_1	251	21	0.72206	31.8
		V_2	139	45	0.16880	65.7
		V_3	359	37	0.10913	70.7

ECHANT	N		Azimuth (°)	Dip (°)	S	θ(°)
PSO-104	47	V_1	070	70	0.48921	45.6
		V_2	323	07	0.29567	57.1
		V_3	230	19	0.21511	62.4
FT-105	38	V_1	044	65	0.70234	33.1
		V_2	188	21	0.18395	64.6
		V_3	285	13	0.11370	70.3
FT-106	47	V_1	235	60	0.76612	28.9
		V_2	067	30	0.16261	66.2
		V_3	335	05	0.07126	74.5
FT-107	30	V_1	311	65	0.48364	45.9
		V_2	131	25	0.34570	54.0
		V_3	040	00	0.17066	65.6
FT-108	52	V_1	145	28	0.73941	30.7
		V_2	051	05	0.15933	66.5
		V_3	313	61	0.10126	71.4
FT-109	26	V_1	316	61	0.77220	28.5
		V_2	074	15	0.18840	64.3
		V_3	172	24	0.03940	78.6
FT-110	49	V_1	318	29	0.62021	38.0
		V_2	047	00	0.30242	56.6
		V_3	139	61	0.07737	73.8
FT-111	35	V_1	119	58	0.81723	25.3
		V_2	000	17	0.09803	71.8
		V_3	260	26	0.08474	73.1

II-D Clay mineralogy

Preparation of the samples for X-Ray diffraction is discussed below and the results are shown on Table A-4.

The clay fraction (<2μm) of selected samples was separated by sedimentation in a sodium oxalate solution after removal of organic matter, calcium carbonate and iron oxide following methods described by Carson and Arcaro (1983). Sodium hypochlorite was used to remove organic matter (Anderson, 1961). Calcium carbonate was dissolved with sodium acetate and iron coatings were extracted with a sodium citrate-bicarbonate-dithionite solution, these procedures are described by Mehra and Jackson (1960). Mounts of the samples were prepared following the filter-membrane peel technique proposed by Drever (1975) using 75 mg aliquots.

Another series of samples was irradiated without chemical preparation. All samples were glycolated by a glycerol spray prior to diffraction. The samples have been irradiated in a Siemens diffractometer using a Cu cathode (CuKα = 1.5418Å). Goniometer rate was 2^{o} 2θ/min..

Peak heights were measured following the suggestion of Rieck et al. (1979) and the width at middle-height of the illite first-order peak measured to give a general idea of the amount of interstratified clay minerals which are believed to cause the presence of a shoulder on the low-angle side of the 9.9Å peak. The width to height peak ratio (L/10Å) should reflect the crytallinity of illite but , in this case, it probably does not.

TABLE A-4

CLAY MINERALOGY CHARACTERISTICS-A

UNIT	SAMPLE	14/10Å	7/10Å	L/10Å
98-A	1	0.48 ± 0.10	1.48 ± 0.34	0.27 ± 0.16
	2	0.56 ± 0.10	1.74 ± 0.06	0.36 ± 0.04
	3	0.48 ± 0.12	1.36 ± 0.31	0.37 ± 0.14
99-C	4	0.23 ± 0.04	0.75 ± 0.07	0.15 ± 0.03
	5	0.26 ± 0.01	0.99 ± 0.08	0.11 ± 0.02
	6	0.29 ± 0.03	1.02 ± 0.02	0.16 ± 0.03
59-A	7	0.25 ± 0.06	0.74 ± 0.04	0.25 ± 0.07
	8	0.46 ± 0.03	0.93 ± 0.11	0.25 ± 0.06
58-C	9	0.77 ± 0.07	1.52 ± 0.02	0.29 ± 0.06
	10	0.69 ± 0.06	1.44 ± 0.08	0.24 ± 0.01
	11	0.44 ± 0.01	1.36 ± 0.07	0.36 ± 0.06
	12	0.40 ± 0.03	1.46 ± 0.13	0.26 ± 0.07
60-C	13	0.48 ± 0.09	1.38 ± 0.17	0.30 ± 0.12
	14	0.65 ± 0.08	1.43 ± 0.11	0.28 ± 0.03
	15	0.54 ± 0.10	1.64 ± 0.25	0.52 ± 0.19
400-B	16	0.77 ± 0.02	1.15 ± 0.05	0.32 ± 0.03
	17	0.58 ± 0.06	1.50 ± 0.21	0.33 ± 0.07
	18	0.43 ± 0.04	1.44 ± 0.32	0.19 ± 0.02
	19	0.46 ± 0.05	1.28 ± 0.04	0.17 ± 0.03
	20	0.33 ± 0.01	1.43 ± 0.19	0.25 ± 0.06

N.B.: For above, three measurements per samples; with chemical pretreatment.

CLAY MINERALOGY CHARACTERISTICS-B

UNIT	SAMPLE	14/10Å	7/10Å	L/10Å
98-A	21	0.62	1.40	0.20
	22	0.60	1.23	0.20
	23	0.51	1.01	0.19
	24	0.36	1.07	0.18
	25	0.44	0.83	0.10
99-C	26	0.26	0.36	0.08
	27	0.24	0.40	0.08
	28	0.23	0.41	0.07
	29	0.25	0.55	0.08
	30	0.34	0.75	0.05
	31	0.34	0.75	0.10
	32	0.42	0.76	0.09
	33	0.29	0.77	0.08
59-A	34	0.31	0.94	0.06
	35	0.44	1.00	0.07
	36	0.32	0.89	0.09
58-C	37	0.26	0.92	0.10
	38	0.34	0.88	0.07
	39	0.36	0.89	0.12
	40	0.37	0.73	0.06
	41	0.41	0.99	0.14
	42	0.30	0.78	0.08
	43	0.29	0.94	0.19
60-C	44	0.28	0.64	0.08
	45	0.31	0.52	0.12
	46	0.34	0.80	0.11
	47	0.44	0.97	0.09
400-B	48	0.34	0.71	0.05
	49	0.32	0.68	0.07
	50	0.38	0.79	0.07
	51	0.35	0.82	0.06
	52	0.25	0.78	0.05
	53	0.29	0.83	0.05
	54	0.27	0.94	0.07

N.B.: For above, one measurement per sample; no chemical pretreatment.

APPENDIX III ISOTOPIC ANALYSES OF CONCRETIONS

Carbon and oxygen isotopic ratios have been measured at the GEOTOP laboratory of the Département des Sciences de la Terre (Université du Québec à Montréal). Powdered samples of calcareous concretions found in tills and glaciolacustrine sediments have been analyzed on a Micromass 602C mass spectrometer following standard gas extraction. Analytical error is ±0.1°/oo for $\delta\ ^{18}O$ and ±0.2°/oo for $\delta\ ^{13}C$. Isotopic ratios are given with reference to PDB (Craig, 1957). Analyses were carried out by M.-A. Cloutier under the supervision of P. Pagé of GEOTOP. Results are shown on Table A-5.

TABLE A-5: RESULTS OF ISOTOPIC ANALYSES

Sample	Unit	$\delta^{13}C/PDB$ $^{o}/oo$	$\delta^{18}O/PDB$ $^{o}/oo$
3a	98-A	-20.9	-14.9
4	98-A	-21.2	-15.0
5	98-A	-21.8	-15.1
6	98-A	-20.6	-15.3
7	98-A	-21.3	-15.3
8	98-A	-21.8	-10.1
10	99-109C	-21.1	- 9.6
11	99-109C	-17.7	-12.5
12	99-109C	-20.2	-13.8
14	99-109C	-19.6	-13.0
15	99-109C	-20.7	-14.2
18	99-109C	-16.1	-13.5
19	99-109C	-17.7	-13.3
62a	99-109C	-18.8	-13.2
62b	99-109C	-19.3	-13.6
79	99-109C	-10.3	- 7.4
83	99-109C	-19.8	-13.6
9	99-F	-22.3	-14.8
12-2	99-F	-19.2	-13.6
16	99-F	-20.6	-14.2
64	99-F	-20.2	-15.5
80	99-F	-23.5	-10.9
81	99-F	- 9.4	-15.4
65	98-E (striated)	-21.0	-15.3
72	98-E (striated)	-19.9	-12.9
73	98-E (striated)	-21.2	-14.9
74	98-E (striated)	-21.7	-15.0
75	98-E (striated)	-20.3	-14.9
76	98-E (striated)	-19.3	-14.8
77	98-E (striated)	-20.4	-14.7
78	98-E (striated)	-20.0	-14.1
70	60-A	-19.4	-10.0
60	59-A (iron rich)	-10.1	- 5.2
63	59-A (iron rich)	- 8.3	- 6.7
68	59-A (iron rich)	-10.9	- 6.0
69	59-A (iron rich)	- 8.7	- 5.6
99	59-A (iron rich)	-21.4	-10.9
98	58-C	+ 4.0	- 8.4

APPENDIX IV THERMOLUMINESCENCE DATING APPARATUSES

The TL reader used at the Physics Department of Simon Fraser University is similar to the one described in Aitken (1974). The mineral grains settled on a small aluminum disc are heated on a kanthal heating strip. A thermal compound (from Wakefield Eng.) insures a good thermal contact between the disc and the strip. The glow oven is evacuable and, during heating, Argon flows constinuously in the oven at 1L/min at a pressure of 20μm. A 5 ml beaker of P_2O_5 is placed at the bottom of the chamber to remove moisture. The heating rate was $3^{o}C/S$.

Light is measured by a photomultiplier tube (EMI 9635). Two filters are placed between the tube and the sample: an infra-red (heat absorbing) and a Corning 5-58 (blue transmitting) filter. Due to the very high amount of light generated by the samples, neutral density filters were also added in some cases. Photon counts are fed to a multiple channel analyzer from which glow curves can be transferred onto a magnetic tape for processing.

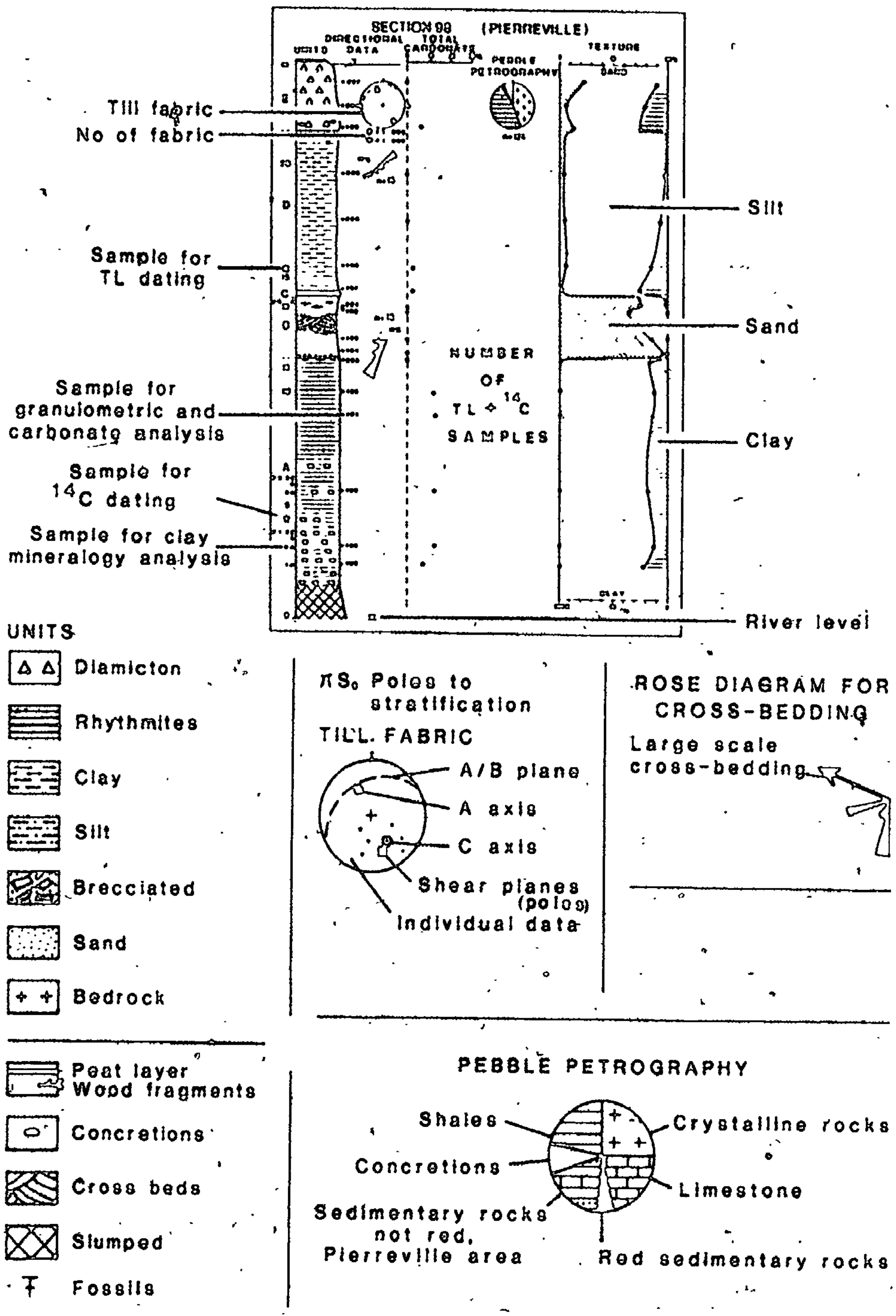
Gamma irradiations were provided by a Gammacell-200 Co-60 source that yielded dose-rates to Quartz of 2.23, 2.11, 1.95 and 1.89 Gy/min, during the four periods during which investigation was carried out. At this stage of research, it was considered that the dose delivered to the sample during its up and down movement should not be taken into account (0.2 Gy).

A multiple-source alpha irradiator (Am-241, 2mCi) was used to measure the a-value.

Description of the alpha-counting equipment can be found in Huntley and Wintle (1978). Potassium was measured by atomic absoption at the Département des Sciences de la Terre (Université du Québec à Montréal).

APPENDIX V

GENERAL LEGEND
STRATIGRAPHIC LOG



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