TH 0842

QUATERNARY GEOLOGY OF THE BAIE-DES-SABLES/TROIS-PISTOLES AREA, QUEBEC, WITH SOME EMPHASIS ON THE GOLDTHWAIT SEA CLAYS

QUATERNARY GEOLOGY OF THE BAIE-DES-SABLES/TROIS-PISTOLES AREA, QUÉBEC, WITH SOME EMPHASIS ON THE GOLDTHWAIT SEA CLAYS

by

JACQUES LOCAT

A thesis

Presented to the University of Waterloo
in Partial Fulfillment of the Requirements
for the Degree of
Master of Science
in
the Department of Earth Sciences

Waterloo, Ontario, 1976

Approved for Department of Earth Sciences

W. A. Gorman

Owen L. White

P F Karrow

Edward C. Appleyard

I hereby declare that I am the sole author of this thesis.

I authorize the University of Waterloo to lend this thesis to other institutions or individuals for the purpose of scholarly research.

Signature

I further authorize the University of Waterloo to reproduce this thesis by photocopying or by other means, in total or in part, at the request of other institutions or individuals for the purpose of scholarly research.

Signature

The University of Waterloo requires the signatures of all persons using this thesis. Please sign below, and give address and date.

RESUMÉ

Les dépots quaternaires cotiers et du plateau adjacent, de la région de Baie-des-Sables/Trois-Pistoles, furent cartographiés, par l'auteur, à l'été 1974. Durant cette même période, huit sites furent choisis pour fins d'études géotechniques. Une attention toute speciale fut accordée aux terrasses marines et aux coulées boueuses de la région.

L'histoire du Quaternaire de la région étudiée peut se diviser en quatre phases principales: (1) pré-wisconsinienne (>60000 ans A.A.), (2) glaciaire (60000 - 14000 ans A.A.), (3) glacio-marine (14000 - 12000 ans A.A.), (4) marine (<12000 ans A.A.).

Cette étude confirme que le dernier mouvement des glaces s'est effectué vers le nord et le nord-est. D'une facon générale, le modèle d'écoulement des glaces, au Fini-glaciaire, proposé par Gauthier (1975) s'applique à la région étudiée.

La phase glacio-marine (vers 14000-12000 ans A.A.) marque le début de la sédimentation marine dans la région étudiée. Aux moins deux types de dépots marins furent mis en place depuis cette période: une argile glacio-marine (caillouteuse) et une argile massive. La transition entre ces deux types d'argiles est representée par une argile massive dite "haute" qui aurait été déposée alors que le front glaciaire gisait sur les premières collines et que le niveau eustatique était encore élevé (environ 120 m a.n.m.). Cette transition indique le passage de la phase glacio-marine à la phase marine (<12000 ans A.A.).

La limite de la transgression marine, dans la région, augmente d'est en ouest; de 115 mètres près de St. Ulric, elle atteint 166 mètres à Trois-Pistoles. Ceci indique un plan incliné vers le nord-est à environ 0.4 m/km.

La faune marine antérieure à environ 10000 ans A.A., representée par seulement quelques espèces de pélécypodes (e.g. Hiatella arctica) et de foraminifères (e.g. Elphidium sp.), reflète des eaux froides et saumâtres. Par la suite les eaux se réchauffèrent et devinrent plus salines, tel qu'indiqué par la venue d'espèces nouvelles (e.g., Portlandia arctica, Astarte sp.). Au total, 30 espèces différentes furent identifiées, ajoutant ainsi 11 nouvelles espèces à la liste établie par Wagner (1962) pour la région de Rivière-du-Loup/Trois-Pistoles. Des sites fossilifères étudiés, le site du delta de contact de glace de St. Fabien est le plus élevé de toute la région du Bas-St-Laurent/Gaspésie, soit à une altitude de 138 mètres. Des fossilles de Hiatella arctica, à ce même site, ont fournis une date au carbone-14 de 13390 ± 690 ans A.A. (QU-271). Les fossilles ayant été collectés dans une poche de till à l'intérieur du delta, me permet de suggerer une date d'environ 13,400 ans A.A. pour la position d'un front glaciaire à St. Fabien.

D'autres dates au C^{14} sur des échantillons pris aux différents niveaux de terrasses marines, ont permis l'établissement d'une courbe d'émergence des terres pour la zone étudiée. Le relèvement relatif des terres se serait effectué en deux phases principales: (1) 13500 à 10000 ans A.A., de 4.0 à 1.0 cm/an environ et (2) depuis 10000 ans de 1.0 à 0.2 cm/an. La transition d'une phase à l'autre coinciderait avec l'émergence de la terrasse de Bic et de l'escarpement Ste-Flavie (environ 25 mètres).

En plus des sites d'études géotechniques, la terrasse de Bic, près de St. Ulric fut étudiée en détail. Le relief de la zone cotière apparait controlé par les dépots meubles. Toutefois, il appert que la pente de la plateforme de Bic est partiellement controllée par son propre talus (escarpement Ste. Flavie) quand ce dernier est decoupé dans la roche en place.

Dans un tel cas, la hauteur de l'escarpement est plus élevée et la pente de la plateforme plus faible. L'étude sismique, à ce même site, à permis de démontrer l'existence d'un relief enfoui. Ce relief consiste en vallées ou sillons orientés parallèlement à l'Estuaire. Les travaux, à St. Ulric, permettent de confirmer les idées antérieures concernant le modelé pré-glaciaire de l'estuaire et du golfe du St-Laurent (Nota and Loring, 1964).

L'analyse de quelques échantillons d'argiles marines de la région indique que le propriétés de ces sediments marins seraient controllées par les dimensions exigues du bassin sédimentaire. Un faible délavage des sels, une meilleure crystallinité des minéraux argileux (illite), et une cimentation plus faible, auraient induis aux argiles marines de la région une faible sensibilité (argiles sensibles, mais non rapides ou "quick").

L'étude au microscope électronique (transmission) de un échantillons d'argiles marines a montré que les particules argileuses (<2 microns) ont une forme irrégulière et qu'elles sont subangulaires. L'analyse par diffraction au rayons-X de cinq échantillons d'argiles révèle la présence de minéraux argileux bien crystallisés et de minéraux non-argileux. Les minéraux suivant furent identifiés: illite, chlorite, interstratifiés associés à la vermiculite, quartz, feldspath, et calcite. L'étude en lame mince et au rayons-X de la microfabrique de deux échantillons d'argiles suggère une orientation de minéraux argileux plus ou moins parallèle au litage, causée soit par l'environnement sédimentaire, l'échantillonnage, ou les deux.

La teneur en tritium et deuterium de l'eau intersticielle d'argiles marines de l'est du Canada fut estimée pour la première fois. Les résultats indiquent que l'argile de Rimouski à une faible perméabilité (peu de tritium), et que les horizons inférieurs sont loins d'être complètement délavés (beaucoup de deuterium). Le caractère massif des argiles de la région pourrait ainsi contribuer à la faible sensibilité observée pour les argiles de la région.

ABSTRACT

The Quaternary deposits of the Baie-des-Sables/Trois-Pistoles area of eastern Québec were mapped along the coast and parts of the upland. At the same time (summer 1974), eight sites were chosen for geotechnical investigations. Special attention was given to the character and origin of marine terraces and earthflows.

The Quaternary geology and history of the Baie-des-Sables/Trois-Pistoles area is divided into four phases: (1) a pre-Wisconsin (>60000 y.B.P.), (2) Ice (60000-14000 y.B.P.), (3) Ice-Sea (14000-12000 y.B.P.), and (4) Sea (post-12000 y.B.P.) phases.

A late ice movement to the north and the northeast was confirmed for the Lower St. Lawrence/Gaspé region. Gauthier's model of deglaciation (1975) was applied to the present area in order to explain the effects of a Laurentian ice-sheet and an Appalachian ice-sheet.

The marine invasion of the Goldthwait Sea left at least two types of marine deposits: the older, stony glacio-marine clay, and a younger massive clay. The transition between these two units is considered to be the "high" massive clay that was deposited when the ice front receded to the edge of the upland while the sea level was at 115 to 166 metres above present sea level.

The marine limit in the area varies from 115 metres near St. Ulric to 166 metres near Trois-Pistoles (a gradient of 0.4 m per kilometer).

Fossil faunal assemblages from the marine deposits comprise 30 species, an addition of 11 species to the previous list for the Rivière-du-Loup/Trois-Pistoles area of Wagner (1962). The highest marine fossil locality in the Lower St. Lawrence/Gaspé region so far discovered is in the ice-

contact delta of St. Fabien at 138 metres above present sea level. This site yielded the oldest radiocarbon date in the area (13390 ± 690 y.B.P.: QU-271). Fossil assemblages from the earlier phases of marine submergence are characterized by pelecypods (e.g., Hiatella arctica) and a few foraminifera (such as Elphidium sp.) typical of cold and brackish water. However, after 10000 y.B.P. fossil assemblages diversified and the presence of Portlandia arctica and Astarte sp. indicates the presence of more saline waters (Wagner, 1970).

The rate of land emergence was approximated by the use of C^{14} dates and is characterized by two main phases. The first, from 13500 y.B.P. to about 10000 y.B.P., was at a rate of about 4.0 to 1.0 cm/year. A second phase, from 10000 y.B.P. until today was at a rate from 1.0 to 0.2 cm/year. The transition from one rate to another coincides with the emergence of the Bic Terrace and the Ste-Flavie escarpment (around 25 metres).

Geotechnical investigations, including drilling, seismic profiles, and penetrometer tests, were carried out to study a few sites close to the marine terraces or earthflows.

The study of the Bic Terrace near St. Ulric has shown that the coastal zone has a relief controlled by Quaternary deposits which cover old channels or valleys subparallel to the St. Lawrence Estuary. These channels were found to become wider and deeper from the edge of the upland toward the estuary. It is believed that the present work confirms previous ideas on the pre-glacial morphology of the Estuary and Gulf of St. Lawrence (Nota and Loring, 1964).

From surface and deep samples, various tests were performed on the marine deposits of the area. The Goldthwait Sea clay, as found on the land, has at least some of its properties controlled by the limited size

of the sedimentary basin. In general, this clay has a low sensitivity compared to the Champlain Sea clays, due to less leaching, abundance of well-crystallized clay minerals, and less cementation. These results partly explain the rather few earthflows that have occurred in the area.

Based on the examination of one sample by transmission electron microscopy, the clay particles of the Goldthwait Sea clays are subangular to angular in shape. The main clay minerals encountered were, in order of importance, illite (mica-like), chlorite, and probably some mixed-layered minerals associated with vermiculite. Primary minerals such as quartz, feldspar, and calcite were also observed in the clay fraction. A microfabric study of this clay was carried out on two samples showing that it has a preferred orientation parallel to the bedding, induced either by sedimentary environment, sampling disturbance, or both.

The content of tritium and deuterium in the clays of Eastern Canada was analyzed for the first time. Results indicate that the clay analyzed at Rimouski has a slow flushing rate (low tritium) and that the leaching processes in the lower horizon analyzed is far from being completed (high deuterium). These results reflect the massive aspect of the marine clay which can be partly responsible for the low sensitivity observed.

ACKNOWLEDGMENTS

The writer wishes to thank the Québec Ministry of Natural Resources (Q.M.N.R.) for providing employment and bursaries in support of this thesis project. To my supervisor, Dr. P.F. Karrow, my sincere thanks for guidance and advice. Thanks are due to Drs. J.A. Cherry, E.C. Appleyard, O.L. White, and W.A. Gorman for invaluable critical reading and suggestions.

The writer wishes to express his appreciation to Dr. J.Y. Chagnon (Q.M.N.R.) for his full support and the freedom he gave me in carrying out the work on which the thesis is based. To D.J. Dion (Q.M.N.R.), who was the coordinator of the project, my sincere appreciation for his co-operation and patience.

Such work is not possible without help from many people. J. Lebuis (Q.M.N.R.) gave me valuable information, some training, and provided discussions that were essential to the work done. The writer appreciates the diligent work and support from his field assistants during winter and summer 1974, namely: C. Bouchard, P. Gagnon, and R. Gosselin. The writer also thanks members of the various field crews that came to work with him in the map area, involving seismic geophysics, drilling, and surveying.

To Dr. P. Lasalle (Q.M.N.R.), my sincere thanks for so kindly providing C^{14} dates, total chemical analyses, and X-ray diffractions, on samples collected by the writer. Dr. F.J.E. Wagner identified most of the fossils collected by the writer; her comments were very helpful. The writer also wishes to thank Dr. R.H. Brown (Chalk River Nuclear Research Centre) for analysing tritium and deuterium content of four samples collected by the writer. Thanks are due to D. Ouellet (Q.M.N.R.) who did most of the laboratory analyses related to engineering properties.

Valuable discussions and comments on this project were kindly given by N.R. Morgenstern (University of Alberta), R. May (University of Alberta), L. Dredge (Geological Survey of Canada), C. Gauthier (G.S.C.), G. Martineau (Université de Montréal), and G. Lortie (McGill University). To my colleagues at the Department of Earth Sciences at Waterloo, my sincere thanks for continual support both scholarly and socially, namely: A. Liard, M. and D. Verge, D.P. Smith, P. Tremblay, G. and D. Nolan.

Finally the writer wishes to thank his parents for continual support and encouragement, and special recognition must be devoted to my wife, Ghyslaine Majeau-Locat, who gave me constant moral support and also did most of the drafting found in this thesis. So to all these people, my sincere thanks for making this research project an interesting and stimulating one.

TABLE OF CONTENTS

CHAPTER

TABLE OF CONTENTS (cont'd)

TABLE OF CONTENTS (cont'd)

***

TABLE OF CONTENTS (cont'd)

LIST OF FIGURES

LIST OF FIGURES (cont'd)

LIST OF FIGURES (cont'd)

LIST OF FIGURES (cont'd)

LIST OF FIGURES (cont'd)

LIST OF TABLES

LIST OF TABLES (cont'd)

CHAPTER I INTRODUCTION

OBJECTIVES

Landslides in marine sediments are perhaps the most important natural hazard faced by the residents of Québec. As part of an ongoing program to evaluate landslide hazards in the St. Lawrence Valley, the Office de Développement de L'Est du Québec (O.D.E.Q.) accepted a proposal by the Service de Géotechnique of the Québec Ministry of Natural Resources (Q.M.N.R.) to study landslide susceptibility in the Rivière-du-Loup/ Ste. Anne-des-Monts area (Fig. 1). The project started in 1972 and had to be completed by April 1975. The writer was involved in the project from August 1973, while he was employed by the Q.M.N.R..

The aim of the project, as of August 1973, was to prepare maps based on mapping of surficial deposits indicating zones susceptible to sliding. The coastal area between Baie-des-Sables and Trois-Pistoles (Fig. 1, and Fig. 2, in pocket) remained unmapped after the work of Lebuis (1973b) and Lee (1962); mapping of that area became the main field work carried out by the writer.

This thesis then provides a description and historical synthesis of the Quaternary geology of the Baie-des-Sables/Trois-Pistoles area, based on the reconnaissance mapping of the area carried out in the summer of 1974. The purely geological aspects are further supplemented by consideration of the problems of slope stability in this area of marine sediments. Since the sensitive deposits in this area are the marine clays, a drilling program was established in order to provide some minimal information on the engineering properties of the clays and their stratigraphic relations, so that a better understanding of their behaviour could be obtained.

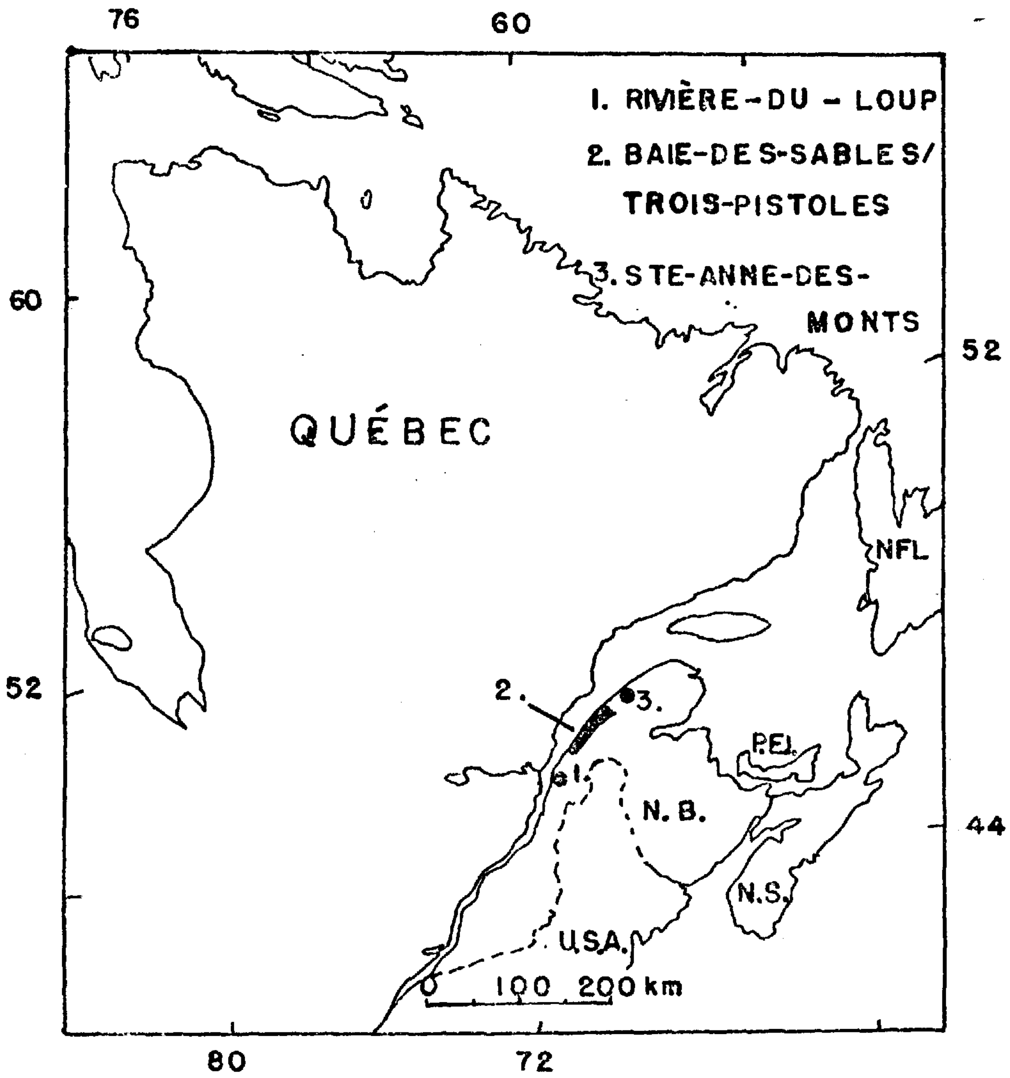


Figure 1. Location Map.

With most of the laboratory analyses performed either by the Q.M.N.R., or a private company (Technisol Inc.), the writer decided to analyse this information, present it, and also gain more understanding of other tools such as electron microscopy and thin sectioning. The thesis based on this work was to form the main basis for the final report to be forwarded to the Q.M.N.R. and O.D.E.Q..

The writer did not have, at that time, the background to provide detailed slope stability analyses. Therefore, parts of this thesis dealing with the engineering properties give only minimal estimates of properties which needed to be assessed in the area, since no such investigation had been carried out before.

Although the thesis deals with many subjects, it forms a whole that contributes to our knowledge of the geology of the area. It also presents basic information that was not fully interpreted by the writer, but should be available to other scientists interested in the beautiful Gaspésie.

GENERAL DESCRIPTION OF THE AREA

The Map Area

The map-area (Fig. 3, about 2400 sq km) is rectangular in shape, oriented southwest-northeast along the south shore of the St. Lawrence Estuary. It extends from Trois-Pistoles in the southwest to the Tartigou River in the northeast, a distance of about 120 kilometers, and extends inland some 15 to 25 kilometers, from the south shore of the St. Lawrence to near the limit of the late-glacial marine submergence.

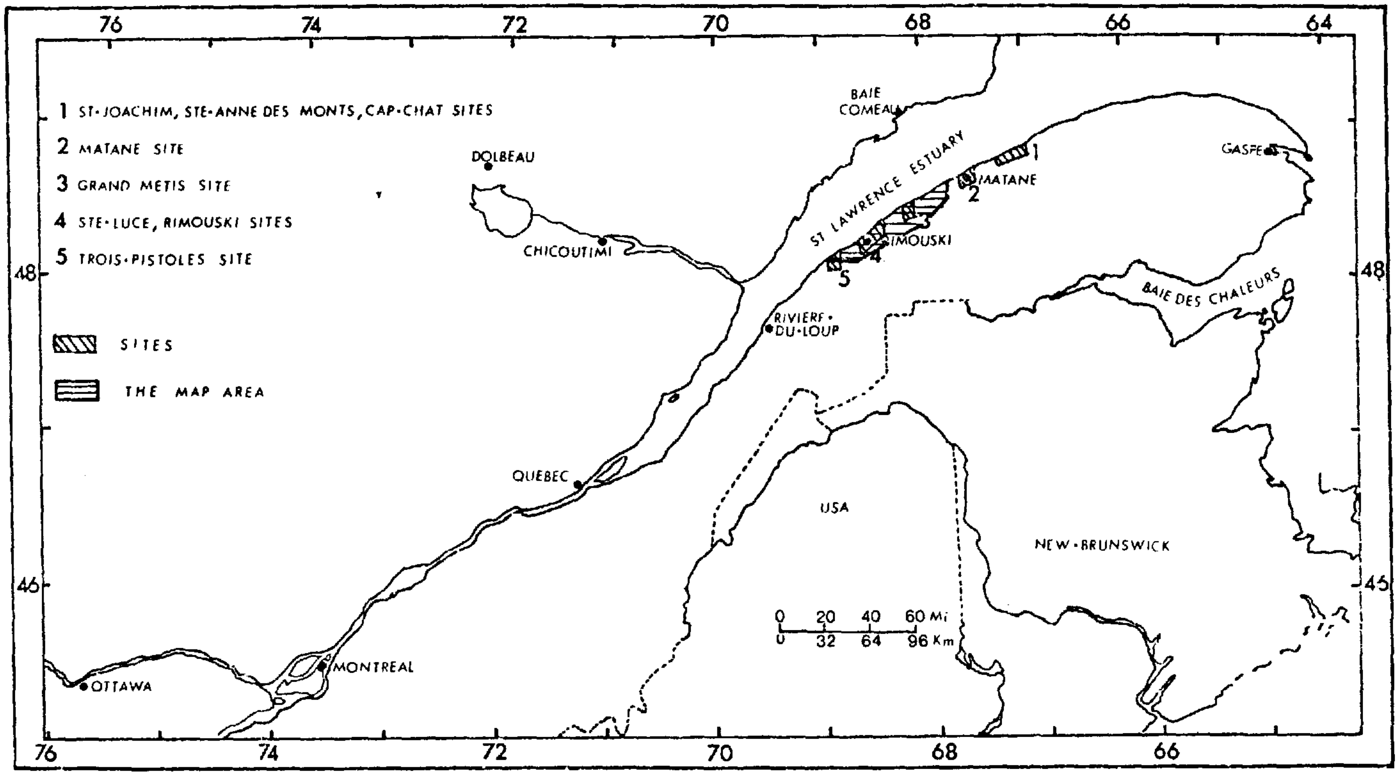


Figure 3. The map area and the sites investigated for geotechnical purposes.

Accessibility, Population and Economy

The area can be reached easily by road, rail or air. Provincial and municipal roads are usually paved while a system of northeast and southwest running (mainly unpaved) secondary motorable roads gives easy access to most parts of the region. The main towns (Fig. 2, in pocket) of the map-area are: Rimouski, Mont-Joli, Price and Trois-Pistoles.

Tourism, peat, and wood industries are the economic base for this part of the country. Hunting and fishing are important attractions for many visitors in the Lower St. Lawrence and Gaspé areas. Commercial fishing has declined from year to year and has now completely disappeared. Limestone and sandstone are exploited for construction, and slate is mined at Mont-Joli to provide clay for ceramic products; otherwise, there are no mineral industries within the area.

Climate

The geographic situation of the area confers either a continental or a marine climate depending upon: distance from the estuary, altitude, and time of the year. Summers are warm and winters are cool to cold, humid and snowy. This would fall in the Db climate of Koeppen's classification system. Average precipitation ranges from 79 to 100 cm with April and July as drier months (Gagnon, 1970).

PHYSIOGRAPHY AND DRAINAGE

The map-area is in part of the Appalachian physiographic region of Canada called the Lower St. Lawrence region. It can be divided into three physiographic units or zones; the coast, the upland, and the mountains (Fig. 4).

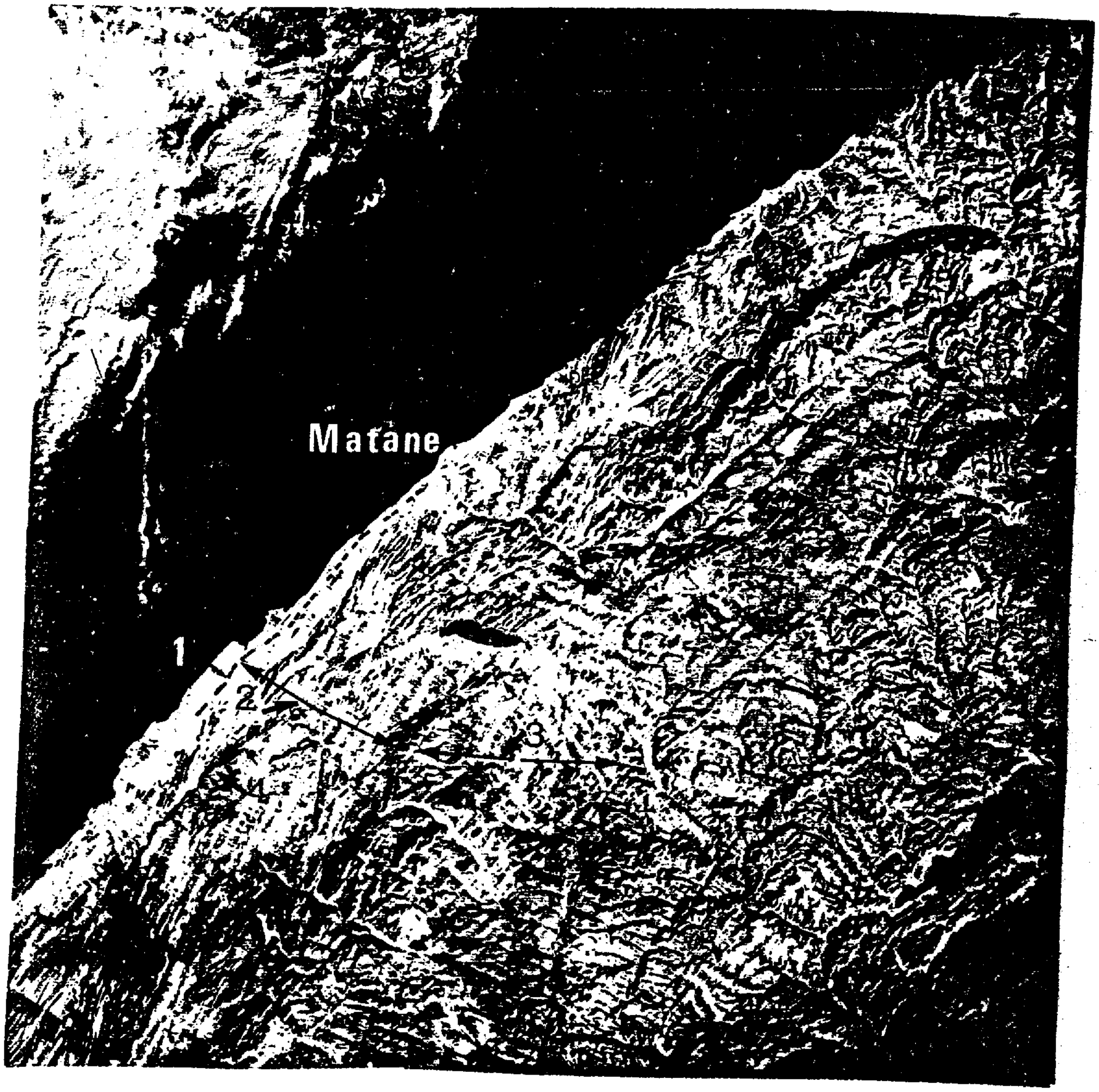


Figure 4. Physiographic units: (1) the coast, (2) the upland, (3) the mountains, and (4) the Neigette Escarpment. Neigette Escarpment marks boundary between Ordovician rocks to the northwest, and Silurian rocks to the southeast (ERTS photo courtesy of the Canada Dept. of Energy, Mines and Resources).

The Coast

The coast (1, Fig. 4) ranges in elevation from sea level to about 182 metres. The local relief is controlled by the Quaternary sediments, defining marine and fluvial terraces. In some areas such as Bic, this gentle relief is broken by "whaleback-like" hills reaching a maximum of 345 metres above sea level. The coast is a rather narrow zone ranging in width from several hundred metres in the Baie-des-Sables area to a maximum of 10 kilometers near Mont-Joli. This zone (the coast) will be described in greater detail in Chapter II.

The Upland

The upland (2, Fig. 4) occupies most of the area, and like the mountains is controlled by bedrock structure and lithology. Elevations vary from 182 to 426 metres above sea level, averaging about 275 metres. The northeast-southwest-oriented hills are composed of limestone, sandstone and conglomerate, while depressions and valleys result from the presence of less resistant slate or of faults. A striking feature in the area is the Neigette escarpment which ends to the northeast at Mont-Comi (575 metres above sea level). The Neigette fault is believed by Liard (1972) to have created this escarpment, which ranges from 182 to 244 metres in height.

The Mountains

The Notre-Dame Mountains (3, Fig. 4) range from 426 metres above sea level to a maximum of 914 metres near La Rédemption. Valleys are deeply incised and have a dominant U-shape. These mountains become the Shick-Shocks Mountains on the east side of Lake Matapédia. The Matapédia Valley is the major valley oriented northwest-southeast.

The Drainage

Rivers and streams discharge into the St. Lawrence Estuary, with the Métis, Rimouski and Trois-Pistoles Rivers as the main effluents (Fig. 2, in pocket). A southwest-northeast trend characterizes these rivers and streams, which curve toward the St. Lawrence Estuary just before their outlet, except rivers which flow into glacial valleys (e.g., Matane River) or along faults oriented at large angles to the estuary, like the Rimouski River in its lower section.

PREVIOUS WORK

The bedrock geology was first studied by Logan in 1884 (Coleman, 1922). Bailey and McInnes (1889, in Coleman, 1922) wrote geological reports on the Gaspé Peninsula. In 1941 De la Rue mapped the area between Mont-Joli, Matane and Lake Matapédia. Recently Liard (1972) and Mukherji (1972) studied in detail the area between Matane and Rimouski but with little reference to the Quaternary deposits. However, the bedrock geology of the Rimouski/Trois-Pistoles area has not been mapped in detail.

R. Bell (1863) visited the area and made a few comments on the Quaternary geology of the Gaspé Peninsula. Chalmers (1894, 1897, 1904) and Goldthwait (1913) were interested in the coast, while the latter concentrated on the raised beaches of the south shore of the St. Lawrence River and Estuary. Coleman (1922) summarized previous work and gave some hypotheses on the glacial geology of the Peninsula.

From 1922 to 1962 few references to the Quaternary geology were made in reports on the bedrock geology; they were often restricted to boulder tracing and glacial striae. Not until 1962 did Lee produce a detailed report on the Rivière-du-Loup/Trois-Pistoles area, while Dionne (1966, 1968c, 1970 and 1972a) studied morpho-sedimentological aspects along the south shore of the St. Lawrence Estuary, extending mostly from Rivière-du-Loup to Trois-Pistoles (Fig. 2, in pocket). Since 1972 detailed mapping in the Gaspé has been carried out for the Q.M.N.R. by Lebuis and David (1972; Lebuis, 1973a, b) and covered the St. Joachin/Matane areas. Therefore, the remaining unmapped area from Trois-Pistoles to Baie-des-Sables became the subject of the present thesis.

At the time of writing research is in progress in the Ste. Anne-des-Monts valley by G. Martineau (personal communication). Also, G. Lortie (1975) is completing his research on ice movement in the Appalachians, while C. Gauthier (1975) is finishing his research on deglaciation in the Appalachians. Thus during the last five years there has been an increased interest in the Lower St. Lawrence/Gaspé region, which should lead to a better understanding of the Quaternary geology of this part of the country. On the north shore of the Estuary, L. Dredge (1975) and J.M. Dubois (1975) are studying the Sept-Iles/Godbout, and Moisie River areas, which should also enlarge the context of the present studies on the south shore.

BEDROCK GEOLOGY

Consolidated rocks in the map-area consist essentially of Cambro-Ordovician and Silurian successions. As pointed out previously, the area between Rimouski and Baie-des-Sables was mapped in detail by Liard (1972) and Mukherji (1972). Regional distribution of Ordovician and Silurian rocks with their main structural features is shown in Fig. 5, and the stratigraphic succession is given in Table 1.

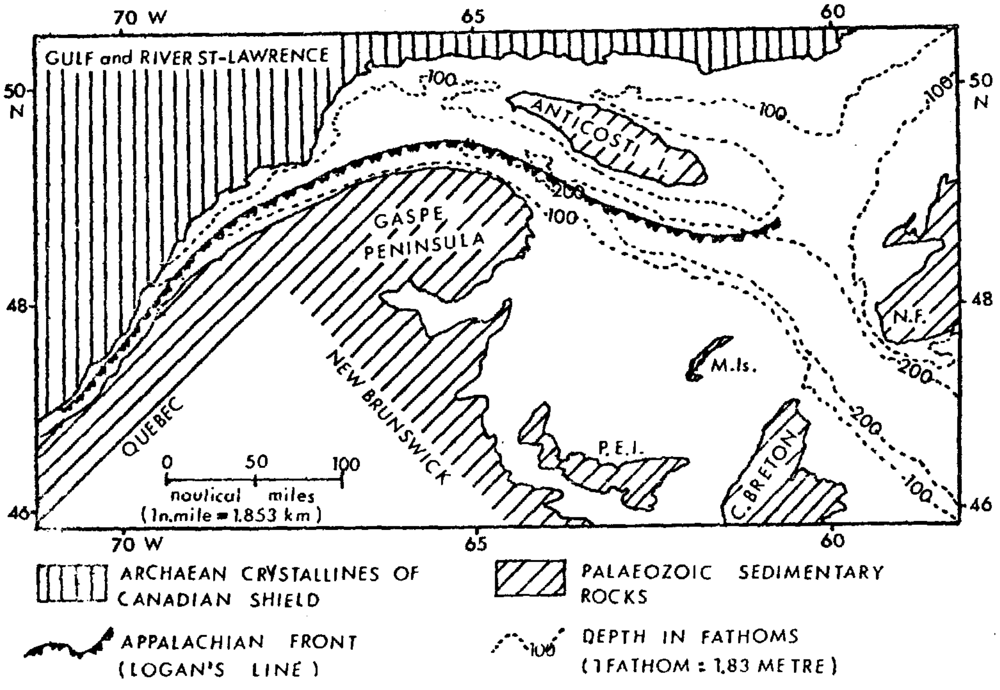


Figure 5. General distribution of Precambrian and Paleozoic rocks in Eastern Canada (from Nota and Loring, 1964).

Table 1 Geological Formations of the Rimouski area from Lajoie, 1971

ERE	PERIODE			FORMATION	DESCRIPTION
CENOZOIQUE	RECENT ET PLEISTOCENE				Blocs erratiques glaciaires Dépôts fluviatiles et lacustres
D I S C O R D A N C E					
PALEOZOIQUE	DEVONIEN INFERIEUR	ESOPUS		YORK RIVER	Arénite feldspathique gris verdâtre Siltstone noir
		ORISKANY		YORK LAKE (4000')	Siltstone calcareux, gris foncé. Grès calcareux Calcarénite
		HELDERBERG		CAP BON AMI (1500' - 2500')	Calcaire argileux Siltstone calcareux Mudstone
	?	"SKALA"			
	? SILURIEN SUPERIEUR	LUDLOW		SAINT-LEON (4000'-12000') Membre de Lac Des Baies	Silstone gris verdâtre, calcareux Conglomérat et grès lithiques Siltstone Peu de grès
				SAYABEC (50-1500')	Calcaire fossilifère, argileux et silteux, gris foncé
		WENLOCK		ROBITAILLE (1500'-2500') ▨ VAL-BRILLANT (50-1000')	Silstone rouge et vert; arénite et conglomérat quartzifère Arénite quartzifère blanche et rose
	SILURIEN INFERIEUR	LLANDOVERY	C_6 SUP. C_1	LAC RAYMOND (5000') MEMBRE DE LAC CASTOR AWANTJISH (600'-2000')	Grès et mudstone tufacés Peu de Chert Conglomérat et grès lithiques Silstone calcareux vert Mudstone vert Peu de Grès
			B_3 MOY. B_1	CABANO (4000' - 8000')	Siltstone gris Grès lithique foliacé Conglomérat lithique
			A_4 INF. A_1	▨	
	D I S C O R D A N C E				
	PRE-TACONIC	ORDOVICIEN ET (?) CAMBRIEN			A. Calcaire rubané Shales noirs B. Schiste ardoisier vert et rouge Arénite quartzifère Conglomérat calcaire

The Ordovician rocks are restricted to the coast and parts of the upland (Fig. 4). The southern limit of Ordovician exposures is abruptly terminated against the Silurian units by a northeast-southwest trending normal fault (Mukherji, 1972) corresponding to the Neigette escarpment (4, Fig. 4). Slate, siltstone, sandstone, limestone and conglomerate form the dominant lithologic types (Mikherji, 1972). Ordovician rocks are represented by the Québec Group (Liard, 1972) consisting of tightly folded red and green slate interstratified with quartzite and argillaceous sandstone.

The Silurian of the map-area is characterized by the Val-Brillant and St. Léon Formations (Béland, 1960). The former is composed of white quartzite with red geothite inclusions 0.5 to 1.0 mm in diameter. This quartzite is used as a tracer for northward ice movement because of its high durability and well known sources. The St. Léon Formation is composed of green microsandstone interbedded with fossiliferous limestones. A calcareous conglomerate up to 60 metres thick is found in this formation at Ste. Blandine (Béland, 1960).

The area west of Rimouski that remains unmapped consists of conglomerates, limestones and sandstones forming ridges, while depressions are occupied by slates.

WORKING PROCEDURES

The field work for this thesis consisted of surficial mapping and geotechnical investigations. The mapping was supplemented by seismic surveys to locate sites for detailed geotechnical studies. Mapping procedures will be described first, then the geotechnical investigations, and finally the laboratory procedures.

Surficial Deposits Mapping

In the spring of 1974 airphoto (1:15840) interpretation permitted the identification of the main geological and geomorphological units, along with the bedrock outcrops and gravel pits. In early May, 1974, field work started with a general reconnaissance of the area. The most recent work near the area was that of Lebuis (1973b) and his system of map units was adopted for use in this area. The mapping commenced at the western limit of Lebuis' work, which is the Tartigou River (Map 22B/13W) and extended to Trois-Pistoles at the east end of Lee's mapping (Lee, 1962), so that the Rivière-du-Loup/Ste. Anne-des-Monts area could be represented by a single and uniform map. Once in the field, a detailed airphoto interpretation was carried out, followed by field checks. When the mapping on airphotos was finalized, it was transferred to a 1:31680 topographic map using a LUZ-Sketchmaster. At the completion of a topographic sheet another check and revision was performed.

During field investigations, surface samples were collected for grain-size analysis, microfossil identification, and qualitative mineralogy, to describe the stratigraphic units and also to solve stratigraphic problems. One hundred and eighty-seven samples were taken, from which about 40 were analyzed for microfossils and qualitative mineralogy. Marine shells were also collected for identification and/or C^{14} dating. Glacial erosion features like "crag-and-tail", striae, and crescentic marks were recorded when possible.

An altimetry survey was carried out for fossil localities, terraces and deltas with two U.S. Army altimeter-barometers with temperature and pressure corrections. Procedures for altimetry were to use one barometer at the base to detect hourly variations in pressure while the other one was taken into the field for readings at 76 sites. It was found that when the wind was from the southwest it was almost impossible to get good results. A few topographic profiles were run using a theodolite at sites selected for detailed geotechnical studies. Determination of marine limit in the area was based upon delta and terrace elevations. Since it is known that, following the deglaciation of the area, ice rafting was an important sedimentary agent in the estuary (Dionne, 1968a), Precambrian boulders may suggest the position of the marine limit. Currents in the estuary pushed floating ice containing rocks from the Shield toward the south shore where they were partly deposited on the shore. It was found (Dionne, 1971; Lebuis, 1973b) that above the marine limit, the number of Precambrian boulders and cobbles decreases drastically from 10-20% to less than 5%. Therefore, a qualitative estimation of the concentration of Precambrian boulders provides us with a good tool to estimate the marine limit. When the concentration of Precambrian boulders appeared to be disturbed by the presence of sedimentary rocks from nearby outcrops (limestone and conglomerate), the marine limit was determined solely from airphotos.

By the end of the summer a few sections had been described to complete the information, and in late October 1974, a general revision was carried out prior to the preparation of the final maps.

Geotechnical Investigations

Investigated sites are shown in Figure 3. As stated previously, sites for geotechnical investigations were determined from surficial mapping and seismic surveys. These investigations had to provide data on the stratigraphy and properties of the marine clays. A seismic reflection program was carried out using an ABEM seismograph for deep exploration, and a hammer seismic, Huntec FS-3, for shallow investigations. Along with some seismic lines we used a Dutch static deep penetrometer which estimates the unremoulded shear strength of the material it penetrates. Results from the penetrometer were correlated with the seismic profiles in order to determine stratigraphic boundaries and borehole sites. Thirty-four test holes were then probed with the deep penetrometer.

The drilling program was divided into two parts: winter and summer. The former was performed by a private company (Technisol Inc.) and the latter by the Québec Ministry of Natural Resources (Geotechnical Services).

Sites for the winter program were selected on the basis of airphoto interpretation. Six test holes were drilled from the end of February to the middle of April, 1974. A cable tool drill was used by Technisol, which was able to penetrate the bedrock or any boulder with a diamond drilling device.

This type of drilling gave us samples 6.3 cm in diameter taken with a Shelby tube sampler 60.9 cm long. Sand and gravel were sampled with a 3.8 cm diameter and 46.0 to 91.0 cm long split spoon. Along with the split spoon sampling a standard penetration test was run. Bedrock samples up to 1.5 metres long and 3.8 cm in diameter were taken. Except for hole number 4 (F-4, App. F), samples were taken every 1.5 metres (5 ft) with a vane test in between when clay was encountered. A report on this work was released in July 1974 by the Technisol Company (Technisol, 1974).

The summer drilling program performed by the Geotechnical Services (Q.M.N.R.) was carried out with an auger drill (Mobil Drill) able to take samples of 7.6 cm (3") in diameter either with a split spoon or a Shelby sampler. This drilling tool was not equipped with a diamond coring device and therefore could not go through any boulder or the bedrock. Nine boreholes were drilled during two and a half months from July to the middle of October, 1974. "Unremoulded" samples were taken every 3.0 metres while remoulded samples were taken in between at the tip of the coring tool. As during the winter program, Shelby tubes were paraffined in the field and sent to Québec city as soon as possible after recovery.

A GEONOR sampler was used for shallow investigations of less than 8.0 metres. From this type of sampler, Shelby tube samples 6.3 cm in diameter and 61.0 cm long could be taken. Samples from the GEONOR were prepared as previously explained.

Samples taken were numbered differently. Surface samples are named by the topographic sheet covering the given area and the sequential number in which they were taken. For example, 22B/12W-13 is the 13th sample that was taken within the topographic sheet 22B/12W. Cores are identified by the name of the organization, the type of sampling, a sequential number, and the calendar year they were taken. TB represents samples taken by Technisol Co., while FT and FB are for the Geotechnical Services (Q.M.N.R.). FT is related to the Mobil Drill equipment and FB to the GEONOR sampler. No indication of the borehole is given in this type of identification.

Laboratory Procedures

A total of 207 Shelby or split spoon samples were taken during the drilling program. Various samples were analyzed or tested for texture, shear strength, water content, plasticity and liquid limits, angle of internal friction and sensitivity. Most of these tests were performed by the Geotechnical Services Laboratory under the supervision of D. Ouellet, technician.

Total chemical analyses were carried out at the Institut National de la Recherche Scientifique in Ste. Foy; most of the texture analyses on clays for surface samples were done by the Québec Ministry of Transportation (Soil Laboratory). Five samples were sent to Dr. R. Ledoux at the Université Laval for X-ray diffraction analysis. Thin sections of clays were prepared by the author at the University of Waterloo along with two consolidation tests, three shear-box tests, X-ray, scanning and transmission electronic microscopy studies. Laboratory work at the University of Waterloo was closely related to microfabric analysis of the marine clays and was carried out in the Departments of Earth Sciences and Civil Engineering. Most of these tests were run with the A.S.T.M. (1970) standards. Procedures for thin sectioning, scanning and electron microscopy are described later in the text (p. 194).

CHAPTER II GEOMORPHOLOGY AND THE MARINE TERRACES

INTRODUCTION

The Lower St. Lawrence and Gaspé region is rich in landscape features as has been recognized by many visitors for at least a century (e.g., Logan and Bell). This part of the country offers the opportunity of studying geomorphological features created by a number of different agents, such as the sea, rivers, glaciers, and subaerial weathering. All these features have the advantage of being grouped in a narrow zone, facilitating their study.

It is probably for these reasons that many geologists such as H.A. Lee, J.C. Dionne, J. Lebuis and P. David have recently come into the area to study the Quaternary geology and geomorphology. Dionne has spent nearly ten years looking at various aspects of morpho-sedimentology (Dionne, 1963, 1966, 1968a,b,c, 1970, 1971 and 1972a,b).

The present area was included in an extensive airphoto survey of the geomorphology of the Lower St. Lawrence/Gaspé region by Dionne and Héroux (unpublished).

This chapter will first describe the main geomorphological units that were used for airphoto interpretation, then the marine terraces, and more specifically the ones near St. Ulric.

GEOMORPHOLOGICAL UNITS

Geomorphological features are divided into seven groups: bedrock, moraine and ice-contact features, outwash plain and fluvial terraces, deltas, marine terraces and related features, alluvial plains, and finally, peat bogs and swamps. The author is aware that many subunits could be described here; however, the purpose of this section is only to give a description of the main small scale (1:10000 to 1:50000) features as were used for photo interpretation.

Bedrock Features

It has been previously indicated that most of the bedrock is found in hills roughly oriented northeast-southwest. This gentle relief is often broken by fault-line scarps (Neigette escarpment) and is dissected by structurally controlled river valleys. Along the coast, "roches moutonnées" are found with their most striking development at Bic (Fig. 6). Goldthwait (1913, p. 77) mentioned a "well formed roche moutonnée ... severely scrubbed on the south side and torn and roughened on the north".

In areas where the bedrock is covered by a thin deposit of Quaternary sediment sparse vegetation and boulder concentrations often exist.

Moraine and Ice-Contact Features

Morainic ridges were found only near Ste. Blandine (3 kilometers southeast of Ste. Blandine) above the Neigette escarpment. They appear to be irregular, subparallel ridges broken here and there by small eskers. The orientation of these ridges at Ste. Blandine may be partly controlled by the bedrock. Besides this site, no other morainic system was observed in the area, due to the fact that the mapping did not reach far enough inland to cover all glacial sediments.

However, many ice-contact features can be observed, of which the most striking ones are here called "esker complex". Eskers are readily dis-

Figure 6. Roches moutonées (1) and tombolos (2) near Bic, the arrow indicates ice movement. (Photo courtesy of Québec Dept. of Lands and Forests).

tinguished by their usual shape of a sinuous ridge, uncontrolled by the nearby topography. These eskers are usually associated with kame and kettle topography, as observed near Neigette and St. Donat. Between St. Valérien and Ladrière, a complex of eskers and ice-contact sediments was mapped, which may indicate stagnation of the ice in that area.

Kame terraces were noted near St. Mathieu, joining low and irregular platforms on the sides of the valleys.

Outwash Plain and Fluvial Terraces

Outwash plains are rare in the area and were found only in the Neigette valley. However, the paucity of such features is also a function of the area surveyed, which extends only a few kilometers inland.

In the Neigette valley (22C/8W), a complete transition is found; esker, grading into ice-contact sand and gravel, and the outwash plain to the southwest. Other valleys must have been filled, but were partially entrenched to form fluvial terraces.

Fluvial terraces can be divided into two subunits: irregular and regular. The irregular terraces are undulating and discontinuous and, at the highest levels, consist of glaciofluvial (outwash) sand and gravel. The regular terraces are uniform and subhorizontal with their platform dipping downstream and toward the center of the valley. The regular fluvial terraces are at various levels above present-day streams, while the irregular terraces were only found at one level (the highest).

Deltas

Deltas result from streams reaching a baselevel, such as a lake or the sea. Their shape can be modified by littoral currents or subsequent erosion. Old deltas are characterized by a platform, terminated with a foreslope corresponding to the foresets.

Two types of delta were noted in the present area: outwash and fluvial deltas. In the classification adopted here, outwash deltas consist of deltas which are not entrenched by their own streams, so that only one platform is observed. However, the Trois-Pistoles delta, in its higher level, is considered to have been an outwash delta, which was later entrenched by the Trois-Pistoles river, forming a "fluvial" delta (Dionne, 1972a). Such outwash deltas are found at St. Fabien and Luceville (Figs. 7 and 8). The St. Fabien delta was also "disturbed" by the ice, which created a large kettle in the middle. These deltas record the highest sea level in the present area. They do not have any lower level, which indicates that as the ice receded far enough the meltwater was diverted, and sedimentation stopped completely.

Fluvial deltas are found above present-day streams, and they can be connected upstream with fluvial terraces. Thus, they are found at lower altitudes than the outwash deltas and their extent along the same stream decreases along with their elevation above sea level. This may suggest that when the ice melted, stream discharge and the transport of sediment decreased rapidly in such a way that very little sedimentation occurs today. The lowest prominent level of delta in the area is about 75 metres above sea level.

Marine Terraces and Related Features

On the coast, and in valleys filled with marine deposits (Fig. 9), marine terraces are the main geomorphological unit. They are difficult to identify at levels higher than 75 metres above sea level. From about 75 metres to sea level, several well-developed terraces are encountered, with platforms dipping gnetly toward the estuary in a succession of shorelines. Shorelines are very well-developed near deltas (Figs. 6, 10, and 25, p. 55), as they are closer to the source of sediment. The marine terrace also include old channels, filled with organic deposits that comprise

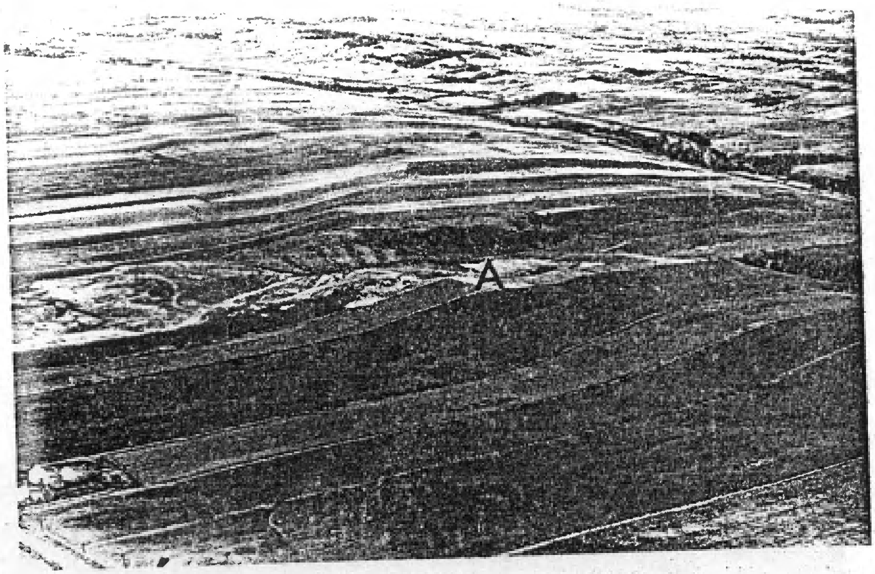


Figure 7. The St. Fabien delta (A, view from the northwest)

Figure 8. The Luceville delta (A, view from the southwest)

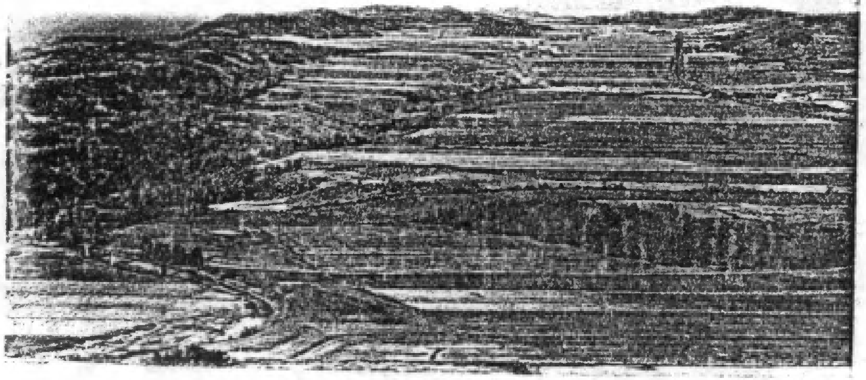


Figure 9. The marine sediments (filling the valley) near St. Simon (in the foreground)

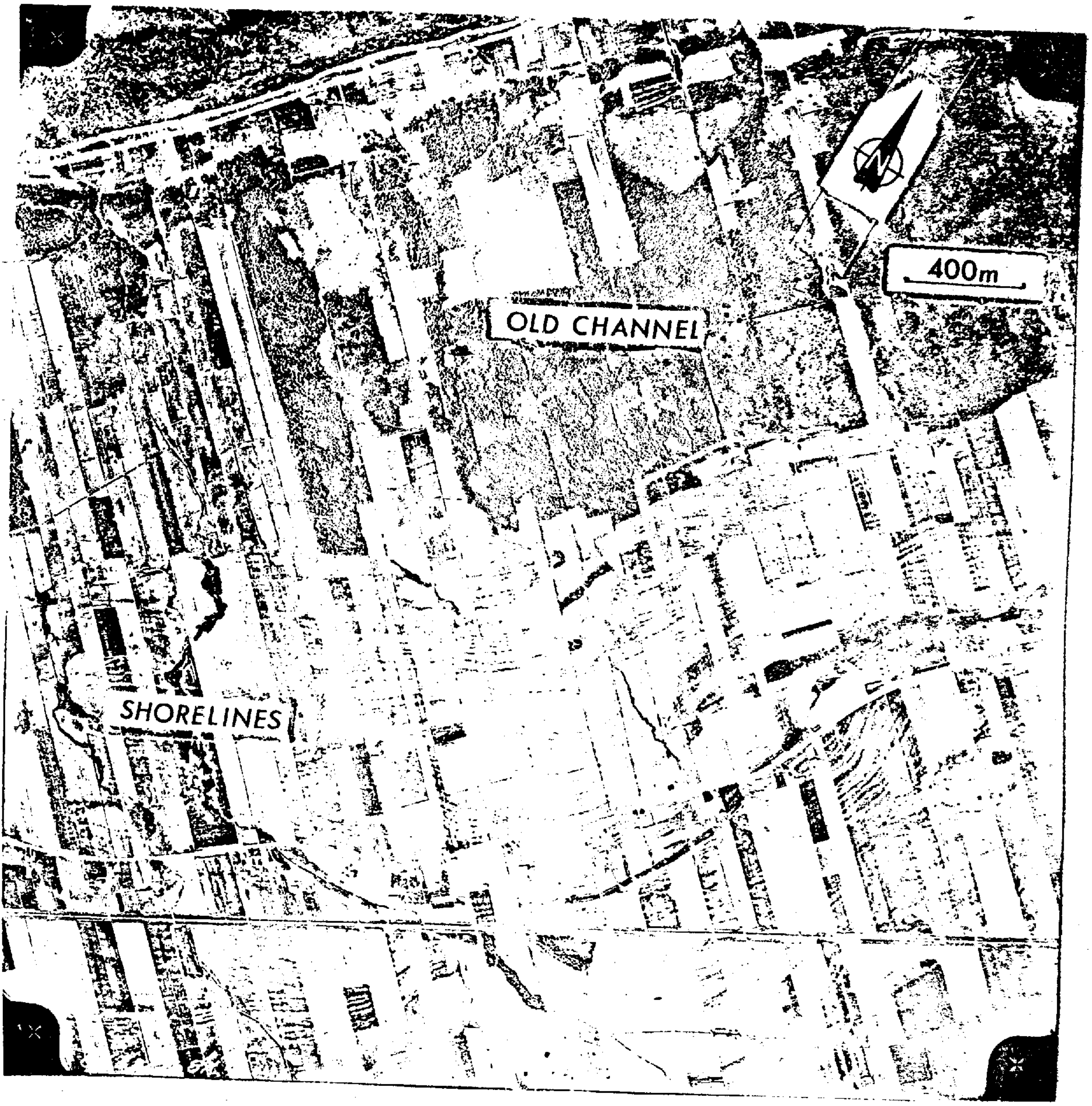


Figure 10. Raised beaches, and peat filling an old channel, on the Bic terrace (about 30 m above sea level) (Photo courtesy of the Québec Dept. of Lands and Forests).

a separate geomorphological unit in the present area. These channels are believed by Lee (1962) to have been cut by longshore currents.

Around hills of bedrock, sandbars and tombolos were formed, and modern examples are especially well shown near Bic (Fig. 6) in a series of tombolos linking almost every island to the land.

The marine terraces are discussed in more detail in the second part of this chapter (see page 28).

Peat Bogs and Swamps

Most of the depressions, either in valleys or in old channels along the coast, are completely or partly filled by organic deposits, sometimes developed into extensive peat bogs such as the Pointe-au-Père and St. Fabien peat bogs (Fig. 11).

Valley bottoms are often covered with organic debris or bogs and most of the small lakes are at an eutrophic stage with Sphagnum slowly covering their surface.

Inland, these units are closely associated with valley bottom silt and probably lacustrine sediments.

Alluvial Plains and Tidal Flats

The main rivers possess an alluvial plain, which is the area along a stream that is submerged by occasional flooding. This unit is very extensive along the Métis River and part of the Neigette River (northeast of the St. Donat esker). The alluvial plain includes features such as oxbows, small bogs, and channels.

A tidal flat is present along the coast where the Matane terrace is almost horizontal (as found near Rimouski between the mainland and Ile St.

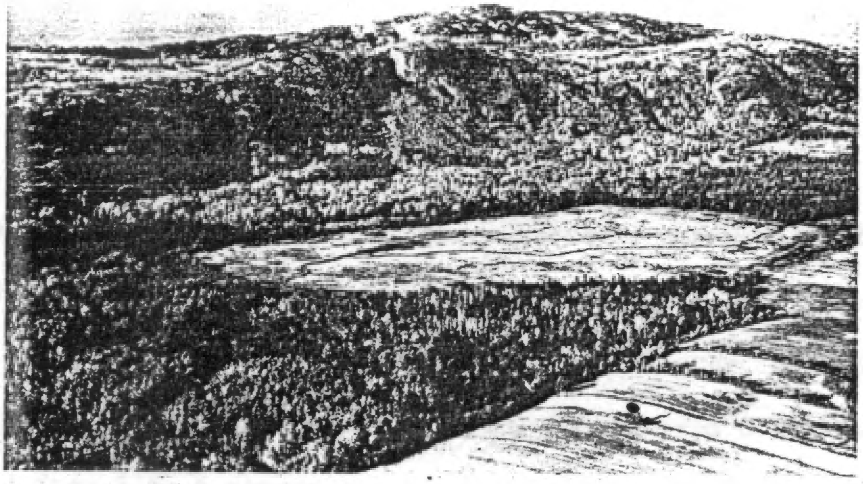


Figure 11. The St. Fabien peat bog (view from the south).

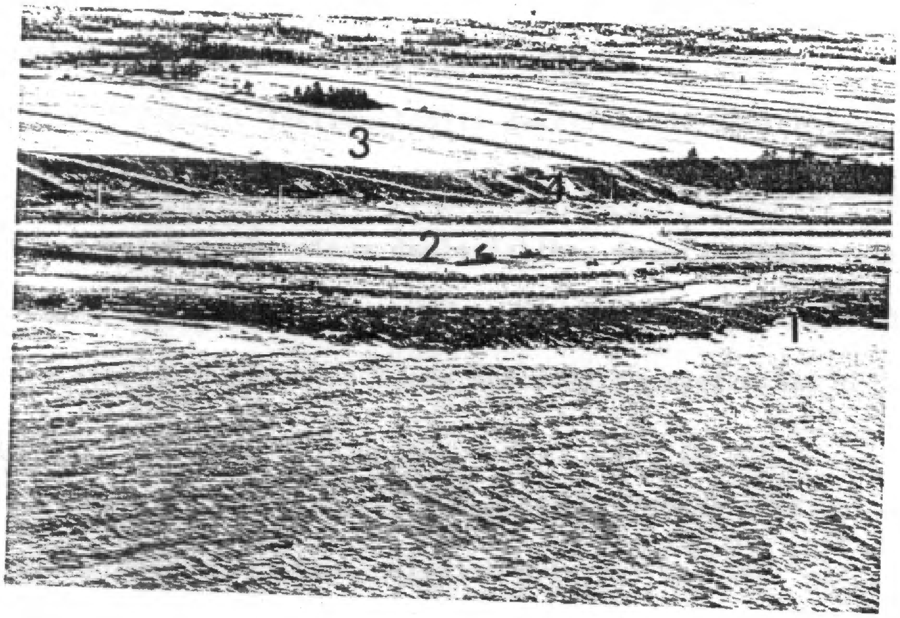


Figure 12. The Matane (1), Ste-Flavie (2), and Bic (3) terraces, and the Ste-Flavie Bluff (4) (view from the north near St. Ulric).

Barnabé). This unit is often represented on topographic maps by the zone between low and high tides. However, tidal flats have not been mapped as such. They were extensively studied by Dionne (1970).

THE MARINE TERRACES

From sea level, going inland, three terraces are usually found (Figs. 12 and 13). Higher terraces exist in Quaternary sediments near deltas, or are limited by a cliff cut in bedrock, especially at, or close to the marine limit. The first terrace (Fig. 13) ranges from 0 to 3 metres a.s.l., the second from 3 to 6 metres a.s.l., and the third from 13 to about 35 metres above sea level.

One of the first workers to study the raised beaches of the Lower St. Lawrence/Gaspé region was R.B. Bell in 1863. Later, Goldthwait (1913, 1933? in Gadd, 1971) studied the raised beaches. More recently, Dionne (1963) investigated the marine terraces in some detail.

Bell (1863) did not systematically describe the marine terraces, but gave many indications of their locations and even then believed that important uplift had taken place since deglaciation, forming these terraces.

The origin of these marine terraces was studied by Dionne (1963, 1972a). The author agrees with Dionne's ideas and will summarize his interpretation of the genesis of the terraces.

The bedrock platform, hereafter named the Mic Mac surface, would correspond to an erosional surface existing prior to the last glaciation and is considered to be at least interglacial (>39,000 y., Lasalle, 1972). This surface was renewed by postglacial wave action and was partially veneered with sediment resulting from cliff erosion, forming the Matane terrace.

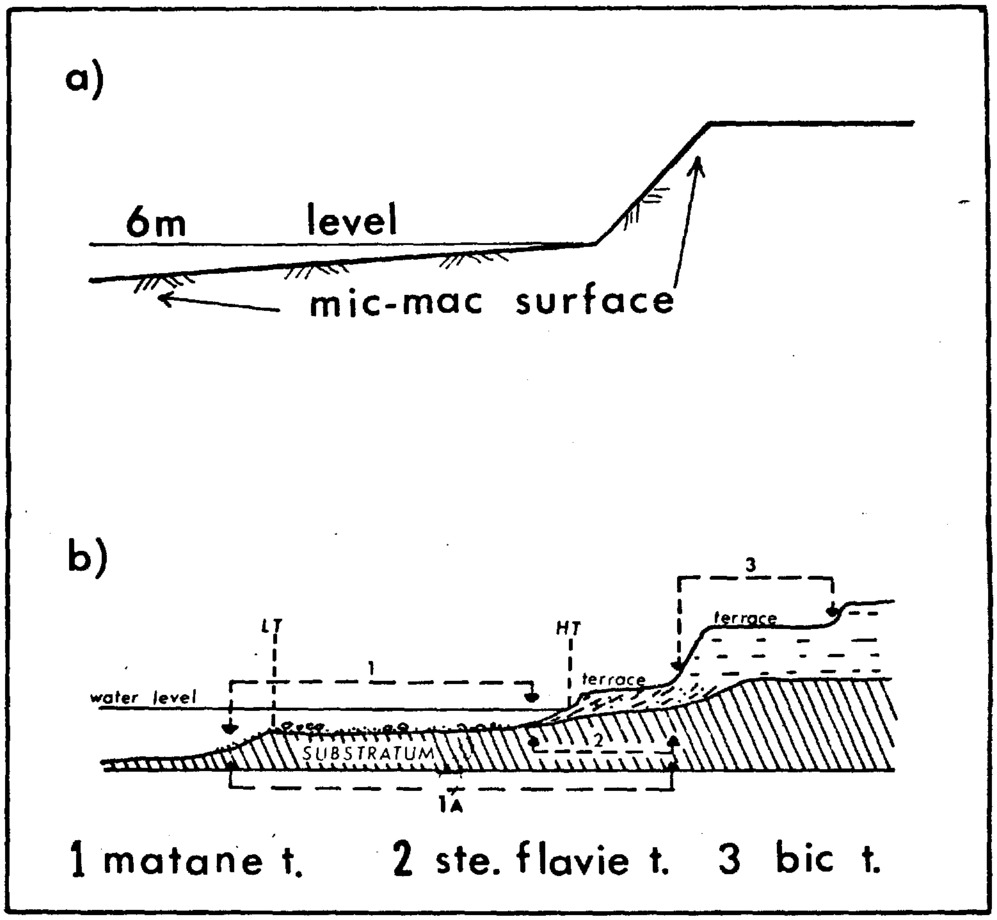


Figure 13. a) The Mic Mac surface
b) The main marine terraces in the present area (modified from Dionne, 1963).

The Ste. Flavie terrace (excluding the escarpment itself) is a depositional terrace of littoral sediment that is younger than the Mic Mac surface and Bic terrace, covering the former and extending to the foreslope of the latter (Dionne, 1972a). Therefore, the Mic Mac platform (or surface) extends under the Ste. Flavie terrace to the scarp when the bluff consists in part or completely of bedrock.

Dionne (1972a) suggests that the Bic (Mic Mac of Dionne) terrace was formed by the filling of depressions between bedrock crests by glaciomarine and marine clay.

Goldthwait (1913; 1933? in Gadd, 1971) studied the marine terraces between Montreal and Gaspé. He pointed out a strong escarpment and a bedrock platform which he named the Mic Mac bluff and terrace (Mic Mac surface, Fig. 13a). He also found that the toe of the Mic Mac bluff was almost consistently near 6 metres a.s.l. (20 foot level). Goldthwait did not separate, from the Mic Mac surface, the recent deposits lying on the bedrock, which deposits form the Ste. Flavie terrace (2 in Fig. 13b).

Dionne (1963, 1972a) identified the second terrace (2, Fig. 13b) but believed that Goldthwait did not mention to which terrace the Mic Mac bluff belonged. Therefore he suggested the naming of three of them according to their order above sea level (from lowest to highest): Rimouski, Mitis, and Mic Mac terraces (1, 2, 3 in Fig. 13b).

However, even if Goldthwait did not mention the terrace 2 (in Fig. 13b), he did name the bedrock platform or surface the Mic Mac terrace (Goldthwait, 1933?; in Gadd, 1971), which name is still in use (Lasalle, 1972). To avoid any confusion, the name Mic Mac will now be restricted to the bedrock surface (including the platform and the scarp). For this reason, the terraces are renamed as follows: Matane, Ste. Flavie, and Bic

(1, 2, and 3 in Fig. 13b). The Ste. Flavie and Bic terraces are named after the towns which lie respectively on the second and third terraces. Then, the 20 foot level observed by Goldthwait (1913) becomes the maximum elevation of the Ste. Flavie terrace. The term Ste. Flavie bluff or scarp should now be used instead of Mic Mac bluff.

The Matane terrace may consist of sand and gravel, clay or bedrock. Its seaward extent is restricted to the shoreline between the high and low tide levels. The width of the Matane terrace varies from a few tens of metres to a few kilometers, as near Rimouski. Inland, it is limited by a scarp below the Ste. Flavie terrace which has a small scarp slope on the sea side which is the bluff of the Matane terrace. Dionne (1972a) noted that the transition between the Ste. Flavie (Mitis of Dionne) and the Matane terrace may be gradational with a break in slope less than 1 metre high.

The Ste. Flavie terrace (Mitis of Dionne, Fig. 12) from 3 to 9 metres above sea level (Dionne, 1972a), varies in width from a few tens of metres to a few kilometers. It is limited inland by the Ste. Flavie bluff, 10 to 30 metres high (called Mic Mac by Goldthwait, 1933?; in Gadd, 1971). This platform consists mainly of littoral sand and gravel. The Ste. Flavie bluff, however, may consist of bedrock, glacio-marine clay, or till (near Matane). At Ste. Flavie this scarp is about 20 metres high and consists of glacio-marine clay resting on bedrock, which occurs below the middle of the cliff. At many locations, the marine clay or till may be covered by a thin layer of littoral sand and gravel. When the Ste. Flavie scarp is cut into Quaternary sediments, its relief is less than when it is cut partly or totally in bedrock, as also observed by Dionne (1963).

The Bic terrace (Mic Mac of Dionne) is limited on the sea side by the Ste. Flavie escarpment. It extends from 13 to 35 metres above sea level.

It is the widest platform in the study area, ranging in width from a few hundred metres to a few kilometers. The terrace is underlain by a variety of sediments but mainly littoral sand and gravel, and organic deposits. Often, it consists of glacio-marine or marine clay (see page 49 for description of sediments). An important channel, sometimes two kilometers wide, was cut into this terrace and filled by organic deposits.

The Bic Terrace near St. Ulric - A Cross-Sectional Study

The author was interested in the marine terraces in the St. Ulric area, because they are very well-developed here (Fig. 12) and the Quaternary geology of the site was already known (Lebuis, 1973b). The initial interest was in estimating which factors control the position of the terraces and their escarpment, and also to get a good description of the bedrock topography.

The site investigated for a cross-sectional study of the Bic terrace is located about 15 km west of Matane and about 10 km east of the Tartigou River, near St. Ulric (Fig. 2, in pocket).

This site was chosen in early summer 1974 prior to any mapping in the Baie-des-Sables/Trois-Pistoles area. This work necessitated one month of seismic survey and a few days of surveying with the penetrometer.

Results

Many seismic lines were run by the seismic crew (Q.M.N.R.) in the St. Ulric area but only results for three sections normal to the estuary are included in the present work. Under good conditions different reflectors at depth could be identified at ±2 or 3 metres. Only cross-section B (Fig. 14, in pocket) was checked with a penetrometer, improving the precision of stratigraphy obtained from seismic profiles. Stratigraphic interpretations were also guided by the work of Lebuis (1973b). The topographic profile was derived from a map with contour interval of 5 metres (±1.5 metres).

The Matane terrace here consists of a narrow bedrock platform. The Ste. Flavie terrace shows up well on Profile A from about 2 to 7 metres above sea level. At cross-section B and C the terrace is disrupted by bedrock that outcrops at the surface. On cross-section A the Ste. Flavie terrace is about 0.2 kilometers wide and consists of littoral sediments.

The Bic terrace platform is between 10 and 25 metres elevation on cross-section A, 20 to 35 metres on B, and about 15 to 30 metres on C, where it is irregular. Inland it is limited by another terrace (Terrace 4) which becomes more important as we approach the Matane delta about 5 kilometers northeast of Profile A. Its width is about 1.4, 2.3, and 0.7 kilometers in Profiles A, B, and C, respectively. The surface sediments consist of littoral sediments, organic deposits and till. The bedrock also outcrops near or at the Ste. Flavie escarpment. On cross-section B deltaic sediments are part of Rivière Blanche delta (Lebuis, 1973b). The Bic terrace is gently dipping toward the estuary at a slope of about 3 to 9 metres per kilometer (0.5 degrees at cross-section A, 0.2 degrees at B).

The bedrock topography on all cross-sections is irregular, showing a series of depressions, subparallel to the coast (northeast-southwest). The two main depressions on cross-sections A and B are below or near sea level. Topographic "highs" in the bedrock indicate at least four platforms (A-1, B-1, B-2, C-1 and C-2). At B-3 the seismic results gave a bedrock surface elevation about 5 metres below sea level, while penetrometer results suggested at least 10 metres below sea level.

On cross-section B the penetrometer permitted the distinguishing of two units of clay: a massive grey clay with an undrained shear strength from 0.2 to 0.3 kg/cm^2, and a lower unit which is a stony clay with a shear strength between 1.2 and 1.7 kg/cm^2. This stony clay could correspond to the "marine" till that outcrops at the escarpment on cross-sections A and C (A-2, C-3). No definite seismic velocity could be attached to the "marine" till. However, if at cross-section C most of the clay is the "marine" till it would have a seismic velocity of about 1500 metres/sec. Except for cross-section B, boundaries within the second reflector (1500-1600 m/sec) are purely hypothetical and were drawn from the results obtained for cross-section B.

Discussion

Combined geophysical-geotechnical studies on marine terraces, the first of their kind, may shed light upon the evolution of the bedrock topography and the genesis of the Bic terrace.

Previous workers in the Estuary and Gulf of St. Lawrence discussed the origin of the topography of the bedrock surface (Press and Beckman, 1954; in Nota and Loring, 1964). They considered that the shape of the Estuary and the Gulf of St. Lawrence is structurally controlled and has been freshened by at least one glaciation. The St. Lawrence River is believed to have drained this part of the continent since Tertiary time (Dresser and Denis, 1944). Therefore, the present-day geomorphology of the river valley is due to both fluvial and glacial erosion controlled by such structural features as the Logan fault.

Near St. Ulric, investigations indicate that a few channels are buried either by marine clay or till and that they become deeper and wider toward the estuary. The local relief of these channels, about 40 metres at the most, is small compared to the maximum depth of the estuary near St. Ulric: 275 metres below sea level (Nota and Loring, 1964). Some platforms are buried (A-1, B-1, B-2, C-1) by Quaternary sediments. They are all at about the same elevation, 15 to 20 metres, dipping at about 1° toward the estuary. This could suggest erosion by water such as that which eroded the platform of the Mic Mac surface.

Buried channels and platforms are oriented northeast-southwest, about parallel to the estuary and the bedrock structure. From the till found lying on the bedrock platform dipping toward the estuary, and the orientation of the buried channels, the bedrock topography results from erosion by the agents of erosion such as ice, for at least one glaciation, and water (fluvial and littoral erosion). As noted by Nota and Loring (1964) the ice had to move to the northeast in a pre-existing valley. This is confirmed by crag and tail to the northeast as found by Lebuis (1973b), who considers that the last movement of the Laurentian ice was to the northeast. However, when compared to the depth of the actual river valley, rather little erosion by the ice would have occurred along the coast.

The Bic terrace is only controlled by surficial sediments. No relation seems to exist between the bedrock topography and the surface of the platform, except for the Ste. Flavie escarpment. The Bic terrace was formed by the last marine submergence (the Goldthwait Sea).

From cross-sections (Fig. 14) it is clear that a succession of events preceded the final formation of the Bic terrace. A stiff stony clay, considered here as a till, was left on the bedrock perhaps as a discontinuous mantle when the ice retreated. During the transgression and regression of the Goldthwait Sea this till was partly eroded while the marine clay was deposited, filling depressions left either by the ice, erosion, or both.

The marine limit near St. Ulric is at 115 metres (Lebuis, 1973b) and probably most of the clay was deposited when the sea was at this level.

As the sea regressed, beach formation followed, covering the previously-deposited clay. At some stages the emergence of the land was much greater than the increase in sea level; in these periods no strong escarpments were cut into Quaternary sediments.

The Bic terrace itself represents a long period of correspondence between the rate of uplift, and eustatic variation, during which period longshore currents cut a shallow channel now filled with peat and organic debris. Such channels are found from about 35 metres to 10 metres above sea level. The Bic terrace is terminated by the Ste. Flavie bluff, controlling the elevation of the platform of the Bic terrace seaward. Where the Ste. Flavie bluff is not controlled by bedrock, the height of the escarpment is lower, showing the "true" minimum elevation of the Bic platform.

CHAPTER III QUATERNARY GEOLOGY OF THE BAIE-DES-SABLES/TROIS-PISTOLES AREA

INTRODUCTION

This chapter will summarize the data obtained by previous workers in the Lower St. Lawrence/Gaspé region and add to it new information accumulated during the present project. As the present map-area is between two previously-mapped areas where some differences of interpretation exist, an attempt will be made here to resolve these differences. While keeping the stratigraphic model as simple as possible, this chapter will present a synthesis of the Quaternary geology of the Baie-des-Sables/Trois-Pistoles area.

As a first step, the stratigraphic units will be presented, with more emphasis on the Golthwait Sea clays. As a second step, a preliminary emergence curve will be discussed from C^{14} dates obtained on marine fossils from the area. Finally, a summary of the Quaternary history of the area will be given according to ideas from previous workers and to present findings.

With only six months available for field work, it was necessary to define minimum criteria for identification and mapping of units. Those employed were the following: morphology, texture, sedimentary structure, qualitative mineralogy, and fossil fauna.

The marine limit was approximated from the highest delta (Gadd, 1972) and by Precambrian boulders (gneiss and anorthosites) concentrated at more than 10% (Dionne, 1971; Lebuis, 1973b). Boulder counts were only made where the proportions were not obvious.

DESCRIPTION OF STRATIGRAPHIC UNITS

As previously indicated (page 13) Lebuis' system of stratigraphical units (Lebuis, 1973b) will be applied to the present area. The units will be described here as they apply to the map-area. The stratigraphic relations of geological units modified from Lebuis and David (1972) are given in Table 2. Their distributions are shown on geological maps (in pocket).

A few stratigraphic sections were studied in more detail and will be given along with unit descriptions. Numbers in parentheses correspond to those found on maps or geological sections. Macrofossil localities for all stratigraphic units are listed in Table 6.

Bedrock, Saprolite and Thin Till (Map unit 1)

This first unit covers most of the area and includes undifferentiated bedrock, saprolite, and till veneer less than 0.9 metres (3 ft) thick. The saprolite is the product of bedrock weathering *in situ* and varies in thickness from a few centimeters to at least 4.5 metres in slate with vertical cleavage (Fig. 15). No pre-Wisconsin deposits or weathered zones or profiles were found underneath the till in the present area, but some occurrences may exist in the area to the east (Lebuis and David, 1972).

Undifferentiated Till (Map unit 2)

Very little till was found in the map-area; often it is only represented by boulders resting on bedrock, or by erratics. No section was observed with more than one till. A silty, fossiliferous, grey till was

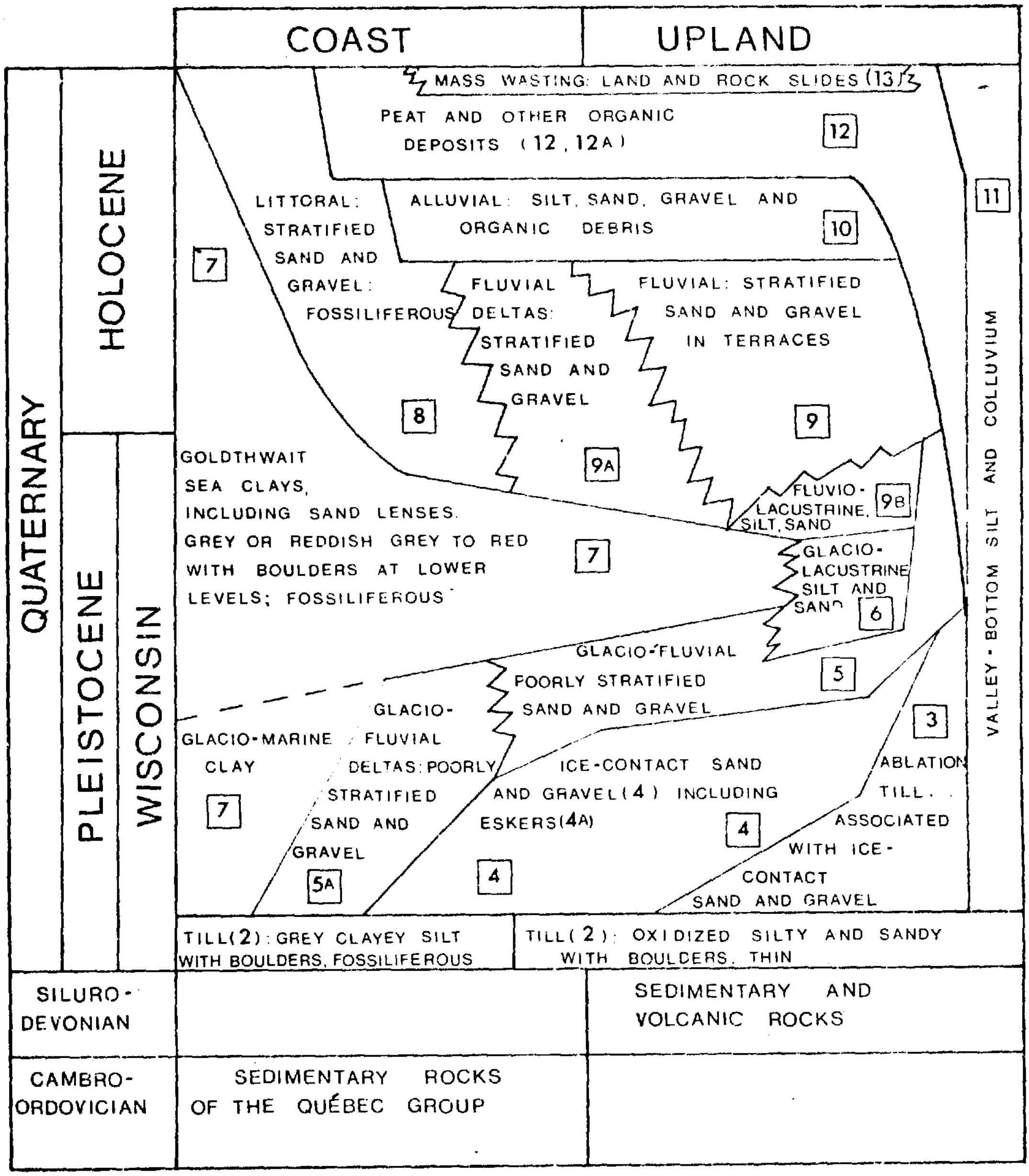


Table 2 Correlation between Stratigraphic Units, for the Baie-des-Sables/Trois-Pistoles area (Modified from Lebuis and David, 1972)

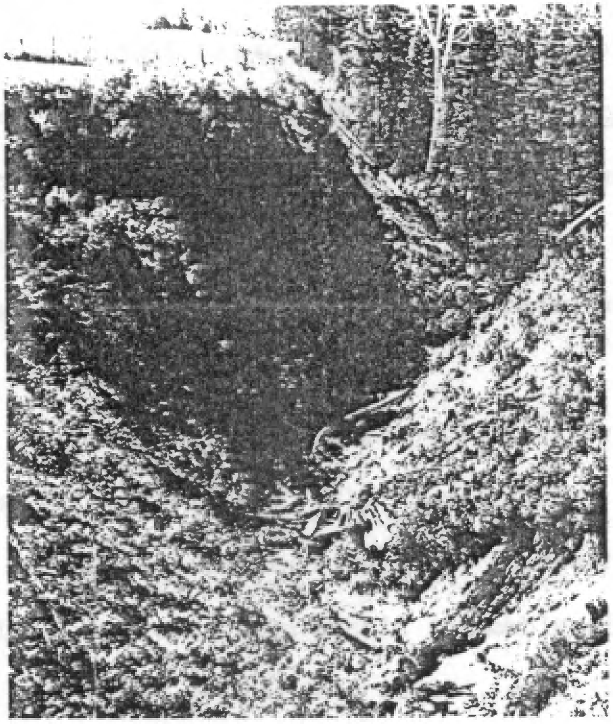


Figure 15. V-shape ravine cut into slate with vertical cleavage (view from the northeast).

Figure 16. The St. Mathieu section: ablation till overlain by glaciofluvial sediments

discovered at St. Valérien, overlain by glaciofluvial sediments. This outcrop is just below or at the marine limit at 131 metres above sea level; only poorly preserved Hiatella arctica are present and could not be collected for C^{14} dating. One sample was taken for texture analysis with the following results: 9% sand, 57% silt, and 34% clay. Striae oriented at N10°E and N30°E on the bedrock were noted on the floor of the gravel pit.

Another grey till outcrop (145 metres above sea level) was encountered at Ladrière (22C/7W). Samples were taken but no texture analyses are avialable for this site. The coarse fraction consisted of subangular sedimentary rocks from pebble to cobble size. This till is similar to the till found more widely inland, underlain by vertical slate and overlain by organic deposits. It was traced about 6 km eastward. At the section studied the till was less than 2 metres thick.

A grey, stony, fossiliferous clay occurs along the shore of the St. Lawrence Estuary. This deposit can be correlated with clayey till described in the Matane area by Lebuis (1973b). However, it is here considered as a marine clay and is discussed further under "Previous Descriptions" (page 49).

Ablation Till and Related Deposits (Map unit 3)

The texture of this ablation till, as observed in the field, varies from sand to subangular boulders. It is usually very poorly stratified. No Precambrian pebbles or boulders were recognized in this sediment. As indicated by Lebuis (1973b) it is often associated with poorly stratified glaciofluvial sand and gravel.

The best exposure of ablation till was found at St. Mathieu (Fig. 2, in pocket) where it was overlain by ice contact sand and gravel (Fig.

16). At. Ste. Blandine (Fig. 2, in pocket) another outcrop of ablation till was noted. There it was associated with ice-contact glaciofluvial sediments. Again in the Neigette Valley, near St. Donat (Fig. 2, in pocket), two large and distinctive erratics were discovered. One is a reefal-type limestone, four metres high (Fig. 17) resting on red and green slate bedrock; it is believed to be derived from the Sayabec Formation to the south and southwest. The second is a block of rhyolitic pillow lavas, 3 metres high, underlain by ablation till (Fig. 18). The source of volcanic rocks is to the south near Lake Matapédia.

The maximum thickness of the ablation till could not be established in the field but from the St. Mathieu site (Fig. 16) it is known to be at least 3 metres thick at some sites.

Ice-Contact Sediments (Map unit 4, 4A)

The term ice-contact sediment refers to stratified silt, sand, and gravel deposited in contact with glacial ice; it often is affected by glacio-tectonic deformations (Fig. 19). Eskers (4A) are also considered as ice-contact sediments but typically form sinuous ridges. Their texture is the same as glaciofluvial sediments.

At the time of the field study only one esker in the area was being worked as a gravel pit and from sections in that pit alone, it was not possible to determine the current direction. For the two eskers found in the Neigette Valley, current direction was interpreted to be northward as indicated by two deltas found close to their distal ends (e.g., Luceville Delta, Fig. 8, p. 23). Lebuis (1973b) found similar evidence in the Matane area. Field and airphoto observations suggest eskers are from 5 to 20 metres high.

Figure 17. Erratic: reefal-type limestone near St. Donat

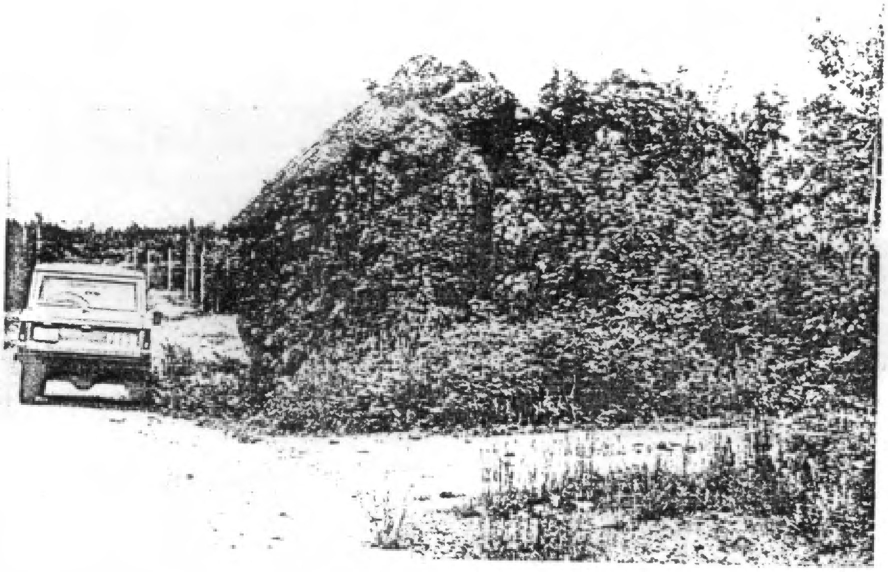


Figure 18. Erratic: rhyolitic pillow lavas, near St. Donat

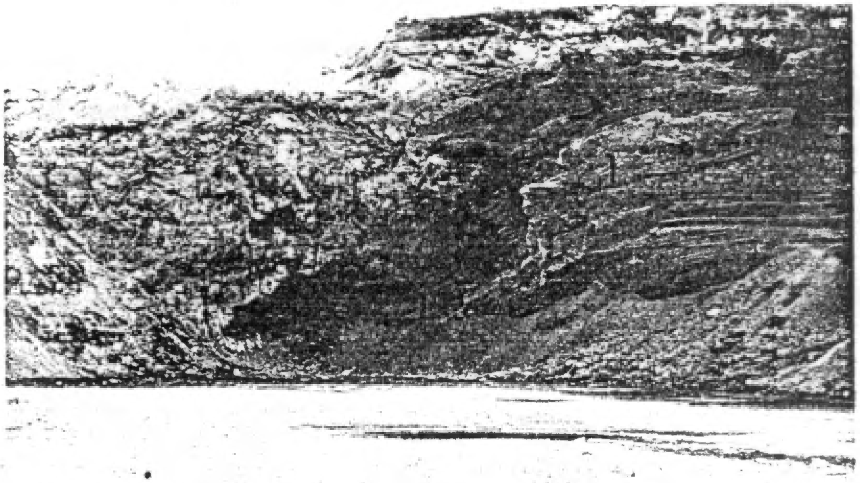


Figure 19. Ice contact sand and gravel in the St. Fabien delta (1: glacio-tectonic deformations, view from the northwest)

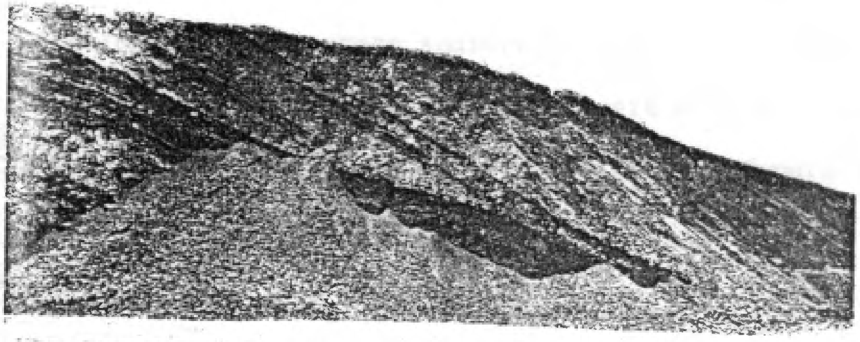


Figure 20. Outwash sediments in the St. Fabien delta (view from the northeast)

Ice contact sediments also occur as kames and kame terraces. No Precambrian pebbles or boulders were identified in this sediment, suggesting that its source was solely Appalachian.

Current directions and sediment sources corroborate Lebuis' conclusion that the ice front receded to the south (Lebuis, 1973b, p. 10).

At St. Fabien (Fig. 19) ice contact sediments enclose a till inclusion all overlain by nondeformed stratified outwash sand and gravel (Fig. 20). At Price, ice-contact deposits dipping up to 40° to the north are overlain by fluvial sediment.

Glaciofluvial Sediments (Map unit 5, 5A)

Glaciofluvial sediments are represented by stratified sand and gravel in deltas, dipping at angles as high as 30° to 35° (Fig. 20). These deposits are restricted to valleys and are found in terraces above present-day streams or close to ice contact sediments.

In the field, glaciofluvial sediments are poorly stratified compared with fluvial sediments (Fig. 29, p. 70) and are not affected by glaciotectonic deformations as ice-contact sediments are. The few pebbles of granite that were found in this type of deposit were well-weathered, and may have been transported prior to the last glaciation. Generally, no Precambrian rocks were identified in these deposits.

From texture analyses on a few samples, this sediment appears to be moderately well to poorly sorted (Table 3; App. E, p. 202). Their cumulative curves are considered nearly symmetrical and of a meso to leptokurtic type. These results suggest an immature sediment deposited with occasional excess in energy.

The Luceville and St. Anaclet (Fig. 2, in pocket) deltas are located on the northwest flank of the last hill before reaching the St. Lawrence

NUMBER	M_z ø	I ø	S_k	K_G	Elev. (m)
22C/7W- 1	1.33	0.89	0.08	1.21	134
3	-0.40	1.84	0.02	1.04	131
8	-1.60	1.70	0.01	0.80	137
22C/7E-45	1.92	2.38	-0.12	----	137

Table 3 Folk's Parameters on Samples from Glaciofluvial Deltas

Co-lor	Sample No.	Sand %	Silt %	Clay %	Spec. grav.	Alt. (m)	Strat. unit no.
GREY CLAY	22B/12W-7	2	43	55	2.66	67	7
	" 17	7	50	40	2.62	67	"
	" 19a	1	42	57	2.58	69	"
	" 12	8	43	49	2.52	104	7/2
	22C/9E- 18	6	48	46	2.76	15	7
	" 25	0	61	39	2.70	79	"
	22C/8W- 18	3	55	42	2.60	89	"
	" 28a	2	52	46	2.72	102	7/9b
	" 24	0	63	37	2.66	102	7
	22C/7E- 7	8	52	40	2.59	131	2/7
	" 13	0	64	36	2.21	103	7
	" 22	1	53	46	2.59	84	"
	" 25	3	46	51	2.73	46	"
	22C/2W- 1	0	60	40	2.70	122	"
	" 20	5	68	27	2.67	118	"
	22C/3E- 19	4	53	44	2.69	122	7/9b
LIGTH BROWN CLAY	22C/9W- 12	9	64	27	2.63	114	7
	22C/7E- 1	1	49	49	2.51	119	"
	" 24	2	64	34	2.72	96	"
	" 30	1	59	40	2.73	101	"
	" 34	0	59	41	2.70	81	"
	22C/3E- 11	23	48	29	2.66	148	"
*DARK CLAY	22C/7E- 42	18	57	25	2.34	96	7
	" W- 31	0	36	64	2.59	76	"
REDDISH BROWN CLAY	22C/9W- 6	2	27	71	2.63	12	7
	22C/8W- 27	1	36	63	2.49	72	"
	" 30	0	43	57	2.62	113	"
	22C/7E- 21	9	52	39	2.58	96	"
	" 31	0	52	48	2.73	67	"
	" W- 35	0	40	60	2.72	148	"
	" 36	1	36	63	2.66	120	"
	" 38	4	44	52	2.70	114	"

* dark grey clay

Table 4 Summary of Grain Size Analyses on Surface-Collected Clay Samples

Estuary, whereas the St. Fabien delta (Fig. 2, in pocket) faces the mountain which lies on the present shore of the St. Lawrence Estuary. Shells (locality D-18, Table 5, p. 60) were found only in the St. Fabien delta. In these deltas, strata dip northwest to northeast toward the Estuary. These deltas were not entrenched by their own stream to form fluvial terraces as was found for the Trois-Pistoles delta by Dionne (1972a). It is believed that when the ice receded far enough to the south, meltwater was deflected toward the present drainage ways.

Marine fossils found in the St. Fabien delta indicate that the body of water into which the delta was built was the sea. The Luceville and St. Anaclet deltas are at a lower elevation and to the east of St. Fabien; it is suggested that these deltas were also formed into the sea.

The greatest thickness of glaciofluvial sediments occurs in deltas, with a maximum thickness of about 20 metres observed at St. Fabien. These deposits usually occur at the surface but could be covered by fluvial sediments and be underlain by ice contact sediments, till, or even marine clay. An example of the latter was found at Trois-Pistoles by Dionne (1972a) in a section in the lowest part of the delta which was partly reworked by the sea into littoral sediments.

Glacio-Lacustrine Sediments (Map unit 6)

Glacio-lacustrine sediments are composed of alternating beds of fine sand and silt. They have limited distribution in the map-area; the same is true in the Matane area (Lebuis, 1973b). Only one section was found at St. Mathieu with medium sand and silty fine sand in alternating layers (Fig. 21). At this section, the lacustrine sediments were at least 3 metres thick with rythmites about 10 cm each in thickness. If these are annual varves, the lake lasted at least 30 years.

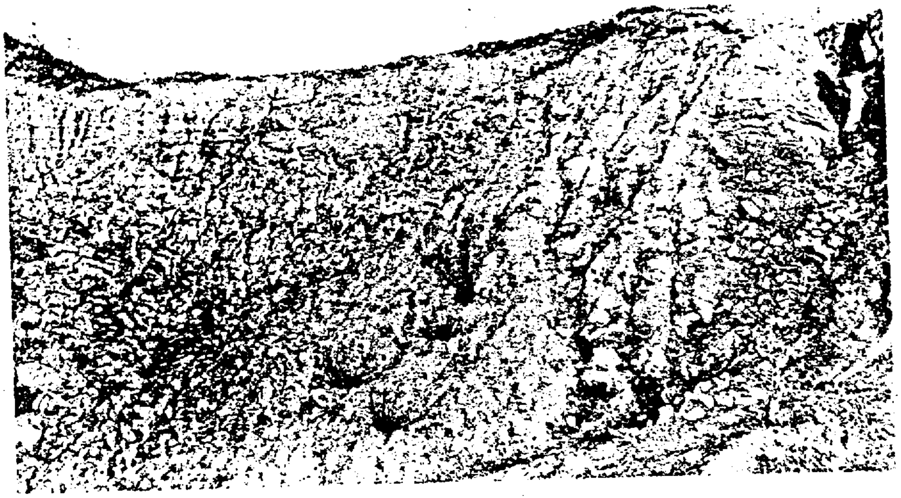


Figure 21. The St. Mathieu section: glacio-lacustrine sediments (view from the northwest)

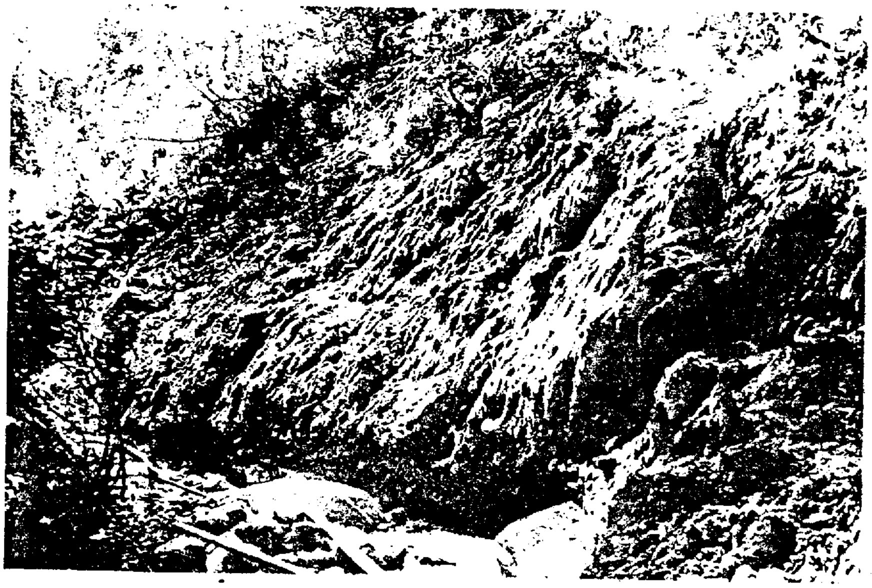


Figure 22. The Grand Métis section in glaciomarine clays (view from the northeast)

No deformations were observed at the St. Mathieu site, which forms a kame terrace-like feature. Laterally and toward the centre of the valley a sandy silt, bearing foraminifera, lies at a lower elevation (overlying lacustrine sediments). This indicates a later connection with the sea when what was damming the glacial lake (moraine, ice ?) disappeared and allowed the sea to enter the valley.

Deep Water Marine Sediment or Marine Clay (Map unit 7)

Since the marine clays were one of the principal interests of the project, they will be discussed here in more detail. Descriptions provided by other recent workers in the region will be summarized first, followed by a summary of observations by the author in the present map-area.

Previous Descriptions

Lee (1962) described the clay units in the Rivière-du-Loup area that were later described in greater detail by Dionne (1968c, 1972a) as the "Trois-Pistoles" clay, the "glacio-marine clay", and the "Middle Goldthwaitian clay". Dionne stated that "they are distinguished by color, limestone content, proportion of clasts, and by other physical, mineralogical and chemical properties" (Dionne, 1972a, p. 24).

The Trois-Pistoles clay consists of a dark grey clay with few boulders, mostly of Appalachian origin (Dionne, 1972a). This clay also occurs up to a maximum altitude of 166 metres above sea level with a maximum thickness of between 50 and 60 metres. The sparse fauna identified by Wagner (1962), consists of Portlandia arctica, Cytheropteron, Elphidium clavatum and Cassadulina islandica. A C^{14} date of 12,700 ± 170 y.B.P. (G.S.C. 102, in Dionne, 1972a) was obtained on Portlandia arctica (98.5 metres above sea level).

The glacio-marine clay is a reddish, grey clay, moderately to very stony. Clasts are subangular, striated, and 75% of Appalachian origin and 25% from the Shield (Dionne, 1972a). The thickness is estimated to be a maximum of 30 metres. At the surface, the clay is usually covered by boulders, 75% of Precambrian origin. Fossil remains found in this clay are the following mollusks: Hiatella arctica, Mya truncata, Portlandia arctica, Macoma balthica, Astarte montagui sp., 2 gastropods, and one Balanus sp. (Dionne, 1972a). Lee (1962) and Dionne (1972a) considered this clay younger than the Trois-Pistoles clay and older than the Middle Goldthwaitian clay. Lee (1962) suggested that the glacio-marine clay was deposited while an ice lobe advanced in the estuary but failed to go farther eastward than the Ile-Verte (between Rivière-du-Loup and Trois-Pistoles) in a northeast direction. He estimated the date of this event between 12,000 to 12,500 y.B.P. No dates are available on the glacio-marine clay.

The Middle Goldthwaitian clay (Dionne, 1972a) is a light grey color, with some subangular to subrounded stones. There is more Precambrian than Appalachian material in this unit, while boulders lying at the surface are 75% of Precambrian origin (Dionne, 1972a). The thickness of this unit varies from a few centimeters up to 20 metres and the clay can be found interbedded with 1 to 5 metres of sand. This clay has a rich fauna, found mostly in muddy sand: 1 brachiopod (Hemithris psittacae), 20 pelecypods and 20 gastropods; ostracods, three cirripeds, annelids sp., echinoids and foraminifera (Dionne, 1972a).

The oldest C^{14} date obtained for this unit is 11,410 ± 150 y.B.P. (G.S.C. 63) at 94 metres above sea level.

Whereas west of the map-area three clays are described (Lee, 1962), Lebuis (1973b) only describes one clay unit to the east - a grey calcareous, massive, fossiliferous and occasionally stony clay with some sand and silt.

Hence it could be concluded that the map-area is located in a transition zone between a single clay unit to the east and three units to the west. These differences between east and west clays may only reflect the widening of the sedimentary basin eastward.

Clays of the Map-Area

Prior to any description of the marine clay we must take into account the variety of sedimentary environments, including the effect of local topography, source of material, and the variation from the near-lagoon to the open sea.

A massive clay is here considered as a clay that does not possess stratification but can be "laminated" if it exhibits partings when it is broken. A marine clay will be laminated while a till will exhibit a fissility.

Stratigraphically, and from boreholes, the oldest clay is a dark grey stony and silty clay that can be related to the glacio-marine clay described by Dionne (1972a). This clay outcrops along the Ste. Flavie escarpment and has its best exposure at Grand Métis (Figs. 22 and 23). It was encountered in boreholes F-5, FR-6, FR-7, FR-8 and FR-9 (App. F, in pocket) lying directly on bedrock, and overlain by a reddish clay in the Rimouski Luceville area, and by a massive grey clay in the Baie-des-Sables/Mont-Joli area. It is sometimes overlain by peat when found near the surface.

This grey stony clay passes laterally into a red stony clay at the Tartigou River section (Fig. 24). Most of the coarse fraction is subangular to subrounded and striated. The material appears to be mainly

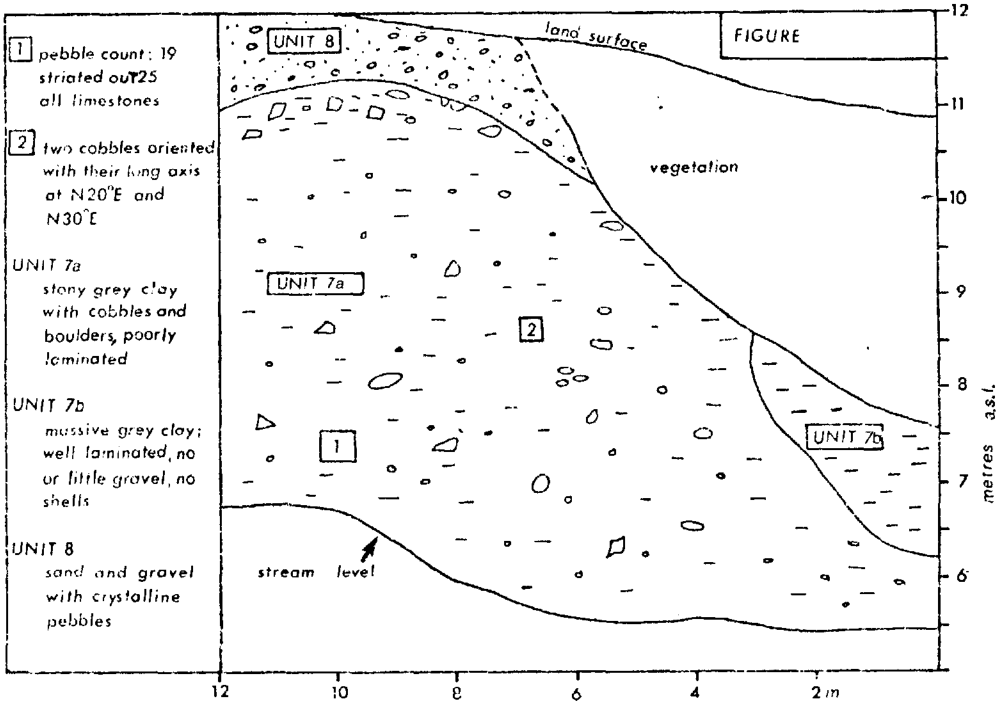


Figure 23. The Grand Métis section: diagram showing the main stratigraphic units.

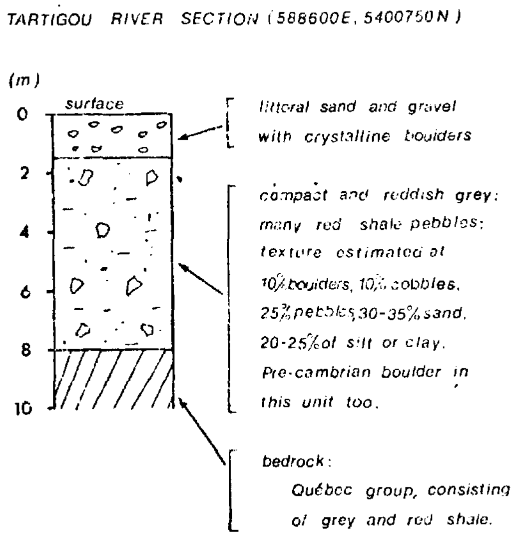


Figure 24: The Tartigou River section in till or glacio-marine clay.

of Appalachian origin (95-100%), based on qualitative field and laboratory (microscope) evaluations. At the Grand Métis section (Fig. 23) 19 pebbles out of 25 were striated and all were derived from Appalachian sedimentary rocks. The greatest thickness for this type of clay was estimated to be 25 metres, at Grand Métis. No macrofossils (shells) were found; but all samples (5) examined contained microfossils, such as foraminifera. The highest elevation of occurrence was determined as 41.0 metres above sea level at Rimouski in borehole number F-5 (App. F, in pocket). At this site, the glacio-marine clay is overlain by 2.0 metres of grey clay, 1.5 metres of sandy clay, followed by a reddish clay.

The previous description corresponds well with Coleman's observation: "At almost every river mouth along the north shore typical blue boulder clay with striated stones may be found ... such boulder clay has, however, not been found more than a mile or two inland and never more than 100 ft above sea level" (Coleman, 1922, p. 12).

The fact that this type of clay does not occur inland more than 2 or 3 km could be an important geological indication of ice rafting or ice front positions, as will be discussed in Quaternary History on page 86.

A light to dark grey clay, weathering near the surface to a light brown clay, is the most widespread type. Its facies and distribution are clearly revealed since it usually occurs at or near the surface, and has often been encountered in boreholes (App. F, in pocket) and penetrometer tests (App. F). It is usually underlain by either bedrock (F-6, App. F) or by the glacio-marine clay (F-6, FR-6-7-8-9) interbedded with a reddish clay near Rimouski (F-5, FR-7, App. F). Also from east to west it changes from a massive clay with a few thin sand lenses to clay with sand lenses up to 3 metres thick in the Trois-Pistoles area. In an excavation at Rimouski, a banded grey, red and brown clay was observed, where the partings were controlled by fine sand laminae. The texture of this clay is summarized in Table 4 (p. 46) but generally is up to 23% sand, 42 to 67% silt, and 23 to 57% clay.

Also, from Baie-des-Sables to Luceville, the marine clay is overlain by littoral sand and gravel and also by organic or peat bog deposits in old channels. Where the clay outcrops, it is in windows in littoral sediments. Many Precambrian boulders (up to 75% of all boulders) lie on this surface (Dionne, 1972a). This relationship continues westward but from St. Anaclet westward a light grey clay is exposed at higher elevation than the well-defined littoral sediments. At Rimouski this clay is very dissected (Fig. 25). Its thickness is estimated at about 60 metres from boreholes at Rimouski, and the topographic map where deeply ravined marine clays are found (22C/7E). Figure 25 shows the deeply ravined clay where it reaches an elevation of 100 metres above sea level. Westerly around St. Fabien and Bic, a dark brown to reddish brown clayey silt outcrops as high as 146 metres. No shells were found but microfossils such as foraminifera were identified. The light grey clay near Rimouski, and the dark brown to reddish brown clay near St. Fabien will be later referred to as the "high" massive clay.

For textural study, clays were divided into three groups on the basis of their color, in order to compare with Dionne's results: light to dark grey clay, light brown clay, and reddish clay. Results are summarized in Table 4, and Figures 26 and 27.

From the triangle diagram (Fig. 26) reddish brown clay tends toward higher clay content while the grey clay and light brown clay are more silty. In Figure 27 the same results are presented on a histogram. This histogram is used to give another idea of transition between clay groups

Figure 25. Intense gulleying (A) in marine clays, and raised beaches (B) near Rimouski. (Photograph courtesy of the Québec Dept. of Lands and Forests, scale is about 1:20,000)

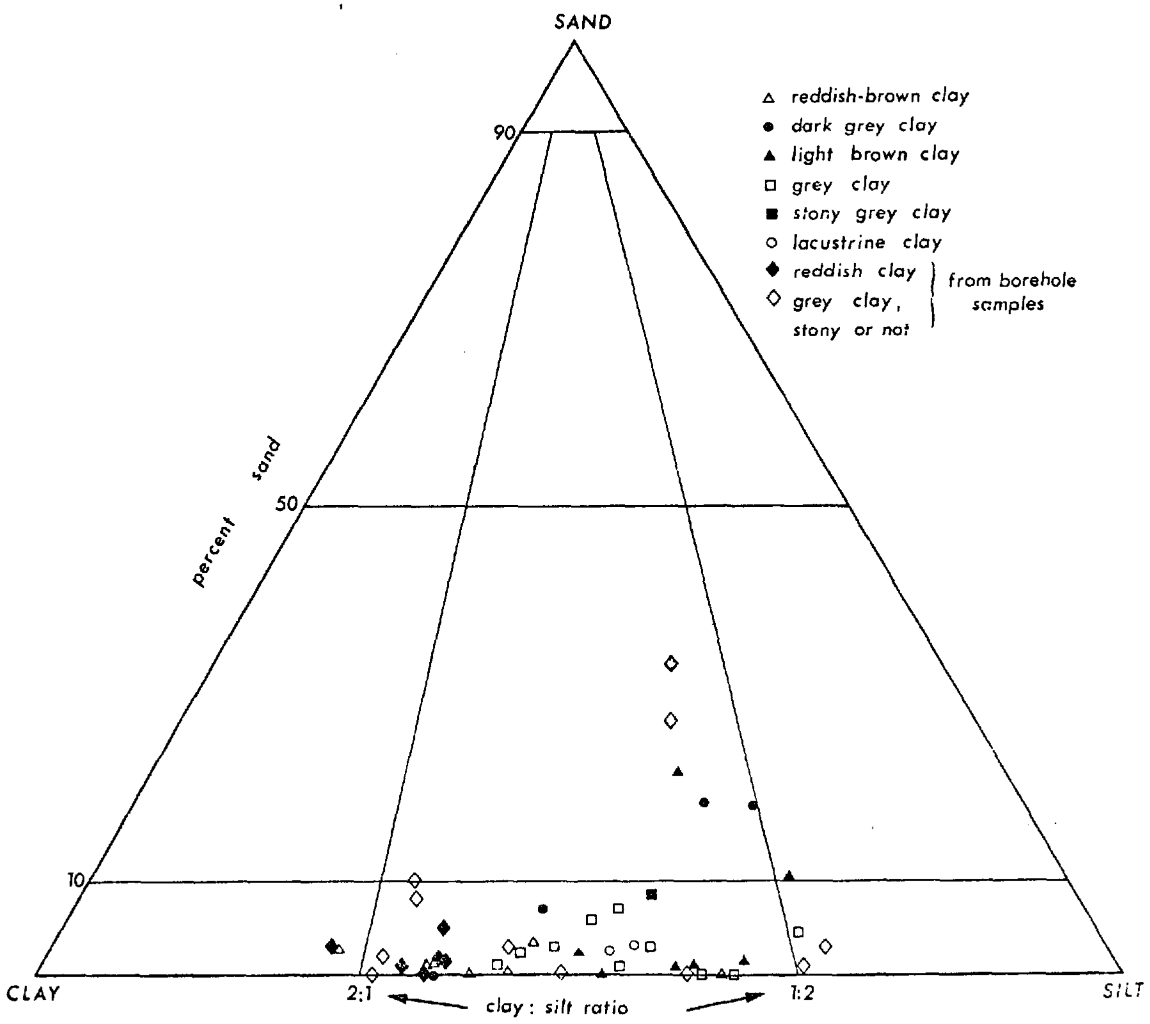


Figure 26. Texture analyses of marine clays represented on a triangular diagram

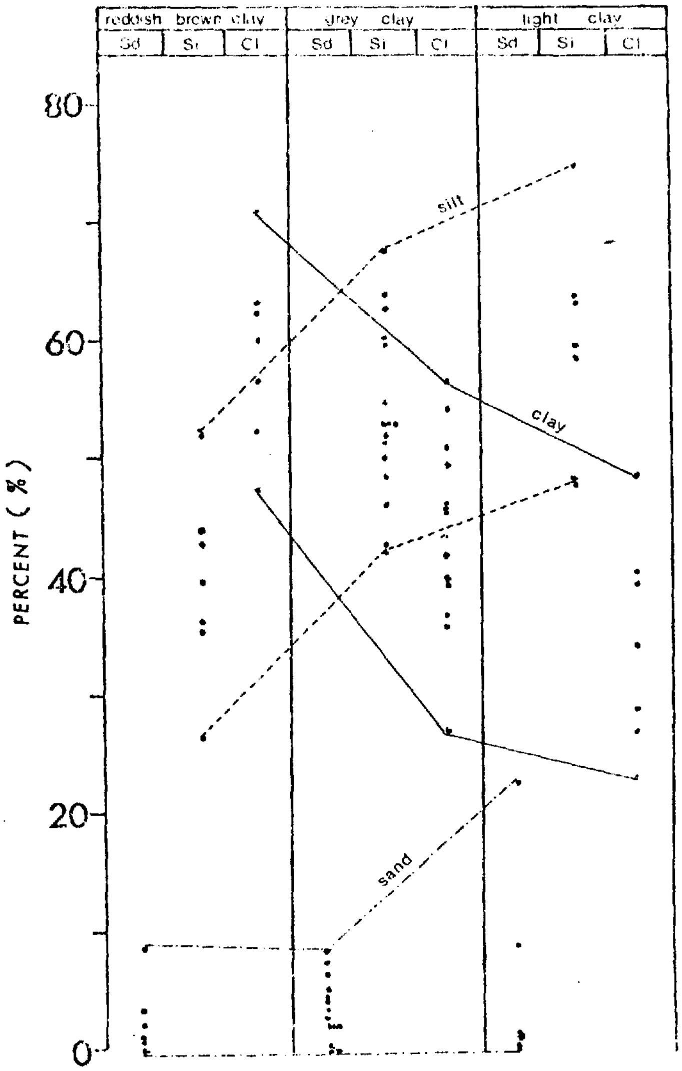


Figure 27: Histogram of sand, silt, and clay fractions of marine clays.

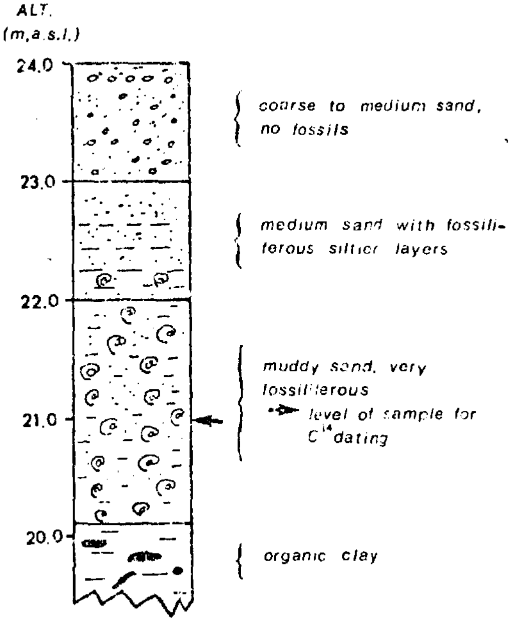


Figure 28: Section in marine sediments near Bic, at fossil locality D 16.

as selected. It shows well the overlapping for all the groups and for the different fractions.

The sand fraction for the clays falls in almost the same bracket, except for one sample of light brown clay. The sand fraction ranges between 0 and 10%, while the silt and clay fractions differ from one group of clay to another. The reddish brown and grey clays overlap on at least 60% of their percentage-distribution. The light brown clay is distinguished mainly by its slightly lower clay content. At Rimouski, a section in a massive grey clay is exposed with a light brown clay near the surface, reflecting oxidation.

From microscopic studies it was found that the reddish brown color is due to a higher proportion of red slate. The grey clay, however, has a higher proportion of grey slate. The writer then suggests that the color is related to the source of material rather than different sedimentary environments. Almost all the clay samples analysed were of "massive" marine clay. Only one sample of "stony" clay was analysed. No study of the matrix of the "stony" clay was performed, therefore the conclusions from the analyses are not applied to the "stony" clay. The "massive" clays of different color have a similar texture. Since no distinction, except for the color, can be applied to the "massive" clay, only two groups can be established: a stony and a massive clay. The massive clay also includes the "high" marine clay which could be considered as the transition between the stony and the massive clays. This "high" marine clay corresponds to the Trois-Pistoles clay (Lee, 1962; Dionne, 1972a).

In summary (see following diagram), marine clays of the map-area can be divided into two groups: glacio-marine, high and massive clays. The glacio-marine clay is the oldest, and the high massive clay was deposited when the ice front receded landwards onto the first hills.

	Rivierè-du-Loup/ Trois-Pistoles area	Trois-Pistoles/ Baie-des-Sables area		Matane area
youngest ↑	Middle Goldthwaitian clay	Massive clay	(1)	Massive clay
	Glacio-marine clay	High massive clay	(2)	("Marine" Till)
	Trois-Pistoles clay	Glacio-marine clay		
oldest		("Marine" Till)		

Fauna

Dionne (1972a) indicates that the grey clay has a richer fauna at lower levels; fossils are concentrated mainly in sandier layers. Also, fewer species were identified at high altitudes, such as at St. Donat (D6, Tables 5 and 6). Main fossil localities are shown in Figure 38 (in pocket).

The following fossils (also listed in Table 5) were identified by Wagner (1975):

PELECYPODA

Nuculana buccata (Steenstrup) ?

Mytilus edulis Linne

Astarte undata Gould juvenile

Serripes groenlandicus (Bruguiere)

Macoma balthica (Linne)

Macoma calcarea (Gmelin)

Mya pseudoarenaria Schlesch

Mya truncata Linne

Hiatella arctica (Linne)

<——FOSSIL LOCALITIES (D...)——>

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
PELECYPODA																											
Astarte undata																X											
Hiatella arctica			X		X	X										X	X	X									
Macoma balthica		X	X		X			X			X	X				X	X	X									
Macoma calcarea	X															X	X										
Mesodesma arctica*									X																		
Mya arenaria			X															X									
Mya pseudoarenaria					X						X						X										
Mya truncata					X	X											X	X									
Mytilus edulis		X	X	X	X		X	X			X	X				X	X										
Nuculana buccata																	X										
Portlandia arctica					X																						
Serripes groenlandi.																X	X										
GASTROPODA																											
Boreatrophon clatha.																X											
Buccinum glaciale											X					X	X										
Buccinum tenue							X									X	X										
Lunatia pallida																X	X										
Natica clausa																X	X										
CIRRIPEDIA																											
Balanus balanus			X		X		X	X								X	X										
Balanus crenatus																X	X										
Balanus hameri						X												X									
FORAMINIFERIDA																											
Bucella frigidia																X	X										
Elphidium frigidium																X											
Elphidium incertum										X			X	X	X	X	X		X	X	X	X	X	X	X	X	X
Elphidium inc. cla.													X	X	X	X				X	X	X	X	X	X	X	X
Islandica islandica													X	X	X				X		X	X					
Islandica teretis										X				X													
Protelphidium orbi.										X			X	X		X									X		X
Pseudopolym. novang*																X											
Quinqueloculina art*																X											
OSTRACODA																											
Acanthocythereis																X											

* identified by the author.

Table 5 Fossil Assemblages

SITE	LOCALITY	ALT. (m)	SEDIMENT	STRAT. UNIT	GEOGR. COORD, UTM	
					EAST	NORTH
1	Tartigou R.	76	clay	7	589150	5398350
2	St. Octave	55	sand-gr.	8	565500	5385150
3	St. Octave	62	" "	"	565700	5384550
4	Mont-Joli	72	" "	"	558650	5382150
5	St. Anaclet	82	sa.-silt	8/7	545950	5370100
6	St. Donat	90	cl.-silt	7	554235	5372250
7	Mont-Joli	6	sand-gr.	8	558200	5385450
8	Luceville	46	" "	"	547400	5372500
9	Baie des Sa.	6	" "	"	582050	5397750
10	Bic	116	cl.-silt	7	521700	5354800
11	Grand Metis	30	sand-gr.	8	566150	5386550
12	St. Octave	55	" "	"	565650	5384750
13	Bic	116	cl.-silt	7	523400	5357000
14	"	131	" "	7/2	519800	5352100
15	"	100	" "	7	523650	5357400
16	"	21	si.-sand	8/7	518300	5355600
17	"	19	" "	"	518175	5355400
18	St. Fabien	147	gr. sand	3	500950	5350000
19	St. Valerien	138	cl.-silt	7/2	522000	5354500
20	Bic	120	" "	7	520400	5353010
21	St. Valerien	116	" "	"	521700	5354800
22	St. Mathieu	116	" "	"	504650	5339500
23	Rimouski	67	" "	"	533900	5363175
24	Ste.Blandine	106	" "	"	534750	5353850
25	Neigette	90	" "	"	552250	5367400
26	Metis	120	bo.-clay	2	575850	5390200
27	Trois-Pistol.	18	cl.-silt	7	488500	5332360

gr: gravel; sa. : sand; cl.: clay; si.: silt;
bo.: bolder.
7/2: marine clay or "marine" till.

Table 6 Location of Fossil Localities

GASTROPODA

Natica clausa Broderip & Sowerby

Lunatia pallida (Broderip & Sowerby)

Boreotrophon clathratus Linne

Buccinum glaciale var. *donovani* Gray

Buccinum tenue Gray

CIRRIPEDIA

Balanus balanus (Linne)

Balanus crenatus Bruguiere

Balanus hameri (Ascanius)

FORAMINIFERIDA

Buccella frigida (Cushman)

Elphidium frigidum Cushman

Elphidium incertum (Williamson)

Elphidium incertum clayatum Cushman

Islandiella islandica (Norvang)

Islandiella teretis (Tappan)

Protelphidium orbiculare (Brady)

OSTRACODA

Acanthocythereis cf. *A. dunelmensis* (Norman)

"These are typical moderately shallow, cold water species" (Wagner, 1975, p. 4). At a few sites (D16-D17), shells for the same species were of different size, with large *Mya pseudoarenaria* up to 5 cm in diameter. At site D-6 many fossils were noted, but included only a few species. *Hiatella arctica* and *Mya truncata* at D-6 had consistent sizes varying not more than 0.5 cm (from 2.0 to 2.5 cm for *Hiatella arctica*, and about 3.0 cm for *Mya truncata*).

The fossils were more abundant in muddy sands (D16, D17, D5) than in sand and gravel (D-11, D12, D7, D4). This indicates that a nearly closed basin sustains more species. However, samples collected in sand and gravel (littoral sediments) forming beaches are better indicators of sea level. Mytilus edulis was commonly found in beach deposits.

Hiatella arctica, Macoma balthica, Mya arenaria and Mya truncata are the highest marine shells ever found in the Lower St. Lawrence/Gaspé region, at 138 metres above sea level near St. Fabien (St. Fabien delta). These fossils, in ice contact sediments, are known to indicate brackish cold water (Wagner, 1970).

The following estimations of temperature and salinity, as derived from fossil assemblages, are purely hypothetical, since no biometric study was carried out by the author on the samples. Derivations are made solely upon the link between fossil assemblages and their environments, and result from the application in this study, of conclusions gathered from students of the Champlain and Goldthwait Seas (Wagner, 1970; Bartlett and Molinsky, 1972; Hilaire-Marcel et al., 1974). One must bear in mind the tolerance of the various species to variations in salinity. This is especially true of species such as Macoma balthica, Mytilus edulis, and Mya arenaria, which can survive with salinities as low as 3.5‰ to 5.0‰ (parts per mille; Wagner, 1970). It is also recognized that "additional evidence for lower salinities is the paucity of the species" (Wagner, 1970, p. 8). Therefore, it is easier to estimate the lowest corresponding salinities. As a guide, results obtained for few species, identified in the Champlain Sea, are reproduced here (Wagner, 1970, p. 9):

Salinity as low as 3.5-7‰: Macoma balthica, Mya arenaria, Mytilus edulis, Macoma calcarea

Salinity not lower than: 7‰ : Astarte montagui vars (?)

8‰ : Mya truncata, Hiatella arctica, Nucula tenuis (?)

20‰ : Portlandia arctica, Nuculana pernula (?)

In general, most of the species encountered are found today in arctic and boreal waters (Wagner, 1970). A recent study by Hilaire-Marcel et al. (1974) supports the idea that Macoma balthica and Balanus co-existed in less than 15 metres of water with an annual mean water temperature greater than 10°C. They also indicate that Macoma balthica, Mya sp. and Hiatella arctica, if together, need an annual temperature greater than 12°C (for Mya sp.). Therefore, temperature can have varied from less than 10°C (Hiatella arctica) to more than 12°C (Mya sp.) with a salinity as low as 8‰ (parts per mille). Astarte sp. needs more than 7‰ and Portlandia arctica more than 20‰, while Mya truncata and Hiatella arctica need more than 8‰ (Wagner, 1970).

On the basis of the occurrence or the absence of the fossils discovered at the different sites the following interpretations are presented:

(1) When the ice front was on the coast and the upland (St. Fabien delta, D18), the marine waters (155-metre level) were cold and brackish with an annual temperature between 10 and 12°C, falling at times below 10°C. The salinity was as low as 8‰ about 13,500 years ago. This is also shown by fossils of Hiatella arctica found in till at St. Valérien and Matane. Therefore the predominance of Hiatella arctica would suggest a mean annual temperature often less than 10°C.

(2) Later the water became more saline and warmer as shown by the presence of Portlandia arctica (D6) which needs a salinity higher than 20‰ (Wagner, 1970). Conditions approaching those of today began at the 25-30 metre level (about 9,000-10,000 years ago) with an increase in the

number of species (D16, D17). The abundance of Mya and the appearance of Astarte sp. at site D16, D17 indicates that the marine water had a salinity of more than 7‰ and a temperature greater than 12°C. The conditions prevailing today in the St. Lawrence Estuary are: a salinity between 26 and 34‰, and a temperature between 1 and 18°C (Loring and Nota, 1973; Jordan and de La Ronde, 1974).

These interpretations are correlated with the conclusions obtained by Bartlett and Molinsky (1972) for the Holocene history of the Gulf of St. Lawrence. Two interesting points that came out of their study were that the association of Elphidium incertum clavatum, E. clavatum, Islandica islandica, I. teretis is "characteristic of transgressing post-Wisconsin seas" (Bartlett and Molinsky, 1972, p. 1213). They also believe that from 14,500 years to 6,400 years B.P. sea level increased by 100 or 200 metres, and it is believed (Walcott, 1972b) that for the last nearly 5400 years the sea level has not changed by more than 5 metres.

In summary, fossil assemblages found in the Baie-des-Sables/Trois-Pistoles area could suggest that the initial marine water to invade the area was cold (10-12°C), brackish (8‰), and much shallower than the present Estuary (100 or 200 metres). Then, as the land uplifted and sea level increased, less and less cold water came from the retreating ice front. In the interval from about 9000 to 10,000 years B.P. the sea water temperature had reached an annual mean of more than 12°C and a salinity higher than 8‰ (8-22‰) permitting more species to inhabit the Estuary. According to Bartlett and Molinsky (1972), only recently (6400 y.B.P.) did conditions approach those of today.

Texture

As shown previously, the marine clay cannot be divided on the basis of color and texture. However, there are at least two main units: a massive clay and a stony clay. The latter, at all sections studied, always underlay the massive clay. In the Matane area, no stony clay was reported but a till made of reworked marine material (fossiliferous and stony) was observed (Lebuis, 1973b). This stony clay correlates with Dionne's glacio-marine clay. The clasts arrived by ice rafting; however, their lithology seems restricted to sedimentary rocks.

The "massive" clay was found interbedded with sand, especially near Matane, Rimouski, and Trois-Pistoles, where it is related to the presence of deltas. At Trois-Pistoles, sand layers are much thicker due to the large size of the Trois-Pistoles delta (in fact the largest in the area). Few boulders were noted in the massive clay, suggesting the decreasing importance of ice rafting that might be comparable to today's intensity.

Unfortunately only one textural analysis is available on the stony clay. Results obtained for the massive clay are displayed in Table 4 (p. 46) and Figures 26 and 27. However, carbonate analysis indicates an interesting difference between till and marine clay. Till has a lower Ca-Do (calcite/dolomite) ratio due to the presence of less calcite. The stony clay has a Ca/Do ratio similar to the massive clay, but with a slightly higher total carbonate content (see Chapter IV, page 119).

Littoral Sediments (Map unit 8)

The littoral sediments consist of boulders (ice rafted) and fossiliferous sand and gravel. Boulders are mainly anorthosite and gneiss from the north shore (Precambrian) and are used along with deltas as markers of the marine limit.

Dionne (1971) studied the proportion of crystalline (Precambrian) rock in sediments of raised beaches with the following results:

Elevation a.s.l.(m)	Number of Sites	Min. (%)	Mean (%)	Median (%)	Max. (%)
5- 50	7	7.8	11.6	10.3	19.2
51-100	12	3.5	15.2	13.0	30.9
> 100	6	4.9	10.4	11.2	13.6

(from Dionne, 1971)

In the Matane area, Lebuis (1973b) indicated a mean of up to 20% of Precambrian clasts in sediments found below the marine sediments, and about 5% for deposits above the marine limit. Therefore, when Precambrian boulders were used to trace the marine limit, 10% of crystalline rocks was the minimum accepted. When present in small percentages, they were noted but not used as indicators.

Sedimentary structures, such as cut and fill, are well developed in fine to coarse sands. Beds dip from 1° to 15°, with a maximum of 25° reported by Lebuis and David (1972) in the St. Joachin de Tourelle area, which they believe reflects the subjacent bedrock topography.

These sediments are commonly fossiliferous, except for coarse sand and gravel deposits considered as high beach sediments. The fauna is restricted to a few species (Tables 5 and 6), often consisting only of _Mytilus edulis_ and _Macoma balthica_.

Most littoral sediments, as shown in Figure 10 (p. 25) are very easy to identify because of their beach forms, which are very well-developed at river outlets. However, near the marine limit, they are discontinuous and often only represented by boulders resting on the marine clay or bedrock. Well-developed shorelines are not found higher than 75 metres above sea level in the Baie-des-Sables region and around 100 metres above sea level near Trois-Pistoles.

From textural analysis (Table 7), one sees the varying character of these sediments: very well to poorly sorted with about 0-18% of silt, 45-100% of sand, and 0 to 40% of gravel.

At a few places, it was difficult to distinguish whether a unit was marine or littoral. For example, at Bic (Fig. 28) there is a complete transition from a marine organic clay to non-fossiliferous sand.

The littoral sediments are usually underlain by marine clay, till or bedrock and overlain by organic deposits in old channels (Fig. 10). From borehole F-5 and a gravel pit west of the Rimouski River, a maximum of 10 metres of littoral sediments has been observed.

Littoral sand and gravel constitute the main source of material for concrete aggregate and are extensively exploited.

Fluvial Sediments (Map units 9, 9A, 9B)

Fluvial sediments include well-stratified sand and gravel lying above present-day streams and rivers and forming successive deltas (9A) due to a regressing base level, usually toward the estuary. When deposited in connection with the sea, fluvial sediments are underlain by marine clay or littoral sediments. Otherwise they may overlie lacustrine deposits, as found in the Neigette Valley near St. Donat (22C/9W), glacio-fluvial, or ice contact sediments.

Fluvial sediments exhibit many sedimentary structures such as ripple marks (Fig. 29) and crossbedding which in deltas, may dip from 5 to 25° toward the estuary. The concentration of 2 to 6 cm (crystalline) cobbles

Sample No.	M_z Ø	S_{kI}	σ_I Ø	K_G	Alt. (m)
22B/12W-2	+0.58	-0.12	0.76	1.16	73
" 31	-0.70	-0.15	2.37*	----	67
22C/9E- 5	+1.43	+0.02	2.55	----	76
" 14	-0.55	-0.001	1.83	0.6	38
" 19	+1.08	+0.03	1.57	1.43	NR
22C/9W- 9a	-1.87	-0.30*	2.85*	----	76
" 9b	+0.37	+0.36	0.64	1.01	"
" 19	+1.08	-0.43	1.94	1.14	85
22C/7E- 20	+1.25	+0.37	0.86	1.27	110
" 33	+0.92	+0.43	0.81	1.41	79
22C/7W- 22	+0.92	+0.50	1.89	1.10	49
" 27	+1.05	+0.51	1.81	1.12	21
" 29	+1.33	-0.03	1.17	1.44	**21**
" 37	+0.83	+0.03	1.44	0.99	107
22C/3E- 5	-0.52	+0.90	2.03	1.09	18
" 6	+0.08	+0.08	1.41	1.19	18
" 7	+0.10	+0.04	2.64	1.02	18
22C/2W- 8	+1.47	+0.22	1.70	0.08	46
Samples from Transition Zones Between Marine (7) and Littoral Sediments (8)					
22B/12W-6	+0.40	-0.07	2.16	1.10	79
" 28	+0.84*	+0.54*	2.59*	----	76
22C/9E- 3	+0.63	+0.23*	2.20*	----	23
22C/8W- 13c	+2.92	+0.75	0.33	1.70	94
" 29	+1.12	+0.29*	2.13*	----	98
22C/7E- 35a	+1.57	+0.30	1.85	0.65	20
" 35	+1.32	+0.30	1.82	0.91	20
" 37	+1.22	+0.19	1.79	0.74	85
22C/3E- 2	+1.40	+0.20	1.92	0.89	15
22C/2W- 10	+0.15	+0.03*	2.83*	----	146

*: Folk's parameters could not be used; see Appendix D.

Table 7 Folk's Parameters for Littoral Sediments

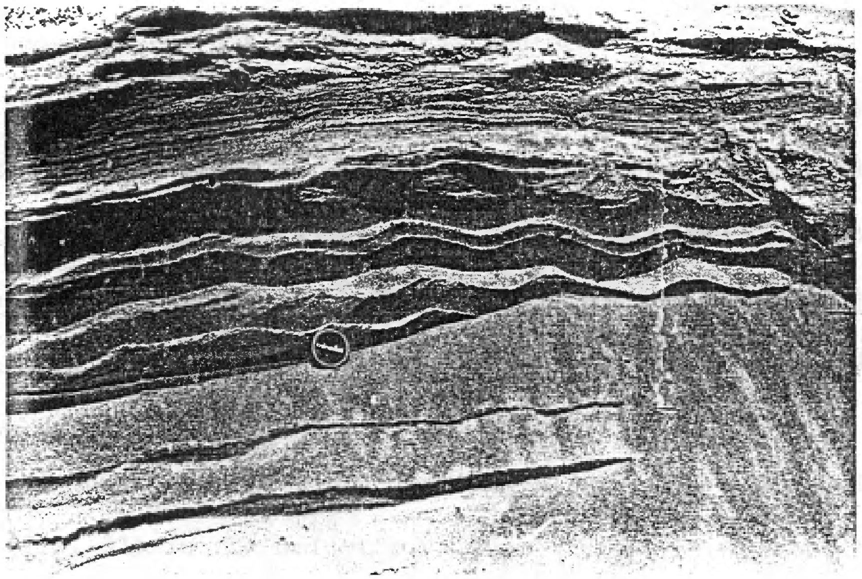


Figure 29. Ripple marks in fluvio-deltaic sands near Rimouski

described by Dionne (1971) over 14 sites gave the following results: mean - 1.8%, minimum - 0%, median - 1.2%, and a maximum of 5.3%.

These results correlate well with our observations that suggest the Appalachian rocks as the main source of sediments. Textural analysis of sediments from delta samples give results displayed in Table 8. Their grain size distributions give: silt, 0-18%; sand, 45-100%; gravel, 0-40%. Eighty-five percent of the cumulative curves show an excess in the fine fraction (+ skewness) with 65% for littoral sediments.

It is interesting to note at this point that one ice-wedge (Figs. 30a,b) was discovered at about 85 metres a.s.l. in a gravel pit exploited near St. Donat in the Neigette Valley. The fluvial sediments are mined mainly for roadfill and because of their shale content do not make good concrete aggregates. Up to 22 metres of fluvial sediments were drilled at Neigette.

The fluvio-lacustrine unit (9B) comprises alternating layers of silty sand and clay (Fig. 31) in the Neigette Valley. This unit represents the last fluvial phase of sedimentation in shallow water that was later covered with an organic mantle. The distribution of this sequence is restricted to the west end of the Neigette Valley, but it helps in understanding the general geology of the Neigette Valley.

Alluvial Sediments (Map unit 10)

Alluvial sediments consist of recent fluvial deposits that occupy the floodplain of present-day streams and rivers, and consist of silt, sand and gravel, in places interstratified with organic material. As pointed out by Lebuis (1973b), they are composed of reworked fluvial and glacio-fluvial sediments. In the Neigette Valley alluvial sediments consist also of marine material, but this is only of local significance.

NUMBER	UNIT	M_z ϕ	I ϕ	S_k	K_G	Elev. (m)
22B/12W-3	9A	1.97	1.54	-0.28	2.01	110
" 4	"	-1.97	1.97	-0.74	0.70	"
" 4b	"	-1.55	1.57	0.02	1.05	"
" 4c	"	-1.53	1.47*	0.12*	1.01*	"
" 4d	"	-1.26	1.43*	0.12*	0.95*	"
" 16	"	2.14	0.72	0.12	1.15	"
22C/9E- 7	"	0.80	2.02	0.07	1.20	79
" 8	"	3.00	1.61	0.64	0.93	"
" 11	"	1.70	2.17	0.13	1.07	81
" 17	9	-0.49	2.33	-0.37	0.76	94
" 24	"	1.22	0.48	0.11	1.73	76
22C/7E- 18	9A	2.45	1.34	0.09	1.07	81
" 28	9	1.05	1.33	0.02	1.39	91

*: formulas other than Folk's were used

Note: 9: fluvial, 9A: fluvio-deltaic

Table 8 Folk's Parameters for Samples of Fluvial Sediments

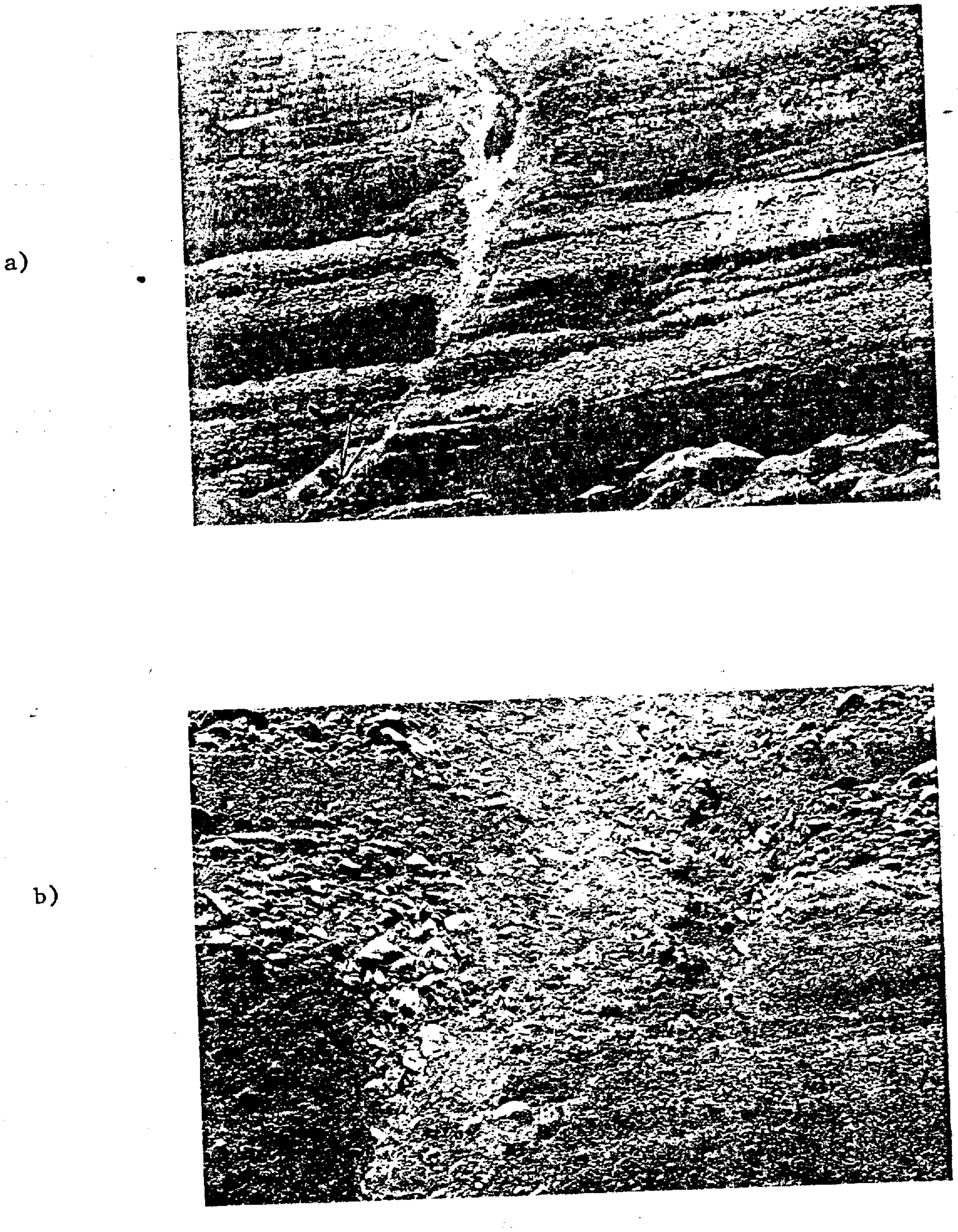


Figure 30. Ice-wedge in fluvial sediments near St. Donat:
a) General view
b) Close-up

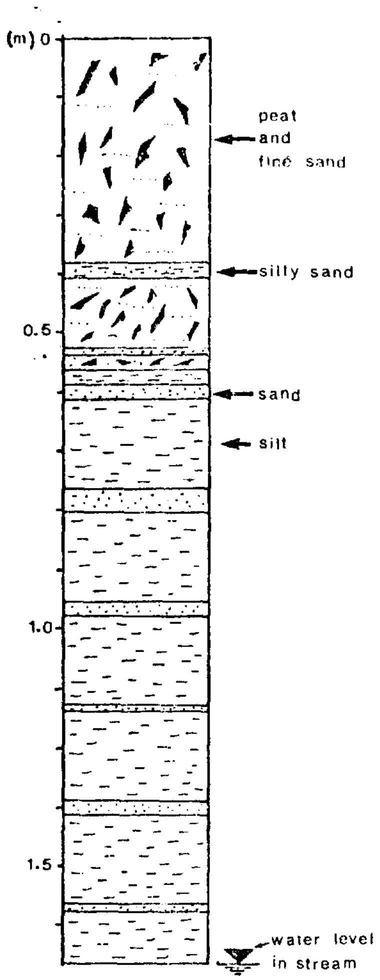


Figure 31: Type section in fluvio-lacustrine sediments, near Ste-Blandine (539400 E, 5358600 N, 100 m a.s.l.).

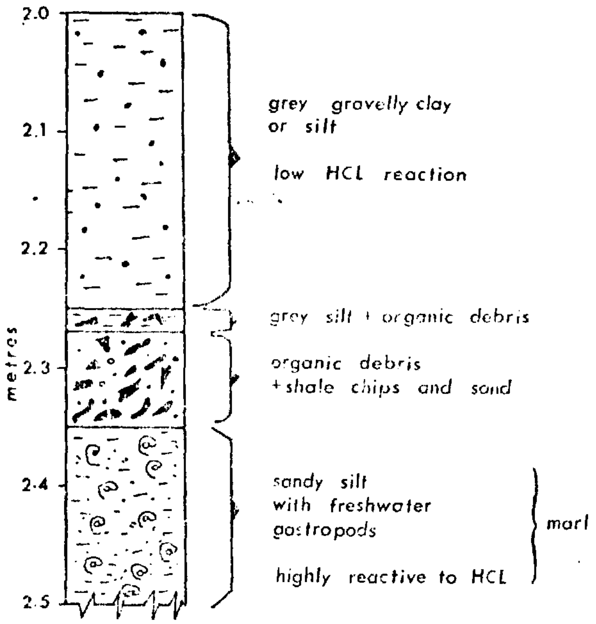


Figure 32: Section showing lacustrine sediments overlain by organic deposits, near Moise.

Mapping of alluvial plains provides planners with a delineation of the area subjected to flooding. The thickness of alluvial sediments was not determined but even areas underlain by less than 0.9 metres (3 ft.) of sediments are included in this unit on the map. Alluvial sediments can be underlain by all the preceding units, and by organic deposits in temporary basins or oxbows.

Valley Bottom Silt and Colluvium (Map unit 11)

A colluvium and valley bottom silt unit was suggested by Lee (1962) to describe sediments moving on slopes (creep) and accumulating at the bottom of valleys. They lie either on bedrock or till as is found in the Ladriere area (map 22C/7W, App. A). As indicated by Lee (1962) the slope movement process started immediately after ice retreat, is still active today, and may be of greater magnitude today because of man-induced erosion.

Organic and Peat Bog Deposits (Map unit 12, 12A)

Organic (12) and peat bog (12A) deposits represent the second most widespread unit after unit 1 (saprolite and thin till veneer). Peat bogs only include "Sphagnum" bogs and were only mapped by airphoto study (Figs. 10 and 11, p. 25 and 27). A good description of bog deposits in the Lower St. Lawrence region is given by R. Gauthier (1971), including the Pointe au Père peat bog at Rimouski (22C/7E, 22C/8W).

Due to its large extent, organic material was mapped only when more than 0.9 metres (3 ft) thick. The underlying units are shown on the map where organic material is less than 0.9 metres thick (e.g., 12/7). For example, organic deposits occupy the old channels of the estuary (Fig. 10,

p. 25) and may be underlain either by littoral sediments, marine sediments, or both.

Inland at Moise, at an altitude of 215 m, one peat bog was cored to a depth of 2.5 metres (Fig. 32). Marls were found at the bottom with fresh-water gastropods; many eutrophic lakes in the area contain marl which is used for soil conditioning on farms. "Lac Peinture" near Neigette (22C/8W) is a good example of an exploited marl-bearing lake; the name is derived from the marl.

Unstable Zone (Map unit 13)

Unstable zones represent known areas of rapid slope processes. They include landslide scars, riverbank failures and rock slides. For example, the Rimouski earthflow is shown as unit 13, as is the rock avalanche of St. Fabien-sur-Mer (Fig. 33). The latter took place in 1967 during a storm and was described by Dionne (1969). The former event took place at Rimouski in 1951 and was investigated by Meyerhoff (1953). The Rimouski earthflow is studied in greater detail in Chapter IV.

A report on "Susceptibility to slope movement" is in preparation (Dion and Locat, 1976), classifying the geological units on the basis of "stability".

EMERGENCE CURVE AND C^{14} DATING

Vertical movement of the land was noted a long time ago in the area by geologists such as Goldthwait (1913) and Coleman (1922). Since the discovery that C^{14} dating could yield absolute ages for organic material (Libby, 1952) this dating method has been used to determine the rate of the movement of the crust.

Figure 33. Rock avalanche at St. Fabien-sur-Mer, which occurred in 1967 (view from the northwest)

This section will present a preliminary emergence curve for the Baie-des-Sables/Trois-Pistoles area, based on C^{14} dates obtained on marine shells (Table 9, Fig. 34).

Sites from which fossils were collected are described in Appendix B-1 (p. 166). For an interesting review of Late Quaternary vertical movement in Eastern North America, the reader is referred to the recent work by Walcott (1972b) who also reviews problems related to C^{14} dating.

Procedures

The sites (Fig. 38, in pocket) for C^{14} dating were chosen from fossil localities (Table 6, p. 61) encountered while mapping the surficial deposits. Samples were collected mostly to determine the emergence curve, but also to date specific sites in the marine sediments in order to estimate the time of the marine invasion or regression, and the rate of uplift.

For the emergence curve (Fig. 34) the main marine terraces were sampled. Care was given to collecting from the Ste. Flavie terrace so that the shells collected could not come from the reworking of higher sediments. Mesodesma arctica (D7, Table 5, p. 60), which is a recent species (Bousfield, 1964) that has never been observed in higher deposits, was found in the Ste. Flavie terrace and was therefore used for dating (QU-265: 2240 ± 140 y.B.P.).

After the sites were chosen and described, their elevation was determined. Site QU-261 was levelled with a theodolite, with the mean sea level datum given at every hour by the Pointe-au-Père station. Other sites (QU-262, D5, D6) were levelled with a U.S. Army barometer. The precision is estimated at ±1 metre for the theodolite, and ±3 metres for the barometer. More than one barometer reading was taken to check the elevation.

LAB. NO.	SITE	GEOGRAPHIC COORDINATES	*ALT. (m)	AGE IN C^{14} y.BP	SEDIMENT	MATERIAL DATED
QU-261	Price D3	48°36'38" Lat.N 68°06'20" Lon.W	62-72	11100 ± 370	sand and gravel	mixed species
QU-262	Mont-Jo. D4	48°35'35" " 68°12'32" "	72-78	11380 ± 470	sand and gravel	*Mytilus edulis*
QU-263	St. Anac. D5	48°29'00" " 68°22'40" "	82-105	12220 ± 450	sandy silt	*Mya* sp.
QU-264	St. Donat D6	48°30'11" " 68°15'55" "	90-126	13360 ± 320	clayey silt	*Hiatella arctica*
QU-265	Baie des Sa. D9	48°43'37" " 67°53'00" "	4-6	2240 ± 140	gravelly sand	*Mesodesma arctica*
QU-266	Luceville D8	48°30'21" " 68°21'30" "	70-73	10400 ± 320	sand	*Mytilus edulis*
QU-267	Grand Metis D11	48°36'47" " 68°06'00" "	30-53	11590 ± 430	silty sand	mixed species
QU-268	St. Octave	48°36'48" " 68°06'22" "	62-64	11360 ± 290	sand and gravel	*Mytilus edulis*
QU-270	St. Fabien	48°18'25" " 68°51'12" "	138-155	12300 ± 260	sandy till	mixed species
QU-271	St. Fabien	48°18'25" " 68°51'12" "	138-155	13390 ± 690	sandy till	*Hiatella arctica*
GSC-1186 (1)	St. Donat	48°30'11" " 68°16'10" "	98-106	12000 ± 160	clay	*Hiatella arctica*
GSC-1216 (1)	Bic	48°22'35" " 68°42'25" "	15-30	9450 ± 150	clayey sand	*Mya pseudoarenaria*

(1): Dionne, 1972. *: minimum and maximum altitude

Table 9. Summary of C^{14} Dates Used in the Construction of the Emergence Curve (QU- Qué. Dept. Nat. Res. Radiocarbon Laboratory; GSC- Geological Survey of Canada Radiocarbon Laboratory)

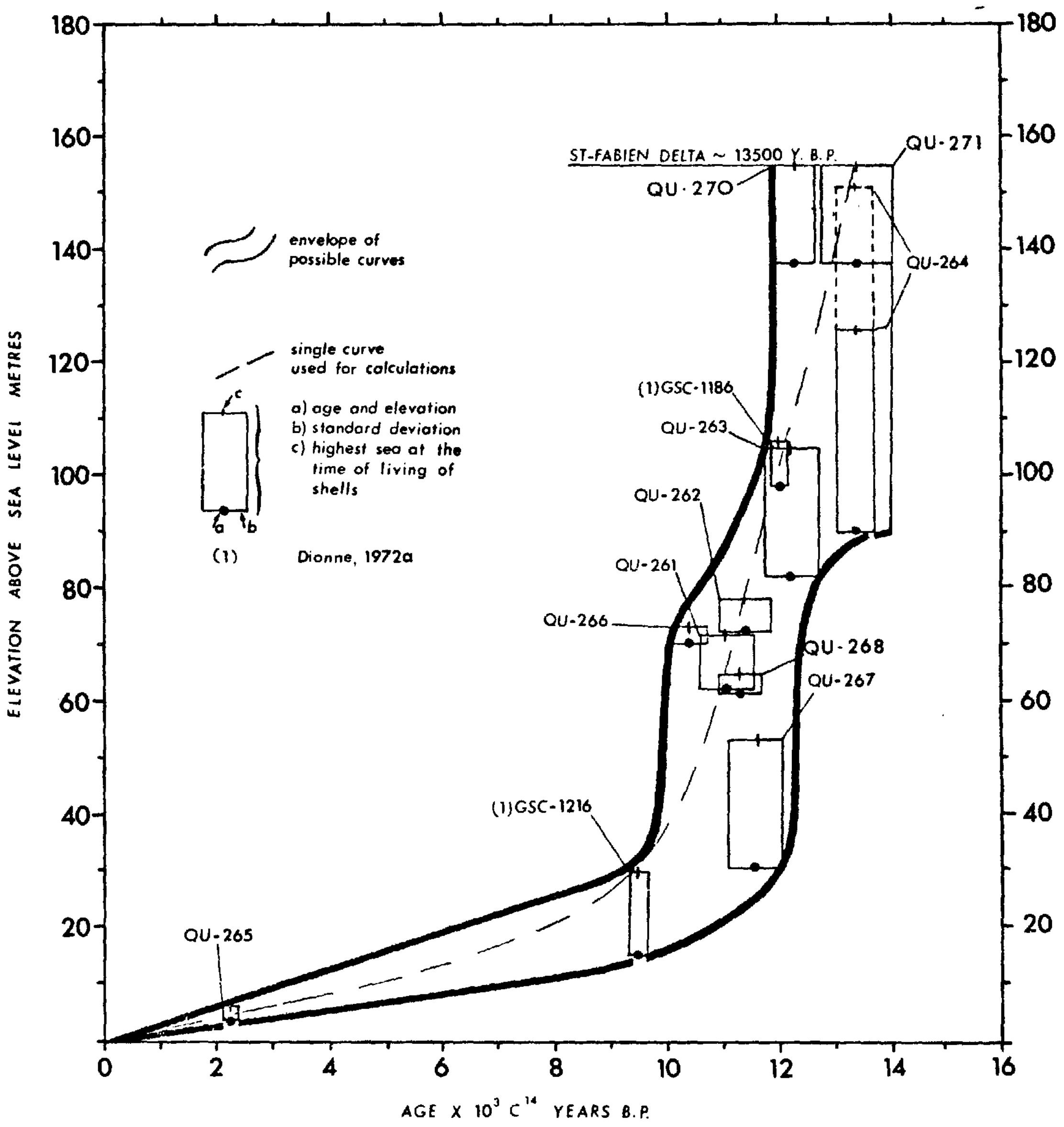


Figure 34. Emergence curve for the Baie-des-Sables/ Trois-Pistoles area.

Shells were collected with a plastic spoon and put in a plastic jar to minimize contamination. Prior to being sent to the laboratory, the shells were cleaned in an ultrasonic bath.

Previous Work

Very little work has been done in the area on glacio-isostatic rebound. The only data available are from Lee (1962) and Elson (1969) for the Rivière-du-Loup area. However, the Lower St. Lawrence/Gaspé region is referred to in work by Andrews (1970), and Walcott (1972b) on vertical movement of the land. Vertical movement had already been suggested by Antevs (1939), Coleman (1922) and Goldthwait (1913) inferred uplift from the presence of raised beaches and terraces. The eastern Gaspé Peninsula was suggested by Walcott (1972b) as a promising area for the study of vertical movement and also the zero uplift contour. Data should soon be available from Lebuis for the Matane area and the Baie-des-Chaleurs area that will be very interesting to compare with the results obtained by Lee (1962) and the present writer.

Results

Results obtained for selected sites are shown in Figure 34 and are given in more detail in Table 9 (see App. B for site descriptions). Data are plotted only as emergence curves with no correction for sea level changes. For calculation of residual uplift, Curray's curve for sea level variations is used with -62 metres and -35 metres at 13,500 and 10,000 y.B.P. respectively.(Curray, 1965). A single emergence curve is used for calculations. This curve is based on land emergence starting with the maximum marine limit at St. Fabien (150-155 m a.s.l.) that is estimated between 13000 and 14000 y.B.P. (Elson, 1969, for the Trois-Pistoles area).

The lower part of the curve coincides with the emergence of the Bic terrace about 10,000 years ago (30 m level).

Boxes displayed in Figure 34 represent variations in age and elevation for each sample, as used by Walcott (1972b). Variations for maximum sea level at each site, are only positive since only shells were collected (assuming negligible upward transport of shells). Because it was difficult to find sites where shells were in living position, the maximum sea level for each site was determined according to the local geomorphology. It is easier to evaluate this level for samples collected in beach sand and gravel than it is for samples in clay. This is shown by boxes of different size in height.

Sites are at the most 80 km apart and therefore differential uplift is to be taken into account since the upper marine limit varies from 155 to 120 in the northeast direction. However, this would apply only to sites directly related to the upper marine limit such as QU-270, QU-271, and possibly QU-264. However, the effect of differential uplift on the emergence curve is difficult to establish since shells were not found in living positions (except for QU-264). If QU-264 is related to the upper marine limit a positive correction of about 25 metres could be applied (see Fig. 34), by taking the upper marine limit plane as sloping northeastward at about 0.4 m/km.

From a level of 155 metres a.s.l. about 13,500 y.B.P. the emergence of the land proceeds rather regularly from a rate of about 4.0 cm/year to a present rate of about 0.2 cm/year. The inflexion of the emergence curve coincides with the formation of the Bic terrace about 10,000 years ago. The other terraces are not shown on the emergence curve because the sensitivity of the results cannot represent small eustatic or isostatic variations.

The residual uplift for the Lower St. Lawrence/Gaspé region can be estimated from the free air anomalies map given by Walcott (1972b) and from the emergence curve itself (Ten Brink, 1974). From Walcott's map, a residual uplift between 35 and 70 metres may be inferred (5-10 mgals; Walcott, 1972b).

The present rate of uplift suggested from the emergence curve of 0.2 - 0.3 cm/year correlates with Meade's estimate of 0.2 cm/year for the Appalachian Mountains (U.S.A.) (Meade, 1971; in Walcott, 1972b). If all the deformation or recovery that is yet to come is due to glacio-isostatic deformations, then a measurable uplift should end between 17,000 to 35,000 years from now. Alternatively, using the following equation (Ten Brink, 1974):

$$U = U_o e^{-kt} \qquad \text{(Eq. 1)}$$

where
U: residual uplift (m)
U_o: highest sea level (m) when uplift started
t: time since recovery in thousands of years
k: constant from curve

it is possible to estimate the residual uplift. By taking any point on the straight part of the curve (Fig. 34), it is possible to calculate k and then to estimate the residual uplift, U. With a value of k of 0.3, the residual uplift would be about 4 metres which, at a rate of 0.2 cm/year, would take about 2,000 years to be almost recovered.

Discussion

The emergence curve obtained for the Baie-des-Sables/Trois-Pistoles area certainly needs the addition of new data to be more precise. C^{14} dates on shells from Bic at 19 and 21 metres above sea level (D16, D17, p. 61) should soon be available. The St. Fabien delta (155 m) in which shells were collected at 138 metres in a pocket of till buried in ice contact sediments, is the highest Quaternary fossil locality and the closest to the marine limit. C^{14} dates of 13,390 ± 690 and 12,300 ± 260 y.B.P. (QU-271, 270) were obtained at this locality. The first date is on Hiatella arctica and the second on mixed species of Hiatella arctica, Balanus sp., Macoma balthica, and Mya arenaria. The error involved in the older is due to a smaller weight and a longer counting time than for the younger date. The youngest date could also represent an average of the different species (P. LaSalle, personal communication).

These results suggest a minimum date for deglaciation at St. Fabien, about 13,400 years ago. The author also correlated the St. Anaclet and Luceville deltas with the St. Fabien delta suggesting that they were built (approximately) at the same time. Therefore, C^{14} dates QU-270 and QU-271 give the departure for the emergence curve proposed here.

The weakest part of the emergence curve is between 9,500 and 6,000 years B.P. where the change in the rate of uplift for the area occurred that may also correspond to the stabilization in the sea level with changes of only ±5 metres since about 6,500 years (Walcott, 1972b).

Many uncertainties are still attached to various measurements of change in sea level in the so-called "tectonically stable" areas. Curray (1965) estimated that the sea level was 62 metres lower about 13,500 years ago while Milliman and Emery (1968) considered it to be about 130 metres lower about 14,000 years ago (122 m for 13,500 y.B.P.). Redfield (1967) estimated the sea level to be about 90 metres lower along the east coast of the United States about 12,000 years ago. It is well recognized that the sea level changed (mainly increased) since deglaciation. However, factors such as subsidence (Redfield, 1967) and tectonic factors (Walcott, 1972a,b) interfere with glacio-eustatic changes in sea level.

From Elson's uplift curve (1969) of the Rivière-du-Loup area the uplift can be shown in four intervals, as calculated by the writer. The first one from 13,500 y.B.P. to 9,700 years B.P. (86 m) - 2.2 cm/year; 9,700 y.B.P. to 8,100 y.B.P. (65 m) - 3.3 cm/year; 8,100 y.B.P. to 7,000 y.B.P. (22 m) - 2.0 cm/year. There are no data for the last part of the curve.

For the estimation of the residual uplift there are more uncertainties in Walcott's approximation (a precision of ±5 mgal) which at a rate of 0.2 cm/year, means ±18,000 years. Estimating from the emergence curve (Ten Brink, 1974) gives more reasonable results (about 4 m). However, it was reported during the summer of 1974, that a company drilled in the Moisie River, east of Sept-Iles, into 244 metres of Quaternary sediments all below sea level (Tremblay, 1974)! If this is due to stream erosion, it suggests that previously the earth's crust had been at a relatively much higher elevation. However, Walcott's method considers as well the effect of sea level rises on crustal deformation, which is considered as an additive factor (Walcott, 1972a). Ten Brink's method only extrapolates the emergence curve, while Walcott's method uses free air anomalies which are directly related to the residual crustal depression.

In summary, the emergence curve obtained from our work still gives a good idea of the relative emergence rebound, suggesting a rather regular rate of emergence between 13,600 y.B.P. and 10,000 years B.P.. The rate of uplift progressed in two main phases from 13,500 y.B.P. to 10,000 y.B.P. from 4.0 to 1.0 cm/year, and since then, from 1.0 to about 0.2 cm/year.

The precision of the emergence curve should be improved greatly by the addition of the C^{14} dates on the Ste. Flavie and Bic terraces.

QUATERNARY HISTORY

Previous work by Lebuis and David (1972), Lebuis (1973a,b), Lee (1962) and Dionne (1963, 1970, 1972a) has provided a general framework for summarizing the Quaternary history of the Lower St. Lawrence and Gaspé regions. Their ideas will be applied to the present area with modifications suggested by the new data from this area.

The author's work has concentrated on the Goldthwait Sea. Therefore, only a brief account will be given of the glacial history of the map-area. Gauthier's model (Gauthier, 1975) will be applied for the beginning of deglaciation.

The Quaternary history is divided into four phases: the Pre-Wisconsin, ice, ice-sea, and sea phases. Each of these phases will be presented in two steps. First the main information will be summarized and second, the history will be described. It is considered that no major ice readvancement took place since the beginning of deglaciation (Lebuis, 1973b).

The Pre-Wisconsin Phase

The Pre-Wisconsin phase is here defined as the period of time preceding the last ice invasion of the study area. "Wisconsin" here refers to the chronostratigraphic period extending from about 60,000 to 14,000 years B.P. (Prest, 1970); information available for this period is almost nonexistent. It also includes an interglacial period older than 60,000 y. B.P.. Authors such as Nota and Loring (1964) consider that the Laurentian channel is a preglacial feature that was only "polished" by glaciation. It is believed (Dionne, 1972a) that the preglacial topography of the area was almost the same as today.

The Mic Mac surface is considered to be an old erosion surface that existed prior to the last glaciation. This is based on striae found on this surface (at low tide) and by a prominent escarpment in places cut into bedrock. Such erosion is not believed to have been possible in the 5 or 6,000 years in postglacial time (Dionne, 1972a). LaSalle (1972) described a section near Québec city where the Mic Mac surface (in bedrock) is overlain by: stratified gravel, stratified sand, silt and clay with organic layers, calcareous till, and marine sediments. A C^{14} date greater than 39,000 y.B.P. (G.S.C., 1539) was obtained for the organic layers. Therefore, the bedrock platform underneath is at least interglacial (LaSalle, 1972).

It must be emphasized that no Pre-Wisconsin sediments were found in the study area. However, up to 4 metres of weathered anorthosite was reported near Sept-Iles (north shore) that may be considered Pre-Wisconsin (L. Dredge, personal communication), and also Lebuis (1973b) suggested that some saprolite could be found overlain by till.

The Ice Phase

The ice phase defines the time taken for the Laurentian ice-sheet to form, cross the St. Lawrence Estuary, reach maximum thickness and extent, and thin substantially during its waning. It ends when the Laurentian ice is divided into a Laurentian sheet to the north and an Appalachian sheet to the south. The ice-phase is estimated to extend from 60,000 to 14,000 y.B.P. in the study area (Prest, 1970).

Data

The history of this phase is based on ice movement determined by glacial erosion features, indicator boulders and glacial deposits such as till.

Striae, crag-and-tail, and crescent marks were found at a few sites (Fig. 35, in pocket). The main work was recently done by Lebuis (1973b) who made a map showing striae and crag-and-tail for the Matane area, and presented results on indicator boulders: Precambrian gneiss and anorthosites, and Appalachian rocks (Val Brillant, St. Léon, etc.). Other indicators such as whaleback-like hills and drumlinoidal features were encountered by Dionne (1972a) in the Rivière-du-Loup/Trois-Pistoles area. In the Mont-Joli area grooves in bedrock (Fig. 36) were found which are good indicators of ice movement. In this area the bedrock consists of soft slate that may have reacted like soil to ice erosion. However, one must be careful in choosing such features that may reflect bedrock structure trending northeast-southwest. Grooves were found by Dionne near Trois-Pistoles and some by the writer in the St. Mathieu/Rimouski area (see Fig. 35, in pocket).

History

From all these observations and from Gauthier's model of deglaciation (Gauthier, 1975) it is then possible to estimate ice movement in the present area.

The Laurentian ice (Dresser and Denis, 1944) crossed the St. Lawrence Estuary, and from Precambrian indicators, the Matapédia Valley was the main pass through to the Appalachians. The Laurentian ice, however, failed to override the Shick-Shock Mountains (Dresser and Denis, 1944; Lebuis and David, 1972). Laurentian ice moved generally south and southeastward as recorded from crag and tail by Lebuis, but no such records were found in the study area, except for scarce Precambrian boulders found above the marine limit.

Figure 36. Drumlinoid and macro-grooves near Mont-Joli developed in slate. (Photograph courtesy of Québec Dept. of Lands and Forests)

About 14,000 years ago, the Goldthwait Sea started to melt the ice in the Gulf of St. Lawrence (Prest, 1970), and as suggested by Gauthier (1975) reversed the ice flow direction mainly by drawdown during calving in the estuary. Warmer waters coming into the Gulf of St. Lawrence would have supplied snow to the mountains (Prest, 1970). This reversal in ice movement created a separation between the Laurentian ice-sheet to the north and the Appalachian ice-sheet to the southeast.

The last sheet that covered the study area was apparently part of the Appalachian ice-sheet. We found a few crag-and-tail features indicating flow to the northwest, north, and northeast (Fig. 35, in pocket). From the data of Lebuis (1973b) and from the trend of whaleback-like hills, the last phase of ice movement was to the northeast, channelled by the estuary and by the mountains and hills also oriented to the northeast-southwest.

The ice moving north and northwest reworked some marine material including shells that were deposited as till (St. Valérien, Matane). Fossils such as Hiatella arctica and Elphidium sp. were identified in the till at St. Valérien (22C/7E) and at Matane (22B/12E). Most of the "marine" till was observed below or at the marine limit. However, near Baie-des-Sables, a clayey till was found at 180 metres a.s.l., well above the marine limit for this area (115 m a.s.l.). It could indicate ice movement during maximum marine submergence.

The ice phase ended when the sea extended between the two ice-sheets with their margins standing in the estuary. When the front of the Appalachian ice-sheet receded to the coast and the upland it marked the beginning of the ice-sea phase, about 14,000 y.B.P..

The Ice-Sea Phase

The ice-sea phase includes the period from about 14,000 y.B.P. to 12,000 y.B.P.. It is represented here by two stages: the coast-upland stage and the upland-mountains stage, both related to ice front positions. The ice-sea phase began with the penetration of the "early" Goldthwait Sea between ice fronts of the Laurentian and Appalachian ice-sheets. It ended when both ice fronts reached the mountains; one to the northwest and the second to the southeast. The ice on the south was cut off from any direct influence with the Goldthwait Sea about 12,000 years ago when the sea level was about 90 metres (11,380 ± 470 C^{14} y.B.P., QU-252).

Data

The ice-sea phase is suggested by glacio-marine sediments, current directions in eskers related to deltas (Fig. 35, in pocket) and hypothetical ice front positions (Fig. 37, in pocket).

A fossiliferous, clayey "marine" till or waterlaid till, was mapped near Matane by Lebuis, and was also recognized at St. Valérien. The Matane till was dated at 13,580 ± 350 C^{14} y.B.P. and 13,450 ± 470 (QU-83, 21 m a.s.l.; QU-84, 15 m a.s.l.; Lebuis, Unpub.). At St. Valérien the "marine" till is at 120 metres above sea level, below the marine limit for this area (150 m a.s.l.). No date could be obtained from the fossil remains of _Hiatella arctica_ at this site because of the high degree of alteration of the fossils.

A glacio-marine clay was described by Dionne (1972a) and the author, extending at least from Trois-Pistoles to Baie-des-Sables. This type of clay could grade laterally into the marine till at St. Ulric. The western extension is suggested by Dionne (1972a) to be near Ile Verte, west of Trois-Pistoles, where it outcrops up to a maximum of 120 metres above sea level. In the study area, this clay was found at a maximum of 41 metres above sea level (from borehole F-5, App. F, in pocket). It is usually restricted to the coast and the transition from the glacio-marine to the massive marine clay is sharply defined in boreholes FR-6, FR-7, FR-8 and F-5.

The author agrees with Dionne's conclusions that the glacio-marine clay was deposited at the margin of the ice front and that its lithology is of Appalachian origin (Dionne, 1972a). Most of the pebbles are striated and the clay also has higher carbonate content (14%) than the massive clay, even higher than the waterlaid till (see page 119 for carbonate analysis).

The highest deposits of marine clay found in the area between Rimouski and Trois-Pistoles (150-166 m a.s.l.) have only scattered boulders or pebbles. Because of its "massive" character, this clay is grouped within the massive clay unit described under "Deep Water Marine Sediment or Marine Clay" on page 49, and is believed to mark the end of the sedimentation of glacio-marine clay (stony clay) in the present area. This change in the texture of the marine clay may have occurred when the ice front of the Appalachian ice-sheet retreated onto the first hills, its meltwater being then controlled by the topography (valleys).

Ice front positions are also suggested by glacio-fluvial deltas such as the St. Fabien, St. Anaclet and Luceville deltas. Fossils were collected from the St. Fabien delta, at 138 metres a.s.l. in a till inclusion that was found within ice-contact sediments. C^{14} dates (QU-270, 271) obtained on these fossils suggest the deglaciation of the area about 13,000 to 13,500 years ago which would also be the maximum date of the marine transgression (highest level).

The Luceville and St. Anaclet deltas were nourished by their respective eskers. Both of the eskers are traced back into the Neigette

Valley and were also traced above the Neigette escarpment (see surficial deposits, map 22C/8W, and Fig. 35, in pocket).

A fossiliferous clayey silt found in the Neigette Valley clearly indicates that the whole valley was invaded by the Goldthwait Sea. At the southeast end of the valley, near Ste. Blandine (22C/8W), the marine clay lies near 112 metres a.s.l. and was noted interbedded with ice-contact sediments in an ice-contact delta at the toe of the Neigette escarpment near the village. The clay appears to overlie ice-contact sediments and is overlain by fluvial sediments which grade laterally into fluvio-lacustrine sediments. In the Neigette Valley, fluvial sediments overlying the marine clay southwest to Neigette, have a glacio-fluvial texture and structure (poorly sorted and stratified), and are morphologically similar to an outwash plain. These deposits are classed as fluvial because these are underlain by marine clays. The sediments in this zone (southwest) were affected by glacio-tectonic deformations, as shown by kettle holes, and one important kettle lake near Neigette. In this zone of the valley fluvial sediments are found up to 128 metres elevation.

At the other end, northeast of Neigette and more precisely to the northeast of the St. Donat esker (Fig. 35, in pocket), the fluvial sediments display the more usual well-developed stratification. They lie at about 90 to 105 metres a.s.l. (instead of 128 m for southwest of Neigette) but were still affected by cold climate, as shown by the presence of an ice-wedge (Fig. 30, p. 73). On the southwest side of the St. Donat esker complex, clays and fluvial sediments overlie ice-contact sediments.

Near St. Donat two important erratics were discovered from which at least the rhyolitic pillow lavas (Fig. 18, p. 43) must come from Lake Matapedia (60 km to the southeast), the only known source in the area. Near St. Donat, the marine clay lies about 90 metres a.s.l. and at one section, grades upward into lacustrine and then, fluvial sediments. The varve-like lacustrine sediments at this site are 1.2 metre thick, made of alternating fine sand and silt with each set about 2.5 cm thick. If these are annual varves the lake would have lasted at least 48 years. If these lacustrine sediments are not only of local significance they would suggest that prior to the end of the high water level in the valley, the sedimentary environment changed from marine to lacustrine with the latter of only short duration.

Along the Métis River, about half a kilometer upstream from Price, near the CN railroad, ice-contact sediments dipping at about 40° to the north and northwest are overlain by fluvial sediments at 75 metres a.s.l.. This information on the Neigette Valley suggests an ice tongue stagnant in the valley with meltwaters flowing to the southwest; then the ice front retreated towards the Métis River. Therefore, the sea entered from the southwest of the valley and then from the northeast near Price.

History

The history of the ice-sea phase in the area is divided into two stages: a coastal-upland and upland-mountain stage.

About 14,000 years B.P. (13,500 B.P., Lebuis, Unpub.) the ice front receded to the coast and the upland. The coast was free of ice earlier than the upland and received sediments mainly from the Appalachian front to the southeast, with some contribution from the Laurentian front as suggested by the glacio-marine clay. This coastal sedimentation started about 13,500 y.B.P. (QU-271) with the sea level at about 155 metres as indicated by the St. Fabien delta. The ice front position at this time is indicated in Fig. 37 (in pocket).

As the ice front receded to a position dated at about 13,000 y.B.P., the sea level stood about the same and the sediment accumulation by ice-rafting from the Appalachian ice front was still significant. At this time, the Luceville and St. Anaclet deltas were formed. The ice then receded into the first hills and valleys. This could have stopped the ice-rafting as indicated by a rather sharp change in the transition from the glacio-marine clay to the "high" massive clay as found between Rimouski and Trois-Pistoles. This "high" marine clay might indicate that when ice-rafting decreased abruptly the sea level was still high. However, perhaps the emergence of the land had already started and at the end of this stage may have reached about 120 metres above sea level.

At this time (around 13,000 y.B.P. - 12,500 y.B.P.) the Neigette Valley was opened to the Goldthwait Sea at the Ste. Blandine outlet, where marine clay is thicker and lies at about 110 metres a.s.l.. However, the valley from Neigette to Ste. Angèle and up to Lake Matapédia was still occupied by the ice. The opening of the Ste. Blandine outlet of the Neigette Valley here indicates the end of the coastal stage about 12,500 years ago.

The upland-mountain stage, for the study area, was of short duration. Once the ice was in the mountains, it had little impact on sedimentation in the Goldthwait Sea. At this point perhaps about 30 metres of glacio-marine clay had been deposited, along with a few metres of "high" massive clay. The highest stratified sediments of the Neigette Valley lie at a lower elevation than the Luceville delta suggesting that when the Neigette Valley opened, the sea had started to regress.

The marine invasion of the Price outlet valley may have been stopped by the ice as shown by ice-contact sediment observed at Price and upstream along the Métis River. When the Price outlet was opened about 12,300 y.B.P. - 12,000 y.B.P. for a short time, the Goldthwait Sea was in the Neigette and Métis Valleys (from 13,300-12,000). When the sea level decreased to

90 metres the valley was gradually filled with glacio-fluvial and fluvial sediment, until the sea level reached 75 metres, creating important fluvial deltas like the Price and Rimouski deltas.

The ice front receded completely onto the mountains where it stagnated for awhile, filling up the Neigette Valley with sediments carried by meltwater as the sea was regressing. A cold climate may still have prevailed as indicated by an ice-wedge (Figs. 30a,b; p. 73) found in fluvial sediments of the Neigette Valley near St. Donat (22C/9E). The end of the upland-mountain stage is indicated by fluvio-lacustrine sediments representing a change from a marine to nearly lacustrine environment, and then closing of the Neigette Valley.

At the formation of the Rimouski and Price deltas, the sea had regressed from most of the valleys (e.g., Neigette Valley) and started depositing the "well defined" littoral sediments, which mark an intense period of sediment transport. This is considered as the end of the Ice-Sea phase about 12,000 years ago (11,380 ± 470 C^{14} y.B.P.; QU-262).

The Sea Phase

The sea phase started about 12,000 years ago when both ice-sheets (Laurentian and Appalachian) were far enough from the Goldthwait Sea that they did not interfere with it. The beginning of this period is marked by deltas around 75 and 80 metres a.s.l.. The author agrees with Dionne's idea (1972a) that the Goldthwait Sea grades into present conditions. Therefore, the sea phase extends from 12,000 y.B.P. until today. The sea phase is divided into stages related to different sea levels.

Data

There is much more information for this phase than for any other, because of the preservation of major features, such as terraces, raised beaches, and the deposits themselves. The data are derived from sediments, geomorphology, lithology, and fossil fauna.

This phase is marked by the deposition of a massive clay which is found up to 75 metres thick. When compared to the glacio-marine clay, it has a lower carbonate content (10%) and a richer fauna that increases with lower sea level (from 20 to 0 m a.s.l., see page 59 under "Fauna"). It is also marked by a decrease in sedimentation to a point where only small deltas were built at Rimouski, Métis and Matane, for example.

Many marine terraces were created at different stages of stability of the sea level as discussed in "Geomorphological Units" on page 28. The main terraces are found at 75, 68, 60, 30, 16, 6 and 3 metres above sea level. The transition from one level to another is well-shown by the regular succession of raised beaches (shorelines). Three prominent escarpments were noted for the 60, 30 and 6 metre terraces. C^{14} dates were obtained for various levels (see Table 9, p. 79 ; Fig. 38, in pocket). This phase is also the time when large channels are formed on the terraces and later filled with organic debris. The decrease in importance of the Appalachian source of sediments is also suggested by a decrease in total carbonate content in the massive clay compared to glacio-marine clay (Table 13, p. 123), and by a higher proportion of Precambrian boulders.

History

The sea stage began about 12,000 years ago (11,380 ± 470 C^{14} y.B.P., at 72 m, QU-262). At this time, large deltas were built at Price and Rimouski, indicating that runoff of meltwaters from glaciers was still important. These sediments were reworked into littoral sediments and at the same time, a massive grey clay was deposited. This constitutes the Price stage (75 m).

From this point the Goldthwait Sea regressed to its present position in the estuary, with stages of equilibrium named as: the Price stage (75-60 m); the Bic stage (60-15 m); the Ste. Flavie stage (15-3 m); and the Matane stage (3-0 m). These stages are accordingly identified by three terraces: the Bic terrace (30 m), the Ste. Flavie terrace (6 m), and the Matane terrace (0 m) (See Chapter II).

It is suggested that the Price stage started about 12,000 y.B.P. and closed around 10,000 y.B.P.. The Price stage may correlate with the Champlain Sea which lasted from 12,000 to 9,500 y.B.P. (Gadd, 1971). The Bic stage, considered as an erosional period, would have existed between 10,000 y.B.P. and 8,000 y.B.P.. The end of the Bic stage is suggested by a date of 8,615 ± 140 C^{14} y.B.P. at 8 metres, from a site near St. Joachin (QU-44; Lebuis, Unpub.). The Ste. Flavie stage would have existed from 8,000 to 1,500 y.B.P. with the younger limit defined by a date of 2,240 ± 140 C^{14} y.B.P. (QU-265) between 4 and 6 m a.s.l.. Subsequently, the Matane stage may have existed for the last 1,500 years. As shown by Dionne (1972a), however, the Matane and Ste. Flavie terraces are found, in places, in transition with almost no break, possibly suggesting that since 6,000 or 8,000 years ago only one stage (Ste. Flavie) could be defined.

The regression of the Goldthwait Sea from the 75-metre level to the 30-metre level marks the last intense period of coastal and offshore sedimentation. When the Rimouski and Price deltas were formed, a grey massive clay was deposited offshore, and is now found overlying the glacio-marine stony clay.

Then as the sea regressed to the 30-metre level a series of shorelines was left over the marine clay. This regression was regular, as shown by the successive well formed beaches (e.g., Fig. 10, p. 25).

At the Bic stage (10,000-8,000 y.B.P.) a period of stability permitted the cutting of large channels which are now filled with peat and organic material. As suggested by Lee (1962) they were formed by longshore currents formed during regression of the sea.

The Ste. Flavie stage (8,000-1,500 y.B.P.) was the time when the Ste. Flavie bluff was freshened or partly eroded. Toward the end of the Ste. Flavie stage, littoral sediments were deposited, as indicated by successive shorelines from 7 to 3 metres above sea level.

The Matane stage (1,500 y.B.P.) approaches the present configuration along the shore. Little sedimentation and erosion now occurs in the estuary on the south shore and according to Dionne (1970) ice-rafting is the major agent of erosion and sedimentation in the estuary.

The sea phase is also marked by the deposition and subsequent erosion of fluvial sediments forming successive fluvial terraces as the land emerged. The deposition "phase" was at its maximum during the Price stage when extensive deltas were built (Rimouski and Price deltas). After the Price stage (75 m), deposition diminished until it reached the conditions of today where very little is being transported and sedimented. Recent fluvial deposits are only represented by recent alluvium in present-day floodplains where fine sand, silt and organic debris are deposited. The discharge of rivers and streams probably decreased drastically when the ice remaining in the mountains completely melted, about 10,000 y.B.P..

The oldest date obtained on organic deposits in the Gaspé is of 9,610 ± 360 C^{14} y.B.P. at Mont Jacques Cartier (Lebuis, Unpub.; G.S.C. 1799; 914 m a.s.l.). This is considered as a minimum date for the deglaciation of the mountains. Vegetation was probably in the valleys before this time as they were freed of ice about 12,000 y.B.P.. Organic debris has only been found in recent alluvium. No study has been carried out on the organic content of the marine clays. Only peat bog deposits on the marine terraces have been investigated (Gauthier, 1971) for economic purposes. The vegetation invasion could coincide with the introduction of freshwater mollusks as found in a section near Moise (Fig. 32, p. 74). Freshwater gastropods are the most common and abundant fossils throughout the Gaspé but no study of them has yet been carried out. Since many lakes and ponds, at different elevations, contain a rich fauna, a detailed study of these deposits should yield valuable results.

CHAPTER IV SOME PHYSICAL AND CHEMICAL PROPERTIES OF THE GOLDTHWAIT SEA CLAYS AND A REVIEW OF THE RIMOUSKI EARTHFLOW

The coastal zone of the Lower St. Lawrence/Gaspé region is expected to be a zone of development over the next few years, so there is a need for geotechnical information. Also, the knowledge that landslides have occurred in the area (Meyerhof, 1953; Matyas, 1964a,b) has emphasized the need for a better understanding of the behavior of the Goldthwait Sea clays.

Eight sites from five areas were investigated (Fig. 3, p. 4 ; App. B), from which samples were analysed in an area extending almost 400 km along the coast from Trois-Pistoles to St. Joachin de Tourelle. First, sites investigated will be described briefly, then the engineering properties will be presented. A comparison between results obtained at Rimouski will be made with other sites in the St. Lawrence and Hudson Bay lowlands.

Thirdly, results obtained by the author on the clay mineralogy and chemistry of the clay will be discussed.

The last section deals with the Rimouski earthflow, for which a re-evaluation of the geomorphological and geological setting will be presented.

DESCRIPTION OF SITES

The sites were chosen on the basis of presence of earthflows (2 sites), and sites with potential hazard with prominent marine or fluvial terraces cut into marine clays, adjacent (4 sites) or not (2 sites) to existing buildings.

The St. Joachin de Tourelle, Ste. Anne-des-Monts, and Cap Chat sites are located in the very narrow coastal zone (less than 1.5 km wide), restricting the sedimentary basin almost only to valleys. In contrast, the Matane, Grand Métis, Ste. Luce, Rimouski, and Trois-Pistoles sites are situated in the open coastal zone (more than 3 km wide). The elevation of sites ranges from 40 to 85 metres. The descriptions of sites include a summary of geological and geomorphological data and the location of boreholes, penetrometer testholes, and seismic lines. Borehole and penetrometer logs (p. 212) are provided separately in Appendix F.

ENGINEERING PROPERTIES OF THE GOLDTHWAIT SEA CLAYS

The engineering properties of the Goldthwait Sea clays were investigated at earthflow sites prior to the present study by Meyerhof (1953), Matyas (1964b) and Conlon (1966). Conlon studied the marine clays along the Toulnustouc River, on the north shore; no regional investigations had been carried out on deposits of the Goldthwait Sea. Dionne (1972a) suggested general values on shear strength for the clay units he encountered in the Rivière-du-Loup/Trois-Pistoles area.

The first attempt to investigate regionally the Goldthwait Sea clays will be reported in this chapter.

Variability of the Results

The selection of drilling sites and samples for testing was based upon the availability of sites and the quality of the samples. There was no random procedure used for sampling. As this procedure provides little assurance that the samples are representatives of the units, evaluation of the data must be done carefully and only in general terms.

"Engineering" sampling is rarely done on a statistical basis since variance in the results can be function of many factors such as: natural variation, selection of sites, sampling, transportation, time lag before testing, handling, discrepancies between different apparatus, theoretical assumptions, and finally, human error (see App. D, p. 197).

Representativity of the results is the weakest point in geotechnical investigations. Hence, engineering geologists should become more aware of statistical analysis in the preparation of sampling and testing program, especially if geologic inferences have to emerge from such a study. Results presented are certainly an estimate of the characteristic of the marine clay. The problem would be to determine how representative the results are of the natural material.

Summary of the Results on Engineering Properties

The data (App. C, p. 180) have been separated into four groups: (1) natural water content, Atterberg limits; (2) shear strength and sensitivity; (3) parameters obtained from the consolidation tests, and (4) cohesion and angle of internal friction. Finally, the results obtained for the Rimouski site are compared with other results from other areas such as Yamaska, Ottawa-Hull, St. Jean Vianney, James Bay, and the north shore (Toulnustuc River).

To summarize the results shown in Figures 39 and 40, the Goldthwait Sea clays have a liquid limit between 20 and 48%, a plasticity index from 10 to 28 with an activity around 0.30 and a clay fraction of 20 to 75% (<2 microns).

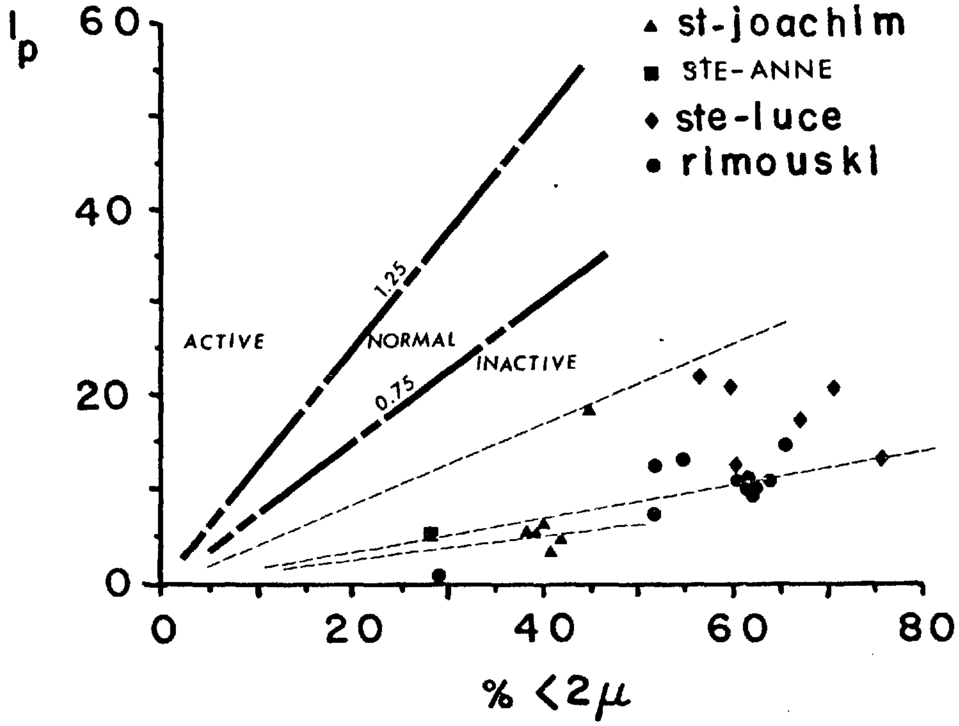


Figure 39. Activity diagram (I_p: plasticity index).

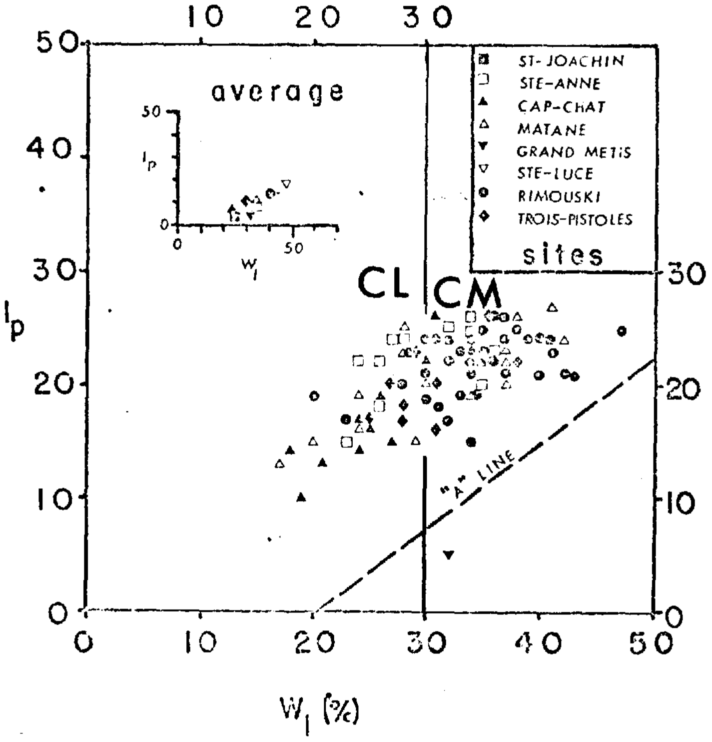


Figure 40. Casagrande diagram (W_l: liquid limit)

From the Casagrande diagram (Fig. 40), the Goldthwait Sea clays have a low to medium plasticity (<50, CL). This clay is also inactive (<0.75, Fig. 39) but with increasing activity with an increase in the clay fraction. Only occasionally did the water content exceed the liquid limit, as obtained in borehole FR-9 (Fig. 56, p. 143).

The lowest shear strength and the highest sensitivity from field testing were recorded at Trois-Pistoles (Fig. 41). In the St. Joachin/Matane region the shear strength varies, with a minimum of 0.4 kg/cm^2 at Cap Chat and a maximum of 1.2 kg/cm^2 at Ste-Anne-des-Monts. However, values are usually around 1.0 kg/cm^2. West of Matane results for shear strength are rather consistent and are found to be around 0.3 to 0.5 kg/cm^2.

Down a soil profile the water content increases with depth along with a decrease in shear strength (see for example, Figs. 54, 55 and 56, pp. 141, 142, and 143). After the maximum water content is reached then the shear strength increases downward. At Fr-8, for example (Fig. 55), this change occurs at about -30 metres.

For the sites studied in the Gaspé, the Goldthwait Sea clays are slightly sensitive to slightly "quick" (1.4 to 16), according to Rosenquist's classification (1952).

A summary of the consolidation test results obtained from the Technisol Company's laboratory is given in Table 18 (p. 187) and the results from the Q.M.N.R.'s laboratory and author's results are given in Table 19 (p. 188). The latter table also includes grain size and other results that help in understanding the behavior of these clays.

Sometimes, as shown in Figure 54 (p. 141), the preconsolidation pressure is less than the effective earth pressure. However, it is impossible to consider the clay as "under-consolidated", perhaps this could be related to

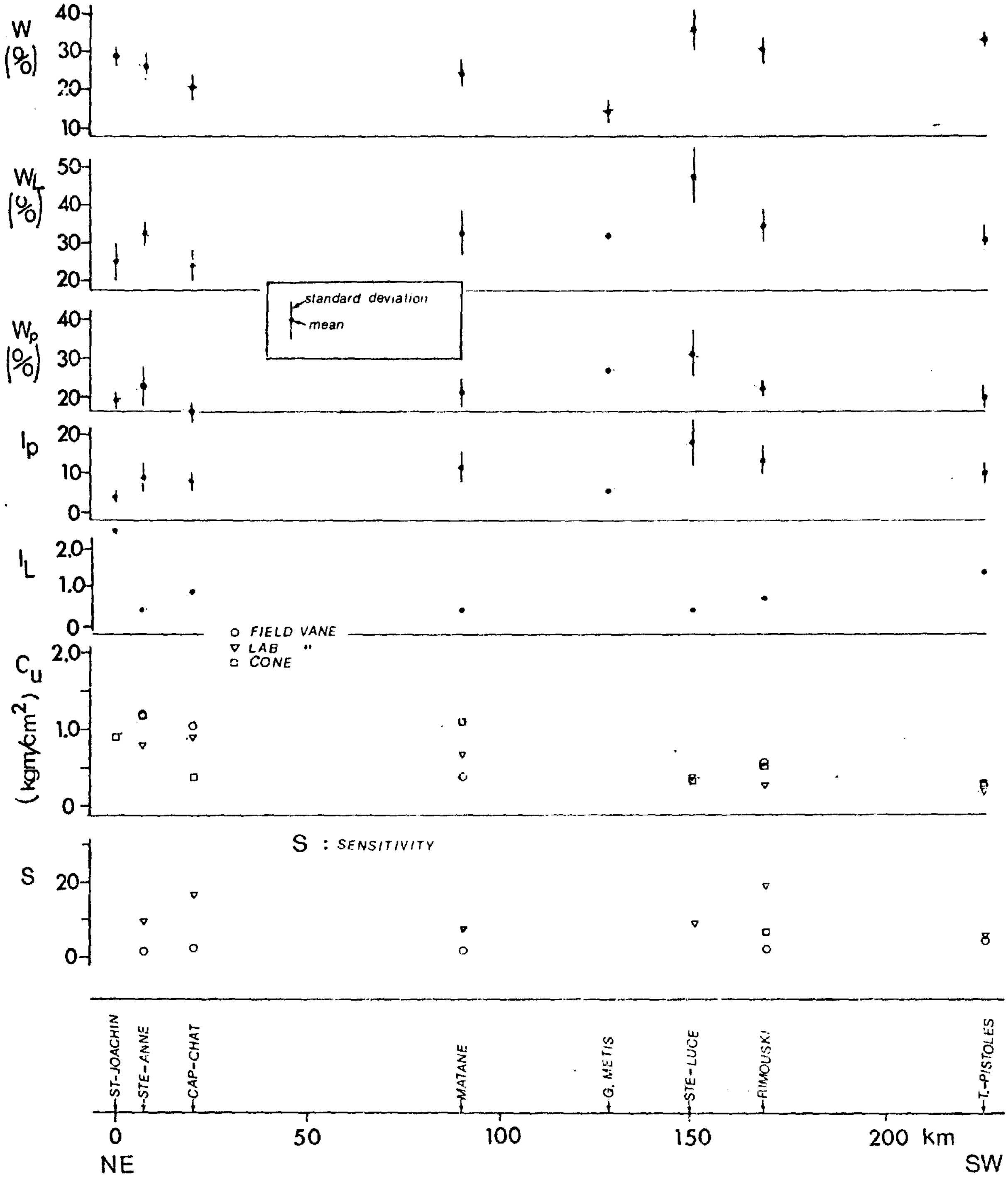


Figure 41. Regional variations of parameters such as water content (W), liquid and plastic limits (W_l,W_p) plasticity and liquidity index (I_p,I_l), shear strength and sensitivity (Cu,S)

sampling disturbance. From results in Tables 18 and 19 this clay is considered as normally consolidated or slightly over-consolidated. A preconsolidation stress as high as 2.5 kg/cm^2 (Table 19, #208) for a sample taken only at 1.5 metre is due either to its unsaturated state in the field or desiccation and chemical alteration phenomena (Dascal and Larocque, 1973).

Results for the compression index Cc vary from 0.1 at St. Joachin to a maximum of 0.6 at Rimouski. Results obtained from various laboratories are comparable (App. C, p. 189) when average results and standard deviation for Technisol and Q.M.N.R.'s tests are shown. The coefficient of compressibility (a_v) being closely related to the compression index (Cc), it is expected the results on a_v should be nearly constant. The coefficient of compression (c_v) varies from 4.1×10^{-4} to 1.4×10^{-3} cm^2/sec (Table 18, p. 187). From the consolidation tests (App. C), the Goldthwait Sea clays were found to have a very low permeability (10^{-8} to 10^{-7} cm/sec), which corresponds more to the permeability of a silty clay (Lamb and Whitman, 1969).

Estimations of the angle of internal friction (ϕ') and the cohesion (c') were determined only on a few samples (App. C). The value of ϕ' (Figs. 42 and 43) varied between 34° and 21° for maximum and residual strength, respectively. The best estimation of cohesion (from the shear box, Fig. 43) was of about 0.05 kg/cm^2. Results for the Rimouski clay indicate a small cohesion under drained conditions. This suggests the clay is normally consolidated, and behaves almost like a cohesionless soil.

Comparison with Other Studies

One can best appreciate the results obtained in the present area by comparing these with studies performed elsewhere. For this reason, the

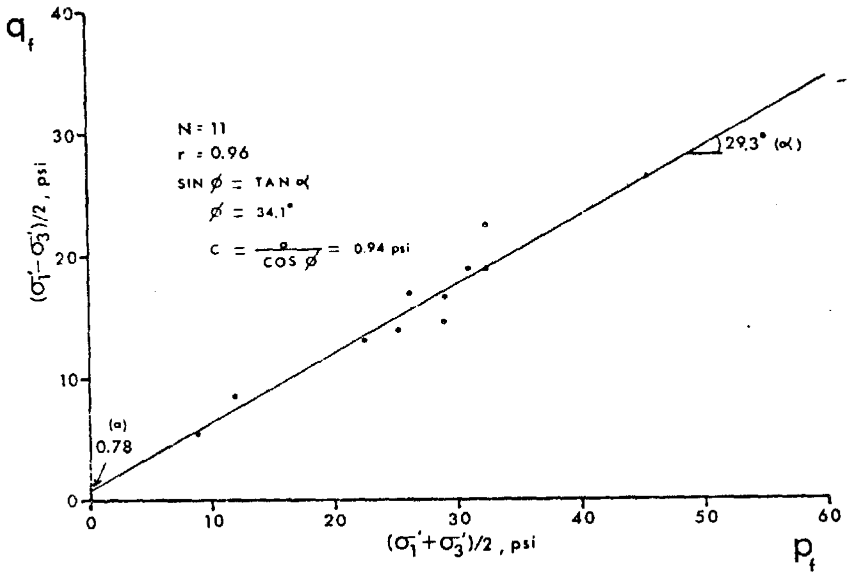


Figure 42. General p-q diagram from consolidated undrained triaxial tests (stresses taken at maximum)

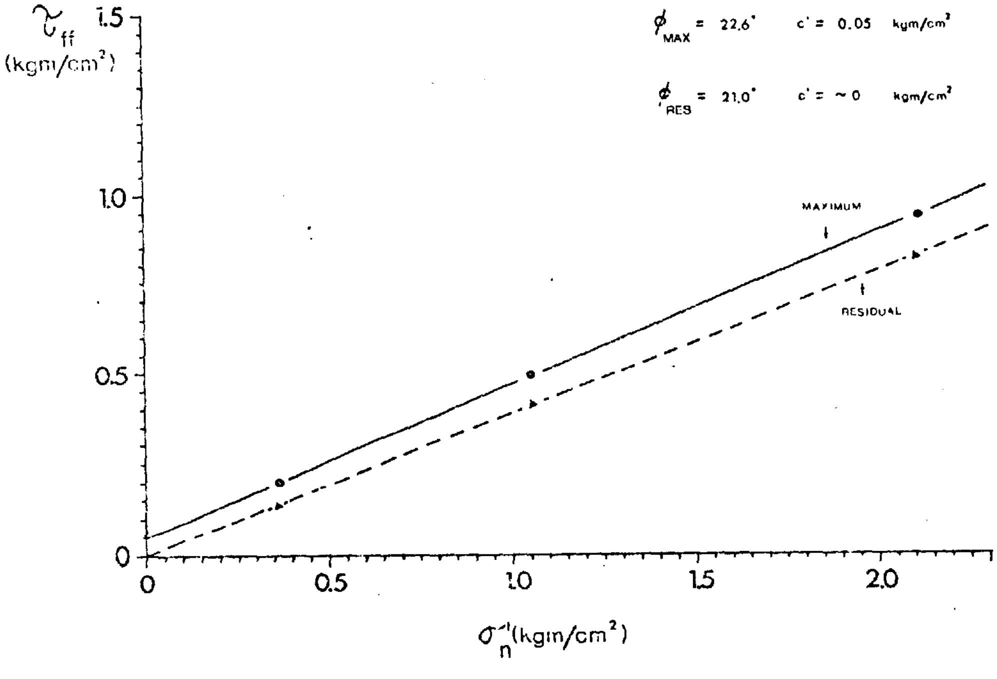


Figure 43. Mohr envelope obtained from the shear-box test

author selected sites corresponding to other Quaternary seas (Fig. 44) of eastern Canada that were synchronous with the Goldthwait Sea. The author does not believe that the sites chosen for the purpose of comparison are fully representative of the area they belong to, especially since all the studies done in the different areas are only "contributions to" and not "determinations of" the physical properties of the marine clays in any area. However, the different environments of each region induced properties that appear to be different in some respects.

It is with this idea in mind that the sites listed in Table 10 were chosen. The Goldthwait Sea is here represented by the Toulnustuc (Conlon, 1966) and the Rimouski (present work) sites. The Champlain Sea is solely represented here by the Yamaska site. The Laflamme and Tyrrell Seas are represented by the St. Jean Vianney (Gravel, 1974) and Rupert (Balliny, 1970) sites, respectively. To characterize these sites, an idea of their environment would help to understand some of the results.

The Yamaska site is located along the Yamaska River beside the village of the same name. A bank failure occurred there in November 1974 and was studied by the Q.M.N.R.; at the time of writing another landslide had just occurred beside the previous one (July 1975). This area is underlain by Paleozoic sedimentary rocks that are part of the St. Lawrence lowlands. The Yamaska site was chosen since it is located in the middle of the St. Lawrence lowlands between the Shield and the Appalachians.

The St. Jean Vianney site was largely investigated after a catastrophic earthflow that took the lives of 33 persons (Tavenas _et al._, 1971) in 1971. At this site, the Quaternary deposits can be found underlain by either Paleozoic or Precambrian rocks. The Lake St. John "lowlands" (Paleozoic) are surrounded by the Precambrian Shield (plateau).

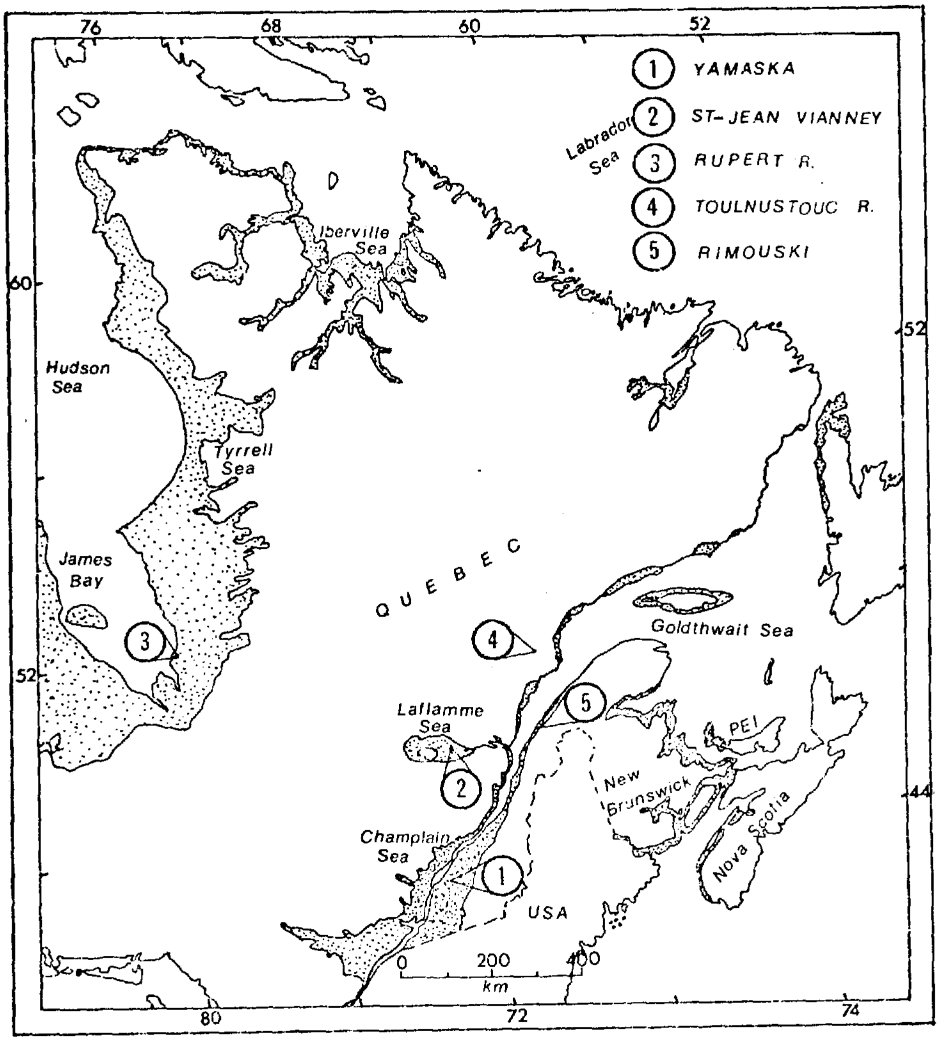


Figure 44. Quaternary Seas of Eastern Canada (Dionne, 1972a), and selected sites.

	YAMASKA (Q.M.N.R.) (1975) 1	ST-JEAN VIANNEY (Gravel, 1974) 2	RUPERT RIVER (Ballivy, 1970) 3	TOULNUSTOUC RIVER (Conlon, 1966) 4	RIMOUSKI (this work) 5
water content (%)	35-73	31-45	26-37	21-36	31
liquid limit (%)	37-69	22-52	24-43	18-25	36
liquidity index	--	0.6-9	0.9-2.2	2.9-3.7	0.7
clay fraction (%)	70-76	53-63	39-47	24-36	30-64
activity	--	--	0.25-0.5	0.11-0.17	0.12-0.34
unit weight (kgm/cm^3 x10^{-3})	1.5-2.0	1.8-1.9	1.8-2.0	--	1.9-2.0
shear strength (kgm/cm^2)	0.2-0.6	0.5-2.5+	--	4.0	0.3-0.6
sensitivity	7-13	4-∞	$>$20	$>$15	2-10
ϕ' (degrees)	21.5-30.5	--	25	36	34
cohesion, c' (kgm/cm^2)	0-3.8	--	0	--	0.05

Note: 1, 2, 3, 4, 5 : sites shown on Figure 4.
-- : not available

Table 10 Comparison of Physical Properties for Different Regions, including the Present Area

The Rupert site is located in the Hudson Bay lowlands also surrounded by the Precambrian Shield which, in the Hudson Bay area, has a smoothed and low relief topography.

The Toulnustouc site is within the Precambrian Shield where the sedimentary basins are restricted to glacial valleys.

Results obtained at Rimouski for water content, clay fraction and liquid limit are quite similar to those of the St. Jean Vianney, Rupert and Toulnustouc sites, with lower value of liquid limit for the Toulnustouc site. The liquidity index and sensitivity are lower at the Rimouski site.

The undrained shear strength at Rimouski is similar to results obtained at Yamaska, while results at least greater than 2.5 kg/cm^2 were obtained at St. Jean Vianney and Toulnustouc (as high as 4.0 kg/cm^2). For these two sites, high values of undrained shear strength may be due to cementation caused by iron oxide (see Lefèbre and Larochelle, 1974; Conlon, 1966).

High values of water content obtained at Yamaska correspond to a high clay content (more than 60%). Also, at this site, the surrounding landscape is smooth and the sedimentary basin is much larger than at other sites, i.e., the clays were deposited in quieter waters.

At Rimouski, the low values for the clay percentage and the water content are probably related to the fact that the sediments were deposited in a restricted basin. This is more obvious for a site such as Toulnustouc, which is restricted to a glacial valley.

The influence of the salinity of the former sea waters is difficult to assess. From fossil records only, it appears that the salinity was between 10 and 20‰ at the time the massive clay was being deposited.

The low sensitivity of the marine clays of the present area (e.g., Rimouski site) is the most striking difference and thus need more consideration. Some causes of quick clays in eastern Canada were recently summarized by Crawford (1968), Sobotka (1974), and McKyes et al. (1974), and are as follows: salinity, leaching of salts subsequent to deposition of the sediments, reworking of marine sediments by freshwater, types of clay minerals, and cementation (by amorphous coating of ferric oxide). Differences in the magnitude of these factors are believed by the writer to have produced a non-quick clay (but still sensitive).

A study of tritium and deuterium on two samples of the Rimouski clay (see p.134) indicates that the lowest portion of the soil profile is far from being completely leached (high deuterium), and that the groundwater has a slow flushing rate (dead in bomb tritium). These results reflect the massive character of the Rimouski clay (low permeability, few sandy layers), and also that little reworking of the marine sediments have occurred.

As observed by Gillot (1971) and the writer (see p. 119 , there are more well-crystallized clay minerals (illite) in the clay of the present area, than elsewhere in areas of sensitive clays. This would induce a higher degree of orientation of the platy particles, as could also be suggested by the study of the microfabric of two samples of Rimouski clay (see p.128). Results from triaxial and direct shear tests on this clay indicates a much lower degree of cementation than found in quick clays (see Conlon, 1966); this is shown by a low peak strength value. This low degree of cementation could be due to a lower content of amorphous coating of ferric oxide (McKyes et al., 1974). Therefore, a less random structure and less cementation contribute to the low sensitivity.

On a regional basis, most of the marine clays are underlain either by clayey till or bedrock. The writer also observed that there are no buried valleys, or present-day rivers in the area, where the base would be much lower than the Matane terrace. This is quite different from the situation along and within the Shield where glacial valleys are buried under tens of metres of sediments and where marine clays are underlain by thick glaciofluvial sediments. The marine clays along the Shield were deposited along with large deltas (source of sand), giving the banded character to the marine sediments (sand-clay) in areas such as St. Jean Vianney and St. Urbain (Gravel, 1974; Chagnon, 1969). Therefore, it can be assumed from these considerations that the regional groundwater system in the present area differs greatly from areas along the Shield. Since only few sand layers can be found interbedded with clay, uplift pressure (high pore pressure in sand layers) is not common in the present area and this could explain the scarcity of earthflows.

If the factors influencing behavior of sensitive clay masses are well-recognized, their specific contributions still are imprecisely known. The writer hopes that this discussion on the sensitivity of the marine clays in the area raised some interest for comparitive studies that would increase our knowledge about these different factors.

MINERALOGY AND CHEMISTRY

In this section the clay mineralogy and the chemistry of the Goldthwait Sea clay will be discussed. Only a few samples were analyzed, hence, data and conclusions are not considered fully representative of the area. However, for some aspects such as geochemistry, results obtained might indicate new orientations for future research.

The author presents here some data on clay mineralogy, carbonate content, and tritium and deuterium analyses. This section also includes a qualitative study of the microfabric of the Goldthwait Sea clays using thin sections and X-rays. The main minerals and clay minerals identified are listed in Table 11 with qualitative indications as to their abundance. An example of X-ray diffraction on powder and oriented preparations is displayed in Figures 45a and b for sample FT-185-74 (Ste. Anne-des-Monts).

Previous Work

The mineralogy and chemistry of the Goldthwait Sea clays was first studied by Mercier and Zemgals (1965) and Gillot (1970, 1971). Some data on total chemical analysis are also given by Dionne (1972a). Research is presently underway by L. Dredge (personal communication) and J. Lebuis (personal communication) on the mineralogical composition of the Goldthwait Sea clays. Unfortunately, none of this current data is available and hence, cannot be included in the present discussion.

Clay and Non-Clay Minerals

Clay and non-clay minerals were studied with an X-ray diffractometer and a petrographic microscope.

Five samples were "X-rayed" by R. Ledoux at the Université Laval using a Phillips RN1011 X-ray diffractometer. X-ray diffraction was performed only on the clay fraction ($<2\mu$) with powder and oriented preparations. Qualitative mineral analysis was carried out by the author on 80 samples during the field work, using a Monocular Zeiss microscope working under reflected light with a magnification power of up to 50 times.

Sample No.	I	C	CVS	QZ	F	Ca	Fe	A
153	pr (a)	a	pr	a	pr (tr)	a (pr)	tr (-)	tr
185	pr (a)	a	pr	a	a (pr)	a (pr)	tr (-)	tr
224	pr (a)	a	pr	a	pr	pr (tr)	tr (-)	tr (-)
232	a (a)	a	pr	a	pr	pr (tr)	tr (-)	tr (-)
240	pr (a)	a	tr (pr)	a	a (pr)	a (tr)	tr (-)	tr

sources: sample 153, Matane; 185, St-Anne; 224, Ste Luce; 232 and 240, Rimouski.

Note:
a: abundant
pr: present
tr: traces
- : no trace at all
(a): estimation from oriented preparation, when it is different.

I : illite (mica-like)
C : chlorite
CVS : chlorite, vermiculite, smectite
QZ : quartz
F : feldspar
Ca : calcite
Fe : iron element
A : amphibole

Table 11 : Qualitative estimation of more common clay and non-clay minerals for five samples of the Goldthwait Sea clays (X-rayed by R. Ledoux, Université Laval).

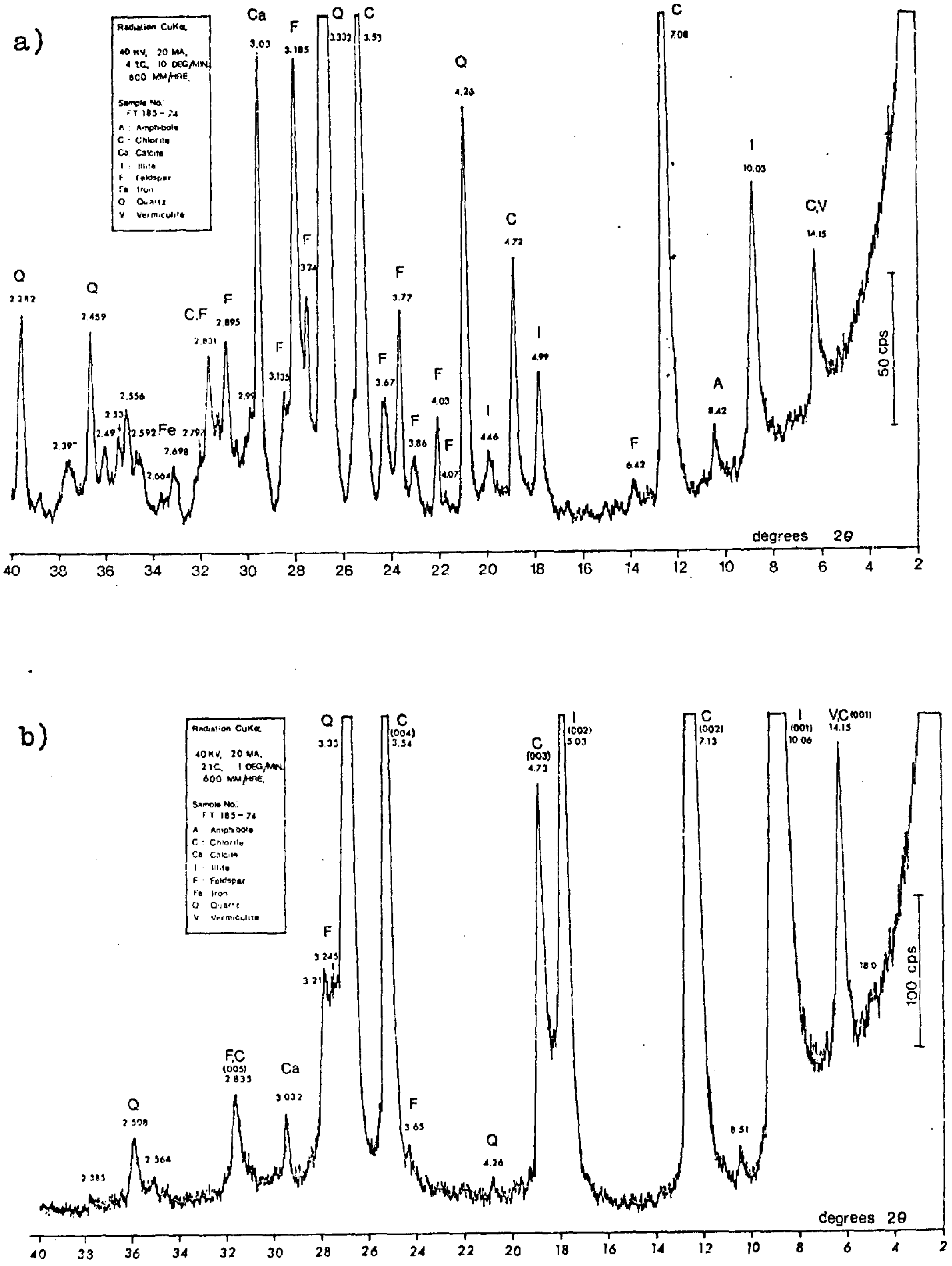


Figure 45. Diagrams of X-ray diffraction: a) powder specimen, b) oriented specimen. (X-rayed by R. Ledoux, Université Laval).

The author analyzed Ledoux's diffraction patterns and ran 2 samples himself with similar results. Only Ledoux's diagrams will be discussed because they display clearer peak separation. Samples came from Ste. Anne des Monts, Matane, Ste. Luce, and Rimouski. Two samples from Rimouski were analyzed to estimate the consistency of the mineralogy at one site. The number of samples analyzed cannot be fully representative of the area but at least gives a minimal evaluation of the mineralogy of the Goldthwait Sea clays in the present area.

The main minerals and clay minerals were identified with the A.S.T.M. cards. Illite (mica-like) and chlorite, respectively at 10.0 Å and 14.0 Å show an integral series of basal reflections (001, 002, 003 and also 004 for chlorite, see Fig. 45b). Mercier and Zemgals (1965) estimated the abundance of the clay minerals as illite 65 to 85% and chlorite 15 to 34%, with no indication of the percentage of the clay fraction (<2μ) in the 25 samples analyzed. Gravel (1974) calculated for the St. Jean Vianney clay that the average value of the amount of clay minerals was 29.8% as follows: illite, 21.1%; chlorite, 3.9%; vermiculite, 2.6%, and smectite, 2.2%. Gravel (1974) also concluded that clay minerals were found mainly within the 0.2 to 20 microns fraction of the samples analyzed which had about 80% of their particles smaller than 20 microns (silty clay).

A mixed-layer clay mineral of mica-vermiculite is suggested by a weak peak at 18.0Å (Fig. 45b). Since vermiculite could exist in the clay fraction analyzed, then the peak at 14.0Å could also belong to vermiculite (see Fig. 45b).

Quartz and feldspar were found in abundance in every sample (see Table 11). Calcite is also present along with some traces of amphiboles.

Iron oxide (Fe_2O_3) is recognized by its peak at 2.69A, which is also confirmed from total chemical analysis done by the Centre de Recherches Minerales (Q.M.N.R.: Table 12). The finding of primary minerals (quartz, feldspar, calcite, etc.) has also been confirmed by previous workers (Gillot, 1971; Gravel, 1974).

A few particles from the clay fraction of one sample were isolated by the writer for study under an electron microscope (transmission). It shows that particles are irregular in shape and angular to subangular (Fig. 46). However, crystals such as calcite (?) and illite (?) were also observed (Figs. 47 and 48).

Gillot (1971) considered that his sample from St. Joachin de Tourelle had more clay minerals originating from Appalachian rocks since he found that the illite at this site was well-crystallized. Results of total chemical analysis (Table 12) indicate that the bulk composition of the four samples analyzed is similar to that of a shale.

Results obtained on mineralogy and chemistry suggest that sedimentary rocks, such as slate, contribute to a large extent to the mineralogical composition of the Goldthwait Sea clays in the present area. Sedimentary rocks of the area (namely slate) contain appreciable amounts of illite which, being well-crystallized, would reflect a more mature crystallinity than illite (mica-like) minerals originating from the Shield. A greater amount of well-crystallized clay mineral should influence the relative proportion of amorphous material. This remains to be investigated.

Carbonates

The carbonate content was determined by the author for 21 samples of glacial and marine sediments using the Chittick apparatus with the pro-

	1	2	3	4	5	6	7	8	9	10
SiO_2	54.62	55.75	59.96	57.32	55.10	56.46	43.14	57.07	31.16	54.28
Al_2O_3	17.31	17.21	16.92	17.60	16.40	15.77	10.19	16.63	17.00	14.51
MgO	3.14	3.17	3.30	3.12	4.40	3.06	5.82	4.29	1.99	2.99
CaO	4.88	3.02	3.20	3.21	5.30	6.51	14.95	2.80	5.00	5.04
Na_2O	1.10	1.82	1.64	2.11	1.40	3.67	2.00	3.00	3.49	1.21
TiO_2	0.82	0.72	0.89	0.85	2.10*	0.66	0.36	0.32	----	0.42
MnO	0.02	0.08	0.09	0.08	----	0.07	0.08	0.09	0.06	----
Fe Fe_2O_3	6.61	6.40	6.77	6.58	5.70	4.72	5.94	9.85	9.77	6.39

*: fraction from 2 to 0.2 micron

1: Matane, FT-153-74
2: Ste-Luce, FT-224-74
3: Rimouski, FT-232-74
4: Rimouski, FT-240-74
5: St-Joachin, Gillott 1971
6: St-Jean-Vianney, Gravel 1974
7: Rupert, Ballivy 1970
8: Rupert, Ballivy 1970
9: Riviere-du-Loup, Dionne 1972
10: Average clay, Clark, from Gillott 1971

Note: Water analyses were not included since they were estimated on the total sample (for those of the present area).

Table 12. Total Chemical Analyses on Samples from the Present Area and Various Studies (data in %)

Figure 46: Electronic microscope (E.M., transmission) photograph of the fraction smaller than 5 microns (X 10,000), of a marine clay collected along the Matane River.

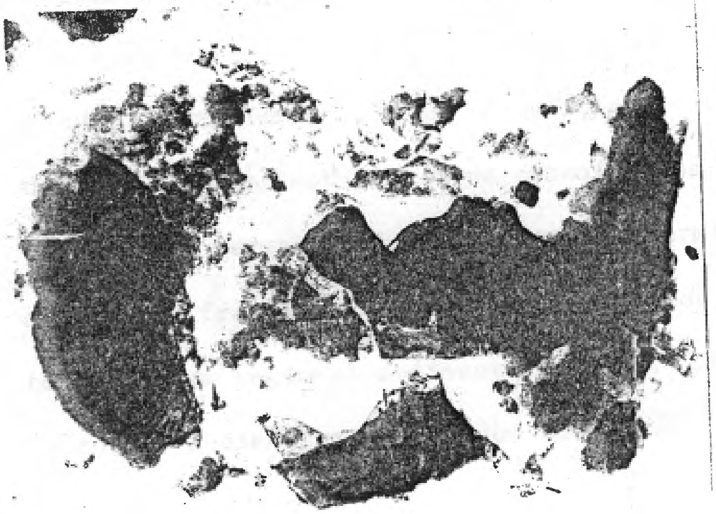


Figure 47: E.M. photograph (Transmission) of calcite (?) (X 15,000).

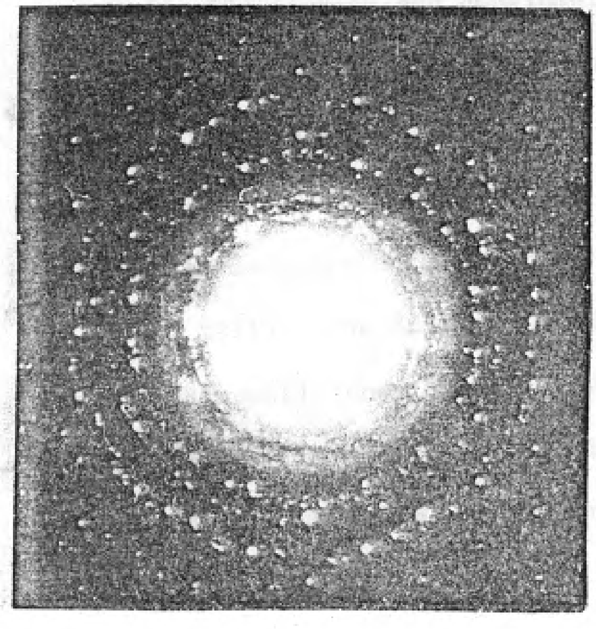


Figure 48: E.M. (Transmission) photograph of the microdiffraction pattern of a clay mineral (hexagonal, illite ?).

cedure suggested by Dreimanis (1962). Results for carbonate analyses (calcite and dolomite) are given in Table 13.

The total carbonate content varies from about 4 to 14%, with the maximum for the area, at Grand Métis (14.2%). Till appears to have less carbonate than marine clay. In fact, the lowest result was on a sample of till from Ladrière, about 8 km inland. The Goldthwait Sea clays in the Baie-Comeau/Sept-Iles area contain less than 1% of carbonates (L. Dredge, personal communication). Therefore, carbonates found in the silty clay fraction for the Baie-des-Sables/Trois-Pistoles area would have to come from regional sedimentary rocks. The general distribution of the Paleozoic sedimentary rocks and the Logan fault are shown in Figure 5 (p. 10). The Appalachian rocks extend to the Logan fault in the estuary and Gulf of St. Lawrence (Nota and Loring, 1964). Hence, the source of sedimentary rocks extends to the middle of the St. Lawrence Estuary for the present area. If the sedimentary rocks submerged in the estuary belong to the Québec Supergroup (Cambrian to Middle Ordovician), little carbonate may have come from these rocks since they consist of slate,and a few beds of sandstone and conglomerate. However, the bedrock geology of the estuary is not known well enough to completely eliminate this zone as a source of carbonates.

On the other hand, formations such as Val Brillant, St. Léon and Robitaille do contain carbonates in the form of calcite and dolomite (Lajoie, 1971). The Sayabec Formation, which outcrops about 8 km southeast of Rimouski, consists of very fossiliferous limestone and may be considered as the main source of carbonates for the area. As stated in Chapter I (p. 9), these formations are part of the Siluro-Devonian rocks which outcrop to the south of the Neigette escarpment (see Fig. 4, p. 6).

Sample No.	Alt. (m)	Locality	Ca %	Do %	Ca/Do	Total %	Sediment
TB-28	25	Matane R.	7.5	3.4	2.2	10.9	marine cl.
208	24	Ste. Luce	3.5	4.0	0.9	7.5	"
222	7	"	4.4	4.0	1.1	8.4	"
224	5	"	4.4	3.5	1.2	7.9	"
227	-1	"	3.8	5.4	0.7	9.2	"
4-1	5	Grand Mét.	6.9	6.5	1.0	13.4	mar. gr.
4-2	8	6.6 "	6.6	7.6	0.9	14.2	"
4-3	9	"	6.4	7.2	0.9	13.6	"
4-4	7	"	4.6	5.0	0.9	9.6	marine cl.
4-5	27	"	5.6	7.0	0.8	12.6	"
1-3	22	Petite M.	4.2	4.4	1.0	3.6	till
2-1	10	"	3.3	5.4	0.6	8.7	"
2-2-B	11	"	2.6	6.4	0.4	9.0	"
2-4	16	"	4.6	5.4	0.85	10.0	marine cl.
D18	146	St. Fabi.	2.4	4.2	0.6	6.6	till (sand)
22C/2W16	122	St.Mathi.	1.4	2.2	0.6	3.6	lacustrine
22C/7W40	145	Ladrière	1.8	1.8	1.0	3.6	till
22B/12W32	12	Tartigou	2.2	8.2	0.3	10.4	till (?)
22C/3E14	30	Trois-P.	4.1	5.1	0.8	9.2	marine cl.
22B/12W30	14	Tartigou	5.5	6.5	0.8	12.0	"
22C/3E9	99	Trois-P.	3.0	2.2	1.4	5.2	"

Table 13. Carbonate Analyses from Samples Collected During the Summer of 1974 in the Trois-Pistoles/Matane Area.

To give an idea of the amount of carbonate in the Siluro-Devonian rocks surrounding the present area, the following results were obtained from Lajoie (1971) on a few samples.

Formation and its thickness in metres	Sample #	% of rock as cement	Mineral
Val Brillant* 115-300	CG-2	20	Ca
	LL12-1	77	Ca, Do
	L19-1	7	Si, Do
	L19-3	10	Do
	L5-4	2	Do, I.O.
Robitaille** 450-750	LL-16-8	4	Si, Do
	C29-5S	95	Do
Sayabec 15-450	fossiliferous limestone with silt and clay (dark grey)		

Ca: calcite, Do: dolomite, Si: silica, I.O.: iron oxide
* from Lajoie, 1971, p. 54
** from Lajoie, 1971, p. 61

The main source of carbonates for the area is the Sayabec Formation which would yield mainly calcite and some dolomite. The other formations mainly contain dolomite cement. However, it cannot be shown in which amount each formation contributes to the carbonate content of the Goldthwait Sea clays.

Results of carbonate analyses obtained by Dionne (1972a) for the Rivière-du-Loup/Trois-Pistoles area are given in Table 14 along with the author's results. Calculation of calcite/dolomite (Ca/Do) ratios from Dionne's results, calculated by the author, is unreliable and based only on the average calcite and dolomite content. Dionne reported analyses yielding less total carbonates and a much lower Ca/Do ratio. No calcareous formations are reported by Dionne (1972a). Dionne (1971) studied the lithology of pebbles in recent and old beaches and found less than

	DIONNE, 1972			THIS WORK		
	Trois-Pistoles clay	Glaciomarine clay	Middle Goldthwaitian clay	Goldthwait "stony"	Sea clays massive"	Till
Ca (%)	0.7-2.9	2.03	1.0-2.0	3.0-6.9	3.5-7.5	1.8-5.5
Do (%)	2.0-5.7	5.5	1.5-4.0	2.2-7.6	3.4-7.0	1.8-8.2
Ca/Do	0.5	0.4	0.5	0.9-1.4	0.7-1.2 (2.2)*	0.3-1.0
Total (%)	2.7-8.6	7.53	3.5-6.0	5.2-14.2	7.5-12.6	3.6-12.0

*: ratio obtained for one sample from the Matane River.

Note: Ca: calcite
Do: dolomite

Table 14. Comparison with Results on Carbonate Content Obtained by Dionne (1972), and the Present Work

1.5% of limestone or conglomerate (Dionne, 1971) which could explain the lower carbonate content. The proximity of the Precambrian rocks near Rivière-du-Loup may be important in the mixing of Precambrian and Paleozoic rocks and a resulting smaller carbonate content.

The difference in Ca/Do ratio found between clayey till and the marine clay could be used as a basis for distinguishing them. From Fig. 49 it is suggested that till would have a lower Ca/Do ratio due mainly to a decrease in calcite content. This criterion was also used by Ballivy (1970) to identify the marine clay of the Tyrrell Sea which has a carbonate content of around 30%.

Considering that only 21 samples were analyzed for carbonate content, some general trends can be suggested.

The Goldthwait Sea clays (stony or not) have a Ca/Do ratio around or greater than 1.0, while tills are between 0.3 and 1.0. It is interesting to note that the lower Ca/Do ratio for tills seems mainly due to the presence of less calcite (Ca, Fig. 49). The stony clay (Table 14) and the massive clay have comparable values but the stony clay has slightly higher values. The lower results obtained for tills may suggest mixing between crystalline and sedimentary rocks, or might reflect more closely the underlying bedrock.

If we compare the data available on carbonate content of the Goldthwait Sea clays, it is possible to generalize certain trends. On the south shore the total carbonate content increases eastward from about 3 to 9% in the Rivière-du-Loup/Trois-Pistoles area, to 6-14% in the Trois-Pistoles/Matane area. Nota and Loring (1964) evaluated the total carbonate content of the surface sediments in the estuary and Gulf of St. Lawrence. Their analyses yielded 2% to 5% carbonate with a marked increase

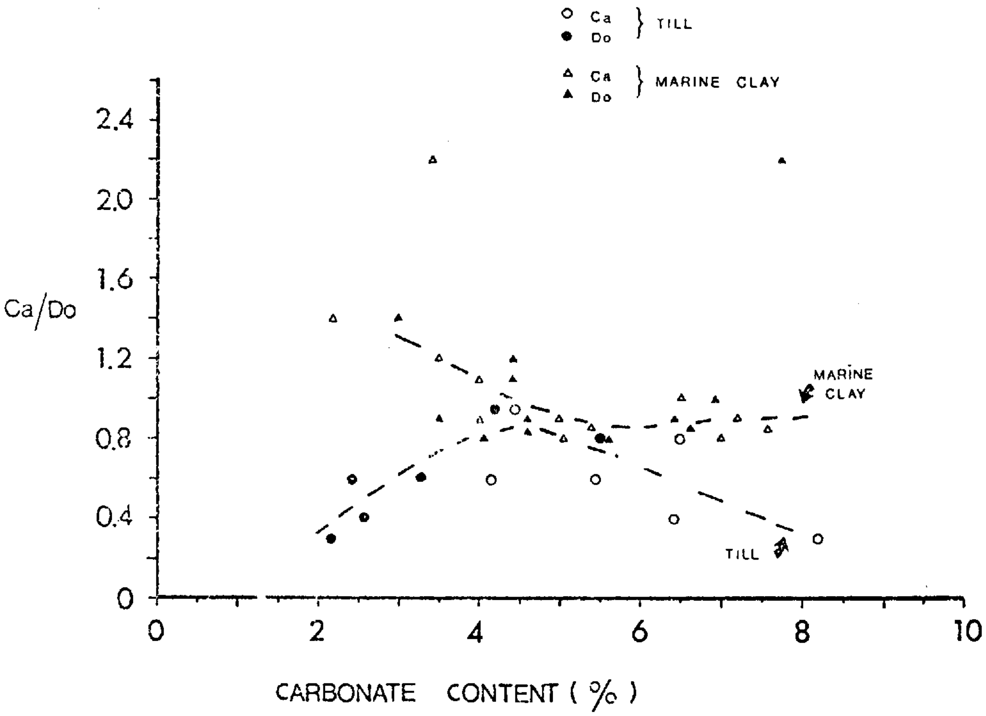


Figure 49. Carbonate content versus calcite (Ca) - dolomite (Do) ratio of some marine clay and till samples.

near Gaspé and Anticosti Island. They found very little carbonate (less than 2%) near Sept-Iles and along the north shore.

Therefore, results obtained on samples from the Goldthwait Sea clays suggest a two-dimensional variation in total carbonate content or that they vary as a function of the distance from the Shield. Carbonates increase from the north shore (less than 1%) toward the south shore (3% to 14%). The total carbonate content also increases from the southwest (3% near Rivière-du-Loup) to the northeast (14% at Grand Métis). Data from samples along the south shore of the St. Lawrence Estuary show a lower carbonate content for recent sediments with values between 2% and 5%. This suggests that the carbonate content of the Goldthwait Sea clays in the area has decreased since deglaciation, as the mixing between crystalline and sedimentary rocks increased in favor of the crystalline rocks. This indicates that it could result from a decrease in the amount of sediments originating from the Appalachian region. It should be possible to prove the decrease by analyses of long cores from the Estuary.

Microfabric

Shape and microfabric of the Goldthwait Sea clays was first studied by Gillot (1970). His work on a sample from the St. Joachin de Tourelle site will be used as a reference for discussion. The microfabric of clay has been investigated by Mitchell (1956), Pusch (1966a,b), Barbaroux *et al*. (1971), Gillot (1970), and more recently by Sobotka (1974) for the Bécancour area.

Various techniques for impregnation have been suggested, from simple impregnation with CARBOWAX 6000 (Mitchell, 1956) to ultrathin section (Pusch, 1966a). The main problem encountered by every author was the preservation of the original structure of the clay sediments.

It appears that the more common method now used in Europe consists of freeze-drying the sample and impregnating it under vacuum with polyethylene glycol (Sobotka, 1974). Even though some breakdown of the structure still occurs, it is easily recognized (Sobotka, 1974). The author did not have the facilities for this type of impregnation, so he decided to use Mitchell's method (1956) using CARBOWAX impregnation (App. C, p. 195), which was also employed by Gillot (1970), and by Quigley and Thompson (1966).

Gillot (1970) used both X-ray diffraction and optical properties to evaluate the microfabric. The first allows quantitative estimation of the orientation of the particles. In this work, only qualitative differences will be pointed out with the diffraction pattern. No account will be given of petrographic microscope observations except that it would be possible to study the sedimentary structures with such thin sections.

Results obtained on sample FT-222-74 from the St. Luce site (7.6 m a.s.l.) are shown in Figure 50.

Peak separation and intensity are found to be greater on a section parallel to bedding for the following peaks: illite (I,001), chlorite (C,002), quartz (Q,4.26 and 3.33 Angstroms), feldspar (F,3.18Å), illite (003), and calcite (Ca,3.03Å). It is then clear that most of the peaks show a preferential orientation toward a plane parallel to the bedding. This is true if we agree that since the long axis of the particle tends to be horizontal, this tends to increase the intensity and sharpness of peaks (Gillot, 1970). This is especially true for I(001,003). The writer believes that any effects caused by the preparation procedures should cancel out for thin sections normal and parallel to bedding.

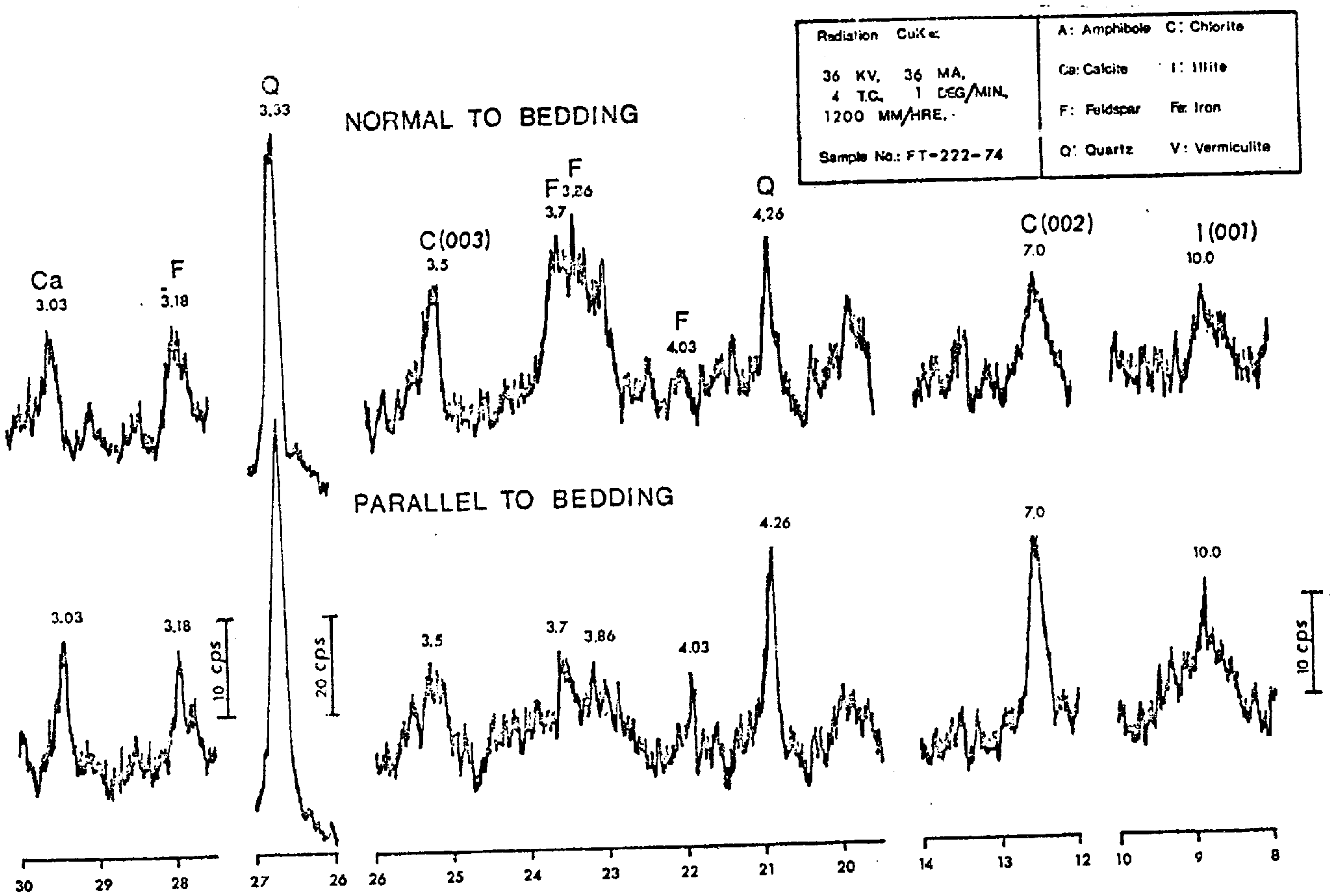


Figure 50. X-ray diffraction diagrams (main peaks) of an impregnated sample of marine clay

Thus it is concluded that the structure of the Ste. Luce clay is not random, as also found by Gillot (1970) for the St. Joachin de Tourelle clay. However, the structure might be due to the effect of sampling with a thin wall tube. Gillot's sample was a block sample. It was not feasible to evaluate the influence of sampling on the microfabric of the marine clay in the present study. It is generally believed that the block sampling does not disturb the structure as much as the thin wall tube (Bozozuk, 1971).

Two possibilities have to be considered. First, if we assume that sampling did not affect the microfabric greatly, then this marine clay has an oriented structure somewhat parallel to the bedding. Second, if we assume that sampling creates the difference, it indicates another way of showing sampling disturbance which could be minimized by using a specimen taken in the middle of a 12.7 cm (5 inch) diameter sample.

The study of microfabric would appear to be a promising technique for further study of the clay deposits of the area. As the degree of compaction of a clayey sediment increases, it is believed that the platy particles show a higher degree of preferred orientation (Quigley and Thompson, 1966). Therefore, for the present area, it would be of interest to apply this technique to the "marine" till (often called glacio-marine diamicton), and the stony and massive clays in order to determine differences in the microstructure. One would expect to observe a higher degree of orientation of clay particles in sediments overridden by glaciers than for normally consolidated clay.

Tritium and Deuterium

Tritium (T) and deuterium (D) are isotopes of hydrogen now commonly used in hydrogeology to study infiltration and groundwater flow (Brown et al., 1972).

Since shallow and deep unremoulded samples of marine clay were available from the present area and from St. Urbain (east of Québec city), Professors P. Fritz and J. Cherry of the University of Waterloo suggested that the tritium and deuterium content of the interstitial water of these clays be determined. The aim was only to look at the possibility of getting some information on the age of the pore water, and to determine whether or not the clays have been flushed with modern groundwater originating from rain and snowmelt. Analysis of tritium (T) and deuterium (D) for the pore water of marine clays provides an estimate of the age and degree of salinity. This is of particular interest in the study of sensitivity of marine clays. It is believed by some that the leaching processes, subsequent to deposition, is responsible, in part, for the sensitivity of some of the marine clays (Penner, 1965). To the author's knowledge there has been no such analysis performed on the Goldthwait or Champlain Sea clays.

Four samples (see page 134) were sent to R.H. Brown, at the Nuclear Research Center at Chalk River for deuterium and tritium analyses. These samples were about 17 cm long by 7 cm in diameter. The Rimouski site (FR-8) was chosen to represent the present area.

The Rimouski site has already been described geologically (App. B-2, p. 178) and the St. Urbain site was investigated by Chagnon (1969), and is still under investigation (Lafleur and Lefèbre, 1975). At the St. Urbain site the stratigraphy can be summarized as follows: a silty clay (clay fraction between 20 and 50%), with occasional sand layers, more frequent near the surface, but becoming thicker downward (e.g. 0.6 cm at a depth of 30 m, Lafleur and Lefèbre, 1975). The surface at the St. Urbain site lies at 100.8 metres a.s.l..

The pore water is taken from the sample by a process called azeotropic distillation. It consists of mixing with toluene at 90°C (boiling point for toluene). The toluene-water mixture is then evaporated and condensed. The tritium (T) was analyzed by "liquid scintillation counting" (R.M. Brown, personal communication).

The criteria use for the interpretation of the results follow those suggested by Brown et al. (1972, p. 9):

"1) The water has a concentration of 3 T.U.. This means that no water younger than 20 years is present. That is, more than 20 years are required for water to reach the sampling point from the recharge area. This is the case of most confined aquifers. Phreatic aquifers can have low tritium content due to (a) very slight infiltration (arid and semi-arid regions), (b) long percolation time (low transmissibility, great depth of water table), (c) age stratification of water below the water table.

2) The tritium content is 3-20 T.U.. A small amount of thermonuclear tritium is present, indicating most probably water of the first test period, 1954-61.

3) The tritium content is 20 T.U.. The water of high tritium-content is obviously of recent origin. If variations occur through the year and are related to the variations in precipitation over the recharge area, the flow-through is rapid and direct and the transit time may be evaluated from the time-lag in appearance of the annual peaks. The variability may also be caused by a seasonal change in the source of the water from different sources, e.g., a tritium-free water of deep circulation and a young water of high tritium content, generally of a more superficial circulation."

The tritium content of the shallow sample (-6.1 m) at Rimouski (FT-231-74) is considered "dead" from the point of view of bomb-tritium. This would indicate a slow flushing rate. Also at the same site, sample FT-240-

Sites and Sample No.	Depth (m)	Water Content (%)	Deuterium (‰)	Tritium T.U. (tritium units)	Tritium Content
St. Urbain					
FT-156-74	3.0	25.0	-80	130± 9	High
FT-162-74	24.4	20.0	-93	23±10	Very low or dead
Rimouski					
FT-231-74	6.1	18.0	-92	9±10	Dead
FT-240-74	33.5	21.0	-50	19± 8	Dead

Notes:

- Data for waters of the St. Lawrence Estuary at Rimouski are (present):

  Tritium : 25 T.U.
  Deuterium: -23‰
  Oxygen 18: -2.3

- The total salt content of the pore water as determined with a conductivity meter give 0.2 mg/l for sample FT-231-74.

- Samples from Rimouski are from borehole FR-8.

---

74 (-33.5 m) has a rather high deuterium content (50‰, parts per mille). Such a value could also indicate contamination by sea water (R. H. Brown, personal communication). For the St. Urbain site there is a much higher flushing rate which is indicated by the high tritium and low deuterium content.

The high tritium content of the shallow sample at St. Urbain may be caused by the numerous sand layers that favor a high horizontal groundwater flow. At Rimouski the low tritium content of the shallow sample may be a reflection of the massive character of the clay.

It is believed (Chagnon, 1968) that some of the salts within the original marine clays were leached away since deposition. This would have occurred at St. Urbain, but at Rimouski the leaching process is not completed near the bottom of the profile. In summary, the St. Urbain clay appears to have a higher flushing rate than the Rimouski clay, and the St. Urbain clay is more completely leached than the Rimouski clay. A relationship between the salinity and the sensitivity has been suggested by previous workers (Rosenquist, 1966; Penner, 1965). Therefore, a study of deuterium and O^{18} could give us a good indication of the paleo-hydrological history of the pore water.

A REVIEW OF THE RIMOUSKI EARTHFLOW

Earthflow occurrences in the St. Lawrence Valley were recently compiled by J.Y. Chagnon (1968). Only two major flows were located in the present area: the St. Joachin de Tourelle (Matyas, 1964a,b) and the Rimouski (Meyerhoff, 1953) earthflows. The Rimouski earthflow will be reviewed in order to establish more precisely the geological and morphological setting. Field data obtained by the Service de Géotechnique (Q.M.N.R.) in the winter and summer of 1974 are used here to detail physical properties of the marine clays at the Rimouski site. The author does not intend to do a detailed stability analysis for this site since no information was collected on pore pressure, but will discuss processes involved in the steps toward the failure of this clay embankment.

Previous Work

G.G. Meyerhof (1953) studied the Rimouski earthflow, and Kerr (1963), and Liebling and Kerr (1965) studied samples from the earthflow to determine the clay mineralogy. The site was also included in studied by Mitchell and Markell (1974), and by Sobotka (1974).

Meyerhof (1953) considered the Rimouski earthflow as typical of a retrogressive slide, originating after river erosion had occurred at the toe of the slope. Later (1957), he defined a retrogressive slide as consisting of blocks of clay and silt that rotate on a clay-water layer which forms a lubricating base, with slicing starting from the foot. The history of the earthflow will be taken from Meyerhof (1953).

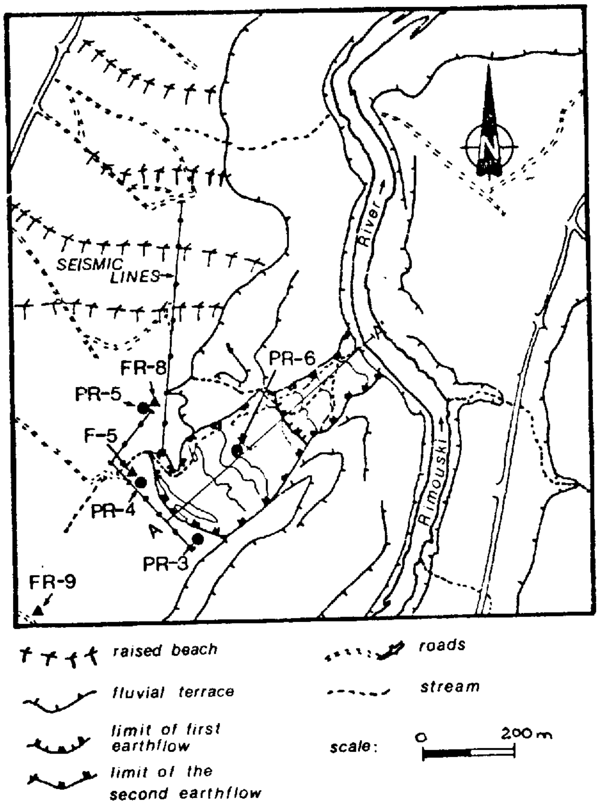
Site and Geology

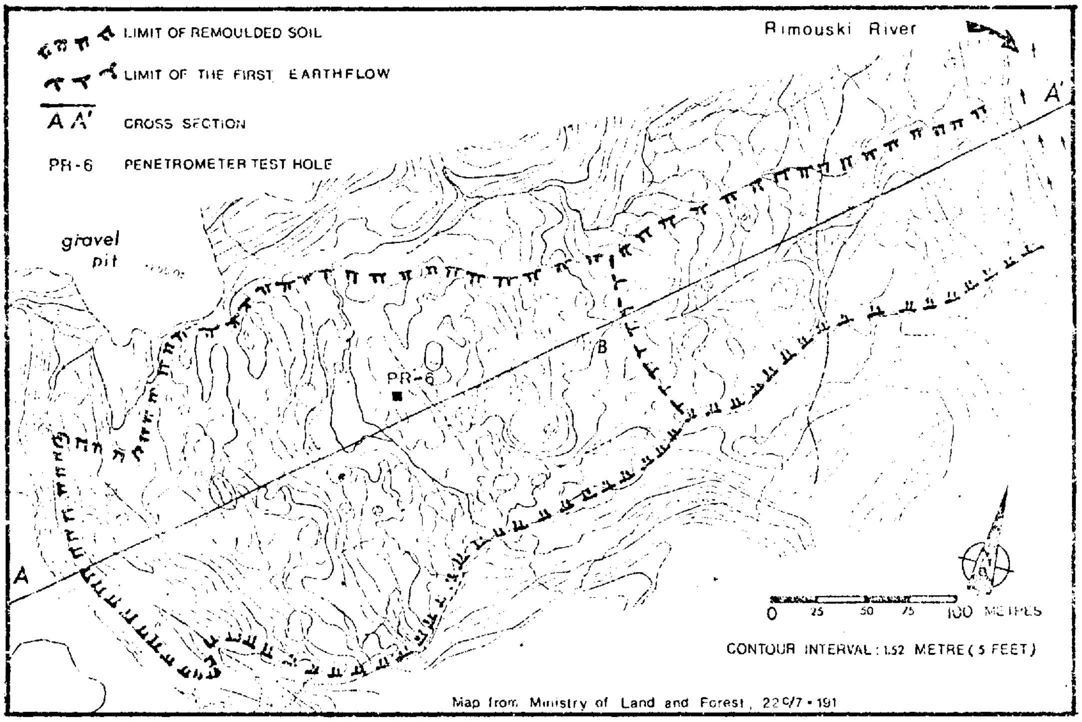
The Rimouski site (see App. B-2, p. 178) is located on the west bank of the Rimouski River. The river has formed many fluvial terraces entrenching marine or littoral sediments. Very well-formed raised beaches exist to the north and northwest of the earthflow (Fig. 51). They are intensively and widely exploited for sand and gravel in this area; because of the high water table, operational mining is not more than 5 metres deep. However, some trenching is in progress along the fluvial terrace, about 800 metres upstream of the earthflow, in order to lower the water table, and thus to increase the depth of mining. The water is diverted into a small stream, already deeply entrenched in fluvial sand and gravel. Bank failures are already active on both sides of the small stream.

The earthflow scar is limited to the south by an old earthflow (100 years old; Meyerhof, 1953). Meyerhof observed that it was limited to the northwest by bedrock outcrop. The Rimouski River flows on bedrock which probably controlled, at least in part, the extent of the earthflow.

The earthflow is about 600 metres long and 200 metres wide (Fig. 52) and the volume of soil involved in this earthflow was estimated by Meyerhof

Figure 51. Geomorphology and site investigations at the Rimouski earthflow.





Map from Ministry of Land and Forest, 22C/7-191

Figure 52. The Rimouski earthflow.

(1953) to be about 750,000 m^3. The remoulded material flowed about 100 metres upstream and about 1 km downstream, flooding part of the lower town of Rimouski (Meyerhof, 1953; Kerr, 1963). Some of the earthflow features described by Karrow (1972) still exist at the site. At least one slump slice ridge is still well-preserved. The hummocky landform of the bowl is created by many small pinnacles that were smoothed with time.

The material that flowed into the river (apron) was eroded away by the stream. The remoulded soil stabilized at a slope of 8° (Figs. 52 and 53). However, the remoulded soil piled up unevenly, forming a small escarpment near the middle of the bowl which is believed to represent the limit of the first earthflow.

The geological setting is given in Figure 53 along with the longitudinal cross section. The stratigraphy was given in Appendix B-2 and could be summarized as follows. The bedrock consists of soft slate overlain by about 2 metres of stony clay, 25 metres of massive clay and then by 12 and 2 metres, respectively, of littoral and fluvial sand and gravel. More detailed information is given in Appendix A, for the surrounding geology.

History of the Earthflow

River bank erosion had been noticed a few days before the first earthflow. According to Meyerhof (1953) the Rimouski earthflow occurred in two phases. On August 3, 1951 in the evening, the first earthflow took place accounting for about 15% of the total disturbed soil. The first earthflow was 122 metres long, 60 metres wide and 15 metres deep (back scarp). After the slide, some springs were noted at the toe. The slide was completed in about 5 minutes.

Three days later, on August 6, 1951, a second and much larger earthflow occurred in the morning. Trees and blocks of undisturbed silt and

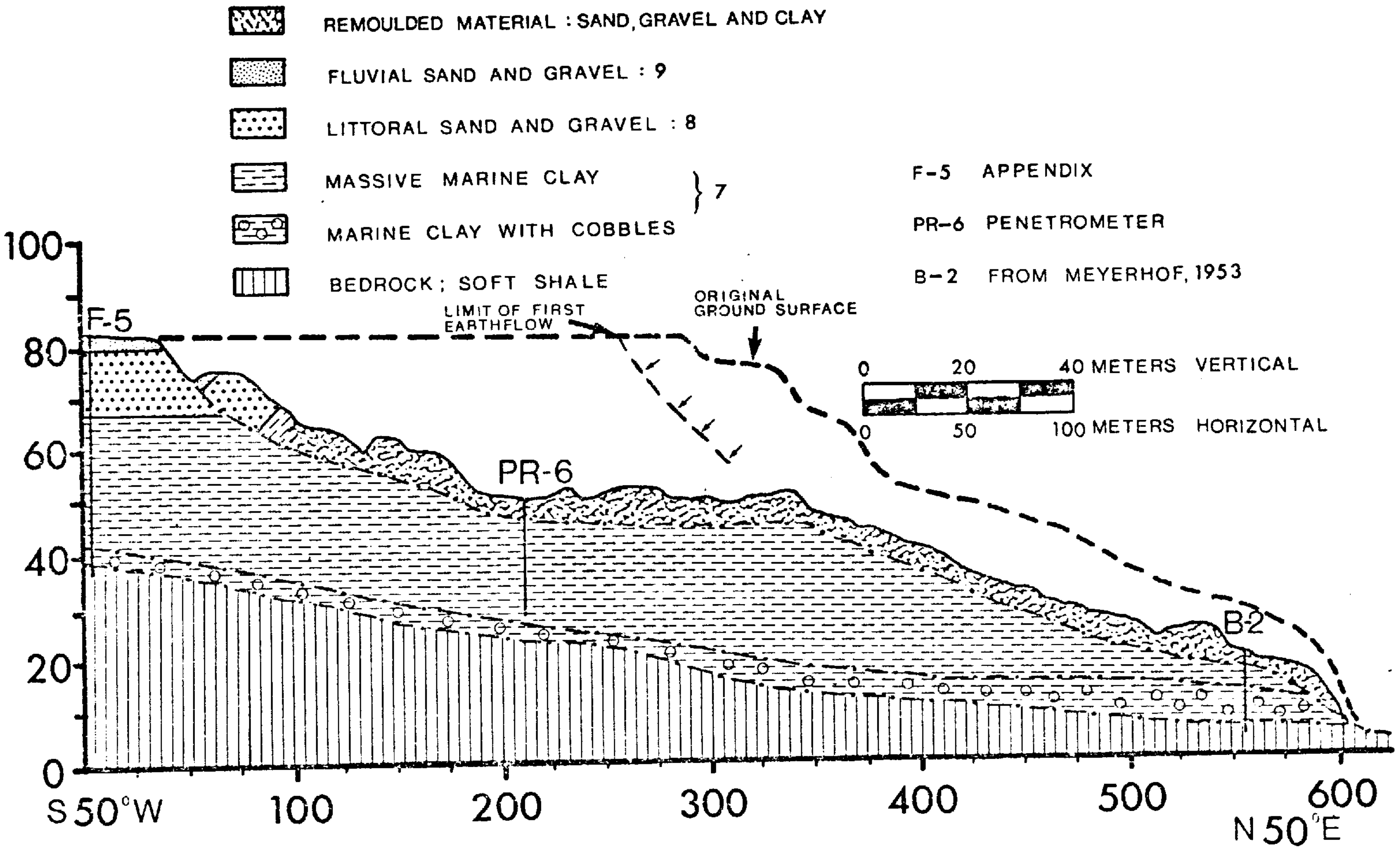


Figure 53. Cross-section showing the geological setting at the Rimouski earthflow

clay flowed into the river, transported by remoulded silty clay. The Rimouski River was dammed to about 1.2 km upstream. As stated previously, the soil flowed upstream and downstream flooding the lower part of the town of Rimouski. This earthflow lasted for about 15 minutes. However, for several days some masses of soil continued to fall from the back scarp which was only 6 metres high.

Meyerhof (1953, 1957) considered this earthflow as a typical retrogressive slide. His interpretation is supported by the presence of slump slice ridges. The first slide affected a much steeper wooded zone, where blocks of undisturbed soil up to 4 metres in height were noted sliding into the river.

Since then, no more movement has been observed. However, springs still exist at the sand and clay interface (upper part of the profile, Fig. 53). Also, the river has cut down the remoulded material and reshaped its banks, which are already steep as shown by the topographic map (Fig. 52).

Soil Conditions at the Rimouski Site

Field work including mapping (22C/7E), drilling (F-5, FR-8, FR-9), penetrometer probing (PR-3, PR-4, PR-5, PR-6), and a seismic survey enabled us to construct geotechnical profiles (Figs. 54, 55, and 56).

A summary of the results have already been presented in Table 10 (p. 111) and are compared here with the following results from previous studies. The lowest shear strength (Cu) obtained at this site was about 0.1 kg/cm^2 (FR-8 at -26.4 m) and the highest sensitivity measured with the field vane test did not exceed 2 (-24.6 m at F-5).

The highest water content, obtained in boreholes FR-9 (38-39%), may indicate that other boreholes are too close to the escarpment and may give results that are too low.

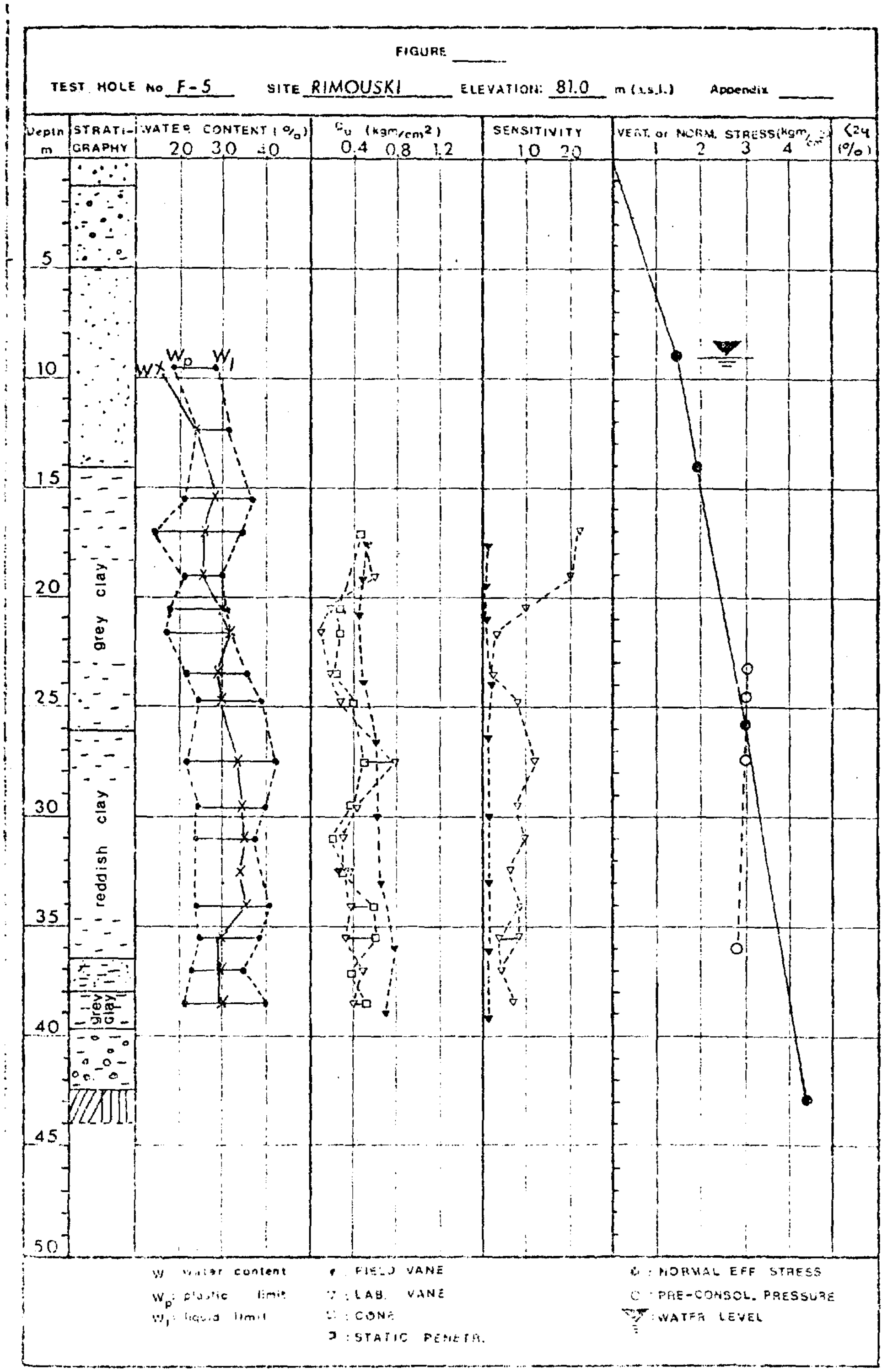


Figure 54. Geotechnical profile, borehole F-5

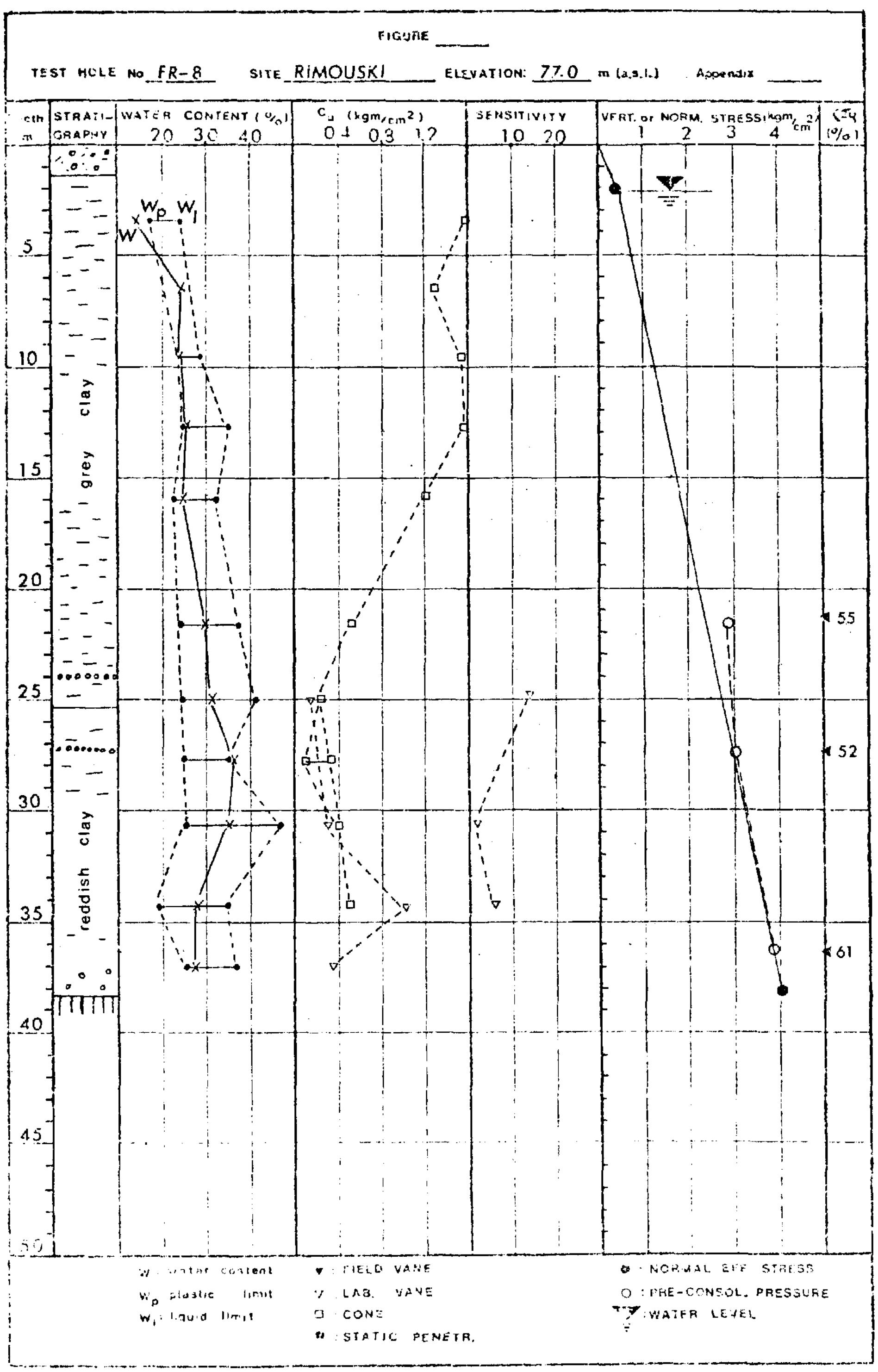


Figure 55. Geotechnical profile, borehole FR-8

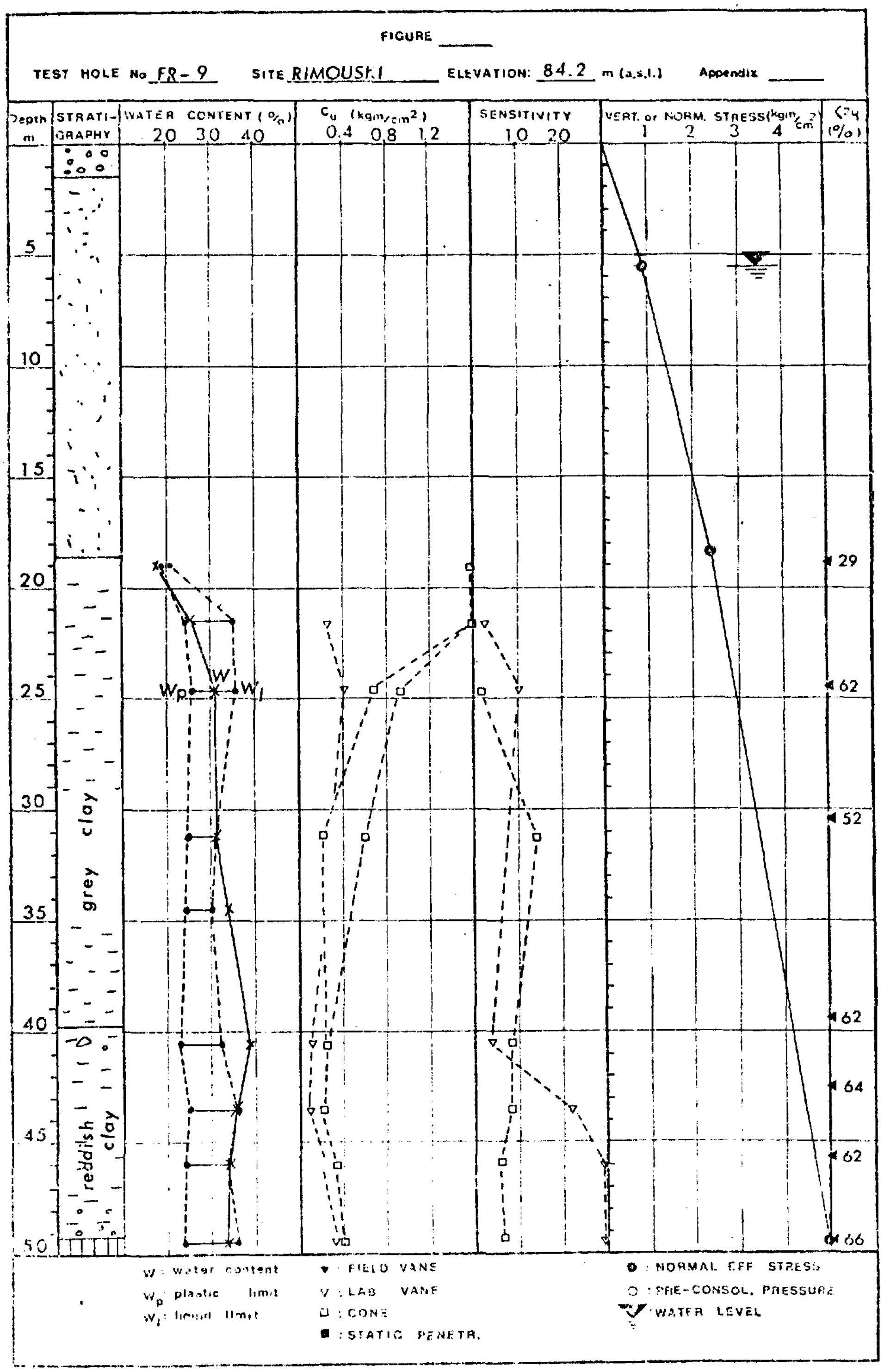


Figure 56. Geotechnical profile, borehole FR-9

The stiff clay noticed by Meyerhof (1953) could correspond to the few first metres (5 to 10 m) of marine clay (Fig. 55).

The position of the water table at the time of the earthflow is not known, but artesian pressures were observed at the toe of the slide. During the current investigations springs could only be seen at the sand-clay interface in the upper part of the profile (Fig. 53).

Only a few samples were analyzed to determine c' and ϕ', the cohesion and the angle of internal friction (Figs. 42 and 43, p. 108). The results of $c'=0$ and $\phi'=21.6°$ are a fairly good estimation of the drained conditions for long-term stability analysis.

A short-term stability analysis required a knowledge of c (Cu) at $\phi=0$ and no drainage, i.e. no change in volume for the period of time considered, which would correspond to the situation during the second slide.

Hoek and Bray (1974) produced "circular failure charts" which can be used to estimate the factor of safety of a typical slope. Figure 57 is used here to represent the first slide that occurred in the lower terrace and is analyzed under effective stress conditions. A value of c' of 0.05 kg/cm^2 was obtained from one test with a value of ϕ' of 23°.

This model corresponds to the "chart number 3" of Hoek and Bray (1974, p. 217) with the water table near the base of the tension crack, which here may correspond to the base of the dried crust.

A factor of safety of 0.96 is obtained from this model which indicates that the model would fail under the given conditions. If the slope is fully drained, the factor of safety becomes 1.8, and 0.9 if fully saturated.

The data used by Meyerhof (1953) and Mitchell and Markell (1974) are summarized below (p. 146) with the results obtained during the summer of 1974. With the data available, Mitchell and Markell (1974) considered the Rimouski earthflow as corresponding to the model shown in Figure 58 which is

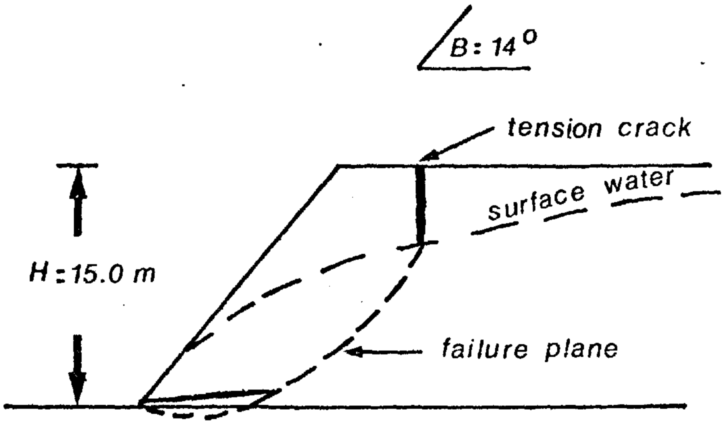


Figure 57. Hoek and Bray's model (number 3) of stability analysis (modified from Hoek and Bray, 1974)

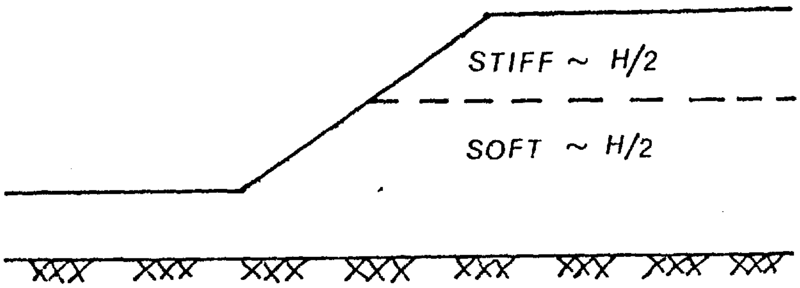


Figure 58. Mitchell and Markell's model of stability analysis (from Mitchell and Markell, 1974)

	First Slide (1953)	Second Slide (1953)	Present (1974)
Water Content (%)	28	28	31
Liquid Limit (%)	40	40	36
Plastic Limit (%)	20	20	22
Liquidity Index	0.4	0.4	0.7
Sensitivity	2	2	2-10
Clay Fraction (%)	high	high	60
Cu (kgm/cm^2)	0.3-0.5	0.5	0.3-0.6
γ (kgm/cm^3)	-	-	0.002
Slope Height (m)	15.2	15.2	15.2
Slope Angle (°)	14	14	14
Slope (bowl) (°)	-	-	8
Depth to Failure (m)	15.2	15.2	35 (max)
Height of back scarp (m)	15.2	6.1	6
Retrogression (m)	122	518	575
Width (m)	61	244	270
Terrace Slope (°)	flat	flat	2
$\gamma H/Cu=Ns$	6.6	10.0	5.0-10.0

Note: -Cu, undrained shear strength; γ, unit weight; H, slope height; Ns, Taylor's stability number.

-Data from Meyerhof (1953), Mitchell and Markell (1974) and the present work.

valuable only for short-term analysis (c' = Cu, ϕ' = 0).

Figure 53, which summarizes the findings of the current work, shows a better model. Field work indicates that the thickness of the hard layer is less than one-half of the slope height (Fig. 55). Our present knowledge of the lowest terrace (at 19 m a.s.l.) only permits us to say that the marine clay is overlain by fluvial sand and gravel since we do not know the thickness of the sand and gravel layer. However, we know more about the second terrace in which the second slide took place.

For the first slide, the base level (hard surface) consists of bedrock. For the second slide, it is in the clay. From Figure 53, the maximum depth to failure is at about 3.5 metres (at PR-6, p. 214). The model suggested by Mitchell and Markell (1974) could represent the second phase of the earthflow where the failure surface is located in the soft clays.

The undrained shear strength for the first slide was estimated between 0.25 and 0.5 kg/cm^2, and 0.5 kg/cm^2 for the second slide. The earthflow originated at the toe of the pre-existing slope. On both sides of the earthflow there is a fluvial terrace lying at 19.8 metres above sea level. The scarp of the lowest fluvial terrace has a local relief of about 15 metres. In previous studies (Meyerhof, 1953, 1957; Mitchell and Markell, 1974) this terrace was taken for the initial slope stability analysis.

Discussion

Field investigations in the summer of 1974 enabled us to determine precisely the engineering properties for the Rimouski site. In general, the results we obtained in the field agree with previous findings. The size of the second landslide is now more precisely known since better topographic maps are available. This could explain the discrepancy in the measurement of the retrogression distance and the slope of the terrace (see p. 146).

Earthflows are known to be controlled by different parameters such as soil properties, topography and stratigraphy. The causes of the origin of the earthflow are often speculated upon (Chagnon, 1968; Mitchell and Markell, 1974) but little attention is given to an embankment prior to its failure.

Meyerhof (1953, p. 42) concluded that "the field investigation indicates that the earthflow at Rimouski was initiated by erosion of the soil, mainly sand, gravel and silt, at the toe. This erosion caused a retrogressive slide from the river to the upper edge. The earthflow had been aggravated by artesian groundwater conditions and soft clay underlying the silt. The observed depth and slope of the earthflow are similar to those found on other earthflows."

Meyerhof (1953) considered that the earthflow was limited to the south by an old landslide and to the north by the bedrock. Mitchell and Markell (1974) suggest that for $N_s<6$ (Taylor's stability number is equal to $\gamma H/Cu$, where H is the height of the slope), the earthflow terminates in retrogressive flow sliding. If $N_s>6$, it terminates only as a result of topographic or stratigraphic controls. N_s is also function of slope angle β and n_d (depth to a firm stratum/height of the slope). Mitchell and Markell (1974) assume $n_d>1$ which is not the case here for the first slide where $n_d=1$ (toe of the slope lies directly on bedrock). However, their model would be valid for the second slide where $n_d>1$.

Rapid river erosion at the toe of the escarpment may have created a short-term instability if the clay could not drain as fast as it was eroded. If we assume that the drainage in the clay of the lowest terrace was not greatly disturbed by the erosion at the toe, Hoek and Bray's model could be applied. The first slide can be considered rotational, and the second slide as a retrogressive type.

Hence it is known that "each retrogression must overcome a greater average shearing resistance" (Mitchell and Markell, 1974, p. 12) as the back scarp becomes further from the initial slope. The writer believes that, as the recessional sliding was going on, the ratio between the amount of non-sensitive soil (sand, gravel, clay crust) and the amount of sensitive soil (soft clay) was probably increasing since the remoulded material started piling up at the toe of the back scarp. This could also explain the decreasing depth to failure from the end of the first slide to the end of the second.

The time lag between the two slides (3 days) could be explained according to Mitchell and Markell (1974, p. 12). They suggest that for some earthflows, sliding creates negative pore water pressure and that it causes a reduction in the pore pressure that may be sufficient "to prevent retrogression at least temporarily."

In summary, the causes of the earthflow were intense erosion at the toe originating retrogressive sliding (Meyerhof, 1953). The earthflow was partly controlled by the stratigraphy and topography at the site (bedrock topography, hard crust). The depth to failure for the first slide was close to the bedrock while it was in soft clays for the second slide. Field and laboratory results obtained during the summer of 1974 are in good agreement with previous observations, with discrepancies due perhaps to improvement in sampling and testing procedures, and topographic maps.

The models applied here suggest that the first slide could have been rotational (Hoek and Bray's model), and that the second was retrogressive (Mitchell and Markell's model).

However, there is a need for a better knowledge of groundwater conditions in order to simulate the evolution of the soil condition.

SUMMARY

The Goldthwait Sea clays of the study area have a water content between 21% and 36%. The Atterberg limits indicate that the clays have a medium to low plasticity (W <50, CL group of Casagrande diagram, Fig. 40). The clay fraction comprises between 27% and 79% of the sediment which, related to the plasticity index, indicates that this clay is inactive (0.1 - 0.5).

The undrained shear strength of the Goldthwait Sea clays varies from 0.2 to 1.2 kg/cm^2 in the saturated zone and more than 2.5 kg/cm^2 in the unsaturated zone. This clay has a rather high remoulded strength with occasional low remoulded values which suggests these clays are slightly sensitive to slightly "quick" (Rosenquist, 1952).

The Goldthwait Sea clays are normally consolidated with a permeability between 10^{-8} and 10^{-7} cm/sec. The angle of internal friction varies from 25° to 34° for the maximum shear strength to about 21° for the residual strength. The cohesion can vary between 0 and 0.1 kg/cm^2. The non-quick behavior of the marine clays in the area can be explained by less leaching of the salts, abundant well-crystallized clay minerals (illite), and little or no cementation (little ferric oxide).

A rapid survey of the clay fraction by means of X-ray diffraction indicated that illite (mica-like) and chlorite are the most abundant clay minerals, probably associated with vermiculite and smectite. High angle of reflections (18A) also suggested the presence of mixed-layer minerals. The clay minerals were also found with primary minerals such as quartz, feldspar and calcite.

The Goldthwait Sea clays of the south shore of the St. Lawrence contain carbonates. The total carbonate content varies eastward from 3% near Rivière-du-Loup to 14% at Grand Métis. The calcite content is between 1% and

7.5% and about the same for dolomite. The Ca/Do ratio varies from 0.4 to 2.2 in the present area.

On other aspects, the sample analyzed for microfabric indicated a preferred orientation, of the platy particles, in a plane parallel to the bedding. This was found to be related to a low, in situ, overconsolidation of the sample, or the sampling disturbance, or both.

Tritium and deuterium analyses indicate that the clays at the Rimouski site contained little tritium, even for the shallow sample, while the deuterium content was much higher in the lower sample. These results suggest that the clay at this site has a lower permeability and that some salt remains in the pore water of the lower levels.

The Rimouski earthflow was initiated by toe erosion and probably maintained for a short period of time by artesian pressure. The first failure in the clay mass occurred as a rotational slide, and the second failure, as an extensive retrogressive slide. The time lag between the two failures can be due to a temporary decrease in pore pressure near the first scarp.

CHAPTER V CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations will be listed as they emerged from the study.

CONCLUSIONS

(1) The marine terraces called Rimouski, Mitis, and Mic Mac by Dionne (1963) are renamed respectively as the Matane, Ste. Flavie, and Bic terraces, and the Mic Mac terrace (of Goldthwait, 1933?; in Gadd, 1971) is named the Mic Mac surface.

(2) The buried bedrock channels underneath Quaternary sediments near St. Ulric become wider and deeper toward the St. Lawrence Estuary, and are oriented northeast-southwest.

(3) The slope of the platform of the Bic terrace, and its foreslope, near St. Ulric, are controlled by the bedrock. Where the bedrock does not outcrop, the slope of the terrace is about two times greater and the height of its foreslope smaller.

(4) The use of a static penetrometer and seismic survey proved to be satisfactory for determining stratigraphic profiles.

(5) The present work confirms the idea that the last phase of the ice movement for the St. Lawrence/Gaspé region, was to the north and northeast (Lebuis and David, 1972; Lebuis, 1973a,b; Gauthier, 1975).

(6) Two types of marine sediments (clay) can be distinguished on the basis of texture: a glacio-marine clay (stony) and a massive clay.

(7) The "high" massive clay (Trois-Pistoles clay of Lee, 1962 and Dionne, 1972a) was deposited when the ice front was on the edge of the upland while the relative sea level was still high (120 m). This clay is considered as the transition from the glacio-marine to the massive clay.

(8) The color of the marine clay is mainly a function of the source of the sediments (reddish - red slate; grey - grey slate).

(9) The rate of land emergence can be divided into two main parts: from about 13,500 to 10,000 y.B.P., 4.0 to 1.0 cm/year; 10,000 y.B.P. to the present, 1.0 to 0.2 cm/year.

(10) Microfossils (foraminifera and ostracods) proved to be very useful in determining the marine origin of a sediment.

(11) Carbonate analyses indicated a good possibility of distinguishing between till (lower Ca/Do ratio), stony or glacio-marine clay (highest carbonate content), and massive clay.

(12) Total carbonate content in marine clay increases with increasing distance from the Shield. It increases from the north shore (1% near Baie Comeau) to the south shore where it increases easterly from 3 to 4% near Rivière-du-Loup to 14% at Grand Métis.

(13) The Goldthwait Sea clays of the present area are considered to be sensitive but not "quick" clays. This could be explained by less leaching of the salts, abundance of well-crystallized clay minerals (illite), and little or no cementation (less ferric oxide ?).

(14) Physical properties of the Goldthwait Sea clays are typical of restricted sedimentary basin-like regions such as St. Jean Vianney and the Toulnustouc River, as indicated by a lower clay and water content, and by a poor sorting of the sediments.

(15) Hoek and Bray's model could be applied for the initial phase of the Rimouski earthflow (model "number 3") where the failure plane is controlled by the bedrock (rotational slide). Mitchell and Markell's model is valid for the second phase of the earthflow where the failure plane cut into the soft material (retrogressive slide).

RECOMMENDATIONS

(1) Offshore seismic survey and drilling performed in the Gulf and Estuary of the St. Lawrence should be extended to the coast and include a penetrometer survey so that geological units could be correlated with those on land.

(2) Mapping of Quaternary sediments should be carried out as soon as possible in order to complete work by David, Lebuis, Lee, Dionne, and Locat. Also, there is a large unmapped area between Rivière-du-Loup and Québec City which corresponds to the area lying between the Champlain Sea and the Goldthwait Sea.

(3) The study of microfossils (foraminifera and ostracods) in Eastern Québec is limited to offshore investigations. Since they were found in the present area a regional "on-land" investigation, including deep drilling, will permit a better understanding of past environments. This work could be related to another survey on freshwater fossils which are the most widespread and abundant in the area. This last survey could be carried out for some of the many lakes or peat bogs throughout the area together with palynological studies. The St. Lawrence/Gaspé region offers a variety of environments rather close to each other.

(4) A more extensive study of the carbonate content of the marine clays and tills of the area should increase our knowledge of ice movement and sea transgression and regression.

(5) If any drilling is to be performed in the area for stratigraphic purposes the following sites should be of promising interest: St. Ulric, Grand Métis and St. Fabien. At the first two sites, Quaternary deposits were found below sea level and they could yield information on early

sedimentation in the area. The Neigette Valley, including the Métis River, needs more detailed investigation. This region is located along a major axis of ice movement and its study from Price to Lake Matapédia will probably indicate how the Laurentian ice moved in the area, and how it interacted with the Appalachian ice sheet.

(6) The Rimouski and Matane area should be investigated to determine more precisely the extension and the physical properties of the marine clays. This study should supply more information on cohesion, angle of internal friction and stress history. Since the marine clays were found to be sensitive and form rather steep slopes any further development or urbanization should be preceded by a detailed slope stability analysis, if such development must be located near this type of slope at all.

(7) Extensive quarrying in sand and gravel near Matane and Rimouski should be controlled in such a way that it will not increase bank erosion, causing further instability. Also, this exploitation of sand and gravel near these towns is destroying the landscape while the old pits are used for garbage disposal. Therefore, it is of a great importance that the land use in the area be attached to a plan that will take these considerations into account.

(8) A substantial rock avalanche occurred at St. Fabien-sur-Mer in 1967. This area along the coast is of great interest for tourism. These escarpments should be studied in more detail to anticipate or prevent any further avalanches of this size.

(9) Tritium and deuterium analyses on marine clays (interstitial water) and the surrounding groundwater should be used to study the relationship between sensitivity, salinity, and permeability.

CITED REFERENCES

A.S.T.M.
1970: Special Procedures for Testing Soil and Rock for Engineering Purposes. A.S.T.M., STP479, 5th Ed., 630 p.

ANDREWS, J.T.
1970: A Geomorphological Study of Postglacial Uplift with Particular Reference to Arctic Canada. Inst. Brit. Geogr., London, Spec. Publ. 2, 156 p.

ANTEVS, E.
1939: Late Quaternary Upwarping of Northeastern North America. Jour. Geol., 47: 707-720.

BALLINY, G.
1970: Contributions à l'Etude des Caractéristiques Géologiques et Géotechnique des Dépôts d'Argile du Nord-Ouest du Québec (Région de Matagami-Rupert). M.Sc. A. thesis, Ecole Polytechnique, Montréal, published by the Hydro-Québec, Montréal, Qué., 222 p.

BARBAROUX, L., CHAUVAUX, M., MOREL, Y., and OTTMAN, F.
1971: Quelques Applications de la Lyophilisation à l'Etude des Sediments Meubles ou en Suspension en Lames Minces ou au Microscope Electronique. Rev. Géogr. Phys. et de Géol. Dyn., XII, fasc. 4: 369-378.

BARTLETT, G.A., and MOLINSKI, L.
1972: Foraminifera and the Holocene History of the Gulf of St. Lawrence. Can. Jour. Earth Sci., 9: 1204-1215.

BELAND, J.
1960: Région de Rimouski-Matapedia. Qué. Min. Nat. Res., R.P. 430, 20 p.

BELL, R.
1863: On the Surficial Geology of the Gaspé Peninsula. Canadian Naturalist, VIII: 175-183.

BOUSFIELD, E.L.
1964: Shells. Natl. Museum Can., 89 p.

BOZOZUK, M.
1971: Effect of Sampling, Size and Storage on Test Results for Marine Clays. Am. Soc. Test. Mat., Sp. Tech. Publ., 483: 121-131.

BROWN, R.H., KONOPLYANTSEV, A.A., and KOVAKVSKY, V.S.
1972: Groundwater Studies: An International Guide for Research and Practice. UNESCO, Studies and Reports in Hydrology, no. 7, sec. 10: 1-18.

CHAGNON, J.Y.

1968: Les Coulées d'Argiles dans la Province de Québec. Naturaliste Canadien, 95: 1327-1343.

1969: Etude des Phénomènes d'Erosion et des Dépôts de Surface dans la Région de Baie St. Paul/St. Urbain. Qué. Min. Nat. Res., E.S. 3.

CHALMERS, R.

1894: Report on the Surface Geology of Eastern New Brunswick, Northwestern Nova Scotia, and Portion of Prince-Edouard Island. Geol. Surv. Can., Ann. Rept., VII, Rept. M, 149 p.

1897: Report on the Surface Geology and Auriferous Deposits of Southeastern Québec. Geol. Surv. Can., Ann. Rept., X, Rept. J, 160 p.

1904: Surface Geology of Eastern Québec. Geol. Surv. Can., Ann. Rept., XVI, Rept. A: 250-263.

COLEMAN, A.P.

1922: Physiography and Glacial Geology of Gaspé Peninsula, Qué. Geol. Surv. Can., Bull. 34, 52 p.

CONLON, R.J.

1966: Landslide on the Toulnustouc River, Québec. Can. Geotech. Jour., 3: 113-144.

CRAWFORD, C.B.

1968: Quick-Clays of Eastern Canada. Engineering Geology, 4: 239-265.

CURRAY, J.R.

1965: Late Quaternary History, Continental Shelves of the United States. In: Quaternary of the United States. Edited by H.E. Wright Jr., and D.C. Frey. p. 723-735.

DASCAL, O., and LAROCQUE, G.S.

1973: Caractéristique de Compressibilité des Argiles du Complexe Nottaway-Broadback-Rupert (Baie James). Can. Geotech. Jour., 10: 41-63.

DE LA RUE, A.E.

1941: Région du Lac Matapedia. Qué. Min. Nat. Res., R.G. 9, 46 p.

DE LORY, F.A., and SALVAS, R.J.

1967: An Investigation of Discrepancies in Undrained Shearing Strength Test Results in Clay. Ont. Joint Programme, D.H.O., Rept. 45, 63 p.

DION, D.J., and LOCAT, J.

1976: Cartes d'Aptitudes, et Propriétés Géotechniques des Dépôts Meubles de la Région de Rivière du Loup/St. Joachin de Tourelle. Qué. Min. Nat'l. Res., Service de Géotechnique, in preparation.

DIONNE, J.C.
1963: Le Problème de la Terrasse et de la Falaise Mic-Mac. Rev. Can. Geogr., 17: 9-25.

1966: Le Delta Fini-glaciaire de la Trois Pistoles. In: Atlas du Bas St. Laurent, Gaspésie, Iles de la Madeleine, Québec. Edited by Province of Québec.

1968a: Morphologie et Sédimentologie Glacielle, Littorale du St. Laurent. Zeitsch. f. Geomorph. Suplbd. no. 7: 56-84.

1968b: Action of Shore Ice on the Tidal Flats of the St. Lawrence Estuary. Maritime Sediments, 4: 113-115.

1968c: Carte Morphosédimentologique de la Région des Trois-Pistoles. Rev. Géogr. Montréal, XXII: 55-64.

1969: Note sur un éboulement à St. Fabien-sur-Mer, Côte sud du St. Laurent. Rev. Géogr. Montréal, XXIII: 365-368.

1970: Aspects Morphosédimentologiques du Glaciel, en Particulier des Côtes du St. Laurent. Paris, Université de Paris, Doct. Thesis, 412 p.

1971: Nature Lithologique des Galets des Formations Meubles Quaternaires de la Région de Rivière-du-Loup/Trois-Pistoles, Québec. Rev. Géogr. Montréal, XXV: 129-142.

1972a: Le Quaternaire de la Région de Rivière-du-Loup/Trois-Pistoles, Côte Sud de l'Estuaire du St. Laurent. Centr. Rech. Forest. Laur., Québec, Rap. Inf. Q-F-X-27, 95 p.

1972b: Etude Morphométrique des Galets des Formations Meubles Quaternaires de la Région de Rivière-du-Loup/Trois-Pistoles, Québec. Rev. Géogr. Montréal, XXVII: 139-156.

DREDGE, L.
1975: Surficial Geology, Sept Iles - Cap Chat. Geol. Surv. Can., Paper 75-1-A: 401.

DREIMANIS, A.
1962: Quantitative Gasometric Determination of Calcite and Dolomite by using Chittick Apparatus. Jour. Sed. Petrology 32: 520-529.

DRESSER, J.A.
1912: Reconnaissance along the National Transcontinental Railway in Southern Canada. Geol. Surv. Can., Memoir 35, 42 p.

DRESSER, J.A., and DENIS, T.C.
1944: Geology of Québec, Vol. II, Descriptive Geology. Qué. Min. Nat. Res., R.G. 20.

DUBOIS, J.M.
1975: Le Quaternaire de la Côte Nord de l'Estuaire Maritime du St. Laurent. Geol. Surv. Can., Paper 75-1: 403-405.

EDEN, W.J., and KUBOTA, J.K.
1961: Some Observations on the Measurements of Sensitivity of Clays. Proc. Am. Soc. Test. Mat., 61: 1239-1249.

ELSON, J.A.
1969: Late Quaternary Marine Submergence of Québec. Rev. Geogr. Montreal, XXIII: 247-258.

FOLK, R.L.
1968: Petrology of Sedimentary Rocks. Hemphill's ed., Austin, Texas, 169 p.

GADD, N.R.
1971: Pleistocene Geology of the Central St. Lawrence Lowlands. Geol. Surv. Can., Memoir 359, 153 p.

1972: Marine Deposits, Gatineau Valley, Québec. Geol. Surv. Can., Paper 72-1: 156-157.

GAGNON, R.M.
1970: Climat des Chic-Chocs. Qué. Min. Nat. Res., M.P. 36, 103 p.

GAUTHIER, C.
1975: The Reversal of Glacial Movement During the Deglaciation of the Chaudière River Region, Québec. Abs. 28th Ann. Meeting, Geol. Ass. Can., p. 760.

GAUTHIER, R.
1971: Etude de Cinq Tourbières du Bas St. Laurent, I: Ecologie, II: Tourbe Litière. Qué. Min. Nat. Res., E.S. 10, 25 p.

GILLOT, J.E.
1970: Fabric of Leda Clay Investigated by Optical, Electron-Optical, and X-ray Diffraction Methods. Engineering Geology 4: 133-153.

1971: Mineralogy of Leda Clay. Mineralogist 5: 797-811.

GOLDTHWAIT, J.W.
1913: The Post-glacial Marine Submergence. 12th Int. Geol. Conf., Guidebook No. 1, part 1, Geol. Surv. Can. 16, 66: 77-79.

GRAVEL, J.Y.
1974: Minéralogie de l'Argile Champlain de St. Jean Vianney. Université Laval, unpublished M.Sc. thesis, 42 p.

GRIM, R.E.
1968: Clay Mineralogy. Second Edition, McGraw-Hill Co., New York, 596 p.

HILAIRE-MARCEL, C., PRICHONNET, G., and DE BOUTRAY, B.
1974: Les Facies du Pléistocene Marin des Colines d'Oka, Québec. Naturaliste Canadien, 101: 781-802.

HOEK, E., and BRAY, J.W.
1974: Rock Slope Engineering. Inst. of Min. Metall., London, 309 p.

JORDAN, F., and DE LA RONDE, M.S.
1974: T-S Observations in the St. Lawrence System from Goose Cap to Scotian Shelf, 10 May - 23 May, 1973. Bedford Inst. of Oceangr., BI-D-74-4, 65 p.

KARROW, P.F.
1972: Earthflows in the Grondines and Trois Rivières Areas, Québec. Can. Jour. Earth Sci., 9: 561-573.

KERR, P.G.
1963: Quick-Clay. Scientific American, 209: 132-142.

LADANY, B., and EDEN, W.J.
1969: Use of Deep Penetration Test in Sensitive Clay. Proc. 7th Int. Conf. Soil Mech. Found. Eng., Mexico, Session One: 225-230.

LAFLEUR, J., and LEFEBRE, G.
1975: Synthèse des Données pour le Glissement de Terrain de St. Urbain, Cté de Charlevoix, Rapport l'Université de Sherbrooke, March, 1975, 28 p.

LAJOIE, J.
1971: Région des Lacs Prime et des Baies. Qué. Min. Nat. Res., R.G., 139, 85 p.

LAMB, T.W.
1951: Soil Testing for Engineers. John Wiley & Sons Inc., New York.

LAMB, T.W., and WHITMAN, R.V.
1969: Soil Mechanics. John Wiley & Sons Inc., New York, 533 p.

LASALLE, P.
1972: Interglacial Sediments in the Québec city area. 24th I.G.C., Abstracts: 372-373.

LEBUIS, J.
1973a: Géologie du Quaternaire de la Région de Cap Chat, Comtés de Gaspé-Nord, Matane, et de Matapédia. Qué. Min. Nat. Res., G.M. 28584, 11 p.

1973b: Géologie du Quaternaire de la Région de Matane-Amqui, Comtés de Matane et Matapédia. Qué. Min. Nat. Res., D.P., 216, 18 p.

LEBUIS, J., and DAVID, P.P.
1972: Région de Courcelette-Tourelle, Comtés de Gaspé-Nord et de Matane (Géologie du Quaternaire). Qué. Min. Nat. Res., G.M. 27623, 25 p.

LEE, H.A.
1962: Surficial Geology of Rivière-du-Loup/Trois-Pistoles Area, Québec. Geol. Surv. Can., Paper 61-32, 2 p.

LEFEBRE, G., and LAROCHELLE, P.
1974: The Analysis of Two Slope Failures in Cemented Champlain Clays. Can. Jour. Earth Sci., 11: 89-108.

LIARD, P.
1972: Géologie de la Région de Mont-Joli/Matane. Qué. Min. Nat. Res., D.P., 202, 7 p.

LIBBY, W.F.
1952: Radiocarbon Dating. University of Chicago Press, 175 p.

LIEBLING, R.S., and KERR, P.F.
1965: Observations on Quick-Clays. Geol. Soc. Am. Bull., 76: 853-878.

LORING, D.H., and NOTA, D.J.G.
1973: Morphology and Sediments of the Gulf of St. Lawrence. Bulletin of the Fisheries Research Board of Canada, no. 182, 147 p.

LORTIE, G.
1975: Direction d'écoulement des Glaciers du Pléistocene des Cantons de l'Est du Québec. Geol. Surv. Can., Paper 75-1-A: 415-416.

MATYAS, E.L.
1964a: Landslide at St. Joachin-de-Tourelle, Québec. Nat. Res. Council of Can., Div. Build. Res., unpublished Spec. Report No. 191, 4 p.

1964b: Analysis of the Landslides at St. Joachin-de-Tourelle. Nat. Res. Council of Can., Div. Build. Res., unpublished Spec. Report No. 193, 5 p.

McKYES, E., SETHI, A., and YONG, R.N.
1974: Amorphous Coating on Particles of Sensitive Clay Soils. Clays and Clay Minerals, 22: 427-433.

MERCIER, H., and ZEMGALS, L.K.
1965: Evaluation de Vingt Echantillons d'Argile Provenant du Comté de Rivière-du-Loup, Qué. Min. Energy Mines and Res. Can., Mines Branch, unpublished, MPT-65-10, 11 p.

MEYERHOF, C.G.
1953: Field Investigations of the Earthflow at Rimouski. 7th Can. Soil Mech. Conf. Proc.: 40-45.

1957: The Mechanics of Flow Slides on Cohesive Soils. Géotechnique, 7: 41-49.

MILLIMAN, J.D., and EMERY, K.O.
1968: Sea Levels During the Past 35,000 Years. Science, 162: 1121-1122.

MITCHELL, J.K.
1956: The Fabric of Natural Clays and its Relation to Engineering Properties. Proc. Highway Res. Board, 35: 693-713.

MITCHELL, R.J., and MARKELL, A.R.
1974: Flowslides in Sensitive Soils. Can. Geotech. Jour., 11: 11-31

MUKHERJI, K.K.
1972: Preliminary Report on Ste. Blandine (west and east half) Area, Rimouski-Matapédia County, Qué. Qué. Min. Nat. Res., D.P., 196, 15 p.

NOTA, D.J.G., and LORING, D.H.
1964: Recent Depositional Conditions in the St. Lawrence Estuary and Gulf - A Reconnaissance Survey. Marine Geol., 2: 198-235.

PENNER, E.
1965: A Study of Sensitivity in Leda Clay. Can. Jour. Earth Sci., 2: 425-441.

PREST, V.K.
1970: Quaternary Geology of Canada. In: Geology and Economic Minerals of Canada. Geol. Surv. Can., Rept. 1, Chapter XII: 676-764.

PUSCH, R.
1966a: Investigation of Clay Microstructure by using Ultra-Thin Sections. Statens Geotekniska Institut, Stockholm, 15, 6 p.

1966b: Quick-Clay Microstructure. Engineering Geology, 1: 433-444.

QUIGLEY, R.M., and THOMPSON, C.D.
1966: The Fabric of Anistropically Consolidated Sensitive Marine Clay. Can. Geotech. Jour., 2: 61-73.

REDFIELD, A.C.
1967: Postglacial Changes in Sea Level in the Western North Atlantic Ocean. Science, 157: 687-692.

ROSENQUIST, I.Th.
1952: Consideration on the Sensitivity of Norwegian Quick-Clays. Geotechnique, 3: 195-200.

1966: Norwegian Research into the Properties of Quick-Clays - A Review. Engineering Geology, 1: 445-450.

SOBOTKA, G.
1974: Contribution à l'Etude des Argiles de la Mer Champlain, Bécancour, Québec. Qué. Min. Nat. Res., and Centre de Géologie de l'Ingénieur de l'Ecole Nationale des Mines, Research Rept., unpublished, 50 p.

TAVENAS, F., CHAGNON, J.Y., and LAROCHELLE, P.
1971: The St. Jean Vianney Landslide: Observations and Eye-witness Accounts. Can. Geotech. Jour., 7: 463-478.

TECHNISOL INC.
1974: Forages. Qué. Min. Nat. Res., N/D 443.

TEN BRINK, N.W.
1974: Glacio-Isostasy: New Data from West Greenland, and Geophysical Implications. Geol. Soc. Am. Bull., 85: 219-228.

TREMBLAY, G.
1974: Géologie des Dépôts de Surface de la Région de Sept-Iles/Port-Cartier, Québec. Qué. Min. Nat. Res., open file, D.P. 304.

WAGNER, F.J.E.
1962: Report on Shells from Riviere du Loup/Trois Pistoles Area, Que. Collected by H.A. Lee, 1961. Geol. Surv. Can., Fossil Report Pl: 1-63.

1970: Faunas of the Pleistocene Champlain Sea. Geol. Surv. Can., Bull. 181, 104 p.

1975: Report on Fossils from the Trois-Pistoles/Matane Area, Québec. Submitted by J. Locat, January 1975. Unpublished Report, AGC-Pl-2-1975, 4 p.

WALCOTT, R.I.
1972a: Past Sea Levels, Eustasy and Deformation of the Earth. Quat. Res., 2: 1-14.

1972b: Late Quaternary Vertical Movements in Eastern North America: Quantitative Evidence of Glacio-Isostatic Rebound. Rev. Geoph. Space Phys., 10: 849-884.

APPENDIX A

GEOLOGICAL MAPS

The following National Topographic sheets were completely or partly covered during the summer of 1974:

22B/13W : completed
22B/12W : parts
22C/9E-W: completed
22C/8E-W: parts
22C/7E-W: parts
22C/6E : completed
22C/3E : parts
22C/2E-W: parts

The geological maps were grouped by sets of two when it was possible to do so. For example, 22C/9E and 22C/8E were put together.

The following diagram (p. 165) is the legend that refers to geological maps. Some maps enclosed here do not show the longitudes since they were cut to be placed together. The present maps are still preliminary.

MAP UNIT	DESCRIPTION
13	Sediments related to mass wasting, but only including landslides, zones of active erosion, and rock avalanches.
12 12A	Organic deposits (map unit 12) and peat bogs (12A) consisting mainly of plant debris.
11	Colluvium and valley-bottom silt consisting of fine to coarse material.
10	Alluvial sediments, similar to fluvial sediments (map unit 9), but originating from flooding by present-day streams. It consists of stratified fine to coarse material including plant debris.
9 9A 9B	Fluvial sediments made of stratified silt, sand, and gravel, forming terraces (map unit 9) and deltas (9A) above present-day streams. It also includes a unit of fluvio-lacustrine sediments (9B) mapped only in the Neigette Valley area (22C/8W, 22C/7E).
8	Littoral sediments consisting of fossiliferous and stratified silt, sand and gravel, commonly forming marine terraces. This sediment shows abandonned beach lines which are well developed near river outlets.
7	Undifferentiated Goldthwait Sea clays (silty clay, in places, interbedded with sand), in places, very fossiliferous. This unit includes a stony and massive clay (glacio-marine and massive clays).
6	Glacio-lacustrine sediments, mainly consisting of stratified (banded) fine sand and silt (rare in the map area).
5 5A	Glaciofluvial stratified sand and gravel found in discontinuous terraces (map unit 5) and forming the highest deltas (5A).
4 4A	Ice contact sand and gravel, poorly stratified and showing glacio-tectonic deformations (map unit 4). This unit also includes eskers (4A) consisting of poorly to well stratified sand and gravel.
3	Ablation till associated with ice contact sediments (map unit 4) consisting of unstratified to poorly stratified sand, gravel, and blocks.
2	Undifferentiated till including a thin oxidized silty and sandy till with boulders, and a grey (unoxidized) till consisting of reworked marine sediments (found only along the coast).
1	Bedrock and thin oxidized till (less than 0.9 metres), the bedrock consists of shales, slates, limestones, sandstones, conglomerates, and volcanic rocks.

SCALE; 1 : 50,000

APPENDIX B

SITE DESCRIPTIONS

B-1 C^{14} Dating Sites

Site D3 (QU-261), near Price, is in littoral sands and gravels below the Price delta (76 m a.s.l.). The fossils were at 62 metres above sea level in a gravelly sand layer. The surface of this site is at 64 metres above sea level. Mytilus edulis is the dominant species but is mixed with Macoma balthica, Hiatella arctica, Mytilus edulis, Balanus sp., and Mya arenaria. The author estimates that the sea level represented by these fossils is somewhere between 62 and 76 metres above present sea level. The shorelines at this site are very well-defined, and disappear at 70 metres, which is suggested as the possible marine limit at the time these shells were living.

Site D4 (QU-262) is located about 1.5 km to the west of Mont-Joli. Shells were collected in coarse sand overlain by oxidized fine sand. At this site, the littoral sediments form a terrace in which the section was cut. Only two species were noted: Mytilus edulis and Balanus sp. (only one piece). Most of the Mytilus edulis were fresh in this very recently exposed section (open for less than two months) and were collected for C^{14} dating. The shell locations were surveyed at 75 metres a.s.l. and are believed to correspond to a maximum of 75 m (cf. Price delta about 7 km east).

Date QU-263 comes from site D5 west of St. Anaclet at 82 metres a.s.l.. Fossils were observed and collected in a fiarly fresh ditch (V-shape, no vegetation). They were found in a clayey sand (grey) overlain by a thin deposit of littoral fine to medium sand. Many species were collected (D5, Table 5) and the C^{14} date was obtained for Mya sp.. At D5 the elevation is

82 metres above sea level. These sediments may be closely related to the St. Anaclet delta to the south (125 m a.s.l.). The level of 105 m above sea level was chosen as the sea level represented on the basis of the highest littoral deposits surrounding the sites.

The St. Donat fossil locality (D6) was also chosen for C^{14} dating (QU-264). Shells are of Hiatella arctica, Mya truncata and Balanus hameri. Most of the bivalves were well-preserved and Balanus basal plates were found on a few pebbles and cobbles. Shells could be traced at least 100 metres upstream. Shells were found in a marine clay grading upward into lacustrine varved sediments (48 couplets:48 years), in turn overlain by fluvial sand and gravel. The marine silty clay, the lacustrine, and the fluvial sediments dip toward St. Donat (Neigette Valley). At this site, a bedrock outcrop of shale was buried by this very fossiliferous clay. The shells were taken at a level of 88 metres a.s.l.. Because other shells could be observed upstream for simplicity an elevation of 90 metres was given. A date of 13,360 ± 320 C^{14} y.B.P. was obtained on shells of Hiatella arctica. About 2 km from our site, Dionne (1972a) has a date of 12,000 ± 160 C^{14} y.B.P. (G.S.C. 1186) for Hiatella arctica sampled at 98 metres above sea level.

Our site was in the streambank beside the narrow paved road which crosses the stream about 4 metres upstream. Contamination might be expected from either the stream or the paved road (a source of dead carbon) even in shells collected deeply enough on the stream bank (about 0.5 m). The date for QU-264 is close to the time of deglaciation about 13,500 y.B.P. (Elson, 1969) for the Rivière-du-Loup/Trois-Pistoles area. Elson (1969) dated the marine limit (166 m) near Trois-Pistoles with a date of 12,720 ± 170 C^{14} y.B.P. (G.S.C. 102) at 98.5 metres above sea level. Therefore, if our date

(QU-264) also marked the time of the marine limit in the Luceville/St. Donat area, it must be related to the Luceville delta at 126 metres above sea level.

The site for QU-265 (D9) is located near the village of Baie-des-Sables on the Ste. Flavie terrace. The shells of Mesodesma arctica were taken from littoral sediments made of gravelly sand at a level of 4 metres a.s.l.. We were interested in this fossil locality for C^{14} dating because the species encountered has never been found in higher deposits, so that we could not expect these shells to have been reworked from higher levels. At this site, about 50% of the shells were broken but we only used the unbroken valves for C^{14} dating. The date of 2240 ± 140 C^{14} y.B.P. correlates well with results obtained by Lebuis on the Ste. Flavie terrace near Matane with dates around 2,000 years (Lebuis, personal communication).

QU-266 (D8, 10,400 ± 320 C^{14} y.B.P.) is situated about 3 km to the southwest of Luceville. Shells of Mytilus edulis were collected from a gravel pit in littoral sediments at 70 metres above sea level. The gravel pit extends about 50 m into the marine terrace, at this site. Other species such as Macoma balthica and Balanus sp. were also noted. The terrace itself lies at about 73 metres and is taken for the highest sea level when the shells were alive.

QU-267 (D11, 11,590 ± 430 C^{14} y.B.). came from shells taken near Grand Métis (22C/9E) about 10 km east of Mont-Joli, on the Bic terrace at an altitude of 30 metres a.s.l.. The site sampled is near the southeast edge of the old channel. The only species that had unbroken valves was Macoma balthica.

Gastropods and Mya sp. were also sampled. The date was obtained from mixed species and might indicate reworking of higher deposits; this is also suggested by the location of the site within the old channel which was an erosion zone. The maximum sea level given to this site is about 53 metres, which corresponds to adjacent shorelines. However, the site is located on a cultivated field and shells were collected only about 30 cm below the ground surface. The shells could be contaminated either by humic acid, carbonate fertilizers, or both.

The site for QU-268 (D12) is located near the village of St. Octave-de-Métis. The shells of Mytilus edulis were taken from littoral sediments made of medium sand to medium gravel at an elevation of 61.6 metres a.s.l., in a gravel pit. The shells were not found in living position, but they were hard and about 4.0 cm long. Only debris of Balanus sp. and Macoma balthica were observed. The top of the section is about 2.4 metres above the fossiliferous layer and is the crest of a raised beach. No contamination could be observed. The elevations at this site were levelled with a theodolite.

The site for QU-270 and QU-271 (D18, 12,300 ± 260 and 13,390 ± 690 C^{14} y.B.P.) is located near the village of St. Fabien. A fossiliferous till inclusion was found within ice-contact sediments in the St. Fabien delta at an altitude of 138 metres a.s.l.. The delta reaches a maximum elevation of 155 metres a.s.l.; this is taken as the maximum sea level corresponding to this site. Shells collected were found broken, unbroken, and occasionally with paired valves. Mixed species of Hiatella arctica, Balanus hameri, Macoma balthica, and Mya arenaria were used for QU-270, and only Hiatella arctica for QU-271. This site is one of the most important, since it is the highest Quaternary marine macrofossil locality ever found in the Gaspé.

Other site descriptions, from previous workers, can be found in their publications. The author determined the upper sea level for the following dates: G.S.C. 1186 and G.S.C. 1216 (Dionne, 1972a). "GS" date is from the

Rivière-du-Loup area, about 120 km west of Mont-Joli (Walcott, 1972b), but is not shown on the emergence curve because it is too far west.

The date of 9450 ± 140 C^{14} y.B.P. (G.S.C. 1216) obtained by Dionne (1972a) near Bic at 14 metres a.s.l., was also referred to a higher sea level of about 30 metres, which corresponds to our field observations in the Bic area.

The date of 12,000 ± 160 C^{14} y.B.P. (G.S.C. 1186) (Dionne, 1972a) was discussed earlier and is associated with a marine limit close to the one obtained for QU-263 (D5).

B-2 Geotechnical Sites

The St. Joachin de Tourelle Site

This site covers both sides of Tourelle Creek (Fig. 59) at its outlet into the Gulf of St. Lawrence.

In May, 1963 a small earthflow occurred on the west bank of the Tourelle Creek (Fig. 60), followed by a larger one on December 11, 1963. Data on the landslide site were published by Matyas (1964a,b) and Gillot (1970, 1971).

The aim of the present study was to sample the marine deposits and also to look at the relation between the extent of the earthflow and the bedrock topography.

The Quaternary geology map for this region was prepared by Lebuis and David (1972). The local distribution of the surficial sediments (Fig. 59) suggests that the marine silty clay (unit 3, not shown in Fig. 59) is overlain by littoral sand and gravel (unit 4). The bedrock (unit 1A) outcrops a few tens of metres to the northeast of the earthflow scar. Lebuis and David (1972) indicated that littoral sand and gravel usually dip at 5 to 11° but dips could be as high as 23° when close to a bedrock escarpment.

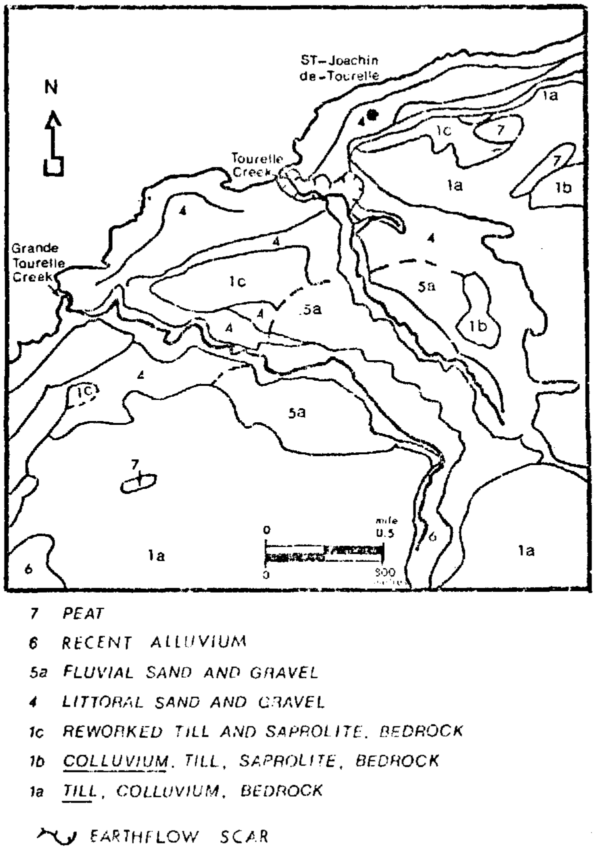


Figure 59. Quaternary Geology (surficial map) near St-Joachin-de-Tourelle (from Lebuis and David, 1972).

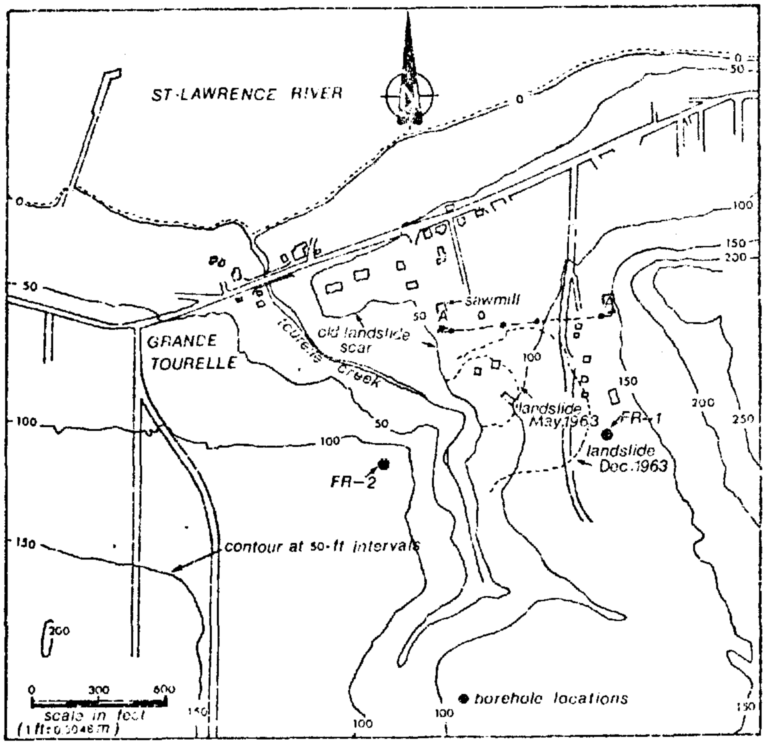


Figure 60. The St-Joachin-de-Tourelle site (modified from Matyas, 1964a).

Two test holes (FR 1, FR-2) were drilled and a few seismic lines were run at the site. Few samples of the marine silt could be taken owing to the low cohesion of the silt (as was pointed out also by Matyas, 1964a).

The Ste. Anne-Des-Monts and Cap Chat Sites

Ste. Anne-des-Monts and Cap Chat towns are 10 km apart on the south shore of the St. Lawrence River (Fig. 61). Ste. Anne-des-Monts (to be referred to as Ste. Anne) site is located along fluvial terraces of both the Petite Ste. Anne (FR-3) and Ste. Anne (FR-3, F-1) Rivers. The Cap Chat site (F-2) is on an extensive marine terrace on which is situated the town of Cap Chat (Fig. 61).

For these sites particular attention was paid to the relationship of prominent terrace scarps and adjacent buildings. At the location FR-3 a bank failure occurred in July 1974, and thus it was decided to core this marine clay on the east side of the Ste. Anne River.

The Quaternary geology of this district (Fig. 61) has been described by Lebuis (1973a). At FR-3, a thin fluvial deposit is underlain by marine clay. At FR-4, the clay is overlain by fluvial sand and gravel and is underlain by fluvial and finally glacio-fluvial sand and gravel. At F-1 the marine clay was overlain by littoral and then fluvial sand and gravel; the marine clay was underlain by alternating layers of silty sand and silty clay. The bedding suggested the possibility that these are lacustrine deposits which is consistent with the description by Lebuis and David (1972) of interdigitation between marine clay and lacustrine sediments in the Ste. Anne River valley.

The location of field investigations consisting of deep drilling and seismic lines is given in Figure 61. The deep penetrometer was tried without success, due to the stiff and unsaturated nature of the clay.

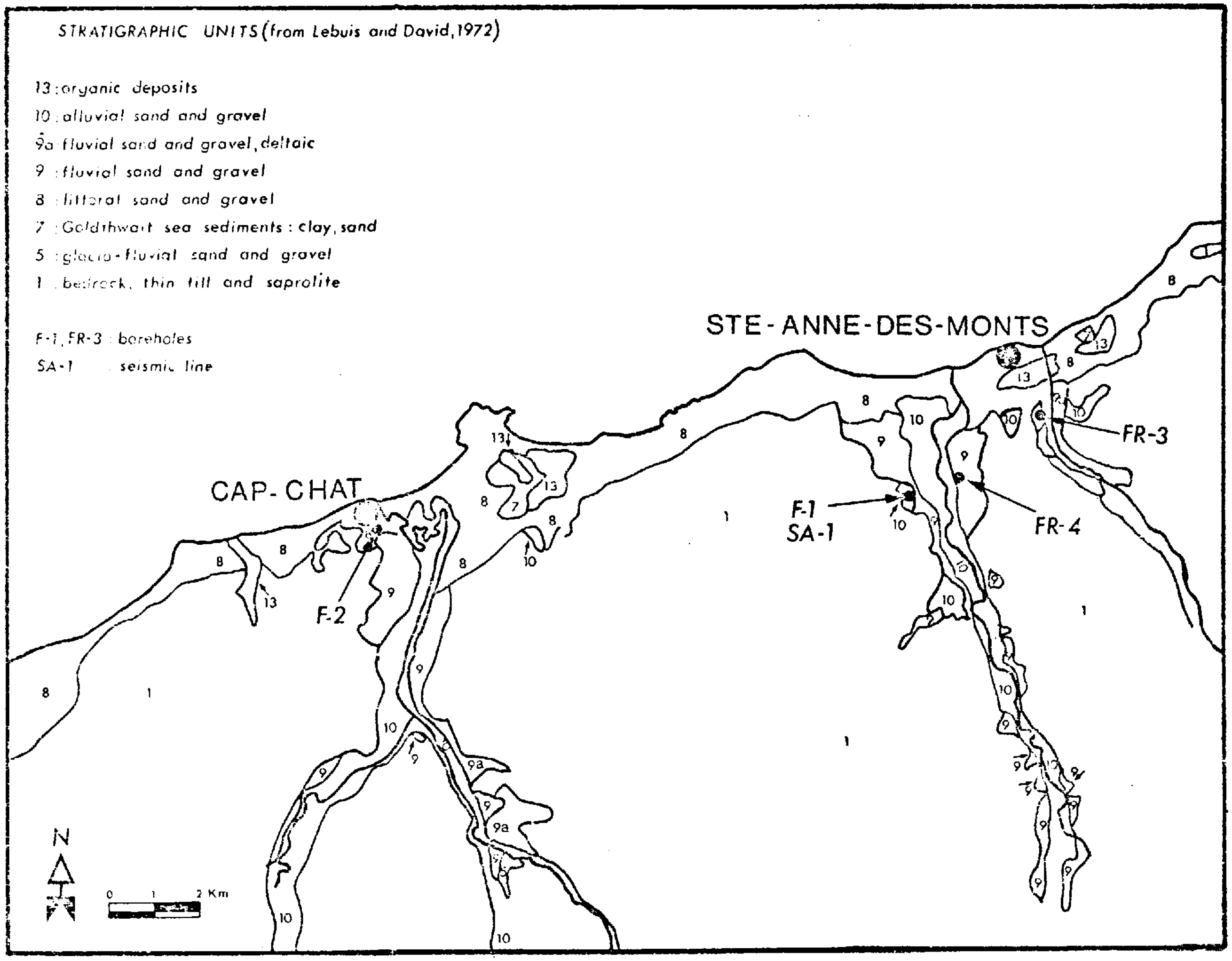


Figure. 61. Surficial deposits near Cap-Chat and Ste. Anne des Monts (from Lebuis and David, 1972)

The Matane Site

The Matane site (Fig. 62) is located at the outlet of the Matane River. The research was mostly concentrated on the east shore of the river in the zone surrounding the Matane Hospital. This site also includes parts of fluvial terraces about 1.5 km upstream from the hospital on the west bank of the Matane River.

Few reports on geotechnical investigations were available for the zone opposite the hospital, on the south shore. At this site, the soil properties surrounding the hospital (F-3) and also to the southeast (FR-5, Fig. 62) were of interest. The town of Matane has chosen this zone for urban development in the next few years.

The regional Quaternary geology is given in Figure 63 from Lebuis (1973b). It shows that the site is located on a marine terrace where the littoral sediments are underlain by marine clays and fluvial sand and gravel (F-3). This terrace is bordered on the west by the Matane River and on the east by an old channel of the river. Upstream, fluvial and glacio-fluvial sand and gravel are occasionally separated by marine clay.

The location of field investigations is shown in Fig. 62 including the site of three boreholes (F-3, 4, 1), penetrometer holes and several seismic lines. The site studied for the geomorphology of the marine terrace is still indicated in Figure 14.

The Grand Métis Site

The Grand Métis site is located about 10 km east of Mont-Joli. The area covered by the investigation lies along a small stream cutting into the marine terrace (Fig. 64).

The area was mapped before the geotechnical investigation. Marine clays were found laterally overlain by littoral sediments (22C/9E, App. A).

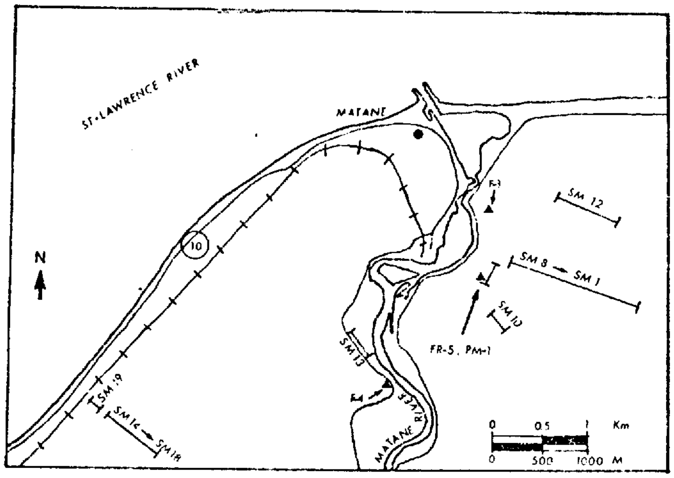


Figure 62. The Matane site

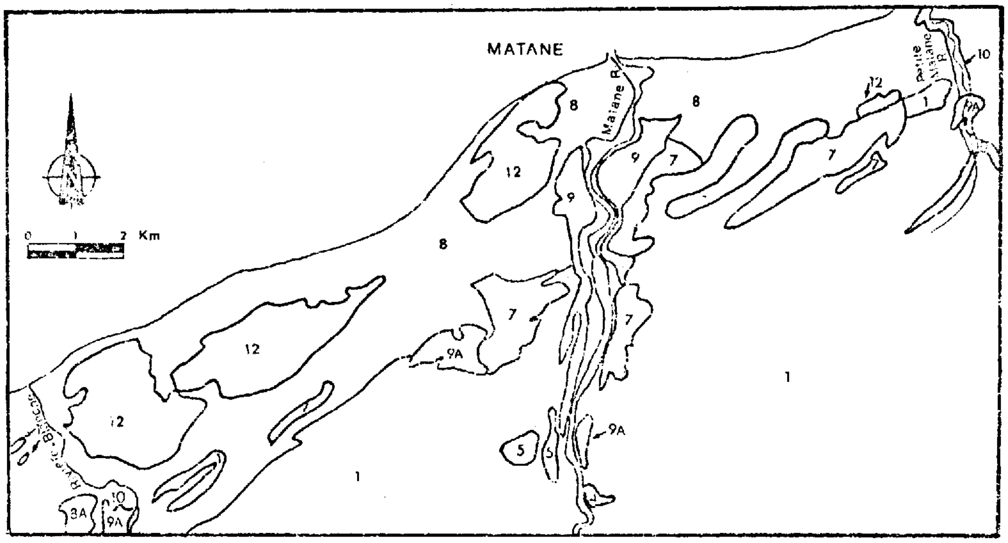


Figure 63. Surficial deposits near Matane (from Lebuis, 1973b)

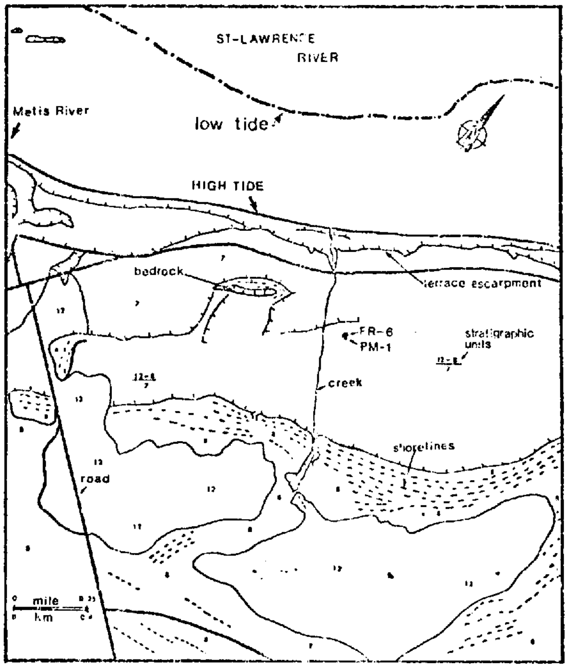


Figure 64. The Grand Metis site (see Appendix A for geological units).

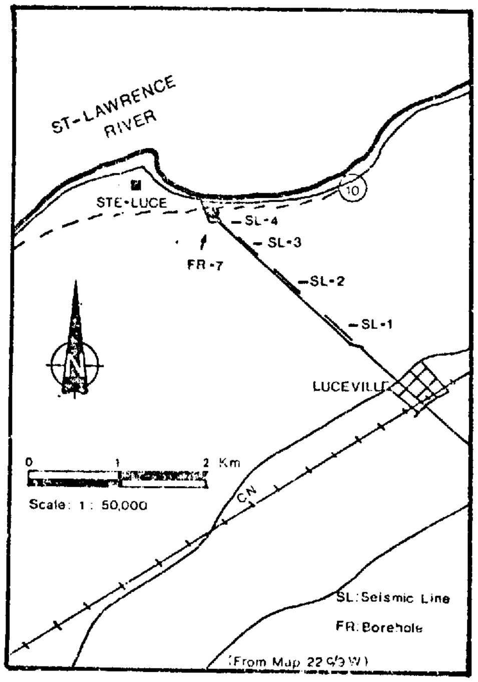


Figure 65. The Ste-Luce site.

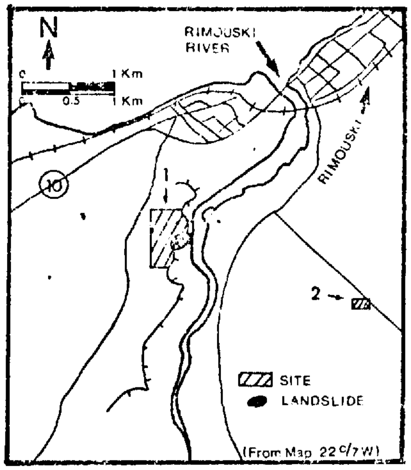


Figure 66. The Rimouski site

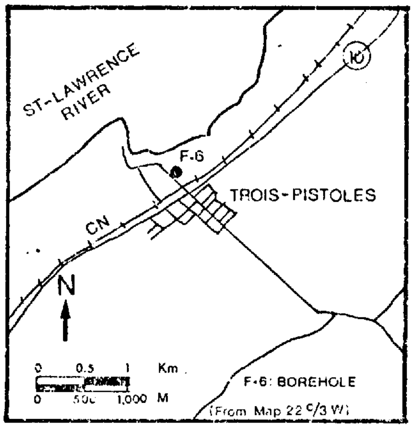


Figure 67. The Trois-Pistoles site.

Many Precambrian boulders were found at this site resting on the marine clay or within organic deposits overlying the clay. A high terrace escarpment with a local relief of 27 metres extends along the St. Lawrence Estuary. This escarpment consists of marine clay as described in Figure 23. More attention was given to the stream deeply eroding the edge of the terrace, causing important bank failures. The study at this site also included work to establish the bedrock topography underneath the marine clay. However, detailed locations of the seismic lines are not available at the time of writing.

The locations of the field investigations are shown in Fig. 64. Many problems were encountered in sampling the marine clay. For example, many Shelby tubes were damaged by the presence of numerous cobbles and pebbles. Four penetrometer testholes and several seismic lines will supplement data from the drilling.

The Ste. Luce Site

The Ste. Luce site is located northeast of the intersection of Highway 10 and the Luceville Road near Ste. Luce-sur-Mer. This village is situated along the St. Lawrence Estuary about 15 km east of Rimouski (Fig. 65).

The Quaternary geology, as shown in Appendix A (22C/9W) is similar to the Grand Métis site. The bedrock outcrops only along the shore for a few hundred metres on both sides of the site. The marine terrace is underlain mostly by reddish clay, overlain either by littoral sediments, or peat, or both, which include Precambrian boulders. Furthermore, at the Ste. Luce site, the local relief is the same as at Grand Métis, i.e., about 26 metres. However, the organic deposit found about 1.5 km to the SE is thicker, and the old estuary channel is very well-defined.

Field investigations are indicated on Figure 65 and include one borehole (FR-7), three penetrometer testholes (P), and a seismic line along the Montée-de-Luceville. Many good samples were taken with a recovery usually around 60%.

The Rimouski Site

The Rimouski site (Fig. 66) is at the site of an earthflow on the west side of the Rimouski River, about 2 km upstream from its outlet. This zone is heavily exploited for sand and gravel and is also used as a waste disposal area.

Meyerhof (1953) studied the Rimouski landslide. However, little had been done on the geology of the site. Therefore, our investigation produced a detailed map of the bedrock and the Quaternary sediments. The engineering properties of the marine clay at this site also needed elaboration. More information is given in Chapter IV on the Rimouski landslide.

The surficial mapping, as shown on sheet 22C/7E (App. A) indicates that the marine clay is either overlain by littoral or fluvial sand and gravel. This site is surrounded by fluvial and marine terraces with their surfaces broken here and there by bedrock outcrops.

This site was the most intensively investigated as shown (Fig. 51) by the number of boreholes (F5, FR-8, FR-9), of penetrometer testholes (PR-3, PR-4, PR-5, and 6) and of seismic lines (SR-1 to SR-11).

The description of the stratigraphy is shown in Fig. 53 in Chapter IV.

The Trois-Pistoles Site

The Trois-Pistoles site, at the edge of the town of Trois-Pistoles, is the westernmost site. It is located at the northwest end of the town (Fig. 67).

The site is located on the Bic terrace near the Ste. Flavie bluff, which has a local height of 20 metres.

The Quaternary geology of this site was studied by Lee (1962) and is given on sheet 22C/2E (App. A). The marine clays are overlain by littoral sand and gravel with the bedrock outcropping nearby at sea level.

Only one borehole (F-6) was put down at this site (Fig. 67).

APPENDIX C

LABORATORY ANALYSES AND RESULTS

Water Content and Atterberg Limits

The water content and Atterberg Limits were determined for at least every clayey or silty sample collected by coring devices. For every tube collected, the water content (W) was determined at both ends and in the middle. It was also calculated on samples taken for tests such as triaxial and consolidation test. At least one test of Atterberg Limits was performed on every tube of clayey or silty soil.

These tests have the advantage of being performed on remoulded samples. However, hand samples taken at the tip of the coring tool tend to give higher water content (see FR-7, Appendix F).

The water content, given in % was calculated from the following equation:

$$W\ (\%) = (W_w/W_s) \times 100 \qquad \text{(Eqn. 2)}$$

where W (%) =water content in %, w =weight of water in gm, and s =weight of dry soil in grams.

Samples were also tested for Atterberg Limits using the A.S.T.M. standards (A.S.T.M., 1970). The plasticity and liquidity index were calculated with the following equations:

$$I_p = W_l - W_p \qquad \text{(Eqn. 3)}$$

$$I_l = (W - W_p)/I_p \qquad \text{(Eqn. 4)}$$

where I_p = plasticity index, W_l = liquid limit in %, W_p = plastic limit in %, I_l = liquidity index, and W = water content (%).

Results obtained for the Goldthwait Sea clays in the investigated area are given in Table 15. Standard deviation (SD) and the minimum number (N) of analyses are also supplied in Table 15. This table includes results for the saturated zone only for parameters such as water content (W) and plasticity index (I_p).

The low water content of 14% at Grand Métis may reflect sampling difficulties indicated in Appendix D, but hand samples at this site still give low values, if not the same.

Shear Strength and Sensitivity

The shear strength is the ultimate resistance of a soil to shear stress over which a failure takes place; it is represented by Cu when in an undrained condition. The sensitivity is the ratio of the undisturbed shear strength to the remoulded shear strength for the same soil, at the same water content. As pointed out by Penner (1965) the main difficulty with very sensitive clay is to determine accurately the undisturbed strength.

Three instruments were used to measure the shear strength. A field vane test (carried out during the winter program), a laboratory vane, and cone tests. The penetrometer also directly evaluates the shear strength; it has proven to be good because measurements are taken in the field while it penetrates the soil (Ladany and Eden, 1970). In addition, it gives almost continuous results in a vertical profile.

From the penetrometer test the resistance at the tip of the probe yields the bearing capacity: q_p, which has the following relation with the shear strength (Cu):

$$q_p = p_o + Cu\ N_c \qquad \text{(Eqn. 5)}$$

SITES	w(%)		w_l (%)		w_p (%)		I_p		I_l		N
	M	SD	M	SD	M	SD	M	SD	M	SD	
St-Joachin(1)	29.5	2.5	24.7	5.7	18.6	1.7	4.3	1.4	2.5	--	10
Ste-Anne	25.7	3.5	33.3	3.3	23.4	4.6	9.3	4.5	0.4	0.6	6
Cap-Chat	21.1	3.0	23.8	3.6	15.6	3.0	8.3	2.0	0.9	0.6	10
Matane	24.6	3.5	32.8	6.1	21.1	3.6	11.4	4.9	0.5	0.5	15
Grand Metis	14.0	3.0	32.0	---	27.0	--	5.0	--	--	--	1
Ste-Luce	36.1	5.2	48.0	8.0	31.0	6.0	18.0	7.0	0.4	0.1	7
Rimouski	30.7	3.1	35.3	3.7	22.4	2.5	12.9	4.0	0.7	0.4	33
Trois-Pistol.	33.0	2.5	30.6	3.8	20.2	3.1	10.4	2.9	1.4	0.7	11

w(%) : water content in %

w_l(%) : liquid limit in %

w_p(%) : plastic limit in %

I_p : plasticity index

I_l : liquidity index

N : minimum number of samples analysed

(1) : from Matyas 1964a

Table 15 Results for Water Content and Atterberg Limits where p_o = total overburden pressure (kg/cm^2), N_c = bearing capacity factor.

In order to obtain the shear strength one must define N_c, the bearing capacity factor. This value is assumed to be valid on a regional basis (Ladany and Eden, 1970). For defining N_c results obtained in Cu from the vane test were used, assuming p_o as negligible and a value of 13.0 was found. The same results were obtained for the Becancour area, near Trois-Rivières (R. Maranda, personal communication).

Shear strength values were also obtained in the laboratory with a laboratory vane, unconfined compression, and falling cone tests. Sensitivity could be determined only with the vane and the falling cone tests. For the first, the shear strength ratio of the unremoulded and remoulded stages gives the sensitivity. The sensitivity determined from the falling cone can be estimated with the following methods (Eden and Kubota, 1961):

(1) Sensitivity = unremoulded shear strength/remoulded shear strength (Eqn. 6)

(2) Sensitivity = $[(H_r)^2/(H_n)^2]$ = remoulded penetration^2/ unremoulded penetration^2 (Eqn. 7)

Sensitivity values using the falling cone test were determined on several samples for the Rimouski clay (FR-9). Table 16 summarizes the results obtained from the falling cone test compared to the lab vane test.

Penner (1965) suggests calculating the sensitivity in using the shear strength from the penetrometer and the remoulded results obtained from the lab vane test. This was done for one site, at Rimouski, for borehole F-5 where results on laboratory vane tests are apparently more consistent.

As shown in Table 17 where the natural or unremoulded shear strength is essentially constant.

However, the sensitivity values are not consistent, particularly for the laboratory vane test (L.V.T.).

Sample No. and depth in metre	W %	Lab Vane Test kgm/cm^2		Sens.	Lab Cone Test kgm/cm^2		Sensitivity	
		Nat.	Rem.		Nat.	Rem.	1	2
FT-247-74	30.9	0.45	0.045	10	0.97	0.67	1.4	1.4
24.3					0.83	0.67	1.2	
FT-248-74	29.1				0.63	0.05	12.6	6.9
30.5					0.63	0.09	6.9	2.3
FT-251-74	34.5	0.09	-----	—	0.18	0.02	8.2	1.4
39.6		0.11	0.04	2.8				
FT-252-74	36.0	0.40	0.005	8	0.18	0.03	6.4	6.2
42.6		0.11	0.005	22				
FT-253-74	31.5	0.20	0.005	39	0.31	0.06	4.8	5.8
					0.33	0.06	5.1	4.5
FT-254-74	35.3	0.32	0.005	64	0.33	0.06	5.5	4.8
48.7		0.31	0.005	63	0.37	0.06	6.0	5.2

Note: These samples were taken from borehole FR-9 (Rimouski).
1 and 2 refer to the methods to calculate the sensivity in using the lab cone test.

Table 16 : Summary of results on lab vane and cone tests.

SITES	SHEAR STRENGTH (kgm/cm^2)					SENSITIVITY			W %	N
	PEN	F.V.T.	L.V.T.	CONE	UNI-A.	F.V.T.	L.V.T.	CONE		
ST-JOACHIN				0.95 (0.6)					30	2
STE-ANNE		1.2 (0.2)	0.8 (0.2)	1.2 (0.6)		1.4 (0.2)	9 (7)		26	4-5
CAP CHAT			0.9 (0.5)	0.4 (0.1)	0.3 (0.2)	2.0 (0.3)	16 (15)		21	2-7
MATANE		0.4 (-)	0.7 (0.1)	1.1 (0.4)		1.4 (-)	6.3 (6.0)		25	1-10
STE LUCE		0.4 (0.2)	0.3 (0.1)	0.3 (0.1)			8 (6)		35	2-19
RIMOUSKI	0.6 (-)	0.6 (0.1)	0.3 (0.2)	0.5 (0.3)	0.3 (0.1)	1.4 (0.8)	18 (20)	6 (3)	31	8-57
TROIS-PISTOLES		0.3 (0.4)	0.2 (0.1)	0.3 (0.1)	0.2 (0.1)	3.0 (2)	4 (2)		33	5-12

Note:
PEN : penetrometer
F.V.T.: field vane test
L.V.T.: lab vane test
UNI-A.: uniaxial test (unconfined)
(0.2) : standard deviation

W; water content (average)
N: minimum and maximum number of analyses

Table 17 Results on Shear Strength and Sensitivity for the Different Sites Investigated, from Different Analyses

Table 16 indicates that the laboratory vane test was unreliable for estimating the sensitivity due to a failure in the apparatus mechanism. Therefore, results from laboratory vane tests for sensitivity are of doubtful validity. This was strongly suggested by a much higher standard deviation, about twice as great, as for other apparatus.

To summarize results obtained on the Goldthwait Sea clays, Table 17 presents values obtained at different sites with the methods discussed previously. Data were taken for samples with at least average water content. The minimum and maximum number of samples (N) analysed is also given along with the standard deviation (SD) in parentheses.

Pre-consolidation Pressure and Related Parameters

Consolidation tests were run on samples 5.08 and 7.62 cm in diameter (2 and 3 inches). Preparation and testing were executed following A.S.T.M. 2435-70 on blocks 5.08 and 4.4 cm in diameter and 1.9 cm high. Cells with an inside diameter of 4.4 cm were used on samples 5.08 cm in diameter taken during the winter drilling program while cells 5.08 cm in diameter were used on samples from summer drilling.

Vertical deformation on samples 5.08 cm in diameter was measured only after 24 hours of consolidation, except for 2 samples tested at the University of Waterloo where deformation readings were taken for every loading or unloading stage. Samples tested by Technisol Co. (4.4 cm in diameter) had readings of vertical strain taken at every two loading stages. Also tests from Technisol do not include the unloading phase of the test. However, both Technisol and the author's results at the University of Waterloo allowed the calculation of the permeability (k) and the coefficient of consolidation (c_v, Tables 18 and 19).

Sample No.	depth (m)	W %	e_o	e	c_v cm^2/sec $x10^{-3}$	C_c	a_v cm^2/kgm $x10^{-2}$	k cm/sec $x10^{-7}$	P_c kgm/cm^2	γ' kgm/cm^3 $x10^{-3}$	F #
19	21.3	22.2	0.598	0.525	14.0	0.24	1.33	3.5	8.5	1.16	1
39	15.2	22.2	0.599	0.479	1.5	0.10	0.8	0.2	4.8	1.18	2
25	7.0	23.4	0.632	0.562	3.2	0.16	2.0	1.1	4.5	1.11	3
27	8.8	24.2	0.653	0.590	0.4	0.28 0.15	4.7 2.6	0.3 0.2	7.0	1.60	"
29	10.6	25.2	0.683	0.590	1.3	0.16	2.0	0.4	2.8	1.46	"
49	22.8	29.8	0.805	0.710	2.3	0.20	2.8	0.9	3.1	1.03	5
50	24.3	30.2	0.815	0.733 0.677	1.5	0.20	9.8 2.6	2.0 0.6	2.3 3.7	1.04	"
51	27.4	35.0	0.845	0.770	1.2	0.28	6.7	1.0	3.0	0.96	"
53	30.5	39.8	1.075	0.964	0.9	0.63	28.0	2.6	1.7	0.90	"
60	4.5	29.2	0.788	0.705	3.1	0.33	4.1	1.8	3.8	1.00	6
63	9.1	35.8	0.966	0.820 0.787	3.1	0.28	6.1 4.1	2.3 1.6	2.1 2.8	0.93	"

Note: W: water content
e_o: void ratio (initial)
e: void ratio to calculate C_c
c_v: coefficient of compression
a_v: coefficient of compressibility
C_c: compression index

k: permeability
P_c: preconsolidation pressure
γ': effective specific weight
F: borehole (Technisol Inc.)

Table 18 Consolidation Test Results from Technisol Inc.

Sample No.	depth (m)	Sa %	Si %	Cl %	W %	P_c kgm/cm^2	C_c	a_v cm^2/kgm	W_l %	W_p %	I_p	Bore-hole # FR-
208	1.5	1.2	40.2	59.8	23.0	2.5	0.27	8.0 $\times 10^{-2}$	42	30	12	7
209	4.6	2.0	31.0	67.0	30.0	1.5	0.25	1.8 "	43	26	17	"
211	12.2	3.0	26.0	71.0	44.0	2.5	0.23	1.2 "	59	39	20	"
222	18.3	10.	30.0	60.0	36.0	1.1	0.30	6.5 "	46	25	21	"
224	21.3	12.0	33.4	55.0	34.0	1.32	0.50	6.1 "	46	24	22	"
236	21.3	3.0	42.0	55.0	29.0	2.9	0.23	1.7 "	37	24	13	8
238	27.4	0.0	48.0	52.0	36.0	3.0	0.43	3.1 "	35	23	12	"
241	36.6	8.0	31.0	61.0	27.0	3.8	0.35	1.7 "	37	26	11	"

Note:

Sa: sand
Si: silt
Cl: clay
W: water content
W_l: liquid limit
W_p: plastic limit
I_p: plasticity index
P_c: preconsolidation pressure
C_c: compression index (dimensionless)
a_v: coefficient of compressibility

Table 19 Consolidation Test Results and Other Related Tests (Service de Geotechnique, Q.M.N.R.)

The consolidation test could be considered as being the record of a confined one-dimensional compression (ΔH) versus time ($\sqrt{t}$, Fig. 68) and as a function of change in effective vertical stress (σ_v', Fig. 69). The first relation, ΔH vs $\sqrt{t}$, is useful for calculating the permeability (k) and the coefficient of consolidation (c_v). The latter, e (void ratio) vs log σ_v' (Fig. 69) permits the estimation of consolidation pressure (P_c), the compression index (C_c), and the coefficient of compressibility (a_v).

The pre-consolidation pressure (P_c) is determined by the Casagrande method (Fig. 69). The results obtained give an idea of the history of the sediment (Crawford, 1968). The knee obtained on the curve in Fig. 69 is obtained when the applied stress (σ_v') is greater than the past stress conditions maintained on the soil sample in situ; the change in void ratio became more important as the load increased.

Bozozuk (1971) suggests that the less pronounced the knee on the e - σ_v' curve (Fig. 69), the greater the disturbance of the soil, either during sampling, transport, or preparation. Dascal and Larocque (1973) noted that even for undisturbed block samples of clay, the same phenomenon occurs for deeper samples; indicating a more important second compression (Fig. 68).

	C_c		a_v	
	Average	Standard Deviation	Average	Standard Deviation
Technisol	0.25	0.1	5.5(3.8)*	6.7(2.5)*
Q.M.N.R.	0.29	0.1	3.7	2.7

* omitting sample *TB-53-74 which has very different properties

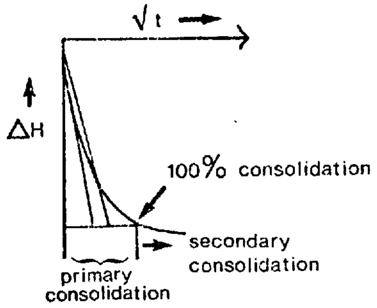


Figure 68. ΔH versus $\sqrt{t}$ diagram

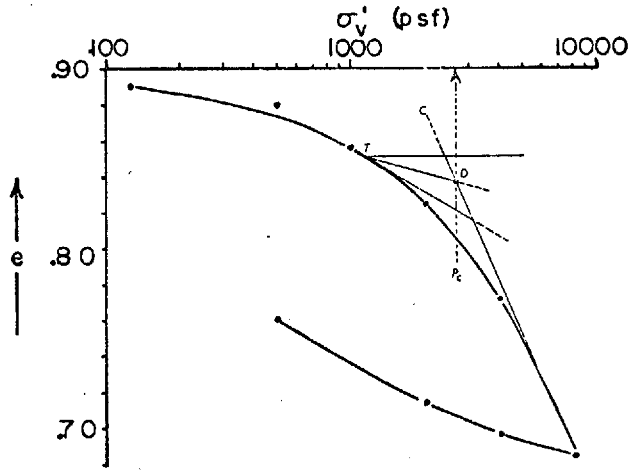


Figure 69. Δe versus σ_v' diagram

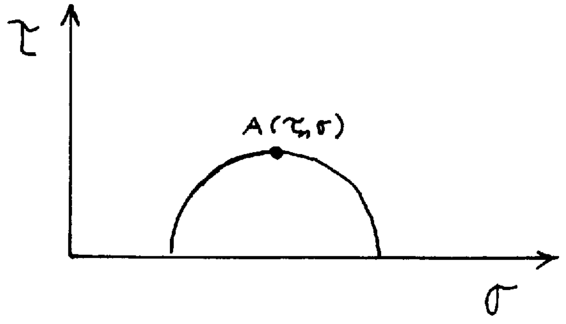


Figure 70. Mohr circle diagram

The compression index (C_c) and the coefficient of compressibility (a_v) are estimated from the following equations:

$$C_c = [\Delta e/\Delta(\log \sigma_v')] \quad \text{(Eqn. 8)}$$

$$a_v = (0.435\ C_c/\sigma_v') \quad \text{(Eqn. 9)}$$

where e: void ratio, dimensionless, σ_v': average $\sigma v'$ used to calculate C_c, $\sigma v'$: kg/cm^2, and a_v: cm^2/kg, C_c = dimensionless. Both C_c and a_v are taken from the virgin or straight part of the curve (Fig. 68). The coefficient of consolidation (c_v) is then calculated with the following formula:

$$c_v = (T\ H^2/t) \quad \text{(Eqn.10)}$$

where T: time factor, dimensionless, H: 1/2 the height of the sample allowing for double drainage at the top and bottom, and t: time in seconds for the given stage of compression.

The coefficient of consolidation (c_v) is here calculated after 50% of the primary consolidation (at t=50%), so that an average is obtained. Therefore,

$$c_v = (T_{50}\ H^2/t_{50}) \quad \text{(Eqn.11)}$$

where T is calculated from the following equation:

$$T = [(\Pi/4) + U^2] \quad \text{if } U<60\% \quad \text{(Eqn.12)}$$

Then equation 11 could be rewritten as

$$c_v = (0.197\ H^2/t_{50}) \quad \text{(Eqn.13)}$$

This value of c_v can be estimated for every load increment. The permeability (k) was estimated from the consolidation test using the value of c_v from the following equation:

$$c_v = [k_z(1+e)/a_v\gamma_w] \quad \text{(Eqn.14)}$$

To determine k, equation becomes

$$k_z = (c_v\ a_v\ \gamma_w/1 + e) \quad \text{(Eqn.15)}$$

where k_z = vertical permeability in cm/sec (vertical), c_v = coefficient of consolidation; cm^2/sec, a_v = coefficient of compressibility; cm^2/kg, and γ_w = unit weight of water; kg/cm^3.

The results obtained are listed in Table 18. The values of k vary only between 10^{-7} to 10^{-8} cm/sec throughout the area. One would expect a decrease in permeability as the clay fraction increases. These results are indirectly obtained and based on parameters that are already imprecise.

Angle of Internal Friction (ϕ') and Cohesion (c')

The angle of internal friction (ϕ') and the cohesion (c') are the most important parameters needed for any slope stability analysis. The cohesion (c') is considered to be the shearing resistance due to intrinsic stresses (Crawford, 1968).

These parameters could be determined by triaxial test (drained or undrained) or by a shear box test (consolidated-drained test). Results are obtained using Coulomb's law:

$$\tau ff = c' + \sigma_v' \tan \phi' \qquad \text{(Eqn. 16)}$$

where τff = shear strength at failure (kg/cm^2), $\sigma v'$ = vertical effective stress (kg/cm^2), c' = cohesion (kg/cm^2), and ϕ' = angle of internal friction (degrees).

In the case of the shear box test the failure plane is known and results for ϕ' are usually 1 or 2 degrees lower than the results obtained with the triaxial test (Lamb, 1969). Residual shear stress is also used to evaluate long-term stability of an embankment where c'=0.

Results obtained from triaxial tests were plotted on a p-q diagram (Fig. 70), since one triaxial test was carried out by Technisol for each sample. To achieve a more accurate estimation, the author decided to run

Locality	Borehole No.	Sample No.	Depth m	γ PCF	ω_i %	ω_f %	σ_1' P.S.I.	σ_3' P.S.I.	$(\sigma_1'-\sigma_3')/2$ P.S.I.	$(\sigma_1+\sigma_3)/2$ P.S.I.	ε_f %	ε_{rate} in/min
Ste.Anne	F-1	TB-19-74	21.3	135	22.5	-	71.7	19.0	26.4	45.4	7.4	.0018
Cap Chat	F-2	TB-38-74	35.5	137	16.8	19.4	54.8	9.8	22.5	32.3	12.0	.0024
Matane	F-3	TB-26-74	8.5	129	21.8	25.3	35.5	9.3	13.1	22.4	12.0	.0024
Matane	F-3	TB-30-74	12.8	129	23.3	23.3	42.9	9.3	16.8	26.1	10.0	.0024
Rimouski	F-5	TB-48-74	21.6	123	28.4	25.7	49.0	12.8	18.1	30.9	9.1	.0024
Rimouski	F-5	TB-50-74	24.7	125	28.5	26.9	51.1	14.7	18.2	32.9	9.0	.0024
Rimouski	F-5	TB-52-74	27.7	122	29.8	30.0	45.5	12.5	16.5	29.0	10.5	.0024
Rimouski	F-5	TB-53-74	30.8	122	35.6	29.4	38.8	11.3	13.8	25.1	8.9	.0024
Rimouski	F-5	TB-56-74	35.4	119	31.4	34.2	43.4	14.4	14.5	28.9	6.8	.0024
Trois-Pistoles	F-6	TB-60-74	4.4	124	26.5	27.0	20.4	3.4	8.5	11.9	4.6	.0024
Trois-Pistcles	F-6	TB-61-74	6.4	114	33.6	33.7	14.2	3.4	5.4	8.8	11.6	.0024

γ: total unit weight
ω_i,ω_f: water content, initial (i), and at failure (f)
$\sigma_1'\sigma_3'$: maximum and minimum effective deviator stresses
ε_f: strain at failure

Table 20: Results obtained from Consolidated Undrained triaxial tests (tests from Technisol Inc., 1974)

a shear box test on a sample from the Rimouski site (FR-8). Results are shown in Figure 43.

However, results on a shear box test tend to give shear strength at failure much lower than with a triaxial apparatus (Lefèbre and Larochelle, 1974). On the other hand, this test is good for obtaining residual shear strength.

Shape

Shapes of clay-size particles were studied with an electron microscope having a magnification power of 500,000 times and a resolution power of 2 Angstroms. However, the range of magnification used varied between 2000 and 24,000 times. Sample 22B/12W-29, from the Tartigou River, was analysed. The technique of preparation is similar to that of X-ray diffraction. A few grams of dry sample (10-20 gms) are put in a burette filled with distilled water. After shaking thoroughly, the mixture is allowed to settle. After 30 minutes a drop of the remaining liquid is taken at five cm below the water surface in the burette. The drop is then put on a 40-mesh grid coated with carbon, and air-dried.

Once the sample is mounted in the microscope, it is possible to examine the shape of the particles or to study them individually by means of the microdiffraction patterns.

Several photographs were taken with the camera built into the microscope. On Figure 46 the particles are seen to be angular, as found by Gillot (1970). Particles with zonations (Fig. 46) may be considered as quartz. One crystal of rhombohedral calcite was isolated (Fig. 47). Figure 48 gives a typical example of the microdiffraction of a clay mineral with the typical hexagonal pattern (Grim, 1968).

Microfabric (technique)

This method consists of putting the wet sample (natural water content) of about 2.5 x 1.0 x 1.0 cm, in a melt of CARBOWAX 6000 melted at 60°C for three days (Mitchell, 1956). The sample is then cut into a thin section using standard techniques except that all the work is done by hand, and with kerosene, and the section is mounted on a glass slide with a cold epoxy cement. For the sample prepared, three days of impregnation was not found to be enough, but six days were found to be effective. No volume change was observed with this process but it was difficult to get an accurate measurement of the size of the sample (±1/2 mm). Once the sample is mounted on the glass it is run through X-ray diffraction procedures. After the diffraction, the sample could be covered with a cover glass and studied with a petrographic microscope.

Grain Size (Texture)

The following equations from Folk (1968) were used to calculate different parameters. The values of ϕ were taken from a probability curve. Equations preceded by *** were used when the curve did not extend to the 5%, the 95%, or both.

1) Graphic mean (M_z):

$$M_z = (\phi_{10} + \phi_{50} + \phi_{84})/3$$

2) Uniformity (I)

$$\sigma_I = (\phi_{84} - \phi_{16})/4 + (\phi_{95} - \phi_5)/6.6$$

*** $\sigma_G = (\phi_{84} - \phi_{16})/2$

3) Skewness or asymmetry (S_{kI})

$$S_{kI} = (\phi_{16} + \phi_{84} - 2\phi_{50})/2(\phi_{84} - \phi_{16}) + (\phi_5 + \phi_{95} - 2\phi_{50})/2(\phi_{95} - \phi_5)$$

*** $S_{kG} = (\phi_{16} + \phi_{84} - 2\phi_{50})/(\phi_{84} - \phi_{16})$

4) Kurtosis or peakedness

$$K_G = (\phi_{95} - \phi_5)/2.44(\phi_{75} - \phi_{25})$$

NOTE: Grain-size cumulative curves were grouped on the basis of geological units; those related to the Neigette Valley were also grouped. Any information on detailed location (or related to) can be obtained at the Service de Geotechnique (Q.M.N.R.).

APPENDIX D

DISCUSSION OF FIELD AND LABORATORY PROCEDURES

The results obtained in the present study are more or less influenced by sampling procedure and, probably even more by the location of the sites chosen for geotechnical investigations. Laboratory procedures such as handling, and cutting of samples, can alter the results.

Field Procedures

The sites investigated were usually related to escarpments in marine clays. Some boreholes (F-1, 2 and FR-4, for example) could be located too close to the scarp itself as shown by the difficulty in using the penetrometer at Ste. Anne-des-Monts, and by the depth at which the maximum water content is reached. For example, at the Rimouski site, results obtained for borehole FR-9 are different from those for borehole FR-8 and F-5.

The sites chosen do not cover all the types of clay encountered in the area. It was almost impossible to get good samples of the glacio-marine clay (stony). Also, no samples (except hand samples) of the "high" massive clay were collected.

Sampling problems were encountered in the St. Joachin-de-Tourelle and Cap-Chat region because of the silty texture of the material, which behaved almost like a cohesionless soil (Matyas, 1964a, b). The different sizes of the sampler used during the winter and summer program (Chapter I) is responsible for some of the discrepancies in the laboratory results (Bozozuk, 1971). Field vane procedures for Ste. Anne-des-Monts are of doubtful reliability since readings were taken only at the time of failure and sometimes the vane apparatus was forced into the soil with a hammer!

One must note the problems related to winter drilling such as control of the temperature and the transport of the samples to the laboratory. The road conditions in winter were especially bad while in the summer samples may have suffered from overheating.

Laboratory Procedures

Even if the tests were performed as soon as possible, it is recognized that the storage time may affect the results (Bozozuk, 1971). The longer the storage time is, the lower are the preconsolidation pressures (Bozozuk, 1971). This, added to handling and preparation of samples for testing, could be responsible for unusually low values of preconsolidation pressure obtained at F-5, for example.

Machine defects were encountered in the laboratory vane test (L.V.T.) apparatus. Also human error in observations and readings can affect the results.

However, tests were performed by two different laboratories and only small discrepancies were observed, which indicates that in general, the laboratory procedures were satisfactory.

Any correlation from one part of the area to another is made between samples with similar texture. Only a few texture analyses were carried out on the Goldthwait Sea sediments. These data are mainly available for the Rimouski site.

Discrepancies between undrained shear strength test results in clays have been studied in detail by De Lory and Salvas (1967). They concluded that the field vane test will tend to give lower values in normally consolidated clays. They also showed that lower results of shear strength obtained in the laboratory are due to some disturbance and changes in stress conditions (in situ).

Measurements of sensitivity of clay are not consistent from one type of testing to another, even for the same sample. Investigations by Eden and Kubota (1961), and Penner (1965) suggest that the sensitivity is usually underestimated (for highly sensitive clays) due to the insufficient sensitivity of the apparatus in measuring the remoulded strength.

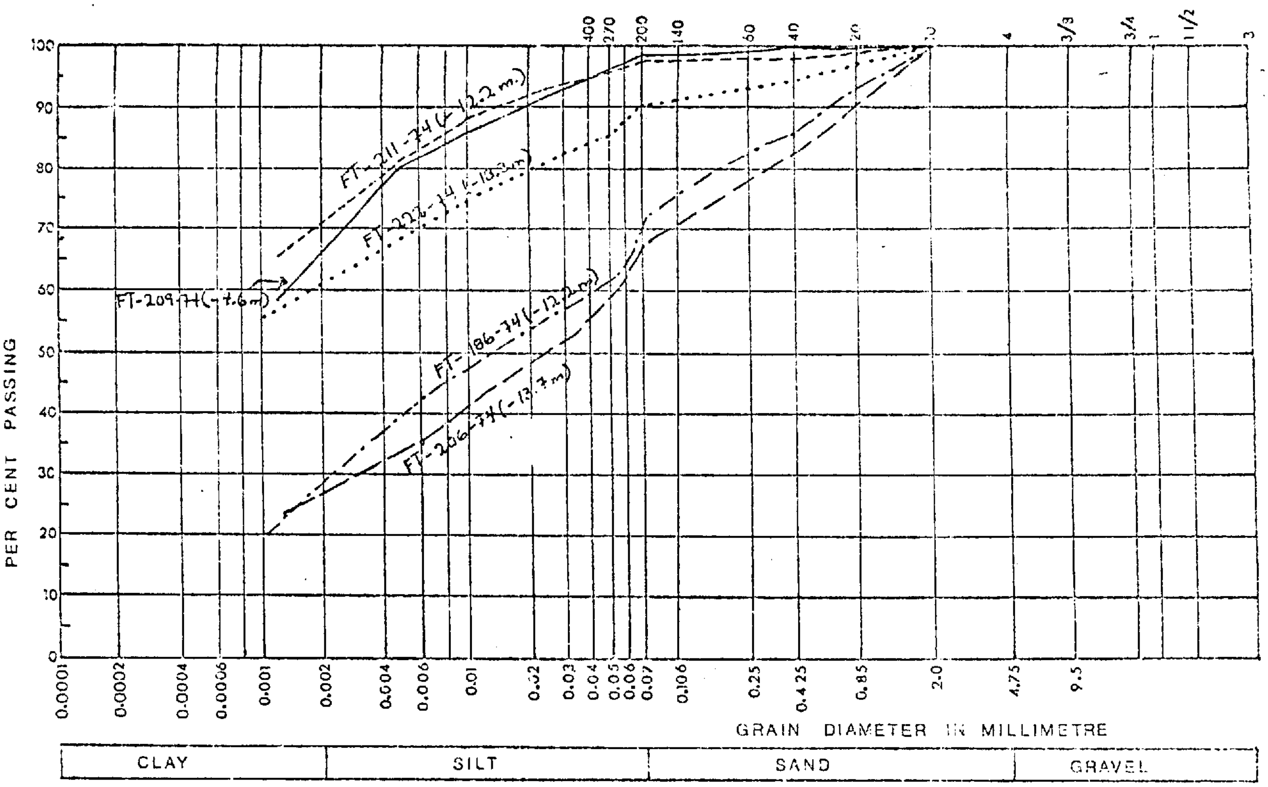
Fortunately, when the laboratory results are averaged for each apparatus used, the agreement between the data is improved. In this case, results for the same borehole are satisfactory (see FR-8, FR-9, F-5).

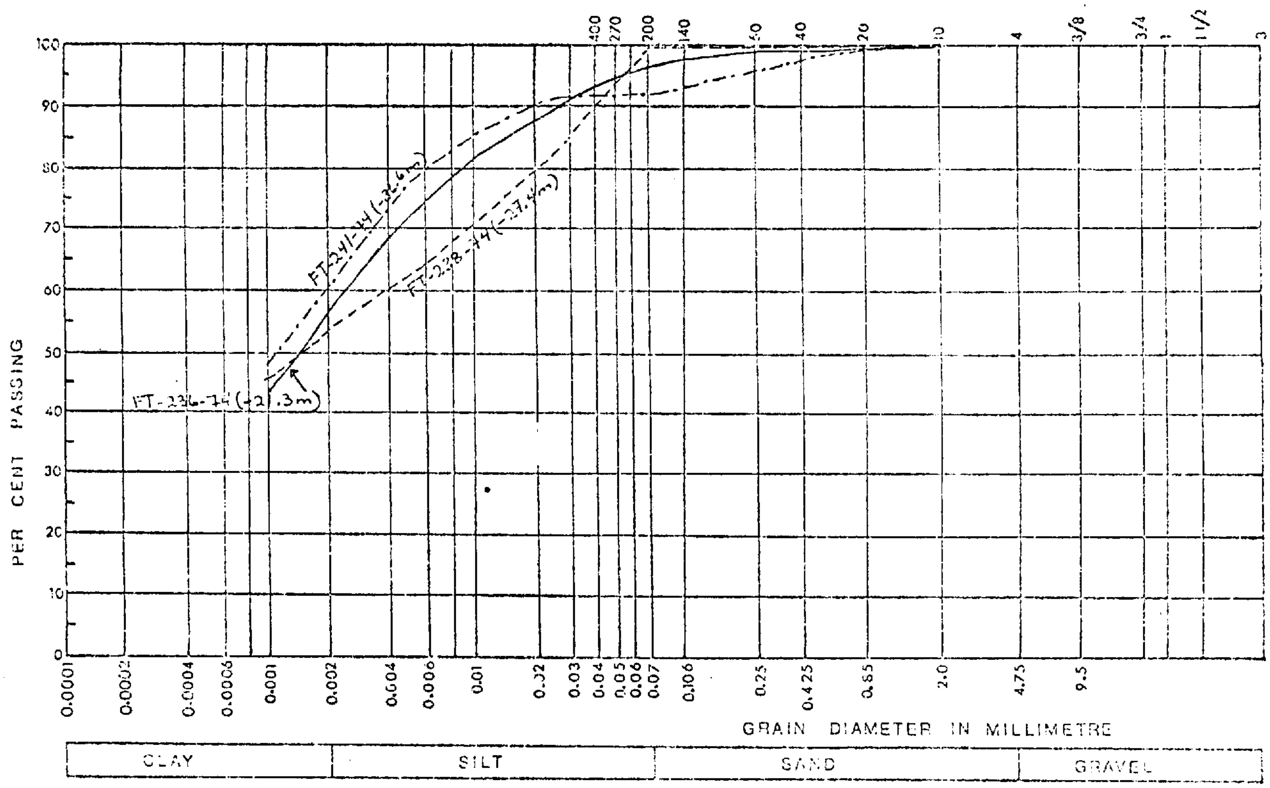
Results obtained in the present area are generally consistent with the ones obtained by previous workers (Meyerhof, 1953; Matyas, 1964a, b; Dionne, 1972a). Even if correlation between one site and another is very difficult, if not impossible, with the amount of data accumulated, the results for each site are believed to represent the main characteristics of the site. It is the author's belief that variations in properties from one site to another mainly represent the different sedimentary environments encountered in the area. From Trois-Pistoles to St. Joachin-de-Tourelle the coast is generally narrowing with some widening near Mont-Joli and Matane. For example, results obtained by Matyas (1964b) at the St. Joachin site, correspond well to Conlon's results (1966) along the Toulnustouc River mainly because of the texture, which is directly influenced by the size of the sedimentary basin.

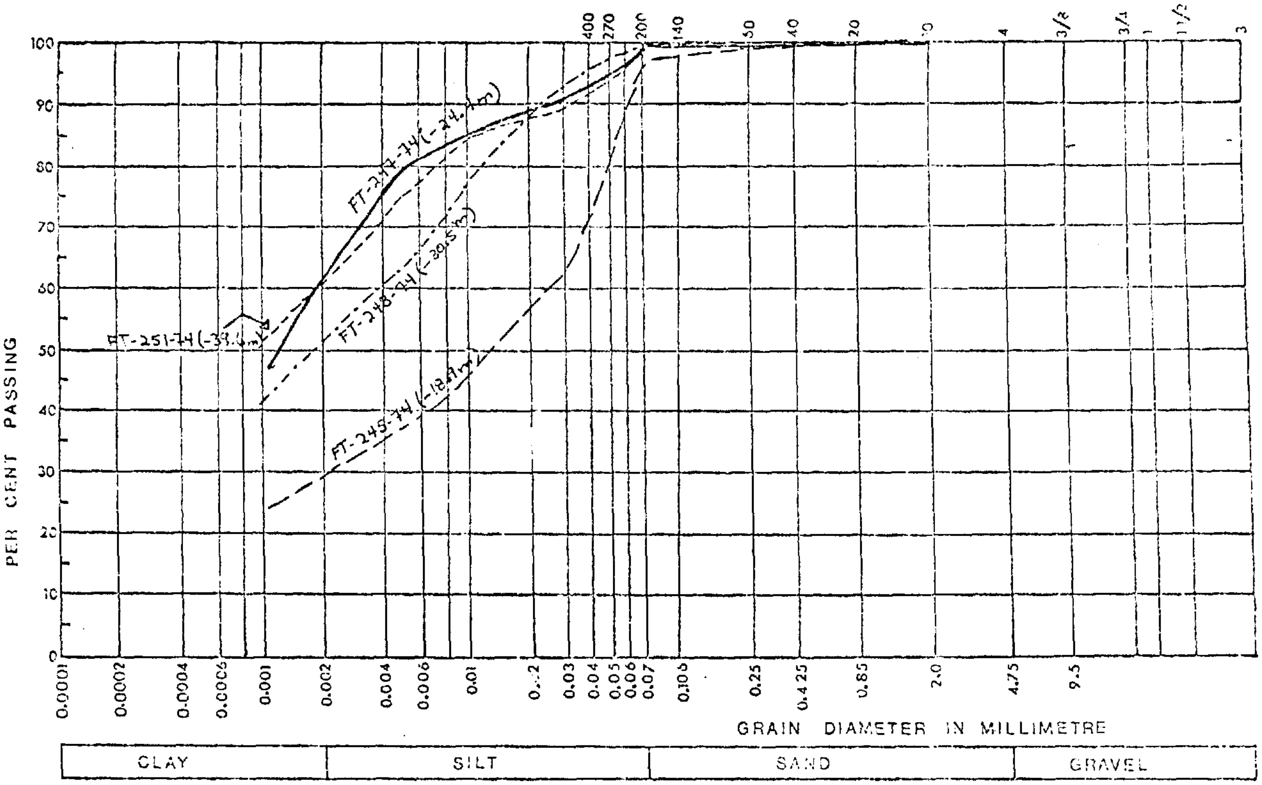
APPENDIX E

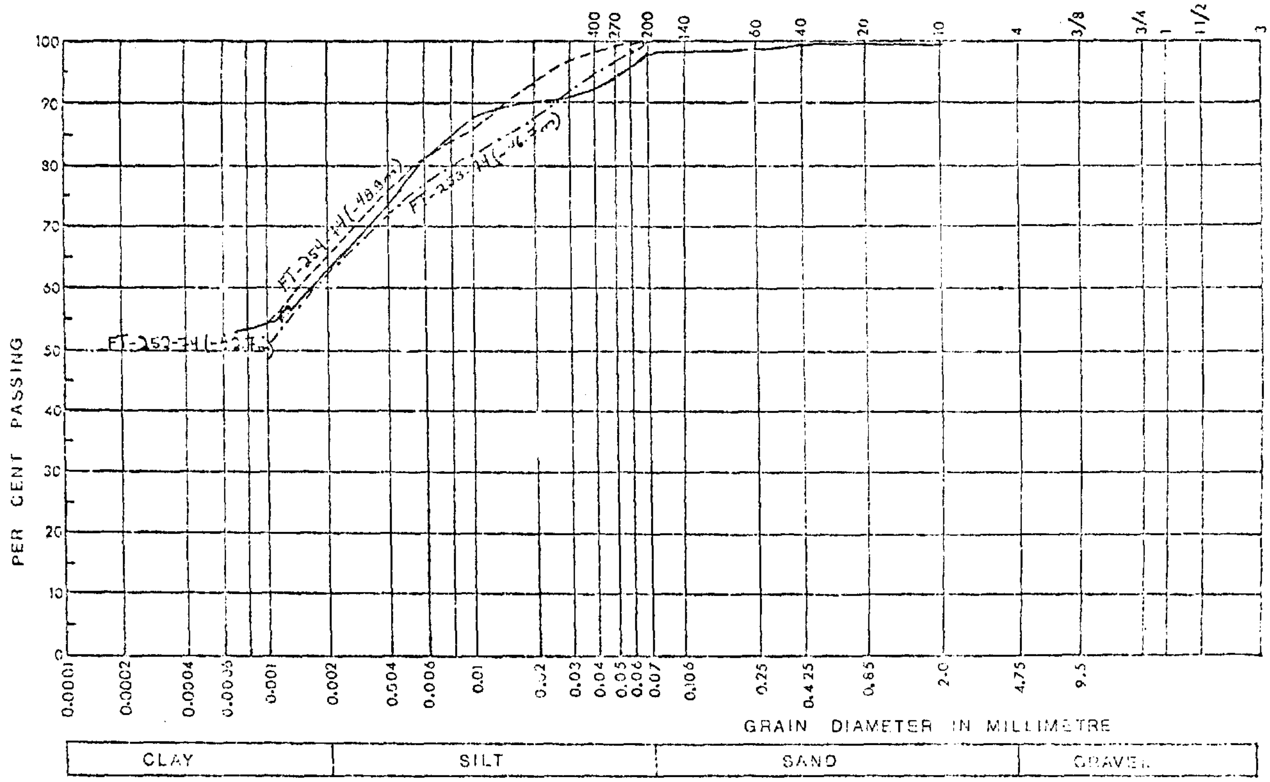
TEXTURE ANALYSES

FROM BOREHOLE SAMPLES

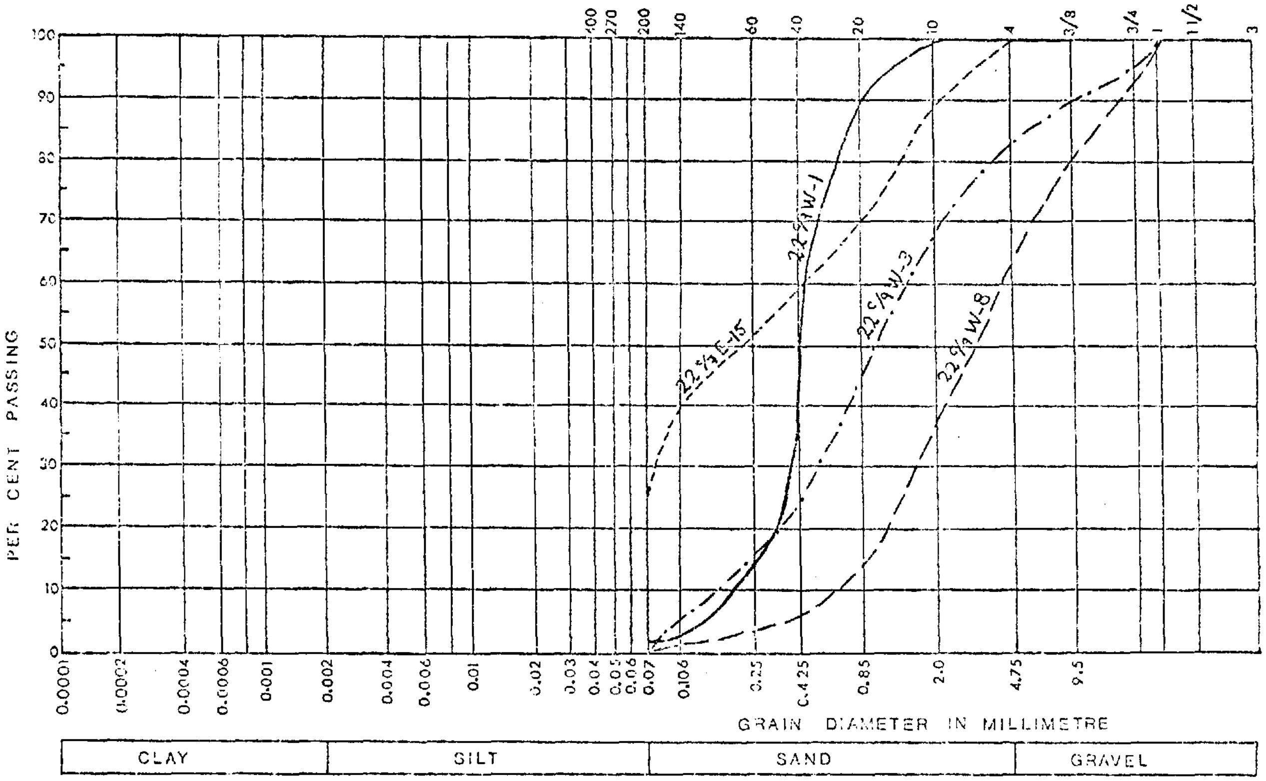




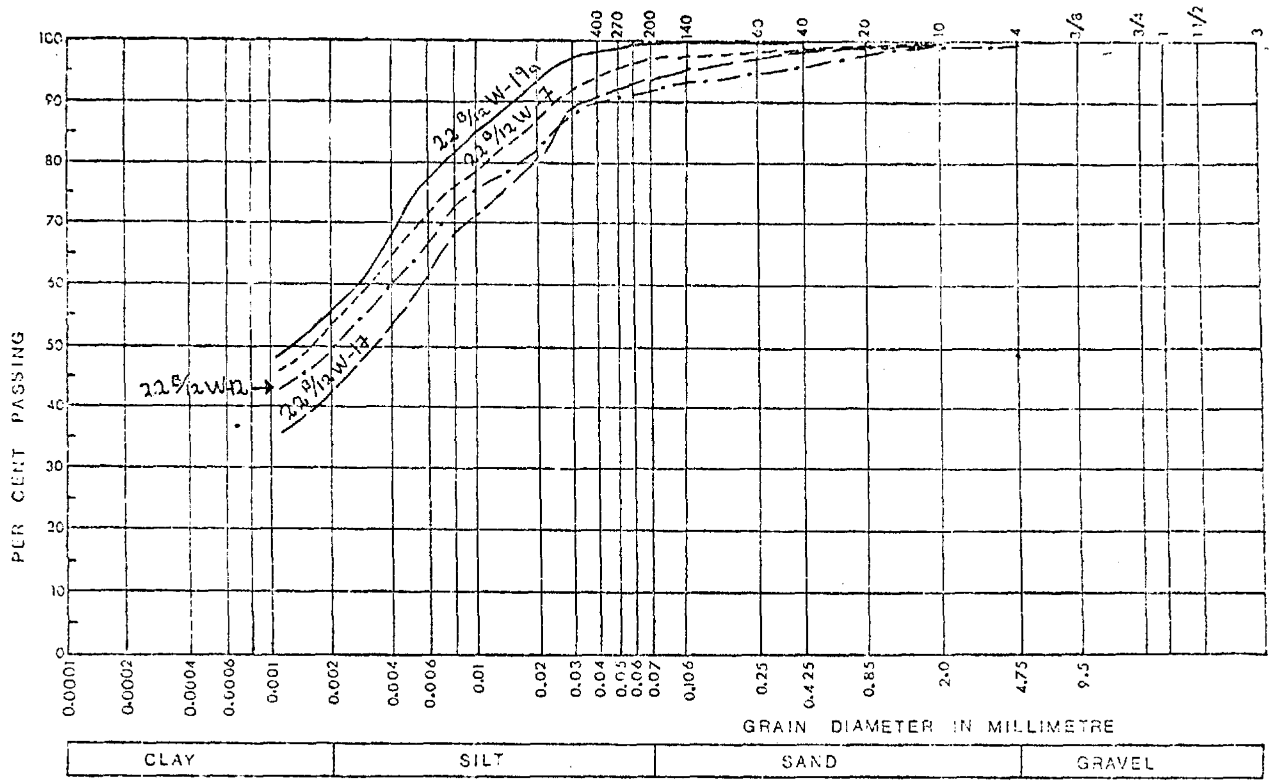

400
270
200
140
60
40
20
10
4
3/8
3/4
1
1 1/2
3
100
90
80
70
60
50
40
30
20
10
0
PER CENT PASSING
FT-247-74(-24.4m)
FT-248-74(-30.5m)
FT-251-74(-39.6m)
FT-245-74(-18.9m)
0.0001
0.0002
0.0004
0.0006
0.001
0.002
0.004
0.006
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.106
0.25
0.425
0.85
2.0
4.75
9.5
GRAIN DIAMETER IN MILLIMETRE
CLAY
SILT
SAND
GRAVEL

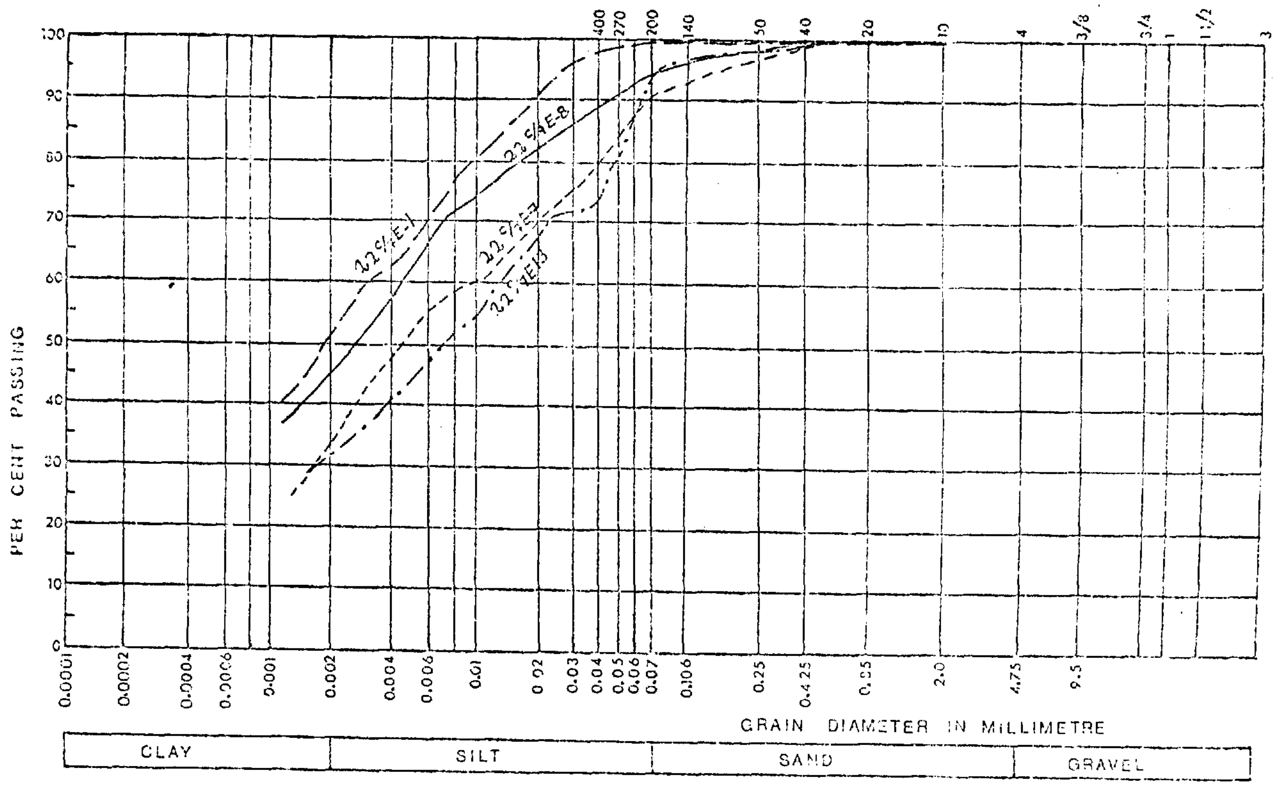

400
270
200
140
60
40
20
10
4
3/8
3/4
1
1 1/2
3
100
90
80
70
60
50
40
30
20
10
0
PER CENT PASSING
FT-254-74(-48.9m)
FT-253-74(-46.3m)
FT-252-74(-52.7m)
0.0001
0.0002
0.0004
0.0006
0.001
0.002
0.004
0.006
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.106
0.25
0.425
0.85
2.0
4.75
9.5
GRAIN DIAMETER IN MILLIMETRE
CLAY
SILT
SAND
GRAVEL

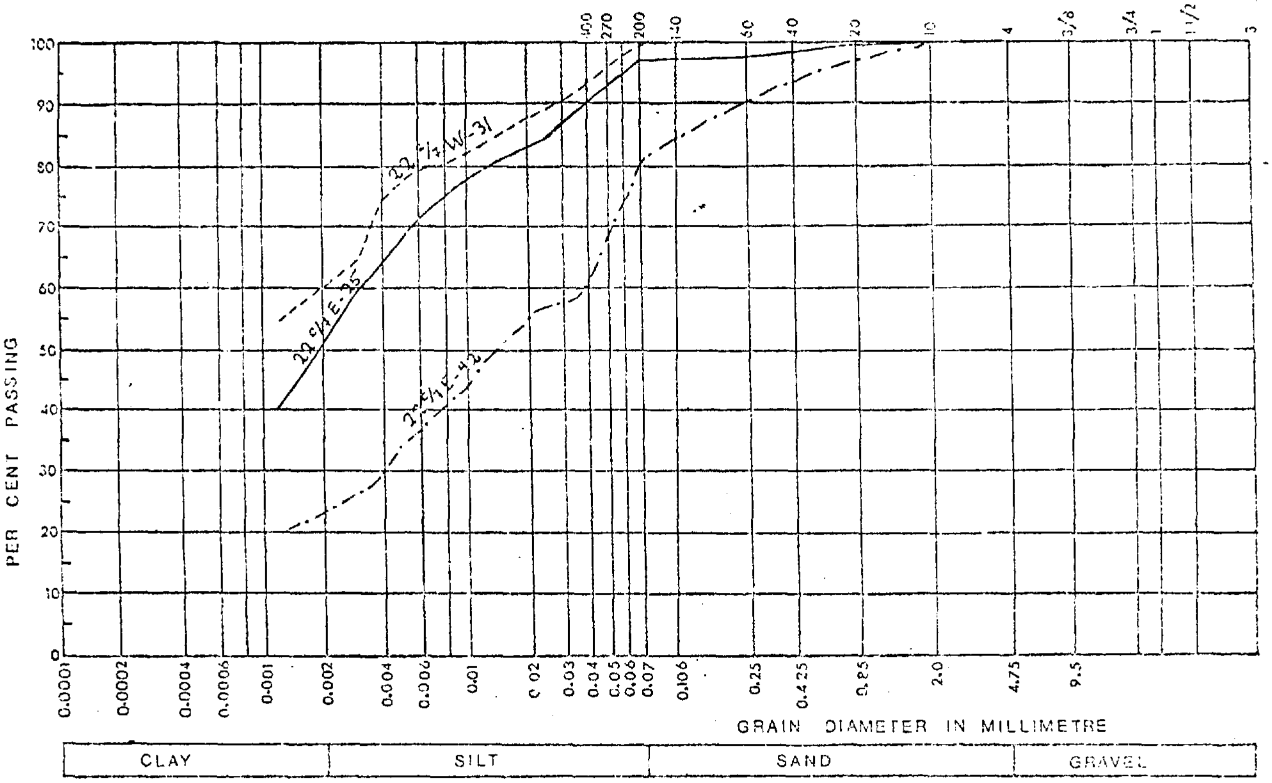
GRAIN-SIZE CUMULATIVE CURVES
FOR GLACIOFLUVIAL SEDIMENTS

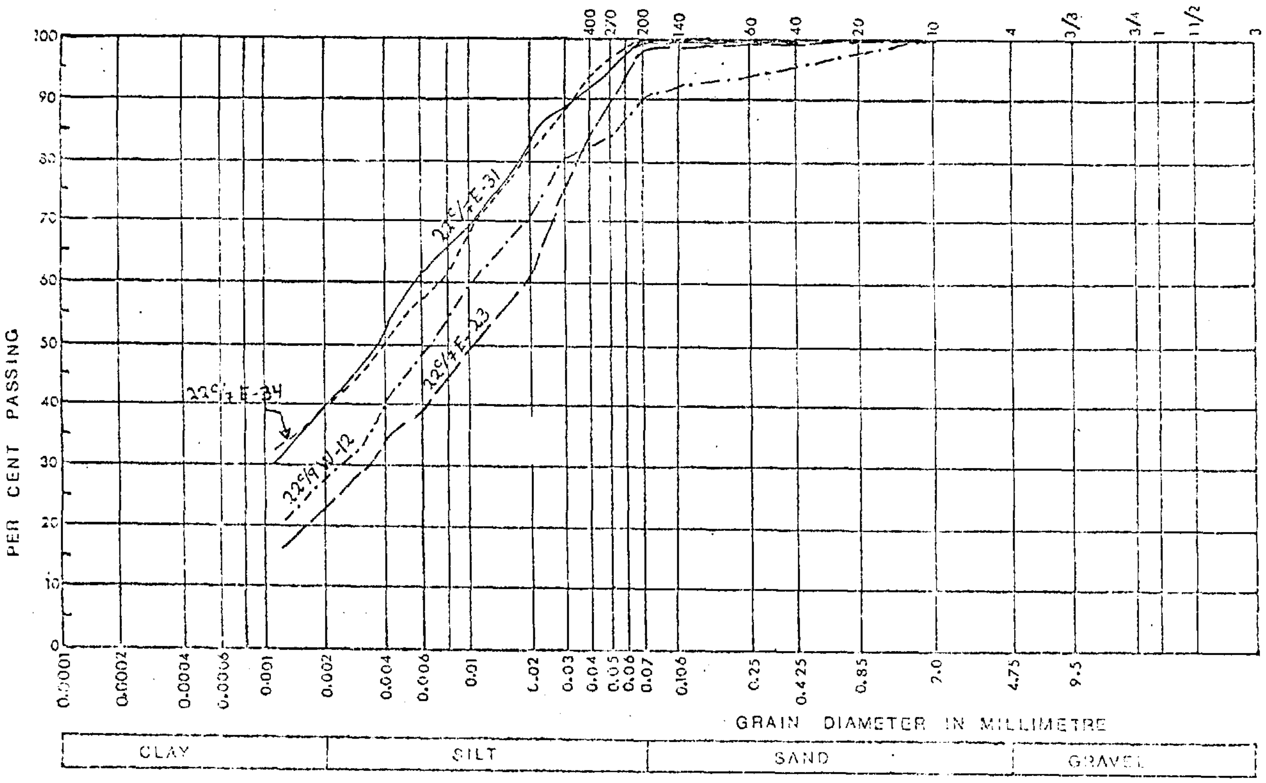


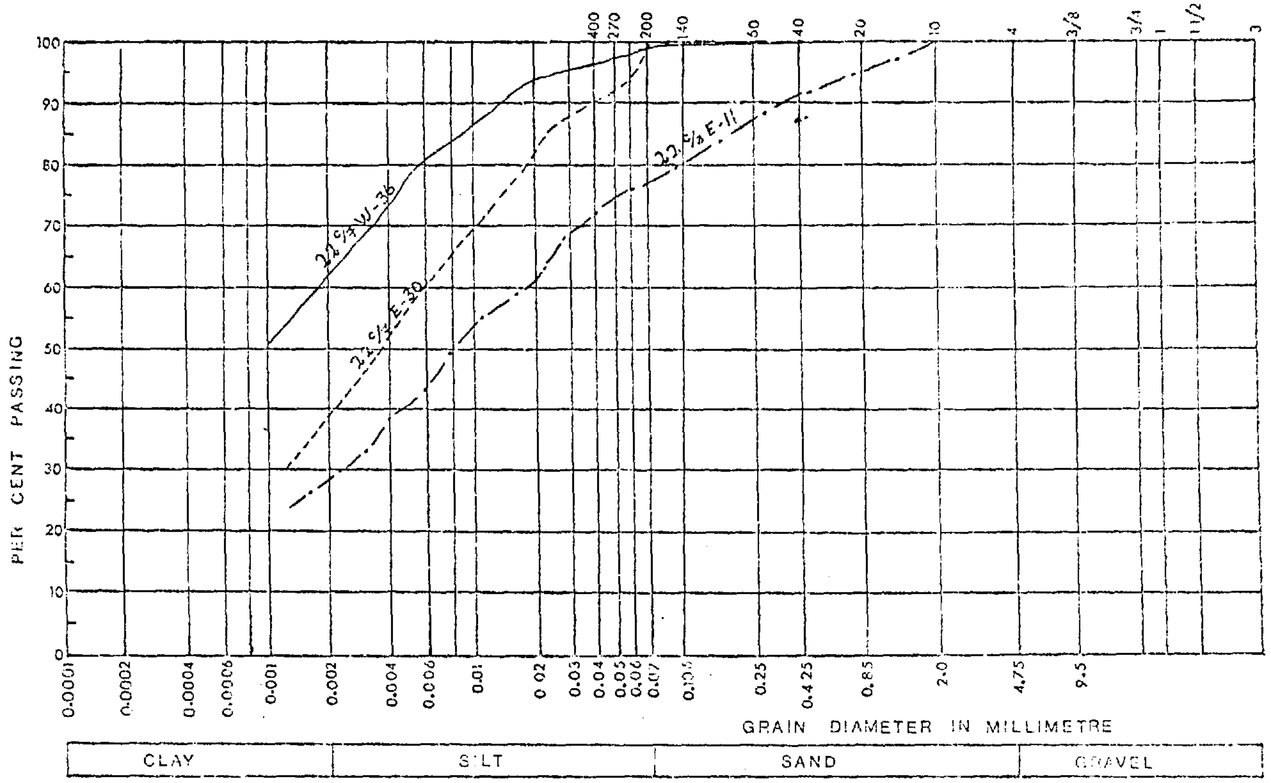
GRAIN-SIZE CUMULATIVE CURVES FOR MARINE CLAYS (map unit 7)

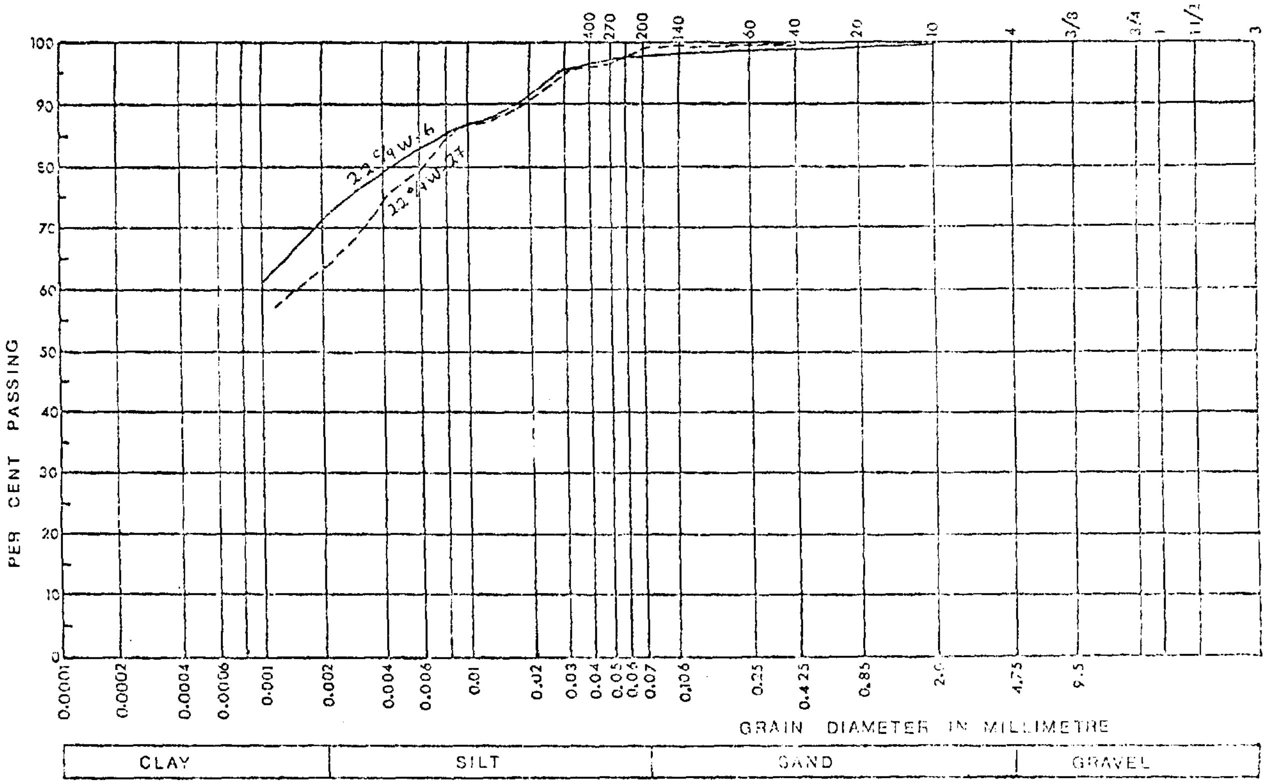


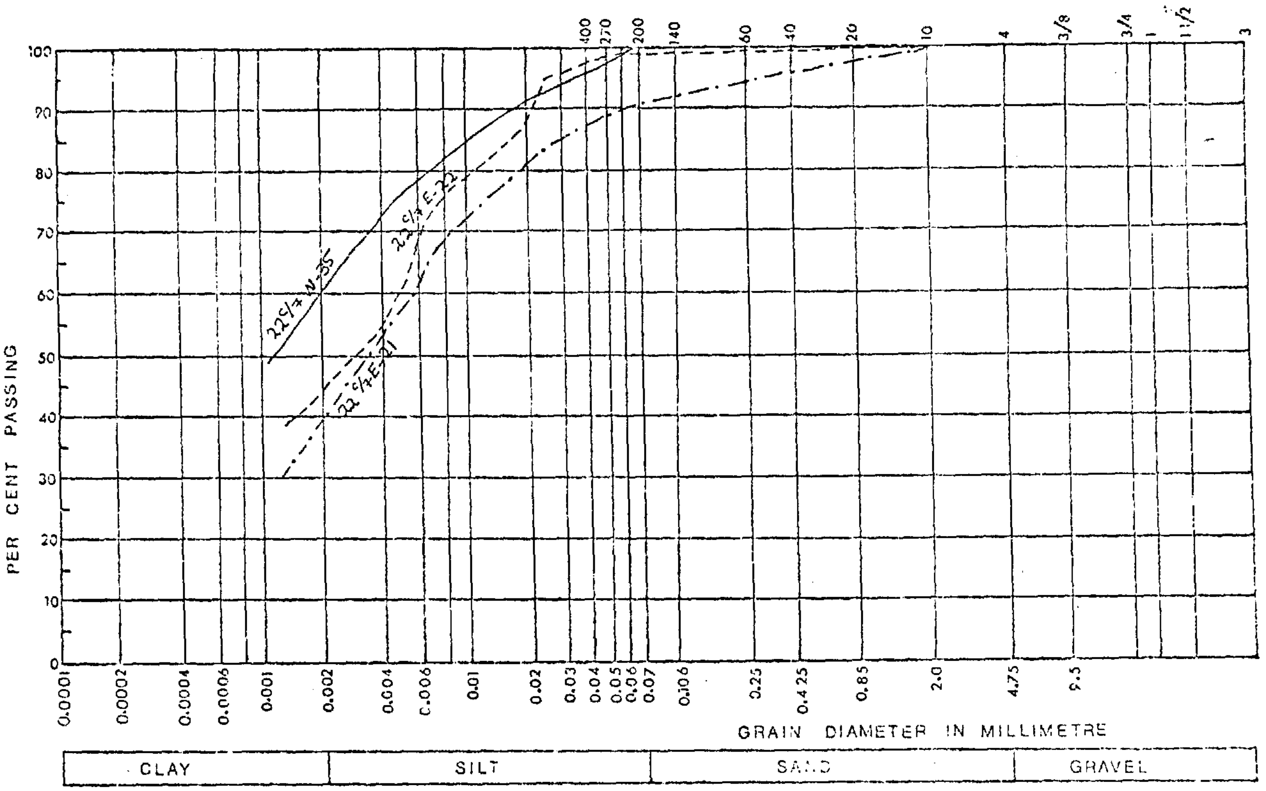


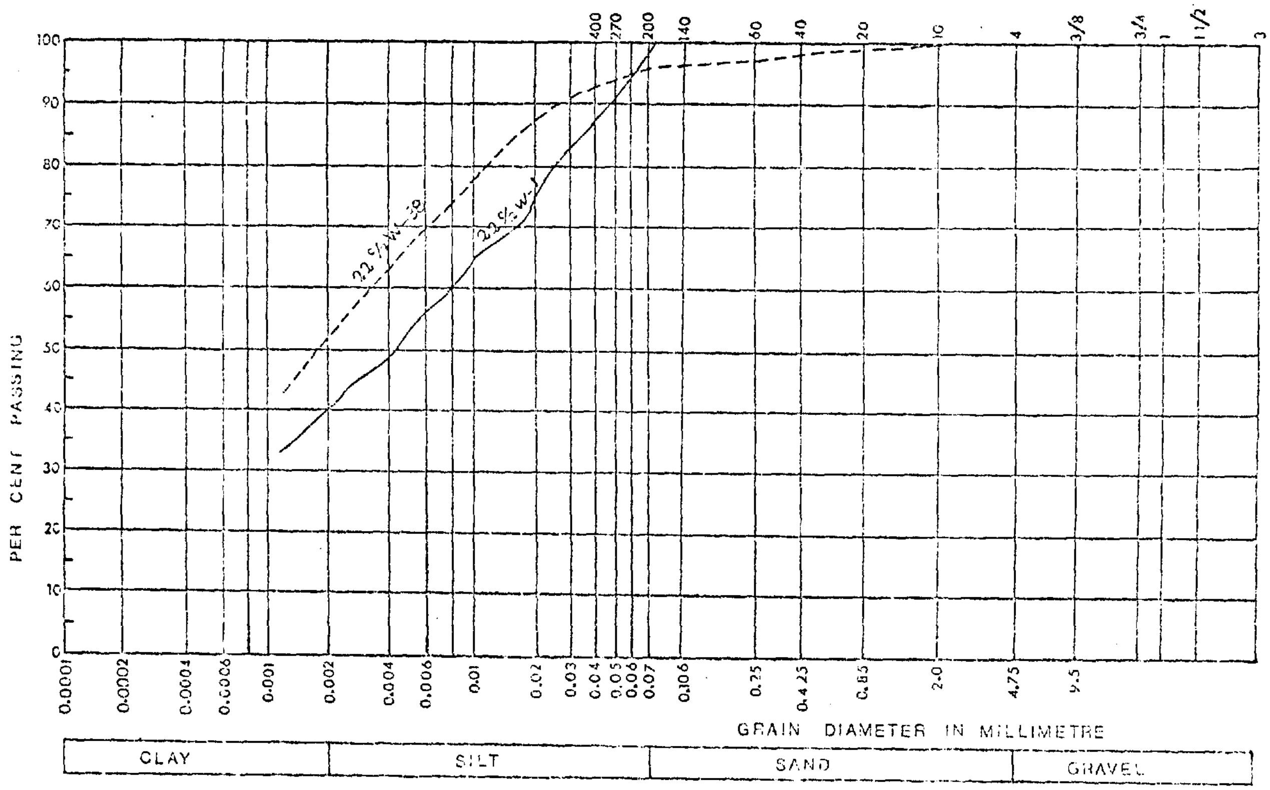

400
270
200
140
60
40
20
10
4
3/8
3/4
1
1 1/2
3
100
90
80
70
60
50
40
30
20
10
0
PER CENT PASSING
22 c/7 W-31
22 c/7 E-35
22 c/7 E-42
0.0001
0.0002
0.0004
0.0006
0.001
0.002
0.004
0.006
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.106
0.25
0.425
0.85
2.0
4.75
9.5
GRAIN DIAMETER IN MILLIMETRE
CLAY
SILT
SAND
GRAVEL


400
270
200
140
60
40
20
10
4
3/8
3/4
1
1 1/2
3
100
90
80
70
60
50
40
30
20
10
0
PER CENT PASSING
22c/7 E-34
22c/9 W-12
22c/7 E-31
22c/7 E-23
0.0001
0.0002
0.0004
0.0006
0.001
0.002
0.004
0.006
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.106
0.25
0.425
0.85
2.0
4.75
9.5
GRAIN DIAMETER IN MILLIMETRE
CLAY
SILT
SAND
GRAVEL

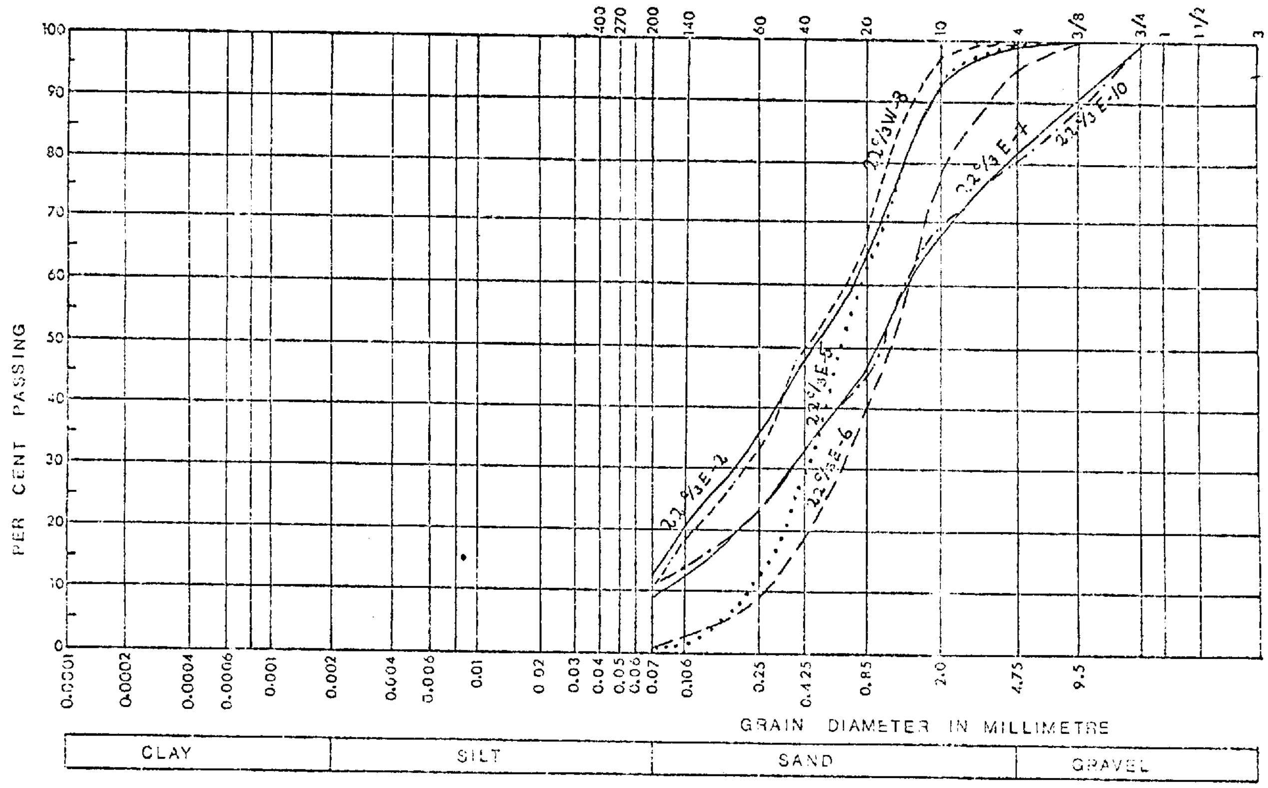

PER CENT PASSING
100
90
80
70
60
50
40
30
20
10
0
400
270
200
140
60
40
20
10
4
3/8
3/4
1
1 1/2
3
0.0001
0.0002
0.0004
0.0006
0.001
0.002
0.004
0.006
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.105
0.25
0.425
0.85
2.0
4.75
9.5
GRAIN DIAMETER IN MILLIMETRE
CLAY
SILT
SAND
GRAVEL
22°/₄W-36
22°/₃E-30
22°/₃E-11

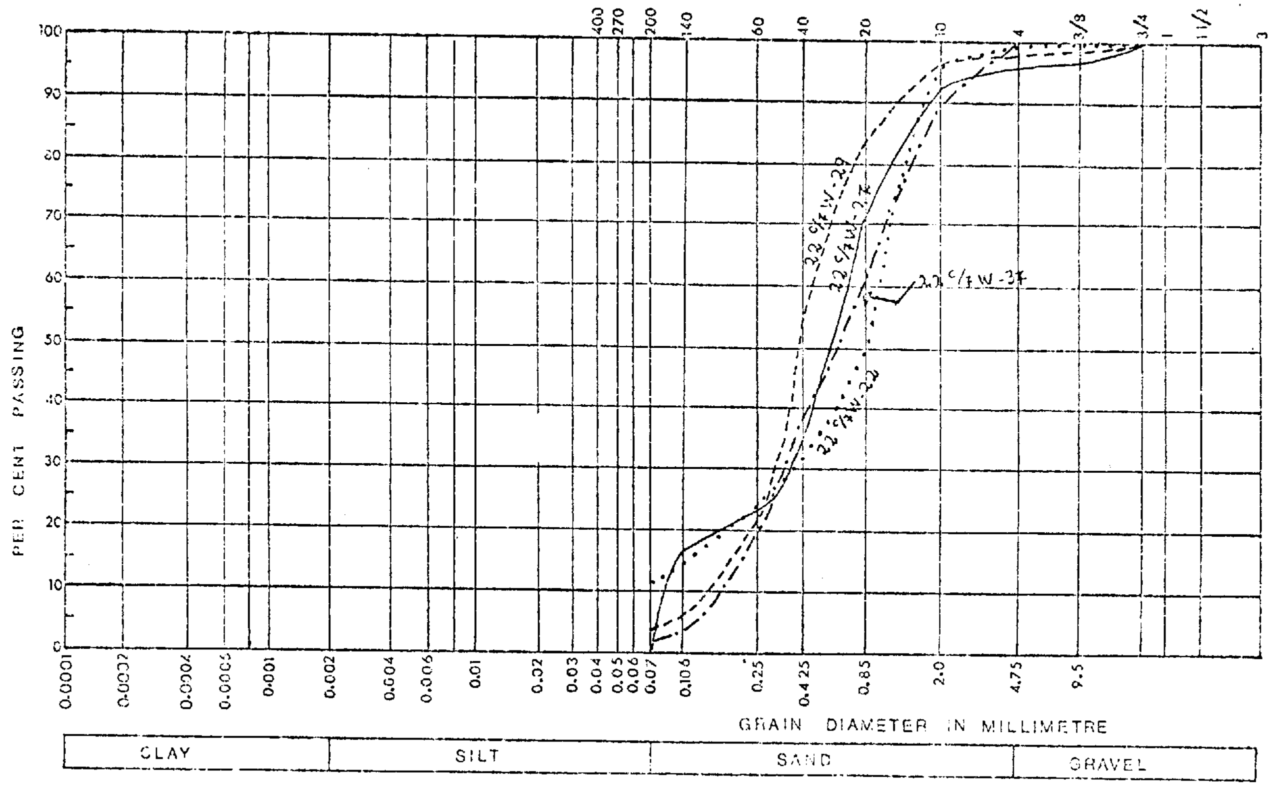

PER CENT PASSING
100
90
80
70
60
50
40
30
20
10
0
400
270
200
140
60
40
20
10
4
3/8
3/4
1
1 1/2
3
0.0001
0.0002
0.0004
0.0006
0.001
0.002
0.004
0.006
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.106
0.25
0.425
0.85
2.0
4.75
9.5
GRAIN DIAMETER IN MILLIMETRE
CLAY
SILT
SAND
GRAVEL
22°/₄W-6
22°/₄W-27

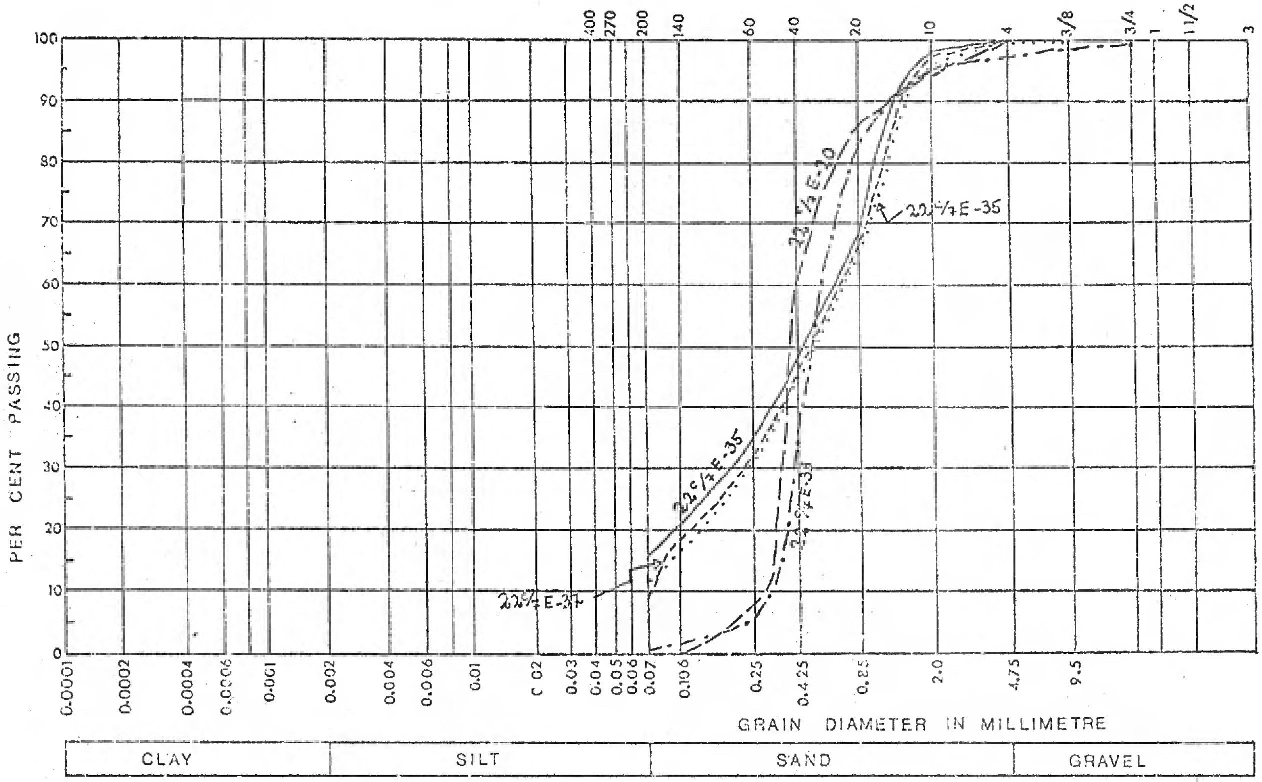

400
270
200
140
60
40
20
10
4
3/8
3/4
1
1 1/2
3
PER CENT PASSING
100
90
80
70
60
50
40
30
20
10
0
22%/4 W-35
22%/4 E-22
22%/4 E-21
0.0001
0.0002
0.0004
0.0006
0.001
0.002
0.004
0.006
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.106
0.25
0.425
0.85
2.0
4.75
9.5
GRAIN DIAMETER IN MILLIMETRE
CLAY
SILT
SAND
GRAVEL


400
270
200
140
60
40
20
10
4
3/8
3/4
1
1 1/2
3
PER CENT PASSING
100
90
80
70
60
50
40
30
20
10
0
22%/W-38
22%/W-1
0.0001
0.0002
0.0004
0.0006
0.001
0.002
0.004
0.006
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.106
0.25
0.425
0.85
2.0
4.75
9.5
GRAIN DIAMETER IN MILLIMETRE
CLAY
SILT
SAND
GRAVEL

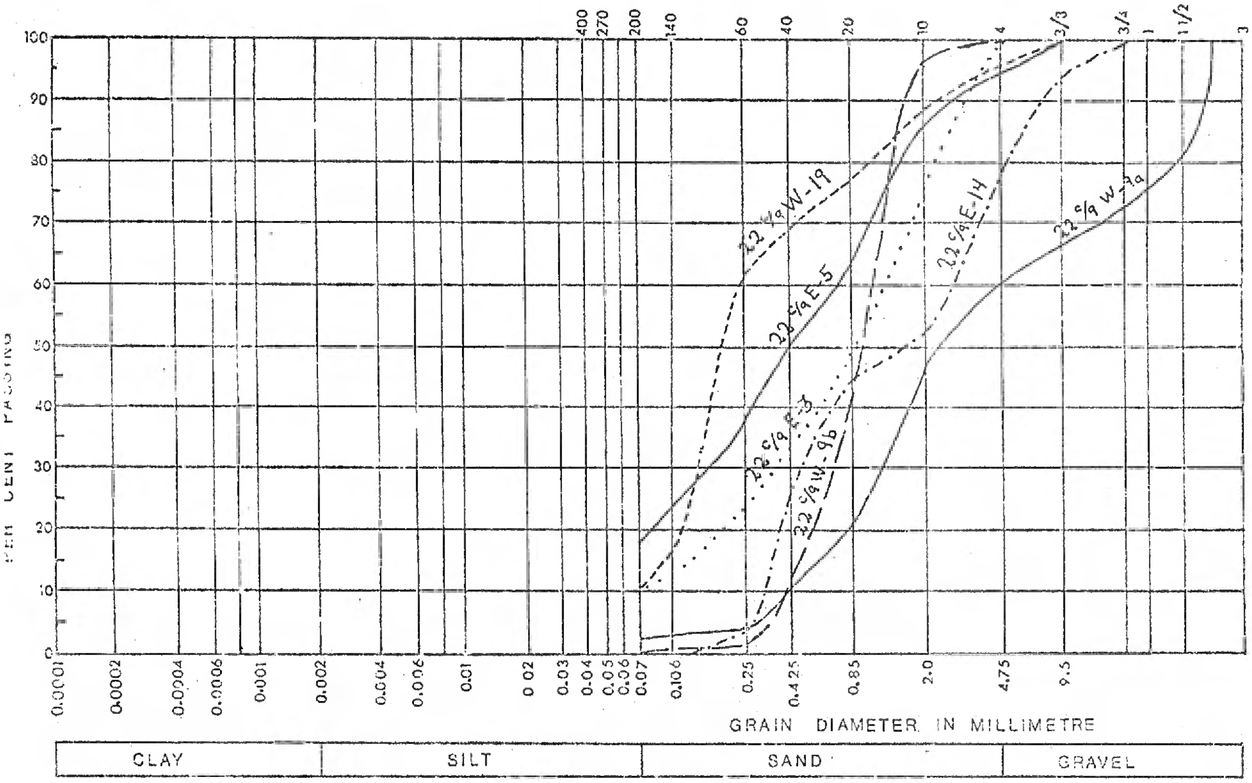
GRAIN-SIZE CUMULATIVE CURVES FOR LITTORAL SEDIMENTS (map unit-8)



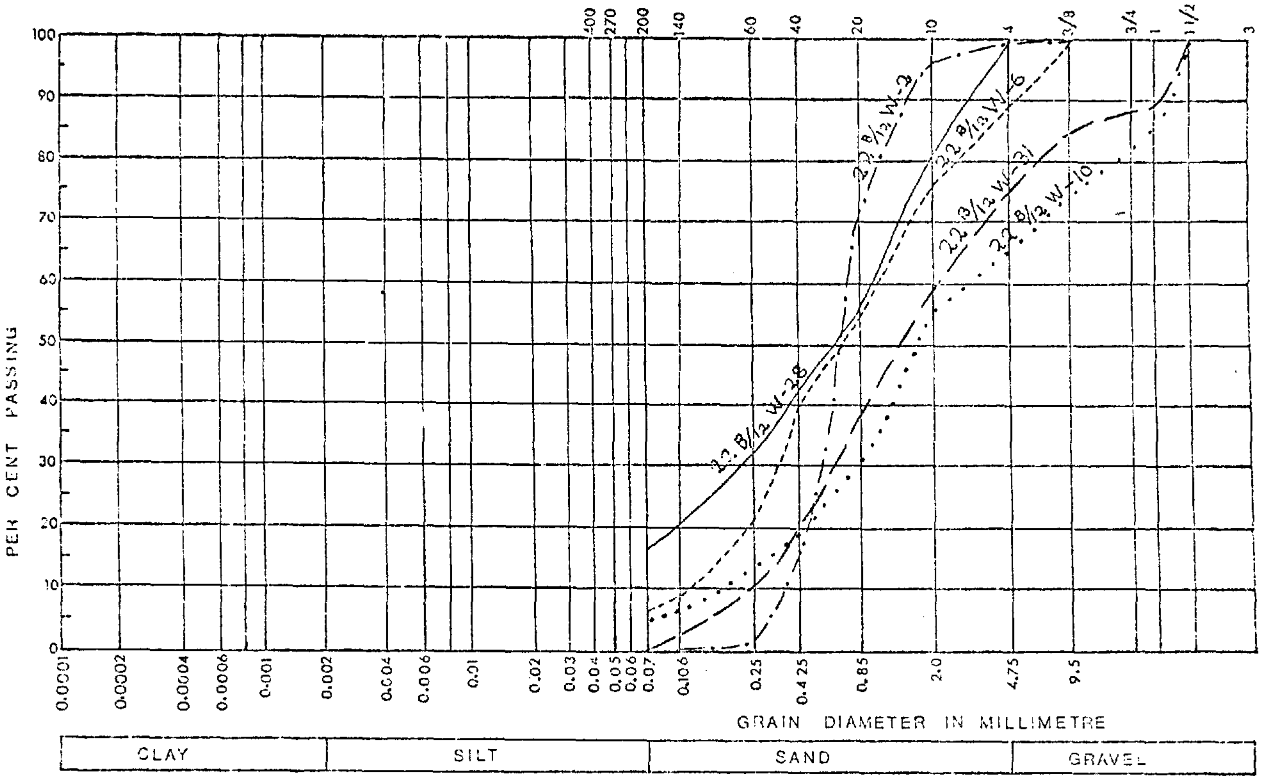




400
270
200
140
60
40
20
10
4
3/8
3/4
1
1 1/2
3
100
90
80
70
60
50
40
30
20
10
0
PER CENT PASSING
22c/7 E-30
22c/7E-35
22c/7E-35
22c/7E-37
22c/7E-33
0.0001
0.0002
0.0004
0.0006
0.001
0.002
0.004
0.006
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.106
0.25
0.425
0.85
2.0
4.75
9.5
GRAIN DIAMETER IN MILLIMETRE
CLAY
SILT
SAND
GRAVEL

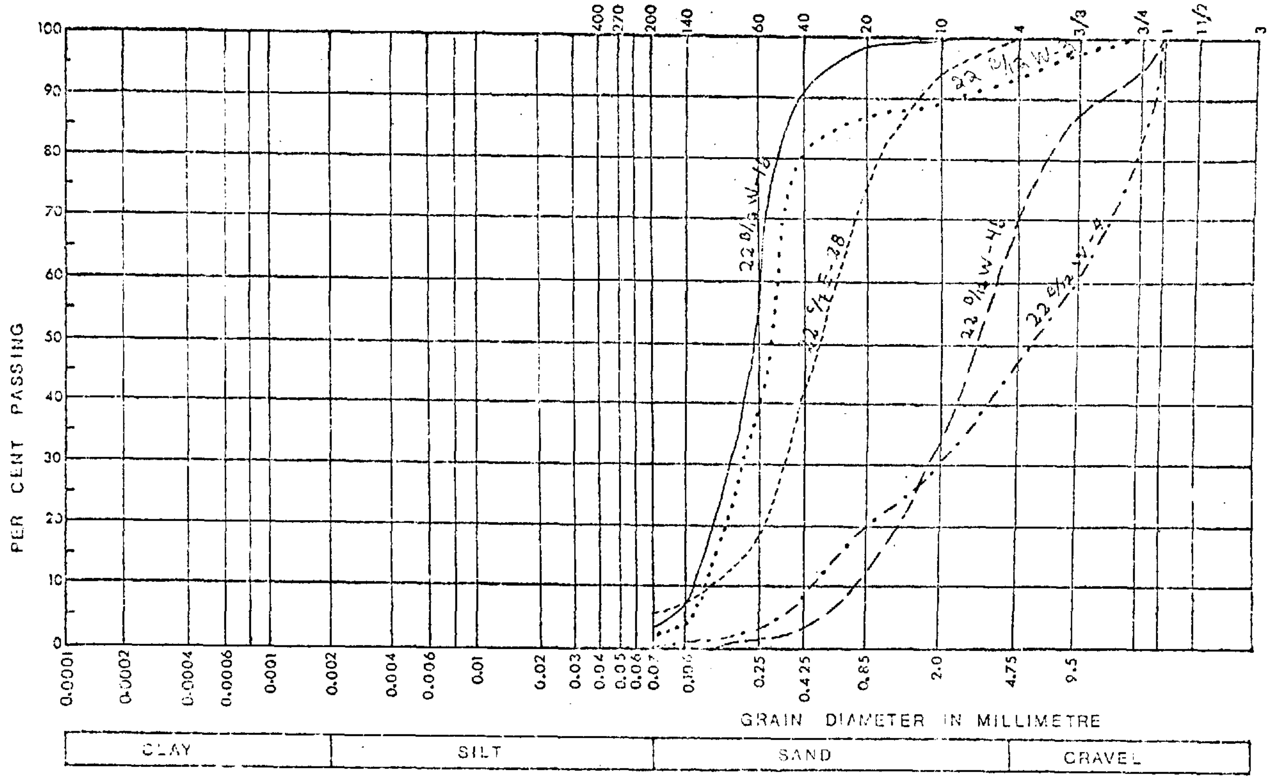


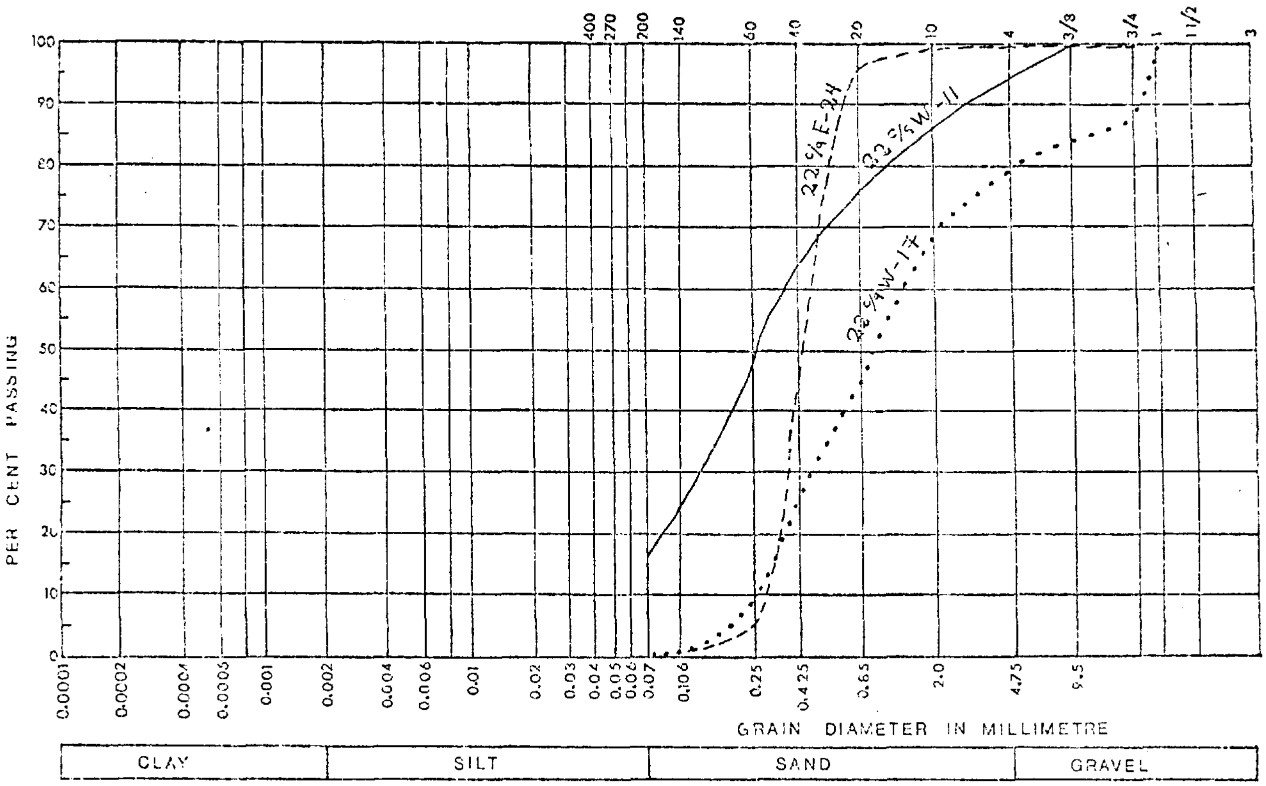
400
270
200
140
60
40
20
10
4
3/8
3/4
1
1 1/2
3
100
90
80
70
60
50
40
30
20
10
0
PER CENT PASSING
22c/9 W-19
22c/9 E-5
22c/9 E-3
22c/9 W-9b
22c/9 E-14
22c/9 W-9a
0.0001
0.0002
0.0004
0.0006
0.001
0.002
0.004
0.006
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.106
0.25
0.425
0.85
2.0
4.75
9.5
GRAIN DIAMETER IN MILLIMETRE
CLAY
SILT
SAND
GRAVEL

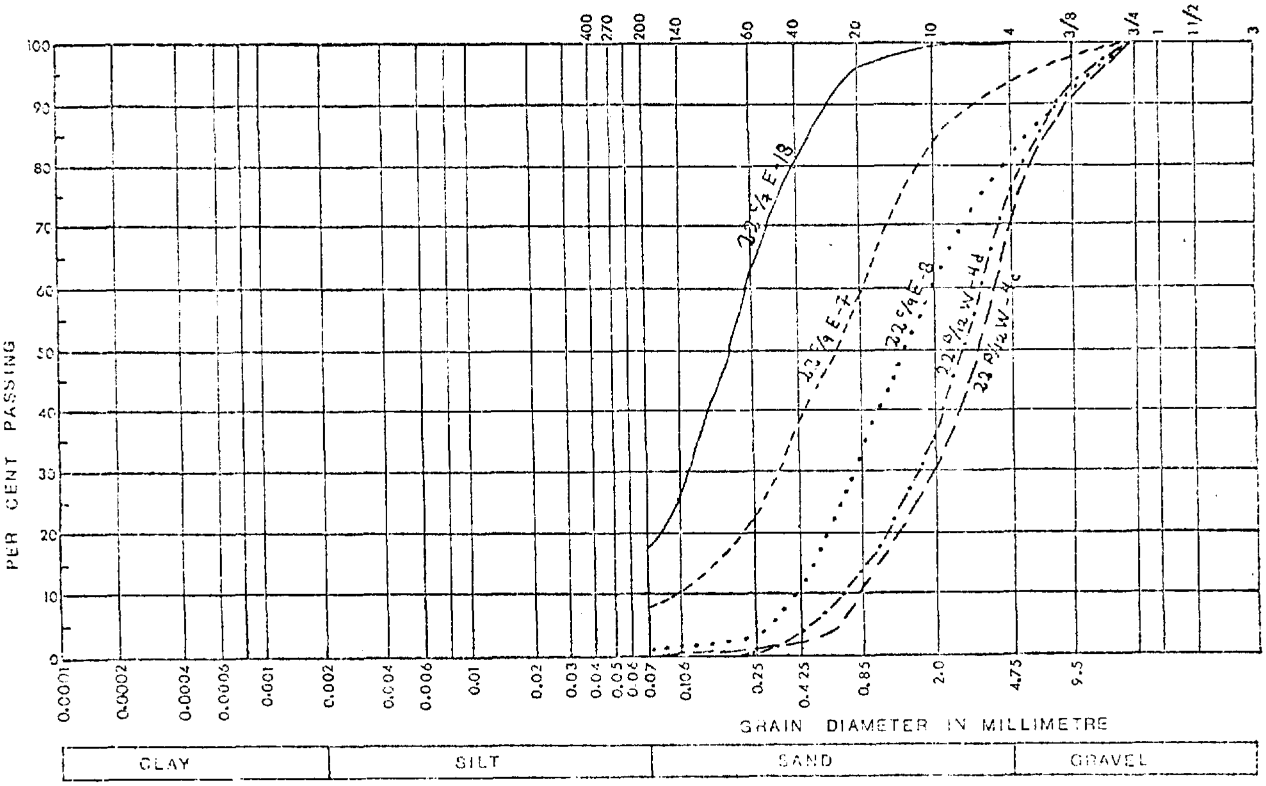


GRAIN-SIZE CUMULATIVE CURVES

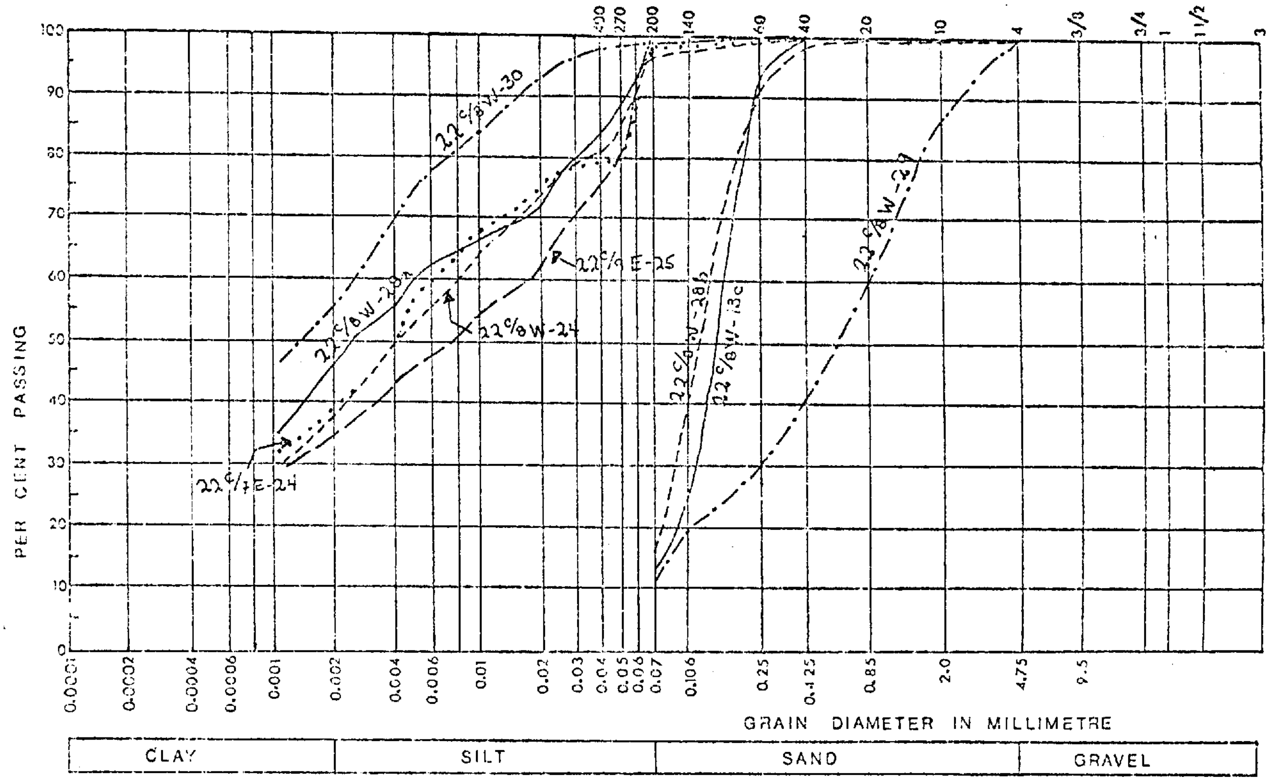
FOR FLUVIAL SEDIMENTS (map unit 9.9A)




400
270
200
140
60
40
20
10
4
3/8
3/4
1
1 1/2
3
100
90
80
70
60
50
40
30
20
10
0
PER CENT PASSING
22 c/4 E-24
22 c/5 W-11
22 c/4 W-17
0.0001
0.0002
0.0004
0.0006
0.001
0.002
0.004
0.006
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.106
0.25
0.425
0.65
2.0
4.75
9.5
GRAIN DIAMETER IN MILLIMETRE
CLAY
SILT
SAND
GRAVEL

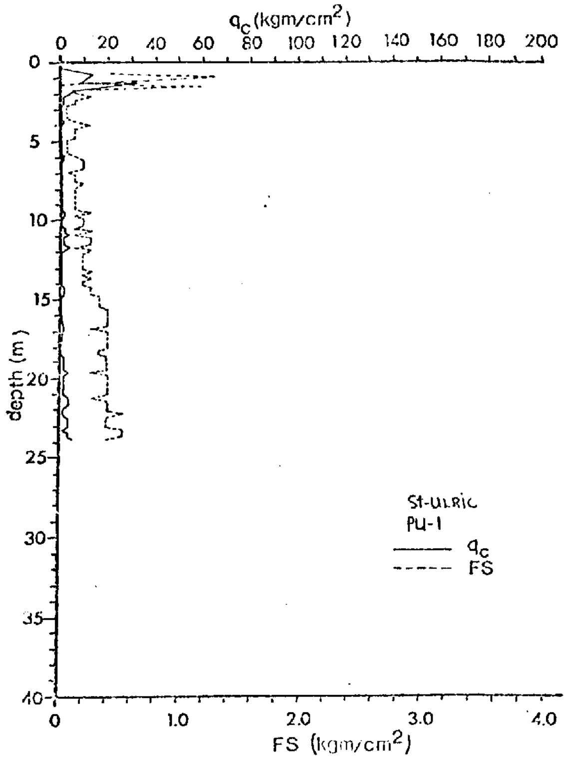

400
270
200
140
60
40
20
10
4
3/8
3/4
1
1 1/2
3
100
90
80
70
60
50
40
30
20
10
0
PER CENT PASSING
22 c/4 E-18
22 c/9 E-7
22 c/9 E-8
22 c/12 W-4d
22 c/12 W-4c
0.0001
0.0002
0.0004
0.0006
0.001
0.002
0.004
0.006
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.106
0.25
0.425
0.85
2.0
4.75
9.5
GRAIN DIAMETER IN MILLIMETRE
CLAY
SILT
SAND
GRAVEL

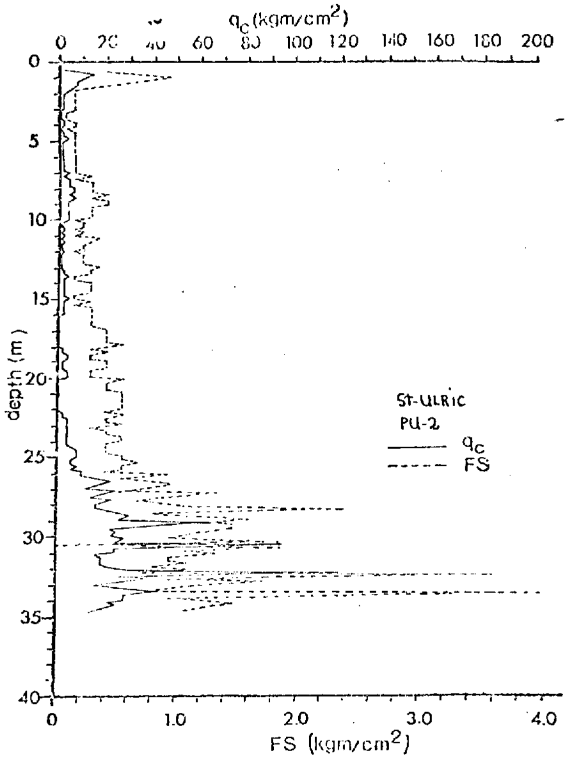
GROUPING OF THE CUMULATIVE CURVES FOR THE NEIGETTE VALLEY
(some were given previously)

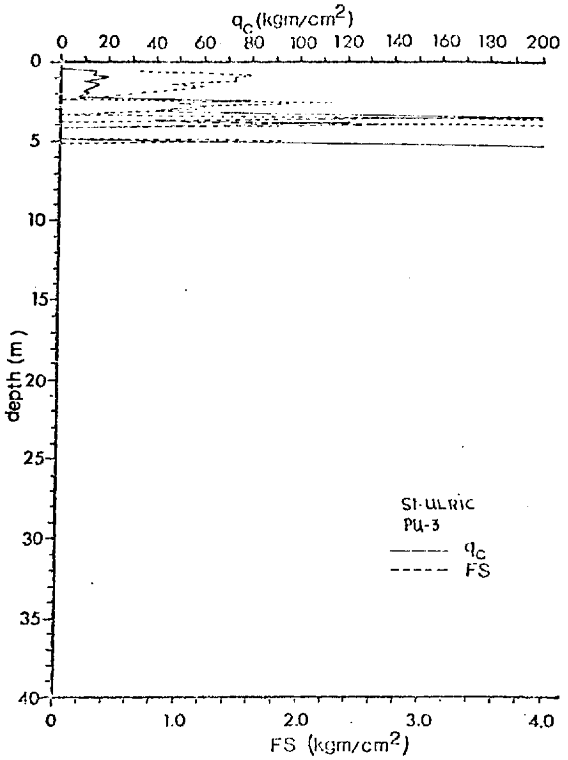


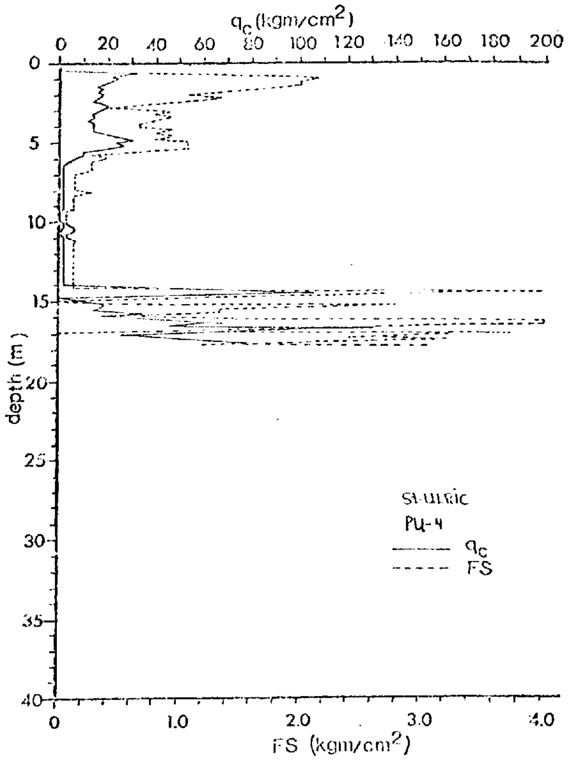
APPENDIX F

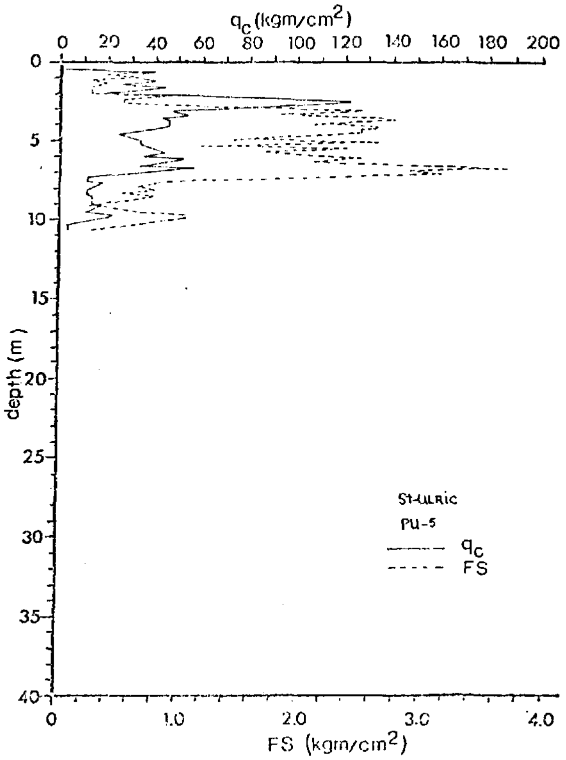
PENETROMETER LOGS
(Static penetrometer)

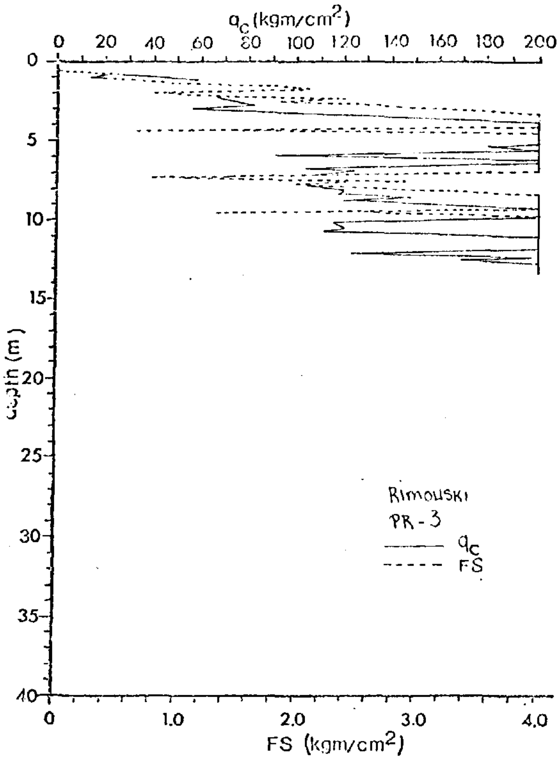


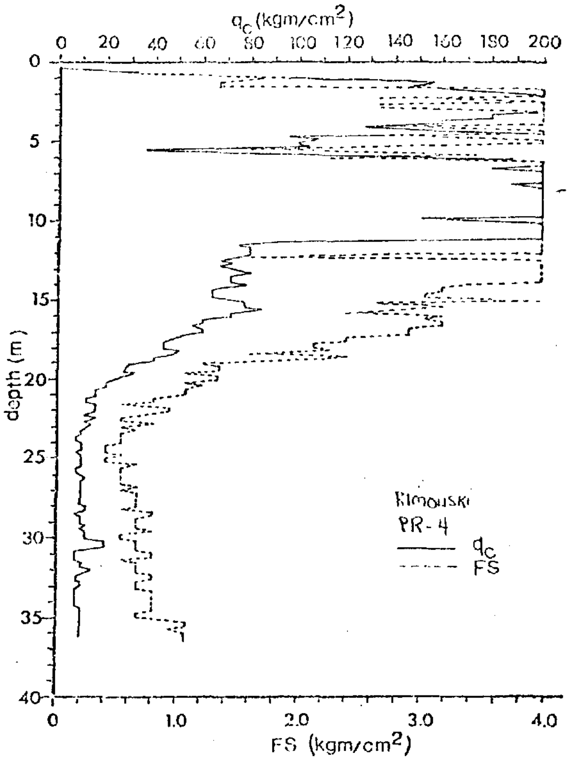


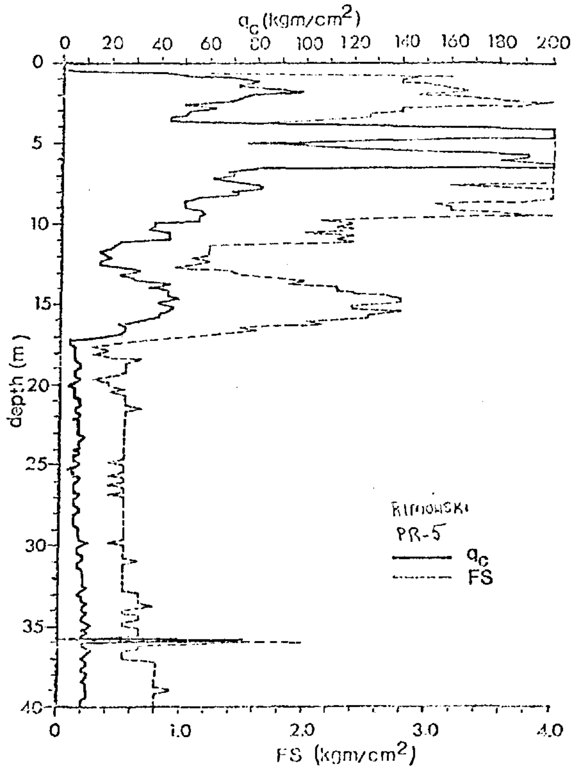


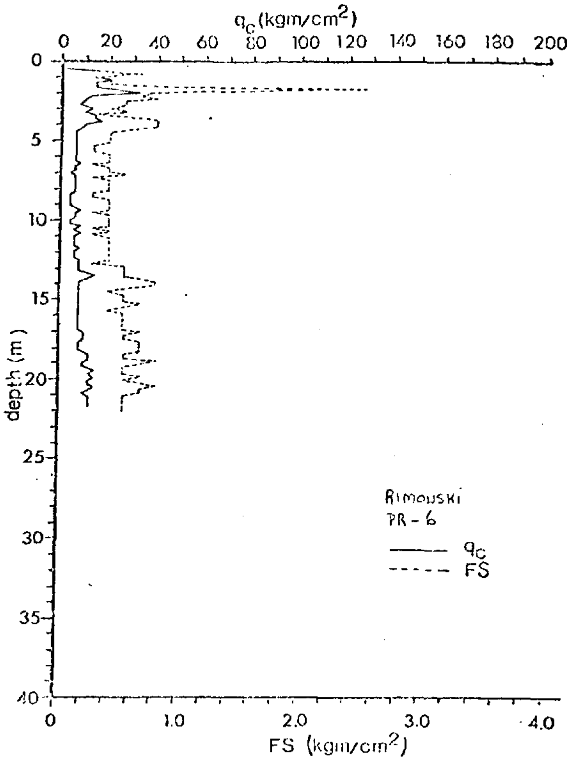


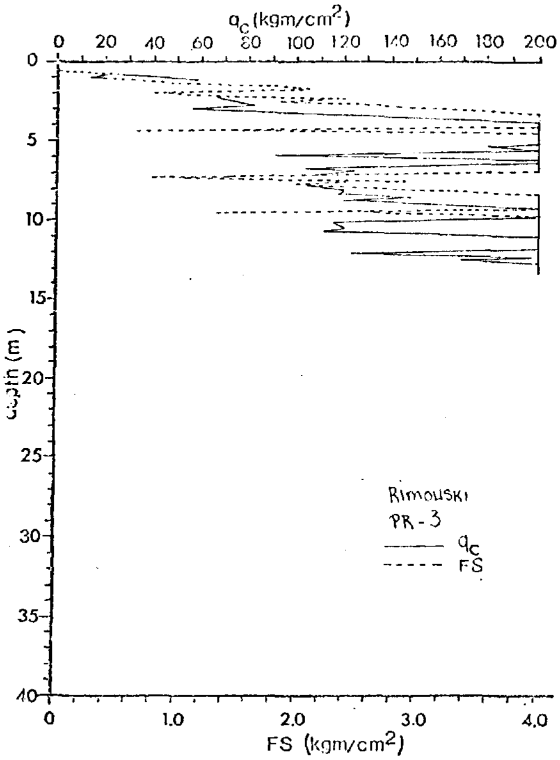

q_c (kgm/cm²)
0 20 40 60 80 100 120 140 160 180 200
depth (m)
0 5 10 15 20 25 30 35 40
St-ULRIC
PU-5
q_c
FS
0 1.0 2.0 3.0 4.0
FS (kgm/cm²)

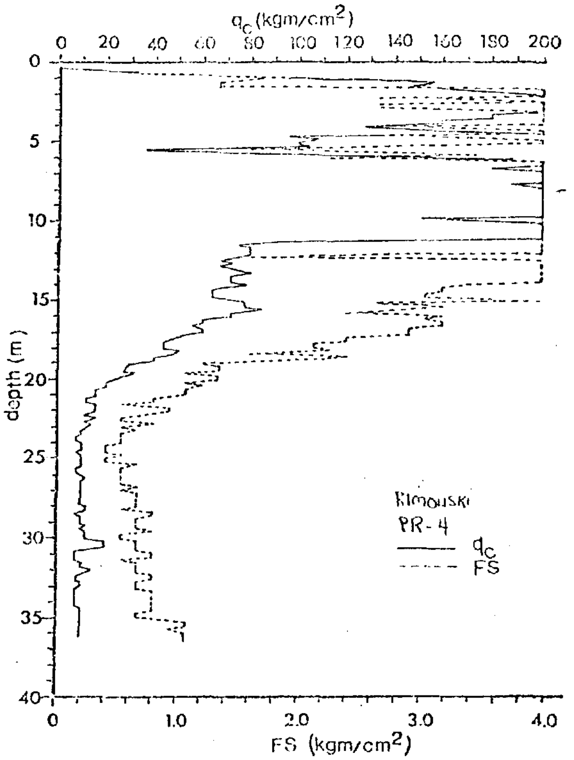

q_c (kgm/cm^2)
0 20 40 60 80 100 120 140 160 180 200
depth (m)
0 5 10 15 20 25 30 35 40
0 1.0 2.0 3.0 4.0
FS (kgm/cm^2)
Rimouski
PR-3
q_c
FS

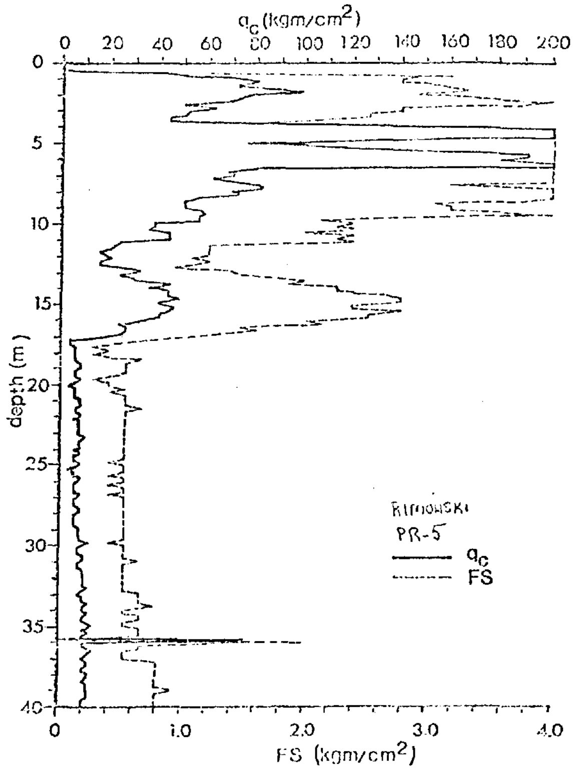

q_c (kgm/cm^2)
0 20 40 60 80 100 120 140 160 180 200
depth (m)
0 5 10 15 20 25 30 35 40
0 1.0 2.0 3.0 4.0
FS (kgm/cm^2)
Rimouski
PR-4
q_c
FS

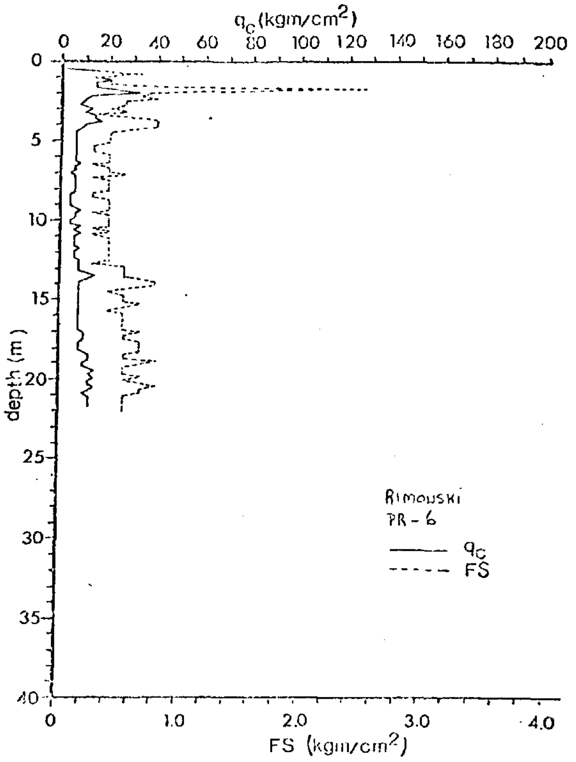

q_c (kgm/cm^2)
0 20 40 60 80 100 120 140 160 180 200
depth (m)
0 5 10 15 20 25 30 35 40
0 1.0 2.0 3.0 4.0
FS (kgm/cm^2)
Rimouski
PR-5
q_c
FS


q_c (kgm/cm^2)
0 20 40 60 80 100 120 140 160 180 200
depth (m)
0 5 10 15 20 25 30 35 40
0 1.0 2.0 3.0 4.0
FS (kgm/cm^2)
Rimouski
PR-6
q_c
FS


qc (kgm/cm2)
0 20 40 60 80 100 120 140 160 180 200
depth (m)
0 5 10 15 20 25 30 35 40
Rimouski
PR-3
qc
FS
0 1.0 2.0 3.0 4.0
FS (kgm/cm2)


qc (kgm/cm2)
0 20 40 60 80 100 120 140 160 180 200
depth (m)
0 5 10 15 20 25 30 35 40
Rimouski
PR-4
qc
FS
0 1.0 2.0 3.0 4.0
FS (kgm/cm2)


qc (kgm/cm2)
0 20 40 60 80 100 120 140 160 180 200
depth (m)
0 5 10 15 20 25 30 35 40
Rimouski
PR-5
qc
FS
0 1.0 2.0 3.0 4.0
FS (kgm/cm2)


qc (kgm/cm2)
0 20 40 60 80 100 120 140 160 180 200
depth (m)
0 5 10 15 20 25 30 35 40
Rimouski
PR-6
qc
FS
0 1.0 2.0 3.0 4.0
FS (kgm/cm2)