1986TS027

GEOLOGICAL CHARACTERISTICS OF THE MONTREAL REGION RELEVANT TO THE DISPOSAL OF LIQUID WASTE IN DEEP WELLS

FICHE DESCRIPTIVE DE DOSSIER

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Numéro du dossier :	1986TS027	Code gouvernemental :	0025 ()
Nom du dossier :	RAPPORT DES TRAVAUX / 1986RS027		
Informations supp. :			
Grande-catégorie :	PERM	Permis	
Catégorie :	TS	Rapport statutaire	
Sous-catégorie :	G	Général	
Intervenant :	Tioxide		Actif (O/N) : O
Archivé ou Indexé[1] :		Numéro de GM[2] :	
Date d'indexation[3] :	/ /		Classeur : 6
Date pré-archivage[3] :	/ /		Tiroir : 0
No pré-archivage :	0		Boite : 0

Groupe Exploration 29/08/97

Légende:

1 A: Archivé; I: Indexé.
2 Le numéro de GM correspond au numéro tel que spécifié par le Secteur des mines.
3 Format de la date: AA/MM/JJ.

REPORT NO. 1669-0-1
GEOLOGICAL CHARACTERISTICS OF THE MONTREAL REGION RELEVANT TO THE DISPOSAL OF LIQUID WASTE IN DEEP WELLS

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FEBRUARY 24, 1984

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SUMMARY

This report entails the results of the review and assessment of the geologic characteristics of the subsurface materials underlying the Montreal Region, with emphasis on the Varennes and Sorel areas. The purpose of the study was to evaluate the geologic suitability of the subsurface strata for the disposal of liquid waste in deep wells.

The study region is underlain by glacial till, marine clay and sand deposits, which attain a combined thickness of approximately 100 ft in the Varennes area, and more than 200 ft in the Sorel area. These soils are underlain by the near horizontally layered sedimentary rocks which extend to an elevation of approximately 5000 ft below sea level in the Varennes area, and 3700 ft below sea level in the Sorel area. In both areas the sedimentary rocks are underlain by the Precambrian basement rocks, predominantly granites and granitic gneisses.

The sedimentary rock strata comprise, from the bottom up, the sandstones and conglomerates of the Potsdam group, the dolomites of the Beekmantown group, the dolomitic limestones and shales of the Chazy group, the limestones of the Black River and Trenton groups, and the shales of the Utica, Lorraine and Richmond groups.

In general, a potentially suitable disposal well must have geological strata at the injection section with sufficient porosity, permeability and volume to act as a reservoir. The disposal strata must be isolated from fresh water sources and life environment by impervious caprock confinement. In the satisfaction of these general requirements, two reservoir - caprock scenarios may be considered in the Montreal Region,

a) reservoir in the Precambrian basement rocks, and b) reservoir in the Potsdam group of sandstones and conglomerates.

The results of the assessment of the two scenarios indicate that in terms of mineralogical and structural homogenity, hydrogeology, porosity, permeability, chemical inertness and seismo-tectonic considerations the Potsdam group of sandstones and conglomerates appears to be superior to the Precambrian igneous basement rocks for the purpose of deepwell disposal of liquid waste.

In the Varennes area the potentially suitable reservoir horizons may be found in the Covey Hill formation of the Potsdam group, located approximately between the elevations of 5000 ft and 4000 ft below sea level. The reservoir must be isolated by adequate confinement from the fresh water sources in the Trenton limestone, located between the elevations of approximately 2230 ft and 1600 ft below sea level. This confinement is provided by the relatively impervious dolomites, dolomitic limestones, shales and shaly sandstones in an aggregate thickness of approximately 1700 ft.

In the Sorel area the potentially suitable reservoir horizons may also be found in the Potsdam group of sandstones located approximately between the elevations of 3700 ft and 3300 ft below sea level. Isolation from the aquifers of the Trenton group, located between the elevations of 2550 ft and 1800 ft below sea level, approximately, is provided by the relatively impervious and predominantly dolomitic rocks of the Beekmantown and Chazy groups, in an aggregate thickness of approximately 750 ft.

The results of the review and assessment of the available geologic data indicate that the Varennes and Sorel areas may be ranked as areas geologically suitable for the deepwell disposal of liquid waste, warranting further study and subsurface exploration.

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1. INTRODUCTION

Today the public is experiencing an unprecedented increase in the awareness of the need for a safe and healthy environment. Some of the results of this awareness are the restrictions imposed on the disposal of industrial wastes.

The injection of liquid wastes into deep wells may provide an economical and acceptable method of disposal when concentrated, toxic or odorous wastes must be disposed of in an area having strict pollution control regulations. The deepwell disposal method has been practiced in North America for the last 25 years.

Fundamentally the method involves the underground storage of liquid wastes in the pores and fracture voids of an isolated geological formation which already contains water unobtainable or unusable. Although simple and recommendable in concept, the legal and technical procedures required for deepwell disposal may be complicated, and most importantly, the disposal area must be geologically suitable for deepwell disposal practices.

A suitable well must have geological formations at the injection point with sufficient porosity, permeability, and volume to act as a reservoir. The injection horizon, which is the level at which the waste liquid will be stored, should be well below the level of the circulation of fresh water used for human consumption. Generally sandstones, limestones, and certain Precambrian igneous rocks may form geologically suitable reservoir horizons.

The disposal strata must be isolated from freshwater aquifers by impermeable confinement, provided by materials such as shale, evaporites and clay. If the reservoir rocks contain oil, gas or other resources, the protection of these must be observed. The lateral movement of the injected waste in the reservoir must be anticipated, since the waste may find its way into previously drilled wells which project through the reservoir level at some distance from the injection well. Areas of volcanic rock intrusions are generally not suitable because of inherent fissures and fractures which may allow the escape of waste into fresh water sources. Reactions between the waste material and the reservoir rocks may be either counterproductive or beneficial to waste disposal. The reactions with the soluble carbonates could be beneficial to the reservoir volume if no undesireable precipitates result. Plugging of voids and pores may be caused by some precipitates, solids or suspended matter. Seismo-tectonic stress field in the reservoir region must be such that the induced reservoir pressures do not cause sudden stress adjustments.

In this report the geological, structural and tectonic characteristics of the rock groups and formations underlying the St. Lawrence Lowland are reviewed, discussed and evaluated, with reference to the Montreal Region in general, and the Varennes and Sorel areas in particular, relevant to the deepwell waste disposal practice. The information analyzed entails regional soil survey maps, geologic and structural maps, groundwater survey maps, tectonic and seismic criteria, water well logs, exploration drilling logs, site specific data from previous projects, and related reports and publications.

2. GEOLOGIC EVOLUTION OF THE REGION

The Montreal Region, comprising for the purpose of this study the city of Montreal and its surroundings to the northeast as far as Sorel, is located in the physiographic subdivision of Central St. Lawrence Lowland (Fig. 1). In the Province of Quebec this Lowland includes the area between the Ottawa and St. Lawrence Rivers, straddles the St. Lawrence River as far as Quebec City, and extends a short distance beyond on the north shore only. Physiographically it is a lowland bounded on the northwest by the Laurentian Upland, on the southeast by the Appalachian Highland, and on the south by the Adirondack Massif. Geologically the Central St. Lawrence Lowland is a low-lying plain underlain by relatively unfolded Paleozoic rock formations of sedimentary origin. The rock strata are arranged in a northeasterly trending synclinal structure, the axis of which lies southeast of the St. Lawrence River.

A resume of the evolution of the Central St. Lawrence Lowland in terms of geologic events and time is given in Table 1 at the end of this section.

The Laurentian Upland, bordering the Central St. Lawrence Lowland on the northwest, is formed mainly by igneous and volcanic rocks of the Precambrian time. In a few areas within the Montreal Region small outcrops of Precambrian basement rocks can be seen and consequently it is assumed that the sedimentary rocks of the Central St. Lawrence Lowland are underlain by Precambrian rocks generally similar to those of the Laurentian Upland. At the beginning of the Cambrian Period the basement was probably an upland of moderate relief, undergoing erosion.

Late in the Cambrian Period the waters of the expanding Appalachian geosyncline southeast of the Montreal Region began to invade the Precambrian uplands. The invading sea deposited muddy sands, which after repetitious shifting and washing became the constituents of the sandstone and conglomerate formations of the Cambrian Period. These rock formations constitute the Potsdam group.

At the end of the Cambrian Period the sea became shallow to lagoonal, which resulted in the deposition of dolomite. As the shallow and fluctuating sea kept pace with the submerging land, the dolomitic deposits of the Upper Cambrian-Lower Ordovician Period attained a considerable thickness. Interbedded with some limestone and shale, these rocks form the Beekmantown and Chazy groups.

The events of the Ordovician Period relevant to the Central St. Lawrence Lowland are characterized by repetitious invasions and withdrawals of the seas. During the invasion periods mainly detrital sediments were deposited by the seas, and formed subsequently into interbedded sandstones and shales. As the water depth increased, limestones were formed. In the Middle Ordovician Period Quebec with the rest of North America experienced one of the greatest submergencies of all geologic time, and great thicknesses of limestone were deposited within the boundaries of the Central St. Lawrence Lowland. These limestones constitute the Trenton group.

The end of the Ordovician Period is characterized by rapid, massive deposition of mud, which had its source in the now rising Appalachian geosyncline southeast of the Montreal Region. The muds subsequently became the thick shale deposits of the Upper Ordovician Period known as the Utica, Lorraine and Richmond groups. These shales are the last of the inherent sedimentary rock formations to be found in the Montreal Region.

At the close of the Ordovician Period the rising of the Appalachian geosyncline intensified, culminating in the Taconic Orogeny and the formation of the first generation of the Appalachian Mountains. The Montreal Region was relatively close to this crustal disturbance, and as a consequence, the horizontal strata of the sedimentary rocks underlying the region became gently folded, faulted and regionally tilted.

The record of the geologic evolution of the Montreal Region during the late Paleozoic and early Mesozoic Eras is fragmentary. A sea was spread over most of Southern Quebec and presumably limestone formations were accumulated, but subsequent withdrawal of the sea, followed by erosion of long duration, erased all evidence of events between the Devonian Period and the Cretaceous Period.

In the Early Cretacious Period the Montreal Region experienced volcanic activity, the result of which was the formation of the Monteregian Hills (Mounts Royal, Saint-Bruno, Saint-Hilaire, Rougemont, Johnson, Yamaska, Shefford, and Brome). The volcanic activity was accompanied by the intrusion of satellitic dykes and sills into the sedimentary rock formations adjacent to the Monteregian Hills.

The events of the remainder of the Cretaceous Period and all of the Tertiary Period are characterized mainly by erosion, until the commencement of the glaciation and the accumulation of the glacial deposits in the Quaternary Period. As a result of the subsequent deglaciation the Central St. Lawrence Lowland was occupied by the Champlain Sea from about 13 000 to 10 000 years ago, and the older glacial deposits were covered by marine clays and sands. The disappearance of the Champlain Sea left the form of the land surface of the Montreal Region much as seen today.

In summary, the rock forming processes resulting from the crustal submergencies and emergencies are clearly reflected in the stratigraphic column of the Montreal Region. The ancient crystalline basement rocks are overlain, first, by the relatively coarsely detrital, durable sediments (sandstones) derived from pre-existing rocks by disintegration and sorting of long duration. These are followed by carbonate deposits (dolomites and limestones) of largely chemical origin (physico-chemical, inorganic and biochemical) formed in relatively deep seas. And lastly the argillaceous rocks (shales, siltstones), originally silt and clay muds, the well sorted, very fine grained products of rock decomposition and long-continued transportation.

TABLE 1

GEOLOGIC HISTORY OF THE ST. LAWRENCE LOWLAND

Eras	Periods	Millions of years B.P.	Events
	Quaternary		Montreal today. Glaciation and Champlain
Cenozoic		1	submergence.
			Erosion
	Tertiary		
			Igneous activity.
		60	Monteregian Hills.
	Cretaceous		
		140	
Mesozoic	Jurassic		
		175	
	Triassic		Erosion
		200	
	Permian		
		240	
	Carboniferous		
		310	
	Devonian		Short submergence
		350	
	Silurian		Emergence and erosion
		380	
			Taconic mountain building. Deposition of shales. Utica,
Paleozoic			Lorraine and Richmond groups.
	Ordovician		
			Deposition of limestones Trenton group Continued submergence Deposition of dolomite Beekmantown and Chazy groups
		450	Deposition of sedimentary strata,
	Cambrian		predominantly sandstone Potsdam group.
			Marine inundation
		540	Precambrian upland
	Late		Long continued erosion of
Precambrian		1000	mountainous terrain.
	Early		Igneous and volcanic basement rocks, crystalline.
		2000+	

Project No.: 1669-0 Figure No.: 1

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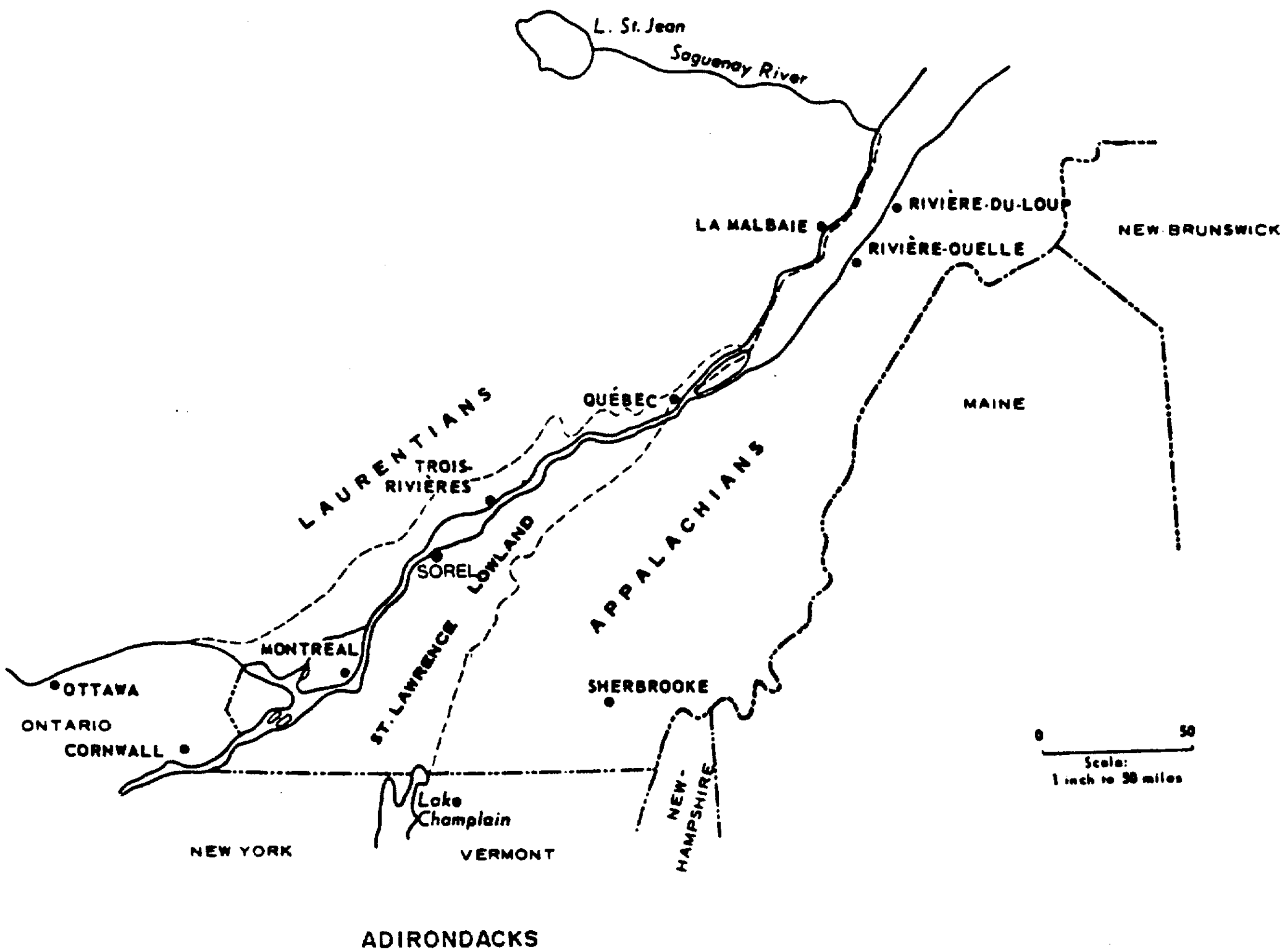

FIG. 1 ST. LAWRENCE LOWLAND LOCATION PLAN

3. SURFICIAL DEPOSITS

The Quaternary Period, which began approximately one million years ago, consists of four glacial advances and interglacial periods. The present time can be regarded as the last of the interglacial periods, which so far has lasted somewhat less than 10 000 years.

The mantle of overburden that overlies the bedrock surface of the Montreal Region is the result of glacial and related events of the last, or Wisconsinan Glacial Stage, the last 125 000 years of the earth's history (Fig. 2). The elevations of the bedrock surface at Varennes and Sorel are in the range of 10 m (30 ft) and 55 m (165 ft) below sea level, respectively.

3.1 Tills

The final retreat of the Wisconsinan glaciers left behind a thick covering of glacial till, an unsorted, unstratified mixture of silt, clay, sand, gravel and boulders. The till commonly rests directly on the bedrock, occurring in ridges, mounds and flats. Being uneven in composition, it is also uneven in distribution and thickness.

In the Montreal Region three types of till have been recognized, as shown in table below:

TABLE 2

Tills of the Montreal Region

Time of deposition years B.P.	Geological Unit	Description
12 500		
	Upper till	Clay-silt till, locally sandy or stony where directly overlying gravels, stony till on bedrock.
25 000		
	Middle till	Glaciolacustrine clay and silt. Glacio fluvial sand and gravel. Glacial silty sand, in places cobbly to bouldery
55 000		
	Basal till	Dense, variably stony silt-sand till. Commonly bouldery. Believed to rest on bedrock.
70 000		

The Basal till is generally a stony, silty material with many cobbles and boulders, has a density of 135 to 155 lbs/ft^3, and an unconfined compressive strength of 3 to 4 t/ft^2. In most cases an acceptable foundation medium, it is relatively expensive to excavate, and difficult to compact when its water content is above optimum.

The Middle till is a stratified deposit, occasionally extremely quick (quicksand) when saturated, and subjected to vibration. It is generally well compacted, and steep slopes stand well in excavations, except where the till is excessively wet. The unconfined compressive strength of the Middle till drops on the average from 7 t/ft^2 to 1 t/ft^2, as the moisture content increases from 15 to 23 percent.

The Upper till is a stone-poor silty till with unit weight in the range of 115 to 135 lbs/ft^3. The N value (blow count) in the standard penetration test is typically between 20 and 30.

In the Varennes and Sorel areas the till, predominantly of the Basal type, has a thickness in the range of 5 m (15 ft).

3.2 Marine Clays and Sands

After the Wisconsinan glaciers had retreated north from the study region, the Champlain Sea spread up the St. Lawrence Valley. Clay was deposited in the deep water of the sea.

The marine clay ranges generally from a sandy clay to an inorganic clay of high plasticity with a sensitivity of 3 to 10. The typical liquid limit of 70 percent is frequently approached, and readily exceeded when the clay is exposed in excavations.

Some of the physical characteristics of the clay of the Montreal Region are tabulated below.

TABLE 3

Atterberg Limits of the Marine Clay

Property	Range	Average
Natural water content, %	40-76	57
Liquid limit, %	34-78	59
Plastic limit, %	16-43	27
Plasticity index	6-47	32

The in-situ shearing resistance of the Champlain clay is in the range of 500 to 1500 lbs/sq. ft.

In the Varennes area the marine clay is approximately 90 ft thick, overlain in places by relatively thin deposits of sand and gravel. In the Sorel area the clay is about 120 ft thick, overlain by sands and gravels which may attain a combined thickness of 100 ft or more.

3.3 Emanations of Gas

One of the inherent functions of the marine clay in the general vicinity of Montreal is its efficient capping of natural gas, which has been struck by wells, in many cases at the surface of the bedrock. Some of the more significant gas occurrences are tabulated below:

TABLE 4

Gas Occurrences in the Central St. Lawrence Lowland Region

Location	Year of boring	Initial yield (cu. ft/day)
Mascouche	1885	50,000
St-Grégoire	1883	100,000
Yamachiche	1905	200,000
Verchères	1907	250,000
Pointe du Lac	1955	5,000,000

In these and many other wells the gas apparently emanates from overburden near the bedrock surface or from the surface layer of the bedrock below, as a rule explosively. Although natural gas has been used in former times domestically by some of the inhabitants of the St. Lawrence Lowland, nowhere in the Montreal Region has gas been found in commercial quantities. During drilling and excavation works the possible occurrences of natural gas at the overburden - bedrock contact in areas of relatively thick marine clay deposits have to be considered.

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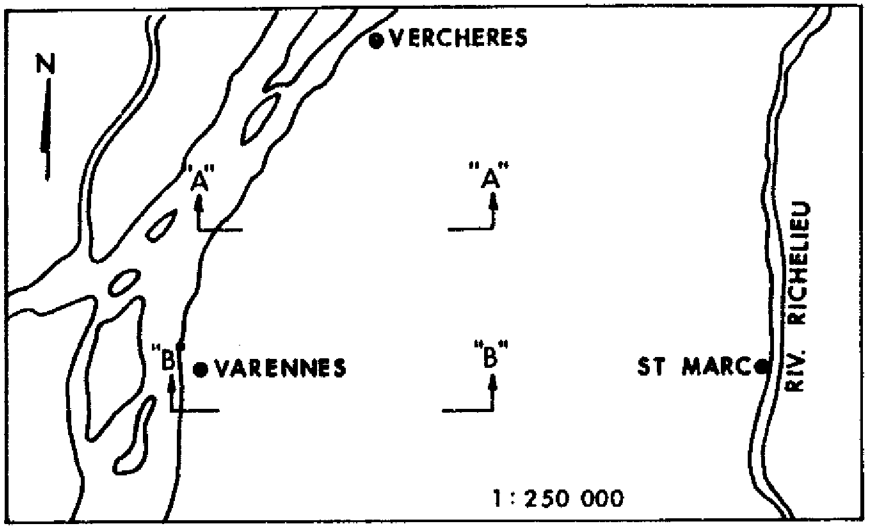
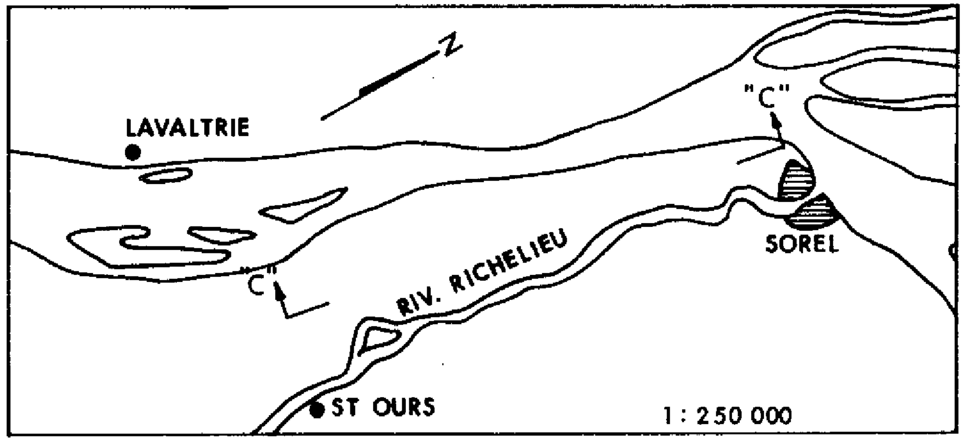
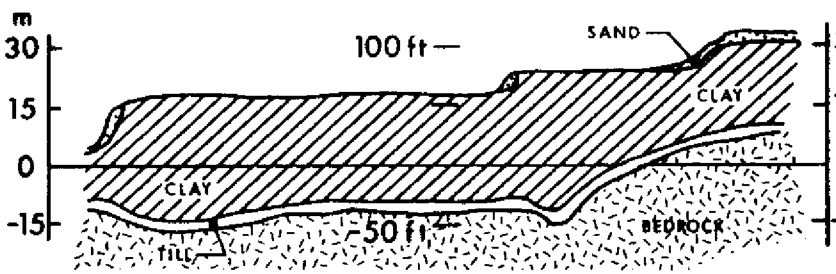
FIGURE NO 2







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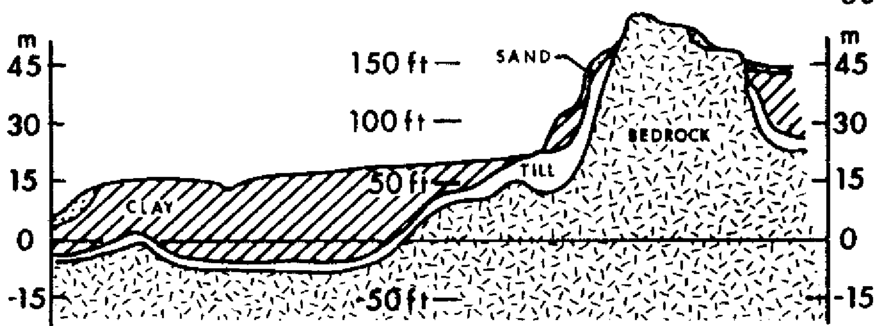

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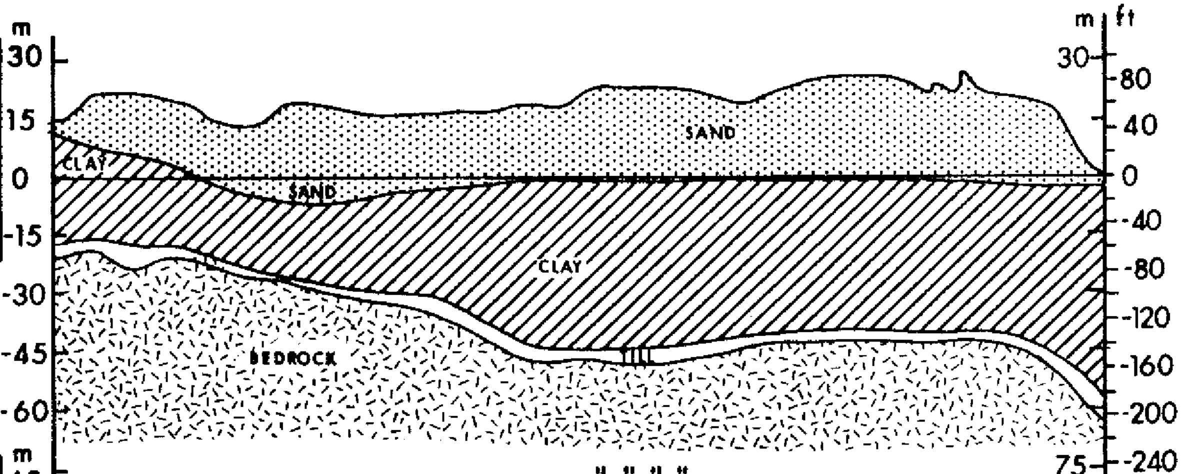

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SURFICIAL DEPOSITS
VARENNES-SOREL AREAS

BIBL. REF. NO 18 & 19

FIGURE NO. 2

4. BEDROCK STRATIGRAPHY AND LITHOLOGY

4.1 Precambrian Basement Rocks

In the Montreal Region the southeastern flank of the Precambrian Shield, constituting the Laurentian Upland, follows roughly the Lachute - Rawdon-St. Norbert line. As it disappears under the strata of the Cambrian and Ordovician sedimentary rocks of the St. Lawrence Lowland, the surface configuration of the Precambrian basement rocks becomes largely a matter of conjecture. Some information, however, regarding the basement, as well as the overlying rock strata, can be obtained from the logs of oil and gas exploration wells put down in the Montreal Region by various exploration companies of the past. In the text below, these wells are numbered in accordance with the system used in the Q.D.N.R. publication S-75. The well locations, the bedrock geology of the study region, and the geological sections relevant to the Varennes and Sorel areas are shown on Drawing No. 1669-0-01 of this report.

In the Montreal Region, the only rock outcrops of indubitable Precambrian origin apart from those of the Laurentian Upland are the granites, syenites, diorites, quartzites, paragneisses and recrystallized limestones of the Oka area. At Cartierville, on the north side of the Island of Montreal, two small outcrops of anorthosite rock may represent pinnacles of the Precambrian basement jutting through the surrounding sedimentary rocks. Half-way between Cartierville and St. Jerome a deep exploration boring known as the Mallet well (well No. 79) was drilled in 1937-38 to the elevation of approximately 3000 ft below the sea level without encountering the Precambrian basement. In the area between the flank of the Laurentian Upland (St. Jerome) and Cartierville this indicates a basement surface relief of at least 3000 ft.

In the Montreal Region two other wells (wells No. 57 and 58) have reached the Precambrian basement rocks, the former at an elevation of 3075 ft, and the latter at an elevation of 3320 ft below sea level. In the Sorel area well No. 8 was drilled to the depth of 2543 ft without reaching the Precambrian basement. In the Nicolet county, south of the St. Lawrence River, the Precambrian basement was reached at an elevation of about 5000 ft below sea level (Canadian Seaboard St-Angèle No. 1 well). Interpolation of the structural and stratigraphic data of the well logs indicates that in the Varennes and Sorel areas the Precambrian basement rocks may be encountered at the elevation ranges of 5000 ft and 3700 ft below sea level, respectively. The Precambrian basement is expected to reach much lower elevations at the axis of the St. Lawrence Lowland syncline several miles southeast of the Varennes and Sorel areas. However, it must be kept in mind that the configuration of the basement surface may be irregular.

The information regarding the configuration of the surface of the Precambrian basement is meagre, and it can only be concluded from evidence at hand that there probably was a relatively mountainous terrain over most of Southern Quebec prior to the commencement of the deposition of the sedimentary strata. In the Montreal Region, the basement rocks and structures are probably similar to those outcropping along the flank of the Precambrian Shield (the Laurentian Upland). A detailed study of the Precambrian structure and stratigraphy along the flank of the Laurentian Upland would result in a better understanding of the geology of the basement underlying the St. Lawrence Lowland. This study should entail the nature of the formational units, lateral lithographic changes, structure fabric, and geotectoniques. The available mapping results indicate in general that the basement underlying the Montreal Region comprises igneous and metamorphic rocks such as granite, granitic gneiss, pegmatite, anorthosite, quartzite, and crystalline limestone (marble).

No reliable in situ measurements of the porosity of the Precambrian basement rocks are available. Review of the reports relevant to the liquid waste disposal project of the Rocky Mountain Arsenal Well near Denver, Colorado, in 1962-65, indicates that there the reservoir rock, encountered at a depth of about 11950 ft, is of Precambrian age, and in nature and origin not unlike the basement rock of the Montreal Region. The porosity of the Denver reservoir rock determined by the neutron log method, was found to be in the range of 6 percent porosity, $\pm$ 2 porosity percent, the porosity consisting predominantly of open fractures. A similar porosity range may conceivably apply to the Precambrian basement rocks of the Montreal Region.

4.2 The Potsdam Group

In the Montreal Region the Potsdam group of rocks consists predominantly of sandstone and conglomerate formations which overlie the Precambrian basement rocks.

Prior to the commencement of the Cambrian Period, the rocks of the Precambrian basement had been subjected to subaerial weathering of such a long duration that only the most resistant minerals, predominantly quartz, remained as constituents of sand in a desert like environment. Marine inundation which began in the Early Cambrian, immersed these sands and deposited the detritus which was too coarse for the currents to carry away. Due to the basement surface relief, which in the Montreal Region was probably in the range of 3000 ft, the thickness of the Potsdam sandstone and conglomerate rocks could be variable.

The thicknesses of the Potsdam group penetrated by the oil and gas exploration wells in the Montreal Region are tabulated below:

TABLE 5

Well Penetrations of the Potsdam Group

Well no. (Q.D.N.R.)	General location	Thickness of Potsdam penetrated feet	Remarks
1	Melocheville	1657	Lower contact not reached
112	Melocheville	2184	Lower contact not reached
111	St-Hubert	555	Lower contact not reached
79	Ste-Thérèse	1942	Lower contact not reached
57	St-Vincent de Paul	1969	Lower contact reached
85	Terrebonne	411	Lower contact not reached
58	Mascouche	1456	Lower contact reached
88	L'Assomption	281	Lower contact not reached
75	Verchères	100	Lower contact not reached
80	De Lanaudière	280	Lower contact not reached
12	Maskinongé	243	Lower contact not reached

The surface exposures and well penetration thicknesses of the Potsdam group of rocks are unsatisfactory in yelding a reliable concept of the three dimensional extent of the group in the Montreal Region. In general, the Potsdam sandstone is exceptionally thick in the southwestern part of the region (in the range of 2 000 ft), but thinning northward. It has not been encountered beyond the line of Maskinonge - St. Francois River. Within the region bordered by the Oka Precambrian outcrops, the Laurentian Upland, the St. Germaine Complex of the Appalachian front, and the Maskinonge - St. Francois River line, the Potsdam beds conform to the synclinal structure of the region, i.e. they dip gently in the easterly direction towards the axis of the St. Lawrence Lowland syncline. Cross-sections drawn through wells No. 58 and 75, and wells No. 88 and 75 indicate a gentle easterly dip of the Potsdam beds. A thickness of the

Potsdam group of 1456 ft is indicated by well No. 58 near Mascouche. Considering the relatively minor variations in the thicknesses of the overlying rock groups of the region in the down-dip direction, the thickness of the Potsdam group in the Varennes area is believed to be in the range of 1450 ft. The elevation of the top of the Potsdam group would be in the range of 3550 ft below sea level in the Varennes area. Based on the field observations, width and dip calculations of surface exposures, and the well records, the thickness of the Potsdam group in the Sorel area is estimated to be 400 ft, with the top of the group at an elevation of 3300 ft below sea level.

The Potsdam group consists predominantly of light grey to white, clean, well - indurated sandstones. Ninety-eight percent or more of the rock is made up of quartz grains. The grains range in size from an average of half a millimeter in diameter upwards. Some beds, particularly near the base of the group, are conglomeritic and contain quartz pebbles up to one inch in diameter. Shale partings occur between some of the upper beds, and in the upper part of the group fine siliceous shale several tens of feet thick, have been encountered. In many occurrencies the Potsdam sandstone is suitable for glass making. The following composition of the sandstone applies to the Melocheville area:

SiO_2	98.25%
Fe_2O_3	0.16%
Al_2O_3	0.17%
CaO	0.70%
Loss on ignition	0.35%
Total	99.63%

A few available determination results of the porosity of the Potsdam sandstone show that for the most part the rock porosity is in the 2 to 3 percent range (intergranular) but values of 10 to 15 percent have been determined for the bottom part of the group. A considerable range in porosity and permeability is indicated due to the varying degrees of cementation, grain size and fracture density in the sandstone.

The clean coarse grained quartz sandstones and conglomerate of the lower part of the Potsdam group may contain significantly porous zones, although in the upper part where penetrated by the wells, the rocks show a high degree of cementation. It may be thus concluded that the upper part of the group forms a relatively impervious potential cap horizon over the lower part of the group. These definitions of the Potsdam group apply to the Varennes as well as to the Sorel areas.

Occurrencies of gas in the Potsdam sandstones have been relatively insignificant. Well No. 79 (the Mallet well, at Ste. Therese) entered Potsdam sandstone at the depth of 1094 ft and penetrated 1942 ft of the sandstone without reaching its base. The well encountered gas in the Potsdam group at the depths of 1457 ft, 1630 ft, 1644 ft, and 2313 ft, the deepest encounter yielding most gas, a continuous flow of six hours duration. The final depth of the well was 3036 ft. No commercial quantities of gas have been found in the Potsdam group.

4.3 The Beekmantown Group

At the end of the Cambrian Period and the beginning of the Ordovician Period the sea in which the Potsdam sands were deposited, became relatively shallow, and calcium carbonate was deposited on the sea floor. Under the partly lagoonal conditions the calcium carbonate was replaced by magnesium carbonate obtained from the sea water, resulting in the residue of calcium - magnesium carbonate, or dolomite. Thus the Beekmantown group of rocks, conformably overlying the Potsdam sandstones, were formed, constituting thick series of beds of dolomite and dolomitic limestone, with minor amounts of interbedded limestone, shale and sandstone.

In the Montreal Region the Beekmantown group is well represented in the oil and gas exploration well records. The thicknesses of the Beekmantown group penetrated by the wells in the past are shown in the table below:

TABLE 6

Well Penetrations of the Beekmantown Group

Well No. (Q.D.N.R.)	General location	Thickness of Beekmantown penetrated, ft	Remarks
111	St-Hubert	890	Lower contact reached
19	Verdun	855	Lower contact not reached
57	St.Vincent de Paul	807	Lower contact reached
79	Ste. Therese	814	Lower contact reached
85	Terrebonne	615	Lower contact reached
58	Mascouche	764	Lower contact reached
46	L'Assomption	60	Lower contact not reached
88	L'Assomption	338	Lower contact reached
75	Vercheres	941	Lower contact reached
80	De Lanaudière	400	Lower contact reached
12	Maskinongé	177	Lower contact reached

As indicated by the logs of wells No. 58 and 75, in the Varennes area the thickness of the group, by interpolation, is probably in the range of 850 ft, with the top of the group at an elevation of about 2700 ft below sea level. Along the flank of the Laurentian Upland the Beekmantown group can be traced on surface outcrop as far as Berthierville near Lac St. Pierre. The thickness of the group diminishes northeastward along the northwestern margin of the St. Lawrence Lowland syncline, and the group probably pinches out before reaching the St. Maurice River. In the central part of the syncline, opposite Trois Rivières, the group is about 350 ft thick. A thickness of 400 ft for the Beekmantown dolomite in the Sorel area appears, therefore, conceivable, as indicated by the log of well No. 80, with the elevation of the top of the group at 2900 ft below sea level.

Lithologically the Beekmantown rocks can be divided into three subdivisions. The lower part of the group consists mainly of finely crystalline dolomite with interbeds of sandstone, the latter with dolomitic cement. The middle part of the group consists of dense, crystalline as well as granular dolomites, with minor beds of siltstone, shale and limestone. In the upper part of the group dolomite plays a subordinate role, and a variety of rock types are present - limestone, shale, sandstone and dense dolomite, in structure thin to thick bedded.

As a whole, the Beekmantown group consists of 70 percent dolomite, 25 percent shale, and 5 percent limestone, interbedded.

In general the potentially porous and permeable limestone and sandstone beds are relatively insignificant constituents in the group; by far most of the beds of the group are dense, thick-bedded, fine to very fine grained or crystalline, well cemented dolomites, indicating an overall low porosity and fracture permeability. Considering also the relatively high percentage of shale, the Beekmantown group has the characteristics of a potential cap formation.

4.4 The Chazy Group

Rocks of the Chazy group are exposed along the southwestern end of the St. Lawrence Lowland syncline, and for a distance of about 20 miles along its northwestern limb, from Ste. Therese to the Berthier County.

The end of the Beekmantown sedimentation denotes the withdrawal of the Early Ordovician sea and the subsequent invasion of the region, in Middle Ordovician, by another sea, probably from the south. The new sea of the Middle Ordovician Period brought with it much detritus, which in the early stages of the deposition comprised sands and muds. When the sea deepened limestones were accumulated.

In the Montreal Region the Chazy group has been penetrated by the following wells:

TABLE 7

Well Penetrations of the Chazy Group

Well No. (Q.D.N.R.)	General location	Thickness of Chazy, penetrated ft	Remarks
111	St-Hubert	452	Complete section
19	Verdun	377	Complete section
57	St. Vincent de Paul	294	Surface exposure
79	Ste. Therese	270	Surface exposure
85	Terrebonne	390	Complete section
58	Mascouche	205	Complete section
46	L'Assomption	260	Complete section
88	L'Assomption	414	Complete section
75	Vercheres	474	Complete section
80	De Lanaudière	420	Complete section
8	Berthierville	348	Complete section
12	Maskinongé	30	Complete section

The thickness of the Chazy group varies between 205 ft in well No. 58, Mascouche area, and 474 ft in well No. 75, Verchères area. It can safely be assumed that in the Varennes area the thickness of the group is in the range of 470 ft, as indicated by well No. 75, with the top at an elevation of 2230 ft below sea level. Chazy rocks are not known north of the St. Lawrence River beyond the St. Maurice River. The group is, however, reported to be 410 ft thick at St. Gregoire, opposite Trois Rivières. As indicated by well No. 8 near Berthierville, the thickness of the group at Sorel can safely be taken as 350 ft, with the top at an elevation of 2550 ft below sea level.

The basal beds of the group are for the most part clean, fine grained, quartz sandstones with generally small amounts of cement, and consequently relatively porous. The sandy development of the base of the group has a thickness of 50 ft at Varennes, and probably less in the Sorel area.

The middle part of the group consists of shales with interbeds of limestone and sandstone. The limestones and dolomites of the upper part of the group are coarse to fine grained detrital to crystalline. Crystallisation of the detrital rocks generally heals the fractures in the rock so that the existing porosity and permeability of the group may be probably relatively low. The limestones and dolomites comprise about 42 percent of the Chazy group, as indicated by well No. 79, Ste. Therese area. In many other areas, however, the limestones and dolomites comprise a much higher percentage of the group. Considering all of the Chazy sections penetrated by the wells in the Montreal Region, 75 percent of the rocks are dense dolomite and limestone, 13 percent sandstone and 12 percent shale. This compositional distribution applies in general to the Varennes area, as well as to the Sorel area.

In the light of the relatively low percentage of sandstone, which may have a signifiant porosity, and the high percentage of dense limestone and dolomite, the porosity and permeability of which appear to be relatively low, the Chazy group cannot be considered as a potential reservoir horizon. Instead, because of the considerable shale content, the group may have the characteristics of a cap horizon.

4.5 The Trenton Group

The Chazy time ended by a complete withdrawal of the sea in Southern Quebec, followed by a relatively short period of subaerial weathering. The invasion of the region by another sea from the west commenced, and the subsequent immersion was to continue to the end of the Ordovician Period.

The first sediments deposited in the new sea form the relatively thin (50 ft) Black River group of rocks. Differing from the Trenton group of rocks faunally, the Black River rocks are insignificant in volume, entailing in the Montreal Region a total thickness of 50 to 70 ft. Lithologically the Black River rocks consist of dolomite, limestone and lesser amounts of shale, not unlike the rocks of the Chazy group. The Black River rocks are of significance as a marker horizon, a forerunner to the Trenton group. The top elevations of the Black River group are approximatively at 2180 ft and 2500 ft below sea level, in the Varennes and Sorel areas, respectively.

The beginning of the deposition of the Trenton group of rocks is marked by the deepening of the waters in which chemically precipitated calcium carbonate could form undisturbed by currents and the fluctuations of the sea level. During the Trenton time Quebec with the rest of North America experienced one of the greatest submergencies of the continent. In spite of the seemingly uniform deep sea depositional environment, the Trenton group is relatively heterogenous in terms of limestone lithology.

In the Montreal Region the thickness of the Trenton group varies between 434 ft and more than 990 ft as indicated by the logs of the exploration wells tabulated below:

TABLE 8

Well Penetrations of the Trenton Group

Well No. (Q.D.N.R.)	General location	Thickness of Trenton penetrated, ft	Remarks
85	Terrebonne	540	Surface exposure
58	Mascouche	683	Complete section
84	Riv. de Prairie	705	Complete section
46	L'Assomption	590	Complete section
88	L'Assomption	777	Complete section
75	Vercheres	660	Complete section
56	Longueil	990	Complete section
32	St. Hubert	920	Complete section
111	St. Hubert	838	Complete section
80	De Lanaudière	780	Complete section
8	Berthierville	735	Complete section
12	Maskinongé	434	Complete section

In terms of the significant lithologic variations, the Trenton group can be divided into three subdivisions, Lower, Middle and Upper Trenton.

The Lower Trenton rocks are predominantly fine to coarse grained crystalline to detrital limestones. They contain rare porous horizons which occasionally yield droplets of petroleum on freshly broken rock surfaces. Some beds may contain black carbonaceous matter. The thickness of the Lower Trenton varies from about 30 ft in the Montreal area to more than 200 ft at the south end of Lac St. Pierre.

The Middle Trenton rocks are very fine grained, thin to medium bedded limestones with thin shaly interbeds and partings. In the Montreal Region the thickness of the Middle Trenton varies from 375 ft in the Montreal area to 100 ft near Berthierville.

The Upper Trenton beds comprise mostly dense, dark grey limestone (Tetreauville formation), alternating regularly with thin shaly interbeds. The average thickness of the Upper Trenton is in the range of 400 ft in the Montreal area, and about 120 ft near Berthierville.

The Trenton group limestones of the northwestern limb of the St. Lawrence Lowland syncline are progressively replaced toward the southeast by shale. Well borings indicate that in the Montreal Region the whole section of the Trenton group is predominantly limestone. Near St. John, where the Trenton group is about 2000 ft thick, shales predominate.

The logs of exploration wells No. 46, 75, 88 and 8 indicate the thicknesses of the Trenton group divisions as follows:

TABLE 9
Divisions of the Trenton Group

	Well No. 46	Well No. 75	Well No. 88	Well No. 8
Upper Trenton	250 ft	320 ft	483 ft	270 ft
Middle Trenton	340 ft	290 ft	195 ft	330 ft
Lower Trenton	50 ft	50 ft	99 ft	135 ft
TOTAL	640 ft	660 ft	777 ft	735 ft

It can be assumed that in the Varennes area the thickness of the Trenton group is at least 600 ft, as indicated by well No. 75. The elevation of the top of the Trenton at Varennes is approximately in the range of 1600 ft below sea level. As indicated by well No. 8, the thickness of the Trenton in Sorel area may be at least 700 ft, with the top at an elevation of 1800 ft below sea level.

As stated previously, in many places the Trenton limestone, when freshly broken, shows occasional small cavities and vugs which contain droplets of oil. This has generated considerable interest in the Trenton formations, although to date no commercially significant quantities of oil or gas have been found. Porosity and permeability studies of the Trenton rock specimens have been carried out in the past. The study results indicate that the limestones are predominantly dense micrites, i.e. with calcite crystals in sizes less than 5 microns. There is no evidence of significant primary porosity or solution, except for a few isolated calcite lined vugs. Where minor primary porosity does occur, the pores are generally so small as to be imperceptible, and the permeability due to primary porosity so low that the limestones can be excluded as potential petroleum reservoir rocks. Available data on the Lower Trenton formation indicate porosities of 0.57 to 0.62 percent, and permeabilities of less than 0.01 millidarcy.

Due to the relatively high fracture porosity and permeability, the Trenton limestones of the Montreal Region have long been recognized as competent reservoir rocks for artesian water. This significant characteristic of the Trenton group is discussed in Section 6, Hydrogeology.

4.6 The Utica Group

Subsequent to the passage of most of the Ordovician Period, the sea in which the Trenton limestones were formed, commenced receiving large quatities of muds. The muds originated from the rising Appalachian geosynclinal belt, and spread over the submerged northeastern North

America. The deposition of the muds culminated in the formation of the shales of the Utica group.

The Utica shales have an extensive development, extending from Toronto through Ottawa, east to Richelieu River, and north to Quebec City. These shales lie disconformably upon the Upper Trenton limestone. The shales are dark grey to black, slightly silty, finely micaceous, and occasionally calcareous. Pyrite is present as nodules or fine grained disseminations throughout the shale. Thin interbeds or lenses of dolomitic siltstone and fine grained sandstone occur in the shale.

The thickness of the Utica shale in the Montreal Region can be deduced from the exploration well boring logs, as tabulated below.

TABLE 10

Well Penetrations of the Utica Group

Well no. (Q.D.N.R.)	General location	Thickness of Utica group penetrated, ft	Remarks
58	Mascouche	70	Surface exposure
84	Riv. de Prairie	228	Surface exposure
46	L'Assomption	415	Surface exposure
88	L'Assomption	386	Complete section
75	Vercheres	535	Complete section
78	Anjou	80	Surface exposure
56	Longueuil	435	Surface exposure
32	St. Hubert	408	Complete section
111	St. Hubert	408	Complete section
80	De Lanaudière	450	Complete section
8	Berthierville	500	Complete section

As indicated by wells No. 88 and 75, the thickness of the Utica shale which in the Montreal area is in the range of 400 ft, increases in the southeasterly direction, from 386 ft near L'Assomption to 535 ft near Vercheres. It can be interpolated that in the Varennes area the Utica shale is about 500 ft thick, with the top at an elevation of 1100 ft below sea level. In the Sorel area the thickness of the Utica is also in the range of 500 ft as indicated by well No. 8, with the top at an elevation of 1300 ft below sea level, approximately.

The permeability of the Utica shale is low, and water well yields are never more than 5 to 10 gallons per minute. Higher yields are encountered mostly in areas where the shale has been intruded by major volcanic dykes.

In general the shales, consisting predominantly of clay minerals,have the sorption characteristics similar to those of clay. They are basically impermeable and excellent barriers to water. It should be noted that due to the high confinement potential of the shale, the disposal of radioactive fuel waste in shale formations is being studied in several countries.

4.7 The Lorraine Group

Above the Utica, and apparently grading into it, lies the Lorraine group of shales. The depositional conditions of the Lorraine group of rocks were slightly different from those of the Utica. The Lorraine group contains beds of fine grained sandstone, and sandy limestone, interbedded in shale.

The shales of the lower part of the Lorraine group of rocks are dark, fissile, finely silty and micaceous, and can be separated from the underlying Utica mainly on faunal grounds. There is a gradual change upward from predominantly shale beds to interbeds of shale, siltstone and sandstone, the sandstone being often lenticular and discontinuous in occurrence.

In the Varennes and Sorel areas the Lorrain shale underlies the overburden.

The Utica and Lorraine shales, similar in most physical characteristics, can be considered as one relatively impervious unit overlying, in the Varennes and Sorel areas, all of the rock groups previously discussed. In the Varennes area the combined thickness of the Utica and Lorraine could be in the range of 1600 ft, as indicated by well No. 75 at Vercheres. The Utica - Lorraine section increases in thickness to the northeast along the south shore of the St. Lawrence from Montreal to Nicolet, and to the east and southeast towards the axis of the St. Lawrence Lowland syncline. Therefore, although a total thickness of the Utica - Lorraine shale is 1085 ft in well No. 8, in the Sorel area the Utica - Lorraine thickness may well reach 1800 ft.

4.8 The Richmond Group

The Richmond group of rocks rests on the Lorraine shales. The Richmond rocks are enclosed within the central part of the St. Lawrence Lowland syncline, bordered almost entirely by the Lorraine group. In its deepest part of the syncline east of St. Lawrence the Richmond group attains a thickness of about 2000 ft. The group consists of calcareous shales, limestones and sandstones, deposited under subaerial conditions. A general gradation from the Lorraine to the Richmond is indicated by the relative decrease of shale and increase of limestone. The Richmond group does not underly the Varennes nor the Sorel area. On plan the Lorraine - Richmond contact lies some 7 miles east of Varennes, and about 3 miles east of Sorel.

Due to the predominance of shales not unlike those of the Utica and Lorraine, the Richmond rocks are also believed to have low porosity and permeability.

5. STRUCTURAL GEOLOGY

Between Quebec City and Montreal the rock formations underlying the St. Lawrence Lowland form a canoe-shaped synclinal basin, the axis of which can be traced from a point on the St. Lawrence River some 20 miles upstream of Quebec City southwestward to the international border. (Fig. 3) Along the northwestern limb of the basin, on the flank of the Laurentian Upland, the sedimentary rock formations dip uniformly southeastward toward the synclinal axis with dip angles of 1 to 6 degrees (average 2 degrees). On this limb the rock formations generally thicken in the down - dip direction. The southeastern limb of the basin, i.e. the part of the basin between its axis and the Appalachian Highland, has a relatively steep northwesterly dip. Along the southeastern margin of the basin the structure is complicated by thrust faults and tight folds, the intricacy culminating within the zone of the St. Germain Complex, which follows the flank of the Appalachian Highland. The structural features of the study region are shown on Fig. 3 and Drawing No. 1669-0-01.

The greater part of the northwestern boundery of the Central St. Lawrence Lowland syncline is a line of scarps, i.e. abrupt lineal cliffs, marking the edge of the Precambrian rocks. These scarps represent a system of steeply dipping faults (the St. Jerome, Rawdon and St. Cuthbert faults) along the flank of the Laurentian Upland, subparallel to the trend of the northwestern limb of the syncline. Movements along these faults have affected the Precambrian rocks as well as the sedimentray rocks of the syncline.

In addition to these boundary faults, it has long been recognized that the rather irregular distribution of sedimentary strata in the Montreal

Region could be accounted for by a system of east-west trending faults with a downward movement of the strata north of the faults. In succession from north to south the faults of significance to the Montreal area are the Bas de Ste. Rose fault, and the White Horse Rapids fault.

Regarding the Varennes area, the Bas de Ste. Rose fault is of immediate concerne. This fault extends east-west for a distance of more than 20 miles, from west of Ste. Therese to several miles east of the St. Lawrence River. The fault is not believed to cut through the entire width of the St. Lawrence synclinal basin. Stratigraphic evidence indicates that a maximum vertical displacement of 600 ft is likely, i.e. the strata north of the fault being 600 ft lower than the corresponding strata south of the fault. The Varennes area lies a short distance north of the Bas de Ste. Rose fault.

The results of the investigations carried out in 1974-75 for the CUM Pumping Station project at the north end of the Montreal Island indicate that in cross-section the Bas de Ste. Rose fault zone is about 60 ft wide. The central part of the zone, about 20 ft wide, consists of black shale completely crushed and altered to an impervious compact soil like material (fault gouge), bounded on the north side by a zone of moderately sheared and altered shale about 15 ft wide, and on the south side by a zone of fractured and brecciated limestone about 25 ft wide.

The major boundary fault in the Sorel area is the St. Cuthbert fault, located 10 miles northwest of Sorel. This fault is believed to displace the Precambrian rocks as well as the sedimentary strata. The vertical displacement of strata caused by the fault is in the range of 500 ft, the strata southeast of the fault having sunk in relation to the corresponding strata northwest of the fault.

In the region south of the St. Lawrence, a major north-south trending fault is indicated at St. Barnabe, some 8 miles north of St. Hyacinthe. This fault, intersecting the southeastern limb of the basin and striking near-parallel to the direction of the synclinal axis, has brought about a vertical displacement of the adjacent strata by some 1100 ft. Based on stratigraphic evidence, the strata west of the fault has been let down in relation to the corresponding strata east of the fault. Where intersecting the shales, the fault zone is believed to be impervious.

The folding in the Montreal Region may be considered in relation to the gross structure of the St. Lawrence Lowland syncline. The two limbs of the syncline are quite different in structure. The beds of the southeastern limb possess much steeper dips than those of the northwestern limb, and as the eastern margin of the syncline is approached, the beds become increasingly folded and faulted within the zone of the St. Germain Complex. The beds of the northwestern limb are on the whole unfolded and have gentle dips (average 2 degrees). Only at the northern end (Portneuf area) and the southern end (Montreal area) of the syncline, where the basin narrows, the strata are significantly interrupted by folding. This folding is, however, hardly discernible north of the Bas de St. Rose fault.

The relative movement of the faults in the Montreal Region has been largely vertical, with little lateral displacement. The vertical displacements may range from a few hundred feet to more than a thousand feet. The northeasterly trending faults (the boundary faults) are regional structures which extend down into the Precambrian basement, where they are believed to be relatively pervious. The east-west trending faults are in all probability confined to the sedimentary rocks of the Lowland, in which they are believed to be relatively impervious.

On the east and southeast the St. Lawrence Lowland syncline is bordered by the St. Germain Complex of highly folded and faulted strata. The St. Germain Complex entails easterly dipping thrust faults and slices which partly overlap the southeastern boundary zone of the syncline.

The Central St. Lawrence Lowland is believed to be part of a graben structure, i.e. a downthrown block between two parallel boundary fault zones. The northwestern boundary fault zone is believed to run along the flank of the Laurentian Uplands, as indicated by the boundary faults mentioned previously, with the southeastern boundary fault zone following the flank of the Appalachian Highlands (the St. Germain Complex). These fault zones originated in the Precambrian basement and extend into the younger overlying sedimentary rocks as a result of crustal adjustments. The St. Barnabe fault is believed to belong to this category of deep regional faulting. The east-west trending faults, such as the Bas de Ste. Rose fault, however, possibly originated due to the Monteregian volcanic activity during the late Cretaceous Period, and do not extend into the Precambrian basement rocks. This assumption is supported by the apparent lack of displacements in the Precambrian rocks of the Laurentian Upland along the extensions of the east-west trending faults.

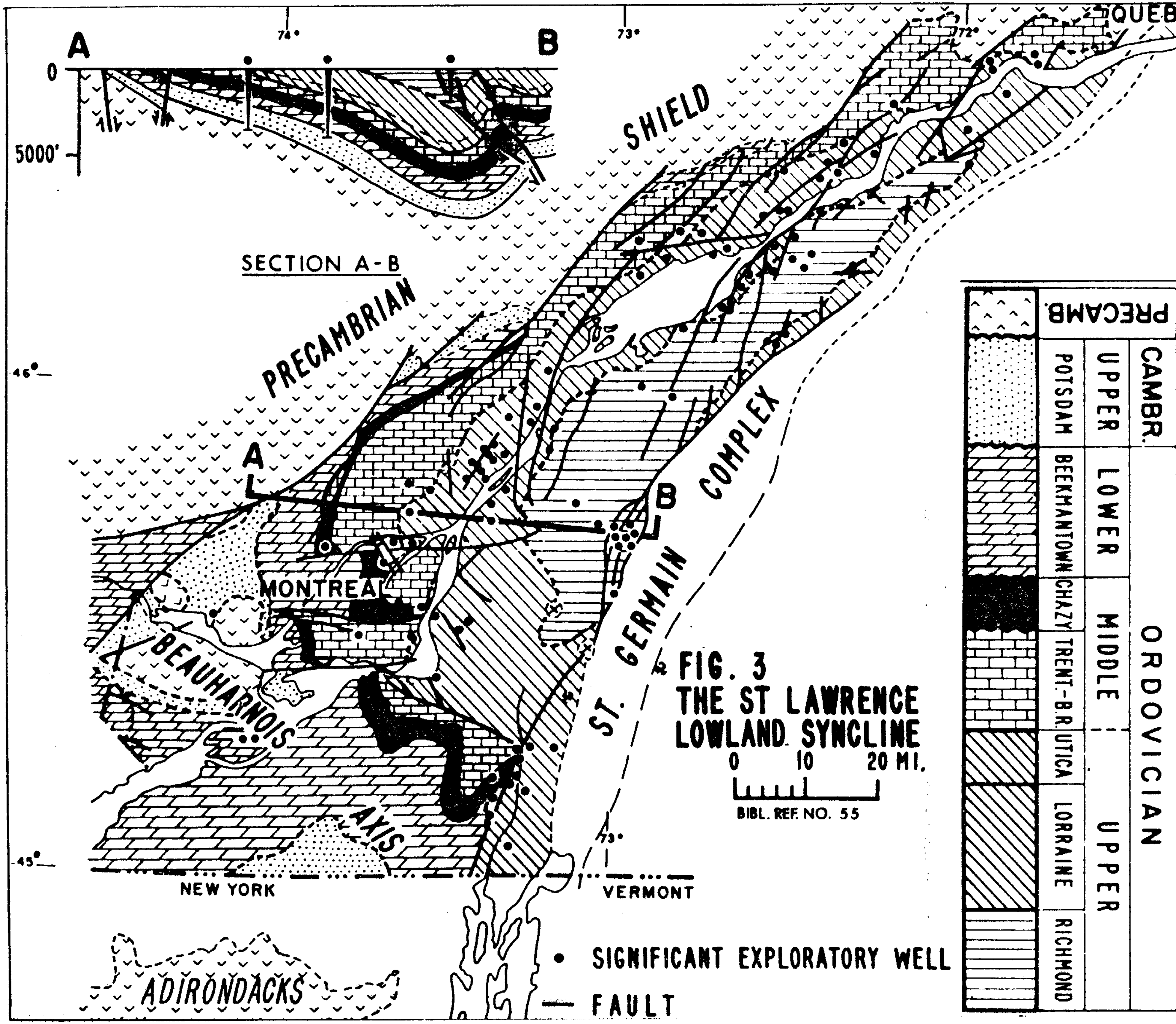


FIG. 3
THE ST LAWRENCE LOWLAND SYNCLINE

Project No. 1669-0

Terratech

Figure No.: 3

6. HYDROGEOLOGY

The source locality of most of the underground water in the Montreal Region is in all probability the higher portion of the plains along the flanks of the Laurentian Upland. The St. Lawrence Lowland plain along the foot of the Upland is at an elevation of about 300 ft, while the middle part of the Lowland has a much lower surface elevation. The waters entering the sedimentary formations along the flank of the Upland, would move underground to the south and east under considerable pressure head, and when the channels and fracture zones through which they pass, are tapped by wells in the Montreal Region, the water rises by virtue of this pressure. It may be expected that the Potsdam sandstone, which outcrops immediately along the edge of the Laurentian Upland, carries water which subsequently rises through fissures into the overlying formations. Records of the wells indicate, however, that the water bearing channels lie chiefly in the Trenton formations, the deeper wells yielding but little water.

It has long been recognized that the Trenton limestones of the Montreal area are competent reservoir rocks for artesian water. The Potsdam sandstone which outcrops immediately along the edge of the Upland, does not appear to be a significant water bearing formation (aquifer). Several past studies of the artesian wells put down on the Island of Montreal indicate that the underground water circulation occurs along fissures and fractures in the limestones and is mainly confined to the first thousand feet below the bedrock surface; below this depth the yield seems to diminish rapidly. The highest yields have been encountered between the depths of 300 ft and 1000 ft below the ground surface, on the Island of Montreal. The stratigraphic sequence relevant to the Montreal Island area is given by wells tabulated below:

TABLE 11

Trenton Group, Montreal Island Area

Well No. (Q.D.N.R.)	Depth below ground surface: Top of Trenton	Bottom of Trenton	Thickness of Trenton encountered
19	Outcrop	163	163
78	156	405 (bottom not reached)	249
111	1248	2086	838
32	1240	2160	920

Wells No. 32 and 111 penetrated the Trenton group from top to base, and an average thickness of 880 ft of the group is indicated. Well No. 78, located in the downtown area on the Island of Montreal, encountered the top of the Trenton at a depth of 156 ft, and remained in Trenton until the depth of 405 ft, without reaching its lower contact. However, considering the thickness of 880 ft for the Trenton, the bottom of the Trenton in well No. 78 would be at a depth of about 1000 ft. It can therefore be concluded that the yields of water generally highest in the Montreal downtown area above the depth of 1000 ft, originate mostly in the Trenton group of limestones.

In this report the gallons referred to are the imperial gallons, unless otherwise specified.

As indicated by the well drilling logs, the water is not confined to any definite water bearing horizon in the Trenton group but is believed to occur in fissures and fractures, which are as a rule vertical to steeply dipping. The flow conditions are complicated by the intrusive dykes and sills which radiate out of the Mount Royal intrusive plug, and by the impervious shale layers in the limestones.

It is believed that the physical characteristics of the Trenton limestones, and particularly those relating to the limestones as aquifers in the Montreal area, apply also to the Trenton rocks underlying the Varennes and Sorel areas. The relatively close vicinity of the Trenton outcrops to the flank of the Laurentian Upland, and the relatively large recharge area of the Trenton group northwest of Varennes and Sorel would enhance the flow volume in the Trenton.

The waters in the Montreal Island area are generally high in sodium carbonate (basic waters) and consequently have small dissolving power upon the limestone through which they pass. The sodium carbonate in the waters is believed to have originated in part from the dike rocks related to the Mount Royal intrusives, which contain unusually high amounts of sodium. Waters entering the Trenton from the Precambrian rocks of the Laurentian Highland are, however, slightly acidic, and consequently in areas where they are not acted upon by the influence of the volcanic rocks of the Monteregian Hills, they may cause some solution of the limestones.

Some understanding of the hydrogeologic conditions possibly prevailing in the study region can be obtained from groundwater studies pertinent to the Montreal Island.

Studies carried out in the early part of this century of some 180 wells operating on the Island of Montreal indicate that chances of striking a water flow of 100,000 gallons or more per diem were best (2 in 3) at a depth range of 400 ft to 700 ft. In most of the wells studied water rose to within 30 ft of the ground surface.

In 1903, a study of 89 wells then operating on the Island of Montreal indicated that the wells were capable of yielding a total of 2,500,000 gallons of water per diem.

The total recharge area on the Montreal Island is about 192 sq. miles, of which the area underlain by the Trenton rocks constitutes 72%. Studies carried out in the late 1970's indicate that the estimated recharge on the island is 31 million gallons per day (31 Mgal/d). The estimated groundwater use has been 2.5 Mgal/d in 1903, 7 Mgal/d in 1915, 10 Mgal/d in 1940, and 4.5 Mgal/d in 1978. Since 1978 there appears to have been an increase in the number of groundwater wells drilled, as the cost of city water increases and the need for nonchlorinated water rises. The depths of the wells indicate that the Trenton group provides most of the fresh water in the area.

The influence that the nature of rocks has on the groundwater is highly variable. A pervious rock has communicating interstices of capillary or supercapillary size. Its degree of permeability cannot be correlated with any standard scale, but is usually expressed as a volume of flow per unit of cross-sectional area per unit of time. Porosity, on the other hand, is a measure of the interstices contained in any particular volume of the rock; it is generally expressed as a percentage which indicates the aggregate volume of interstices of voids to total volume. A high degree of porosity is no assurance of perviousness.

The perviousness of the rock formation, however, from which water is drawn, is indicated to some degree by the yield of the drawing wells. Pertinent to the study region, the following average well yields have been indicated:

a) Precambrian basement rocks: up to 30 gal/min, higher in fault and fracture zones. Porosity 6%.

b) Potsdam group: up to 500 gal/min in basal conglomerates, much less in fine grained sandstones. Porosity 2 to 15%.

c) Beekmantown group: 125 gal/min, but higher in the vicinity of volcanic intrusions. Porosity 5%.

d) Chazy group: up to 10 gal/min. Porosity less than 5%.

e) Trenton group: 500 to 1000 gal/min. Intergranular porosity 0.5%, fracture porosity much higher.

f) Utica and Lorraine groups: up to 5 gal/min, higher near volcanic intrusions.

Hydrochemically the groundwaters of the study region reflect the composition of the reservoir rocks. Calcium bicarbonate predominates in waters drawn from the predominently limestone areas. Magnesium rich waters can be recognized in the areas underlain by dolomitic rocks. Sodium rich waters are associated with the volcanic intrusive rocks.

7. SEISMOLOGY

7.1 Seismic Zones

The first reported Canadian earthquake is known through tradition, said to have occurred between the voyages of Cartier, 1534-35, and originated from the La Malbaie area. Since then there have been numerous earthquakes in Quebec, of which 17 were of magnitude greater than 5.5, with five or six of these 17 of magnitude 7 or greater, as indicated by the table below. Threshold of damage is usually at magnitude 5.

TABLE 12

Earthquakes in Quebec with Magnitude > 5.5

Approx. location of epicenter	Year	Magnitude
La Malbaie and Tadoussac	1534	?
"	1635	6.4
"	1638	7
"	1663	7.5 - 8.0
"	1791	6.4
"	1831	5.5 - 6.0
"	1860	6.5 - 7.0
"	1870	7.0
"	1924	6.1
"	1925	7.0
"	1939	5.8
"	1956	5.6
Montreal	1732	7.0
"	1816	5.5 - 6.0
"	1897	5.6
Temiskaming	1935	6.2

In general the building codes of earthquake-prone countries include provisions for earthquake risk.

The need for specifically Canadian earthquake information was met in the 1953 edition of the Canadian Building Code, which incorporated the first seismic zoning map for Canada.

The Seismic Zoning Map, 1970 Edition, of Canada's National Building Code was the first to present probability estimates of seismic ground motions for the whole of Canada. (Fig. 4A, 4B).

The Canadian National Committee on Earthquake Engineering has recently recommended that new seismic zoning maps along with the associated changes in seismic design provisions be incorporated in the national building code by 1985.

The seismic zoning maps are based on a hazard scale which divides the country into zones 0, 1, 2 and 3, corresponding to zones of anticipated zero, minor, moderate and major damage, respectively.

The western regions of British Columbia lie within the Pacific "ring of fire" and are included in Zone 3 of seismic activity, the zone of maximum seismic hazard, on the Seismic Zoning Map of Canada, 1970 Edition. However, there are two other regions in Canada designated as Zone 3, the eastern Baffin Island, N.W.T., and the Lower St. Lawrence Lowland, extending from about Trois Rivieres northeastward to Sept Iles. The Montreal Region including Sorel lies in Zone 2, although some experts believe that, considering the short nature of the recorded seismic history (1928 onwards) and the anomolous nature of the seismicity in Eastern Canada, the St. Lawrence and Ottawa River Valleys in Quebec should be regarded as potentially Zone 3 region.

7.2 Seismo-Tectonic Mechanisms

The causes of the earthquakes in the St. Lawrence Lowland region are not clearly established.

The geologic and seismo-tectonic conditions (plate tectonics and volcanism) prevailing in the Pacific earthquake belts do not resemble those of the St. Lawrence Lowland region. Thus it has been suggested that the St. Lawrence earthquakes are being generated either by a) the rebound of the region from its depression after the disappearence of the load of the ice of the glacial time or b) rifting (regional faulting of basement rocks) due to continental drift, responsible for the physiography of the St. Lawrence, Ottawa, and Richelieu valleys. (Fig. 5) The latter mode of eartquake generation is at present subjected to intensive research. No direct correlation between the major known faults and earthquake epicenters (vertical projection of the point of earthquake origin on the Earth surface) has been established yet in Eastern Canada, and therefore the post-glacial tectonic uplift and tilting of the near surface crust are considered the most likely causes for generating earthquakes in the St. Lawrence Lowland region. Data available on marine limits and radio-carbon dating indicate that the areas of high seismicity in Eastern Canada have been tilted significantly during the past 20,000 years. It must be noted, however, that although faulting does not appear to be the cause of earthquakes in Eastern Canada, the earthquakes may cause movements along the existing faults.

Concerning rifting (plate tectonics), considerable evidence has been presented in relevant literature that large areas of eastern North America are in strong, nearly horizontal compression, and that modern seismicity in eastern North America may be partly controlled by the action of compressive stress on pre-existing unhealed deepseated faults.

The presence of in-situ inherent compressive stress in the rocks of the Montreal Region has been evidenced in several quarries and excavations. Pop-ups of quarry floors are known to have occurred in the Terrebonne and St. Eustache areas. The pop-ups (ridging and buckling) were encountered after the lithostatic load was removed by quarrying. Compressional structures involving glacial till have been observed in the Pointe Claire and downtown Montreal areas, in relatively shallow depths (in the range of 30 ft). In some areas bedrock is reported to have been found overlying till; although this may be credited to ice-thrust, pre-existing faults in the vicinity of these occurrences may have been the loci of deformation of tectonic origin, and such an origin cannot be ruled out completely. The tectonic data relevant to Montreal Region indicate the existance of a maximum principle horizontal stress acting approximately in the east-west direction.

7.3 Seismic Risk Analyses

Concerning damage, it can generally be assumed that earthquakes felt at magnitude 5 or less would not result in any noticeable damage to buildings founded on bedrock, excepting perhaps cases of weak and delapidated construction. Damage to structures founded on fill or various kinds of overburden (alluvium, marine and glacial deposits), may, however, be expected when subjected to earthquake magnitudes in the range of 5. The nature of the foundation media greatly influences the distribution and extent of damage. In the San Francisco earthquake it was found that if damage on the most solid bedrock was taken as unity, then damage on "made land" ranged from 4.4 to 11.6, and on loose sand from 2.2 to 4.4. The same pattern is particularly true for earthquake damage in the Montreal Region, in view of the extensive marine clay and sand deposits, unless proper measures are considered in the design. Vibration sensitive structures and machinery require of course the utilization of special design measures.

Magnitude is only one of the factors influencing earthquake damage. Of equal importance is the depth of the earthquake, or the location of the point of energy release (the focus) below the epicenter. Deep focus quakes are felt over a wide area, but with relatively low intensity. Shallow focus quakes are felt over a relatively small area but with high intensity at the epicenter. The major Eastern Canada earthquakes have been felt over large distances, indicating deep foci. Records show, however, that the depths of the Eastern Canada earthquake foci are relatively small, generally in the range of about 9 miles. They are felt over large distances probably because of the unique transmitting nature of the Precambrian basement rocks. Thus waves potentially destructive are carried with relatively little loss of energy to great distances, as indicated by the 1925 La Malbaie earthquake, which caused damage to structures founded on soil at distances up to 180 miles or more.

The first aspect to consider in the seismic analysis and evaluation of an engineering structure is whether the probable seismic exposure at the site is a design factor. In the table below the seismic zoning of Canada and the respective firm ground acceleration limits are shown. Firm ground entails bedrock, very stiff clay, dense sand and gravel, generally materials characterized by a shear wave propagation velocity in excess of 1200 feet per second.

TABLE 13

Seismic Zoning and Acceleration Limits

Zone	Acceleration Limits
0	$0 \leq a_{100} < 1\%$ gravity
1	$1 \leq a_{100} < 3\%$ gravity
2	$3 \leq a_{100} < 6\%$ gravity
3	$6 \leq a_{100}$ % gravity

Areas outside Zone 3 have firm ground horizontal acceleration amplitude of less than 6 per cent gravity (g) based on the return period of 100 years. An acceleration of less than 6 per cent g has been observed to be lower than that required to induce soil liquefaction (quicksand). Generally the dynamic loading on structure for such acceleration levels can be accommodated within the normal factors of safety for static analysis. Areas where seismic exposure may be significant are indicated by Zone 3. It should be pointed out that Montreal and Sorel are located now in Zone 2 (Zoning Map, 1970 Edition), but were in Zone 3 in accordance with earlier zoning maps. Consequently areas in Zone 2 near the border with Zone 3 should be examined in more detail.

Considering the above, the Earth Physics Branch of Energy, Mines and Resources Canada was requested to carry out for this study the seismic risk calculations for the Varennes and Sorel areas, Quebec. The results of these calculations are shown in Appendix A of this report. It is indicated that the peak horizontal acceleration (firm ground) for Varennes is 7.0 percent gravity, and for Sorel 5.7 percent gravity with an average annual probability of 1 percent that they will be exceeded (a 100 year return period).

These accelerations must not be related to the Seismic Zoning Map of Canada, 1970 Edition, but rather to the new maps (not published yet), with reference to the research paper "New probabilistic strong seismic ground motion maps of Canada: A compilation of earthquake source zones, methods and results" by P.W. Basham, D.H. Weichert, F.M. Anglin, and M.J. Berry, Earth Physics Branch, Open File No. 82-83, Ottawa, Canada.

It has been stated by the Earth Physics Branch, Ottawa, that the new seismic zoning maps and the associated changes in seismic design provisions will be given in the National Building Code of 1985 for seismic design decisions and guidance. It is more difficult, however, to assess for this study the in-situ compressional tectonic stresses and their potential effects on deep underground structures without appropriate stress measurements. The difficulty is illustrated by the case of the U.S. Army Rocky Mountain Arsenal near Denver, Colorado, where a disposal well was drilled in 1961 to a depth of about 12 000 ft, with the bottom 100 ft in Precambrian granitic rocks similar to those underlying the Montreal Region. Injection of waste fluid into the Precambrian rocks on a routine bases was began on 8 March 1962 and continued through 30 September 1963 at an average rate of about 21 million liters per month. Between August 1964 and April 1965 fluid was put into the well by gravity flow at a rate of about 21 million liters per month. Between August 1964 and April 1965 fluid was put into the well by gravity flow at a rate of 7.5 million liters per month. Thereafter injection under pressure was resumed, at a rate of 17 million liters per month. On 20 February 1966 the injection was stopped because of an apparent connection between the well and the generation of earthquakes in the Denver area. Early studies (Healy, J.H., 1968) appeared to indicate that the injection of fluid into the well had caused the generation of earthquakes in the Denver area, with foci at a depth of about 3 miles.

Subsequent investigations relevant to the physical characteristics of the Denver disposal reservoir had indicated that the reservoir in the Precambrian rocks predominantly consists of fractures and that several parts of the reservoir have significantly different fluid permeabilities. After the cessation of the injections in 1966 the different parts of the reservoir were at different pressures, the most permeable part having the highest pressure. It has been indicated that the resulting pressure gradient, superimposed on the existing inherent earth stress field, may have been the cause of earthquake generation. It was concluded that the relationship between the injection and the earthquakes could not have been predicted when the well was drilled.

As stated previously, there are indications of the existence of inherent crustal stresses in the subsurface of the Montreal Region. The significance of these seismo-tectonic conditions to deep underground structures require careful assessment, and stress measurements during the field exploration stages.

Terratech

Project No.: 1669-0 Figure No. 5

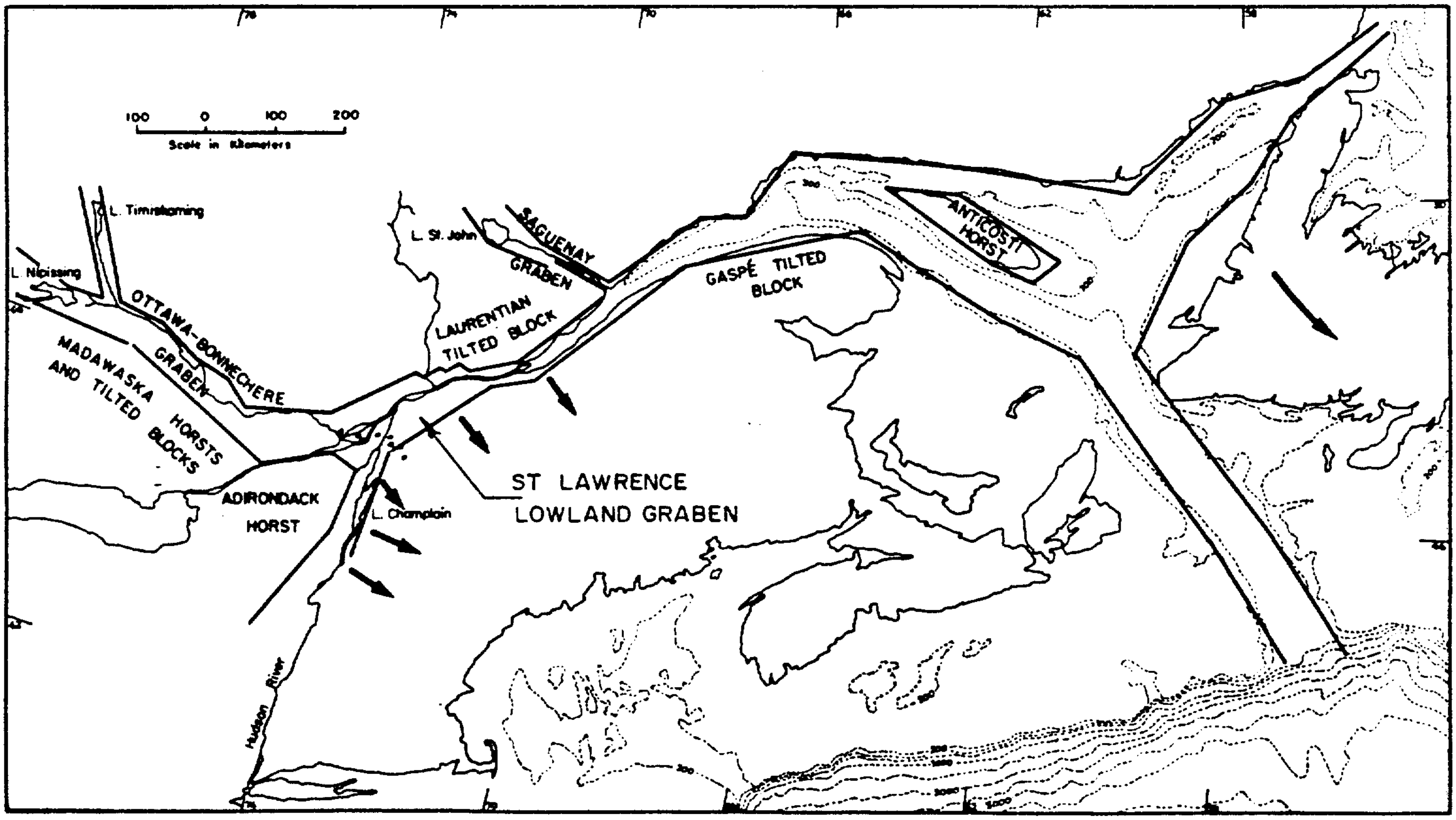


FIG. 5 RIFT ZONES OF THE ST. LAWRENCE SYSTEM

BIBL. REF. NO. 43

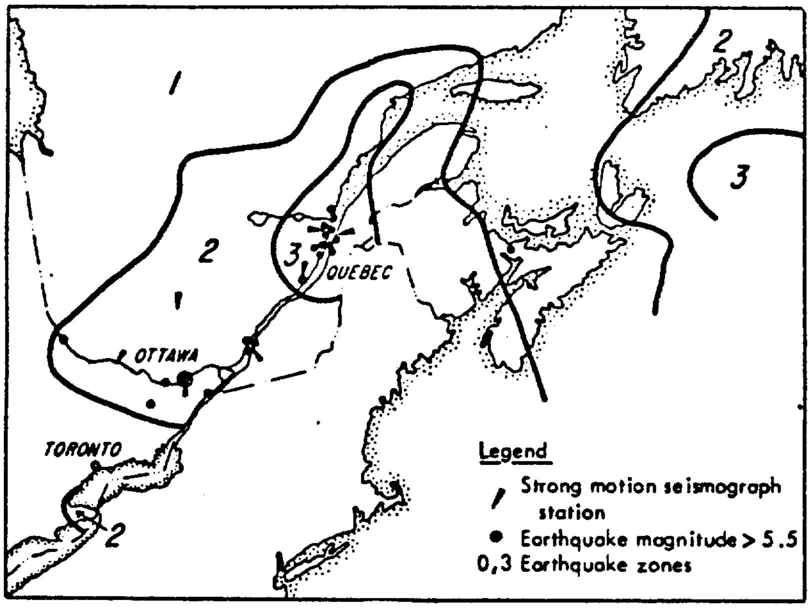


FIG. 4A SEISMIC ZONING MAP FOR EASTERN CANADA

BIBL. REF. NO. 61

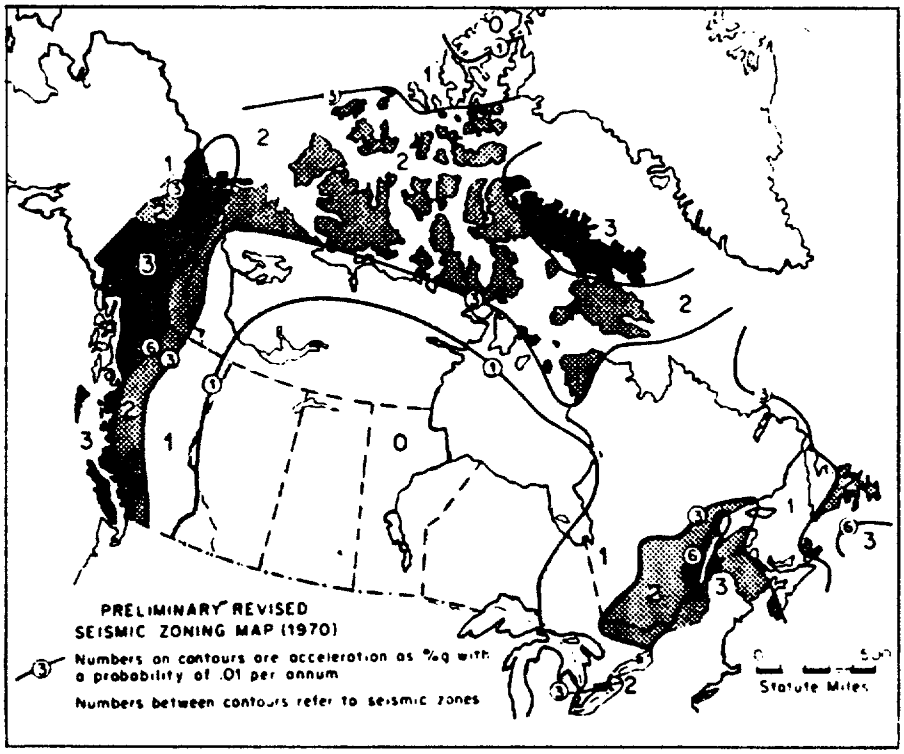


FIG. 4B SEISMIC ZONING MAP FOR CANADA

BIBL. REF. NO. 61

8. RESERVOIR - CAPROCK SYSTEMS

8.1 General Considerations

There are some geological characteristics which apply to the Montreal Region as a whole, affecting all of the rock groups described. Due to the synclinal structure of the region, the rock formations underlying the Varennes and Sorel areas have a general gentle dip in the southeasterly and northeasterly directions, the former indicating the dip of the limb of the syncline, the latter the plunge of the synclinal axis. The southeasterly descent of the sedimentary rock formations entailing the northwestern limb of the syncline, ends at the northeasterly trending axis of the syncline, i.e. at the bottom of the trough or at the greatest depth of the individual formations, some 18 miles distance from Varennes and 10 miles distance from Sorel. East and southeast of the axis the formations curve relatively steeply upwards, terminating against the tightly folded St. Germain Complex. Because of the reversal of the dip at the axis, the rock fracturing in the axis area may be more intense than that at the limbs of the syncline, bringing with it a possible increase in rock porosity and permeability. This, however, may not have a direct influence on the movement of the injected waste in the rock formations. In the Varennes and Sorel areas the injected waste fluid would generally follow the movement of the ground water, which is from higher to lower topography, i.e. from the Laurentian Uplands towards the southeast.

The regional faults may have an influence on the movement of the waste liquid in the rock formations. The permeability of the faults depends on the nature of the rock they intersect. Construction experience indicates that in the Precambrian basement rocks the faults are often pervious and act as channels leading water toward lower hydraulic pressure regions. The faults will probably remain open in the Potsdam sandstone which cannot be easily ground into impervious rock flour and which does not contain sealing clay minerals. Faults in the limestones and dolomitic limestones overlying the Potsdam sandstone may also be partly pervious due to the solubility of carbonates; some early records indicate the presence of solution caves (karst) in some of the Trenton formations of the Montreal area. The faults may be relatively impervious, however in the limestone and dolomite formations which contain horizons rich in shale interbeds. Drilling and excavations in the Lorraine and Utica shales indicate that the faults in the shales are impervious, due to the impervious clayey rock flour produced by the fault movements, and the swelling nature of some of the shale rock. It is believed that where the fault comprises the contact between limestone and shale groups, the characteristics of the shale prevail, and the fault is impervious.

Mount St. Bruno is the closest Monteregian volcanic intrusion plug to Varennes, at a distance of some 10 miles. Observations in the CUM pumping station excavation, about 180 ft deep, at the northern end of the Montreal Island, indicated a virtual lack of intrusion sills and dikes in the area. Therefore, it may be concluded that in the Varennes area the deleterious influence of the volcanic intrusives on rock conditions is insignificant. No outcrops of the volcanic intrusions are known in the Sorel area.

It is conceivable that the Eastern Canada tectonic mechanism, if responsible for the generation of earthquakes in the Lowland region, may be influenced by the injection of fluids into the Precambrian basement, considering the relatively shallow 3 milesdepth of the foci of the earthquakes generated apparently by the deepwell injections into the Precambrian rocks at Denver, Colorado. The existence of horizontal compressive stresses in the sedimentary rocks of the Montreal Region has been indicated. Such a compression may induce movements confined to some pre-existing faults. However, no direct correlation between faults and the earthquake epicenters has been established in Eastern Canada, and the fault movements, if any, appear to be non-earthquake-causative.

Considering the stratigraphy and the geologic characteristics of the rock groups of the Montreal Region, the following three deepwell disposal scenarios may be envisaged;

a) reservoir in the Precambrian basement rocks,
b) reservoir in the Potsdam group,
c) reservoir in the Trenton group.

The stratigraphic columns and the related reservoir-caprock systems of the Varennes and Sorel areas are given in Fig. 6 at the end of this section.

8.2 Reservoir in the Precambrian Basement Rocks

Based on the interpolation of the relevant geologic information, in the Varennes area the Precambrian basement rocks, predominantly granitic gneiss, lie at a depth of about 5000 ft below ground surface. In the Sorel area the depth to the Precambrian basement is in the range of 4000 ft. The surface of the basement rises in the northwesterly direction, outcropping as the flank of the Laurentian Upland some 20 miles from Varennes and 12 miles from Sorel. It descends gently in the northeasterly direction towards Quebec City, and in the southeasterly direction towards the St. Germain Complex, located some 30 miles from Varennes and 20 miles from Sorel. The basement surface has an irregular configuration, and consequently the depths given have to be considered with prudence.

No reliable data relevant to the porosity and permeability of the Precambrian rocks underlying the Montreal Region are available. However, the basement rocks of the Montreal Region are apparently similar in composition, structure and age to those of the Denver area, described previously. Consequently it may be assumed that the basement rocks of the Montreal Region have porosity values similar to those of the Denver area, i.e. in the upper limit range of 6 percent porosity, mainly in the mode of fractures.

The injection interval thickness of the Denver well was in the range of 100 ft (the bottom 100 ft of the well). The value of 6 percent porosity ± 2 porosity percent, and the injection thickness of 100 ft have been used by others to calculate the Denver reservoir area. For a calculated range of total reservoir fluid volumes between 0.6×10^9 and 1.9×10^9 barrels (from the porosity, injection volume, fluid compressibility and pressure data), at the cessation of the injections the reservoir area was found to be 20 sq. miles and 60 sq. miles, respectively, or in terms of radius, 2.5 miles and 4.4 miles, respectively. The reservoir is defined as the total volume of fluid within rock contiguous to the borehole wall in pressure communication with the portion of the borehole wall open to injection.

The confinement of the Denver reservoir was provided by the near-horizontally bedded limestone, sandstone and shale formations in a total thickness of about 11900 ft.

The confinement of the reservoir in the Precambrian rocks of the Varennes and Sorel areas is provided mainly by the overlying rock formations of the Beekmantown, Chazy and Black River groups. If the Trenton group is considered as an aquifer of fresh water used for human consumption, this confinement is essential.

It can be concluded that the Precambrian basement rocks of the Montreal Region appear to have the necessary characteristics of a suitable reservoir for liquid waste disposal, the upper part of the Potsdam group providing the immediate confinement against fluid percolation into the overlying formations. The percolation into the Trenton group is additionally prevented by the Beekmantown, Chazy and Black River rocks of relatively low porosity and permeability. Concerning faults as potential channelways in the Precambrian basement, there are no clear indications that the east-west trending faults such as the Bas de Ste. Rose fault, are continuous into the Precambrian rocks. The Rawdon and St. Cuthbert deepseated boundary faults are located at prohibitive distances both from Varennes and Sorel, considering the reservoir area extents as indicated by the Denver disposal project data.

8.3 Reservoir in the Potsdam Group

In the Montreal Region, including the Sorel area, the Potsdam group of sandstones is divided into two formations, the upper part of the group constituting the Chateauguay formation, the lower part the Covey Hill formation. The Chateauguay consists of fine grained quartz sandstone interbedded by dolomite.Because of the fine grain and siliceous cement of the sandstone the Chateauguay formation may be relatively impervious (2 percent porosity). The underlying Covey Hill formation, however, constitutes coarse grained to pebbly sandstone with basal beds of conglomerate; the degree of cementation ranges from loose-friable to tight. The water wells in it occasionally yield water up to 500 gal/min. The intergranular porosity of rock types similar to that of Covey Hill is known to be in the range of 15%. Consequently certain horizons in the Covey Hill may well have the characteristics of a suitable reservoir. The reservoir would be capped by the relatively impervious Chateauguay formation of the Potsdam group, and by all of the limestone and dolomite formations underlying the Trenton.

The Chateauguay formation (the cap) ranges in thickness between 298 ft (well no. 85) and 221 ft (well No. 88), on the northwestern limb of the St. Lawrence Lowland syncline. Assuming that down-dip in the limb, i.e. in the direction of Varennes from well No. 88 the thickness of the Chateauguay does not change significantly, the Chateaugay formation in the Varennes area would have a thickness of about 220 ft (as in well No. 88). Considering the total thickness of the Potsdam of 1450 ft, the thickness of the Covey Hill in the Varennes area may be in the range of 1230 ft. In the Sorel area the estimated total thickness of the Potsdam group is 400 ft. Study of outcrops indicates that the Covey Hill formation is present in the Sorel area, but the delimitations of the formation at Sorel are not known.

The considerations in favour of the reservoir in the Potsdam group are a) the relatively high mass porosity of some of the Covey Hill strata, b) the chemical inertness of the rocks, and c) the considerable distance of the Potsdam surface exposures from Varennes and Sorel. On the negative side is the possibility that some wells in the Montreal Region may provide water from the Potsdam for human consumption. Vertical and horizontal percolation of waste fluid in the Potsdam along the east-west trending faults such as the Bas de Ste. Rose fault is conceivable. However, in the limestone-dolomite formations overlying the Potsdam these faults are believed to be relatively impervious mainly because of the shale interbeds in these formations, and the recrystallization processes.

It must be pointed out that the percolation of waste fluids in the sedimentary rocks of the Montreal Region, including the Potsdam but excluding the Trenton and the Utica-Lorraine groups, is believed to be predominantly near horizontal, along the stratification joints, which provide the preferred passage under pressure. The percolation in the injection horizon would be probably in the northeasterly direction, parallel to the axis of the syncline, and easterly, in the direction of the groundwater flow.

8.4 Reservoir in the Trenton Group

Although the Trenton group of rocks, predominantly limestones, may constitute suitable reservoir horizons in the physical and geological terms, severe environmental restrictions will have to be considered.

The thickness of the Trenton group is in the range of 600 ft to 700 ft in the Sorel and Varennes areas. The group is capped by impervious shale formations, the total thickness of which may be in excess of 1600 ft at Varennes as well as Sorel. As indicated by the studies of water wells, the highest yields of water, and consequently the highest fracture zone permeabilities occur in the Middle and Upper Trenton formations, located between the elevations of 1600 ft and 2210 ft below sea level in well No. 75, Vercheres area, and between 1390 ft and 1990 ft below sea level in well No. 8, Berthierville area.

The Upper-Middle Trenton has a very low primary porosity (0.5% or less) but high permeability in fracture zones, which have yielded water at the rate of up to 1000 gal/min, some of the wells being artesian (springs).

In the past the Upper-Middle Trenton has been used extensivily as a source of water for human consumption. Although at present time domestic water is obtained primarily from the St. Lawrence by purification, some ground water from the Trenton is still used for human and industrial consumption in the Montreal Region. Even a very remote possibility of polluting this fresh water source would have grave consequences, unless a total confinement of waste fluid or its harmlessness to the environment can be ascertained.

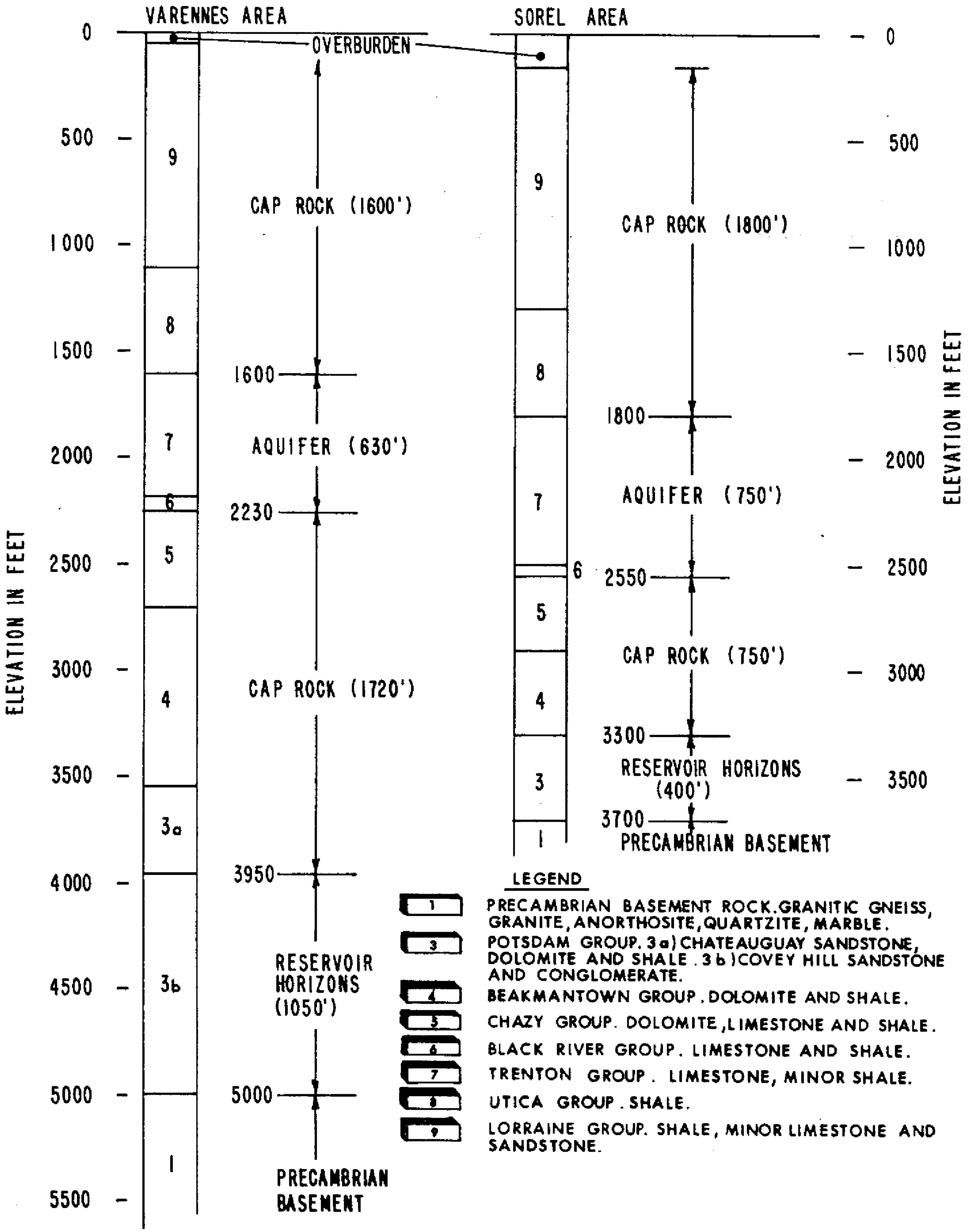
The upward percolation of the waste fluid in the Varennes and Sorel areas is barred by the impervious shale (Utica and Lorraine groups). The percolation southward from the Varennes area may be partly barred by the Bas des Ste. Rose fault, which strikes east-west. The fault is believed to be impervious within the shales, and impervious also when constituting the contact between the shales to the north and the Trenton to the south of the fault. However, when wholly in limestone below the shales, the fault may not be a barrier any longer, and percolation of fluid waste may take place southward and northwestward in the limestone, with a potential point of surfacing at the northern tip of the Montreal Island, some 3 miles west of Varennes.

In the Sorel area the nearest Trenton outcrops are located some 6 miles northwest of Sorel. The communication of the waste fluid with waterwells in the Berthierville area, for example, cannot be ruled out.

In order to determine the geological feasibility of a reservoir in the Trenton group major exploratory efforts are required. It is felt also that the establishing of the environmental feasibility will be extremely difficult, unless it can be shown that the waste fluid is absolutely harmless to the environment.

PROJECT NO. 1669-0 **Terratech** FIGURE NO. 6

STRATIGRAPHIC COLUMNS IN THE VARENNES AND SOREL AREAS



9. SUMMARY AND CONCLUSIONS

The results of the evaluation of the geological and physical characteristics of the rock formations underlying the Montreal Region indicate that in view of the deepwell waste disposal prospects at Varennes and Sorel, three scenarios may be considered. These are:

a) Reservoir in the Precambrian basement rocks
b) Reservoir in the Potsdam group, Covey Hill formation
c) Reservoir in the Trenton group (Upper and Middle formations)

The physical and geological characteristics of the rock groups underlying the Montreal Region are summarized and tabulated in Table 14, at the end of this section.

Deepwell disposal of waste fluid in the Trenton group is considered not feasible on the bases of the major geological exploratory efforts required, and the anticipated environmental restrictions.

Deepwell disposal of waste fluid appears possible in the Precambrian basement rocks as well as in the Potsdam sandstones. In general environmental terms the basement as well as the Potsdam rocks are on an equal rating level - depth, confinement, and distance from the injection section to the nearest surface exposure of the respective formations are equally meritable for both. Some wells may take fresh water from the basement as well as from the Potsdam, but these wells are located most probably in the fringe areas of the Lowland, where the well depths to the water horizons are not prohibitive.

It remains to assess the respective merits and shortcomings of the Precambrian basement rocks and the Potsdam rocks in the geological and physical terms.

It has been assumed that based on the available Denver disposal well data the fracture porosity of the basement rocks in the Montreal Region may be in the upper limit range of 6 percent, with practically no intergranular porosity. In the Potsdam group of sandstones the available values indicate an intergranular porosity of considerable range, the highest known value being 14.9 percent, in the bottom part of the group. Adding the fracture porosity of unknown value, the Potsdam appears superior to the basement rocks, in terms of reservoir porosity.

Due to the random fracture pattern in the basement rocks, the injected fluid, regardless of the length of the injection section, may go down and/or up into the overlying formations, resulting in considerable uncertainties in the calculations of the reservoir volume, area, and the true effective thickness of the injection interval. The sandstones, on the other hand, are near-horizontally stratified, the stratification joints of a relatively equal spacing providing the preferred route of fluid percolation. Because of the relative homogenity of the sandstone rock in composition and structure, the exploration results from a test hole in sandstone can be applied to the rock mass with a reliability factor superior to that for the basement rocks.

In addition to the irregular fracture pattern, the lithology of the basement rocks is variable, comprising rocks of various mineralogic assemblies, including crystalline limestone. The known basement rock exposures surface more than 20 miles from the Varennes area and 12 miles from the Sorel area. The basement rocks have been encountered in the Montreal Region in two wells, No. 57 and 58, located at distances of 8 miles and 12 miles from Varennes, respectively. The lithologic heterogenity of the basement makes interpolation over such distances highly assumptive - in the disposal well areas the basement may comprise generally impervious anorthosite or granite plutons, or relatively soluble marble, unsuitable as waste disposal reservoir rocks. Contrary to the basement, the Potsdam sandstones are relatively homogeneous in composition, comprising 99 percent quartz, and thus inert chemically.

The seismo-tectonic conditions of the St. Lawrence Lowland region are imperfectly understood. It has been indicated, however, that the known earthquake foci are located in the Precambrian basement, at a depth range of 9 miles, and related to some stress mechanism prevailing in the basement. Although the potential injection horizon in the basement rocks would be at a relatively shallow depth, say between 5000 ft and 5500 ft, as compared to the 9 mile depth of the known earthquake foci, superimposure of the injection pressure on the existing stress field in the basement, particularly in consideration of the random fracture systems, and the induced reservoir pressure gradients, may be undesireable. In the Denver area the earthquakes apparently generated by the fluid injection, had their foci at depths of about 3 miles. Consequently injections into the Precambrian basement may be construed as earthquake causative, even if only by precedence.

In summary, the bedrock strata underlying the Montreal Region contains two horizons potentially suitable in terms of geologic criteria for liquid waste disposal by the deepwell method. The horizons considered potentially suitable are located within a) the Precambrian basement rocks, and b) the sandstones and conglomerates of the Potsdam group. In terms of the geologic criteria, and the anticipated reservoir characteristics, the Potsdam group of rocks appears superior to the Precambrian basement rocks, for the meritable reasons of mineralogic and structural homogenity, chemical inertness, porosity and permeability.

The results of the imposure of the reservoir pressures on the tectonic stresses prevailing in the Montreal Region cannot be predicted at this time, but precedence indicates that the Precambrian basement may be pressure sensitive to long term fluid injections.

It is concluded that in the Montreal Region, which for the purposes of this study includes the Varennes and Sorel areas, the Potsdam group of rocks appears to entail adequately confined reservoir horizons geologically suitable for the disposal of liquid waste by the deepwell method. The potentially suitable horizons may be found between the elevations of approximately 4000 ft and 5000 ft below sea level in the Varennes area, and between the elevations of approximately 3300 ft and 3700 ft below sea level in the Sorel area. Based on the results of the evaluations of the available geologic data, it is believed that further studies and subsurface explorations for the deepwell disposal of liquid waste in the Montreal Region are warranted.

TERRATECH

Ralph Kall
Supervising Geologist

GEOLOGICAL ASSOCIATION OF CANADA
RALF KALL
· FELLOW ·

TABLE 14

Summary of Geologic Criteria

Rock Group / Criteria	Precambrian Basement Rocks	Potsdam	Beekmantown	Chazy	Black River	Trenton	Utica-Lorraine
Rock types (predominating)	Granitic gneiss, granite, anorthosite	Sandstone, conglomerate	Dolomite, limestone shale, sandstone	Limestone, dolomite, shale sandstone	Limestone, dolomite, shale	Limestone with shale interbeds	Shale. Interbeds of sandstone.
Mineralogy	Quartz, feldspar, biotite, hornblende. Crystalline	Quartz 99%. Detrital, fine to coarse grained	Carbonates of Ca, Mg. Minor quartz. Cryst. to detrital	Carbonates of Ca, Mg. Minor quartz Cryst. to detrital	Carbonates of Ca, Mg. Cryst. to detrital	Carbonates of Ca Crystalline to fine detrital	Clay minerals, some pyrite
Porosity	6% ± 2% fracture voids	Upper part 2 - 3% Lower part 10-15% Intergranular	Up to 5% Rock mass	Less than 5% Rock mass	Same as for Trenton	Primary up to 0.5%. High fracture porosity	Very low
Permeability	0.1 - 0.8 gal/min/ft Higher in faults	Low in upper part, moderate to high at base	Mostly low, but variable	Very low	Same as for Trenton	Fracture controlled very high in places	Very low to impervious
Yields of water wells	Up to 30 gal/min Higher in faults	Up to 500 gal/min in lower part	125-750 gal/min.	Up to 10 gal/min	Same as for Trenton	500-1000 gal/min, Some artesian.	Up to 5 gal/min, higher near intrusives
Groundwater chemistry	Slightly acidic	Basic, hard	Basic, hard	Basic, hard	Basic, hard	Basic, hard	Basic, hard
Gas emanations	None	Isolated horizons with insignificant yields	Isolated horizons with insignificant yields	None	None. May contain droplets of oil.	Insignificant. May contain droplets of oil	Some at shallow depth, non-commercial
Remarks	Top elevation variable. Permeability and porosity related to fracture density and may be highly variable.	Bottom elevation irregular. Porosity of lower part may exceed 15% due to fracture voids. Chemically inert.	Thickness increasing from west to east. 5% porosity in thin horizontal isolated layers.	Low porosity and permeability due to shale interbeds and fracture healing.	General characteristics like those of lower Trenton, i.e. relatively pervious.	Main fresh water source in the past. Permeability highly variable. Environmental implications.	Overlain by glacial and marine deposits

APPENDIX A

SEISMIC RISK CALCULATIONS

ENERGY, MINES AND RESOURCES CANADA EARTH PHYSICS BRANCH	ENERGIE, MINES ET RESSOURCES CANADA DIRECTION DE LA PHYSIQUE DU GLOBE

SEISMIC RISK CALCULATION *	CALCUL DE RISQUE SEISMIQUE *

REQUESTED BY DEMANDE PAR	R KALL TERRATECH LTD MONTREAL			
FOR SITE POUR SITE	VARENNES, QUEBEC			
LOCATED AT LOCATION	45.67 NORTH/NORD	73.42 WEST/OUEST		
PROBABILITY OF EXCEEDENCE PER ANNUM PROBABILITE DE DEPASSEMENT PAR ANNEE	.01	.005	.002105	.001
PEAK HORIZONTAL ACCELERATION (%G) ACCELERATION HORIZONTALE MAXIMALE (%G)	7.0	10.2	16.0	23.0
PEAK HORIZONTAL VELOCITY (CM/SEC) VITESSE HORIZONTALE MAXIMALE (CM/SEC)	3.0	5.2	9.4	14.5

* REFERENCE
NEW PROBABILISTIC STRONG SEISMIC GROUND
MOTION MAPS OF CANADA: A COMPILATION OF EARTHQUAKE
SOURCE ZONES, METHODS AND RESULTS
P.W. BASHAM, D.H. WEICHERT, F.M. ANGLIN, AND M.J. BERRY
EARTH PHYSICS BRANCH OPEN FILE NUMBER 82-33
OTTAWA, CANADA 1982

23/10/83 15.39.51.

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SEISMIC RISK CALCULATION *

CALCUL DE RISQUE SEISMIQUE *

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DEMANDE PAR

TERRATECH LTD

FOR SITE

POUR SITE

SOREL, QUEBEC

LOCATED AT

LOCATION

46.05 NORTH/NORD   73.08 WEST/OUEST

PROBABILITY OF EXCEEDENCE PER ANNUM PROBABILITE DE DEPASSEMENT PAR ANNEE	.01	.005	.002105	.001
PEAK HORIZONTAL ACCELERATION (%G) ACCELERATION HORIZONTALE MAXIMALE (%G)	5.7	8.3	12.3	17.3
PEAK HORIZONTAL VELOCITY (CM/SEC) VITESSE HORIZONTALE MAXIMALE (CM/SEC)	2.9	4.9	9.0	13.8

* REFERENCE
NEW PROBABILISTIC STRONG SEISMIC GROUND
MOTION MAPS OF CANADA: A COMPILATION OF EARTHQUAKE
SOURCE ZONES, METHODS AND RESULTS
P.W. BASHAM, D.H. WEICHERT, F.M. ANGLIN, AND M.J. BERRY
EARTH PHYSICS BRANCH OPEN FILE NUMBER 82-33
OTTAWA, CANADA 1982

10/02/84 14.46.33.

APPENDIX B

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