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GEOCHEMICAL ZONING OF THE GROUND WATER OF MONTREAL ISLAND

DEPARTMENT OF GEOLOGICAL SCIENCES

M.Sc

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- by -

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Thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the Degree of Master of Science

DEPARTMENT OF GEOLOGICAL SCIENCES,
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ABSTRACT

Preliminary estimates suggest that at least 10% of the present water requirements of Montreal could be drawn from the sub-surface.

Data collected from 1951-3 from 161 wells, ranging in depth from 8 feet to 919 feet, were used in this study to interpret the nature of the ground. Water level data indicated that the ground water flow of the Island is radially outwards from its topographically high areas.

The dominant hydrogeochemical zone of Montreal is one of calcium bicarbonate, which correlates with the Palaeozoic limestones found extensively on the Island. Two other minor zones are superimposed on this. One is magnesium-rich, in the west of the Island, associated with the Beekmantown Dolomite. The other is sodium-rich, found east and north of Mount Royal, a gabbroic stock, and appears to be associated with this and minor intrusions, rather than Quaternary marine clays. Bicarbonate is by far the most important anion, whilst sulphate and chloride achieve significant concentrations locally.

Zonage géochimique de l'eau souterraine
de l'Ile de Montréal

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RÉSUMÉ

Des évaluations préalables suggèrent qu'au moins de 10% des besoins actuelles en eau de Montréal pourraient être tirés de dessous la surface.

Pour interpréter la nature du terrain dans cette étude on a utilisé des données recueillies de 1951 à 1953 de puits s'étendant en profondeur de 2 m à 280 m. Les données du niveau de l'eau indiquaient que l'eau souterraine de l'Ile s'écoule radiallement au dehors des zones topographiques élevées.

Le bicarbonate de calcium dans la zone hydrochimique dominante correspond aux calcaires paléozoiques qui sont très répandus sur l'Ile. Surimposées la-dessus se trouvent deux zones de moindre importance. L'une, à l'ouest de l'Ile, est riche en magnésium associé au dolomite de Beekmantown. L'autre, riche en sodium, se trouve à l'ouest et au nord, de Mount Royal, et semble être associée à ce culot de gabbro et à des autres intrusions mineures plutôt qu'aux argiles marines quaternaires. Surtout le bicarbonate est l'anion le plus important, tandis que le sulfate et le chlorate atteignent en quelques endroits des concentrations importantes.

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The author wishes to express his indebtedness to Dr. R.H. Grice and Dr. G.R. Webber, co-directors of this research whose continuing interest and guidance were an intrinsic part of its completion. A special word of thanks is extended to Dr. J.A. Elson for his help in many ways and to Dr. T.H. Clark for his willingness to make available his very considerable knowledge of the local geology.

Acknowledgment is due to Mr. E.I.K. Pollitt for the use of the data collected by him and to Mr. R. Roy of the ground water branch of the Ministière des Richesses naturelles in Québec City who furnished the records.

Particular gratitude goes to all members of the Geology and other departments who provided useful commentary throughout the investigation.

CHAPTER 1 - INTRODUCTION

1.1 Purpose

There will be an increase in demand for water from 300 million gallons per day (mgd), to an estimated 450 mgd by 2,000 A.D. on Montreal Island. (Montreal Urban Community, 1972). Since there may be a progressive deterioration in the quality of the present surface sources of water, it will be useful to know the chemical zonation and basic flow pattern of ground water in order to plan further development.

1.2 Scope

Adams and Leroy, 1904, were the first to consider the chemistry of the ground water within the Island of Montreal, followed by Cumming in 1915. Subsequently Pollitt made an extensive field study in 1951-3, but did not publish any results. Other hydrogeochemical studies have been carried out in nearby areas by Tremblay (1968) and Freeze (1964).

The scope of this thesis has been defined by the data collected by Pollitt in the most recent comprehensive study in 1951-3 (Fig. 1.1 and Tables 1.1a and 1.1.b). The data are of two types, lithological and chemical, of which the latter is detailed and reliable while the former is less specific and has been augmented from other sources, mainly Clark's thorough mapping and reports of 1952 and 1972, and from personal field observation. Chemical data with a milli-equivalent per litre (meq/l)

FIGURE 11

MAP TO SHOW THE DISTRIBUTION OF THE ORIGINAL DATA ON MONTREAL ISLAND

EACH POINT REPRESENTS
ONE SAMPLED WELL

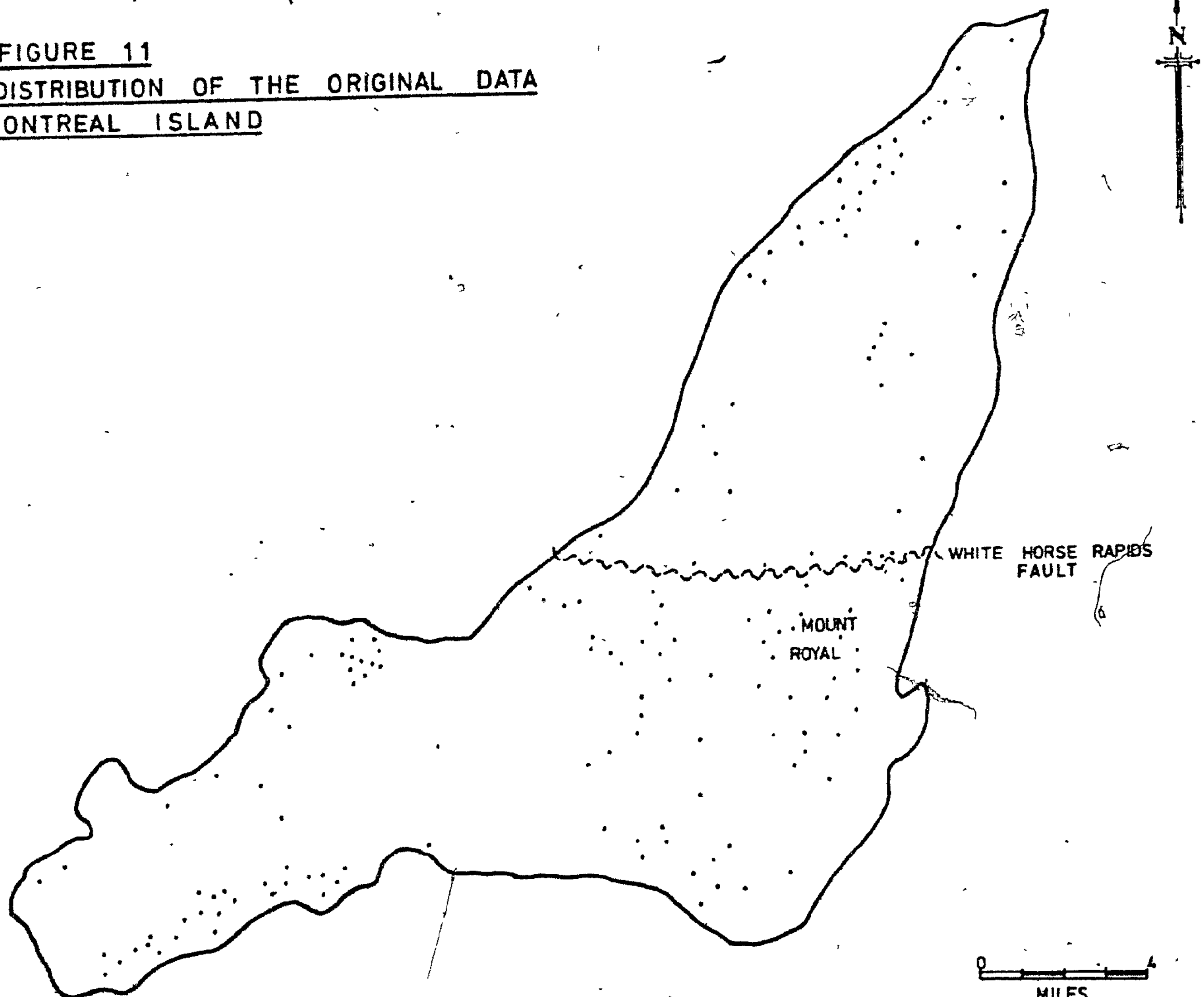


TABLE 1.1a ORIGINAL DATA SHEET - CHEMICAL.

DEPARTMENT OF MINES AND TECHNICAL SURVEYS
OTTAWA, ONTARIO, MINES BRANCH, INDUSTRIAL WATERS SECTION
Water Analysis Report (Parts per Million)

Laboratory Number	6887	6896	6897
Field Number	PM-53-16	PM-53-17	PM-53-18
Location		Montreal area	
Source of Water	Well no. 6	Well no. 5	Well no. 2
Sampling Point	A. Degrosbois 12-3rd Ave. South	G. Renaud 30-4th Ave. South	J. Murray 7-4th Ave. North
Collector		K. Pollitt, G.S.C.	
Analyst			
Date of Sampling		August to September 1953	
Storage (days)			
Sampling Temp. °C			
Test Temp. °C	25.3	25.3	25.3
Diss. Oxygen (O_2)			
Carbon Dioxide			
pH	8.4	8.2	8.0
Colour	5	5	5
Turbidity	slight	slight	slight
~~Alk. as $CaCO_3$~~(Ph-ph)	2.6	0	0
Alk. as $CaCO_3$(MeO)	309	251	344
Suspended Matter:-			
Dried at 105°C			
Ignited at 550°C			
Residue on Evap.:-			
Dried at 105°C			
Ignited at 550°C			
Ignition Loss			
Conductance at 25°C^x	1459	823	821
Hardness as $CaCO_3$:-			
Total	54.7	146	233
Carbonate	54.7	146	233
Noncarbonate	0	0	0
Calcium (Ca)	9.2	24.8	50.0
Magnesium (Mg)	7.7	20.5	26.1
Iron (Fe) Total			
Diss.			
Aluminium (Al)			
Manganese (Mn)			
Sodium (Na)	307	123	97.0
Potassium (K)	6.8	8.0	7.6
Carbonate (CO_3)	3.1	0	0
Bicarbonate (HCO_3)	370	306	420
Sulphate (SO_4)	97.1	64.8	50.6
Chloride (Cl)	215	70.1	37.1
Fluoride (F)	-	0.5	0.6
Phosphate (PO_4)			
Nitrite (NO_2)			
Nitrate (NO_3)	0.20	0	0.4
Silica (SiO_2) Grav.			
Col.	10.8	17.8	20.6
Boron (B)			
Sum of Constituents	1027	480	497

^x Micromhos

Remarks

TABLE 1.1b ORIGINAL DATA SHEET - LITHOLOGICAL

WATER SAMPLES MONTREAL 1951 Oct 9/61

No.	Name	Address	Well No.	Type	Elev.	Depth	Depth to Water	Aquifer	Remarks
PM-1	Continental Can	3455 Cote de Liesse	1	Dr.	135	200	-13	Limestone	Rec'd Feb. 25/52
-2	Barraute Lumber Co.	100 Stinson Blvd.	8	"	134	50	-12	"	
-3	Bissonnette Cut Stone	5001 Cote de Liesse	2	"	133	150	-16	"	
-4	St. Croix Convent	St. Croix Street	5	"	126	250	-6	---	
-5	Ayerst, McKenna & Harrison	1025 Montee St. Laurent	10	"	104	212	-27	Limestone	
-6	Terry Machinery Co.	10030 Montee St. Laurent	100	"	99	110	-17	---	
-7	Webster Industries Inc.	10090 Montee St. Laurent	14	"	98	89	-13	---	
-8	Thibault Ice Co.	2760 Reading	51	"	50	333	-14	Limestone	
-9	Russel-Hipwell Engines	8101 Metropolitan Blvd.	62	"	81	160	---	"	March 27
-10	Wm. C. Hall, Florists	175 Easton	61	"	100	72	-2	"	
-11	Elmhurst Dairy	7460 Upper Lachine Rd.	63	"	153	360	-15	----	
-12	Cote des Neiges Cemetery	4601 Cote des Neiges	110	"	486	486	-50	---	
-13	Pratt Park	Dunlop & Lajoie	15	"	315	770	-60	---	
-14	St. Viateur Park	Bloomfield & Bernard	16	"	243	210	-30	---	
-15	Dominion Preserving	8455 St. Dominique	27	"	145	85	0	Limestone	
-16	Transit Dry Kilns	9500 St. Lawrence	25	"	~~98~~	~~64~~	-5	"	
-17	Frontenac Brewery	5930 de Gaspe	91	"	212	490	-33	"	
-18	Lion Vinegar	4537 Drolet	30	"	174	575	---	---	

Dr. - Drilled

K. Pollitt

balance poorer than 10% were discarded.

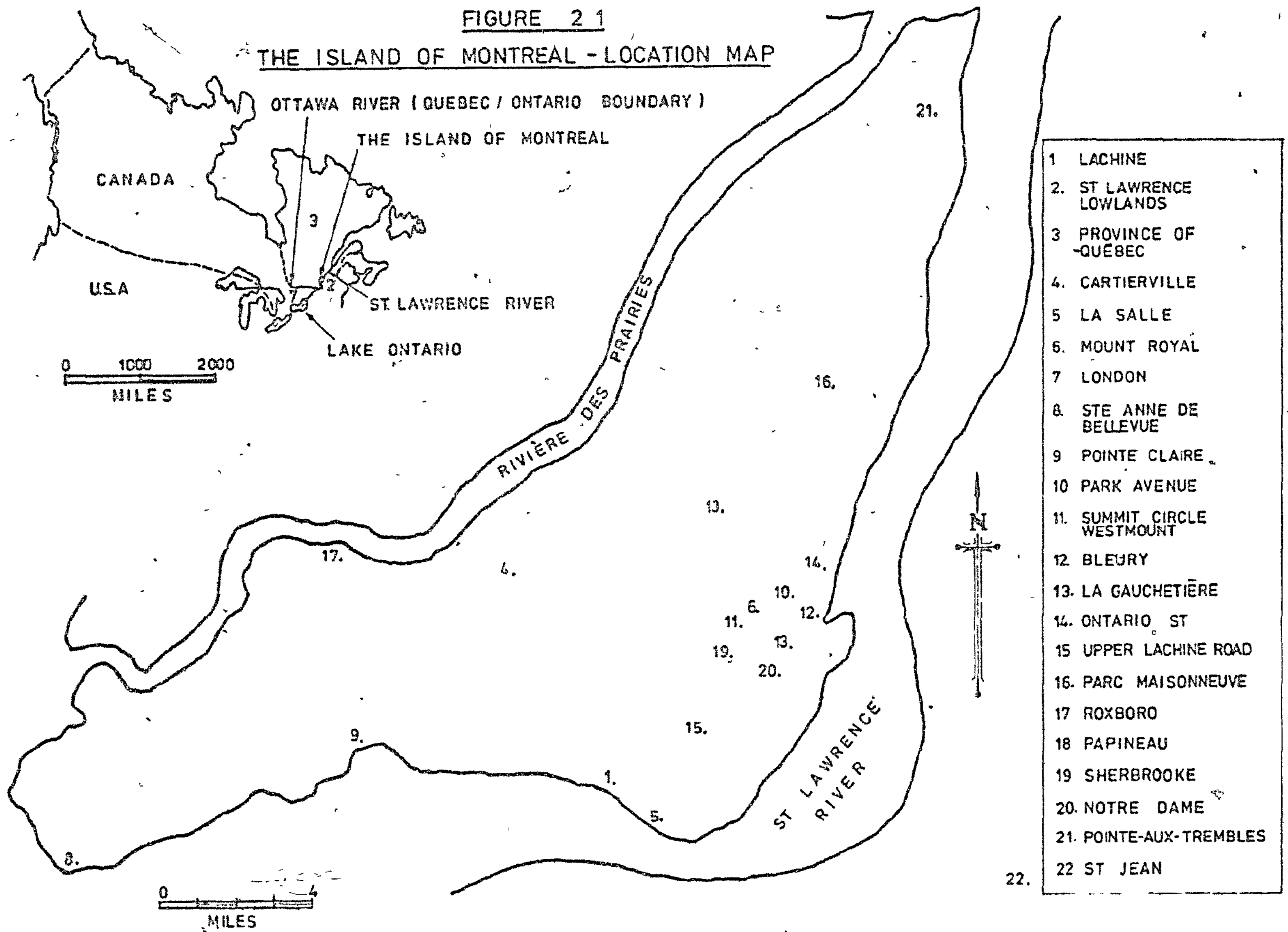
Hydrologic data such as base flow and evapotranspiration rates were taken from work done by Freeze in 1964 in the Lachine-St. Jean area, which is mainly to the south of the St. Lawrence River.

All data were recorded and processed using computer systems developed by the Department of Geological Sciences at McGill University. Further discussion of the type and reliability of the data and its retrieval can be found in Appendix A. Samples of printouts processed by the PLAN programme are included as Appendix D, whilst calculations of saturation indices and other parameters form Appendix C.

This investigation consisted of a study of the hydrochemical species of the ground water of Montreal Island. This was to locate any hydrochemical zones and to ascertain if they correlated with the geology. The first four chapters of the thesis introduce the environment and geology of the predominantly limestone rocks of Montreal, and the factors which determine the general mode of occurrence of ground water. This sequence allows emphasis to be placed on the hydrogeological traits of the system which have relevance in the subsequent discussion of ground water composition and flow. Chapter 5, on the chemistry of water, includes reference to the four major cations, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, the four major anions, HCO_3^-, CO_3^{2-}, SO_4^{2-},

FIGURE 2 1

THE ISLAND OF MONTREAL - LOCATION MAP



Cl^- and to the factors controlling their presence in water, especially that of limestone terrains. Finally analyses are interpreted by means of Schoeller diagrams and horizontal and vertical plots, so that explanations could be given of the location of hydrochemical zones on Montreal Island.

CHAPTER 2 - GENERAL DESCRIPTION OF THE AREA

2.1 Location

Montreal Island is located in the St. Lawrence Lowlands in the southwest part of the Province of Quebec, Canada (Fig. 2.1) between longitudes 73°23' and 73°28' west, and latitudes 45°23' and 45°43' north. It is bounded by the St. Lawrence River to the south and east, and the Rivière des Prairies to the north, and has an irregular triangular shape of area 122,941 acres (Lajoie and Baril, 1954). It is 32 miles in length and has a maximum width from Cartierville to LaSalle of 10 miles (Fig. 2.1 points 4 and 5).

2.2 Physiography

Montreal has elevations between 60 feet and 760 feet above sea level (Fig. 2.2). The lowest land is near the northeastern tip of the Island, while the highest is in the area of Mount Royal (Fig. 2.1 point 6).

2.2.1 Topography

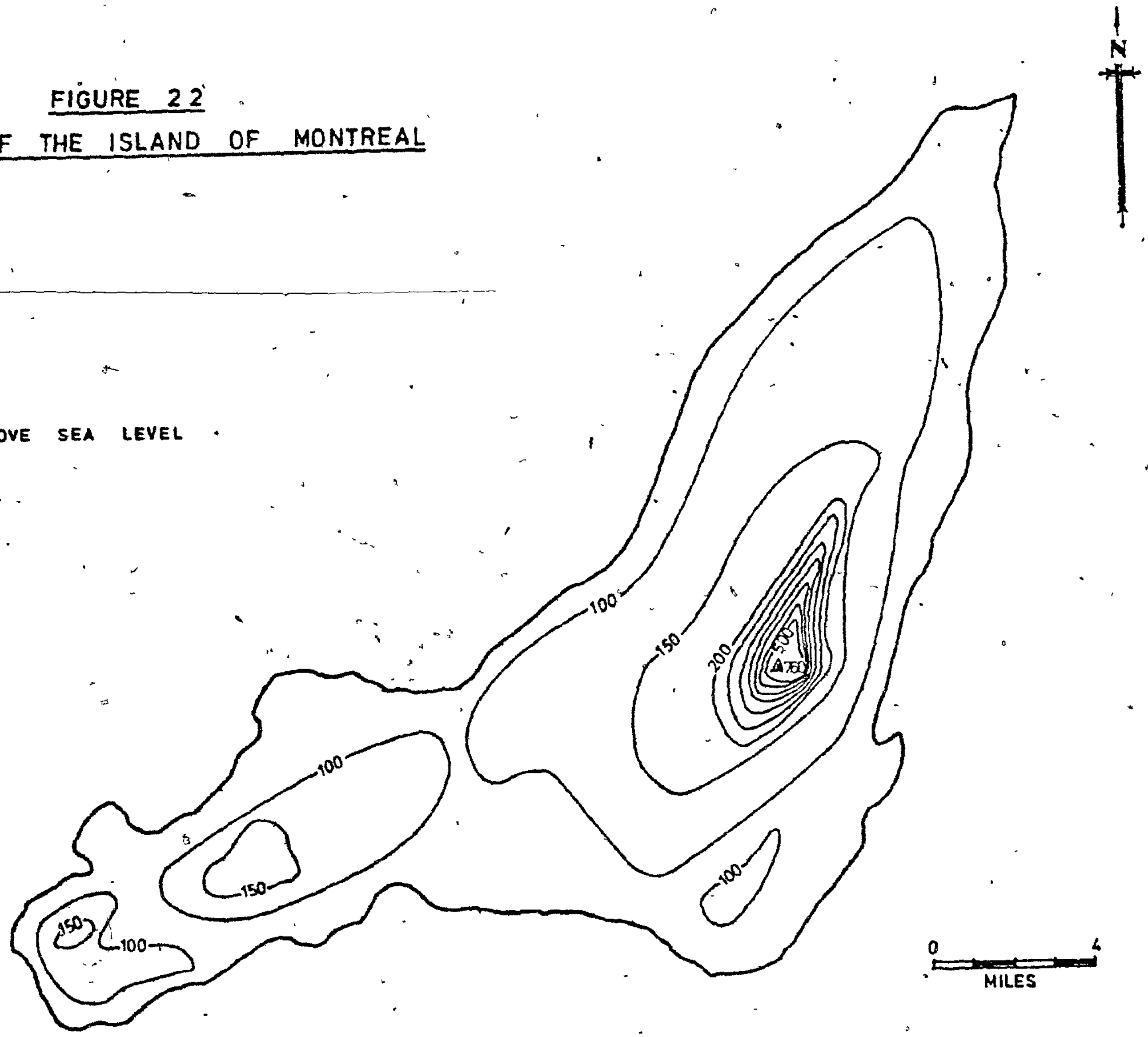
The topography is for the most part flat and reflects the structure of the underlying Palaeozoic strata, modified by a complex pattern of low morainic ridges and glacial activity. Bare outcrops of flat rock are confined mainly to the east of the Island, (Lajoie and Baril, 1954).

2.2.2 Drainage

The Island is drained by small creeks which flow into the

FIGURE 22

TOPOGRAPHIC MAP OF THE ISLAND OF MONTREAL



CONTOURS IN FEET ABOVE SEA LEVEL

50' CONTOUR INTERVAL

St. Lawrence River or the Rivière des Prairies, which are part of the Ottawa River - St. Lawrence River system. The largest streams flow SW - NE, sometimes in abandoned channels of the major rivers. The streams tend to be intermittent, meandering, and often poorly entrenched, though the reverse is true of the last feature if clay is encountered. Drainage of the smoother clay areas is facilitated by secondary ditches but free water flow from these areas is frequently impeded by natural barriers of stony till or bedrock (Lajoie and Baril, 1954). The presence of the following great soil groups, Dark Grey Gleisolic soils, Half-Bogs, Bogs and Alluvial soils, all of which characterise poor drainage conditions, shows there is a relatively impermeable cover (Lajoie and Baril, 1954). Much construction in the last 15 years has modified the natural drainage in detail.

2.3 Climate

The climate of the region is humid continental with a mean annual temperature of 45°F. The summers are warm, but the winters are very cold, with temperatures as low as -27°F. The coldest month, January, has an average temperature of 17°F, while July, the hottest, has an average temperature of 71°F (Table 2.1). The last spring frost is in May while the first autumnal one is at the beginning of October. This represents about 140 frost free days (Tremblay, 1968, p 50). Historically, total precipitation has ranged from 52 inches to 29 inches per annum but a mean for the years shown in Table 2.2 is 43.8 inches (Table 2.2).

TABLE 2.1

THE MEAN TEMPERATURES OF THE YEARS 1945 TO 1954

Year	Temperatures °F January	July	Mean
1945	8.49	69.79	44.42
1946	15.99	69.66	44.87
1947	17.81	70.79	44.14
1948	12.64	70.80	45.09
1949	21.48	73.27	46.45
1950	21.56	69.92	43.98
1951	18.68	70.12	44.81
1952	17.95	73.73	46.10
1953	21.85	71.52	47.54
1954	10.86	68.00	44.21
Mean temperature over 10 years	16.73	70.76	45.15

Station: McGill University Observatory

TABLE 2.2

THE ANNUAL PRECIPITATION OF THE YEARS 1945 TO 1954

Year	Precipitation (inches)
1945	49.36
1946	43.89
1947	44.10
1948	38.05
1949	38.47
1950	43.55
1951	45.11
1952	47.65
1953	36.37
1954	51.72

Mean annual precipitation over 10 year period is 43.8 inches

Station: McGill University Observatory

Note: 10 inches snow equal 1 inch rain

About one third of this is in the form of snow, and at least six months each year are affected by snowfall. The remaining two thirds of the precipitation occurs during the growing season, at which time evapotranspiration is responsible for a loss of about 54% of the annual precipitation (Freeze, 1964, p 8).

2.4 Hydrological Cycle in Montreal

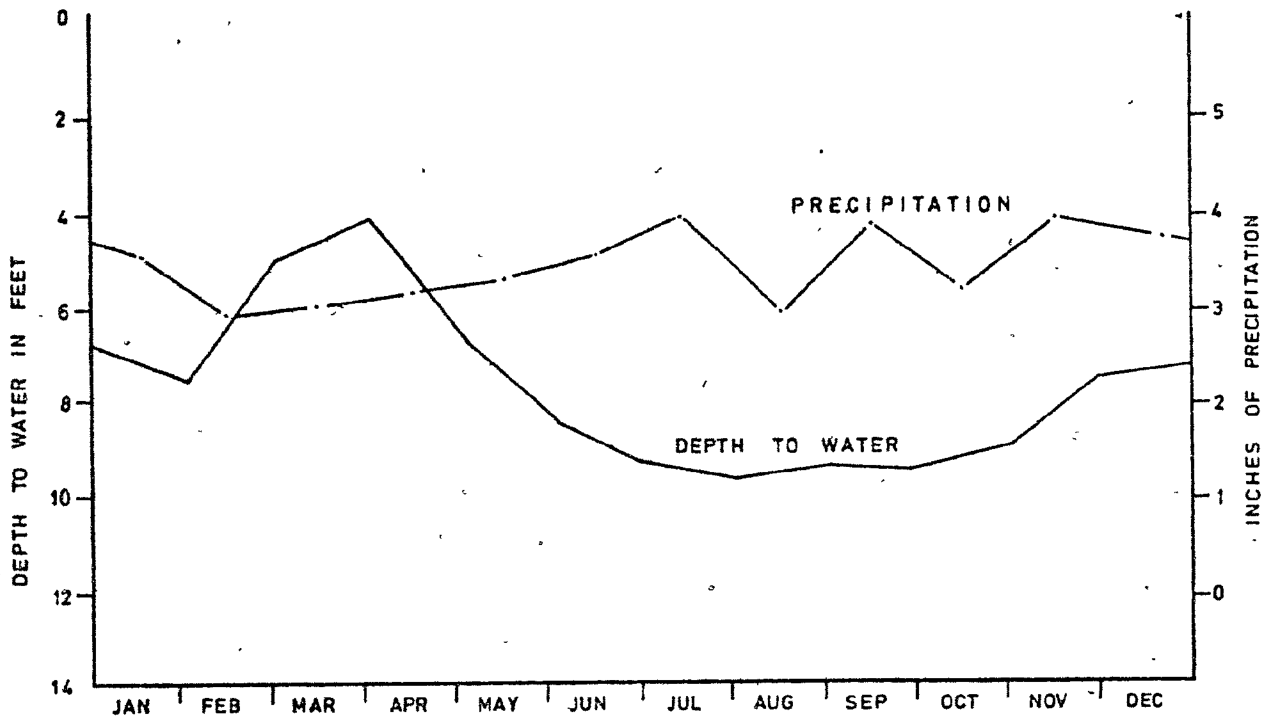
Ground water level depends on climatic conditions. Figure 2.3 (Brown, 1967, p. 102) shows the annual ground water hydrograph in a well in London, Ontario (Fig. 2.1 point 7). Unfortunately no well hydrograph is available from Montreal, however a similar pattern is likely since the climatic conditions of both Montreal and London are comparable. The only difference is the later spring in Montreal which causes the maximum recharge to occur in April/May, at time of ice breakup, rather than in March as shown on the hydrograph.

Fluctuations in the London hydrograph are apparently caused by climatic controls since this well is not affected by local pumping. There is an increase in water level from a winter low at the end of January, to a seasonal high at the end of March. A decline sets in until September, at which time an increase to a second peak in December occurs. Since the precipitation is uniformly distributed (Brown, 1967, p. 100), other factors must influence ground water levels. The maximum recharge takes place in the spring at time of breakup, before increases in evaporation by solar energy and transpiration by plants occur. Subsequently,

FIGURE 2.3

WELL HYDROGRAPH - ANNUAL VARIATIONS AT LONDON, ONTARIO

(AFTER BROWN, 1967)



ground water storage is depleted by vegetation during the growing season, and by natural flow to discharge areas. Recharge again occurs during the autumn, when plant demand is reduced, and continues until infiltration is reduced by freezing of the water in the pore spaces, and precipitation is in the form of snow (Brown, 1967, p. 102).

CHAPTER 3 - GEOLOGY

3.1 Introduction

The quantity and the quality of ground water in any region depends in some measure upon the texture and the mineralogic composition of the rocks, so that the lithology and the stratigraphy are a guide to the development of ground water supplies. Accordingly, the hydrogeological character of each formation has been described in this chapter.

3.2 Previous Work

The earliest acknowledged work on the geology of Montreal was by Sir William Logan in 1863. This has been supplemented by many studies of which the most recent were by T.H. Clark in 1952 and 1972 who gave detailed reports of the stratigraphy and geological history of the Island.

3.3 Stratigraphy

The stratigraphic succession applicable to the Island of Montreal is shown in Table 3.1 (Clark, 1972).

The area is underlain by Precambrian metasediments, paragneisses and igneous rock types, but there is no outcrop of such on Montreal Island. There are two exposures of anorthosite near Cartierville similar to the Precambrian Morin anorthosite, but the relationship to the local sedimentary works is in doubt, and they may be glacial boulders rather than true outcrops. Cambrian Potsdam Sandstone

Era	Period	Rock Unit	Lithology	Thickness in feet	Aquifer Potential	Range of well yields in Quebec gpd	GENERALISED Porosity %	GENERALISED Permeability cm/sec	GENERALISED Specific yield %
		(After Clark 1972)			After Brown 1967 p 110		After Walton 1970 p 33	After Davis and DeWiest 1966 p 164 and pp 348-9	After Walton 1970 p 34
CAINOZOIC	Pleistocene and Recent		Alluvial sand and gravel Champlain Sea Clay Glaciofluvial sand and gravel Till		Excellent Poor Excellent Fair	500,000 - 1.5×10^6	30 - 40 45 - 55 30 - 40 ?20 - 30	10^2 - 1 10^{-7} - 10^{-6} 10^{-2} - 10^{-1} 10^{-5} - 10^{-3}	15 - 25 1 - 10 10 - 20 5 - 15
MESOZOIC	Cretaceous	Monteregian Intrusives	Essexite*, nepheline-syenite dykes, breccia *now considered to be gabbro		Poor	max 80,000	0 - 5	?10^{-1}	1 - 10
PALAEOZOIC	Ordovician	Lorraine Group	Shale, minor sandy shale	1000+	Fair to poor	max 1,000	1 - 10	?10^{-5} - 10^{-3}	
		Utica Group	Shale, minor limestone and sandstone	300	Fair to poor	max 1,000	1 - 10	?10^{-6} - 10^{-3}	
		Trenton Group: Tetreauville formation Montreal formation Mile End formation	Fossiliferous limestone with shaly partings Abundant bedding planes	800	Generally good	0-400,000	0 - 10	10^{-2} - 1	0.5 - 5
		Black River Group: Leray formation Lowville formation Pamelia formation	Limestone: minor shale and dolomite at base	60	Good	ave 10,000 max 600,000	0 - 10	10^{-2} - 1	0.5 - 5
		Chazy Group	Limestone and shale	280	Good	ave 10,000	0 - 10	10^{-2} - 1	0.5 - 5
		Beekmantown Group	Dolomite: dolomitic limestone at top dolomitic sandstone at base	1060	Good	ave 10,000 range 100,000-700,000	0 - 10	10^{-2} - 1	0.5 - 5
	Cambrian	Potsdam Formation	Sandstone, basal conglomerate	0-1700	Good	max 600,000	10 - 20	10^{-2} - 10	5 - 15
PRECAMBRIAN			Igneous and metamorphic rocks						

TABLE 3.1

STRATIGRAPHICAL SUCCESSION AND AQUIFER CHARACTERISTICS FOR THE ISLAND OF MONTREAL is the lowest member of the Palaeozoics and it crops out on the southern shore of the extreme western end of the Island at Ste. Anne de Bellevue (Fig. 2.1 point 8). Overlying this are strata of the Beekmantown, Chazy, Black River and Trenton Groups whose maximum total thickness is about 2,200 feet. They range in composition from dolomite to shaly limestone. They are overlain in the eastern and northeastern parts of the Island by shales of the Upper Ordovician Utica and Lorraine Groups (Fig. 3.1). This sedimentary sequence is cut by the Mount Royal and other intrusions of Cretaceous age.

Glaçial material overlies most of the Island.

3.4 Structure

In general the sedimentary rocks of the area dip gently to the east. There are few outcrops with dips of more than 2°. Steeper dips are found in the eastern part, but even these are usually less than 10°.

The principal fold system is minor and consists of the Ahuntsic syncline and Villeray anticline (Fig. 3.1), and plunges gently to the north-north-east. The eastern limb of the anticline shows the steepest dips, due to the regional dip to the east.

The major fault of the area is the White Horse Rapids fault which cuts approximately east-west across the Island, just north of Mount Royal (Fig. 3.1). There are four other prominent east-

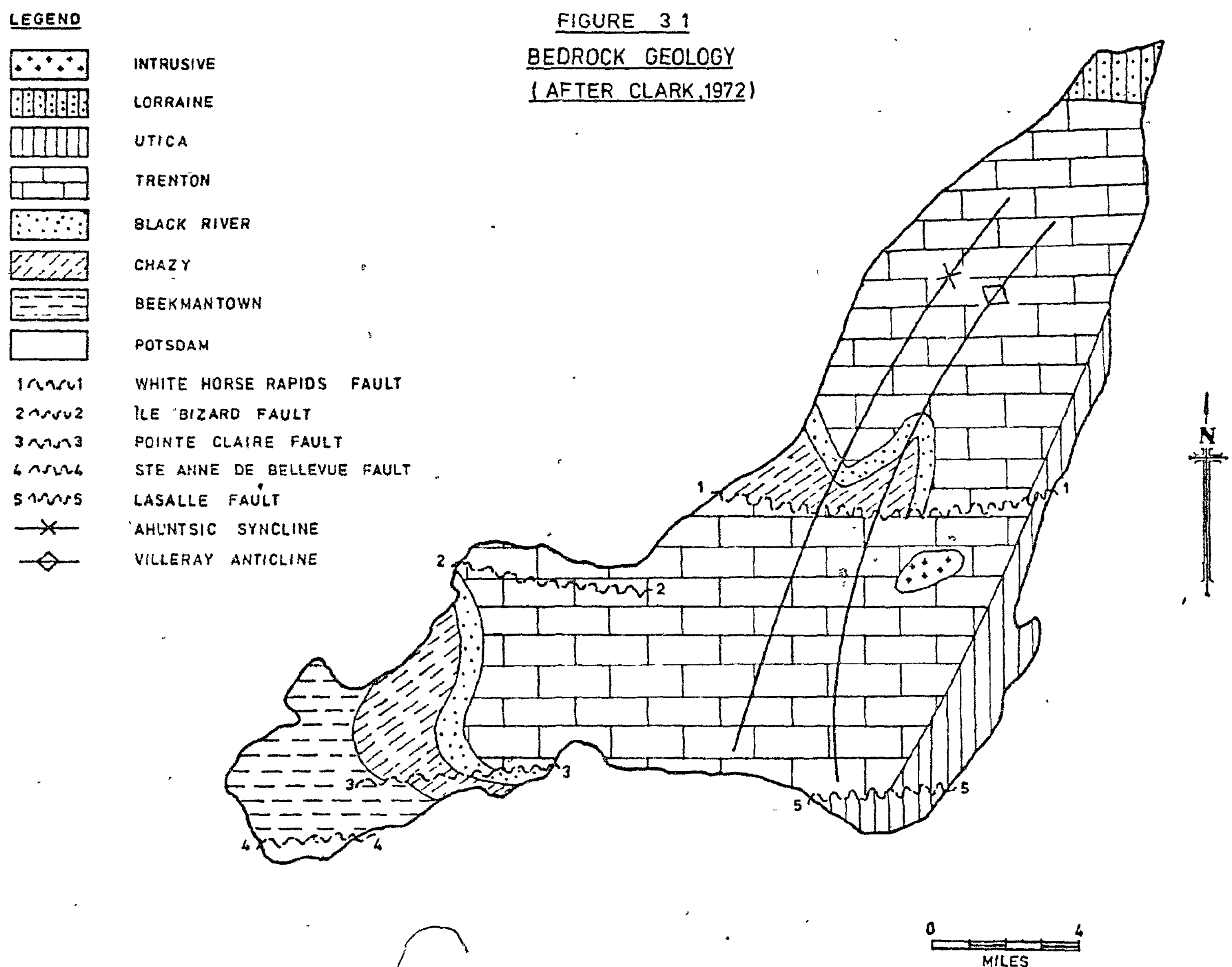


FIGURE 3 1
BEDROCK GEOLOGY
(AFTER CLARK, 1972)

west faults, the Ile Bizard, the Ste. Anne de Bellevue, the Pointe Claire and the Lasalle faults, as well as a number of other minor ones (Fig. 3.2) of varying orientations but of which little is known. Faults may affect the yields of different units by increasing or decreasing the hydraulic connection they have with other aquifers. They may act as positive or negative boundaries to be superimposed on otherwise simple systems. They may also allow passages for saline water from depth to migrate upward and impair an otherwise acceptable ground water supply.

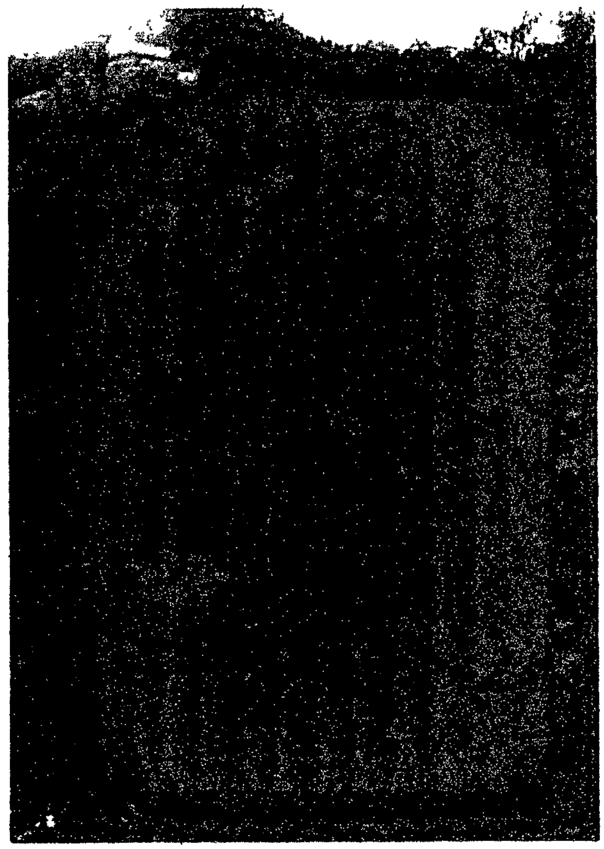
3.5 Hydrogeological Characteristics of Limestone

Limestone can originate from a large number of different sedimentary processes such as the inorganic precipitation of muds, accumulation of shell fragments, etc., thus not only is limestone different from other rock types but it also has many varieties of itself.

The primary porosity and permeability of many of these sediments are modified rapidly after burial due to compaction. so that the original sedimentary structures are poorly preserved. In contrast if the rocks are relatively impermeable and dense to start with, and the rocks are not deformed, the sedimentary structures may persist almost indefinitely. The porosity and permeability of a rock may be primary or secondary. Usually a combination of the two occurs in a given unit. In young limestones primary porosity is relatively high, due to incomplete

FIGURE 3.2

Small Fault at St. Vincent de Paul



consolidation, while permeability is generally low. Secondary porosity is due to diastrophic forces causing joints and fractures (Swinnerton, 1942, p.660), and most features of geologic structure including folds and faults affect the secondary porosity. Thick bedded limestones are brittle so that folding can cause closely spaced joints; thinner or unfolded units will not be so jointed and hence have lower secondary porosities. Generally joints become tighter and less common with increasing depth.

Sometimes the intricate series of small joint planes and fissures can be modified by solution into extensive cavern systems (Penn et al., 1936). Similarly, re-precipitation of calcite can occur causing a diminution in secondary porosity. Other mineralogic changes are possible. The alteration of calcite to dolomite can cause a 13% reduction in volume within a rock which will result in additional pore space (Davis and DeWiest, 1966, p.353) assuming there is no local reprecipitation of the calcium ions as calcite.

The predominant feature of ground water in limestone terrains is it's capricious distribution. Theis (1936, p.33) points out that Palaeozoic limestones rely on their secondary openings, often unpredictably disposed, to store and transmit water. Piper (1932, p.69) notes that limestones of older systems can be very dense and contain no primary pore spaces other than minute openings in the bedding planes; again not conducive for ground water supply.

3.6 Hydrogeology of the Palaeozoic Sedimentary Rocks of Montreal Island

The hydrogeology and generalised history of the Palaeozoic rocks of Montreal are now discussed in terms of their lithological and hydrological characteristics (Clark,1972,and Brown,1967). The surface appearances of these units are illustrated in a series of photographs referenced at the appropriate points. Values of the hydrological properties have had to be generalised as no field tests have been made. Published details of the principal aquifer characteristics for the Island of Montreal are summarised in Table 3.1, along with typical values of porosity, permeability, specific yield and ranges of well yield. Freeze (1964,p.14) suggested the occurrence of three hydrogeological units namely sandstone, carbonate rocks and shale,and gave likely values of transmissivities (Table 3.2).

3.6.1 Potsdam Formation

As mentioned above, the oldest rock which crops out on the Island appears to be the Potsdam Sandstone (Fig. 3.3). It has a maximum reported thickness of 1696 feet. It is a thin to medium bedded white quartz sandstone which is well fractured on the surface. It is composed principally of variably cemented, often rounded and frosted sand grains. It is brittle, and hence well jointed, and is weathered into many fracture zones. It thus possesses both primary and secondary porosity and permeability, and so serves as an excellent aquifer with individual well yields up to 600,000 gallons per day (gpd). in the area to the west of

TABLE 3.2

THE HYDROGEOLOGIC UNITS OF THE ISLAND OF MONTREAL

(AFTER FREEZE, 1964, P. 14)

Hydrogeologic unit	Components	Transmissivity gpd/ft
Sandstone	Potsdam Formation	1,000 to 20,000
Carbonate	Beekmantown Group Chazy Group Black River Group Trenton Group	500 to 7,000
Shale	Utica Group Lorraine Group	300 to 400

FIGURE 3.3

The Potsdam Formation

Montreal Island. From the standpoint of potential yield and water quality, the Potsdam formation is the best of the aquifers found in the Palaeozoic rocks of Quebec (Brown, 1967, p.110), although on Montreal its aquifer potential is reduced because of its small area of outcrop and the depth at which it is found. Freeze (1964) considered the formation to have the highest potential transmissivity of local units (Table 3.2).

3.6.2 Beekmantown Group

The presence of reworked sands in the basal beds of the overlying Ordovician Beekmantown Dolomite indicate that an interval of marine regression and erosion followed deposition of the Potsdam sediments. The Beekmantown Group is about 1000 feet thick, it has a variety of features making it an acceptable aquifer. These are a moderately well developed joint system enhancing fissure flow, bedding characteristics varying from thick to thin, mud cracks, cavities in place of dense dolomite, and rounded sand grains with a calcareous cement liable to weathering (Clark, 1952, pp. 24-31), which promotes the development of secondary porosity and permeability. It weathers to flat, rectangular fragments emphasising the joints and bedding characteristics.

3.6.3 Chazy Group

Following a period of erosion the Beekmantown Group was overlain by the Chazy limestone, which is at least

280 feet thick. This is fossiliferous, and locally dolomitic, and has a great variety in both lithology and degree of bedding. The beds are usually less than 1 foot thick. It has numerous shale horizons but these do not interfere with its total capacity as an aquifer; rather they tend to enhance a horizontal permeability in preference to a vertical one (Fig. 3.4). This prevents mixing, theoretically enabling chemical analyses of ground water to finger print the strata from which they were obtained.

3.6.4 Black River Group

A minor unconformity separates the Chazy from the overlying Black River Group whose three formations total 60 feet, or less than 5% of the whole thickness of the sediments found on the Island of Montreal. The basal Pamelia formation is dolomitic but the top two formations, the Leray and Lowville, are of limestone with bedding ranging from 2 inches to 2 feet, and containing intercalated shale horizons. The Leray formation is massive and forms granular weathering products, while the Lowville is more thinly bedded with some brecciation. All three formations are fine grained and possess numerous joints. Some of these may be 3½ inches wide which enhance its aquifer potential by fracture flow (Figs. 3.5a and 3.5b).

3.6.5 Trenton Group

The Black River Group is succeeded by the Trenton Group

FIGURE 3.4

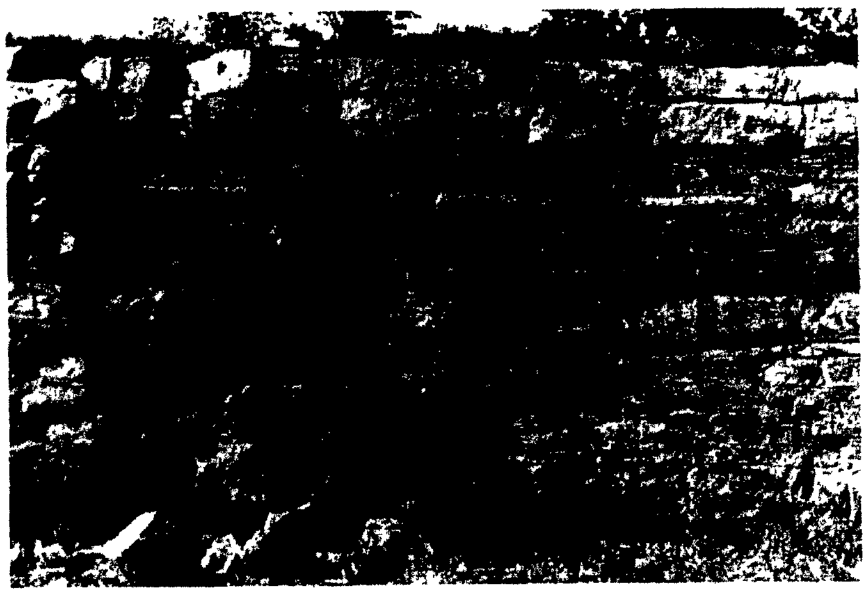
The Chazy Group

FIGURE 3.5a

The Black River Group

FIGURE 3.5b

Jointing in the Black River Group



whose average estimated thickness is 800 feet and whose total outcrop area, some 138 mi^2, is greater than that of any other group on the Island. The group is subdivided locally into three formations: the Tetreauville, at the top, the Montreal and the Mile End formations.

The Mile End formation, the lowest present, is only 25 feet thick but is well stratified (Figs. 3.6a and 3.6b).

The succeeding Montreal formation, whose two members, the St. Michel and Rosemount total 300 feet in thickness, has a great variety in both lithology and bedding. It is basically a dense, crystalline limestone and thus has a lack of primary porosity and permeability. However, it has many bedding planes and weathers easily (Fig. 3.7). These secondary features substantially outweigh the negative primary ones to give it reasonable aquifer potential.

The uppermost formation, the Tetreauville, is similar to the Montreal formation as both are dense. It differs from it, however, because of its lithological uniformity, and its regular bedding, not exceeding 6 inches in thickness, is marked by shaly partings (Fig. 3.8). Bedding joints capable of transmitting water appear in excavations to have a vertical spacing in the range of 5 to 10 feet. An examination of a tunnel, the Park Avenue Collector (Fig. 2.1 point 10), about 8 feet in diameter and ½ mile

FIGURE 3.6a

The Mile End Formation of the Trenton Group

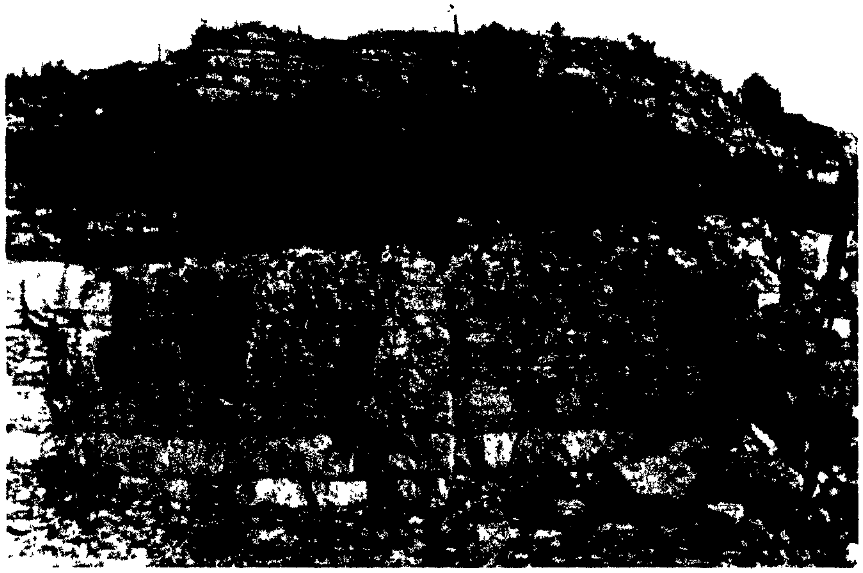


FIGURE 3.6b

Detail of the Mile End Formation

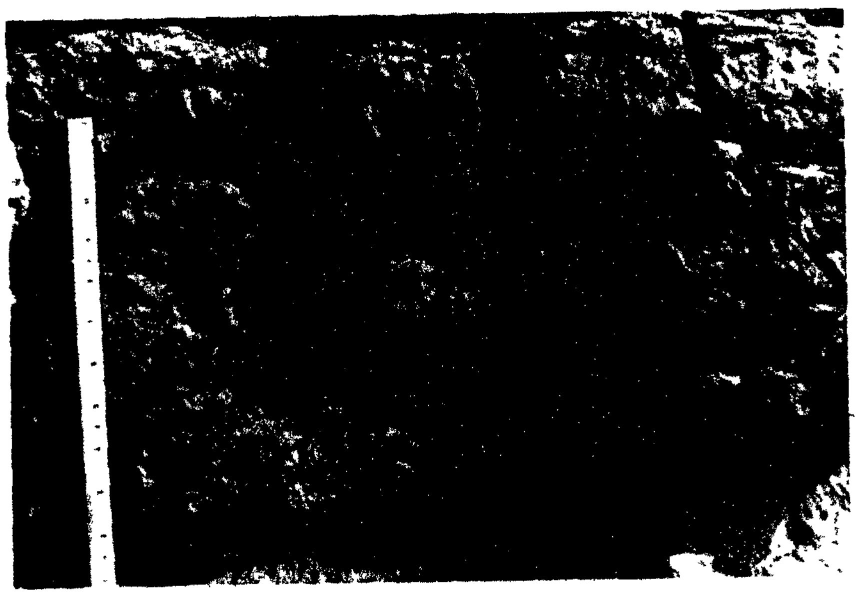


FIGURE 3.7

The Montreal Formation of the Trenton Group

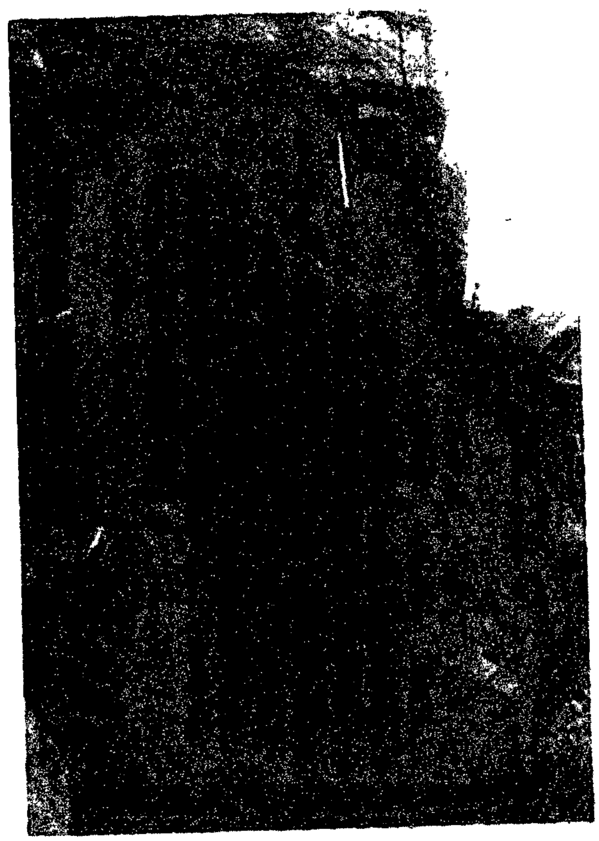


FIGURE 3.8

The Tetreauville Formation of the Trenton Group

long, being driven in this formation, showed it to be remarkably devoid of water. Thus since the bedding and vertical joints are often poorly developed except when exposed in surface excavations, its aquifer potential is less than the other formations of this group.

3.6:6 Utica and Lorraine Groups

The Utica Group of black, occasionally pyritiferous, shales and mudstones overlies the Trenton. There are minor interbeds of limestone and sandstone. Both this and the overlying Lorraine Group generally have a poorly developed fracture system except in the upper weathered zone which is a few inches thick.

3.7 Aquifer Potential of the Sedimentary Rocks

The carbonate rocks of the Beekmantown, Chazy, Black River and Trenton Groups, are characterised by thin to thick beds from less than 1 inch to about 2 feet, and poorly to moderately well developed vertical and horizontal joints. Although the extent of fracturing and development of other openings of these rocks is not everywhere the same, and though there is considerable variation in their aquifer potential, they may be considered as one hydrogeological unit because there is not a major aquiclude within the carbonate sequence.

Wells yielding from 100,000 gpd to 700,000 gpd have been developed in all of these groups, though not specifically on the Island. An average yield is about 10,000 gpd (Brown, 1967, p.110), and from the next chapter this can be seen to be well within the recharge capability of the aquifer.

3.8 Hydrogeology of the Igneous and Associated Rocks

The Palaeozoic sediments of the Montreal area were intruded during Cretaceous time, by plutonic igneous rocks whose remnants now form a series of eight hills. These were called the Monteregian Hills by Adams in 1904, who took the name from Mount Royal the only prominent hill on the Island of Montreal. Mount Royal, in the south central part of the Island, has an area of about 3 mi^2 and an elevation of 760 feet (Fig. 2.2). It consists principally of two plutonic rock types. The most abundant, 90% of the area, is older. It is a medium-coarse grained, variably coloured gabbro, of diverse composition (Fig. 3.9). The younger is a medium grained and light coloured nepheline-syenite. There are dykes and sills related to each type in the immediately surrounding sedimentary rocks. As one goes outward from the mountain they become less common. Most of the dykes are from one to two feet wide, although they range downward to paper thinness and upward to a maximum of 12 feet (Fig. 3.10).

Certain of the minerals of these rocks are unusual. They are chemically alkaline and the amphiboles, specifically hastingsite, are more abundant than the pyroxenes. A more detailed mineralogical inventory is given by Clark (1952, pp. 84-92).

FIGURE 3.9

Essexite (A) with Country Rock Inclusion of Trenton Limestone (B) both cut by Calcite Vein (C)

FIGURE 3.10

Dyke at St. Vincent de Paul

The contacts of the intrusions are marked in places by hornfelsing of the Utica shale. There is also evidence of metamorphism of the limestone, of tilting, crumpling and brecciation. In many places on the north and west sides, the limestone dips outward from the mountain, but this is only of local significance. To the north of the Summit Circle of Westmount (Fig. 2.1 point 11), the crystalline limestone has been subjected to intense local crumpling (Clark, 1952, p.109) (Fig. 3.11), but this may not have noticeably enhanced the permeability of the rock. Although intrusives are generally impervious, certain wells have yielded up to 80,000 gpd in areas close to the contact with the country rock, where the intrusives are fractured.

3.9 Hydrogeology of the Surficial Deposits

Almost the whole area is covered by unconsolidated Recent and Pleistocene sediments (Fig. 3.12) resulting from:

a) glaciation during the Wisconsin stage,

b) marine invasion during the recessional phases of glaciation, and

c) alluvial deposition during and following the withdrawal of the Champlain Sea from the area (Brown, 1967, p 114).

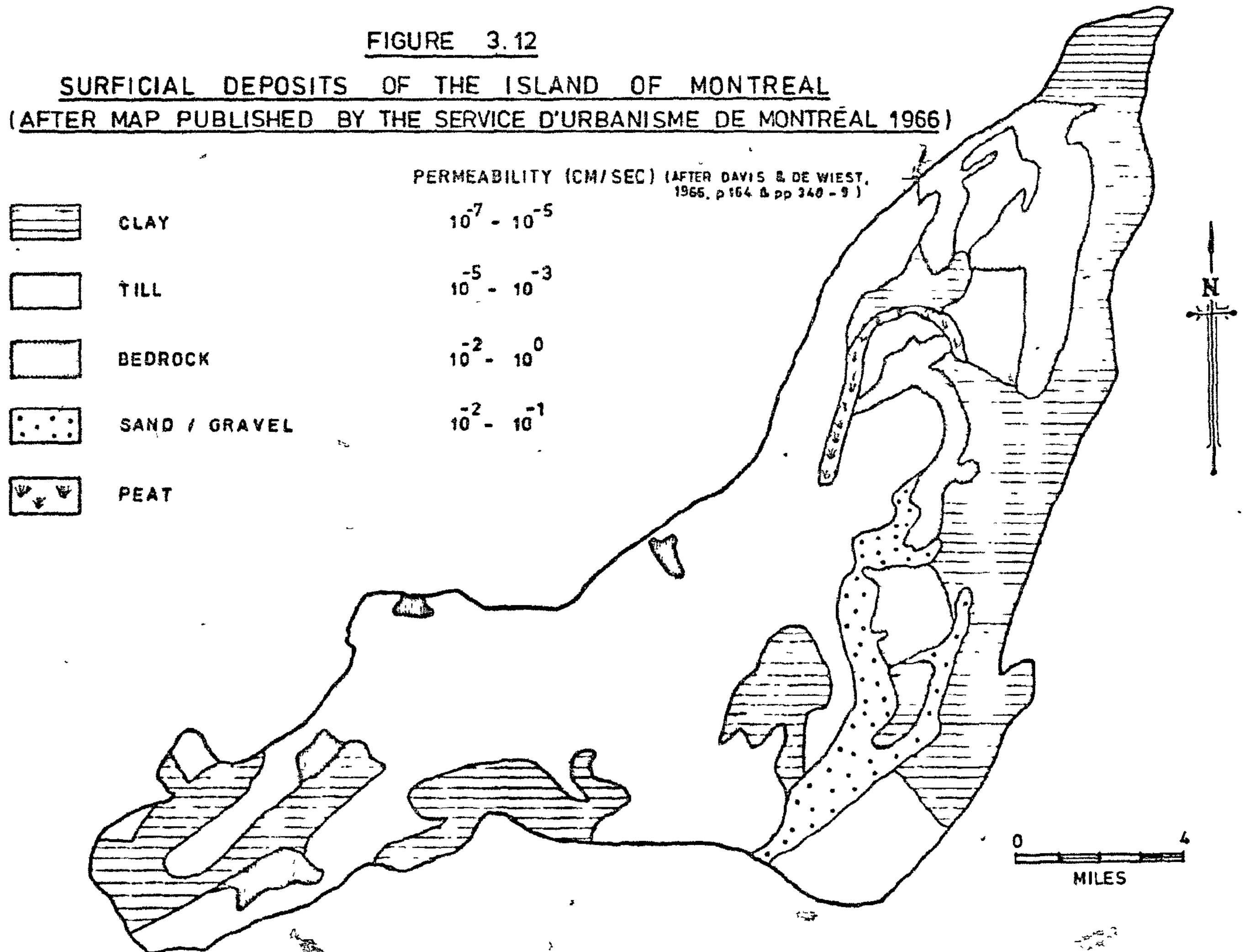
In general the thickness of the surficial deposits increases from the flanks of Mount Royal towards the river banks, though there appears to be a ridge of less deeply buried rock running approximately parallel to Bléury, between Lagauchetière and Ontario streets (Fig. 2.1 points 12, 13 and 14 respectively), and having a width of about half a mile (Stansfield, 1915, p. 48). The whole sequence is a farrago as indicated by Prest

FIGURE 3.11

Local crumpling of the Trenton Limestone

FIGURE 3.12

SURFICIAL DEPOSITS OF THE ISLAND OF MONTREAL
(AFTER MAP PUBLISHED BY THE SERVICE D'URBANISME DE MONTRÉAL 1966)



and Keyser (1962,p.10) who gave the following description "basal stony till is overlain by a complex of till and stratified sediments followed by varved clay silts". These are overlain by an "upper silt till which in turn gives place upward to marine sediments followed by fluvial and bog deposits". The maximum thickness is over 100 feet.

There is a large volume of marine sand and gravel on the flanks of Mount Royal which represents shoreline deposits of the receding Champlain Sea. Wave action reworked the ice contact stratified sediments, deposited initially as the mountain emerged from beneath the ice of the last glaciation. For instance, this type of reworked deposit comprises the bulk of the 100 feet of drift along the prominent Upper Lachine Road scarp (Fig. 2.1 point 15). The unit is "self-draining" (Prest and Keyser, 1962,p.31). Subsequent uplift led to estuarine and fluvial conditions, and in places the resulting deposits contain a high percentage of shale and limestone particles that are loosely packed and water bearing. They are usually less than 10 feet thick but locally attain a thickness of 40 feet. Fluvial sand and gravel occur in a long strand from LaSalle (Fig 2.1 point 5) to Parc Maisonneuve (Fig. 2.1 point 16) (Prest and Keyser, 1962,p.31). Marine clay, though widespread elsewhere in the St. Lawrence Lowlands, tends to be confined to the eastern and southern margins of the Island.

The aquifer potential of the Pleistocene deposits is, for the most part, dependent on the continuity of zones of different grain size characteristics. Most of the coarse grained Pleistocene sediments are those that have been sorted to varying degrees by melt water that flowed from a waning glacier. Other coarse granular deposits are found along river terraces, along the shores of glacial lakes and inland seas. These terrace and alluvial sands constitute some of the best aquifers in the St. Lawrence Valley with some wells, though not on the Island itself, developing yields of up to 1.5 mgd. There is however a buried valley of the St. Lawrence in the southern central part of the Island (Fig.2.1, points 12, 13, 20, 15, 1) which is an excellent aquifer and is utilised by some companies as a source of ground water. Fortunately, the quality of the water has become acceptable for direct use, by the replacement of trapped saline water with fresh water despite the marine stage of the evolution of some of these materials.

Till, which was deposited directly by the glacier with little or no sorting by running water, is generally a poor aquifer but may, in places, contain lenses and pockets of coarse sediments that form small local aquifers (Brown, 1967, p.113). Neither of the tills, one of which is basal and highly compacted, has significant potential as an aquifer except for small local domestic supply.

Much of the area is thus covered by virtually impermeable deposits (K 10^{-6} cm/sec), but the strand of gravel previously mentioned has a permeability nearer 10^{-2} cm/sec. This gravel could accept more recharge than the deposits blanketing most of the bedrock. This is discussed in the next chapter.

CHAPTER 4 - RECHARGE AND MOVEMENT OF GROUND WATER

4.1 Recharge

As discussed in Section 2.4 maximum ground water recharge occurs in Montreal at the beginning of the spring. A second period of recharge is at the beginning of the autumn, before the ground becomes frozen during the winter. Although average rainfall in this area is 44 inches, Freeze (1964, p.8) calculated for the Lachine - St. Jean area to the southeast of Montreal Island (Fig. 2.1 point 22), that the effective recharge is only five inches, due to losses from run off and from evapotranspiration. Montreal itself is much more developed and consequently run off from paved surfaces is likely to be much higher. If 20% of the Island is considered to be unsuitable for recharge then the total volume of water recharged annually is $13{,}505 \times 10^6$ gallons (U.S.) or 37 mgd (Appendix B).

Each lithological group, except the Potsdam, which only has a very small area of outcrop on the Island, can be considered in terms of its recharge and potential yield, a summary of which is given in Table 4.1.

4.1.1 Beekmantown Group

This group is found at the surface in the western part of the Island which is only lightly built-up. Assuming it is recharged only over its outcrop area of 14 mi^2 and

Bedrock aquifer	Outcrop area mi²	Estimated effective recharge area mi²	Estimated average recharge mgd	Estimated potential yield gpm/mi²
		└ assuming 0.24 mgd/mi² ┐		
Mount Royal	3	-	-	
Utica/Lorraine	17	2.5	0.6	25
Trenton	138	123	29.5	144
Black River	6	2.5	0.6	70
Chazy	14	12	2.9	143
Beekmantown	14	14	3.4	167
Total area of Montreal	192	154	37	

Assuming 5" recharge over 80% of the Island
Total recharge = 37 mgd
Present demand = 300 mgd

mi² = square miles
gpm = U.S. gallons per minute
gpd = U.S. gallons per day

TABLE 4.1

RECHARGE ESTIMATES FOR BEDROCK AQUIFERS

not from vertical or lateral leakage from other groups, it can be calculated that it is recharged at 3.4 mgd or 167 gpm/mi². This represents the amount of water that can be withdrawn without mining the ground water reservoir. Although many high capacity wells are found in the fractured dolomites of this group outside the Island, on Montreal itself ground water abstraction has never been high, and most of that which has occurred was for domestic purposes, whose total consumption is believed to have been well within the safe yield. Most of the present supply in the West Island is municipally treated river water.

4.1.2 <u>Chazy Group</u>

The total outcrop area of the Chazy is about the same as that of the Beekmantown ie. about 14 mi². However, as far as recharge is concerned, two other factors should be considered. More of the outcrop area of the Chazy has been built on, thus reducing its effective recharge area. On the other hand, since the Chazy is a good building stone, numerous quarries have been developed which act as natural recharge basins where the relatively impermeable overburden no longer hinders recharge. On balance, the effect of paving is likely to have been more important so that safe yields from this group are likely to be smaller than those from the Beekmantown, perhaps a total of 2.9 mgd, or 143 gpm/mi².

4.1.3 Black River Group

This group crops out on the Island in two narrow bands, the total area of which is only 6 mi^2. The eastern band has been built on and the remaining effective recharge area is only about 2.5 mi^2. This represents a safe yield of 0.6 mgd or 70 gpm/mi^2.

4.1.4 Trenton Group

This group has the largest outcrop area, 138 mi^2, but it has been extensively built on. It is covered however by an area of gravel, 8 mi^2, whose permeability (10^{-2} cm/sec) is higher than the rest of the surficial deposits found on the Island of Montreal. Consequently it can accept recharge not only from precipitation, but also from run off from the less permeable surfaces. The total amount of recharge the Trenton receives is about 29.5 mgd which represents a safe yield of 144 gpm/mi^2.

4.1.5 Utica and Lorraine Groups

These groups are not considered to have any aquifer potential because of their argillaceous nature. However, the upper weathered zone is capable of accepting some recharge, about 0.6 mgd.

The average permeabilities of the overlying materials are composite of many highly variable local ones. Detailed information concerning extent and permeability of individual surficial units is not available to calculate precise recharge in specific areas, however the order of the total recharge on the Island appears to be about 37 mgd.

4.2 General Factors affecting Flow

The ground water level is a measure of the fluid potential at a point. Water will flow from areas of high potential, usually recharge areas, to those of low potential, discharge areas.

The concept of potential was used by Hubbert (1940 and 1953) who formulated the general condition as follows (1953, p.1958) "an element of water at any point possesses potential energy with respect to its environment which when referred to unit mass, we may speak of as its potential, $\emptyset$.

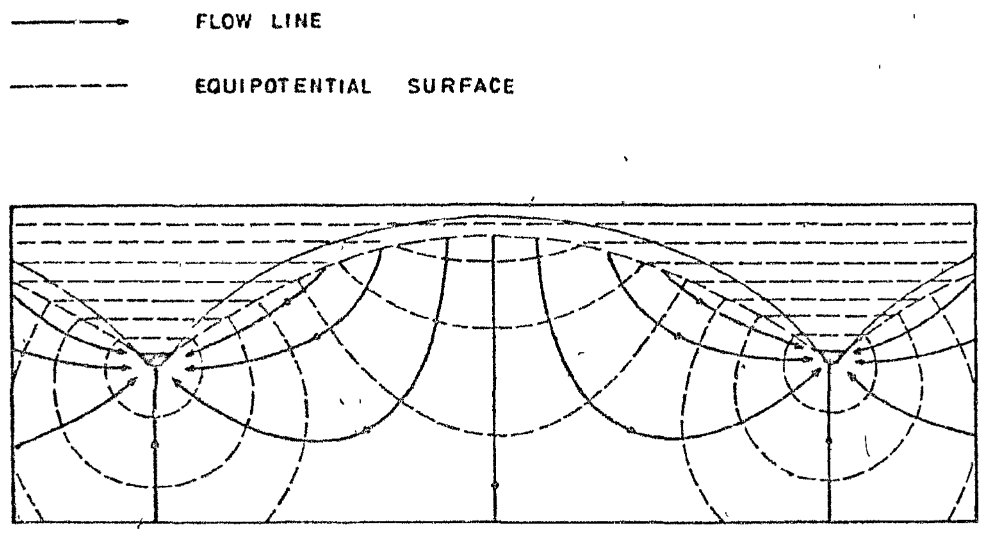
The potential, $\emptyset$, of water at a given point may be thought of as the amount of work that would be required to transport unit mass of this fluid from some arbitrarily chosen standard position and state to the position and state of the point considered".

In his reasoning Hubbert (1940, p.843) "agreed to consider only isotropic media" and he employed only "the macroscopic point of view if the fluid elements we speak of shall be large anough that the irregularities of flow due to the medium need not be considered but only the statistical result" (1940, p.804). With these conditions obtaining he constructed an idealised flow pattern for ground water (Fig. 4.1) (1940, p.843) which consisted of "flow lines everywhere parallel to -grad. ∅ which form an orthogonal system with the family of equipotential surfaces: ∅ = constant". Toth (1962) suggested that Hubbert's model was incomplete, due to incongruities in the relation between total hydraulic head and depth below surfaces in topographically low areas. He proposed a different flow pattern (Fig. 4.2), the necessary conditions for its validity being outlined by Brown (1967, p.48-9).

Meyboon (1962) discussed the ground water flow in a stratified medium consisting of a poorly permeable layer overlying a permeable layer. This model (Fig. 4.3) was called the Prairie Profile, described by Meyboom as follows: "The Prairie Profile consists of a central topographic high bounded at either side by an area of low elevation. Geologically, the profile is made up of two layers of different permeability, the upper layer having the lower permeability. Through the profile is a steady flow of ground water from the area of recharge to the area of discharge. The ratio of permeabilities is such that ground water flow is essentially downward through the material of low permeability and lateral and upward through the underlying more permeable layer". If ground water levels were lowered the chemistry could be changed correspondingly. For example a rock unit with a layer of a soluble mineral, such as gypsum in it, could be left above the saturated zone and hence no longer be dissolved to the same extent. In contrast a lower-

FIGURE 4 1

HUBBERT'S IDEALISED GROUND WATER FLOW PATTERN (AFTER HUBBERT, 1940)



NOTE VERTICAL EXAGGERATION

FIGURE 4 2

TOTH'S GROUND WATER FLOW PATTERN

(After Tóth, 1962)

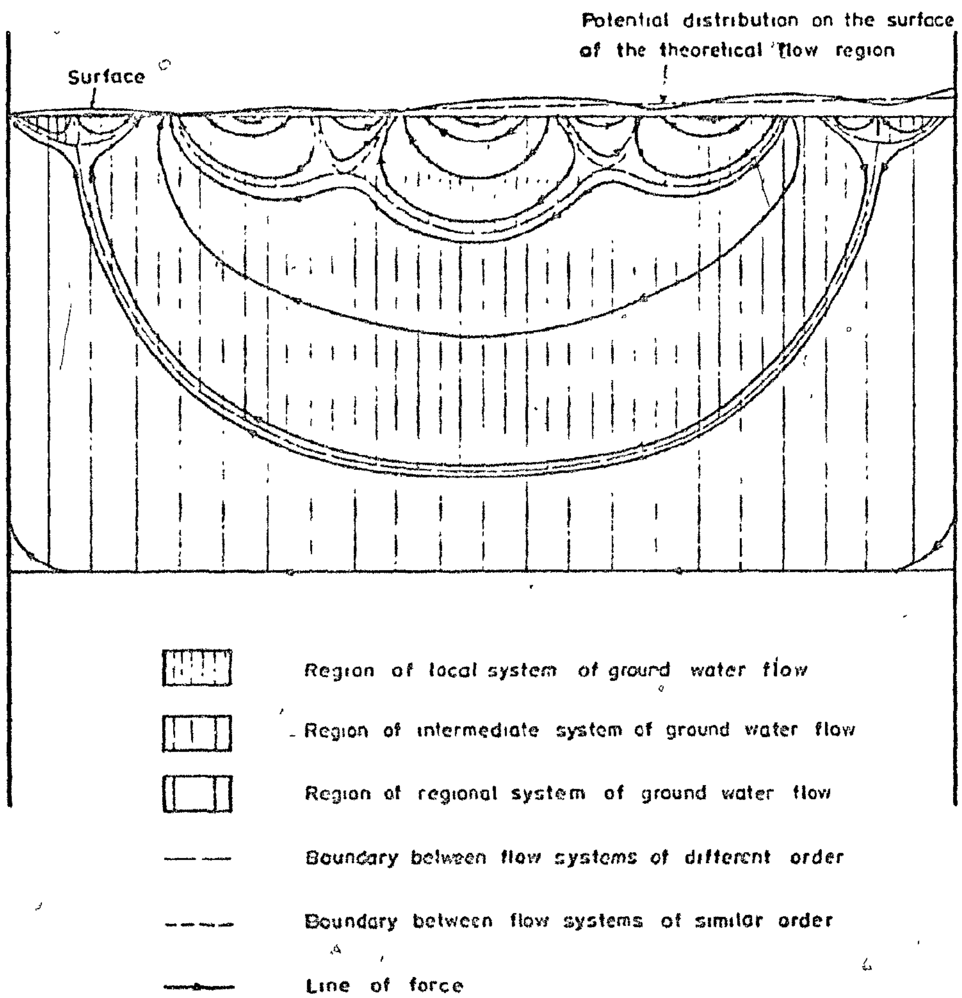
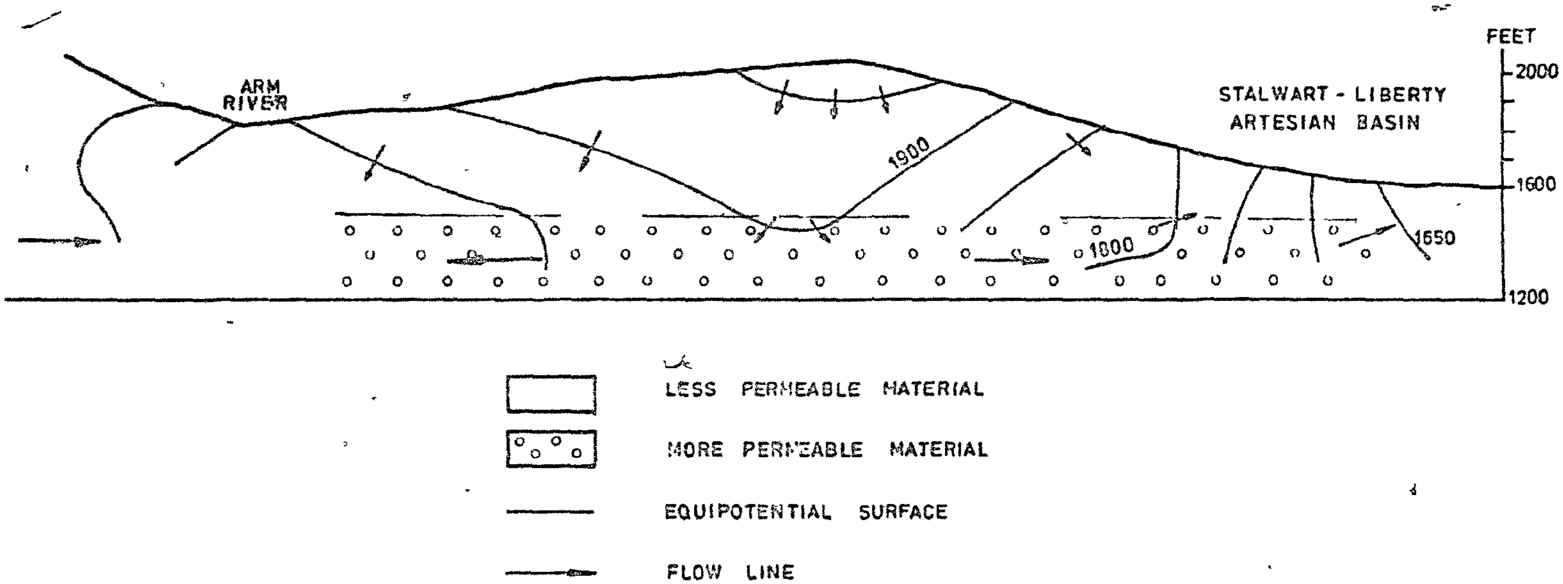


FIGURE 4.3

MEYBOOM'S "PRAIRIE PROFILÈ" GROUND WATER FLOW PATTERN

(AFTER MEYBOOM, 1962)



ing of potential gradients reduces the velocity of ground water flow. The lower the velocity the longer is the contact time between the water and rock and hence the water has a greater chance to become concentrated in dissolved solids.

4.3 Ground Water Movement in Montreal

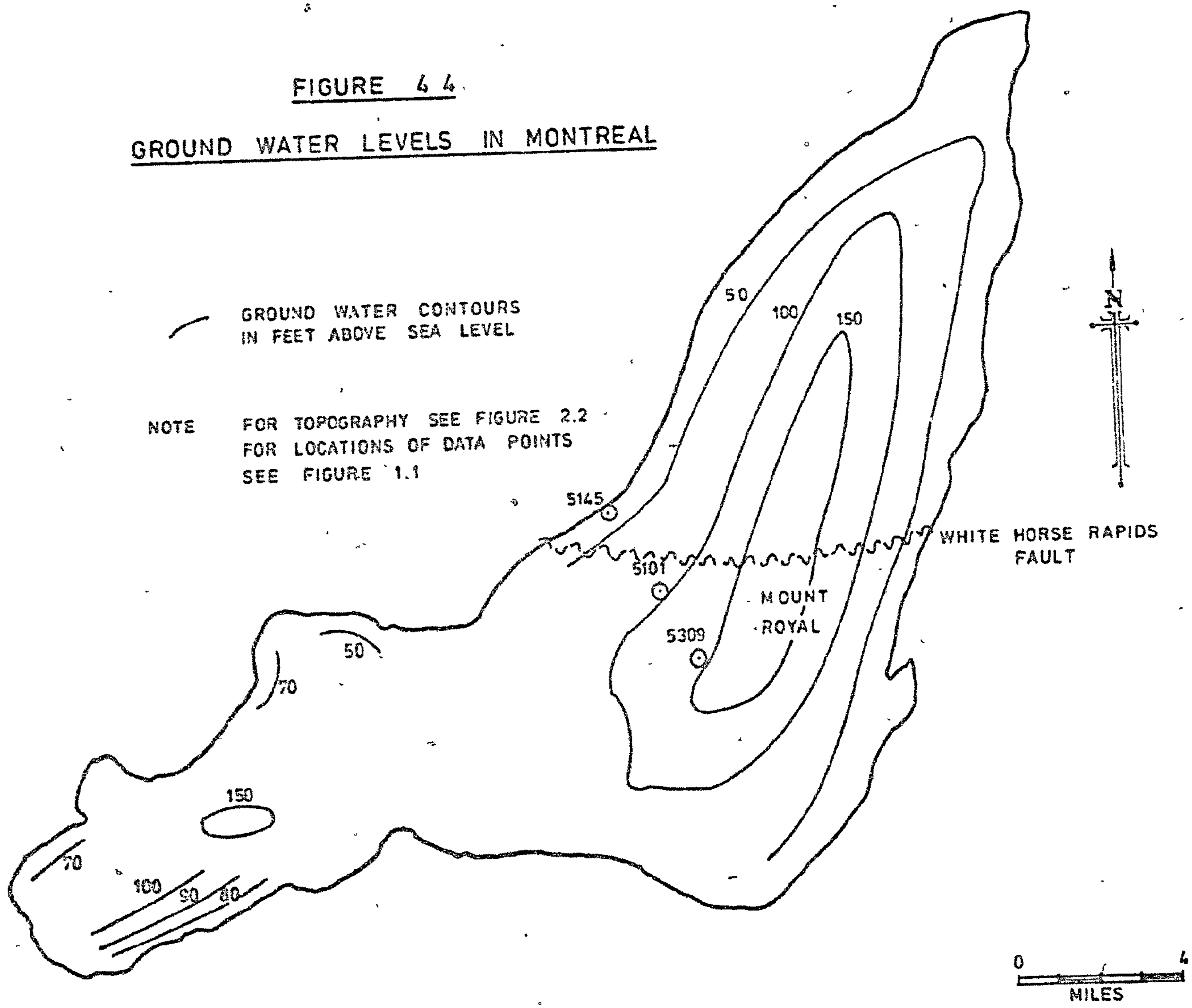
A simple ground water flow pattern can be obtained in Montreal by using Pollitt's ground water levels (Fig. 4.4). These ground water levels were from wells of different depths, in which the contributions from horizons of possibly different potentials were not distinguishable. Nevertheless the pattern is plausible and indicates two approximately radial flows. One is from Mount Royal, the major topographically high point, and the other is from a secondary area of high ground in the western part of the Island. In both cases the directions of flow are towards the periphery of the Island.

Two of the upper geological units of Montreal, the surficial deposits and widespread shaly Tetreauville, have a lower permeability than the underlying units. This, coupled with the topographically high area of Mount Royal, provide the major components of the Prairie Profile of Meyboom, as mentioned earlier, and it would appear that this profile might be appropriate for the flow pattern of the Island.

In Montreal the most common fissure orientation is parallel to the bedding, which tends to enhance ground water flow in a

FIGURE 4.4

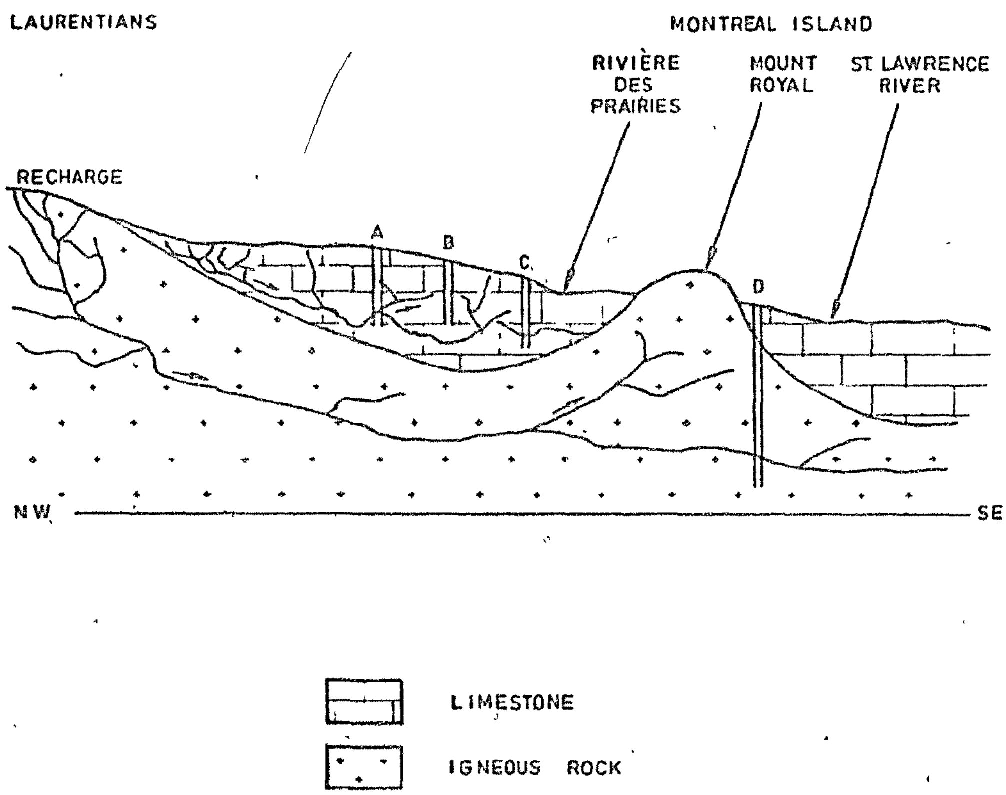
GROUND WATER LEVELS IN MONTREAL



horizontal direction, but local anomalies may occur. Adams and Leroy stated (1904, p.69), "these enlarged fissures evidently form an irregular and complex system of water channels passing through the limestones". This is shown in Fig. 4.5, (after Adams and Leroy 1904) to show how wells located even close together might or might not produce water, depending on the interception of discrete fissures eg. well A would hit water, well B would not. Similarly the quality of any water found could vary considerably, again depending on the type of fissured rock through which the water had flowed, eg. well C would have water of a calcium bicarbonate type, well D probably of a sodium chloride type. In Montreal solution does not seem to have played a major part in modifying the limestone terrain. Few solution features are visible and one cave which was found caused considerable interest (Gibb, 1858). Despite jointing in a vertical direction, the nearly flat bedding planes enhance the horizontal movement of water, an average flow rate of which in Montreal is 3 cm/day. Within the limestone there are innumerable shale layers ranging from less than ¼ inch to 1 foot 6 inches in thickness. These are aquitards and tend to promote further lateral flow which segregates waters. This reduces the chances of water from different strata and different formations mixing and improves the development of chemical zonation. Furthermore there is another modifying influence; that of dykes. According to Adams and Leroy (1904, p.24) "these dykes in their underground extension forming impervious walls crossing the fissures through which water runs, certainly

FIGURE 4 5

SCHEMATIC DIAGRAM TO SHOW THE COURSE OF GROUND WATER ALONG FISSURES (AFTER ADAMS AND LEROY, 1904)



have a very important influence locally in determining the courses taken by the subterranean waters". Thus the water table in limestone terrains is not continuous, due to the high variation of lithology, and it is difficult to map pressure gradients since there is little uniformity in the transmissivity of the formations from place to place (Penn et al., 1936). This phenomenon however was not apparent from, or proven by, the data available in Montreal. Furthermore although there is a high degree of irregularity of flow in carbonate rocks, those with extensive fractures primarily developed in one direction, will have bulk permeabilities that will be strongly anisotropic. Therefore the detailed direction of ground water flow cannot be predicted from the data in Fig. 4.4 by simply drawing orthogonal lines to the ground water contours (Davis and DeWiest, 1966, pp. 354-5). This characteristic was not significant in the present general study.

The unpredictability of ground water movement in limestones is due to geological and lithological controls, as discussed in Chapter 3, and it can be seen that Montreal's system is no exception. Further interpretation of ground water flow is made after subsequent discussion of the chemical zonation of the ground water.

CHAPTER 5 - HYDROGEOCHEMISTRY

5.1 Introduction

One of the earliest references to hydrogeochemistry was by Plinius "Tales sunt aquae, qualis terra per quam fluunt". ("Waters take their nature from the ground through which they flow".) Water is a very complex chemical substance, and when it becomes part of a ground water flow system it is in intimate contact with a variety of minerals with a wide range of abundance and chemical properties (Table 5.1, Davis and DeWiest, 1966, p.112).

This chapter is composed of a review and discussion of the facets of hydrogeochemistry that are significant in this study. The relative importance of various items is demonstrated by a preview and the inclusion of some typical data from the study area. The systematic presentation of data is in the next chapter.

5.2 Sources and Controls of Ground Water Constituents

The source of most dissolved ions is the mineral assemblage in rocks near the land surface. The water that falls as rain or snow contains only small quantities of dissolved mineral matter. Typical analyses of rain are given by Hem (1970, p.50). Since it is both acidic and oxidising, it soon begins to react with the minerals of the soil and rocks with which it comes in contact, and many complex inorganic and organic chemical reactions take place. The amount and character of the mineral matter dis-

TABLE 5.1

DISSOLVED CONSTITUENTS IN GROUND WATER

(After Davis and DeWiest, 1966, p.112)

MAJOR CONSTITUENTS

(Range of concentration 1.0 to 1,000 mg/l)

Sodium	Bicarbonate
Calcium	Sulphate
Magnesium	Chloride
Silica	

SECONDARY CONSTITUENTS

(Range of concentration 0.01 to 10.0 mg/l)

Iron	Carbonate
Strontium	Nitrate
Potassium	Fluoride
Boron	

MINOR CONSTITUENTS

(Range of concentration 0.00001 to 0.1 mg/l)

Aluminium	Phosphate
Barium	Rubidium
Lead	Selenium
Nickel	Uranium

TRACE CONSTITUENTS

(Range of concentration generally less than 0.001 mg/l)

Beryllium	Silver
Gold	Tin
Platinum	Tungsten
Radium	

solved by precipitation depends on the chemical composition and physical structure of the rocks with which it has been in contact, as well as the physical constraints of the system. Crystal size of the minerals, rock texture and porosity, regional structure, and degree of fissuring, affect the rate, and volume of flow, and area of contact. The physical and chemical constraints, such as hydrogen and hydroxyl ion concentrations, redox potential, temperature and pressure, can influence the activity of water passing over and through the rock. Rock temperature increases with depth at the rate of 1.25°F per 100 feet (Davis and DeWiest, 1966, p.303), and increased temperature raises both the solubility of most inorganic solutes, and the rate of dissolution of rock minerals (Hem, 1970, p.41-2). The effect of soluble impurities in rocks on water quality can be far out of proportion to the relative abundance of such salts in the mineral composition of the rocks.

Water is most active, and changes take place rapidly, at the start of a flow system. The rates of change tend to become progressively slower in a given environment as chemical equilibrium is approached, although this is seldom attained. Changes are dependent on what degrees the system can be considered to be open or closed (Hem, 1970, p.51). If the flow system crosses into a contrasting formation the water may suddenly regain its chemical activity relative to the new formation, and a series of changes are initiated that proceed until it again approaches equilibrium with its surroundings.

For this reason changes in the chemistry of ground water are normally rapid at the boundaries between formations, and the chemistry of the water away from the boundaries is closely related to the enclosing geologic materials (Brown, 1967, p. 25). Rocks composed of comparatively insoluble material such as quartz, may have little effect on the chemistry of water flowing through them. Felspars, however, can have an important effect, especially if there is a good availability of H^+ ions to aid solution. Ionic species in water can thus be enriched by chemical attack, but the enrichment depends on the constituents of the involved rock. The two prime factors are availability (Table 5.2 Hem, 1970, p. 7), and solubility (Table 5.3, Schoeller, 1959, p. 55). The more abundant a species is, the more chance there is of it being found in solution. The more soluble a component, the greater is its activity and variety of transportation, and the greater its final concentration in the ground water. A balance exists between these two but a balance which changes from place to place within the flow system. For example, the chloride concentration in ground water is often low close to recharge areas, relative to the concentration in discharge areas, because of the generally low availability of chlorides in spite of the high solubility and mobility of chlorides. Gradually the chloride content of water increases because all available chloride is dissolved and remains in solution. The result is that near discharge areas, or at depth, the chloride ion often predominates.

TABLE 5.2

THE AVAILABILITY IN PPM OF THE MAJOR ELEMENTS IN IGNEOUS AND SOME SEDIMENTARY ROCKS

(AFTER HEM, 1970, p.7)

ELEMENT	SOURCE			
	IGNEOUS	SANDSTONE	SHALE	CARBONATE
Calcium	36,200	22,400	22,500	272,000
Magnesium	17,600	8,100	16,400	45,000
Potassium	25,700	13,200	24,900	2,390
Sodium	28,100	3,870	4,850	393
Carbon	320	13,800	15,300	113,500
Sulphur	410	945	1,850	4,550
Chlorine	305	15	170	305
Nitrogen	46		600	
Fluorine	715	220	560	112

TABLE 5.3

THE SOLUBILITY OF SOME SALTS FOUND IN ROCKS

(AFTER SCHOELLER 1959, p. 64)

SALT	MG/L	TEMPERATURE
$CaCO_3$*	13	18°C
$MgCO_3$*	100	10°C Schoeller 1959, p.55
$CaSO_4$*	2,016	18°C
$NaHCO_3$	96,000	20°C
Na_2SO_4	193,000	20°C
Na_2CO_3	213,000	20°C
$MgSO_4$	355,000	20°C
NaCl	358,000	20°C
$MgCl_2$	546,000	20°C
$CaCl_2$	745,000	20°C

*common in Montreal

This was shown in 1955 by Chebotarev, who proposed a metamorphism of natural waters, and suggested the following generalised scheme, based on over 10,000 analyses, to represent the chemical transition from recharge towards natural discharge areas:

$HCO_3^- \rightarrow HCO_3^- + Cl^- \rightarrow Cl^- + HCO_3^- \rightarrow SO_4^{2-} + Cl^- \rightarrow Cl^- + SO_4^{2-} \rightarrow Cl^-$

5.3 Chemical Zonation

The results of many chemically-based investigations have proved the presence of chemical zones in ground water. Just as rock facies change vertically and horizontally, ground water chemical zones can be delineated. The zones are labelled in terms of their major ions, and these reflect the environments with which the water has been associated. Chebotarev (1955), Schoeller (1959), and Charron (1969), consider that the dissolved anions determine best the character of water and its zonation, and that any water can be classified into one of three groups, depending on the predominance of any of the anions, HCO_3^-, SO_4^{2-} and Cl^-. Dominant ions are those with greater than 25% (in meq/l) of the reactants, and a combination of two such anions give a better indication of the character of the water than just one. There can thus be six subgroups (Herman, 1971, p.8):

SO_4^{2-} -Cl^-, SO_4^{2-} -HCO_3^-, Cl^- -SO_4^{2-}, Cl^- -HCO_3^-, HCO_3^- -SO_4^{2-}, HCO_3^- -Cl^-

The subgroup which is found in any environment depends on a number of factors, such as proximity to recharge, rock type encountered, climate, temperature, Eh, pH and the resultant concentration of total dissolved solids. The value of this last parameter increases with depth due to increased temperature and pressure, for a given residence time.

Herman (ibid) stated that the relative abundance of each anion tends to be associated with specific concentration ranges of the total dissolved solids (T.D.S.) and the depth. In waters with up to 1000 mg/l T.D.S., in the uppermost zone A, HCO_3^- predominates: the medium depth zone, B, has T.D.S. between 1000 and 12,000 mg/l with SO_4^{2-} - Cl^- most important: zone C is Cl^- rich with greater than 12000 mg/l T.D.S.. The T.D.S. of Montreal waters range from 161 mg/l (sample no. 5364, of well depth 750 feet) to 2290 mg/l (sample no. 5117, of well depth 490 feet) in which the predominant ions are HCO_3^- + Ca^{2+} and SO_4^{2-} + Ca^{2+} respectively.

Each of the three generalised zones can be subdivided further on their cation content. Near the recharge area the system tends to be monozonal, zone A, rich only in bicarbonate, but there can be superimposition of all three zones in later stages (Herman, 1971, p.42). Vertical zonation is emphasised by Back and Hanshaw (1971, p.1010), who said that any type of water could be obtained from any geographic point in the Yucatan Peninsula of Mexico if the sampling depth were deepened or shortened. He was considering only very permeable limestone, so it is unlikely that the system is quite as simple in other cases. It does not, however, vitiate the general concept that some degree of vertical zonation is usually present.

5.4 Types of Chemical Reaction in Ground Waters

Modifications to ground waters can occur due to base exchange phenomena, and secondary reactions between primary products. During this process different cations are adsorbed and released from the surfaces of media possessing an unsatisfied negative charge. Clays are the most common exchange materials. The charge can result from internal electrical imbalance and broken bonds round the edges of a species. The frequency of such an occurrence increases with smaller particles, hence the importance of clays in this respect (Grim, 1968, p.189). Any water has positive ionic species capable of satisfying any free negative charge, but two factors control the selection of the cation which will participate. They are abundance and charge or valence. The more abundant, or the more highly charged a cation is, the more likely it is to be adsorbed. The secondary reactions fall into two broad categories, reversible and non-reversible (Hem, 1970, p.16). Within each class three processes can occur: hydration, oxidation-reduction and hydrolysis (Schoeller, 1959, p.55).

5.5 Activity and Ionic Strength

In a reaction a chemical equilibrium is usually attained, and the law of mass action can be used to quantify the reaction. This is true of reactions involving ground water. The law of mass action is strictly applicable only if the solution concentration can be corrected to the activity (Hem 1970 p 18).

In solutions above concentrations of 5,800 mg/l NaCl (ionic strength 0.1) or the equivalent (Hem, 1970, p.19, plate 1), electrostatic effects can alter the mobility of the ions, and hence influence their reacting ability. The ionic strength is a measure of the electrostatic field, and with strength lower than 0.1 the correction for activity is small.

In Montreal, the maximum calculated ionic strength was 0.04597, while the minimum was 0.00426. The values of ionic strength, as well as activities, were obtained from a computer programme (Hoag, 1975, 1976) and are included as Appendix C.

5.6 pH

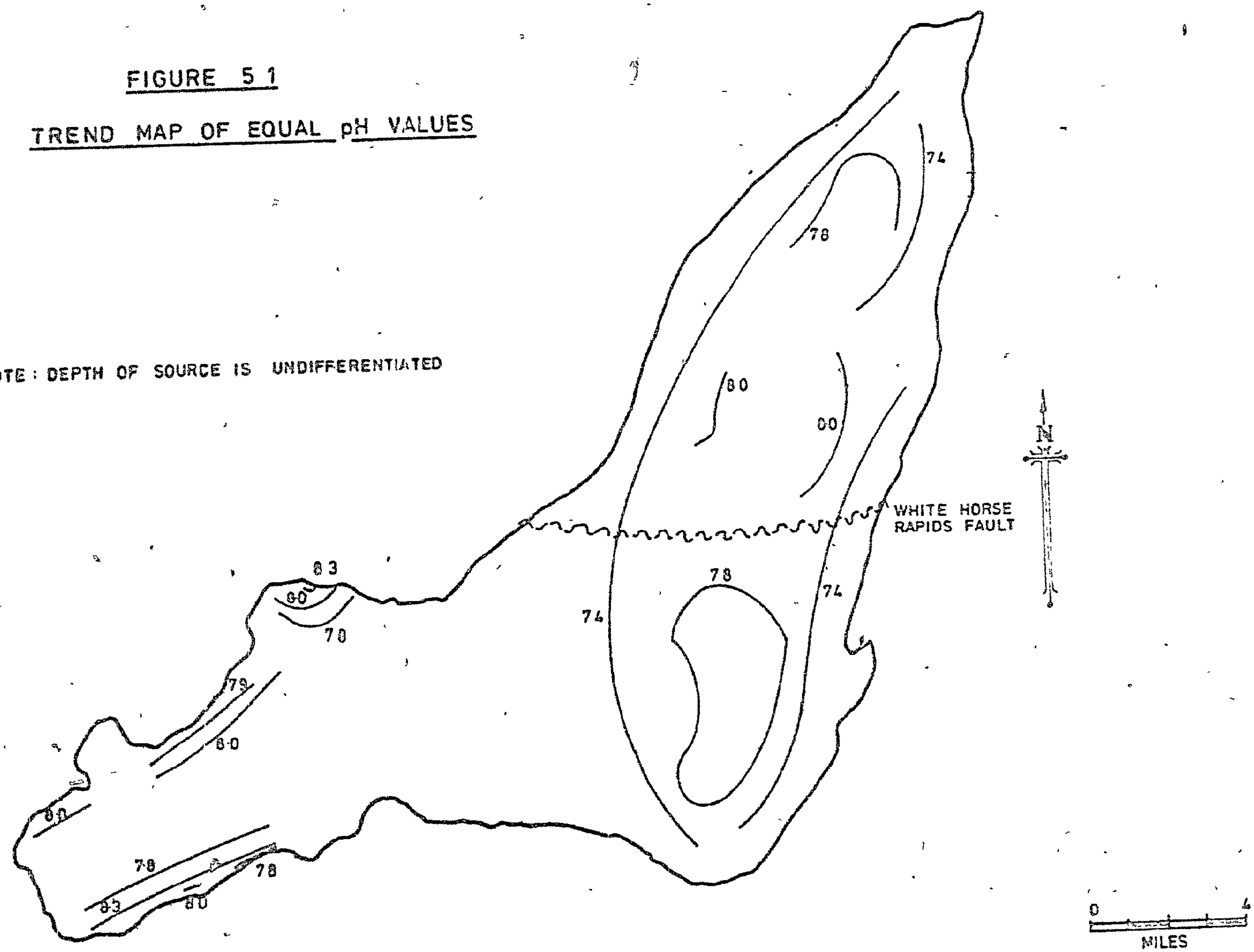
All hydrolysis reactions influence, or are influenced by, pH (Hem, 1970, p.90). Most ground waters have pH values ranging from 6.0 to 8.5, but waters with pHs outside this range are known (Hem, 1970, p.93). In Montreal the observed range was from 6.8 (sample no. 5107) to 8.7 (sample no. 5243). Figure 5.1 shows the variation of pH in Montreal, and that generally the more alkaline water is found to the west of the Island, but no significant trend is apparent from the amount of data available.

The pH of water represents the interrelated result of a number

FIGURE 5 1

TREND MAP OF EQUAL pH VALUES

NOTE : DEPTH OF SOURCE IS UNDIFFERENTIATED



of chemical equilibria. The equilibria in a ground water system are altered on pumping, therefore, even if a measurement taken at the moment of sampling is representative of the original equilibrium conditions in the aquifer, when the water is stored before analysis, the pH is likely to change as the storage environment is almost certain to differ from the original conditions. This is because the in situ pCO_2 of the water will probably differ from that analysed at the time of testing for pH. The pCO_2 controls the concentration of the bicarbonate ion in solution. Since the equilibrium between the two involves the hydrogen ion, the pH is directly affected if the pCO_2 changes.

5.7 General Geochemistry of the Major Ions

The dissolved constituents found in ground water are shown in Table 5.1 (Davis and DeWiest, 1966, p.112). The major ions are described in respect of their possible sources, and the way in which they react in different environments. This section includes discussion of local sources and some geological events which may have influenced the formation of different hydrochemical species and zones. The distribution of different ions is shown on a series of trend maps to illustrate the components of the hydrochemical zones of Montreal. There is a full discussion of Montreal's zonation in Chapter 6.

5.7.1 Calcium

The major source of calcium is the sedimentary rocks, where it occurs as non-silicate minerals in the carbonates such as calcite, aragonite, $CaCO_3$, and dolomite,

$CaMg(CO_3)_2$. It can also be found as the sulphate, eg. gypsum, $CaSO_4 2H_2O$ and anhydrite, $CaSO_4$.

It is an essential constituent of many igneous rock minerals, especially of pyroxenes, amphiboles and felspars. In the last group it is most prominent in the end member - anorthite, $CaAl_2Si_2O_8$. Calcium is also found in metamorphic minerals, eg. tremolite.

Waters from igneous and metamorphic rocks have low calcium contents since the rate of decomposition of the component minerals is slow. The decomposition of anorthite can be represented as follows (Hem, 1970, p.131).

$$CaAl_2Si_2O_8 + H_2O + 2H^+ \rightarrow Al_2Si_2O_5(OH)_4 + Ca^{2+}$$

Given sufficient contact time, the pH may rise to 8.2, at which point calcium carbonate precipitates from the solution. On the other hand, if the hydrogen ions are supplied by sources independent of the dissolved carbon dioxide species, calcium may be brought into solution in amounts greater than the stoichiometric equivalent of bicarbonate. The concentration of HCO_3 is controlled by the pCO_2 (Hem, 1970, p.89).

$$HCO_3^- \rightleftharpoons H^+ + CO_3^{2-}$$

Thus in media relatively rich in H^+ ions the reaction tends to the left, and hence HCO_3^- is a stable species. However, when H^+ became relatively scarce ie. about pH 8.2, the reaction tends to the right with the conversion of HCO_3^- to CO_3^{2-}. In such a system, or where water is in contact with solid gypsum, the maximum calcium concentration that could be reached would generally be determined by equilibria in which gypsum is the stable solid.

Concentration of calcium can also be influenced by cation exchange phenomena since it may be present in the form of adsorbed ions on negatively charged mineral surfaces as in the zeolites, eg. prehnite, or clays, eg. montmorillonite.

The usual range of concentration of calcium in ground water is 10 - 100 mg/l (0.5 - 5 meq/l) (Table 5.4) while on Montreal Island it ranges from 9.2 mg/l (0.5 meq/l) (sample no. 5316) to 425 mg/l (21.2 meq/l) (sample no. 5117) with a mean of 89 mg/l (4.45 meq/l). The areal distribution of calcium is shown on Figure 5.2. This and the distribution of other ions are discussed in the next chapter.

TABLE 5.4

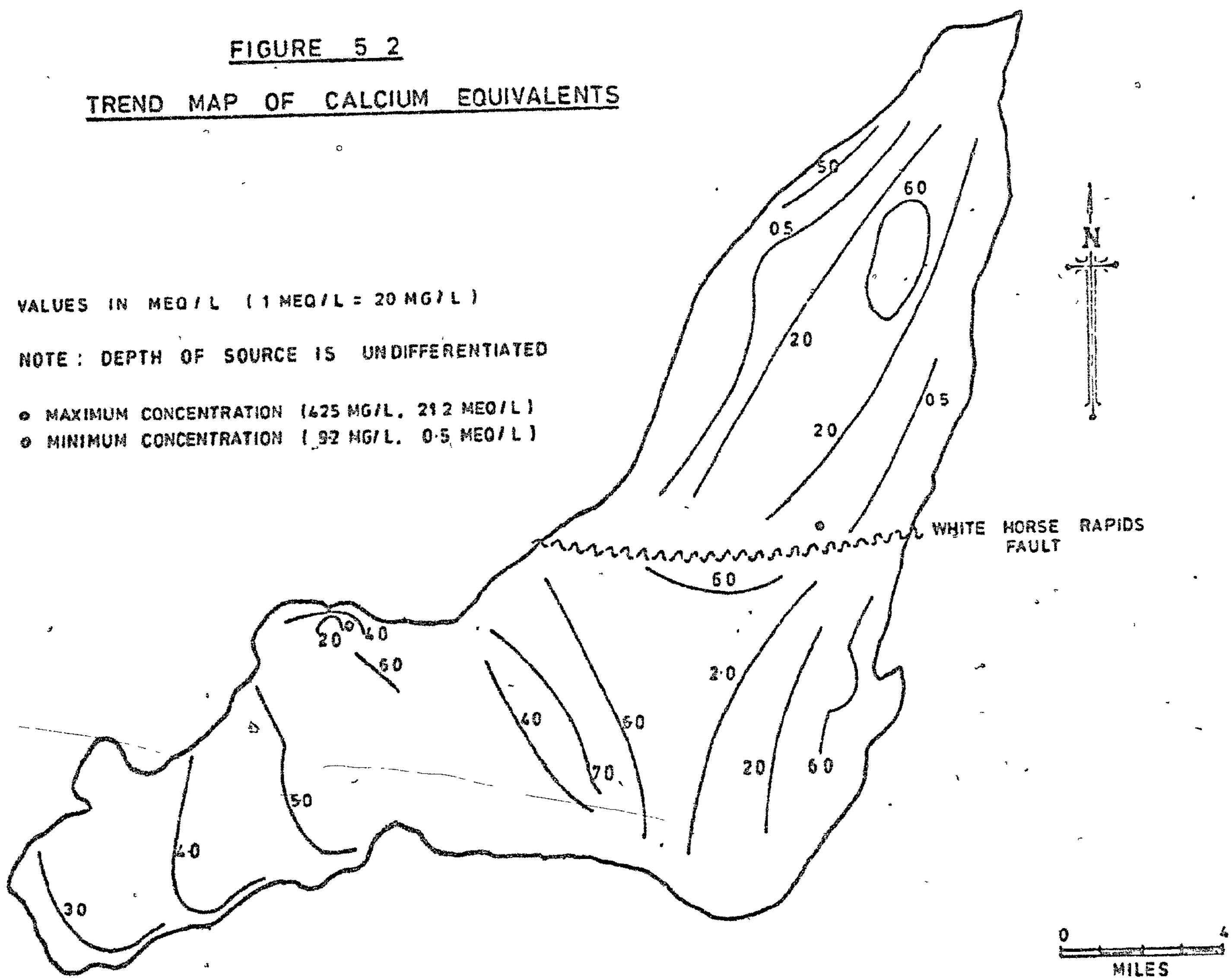
RANGES AND MEAN CONCENTRATIONS OF THE PRINCIPAL IONS IN GROUND WATER

	General range in mg/l (Davis and DeWiest 1966 pp 102-110)	Montreal Values: Range mg/l	Mean mg/l	Mean meq/l	Standard deviation (meq/l)
Ca	10-100	9.2-425	89	4.45	2.74
Mg	1-40; dolomite 100	7.7-90.2	29	2.43	1.44
Na	>100*; igneous and metamorphic 1-20; brine 100,000	2.3-536	75	3.24	4.72
K	1-5	1.2-27			
HCO_3	10-800; usually 50-400	131-689	353	5.78	1.60
SO_4	(0.2) - <100-(100,000)	25.3-1359	142	2.96	2.94
Cl	30; arid 1000; brine 150,000	1.6-651	50	1.41	2.80

* in water with 1000 - 5000 mg/l T.D.S.

FIGURE 5 2

TREND MAP OF CALCIUM EQUIVALENTS



5.7.2 Magnesium

Sedimentary forms of magnesium include carbonates such as magnesite, hydromagnesite and dolomite, and the hydroxide brucite. Magnesium is also found in argillaceous sediments as undecomposed fine particles, and as ions adsorbed on clay minerals. Carbon dioxide increases the solubility of magnesium by conversion of the carbonate to the more soluble bicarbonate:

$MgCO_3 + H_2O + CO_2 \rightarrow Mg(HCO_3)_2$ (Parsons, 1964, p. 27)

Magnesium is a constituent of the ferromagnesian minerals, including olivine, pyroxenes, amphiboles and the dark micas. In altered rocks, magnesium mineral species occur in the clay minerals such as chlorite, and also in serpentine. Serpentine is formed from the alteration of forsterite:

$5Mg_2SiO_4 + 8H^+ + 2H_2O \rightarrow Mg_6(OH)_8Si_4O_{10} + 4Mg^{2+} + H_4SiO_4$

(Hem, 1970, p. 141)

This is a non-reversible reaction but the products can participate in subsequent processes.

Usually, if the total dissolved solid content of ground water is less than 400 mg/l the magnesium content is less than that of calcium, though the reverse is true of water deriving from a dolomitic source, as shown by samples from the Beekmantown Dolomite in the west of Montreal Island. The usual range of concentration of magnesium in ground water is 1 - 40 mg/l (0.1 - 3.3 meq/l), though ground water in dolomitic environments may contain up to 100 mg/l (8.0 meq/l) (Table 5.4). The range of magnesium concentrations found in the Island ground water is from 7.7 mg/l (0.64 meq/l) (sample no. 5316) to 90.2 mg/l (7.4 meq/l) (sample no. 5101) (Fig. 5.3) with a mean of 29 mg/l (2.4 meq/l).

5.7.3 Sodium

Sodium is the principal cation of waters draining igneous terrains, deriving from the weathering of the sodic felspars. It is ordinarily scarce in carbonate rocks. In resistate sediments, sodium may be present in unaltered mineral grains, as an impurity in the cementing material, or as crystals of soluble sodium salts deposited with the sediments, or left in them by saline water that entered them at some later time.

Most sodium compounds are soluble (Table 5.3) and the salts go into solution easily, especially from coarse grained sediments. If the circulation is impaired, as in hydrolyzate sediments, the trapped salts remain for long periods. When sodium has been brought into solution, it tends to remain in that state. There are no important precipitation reactions that prevent the concentration of sodium in water from gradually increasing, in the way that carbonate precipitation controls calcium concentrations. Sodium is retained by adsorption on

FIGURE 5 3

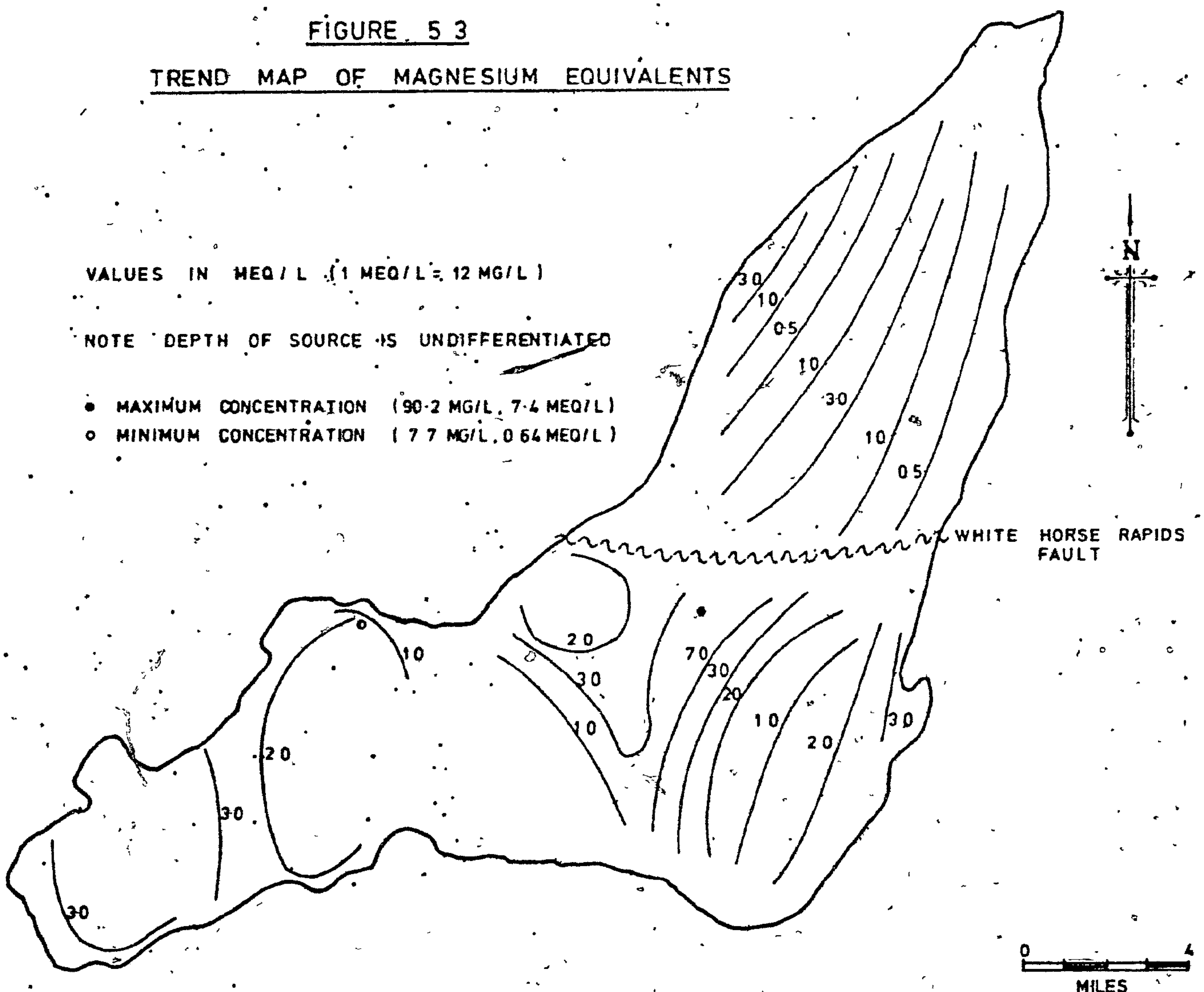
TREND MAP OF MAGNESIUM EQUIVALENTS

VALUES IN MEQ/L (1 MEQ/L = 12 MG/L)

NOTE DEPTH OF SOURCE IS UNDIFFERENTIATED

• MAXIMUM CONCENTRATION (90·2 MG/L, 7·4 MEQ/L)

○ MINIMUM CONCENTRATION (7 7 MG/L, 0 64 MEQ/L)



mineral surfaces, especially clays, but this does not control the solubility of ions.

The Champlain Sea marine episode affected Montreal long after the limestone formations had been laid down, but the chemistry of the ground water, particularly in terms of sodium and chloride, does not reflect this incursion. There was a glacial period prior to the Champlain Sea, during which time till was deposited, and this could have acted as a barrier against saline intrusion. Also subsequent eluting by fresh water of any affected formation could have removed any sea water, assuming that the openings which allowed the sea water in initially were still effective for eluting after the Champlain Sea had disappeared.

The usual concentration of sodium in ground water is less than 100 mg/l (4.4 meq/l) though brines may contain 100,000 mg/l. Igneous and metamorphic terrains produce ground water with a range of 1 - 20 mg/l (0.04 - 0.9 meq/l). The range of sodium concentrations found on the Island is from 4.6 mg/l (0.2 meq/l) (sample no. 5355) to 535 mg/l (23.3 meq/l) (sample no. 5145) while the mean is 75 mg/l (3.3 meq/l) (Fig. 5.4 and Table 5.4).

5.7.4 Potassium

The concentration of potassium is much lower in most

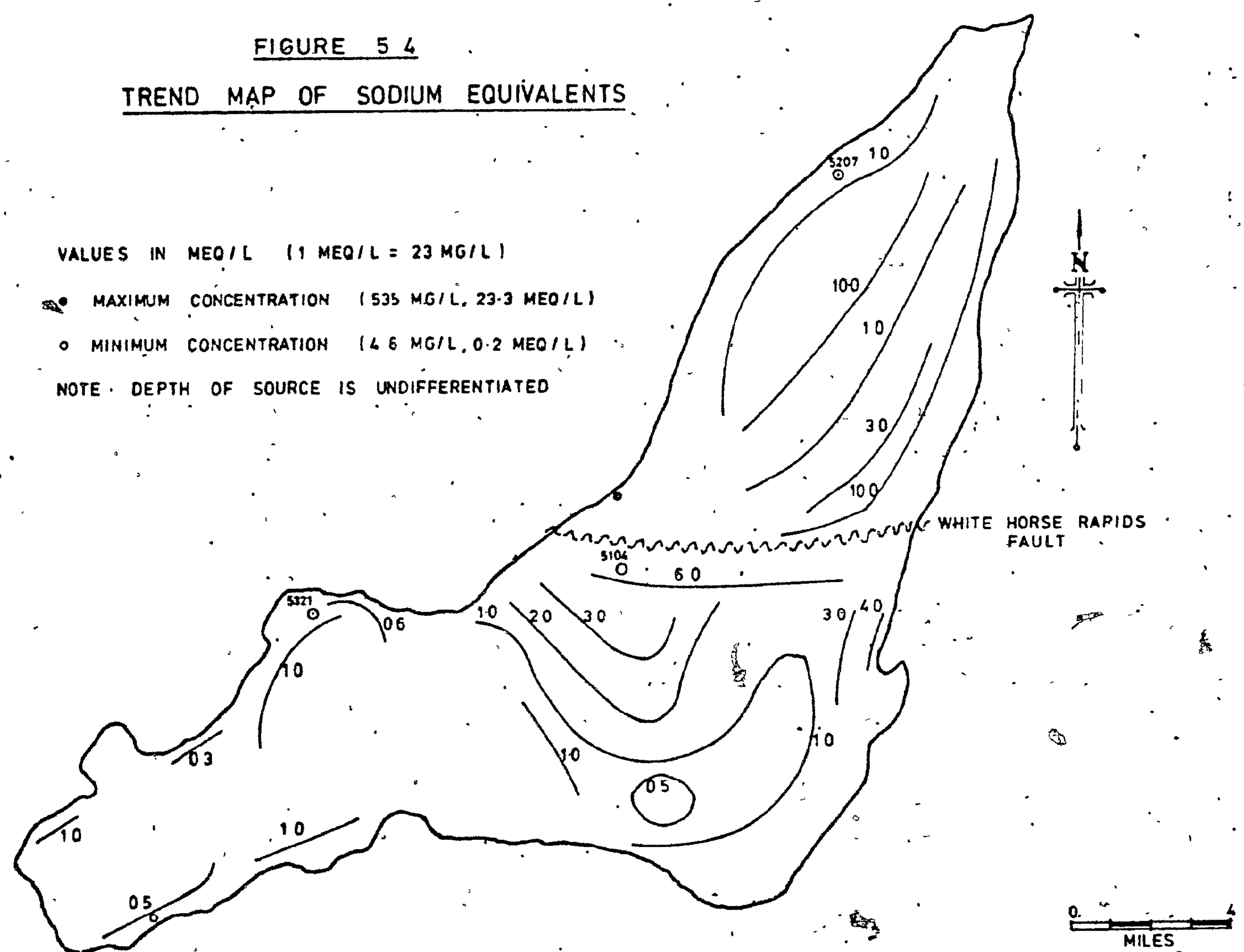


FIGURE 5 4

TREND MAP OF SODIUM EQUIVALENTS

natural waters than that of sodium. This is because potassium tends to be re-incorporated into solid weathering products as soon as it becomes available,from, for example, the weathering of orthoclase: (Herman, 1971, p.17)

$$K_2Al_2Si_6O_{16} + 2H_2O \rightarrow K_2O + 4SiO_2 + H_4Al_2Si_2O_9$$

orthoclase kaolinite

Once adsorbed into some clay mineral structures it cannot participate readily in further exchange, for example

Montmorillonite + K → illite (Parsons, 1964, p.28)

Potassium occurs in evaporite deposits as carnallite $KCl.MgCl_2.6H_2O$, and sylvite KCl, but usually constitutes less than 1% of the cation concentration (Yakutchik and Lammers, 1970, p.102).

The usual range of concentration of potassium in ground water is 1 - 5 mg/l (0.025 - 0.1 meq/l). Its range in Montreal is from 1.2 mg/l (0.03 meq/l) (sample no. 5244) to 27.0 mg/l (0.67 meq/l) (sample no. 5350). This shows that potassium is not particularly abundant, never exceeding 1 meq/l, though small quantity variations might be significant.

5.7.5 Chloride

Chloride is the most abundant anion of sea water, but only a minor constituent of the earth's crust. In ground water the highest concentrations of chloride are usually found in samples taken from points furthest along a flow line, since this would have allowed prolonged contact. Though its availability to normally circulating ground water is low in igneous and metamorphic rock, the solubility of chlorine compounds is high. Solution of sodalite and apatite, as well as the chloride content of liquid inclusions, contribute to the final concentration. More important sources are associated with sedimentary rocks, particularly the evaporites, and in resistates which may include connate brine trapped after marine deposition or incursion. Although Montreal was affected by the Champlain Sea episode, the chemistry of the ground water of the Island does not reflect this, as discussed in Section 5.7.3. Other sources are from volcanic emanations from the atmosphere, and from organic sources (Hoag, 1975 personal communication). Once in solution chloride tends to remain there. It is very passive and does not participate in any reactions causing re-precipitation; nor is it affected by exchange or adsorption. The only common way for it to be concentrated to the point of precipitation is by evaporation, though other ways involving ionic filtration, perhaps utilizing the Gouy Layer, have been suggested as possible mechanisms (Hem, 1970, p.175).

The usual concentration of chloride in ground water is less than 30 mg/1 (0.84 meq/1) but it may reach 1000 mg/1 in arid regions, or 150,000 mg/1 in brines. The lowest chloride concentration found on the Island is 1.6 mg/1 (0.04 meq/1) (sample no. 5338 and others), the highest is 651 mg/1 (18.4 meq/1) (sample no. 5325). The mean is 50 mg/1 (1.4 meq/1) (Fig 5.5 and Table 5.4).

5.7.6 Sulphate

Sulphur is not a major constituent of the earth's outer crust. Though it is widely distributed in igneous rocks as sulphides, most of the sulphates found in sedimentary rocks are leached from the resistate sediments (Rankama and Sahama, 1950, p.752). However, in the presence of aerated water, sulphides, such as marcasite and pyrite, in many sedimentary rocks, can be oxidised to yield sulphate ions. Most sulphates are soluble in water, and the effective solubility can be increased by the tendency to form complex species called ion pairs (Hem, 1970, p.167). Solubility can also increase with ionic strength; for example, the solubility of $CaSO_4.2H_2O$ increases with an increase in sodium chloride content from 2,016 mg/1 at 20°C with NaCl = 0 to 7,300 mg/1 for NaCl = 146.2 g/1. Above this NaCl concentration the solubility of gypsum decreases again (Schoeller, 1959, p.65). An increase in the sulphate concentration is usually accompanied by a similar increase in the concentration of calcium and magnesium.

FIGURE 5.5

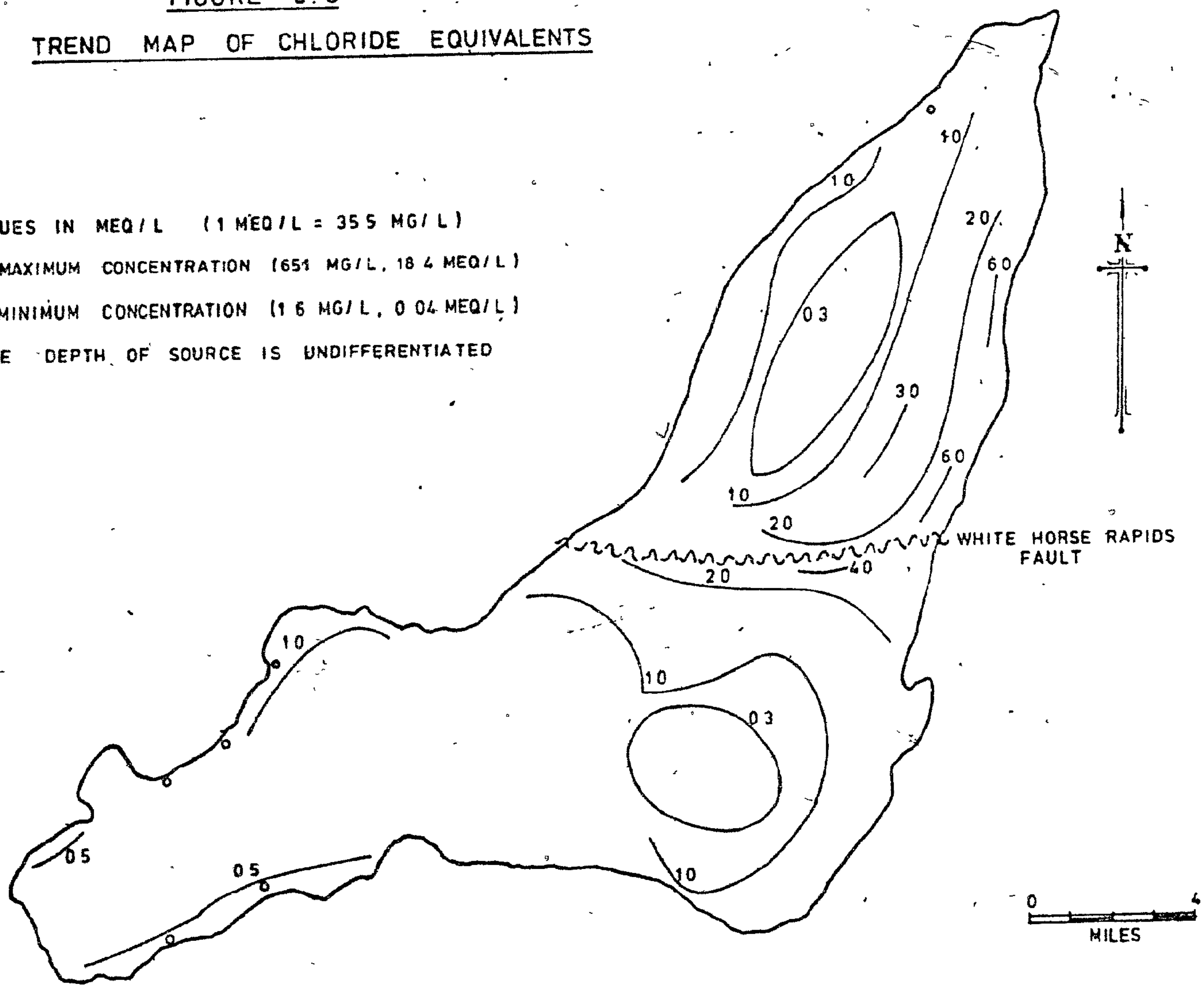
TREND MAP OF CHLORIDE EQUIVALENTS

VALUES IN MEQ/L (1 MEQ/L = 35.5 MG/L)

● MAXIMUM CONCENTRATION (651 MG/L, 18.4 MEQ/L)

○ MINIMUM CONCENTRATION (1.6 MG/L, 0.04 MEQ/L)

NOTE DEPTH OF SOURCE IS UNDIFFERENTIATED



Sulphate forms salts of low solubility with only a few metals. Of the common salts barium sulphate is least soluble, while the sulphates of calcium (gypsum and anhydrite) are the most widespread, and have a solubility of 2,016 mg/l at 20°C. They often occur in evaporite deposits. Although no such deposits are known on the Island, they could have represented a phase in the deposition of the Beekmantown Group from which the maximum concentration of 1359 mg/l (28.1 meq/l) sulphate is found (sample no. 5117). The minimum is 25.3 mg/l (0.5 meq/l), (sample no. 5364), though the mean is 142 mg/l (3 meq/l) (Fig. 5.6 and Table 5.4). The usual concentration of sulphate in ground water is less than 100 mg/l (2 meq/l). The saturation concentration of calcium sulphate is in the order of 1478 mg/l at 10°C.

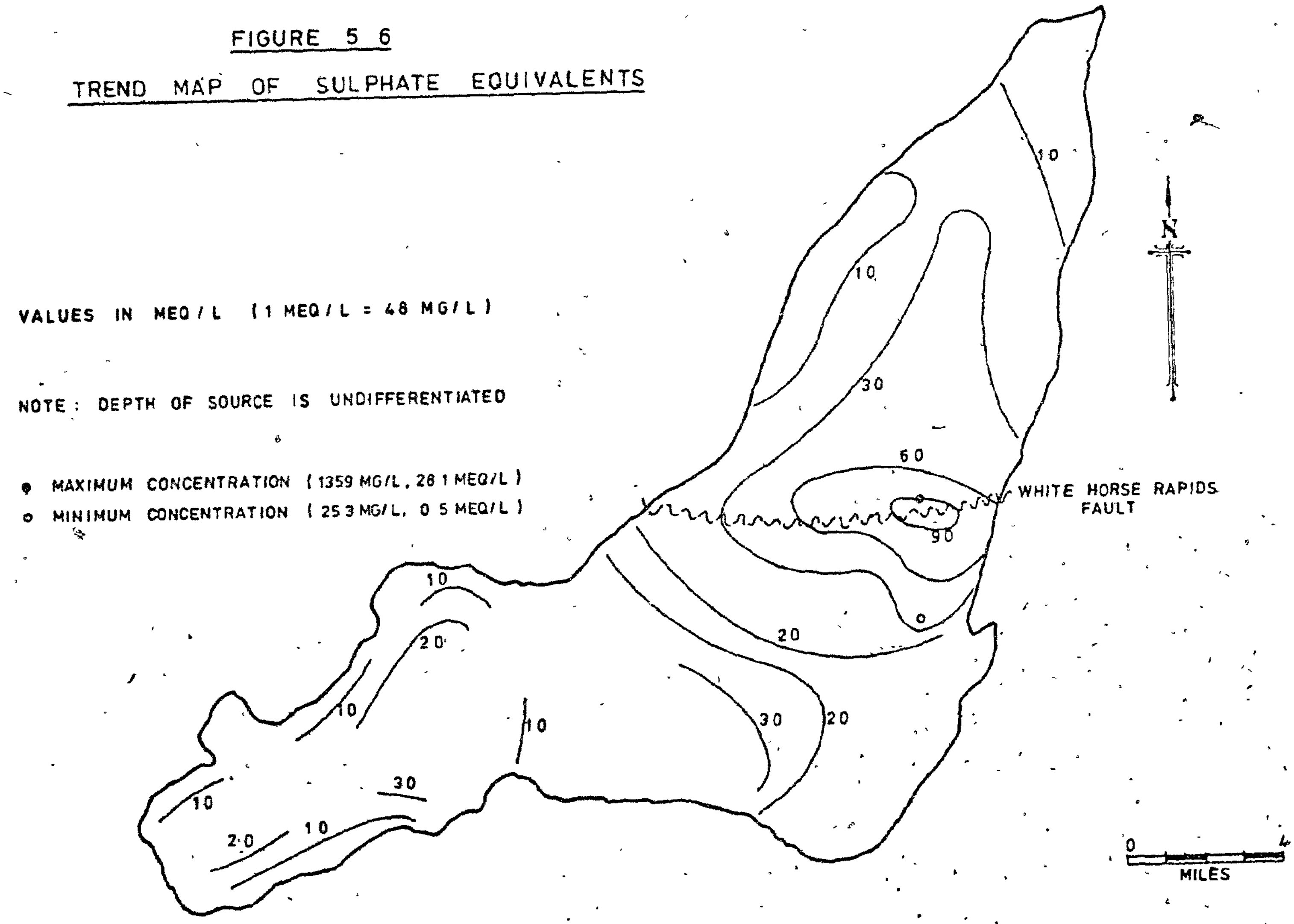
5.7.7 Bicarbonate and Carbonate

The last of the ions to be found extensively in ground water are the bicarbonates and carbonates. These are especially important in limestone terrains that are discussed in the next section. These are the primary contributors to the alkalinity of water, that is, the capacity of a solution to neutralise acid.

Bicarbonate dissociates to carbonate above a pH of 8.2. Below this pH all of the carbonate ions acquire hydrogen to become the bicarbonate species. Similarly, below

FIGURE 5 6

TREND MAP OF SULPHATE EQUIVALENTS



pH 4.5, a further acquisition of hydrogen causes molecules of "carbonic acid" to be formed. Usually the pH of ground water is between 4.5 and 8.2; thus it is the bicarbonate ion which is the most common.

The bicarbonate concentration of natural water generally is held within a moderate range, 50 - 400 mg/1 (0.83 - 6.6 meq/1) by the effects of carbonate equilibria (see below). In Montreal the range of concentrations is from 131 mg/1 (2.1 meq/1) (sample no. 5325) to 653 mg/1 (10.7 meq/1) (sample no. 5219) (Table 5.4. The mean is 353 mg/1 (5.8 meq/1).

5.8 Geochemistry of Limestone Terrains

Montreal is predominantly a limestone area tempered by other lithologies. Therefore a general study of limestone terrains provides a reference for Montreal. Broadly speaking the water in limestones circulates mainly, if not entirely, through fissures, so that the surface area of the rock exposed to attack is small in relation to the volume of water circulating. Further, most of the soluble salts (chlorides and sulphates) are locked in the limestone in highly compact or crystalline forms. Lack of primary interconnected porosity inhibits water reaching these salts at any great depth. The maximum penetration is usually less than thirty feet, facilitated by secondary openings when the limestone is weathering. Even water from more porous limestones is low in sulphates and chloride, but high in bicarbonate. Pure water is neutral, and in the absence of carbon dioxide is capable only of a very limited solution of calcite, a mere 5.4 mg/l (Hem, 1970, p.135). However, often rainwater has a pH of 5.6 (Hem, 1970, p.91) and it can be more acidic in industrial areas (Strong, 1974). Since carbonate rocks dissolve rapidly in acid water, analyses will be high in both calcium and magnesium. There will be little more solution once the water becomes neutral or alkaline (Brown, 1967, p.25).

Carbonate solution produces the most consistently abundant anion in ground water, and is important in establishing the pH. The controlling influence is the partial pressure of carbon dioxide of the gas phase contiguous with the ground water.

$$H_2O + CO_2 \longrightarrow \text{"}H_2CO_3\text{"} \longrightarrow HCO_3^- + H^+$$

In normal atmospheric conditions (760 mm Hg and 20°C) the partial pressure of carbon dioxide (pCO_2) is $10^{-3.6}$ atm. This would allow a concentration of 76.8 mg/l HCO_3^- solution. Since the bicarbonate content of ground water usually exceeds this figure, a secondary source of carbon dioxide must be available. Garrels and Christ (1965, p.88) state that the rôle of carbon dioxide in rain water has been overrated, whereas the effect of hydrolysis and carbon dioxide in the soil atmosphere have been underrated. Respiration in the root zone of plants causes the pCO_2 of soil air to increase to between 0.015 atm. and 0.5 atm., which allows solution to a maximum of 450 mg/l HCO_3^-. Ground water with exceptionally high values has been found in southeast

Virginia by Foster (1951), who explained the production of the required high pCO_2 by the interaction of calcium carbonate, base exchange minerals and carbonaceous material.

In carbonate terrains, where the hydrology is unlike that in other lithologies, due to the solubility of the rock, precise predictions o degree of saturation of the ground water, and hence the likelihood of further solution of the rock, are difficult owing to variations in purity of the rock. For example the calcium phosphate and shale content would change the equilibria at which solution occurs.

The rate of circulation is also important. If it is slow the mineral content of the water is likely to be high, and hence less capable of further solution. Fast moving water will remain aggressive. According to Freeze (1964, p.13) the rocks of Montreal are not porous enought to allow interstitial flow, and ground water movement is by fracture flow at a rate of about 3 cm/day. Yakutchik and Lammers (1970, p.77) say the same of the carbonate rocks in the Big Creek area of Ontario. Grice (1964, p.53) suggests that in rocks with these characteristics, solution should be enhanced due to the high velocity of water within the fractures. In Montreal, despite similar fracture development solution is not extensively manifest. Grice continues, however, by suggesting, in contrast, the possibility of precipitation of calcitic material in fissures in close connection to the surface. This feature has been observed in vertical joints in a tunnel being driven through Trenton limestone in Montreal. An analogous effect is encrustation of carbonate round the screen of a well pumping in calcareous rocks. This is due to a release of pressure from the aquifer, causing a lowering of the pCO_2, which results in precipitation of calcite. The equilibrium of the carbon dioxide bicarbonate-water system is driven to the left. $CO_2 + H_2O \rightleftharpoons "H_2CO_3" \rightleftharpoons H^+ + HCO_3^-$. A loss of 10 mg/l of CO_2 can increase the pH from 7.5 to 8.0 and reduce the solubility of calcite from 35 mg/l to 12 mg/l at 25°C.

The limestones of Montreal have a varying proportion of magnesium to calcium, as might be expected, since most limestones contain a moderate amount of magnesium (Hem, 1970, p.2). In the west of the Island the magnesium content of the rock is sufficiently high, rCa:rMg < 2.0, for the term dolomite (Beekmantown) to be used. Further east, however, the magnesium content becomes more subordinate to calcium (Figs. 5.2 and 5.3).

Water within dolomite rock strata which is at, or below, saturation should contain nearly equal concentrations of calcium and magnesium in terms of meq/l, because in the solution process equal amounts of the two ions will be dissolved. Water that is near or above saturation, however, may have lost some calcium by calcite precipitation, so the water attains a concentration of magnesium greater than that of calcium (Hem, 1970, p.143). This phenomenon is unusual but can occur in brines associated with evaporites, or in water that has participated in reactions with magnesium silicates. The analyses from samples 5352 and 5349 in the west of the Island show this inversion.

Montreal's limestone terrain is modified by an igneous regime, albeit minor, associated with Mount Royal and its accompanying dykes and sills. Flow is through fissures, so it is the development of secondary permeability and porosity in the rocks of Montreal that is important. Whereas in limestones the orientation of fissures is likely to be reasonably uniform, either normal to, or parallel to, the bedding planes, fissure widths are not. In igneous rocks both the fissure orientations and widths are likely to be more random, and hence the associated flow pattern and flow lines harder to predict. However, broadly speaking, in both regimes radial flow is indicated by the available data, with the discharge areas near to the periphery of the Island.

The hydrogeochemistry depends on the physical nature of the rock, the physical conditions of the system, and the chemical nature of the rock. Most of the rocks in the Island are carbonates, and the bicarbonate ion is found to predominate. Since this ion is stable in the ground water conditions present, it is ubiquitous on the Island and the other anions achieve dominance infrequently and only very locally. However, a more detailed discussion of the distribution of the chemical zones, and the principles involved in their delineation is given in the next chapter.

CHAPTER 6 PRESENTATION AND INTERPRETATION OF GROUND WATER ANALYSES OF MONTREAL ISLAND.

6.1 Introduction

The aim of the interpretation of the ground water analyses was to locate the gross hydrogeochemical zones of the Island. This has been carried out with the aid of the plots of analytical results in the form developed by Schoeller (1959).

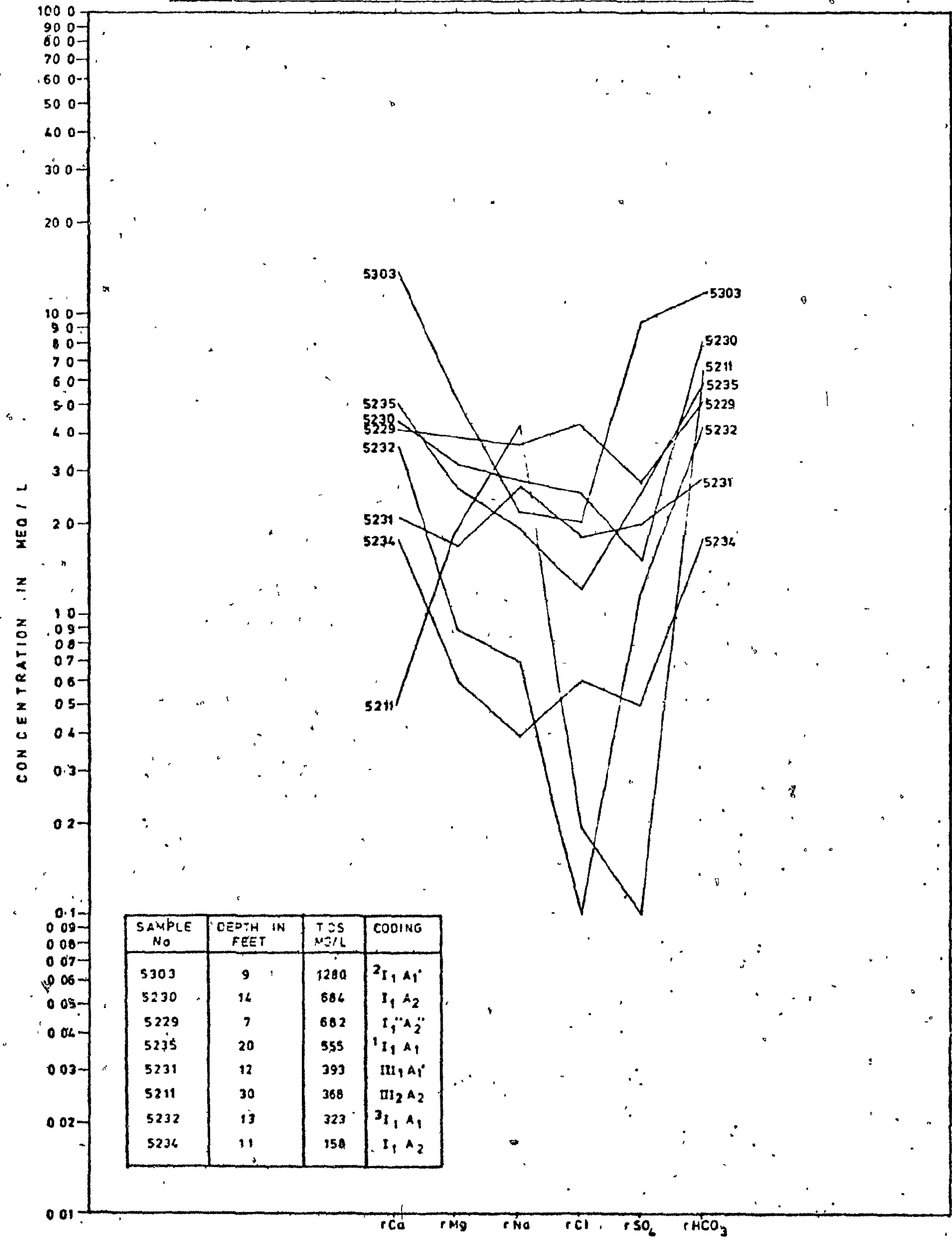
Schoeller's method permitted waters of different chemical types to be recognised as characteristic patterns, so that the relative abundance of each type could be assessed rapidly. Since the calcium-bicarbonate type was found to be so dominant, further delineation of facies was necessary by comparing the concentrations of individual ions, and by using ionic ratios. Each hydrogeochemical facies was then considered in relation to the geology and possible ground water flow patterns.

6.2 Use of Schoeller Diagrams

The concentrations in equivalents of each ion are plotted on lines parallel to the logarithmic ordinate, with the lines, one for each ion, spaced equally along the arithmetic abscissa. Each analysis is represented by the pattern obtained by joining the plotted points with straight lines, as can be seen on Figure 6.1a. Numerous analyses can be plotted on the same diagram which enables rapid comparison of many samples. It is also possible to determine the ratios of the concentrations of individual elements in specific types of water from the inclina-

FIGURE 6 1a

SCHOELLER PLOTS FOR WATER FROM CLAY AQUIFERS



SAMPLE No	DEPTH IN FEET	TDS MG/L	CODING
5303	9	1280	$^2I_1 A_1'$
5230	14	684	$I_1 A_2$
5229	7	682	$I_1'' A_2''$
5235	20	555	$^1I_1 A_1$
5231	12	393	$III_1 A_1'$
5211	30	368	$III_2 A_2$
5232	13	323	$^3I_1 A_1$
5234	11	158	$I_1 A_2$

tion of the connecting lines (Schoeller, 1959, p.69). Furthermore this method provides a means of assessing whether or not a given water is saturated with respect to $CaCO_3$ or $CaSO_4$ at the time of analysis, thereby providing an indication of the former, and most recent environments occupied by the ground water, and hence its flow regime. However, a more rigorous procedure was used for the calculation, by successive approximations of ionic strength and activities, based on Debye-Huckel theory, and assuming ion pairing (Hoag, 1975). The results are in Appendix C.

6.2.1 Waters from Surficial Aquifers

The analyses considered here are of water from wells in surficial deposits. Eight wells were in clay, six in till, two in gravel and one each in sand and gravel, and in sand aquifers. The wells are less than 40 feet deep. The number of samples of each type of water found are as follows:-

13 $Ca(HCO_3)_2$

4 $NaHCO_3$

1 $CaSO_4$

Although it is difficult to generalise with so few samples, the following comments are made.

6.2.1.1 Clay Aquifers

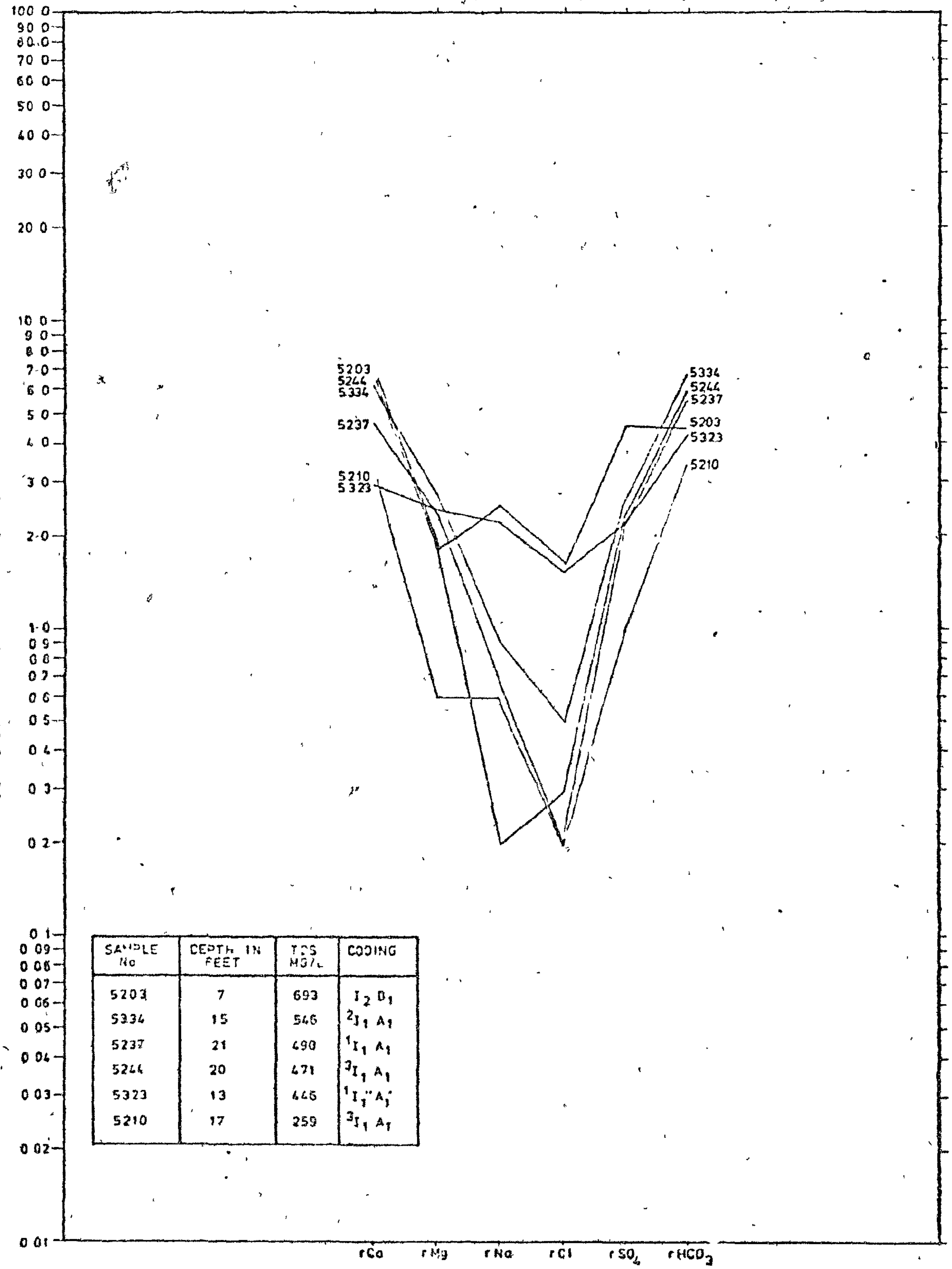
The analyses of samples from the clay environments are plotted on Fig 6.1a. There is a wide variety of both concentrations and patterns, which implies a reasonable abundance and heterogeneous distribution of most ions in the finely comminuted clay material. The plots generally are concave, which indicates a calcium bicarbonate character. Sample no. 5211 is slightly anomalous because its sodium content is much higher relative to calcium and magnesium than the other samples. It resembles the plot for the waters from the sand, and sand and gravel aquifers (Fig. 6.1c) which come from areas where there is marine clay, so the high sodium content is possibly due to base exchange during the passage of water containing calcium and magnesium ions.

6.2.1.2 Till Aquifers

The analyses of water samples from the till sources are plotted on Fig. 6.1b. The plots have an overall concave, or V-shape, which shows not only the calcium bicarbonate character of the water, but also that there is a low content of the more soluble species such as sodium and chloride. This suggests that there has not been sufficient time for the less abundant, more soluble, salts of the till such as sulphates and chlorides, to have been dissolved by any percolating rainwater. The rain itself is relatively deficient in the chloride ion due to the distance from the sea. Only in one

FIGURE 6 1b

SCHOELLER PLOTS FOR WATER FROM TILL AQUIFERS



SAMPLE No	DEPTH IN FEET	TDS MG/L	CODING
5203	7	693	$I_2 D_1$
5334	15	546	$^2I_1 A_1$
5237	21	490	$^1I_1 A_1$
5244	20	471	$^3I_1 A_1$
5323	13	446	$^1I_1$" A_1"
5210	17	259	$^3I_1 A_1$

sample does the sulphate content exceed that of the bicarbonate.

6.2.1.3 Gravel, Sand and Gravel and Sand Aquifers

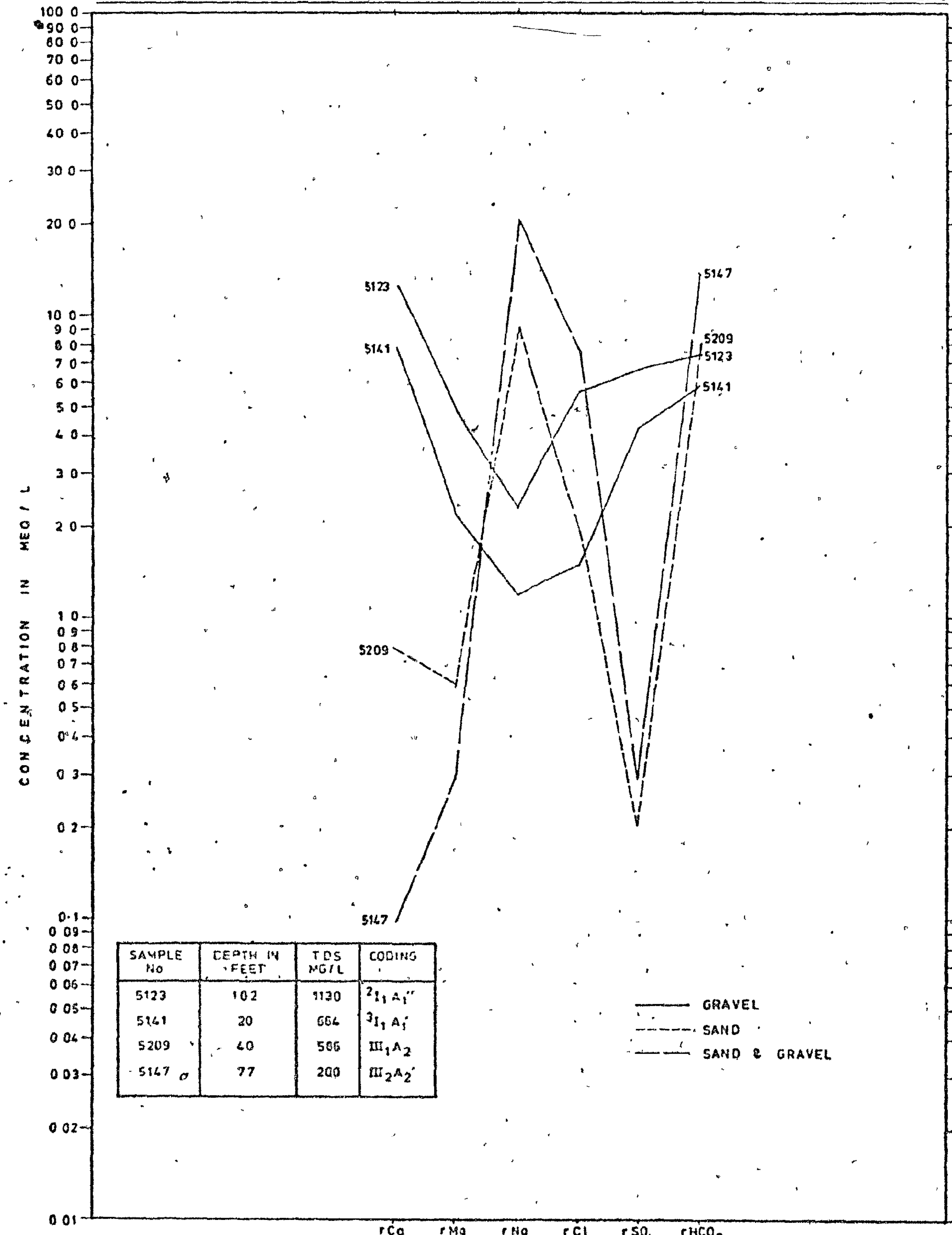
The two analyses of water from wells in gravel aquifers are plotted on Fig. 6.1c. They show the calcium bicarbonate character of the water, but that sulphate is becoming relatively more important. The total concentrations of these samples are comparativély high, > 10 meq/1, and suggest either a long contact time, or that the gravels contain fine grains of easily dissolved minerals within the general gravel composition.

The single sample from a sand and gravel aquifer, and from a sand aquifer, have relatively high sodium and chloride contents. Both plots have patterns very similar to the sample of water from a clay aquifer described above in Section 6.2.1.1.

The main conclusion that can be drawn from the above observations, is that ground water from surficial aquifers tends to have a variable composition. Although calcium bicarbonate water is generally found, the concentrations of the other constituent species is not constant.

FIGURE 6 1c

SCHOELLER PLOTS FOR WATER FROM GRAVEL, SAND & SAND & GRAVEL AQUIFERS



SAMPLE No	DEPTH IN FEET	TDS MG/L	CODING
5123	102	1130	$^{2}I_1 A_1''$
5141	20	664	$^{3}I_1 A_1'$
5209	40	586	$III_1 A_2$
5147	77	200	$III_2 A_2'$

This suggests different depositional histories, or changing chemical influences such as base exchange. Contamination is also possible.

6.2.2 Waters from Bedrock Aquifers

The bedrock of Montreal consists of Palaeozoic sedimentary rocks and Cretaceous igneous rocks. The range of the depths of bedrock wells samples was from 8 feet to 919 feet. Three water samples were obtained from igneous environments, while the remaining 140 were from the sedimentary rock zones. The number of samples of each type of water was found to be as follows:

89 $Ca(HCO_3)_2$

25 $NaHCO_3$

12 $Mg(HCO_3)_2$

6 $NaCl$

6 $CaSO_4$

3 Na_2SO_4

2 $MgSO_4$

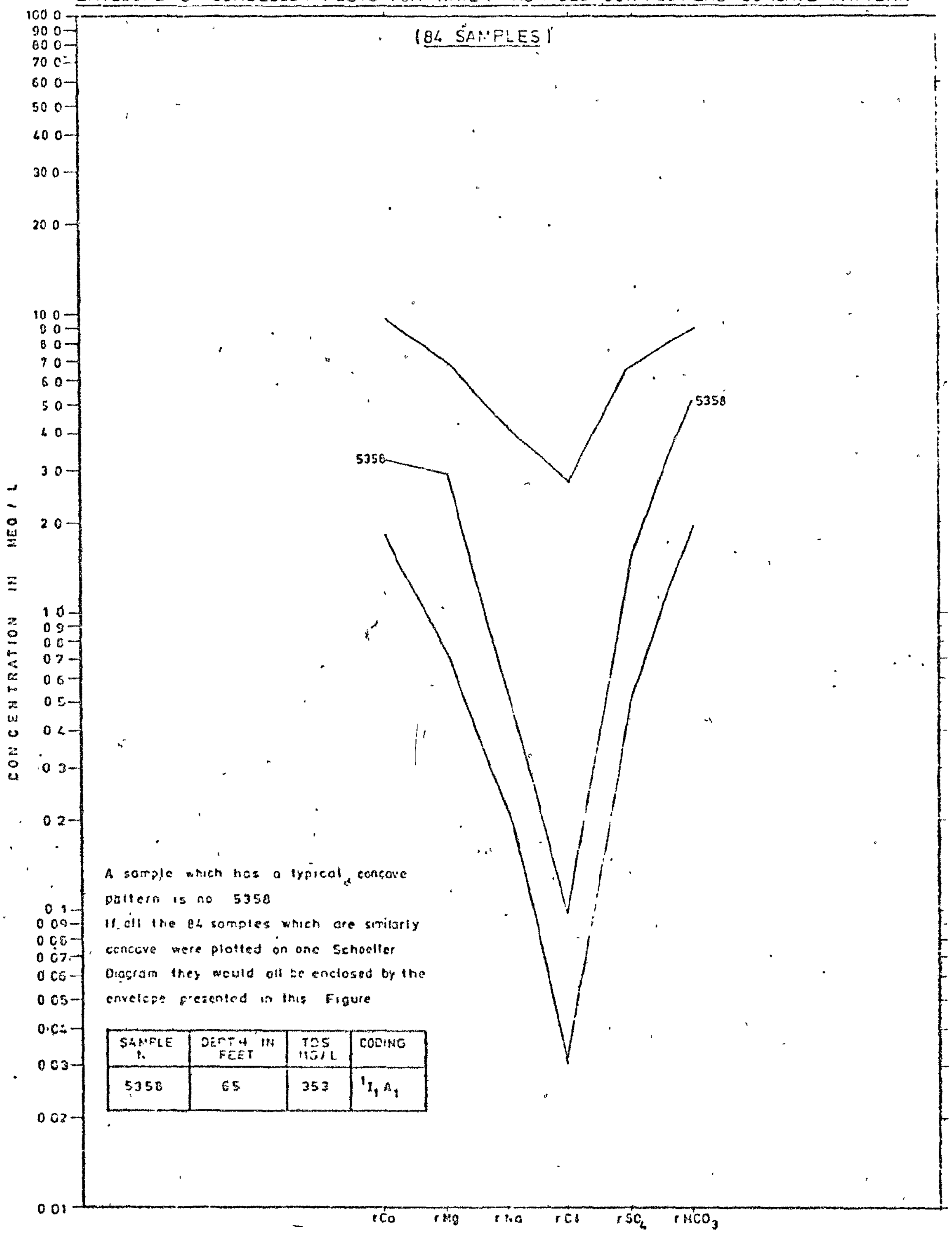
Three envelopes summarising the Schoeller plots are presented as Figs. 6.2a, b, c. These represent the 84 plots which are concave, the 53 which are a mixture of concave and convex, and the 6 which are convex. The full listing of data, printed by computer is included as Appendix D.

The concave pattern is characteristic of waters with a low total dissolved solid (T.D.S.) content, generally less than 600 mg/l. These are usually the calcium bi-

FIGURE 6.2a

ENVELOPE OF SCHOELLER PLOTS FOR WATER FROM BEDROCK AQUIFERS CONCAVE PATTERN

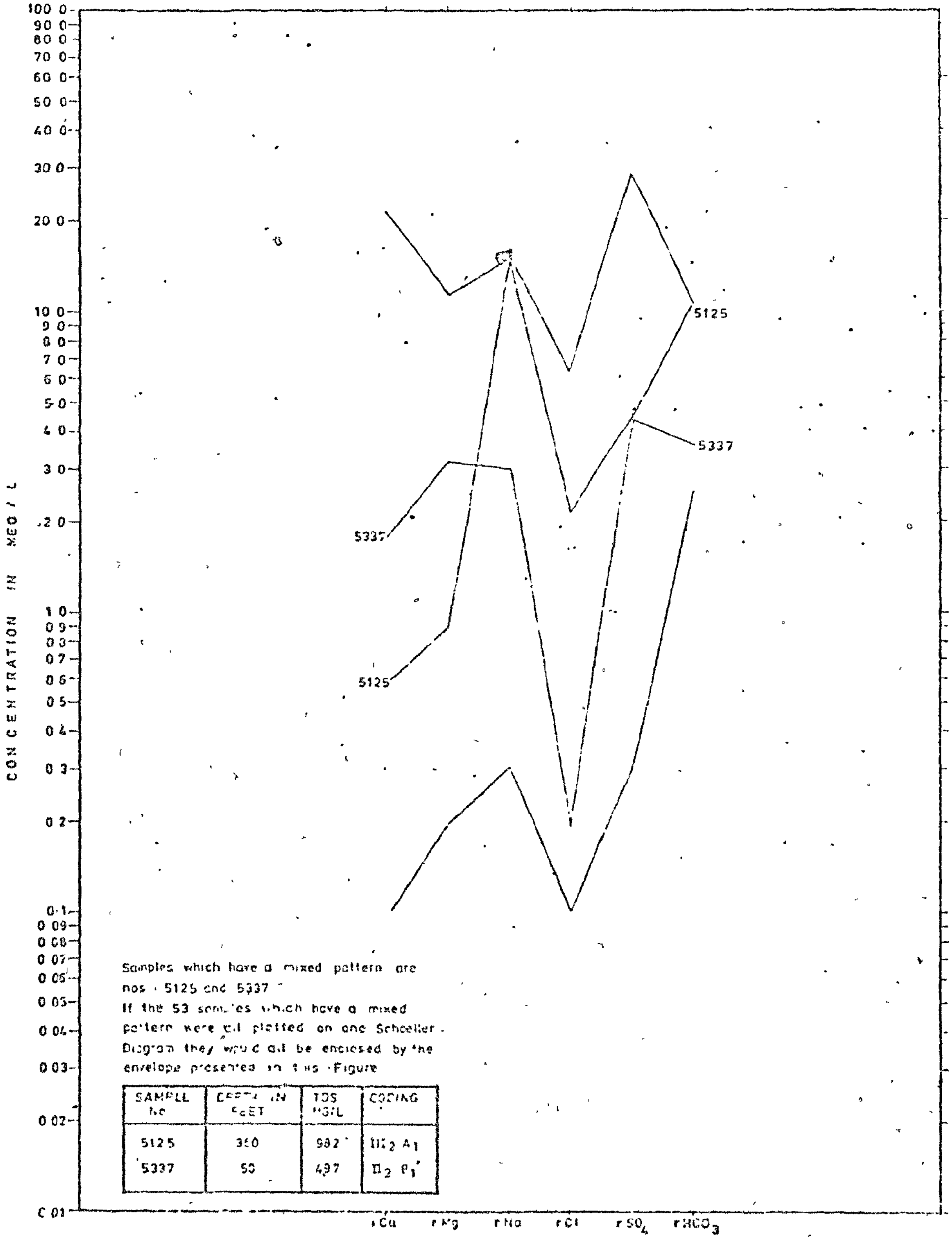
(84 SAMPLES)



SAMPLE N	DEPTH IN FEET	TDS MG/L	CODING
5358	65	353	$^1I_1A_1$

FIGURE 6.2b

ENVELOPE OF SCHOELLER PLOTS FOR WATER FROM AQUIFERS MIXED PATTERN (53 SAMPLES

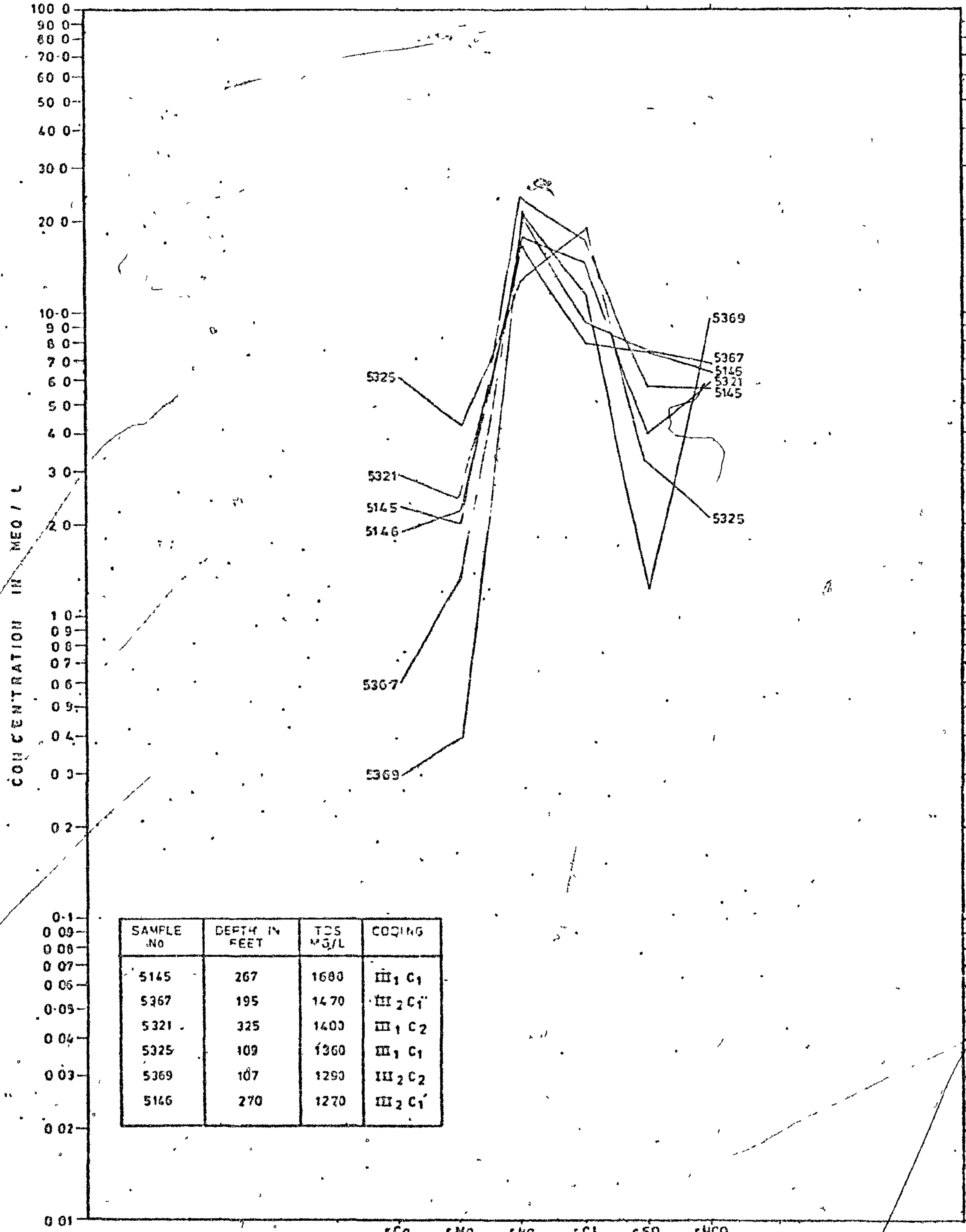


Samples which have a mixed pattern are nos. 5125 and 5337.
If the 53 samples which have a mixed pattern were all plotted on one Schoeller Diagram they would all be enclosed by the envelope presented in this Figure

SAMPLE No	DEPTH IN FEET	TDS MG/L	CODING
5125	350	982	$III_2\ A_1$
5337	50	497	$II_2\ P_1$

FIGURE 6 2c

SCHOELLER PLOTS FOR WATER FROM BEDROCK AQUIFERS CONVEX PATTERN (6 SAMPLES)



SAMPLE No	DEPTH IN FEET	TDS MG/L	CODING
5145	267	1680	$III_1\ C_1$
5367	195	1470	$III_2\ C_1''$
5321	325	1400	$III_1\ C_2$
5325	109	1360	$III_1\ C_1$
5369	107	1290	$III_2\ C_2$
5146	270	1270	$III_2\ C_1'$

carbonate type. The convex pattern is typical for waters with T.D.S. of generally greater than 1000 mg/l and they are usually of the sodium chloride type. The mixed pattern is found from waters with a mean T.D.S. of about 700 mg/l, for example sodium bicarbonate waters.

6.3 Subdivision and Classification of Montreal Ground Water

It was decided to subdivide the group of 126 samples of bicarbonate waters because the group constitued 88% of the total number of samples examined. The $NaHCO_3$ and $Mg(HCO_3)_2$ waters formed small enough sub-groups, but the $Ca(HCO_3)_2$ group of 89 was considered still too large. In 80 of the 89 samples $rCa > rMg > rNa$ and $rHCO_3 > rSO_4 > rCl$, so again further subdivision was decided to be necessary.

6.3.1 Classification of Facies

The detailed classification employed is shown in Table 6.1. It was drawn up after considering the following parameters:

1) the relative abundance in equivalents of three anions HCO_3^-, SO_4^{2-}, Cl^- and the three cations Ca^{2+}, Mg^{2+}, Na^+ to establish the main groups, and

2) the ratios such as $rCa:rMg$

$rHCO_3:rSO_4$

$rHCO_3:rCl$

$rSO_4:rCl$

to provide subgrouping.

CATIONS

GROUP		I		II		III	
subgroup		I_1	I_2	II_1	II_2	III_1	III_2
	in meq/l	Ca>Mg>Na	Ca>Na>Mg	Mg>Ca>Na	Mg>Na>Ca	Na>Ca>Mg	Na>Mg>Ca

Prefix of [1] to cation in subgroup I_1A_1 = rCa:rMg<2.0
Prefix of [2] to cation in subgroup I_1A_1 = rCa:rMg 2.0-3.0
Prefix of [3] to cation in subgroup I_1A_1 = rCa/rMg>3.0

Suffix of ' to anion group means r ratio between the two main anions is<2.0
Suffix of '' to anion group means r ratio between all the anions is<2.0
Suffix of '' to cation group means r ratio between all the cations is<1.5

r denotes values in meq/l

ANIONS

Group	Subgroup (in meq/l)
A	A_1: $HCO_3 > SO_4 > Cl$
	A_2: $HCO_3 > Cl > SO_4$
B	B_1: $SO_4 > HCO_3 > Cl$
	B_2: $SO_4 > Cl > HCO_3$
C	C_1: $Cl > SO_4 > HCO_3$
	C_2: $Cl > HCO_3 > SO_4$

Example (no. 5214) $^2I_1A_1'$

	meq/l
Ca	8.5
Mg	3.2
Na	1.1
HCO_3	7.9
SO_4	4.5
Cl	0.9

Ca>Mg>Na

$HCO_3 > SO_4 > Cl$

rCa:rMg = 2.67

$rHCO_3:rSO_4$ = 1.75

∴ Group I subgroup $_1$ = I_1

∴ Group A subgroup $_1$ = A_1

∴ [2]prefix to cation in subgroup I_1A_1 = $^2I_1$

∴ 'suffix to anion group = A_1'
whole = $^2I_1A_1'$

TABLE 6.1

CODING OF CHEMICAL GROUPING

6.3.2 Ratios of Ions and other Relationships

6.3.2.1 Calcium:Magnesium Ratio

Dolomite is present in the Montreal bedrock so it was thought that the magnesium content would be significant. Accordingly the rCa:rMg ratio was used as a classifier.

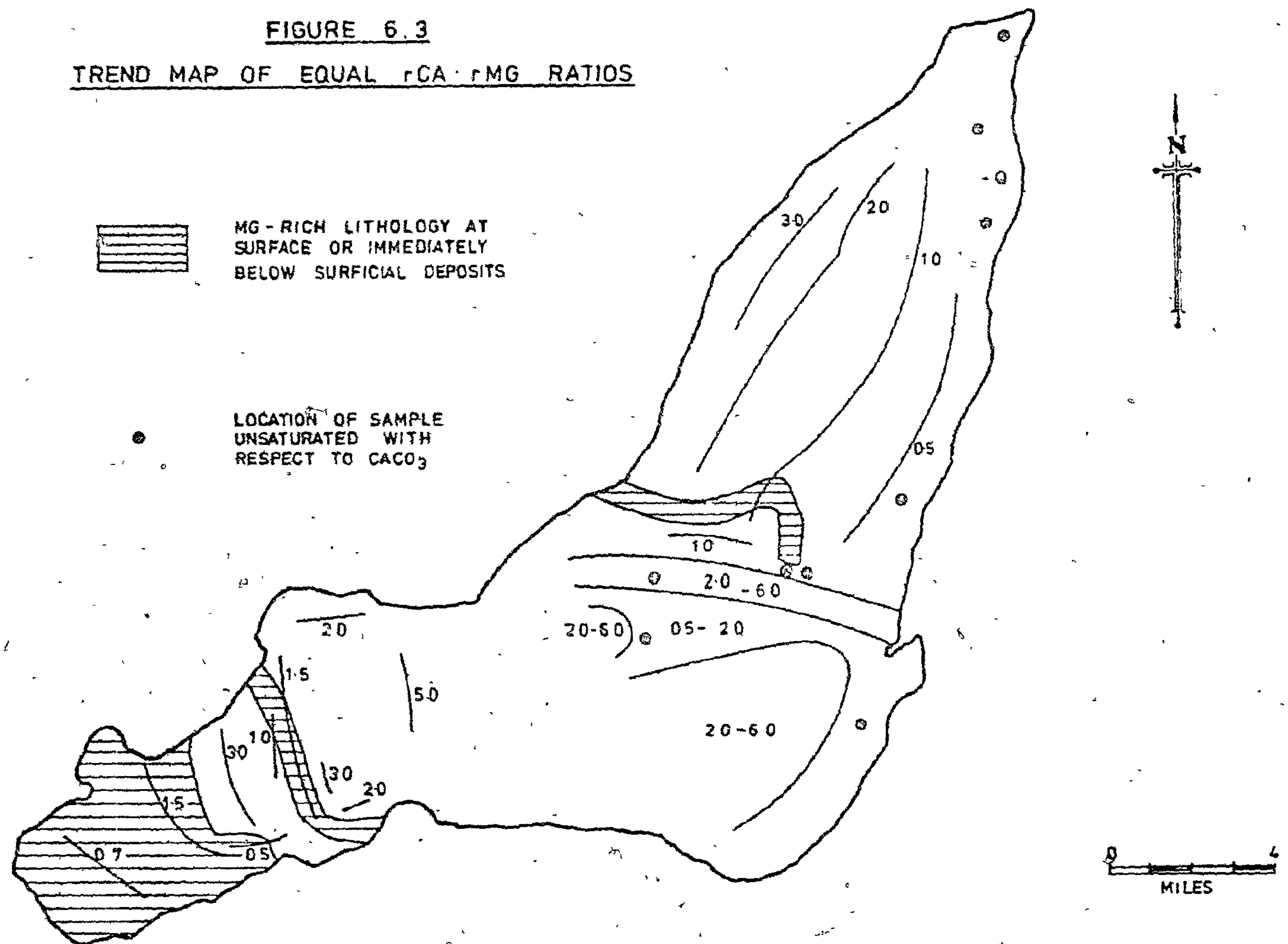
Though magnesium salts tend to be more soluble than calcium ones (see Table 5.3), calcite dissolves more quickly than does dolomite, so one should expect the rCa:rMg ratio to be higher than 1:1 in younger waters, from a dolomite/calcite environment. Analyses from the dolomitic areas were examined, and in every case there was an rCa:rMg ratio between 0.5 and 2.0 (Fig. 6.3). This range was used subsequently to distinguish samples affected by a dolomitic environment. Further subdivision was made on the basis of rCa:rMg ratios in the arbitrary range of 2.0 - 3.0 and greater than 3.0.

6.3.2.2 Base Exchange Index

The base exchange index (b.e.i.), $\frac{rCl - rNa}{rCl}$, illustrates the relative abundance of the sodium and chloride content, and can be used to locate areas of recharge. If one assumes a norm when the meq/1 values of both ions are generally

FIGURE 6.3

TREND MAP OF EQUAL rCA : rMG RATIOS



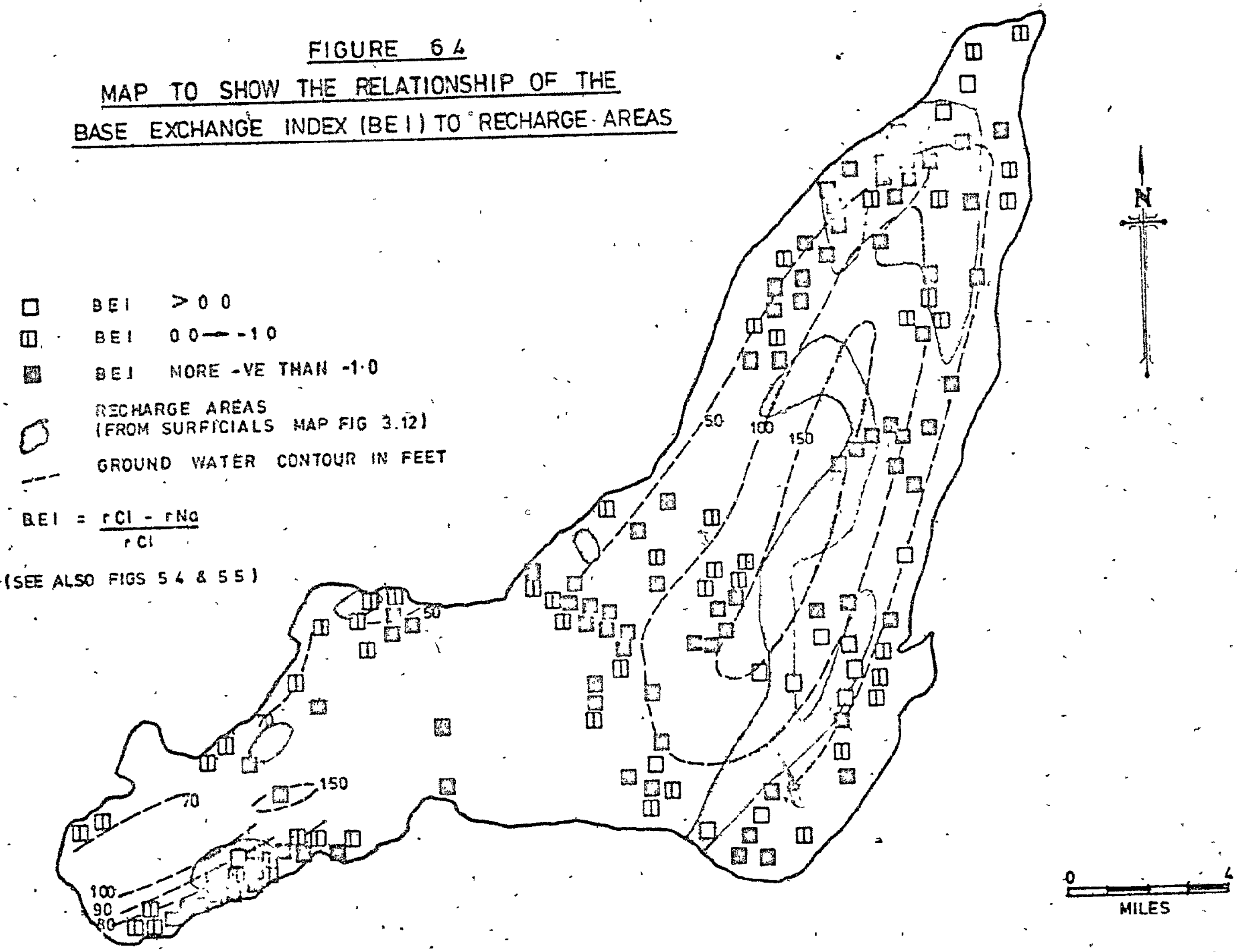
similar, for instance, NaCl in sea water, the principal source, an imbalance can indicate that base exchange (see section 5.4) has occurred, either depleting or augmenting the sodium content.

Most of the analyses considered in this investigation have a negative b.e.i., although 14 samples, or 9%, have a positive b.e.i., ie. rCl > rNa. Of these, two are from clay, one from gravel, one from till, while the rest are from bedrock aquifers. A positive b.e.i. results if there is a relative lack of sodium compared to chloride, so one would expect to find the values of the other two cations comparatively higher, the degree dependent on the amount of exchange, to maintain a balance with the anions present. All bedrock waters with a positive b.e.i., except one magnesium-rich sample, have calcium as the dominant cation. This conforms to Charron's idea (1969) that calcium values tend to be relatively high if a sample has a positive b.e.i. Some Montreal waters with high calcium values do have negative b.e.i., but this is due rather to a lack of chloride rather than a glut of sodium.

A sodium paucity with respect to chloride is almost certain to result from a base exchange phenomenon since both sodium and chloride are extremely soluble, and once these ions are present in solution they tend to remain there. Thus the removal of one without the other is unlikely except by base exchange, in which process sodium may be added or removed from solution, while chloride is unaffected. When a sodium-rich water initially with the Na^+ to Cl^- equivalence encounters a calcium clay, there is exchange of sodium for calcium with the resulting relative altering of concentrations of the cations, and impoverishment of sodium compared to chloride; hence a positive b.e.i. and enhanced calcium value. Similarly a calcium and magnesium-rich water in contact with a marine sodium clay could undergo exchange of calcium and magnesium ions, to increase the sodium content of the water, and produce a negative b.e.i. However the b.e.i. is more strongly negative in areas of recharge, values more negative than - 1.0 represent this, (Fig. 6.4), not necessarily because of high sodium (Fig. 5.4), but due to low values of chloride (Fig. 5.5), since as b.e.i. is indicated by the ratio $\frac{rCl - rNa}{rCl}$ a low chloride or high sodium value causes it to be strongly negative. In topographically high recharge areas of Montreal, rainfall is low in chloride and there are only

FIGURE 6.4

MAP TO SHOW THE RELATIONSHIP OF THE BASE EXCHANGE INDEX (BEI) TO RECHARGE AREAS



low values of chloride derived from local rocks. The distribution of sodium values is shown on Fig 5.4 and average about 3.2 meq/1. The distribution of chloride values is shown on Fig 5.5 and average about 1.4 meq/1. The chloride deficiency is not surprising since limestones are poor in available chlorides (Schoeller, 1959, p.57), and rain in Montreal will be similarly deficient due to its distance from the sea. However the high average concentration of sodium (3.2 meq/1) suggests that a significant amount of sodium has been supplied from igneous rocks, and through tectonic features, such as the White Horse Rapids fault, and the vicinity of the Ahuntsic syncline. Soil analyses might shed further light on this subject. High chloride was found also at the eastern end of the fault.

The b.e.i. results (Fig 6.4) reveal a number of apparently well defined areas of values more negative than -1.0. Some of these areas correlate with areas of known permeable surficial materials and exposed rock, however, it is not clear if the other areas are indicative of unrecognised recharge, or other causes.

6.3.2.3 Saturation with respect to Calcium Carbonate

Another parameter that was assessed was whether the water was saturated in respect of calcium carbonate. A solution is saturated when it is unable to dissolve any further solute. Hoag's method (1975, 1976) provided values of his saturation index, that he defined as sample pH minus the calculated pH of equilibrium (Table C.1, Appendix C).

It was found that at least 10, and possibly up to 22, samples were unsaturated with respect to $CaCO_3$.

Saturation Index

< -0.2	-0.2 to -0.1
3 $Ca(HCO_3)_2$	8 $Ca(HCO_3)_2$
6 $NaHCO_3$	3 $NaHCO_3$
1 $MgSO_4$	1 NaCl

Unsaturation means that the water is still aggressive towards $CaCO_3$, an unusual phenomenon in carbonate terrains, so its occurrence is noteworthy. It is usually indicative of ground water close to recharge, or to ground water which has encountered an area with a high pCO_2, the controlling influence of carbonate solution (see Section 5.7).

The depths from which these unsaturated samples came ranged from 11 feet to 900 feet. Their locations are shown on Fig. 6.3. All except two samples, from a clay aquifer, had the dolomitic ratio of rCa:rMg < 2.0. Even though not all these samples came from known dolomitic horizons, nevertheless the ratio implies that they recently encountered one. The additional magnesium could cause a relative lack of calcium, which in turn could account for the unsaturation of the water with respect to calcium carbonate. The areas of magnesium rich lithology shown on Figure 6.3 do not show the presence of dolomite at depth.

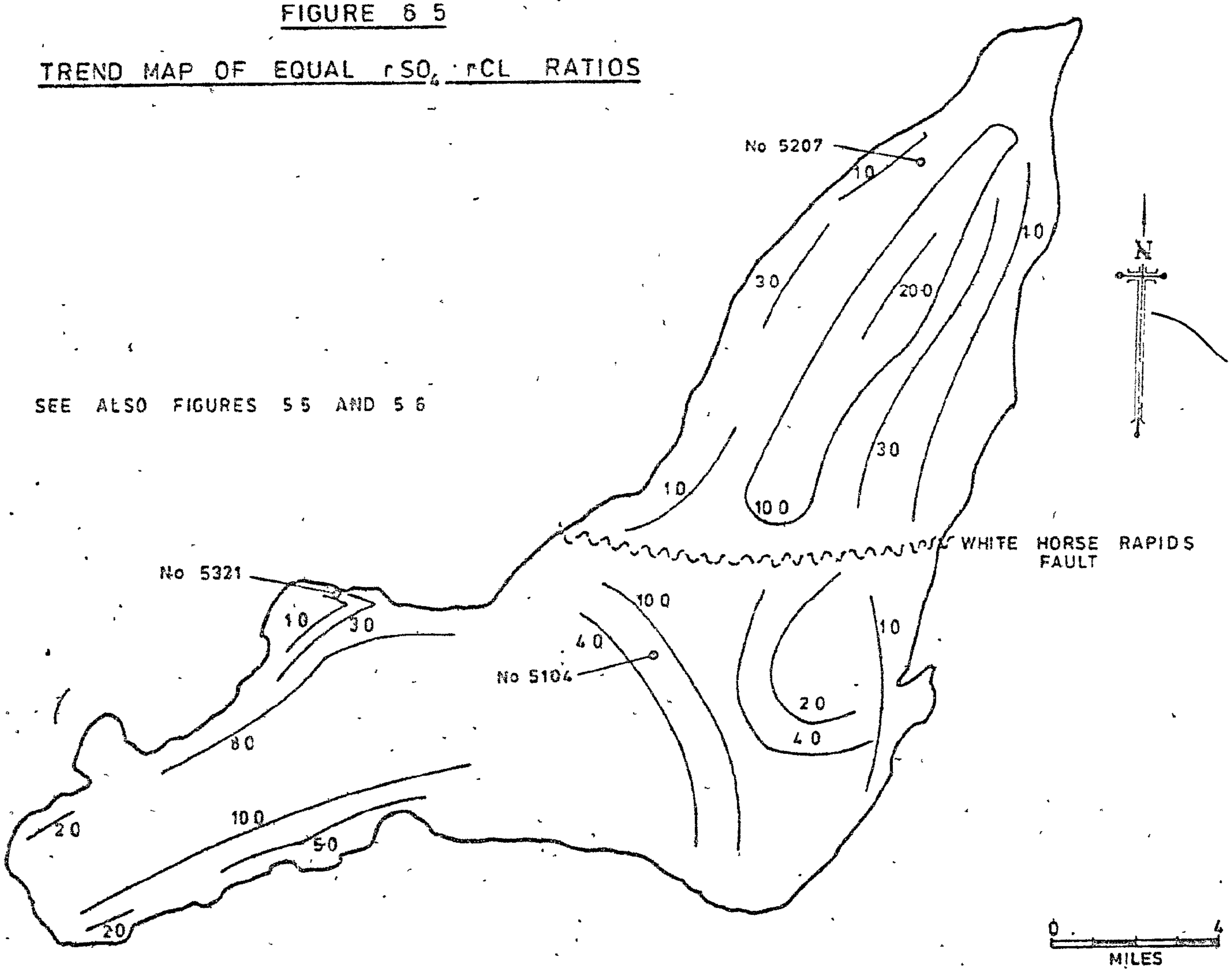
6.3.2.4 Sulphate:Chloride Ratio

The ratio rSO_4:rCl was examined, as it usually decreases down the flow line towards discharge areas where the chloride becomes proportionally more important. The highest value of this ratio is thus found in the probable recharge areas, but due to a low chloride concentration rather than a high sulphate one. Figure 6.5 shows maximum values of the ratio in the central portions of both the west and north of the Island. This

FIGURE 6 5

TREND MAP OF EQUAL rSO$_4$: rCL RATIOS

SEE ALSO FIGURES 5 5 AND 5 6



confirmed recharge in these areas. Also the high values to the west of Mount Royal suggested recharge there too. Locally this generalization may not hold true due to insufficient time for solution to have occurred fully. Chloride values in limestone are naturally low (Schoeller, 1959, p. 57). The highest chloride values are to the north and northeast of Mount Royal, where there are maximum thicknesses of Champlain clay on Utica shale. Elsewhere it can be inferred that the chloride minerals associated with any overlying marine clay do not enter the ground water to any significant extent. This may be because the products of any solution of surficial material which does occur are retained locally by the impermeable nature of the surrounding rock, or because the chloride ion is physically large compared with many of the other major ions in water. In this case it could be expected to be held back in interstitial or pore water in clay and shale while water itself was transmitted (Hem, 1970, p.175).

6.4 Relation of Chemistry to Depth

The rôle played by the depth from which a sample derives, and hence the time available for solution, is considered by comparing chemical groups and the average depth at which each was found. The average depth was computed by summing the full depth of all wells which had the same predominant ion, and dividing the total by the number of wells. Geographical and stratigraphical locations are ignored in this preliminary approach in Table 6.2 in which all lithological groups are assumed to be part of a single hydrogeological unit. The locations are considered in the discussion below.

It can be seen that magnesium and sodium tend to be more dominant in deeper holes than is calcium. This is indicated not only by the data in group III but also in sub-groups I_2 and II_2 since here sodium is the No.2 cation in each case, and the average depth of the sample is greater than when sodium is No.3. However, this does not mean that one will infallibly obtain sodium-rich water at depth, as is shown in the west of the Island where deep wells do not have sodium content because it is not available, ie. there is a geological control (see Section 6.6).

It can be seen on Figures 3.1 and 5.4 that the 6 - 10 meq/l sodium maxima correspond to the Ahuntsic syncline and the White Horse Rapids fault, plus the clay and shale along the river north of this fault. In the first case depth may be predominant in control, while in the second both flows from depth and the marine clay and shale may contribute.

The main magnesium area in the west of the Island (Fig. 5.3) contains a maximum concentration of about 3 meq/l, the same as

CATIONS

		Ca				Mg		Na		
		I_1			I_2	II_1	II_2	III_1	III_2	Mean Depth Anion Group in Feet
		$^1I_1$	$^2I_1$	$^3I_1$						
HCO_3	A_1	$\frac{3898}{38}$ 103	$\frac{1927}{20}$ 96	$\frac{1471}{21}$ 70	$\frac{1005}{6}$ 167	$\frac{878}{10}$ 88	$\frac{917}{2}$ 459	$\frac{2647}{12}$ 221	$\frac{3746}{7}$ 535	142
	A_2	$\frac{407}{1}$ 407	$\frac{750}{1}$ 750		$\frac{200}{1}$ 200			$\frac{264}{2}$ 132	$\frac{392}{4}$ 98	224
SO_4 ANIONS	B_1		$\frac{919}{1}$ 919	$\frac{151}{1}$ 151	$\frac{1386}{3}$ 462	$\frac{200}{1}$ 200	$\frac{50}{1}$ 50	$\frac{600}{1}$ 600	$\frac{370}{2}$ 185	368
	B_2				$\frac{490}{1}$ 490					490
Cl	C_1							$\frac{376}{2}$ 188	$\frac{466}{2}$ 233	210
	C_2							$\frac{325}{1}$ 325	$\frac{107}{1}$ 107	216
MEAN DEPTH OF CATION GROUP IN FEET		110	163	74	280	98	322	234	317	

Dominant ions of each class shown. See Table 6.1 for details

$$\frac{3898}{38} = \frac{\text{Sum of full depth of wells with same predominant ion}}{\text{Number of wells with same predominant ion}}$$

TABLE 6.2

ABUNDANCE OF IONIC SPECIES AND

CORRELATION OF CHEMICAL GROUPS WITH DEPTH on the east shore to the south of the White Horse Rapids fault, on the northwest shore and along the Villeray anticline, but less than the crest or ridge distribution of 7 meq/l to the west of Mount Royal. The loci of these maximum values cannot be correlated more precisely with any other geological features.

Another factor relating to cations is shown with the large I_1A_1 group of 79 wells. There is a steady diminution of depth from 103 feet for dolomitic $^1I_1A_1$ subgroup, to 70 feet in the calcium dominant $^3I_1A_1$ subgroup. This implies that the shallower the well, or the higher in the stratigraphic column from which water is obtained, the lower will be the magnesium content. As such, one can deduce that there is not a strong vertical movement of water upwards from the Beekmantown Group to produce high magnesium values in waters, in the overlying strata. This emphasises the higher horizontal permeability of the bedrock.

Examination of the anions is not as enlightening, since the vast majority are of the A_1 bicarbonate subgroup, and there are insufficient analyses from any of the last three anionic sub-groups to allow acceptable coverage. However, the bicarbonate species are found at shallower levels than the other two anion groups. The A_2 subgroup of nine samples is associated with greater depths than the A_1 subgroup of 101 samples, which is credible since the scarcer, but more soluble, chloride has presumably had a chance to be dissolved in excess of the theoretically more common, but less soluble, sulphate ion. The B_1 sulphate subgroup of 10 samples is found in wells of depth ranging between 50 and 919 feet, averaging 368 feet. It may be noted that bicarbonate has attained a saturation level in 91% of the samples from wells with an average depth 142 feet but the sulphate has not.

To conclude, in Montreal the ground water near the surface is characterised by the two most abundant ions, calcium and bicarbonate. Water from the bedrock aquifers showed saturation in bicarbonate in 91% of the samples. All were undersaturated in sulphate. Although the more soluble sulphate and chloride minerals may be present, their availability is generally low. However, a continuing dissolution of the less available species slowly increases their concentration until they become dominant in 9% of the samples. This is after a sufficient time has elapsed for reaction, usually corresponding with depth. Insufficient data were available to attempt to calculate time of reaction.

The degree of concentration of the water is thus determined, not only by the duration of its contact with the rock and the nature of the rock, but also by the length of trajectory (Schoeller, 1959, p.74). This is shown by considering three wells in this investigation (Fig. 4.4). Well no. 5309 is 60 feet deep and is found at a recharge area adjacent to Mount Royal. It is located near the start of a flow line and the water is of the HCO_3^- type. Well no. 5101 is 200 feet deep and is in the middle portion of the flow line. Its water is of the SO_4^{2-} type. Well no. 5145 is 267 feet deep and is near the edge of the Island at a discharge point. It is at the end of the flow line about 23,000 feet long and its water is of the Cl^- type. The Schoeller diagrams for these three analyses are given in Figure 6.6.

Using Darcy's Law in the form $V = KS$ one can estimate flow time. From Table 3.1 K is taken to be 10^{-2} cm/sec. From Figure 4.4 $S(\frac{dh}{dl})$ is taken to be $\frac{150-40}{23,000}$. Thus $V = 4 \times 10^{-5}$ cm/sec or about 3 cm/day.

This demonstration of flow time and composition along a possible path may be an idealised case but it is believed to be a likely generalization.

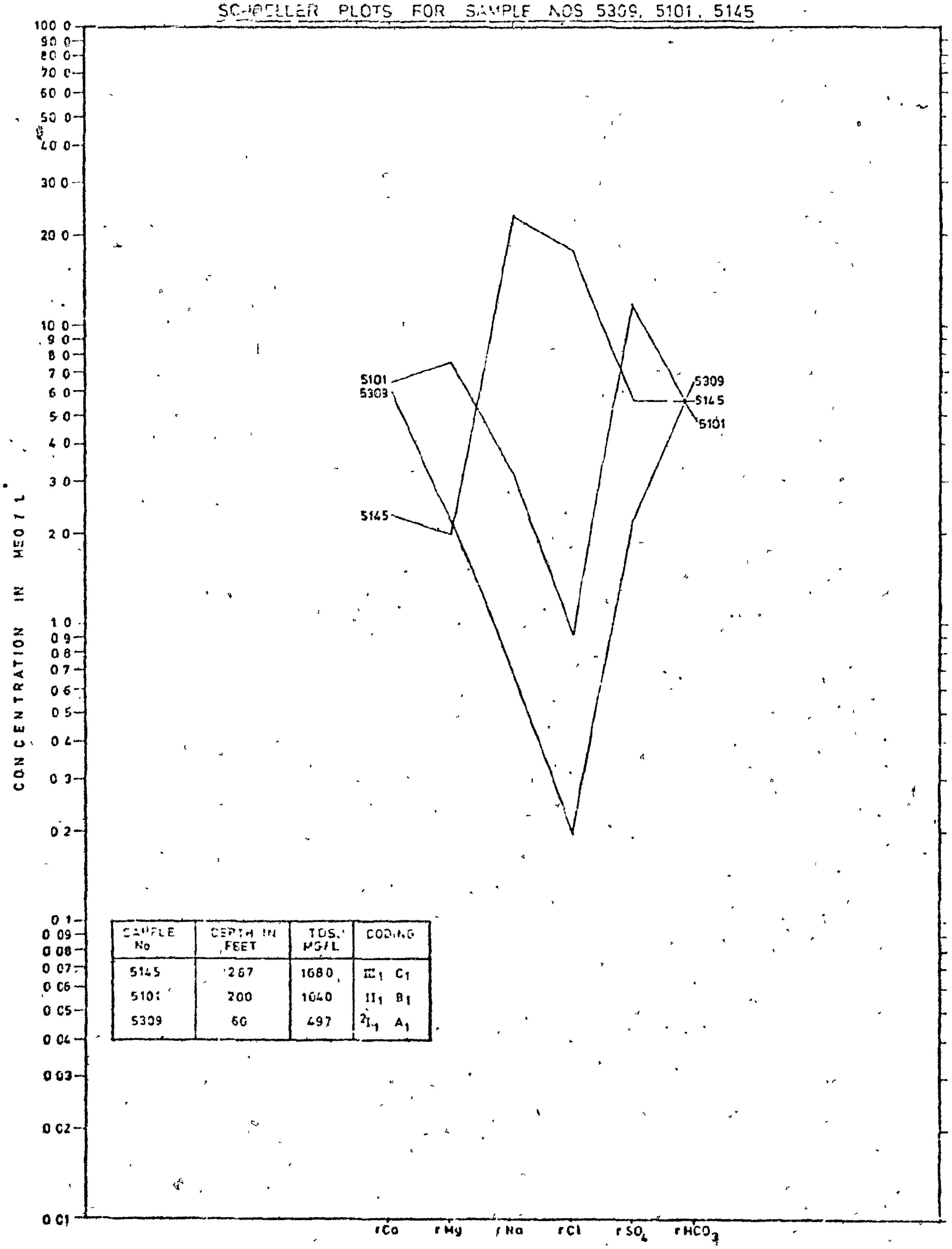
6.5 Ground Water Zonation in Montreal

To study the possibility of hydrogeochemical zonation the Island was divided into three sectors. These western, central and northern sectors each contain different geology. The computer retrieval of the data was printed out in three UTM sectors conforming quite closely to the geological zones (Figure 6.7).

Since zonation is three dimensional the distribution of ions was examined in both horizontal and vertical planes. Only a brief summary of the chemical zonation is given here, but the detail is given in Appendix E, and there is a comprehensive discussion in section 7.3.

FIGURE 6.5

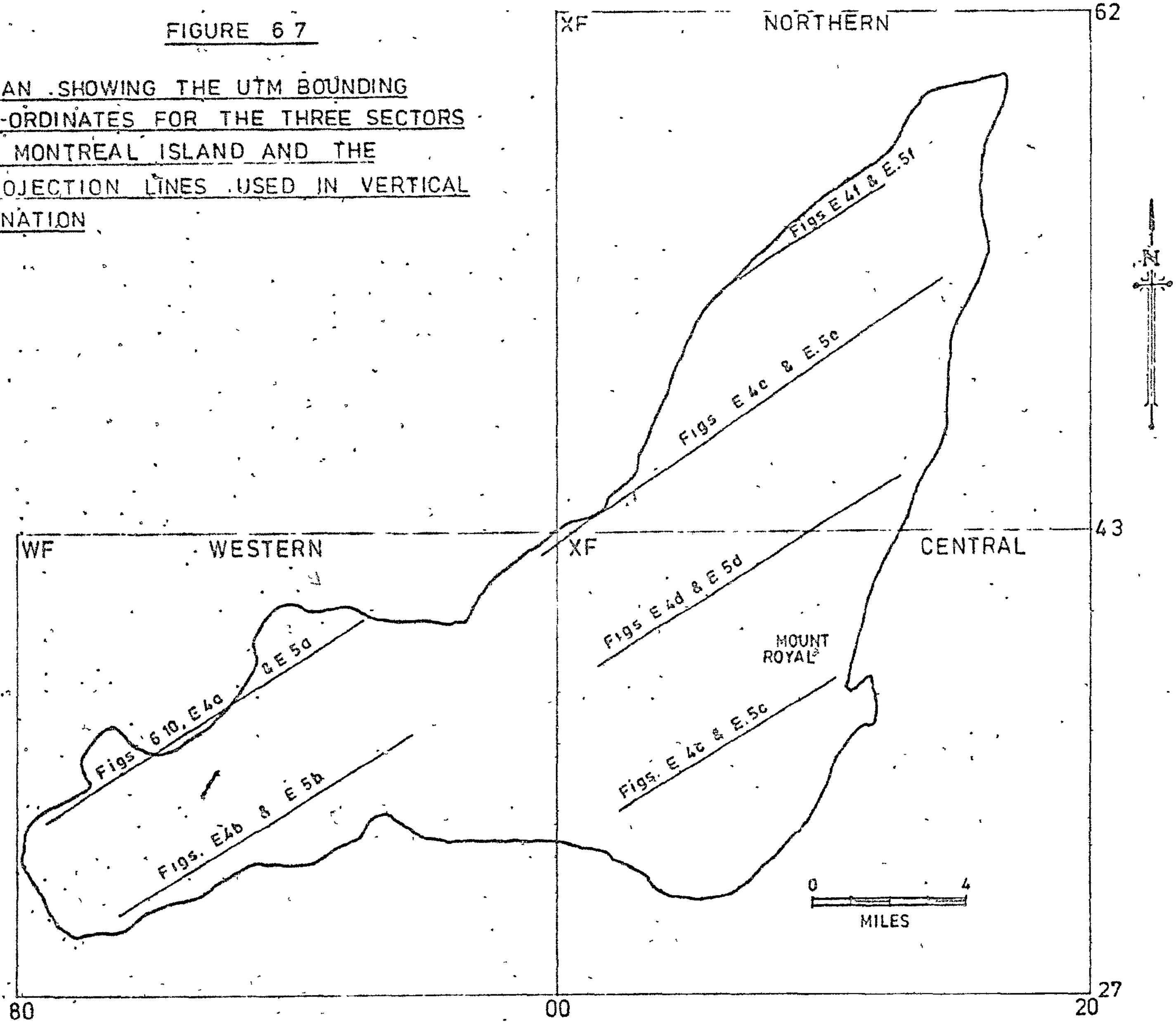
SCHOELLER PLOTS FOR SAMPLE NOS 5309, 5101, 5145



SAMPLE No	DEPTH IN FEET	TDS MG/L	CODING
5145	267	1680	III_1 C_1
5101	200	1040	II_1 B_1
5309	60	497	I_1 A_1

FIGURE 6 7

PLAN SHOWING THE UTM BOUNDING CO-ORDINATES FOR THE THREE SECTORS OF MONTREAL ISLAND AND THE PROJECTION LINES USED IN VERTICAL ZONATION



The overall zonation of the ground water of Montreal is shown on Figures 6.8 and 6.9. Figure 6.8 shows the ubiquity of the bicarbonate ion. It is often associated with sulphate but more usually it is present as the single dominant anion, as in the northern and western sectors.

The main bicarbonate and sulphate, $A_1^{!}$, zone is in the central part of the Island. It is found primarily to the southwest of Mount Royal but it is also represented to the east of the mountain, and also near the south shore in the western sector. The occurrence to the east of the mountain is probably caused by the oxidation of pyrite, while the other occurrences are more likely to result from the solution of sulphate minerals. A high sulphate zone corresponding to the White Horse Rapids fault is shown on Figure 5.6. This could result in part from pyrite oxidation, especially at the eastern end near the Utica shale, but also in part from an upward migration of sulphate-rich water from depth along the fault line. The only other anion group which is noticeable is the sulphate and bicarbonate, $B_1^{!}$, group. This is also found to the east of Mount Royal, and again it is probable that the presence of the sulphide-rich Utica shale is the original source of the sulphate ion. Samples containing chloride to any great extent are lacking, although the few present were found generally adjacent to the White Horse Rapids fault, or to the St. Lawrence River. In the latter case chloride could have been derived from the marine clays.

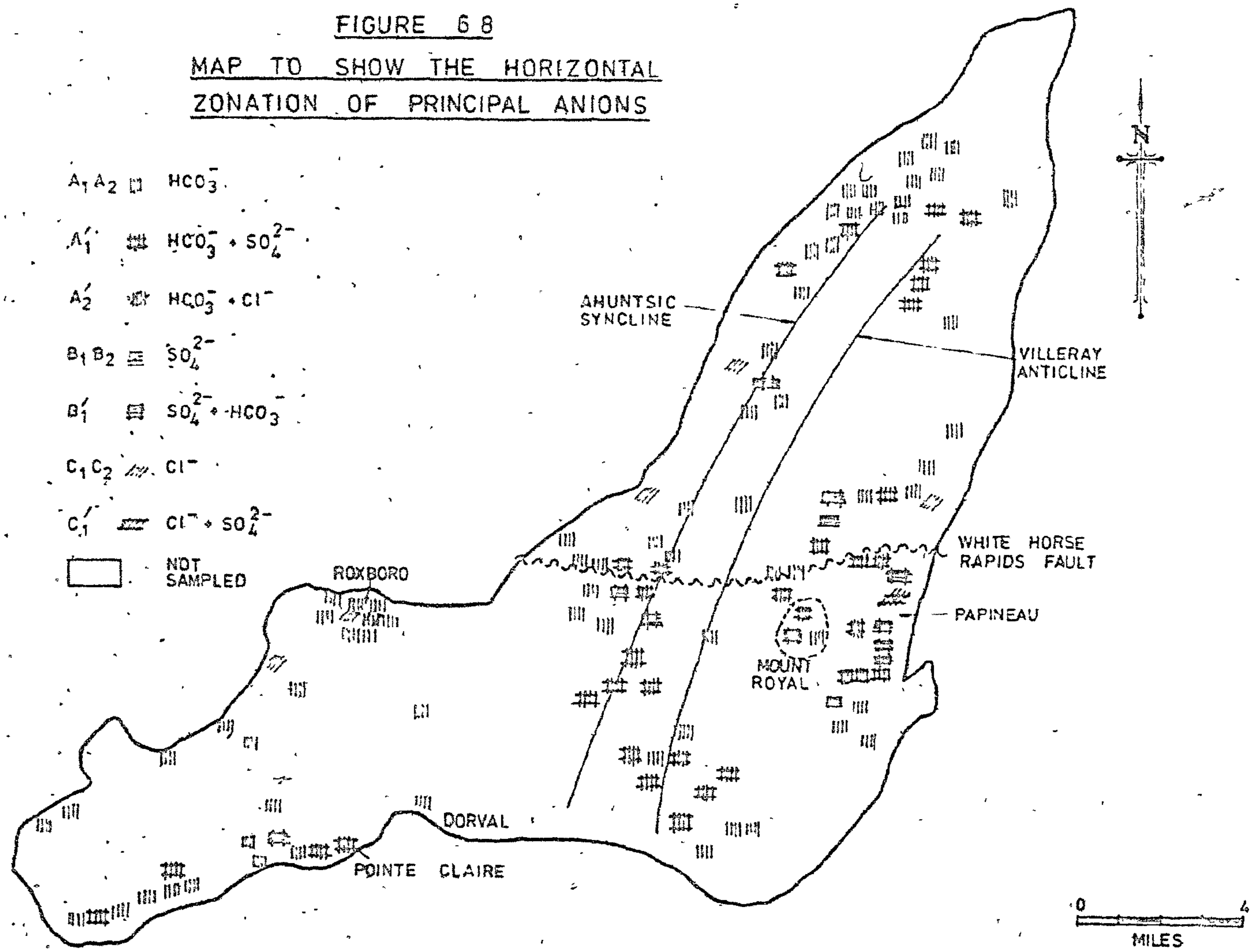


FIGURE 6.8

MAP TO SHOW THE HORIZONTAL ZONATION OF PRINCIPAL ANIONS

FIGURE 6.9

MAP TO SHOW THE HORIZONTAL ZONATION OF PRINCIPAL CATIONS

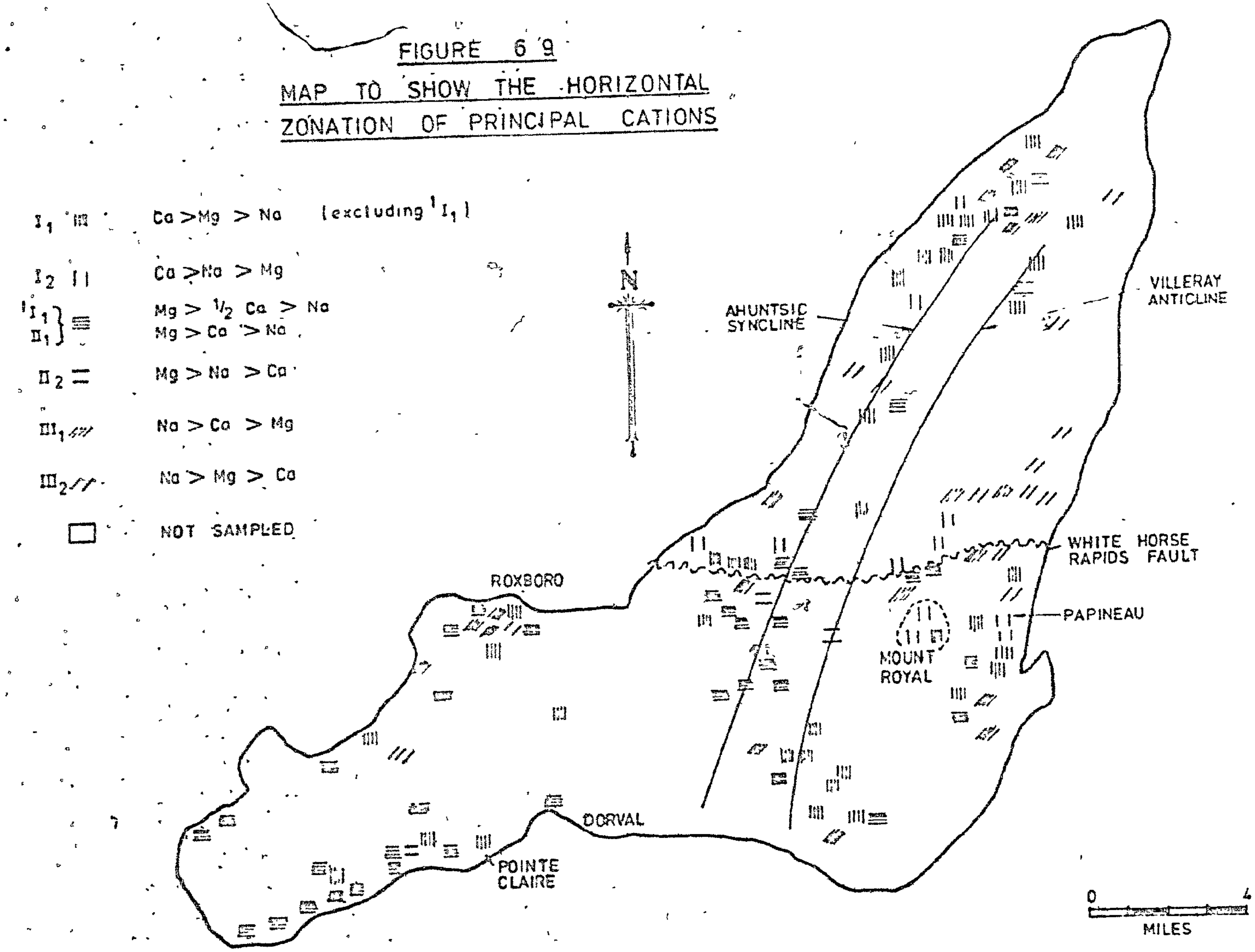


Figure 6.9 shows the horizontal zonation of cations. Here the distribution is ostensibly less dominated by a single cation. However, it should be mentioned that calcium was the most important cation. The figure has been presented to illustrate the significance of magnesium and attention is drawn to the combining of the $^1I_1$ and II_1 groups, and that they are represented by a single symbol.

In the western sector magnesium is the most important cation, and a significant zone is found. There is a close correlation between its presence and that of dolomitic aquifers. The only other important occurrence of magnesium is as a small zone in the central sector to the west of Mount Royal. This zone partially corresponds to the bicarbonate and sulphate zone previously mentioned.

Calcium forms a zone to the southwest of the mountain, where the maximum concentration of 7 meq/l is found (Fig. 5.2), in undifferentiated Trenton limestones. This completes the overlap with the bicarbonate and sulphate zone just referred to. The other zone that calcium forms is in the northwest of the Island, near the axis of the Villeray anticline. There is a noticeable trend of decreasing calcium values to the west of the Island.

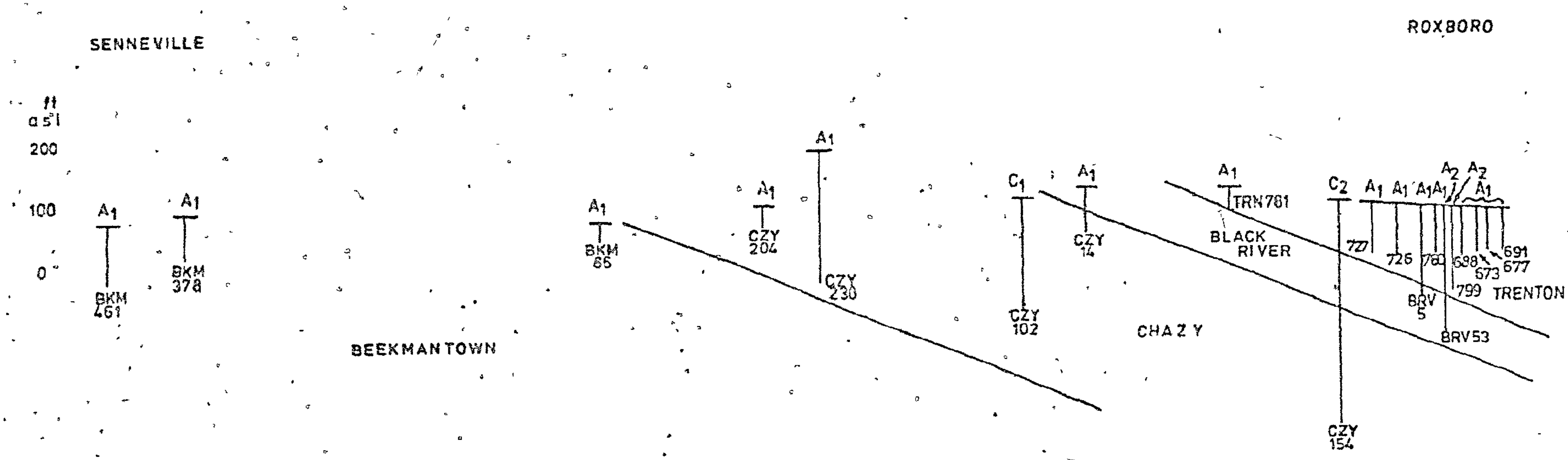
Sodium is found most markedly on the eastern side of the northern and central sectors, probably due to association with intrusives, shales and Champlain Sea clays. Also the White Horse Rapids fault appears to be a significant control. The zone on the northeastern shore corresponds to an area where chloride concentrations were above average. It also forms another zone in the northwest of the Island, somewhat to the east and north of the calcium zone.

To ascertain if there were any zonation vertically, a series of profiles were constructed as in Figures 6.10 and 6.11. This facilitated appraisal of the chemical groups, both as a function of depth and of lithology. The data were, unfortunately, such that it was not possible to deduce discrete contributory horizons. It was decided in the absence of, for example, casing depths, to attribute the chemical type to the horizon reached by the bottom of the well.

The full details are presented in Appendix E but essentially bicarbonate formed the predomiant anion zone and was only infrequently and irregularly interrupted by other groups.

In the cations, correlation of magnesium with dolomitic horizons was found, and also that sodium tended to come from deep wells. Calcium was the dominant cation, and occurred throughout the sequence, cutting across both the controls of depth and lithology.

FIGURE 6.10
SECTION TO SHOW VERTICAL
ZONATION OF PRINCIPAL ANIONS



HORIZONTAL SCALE 1/64,000

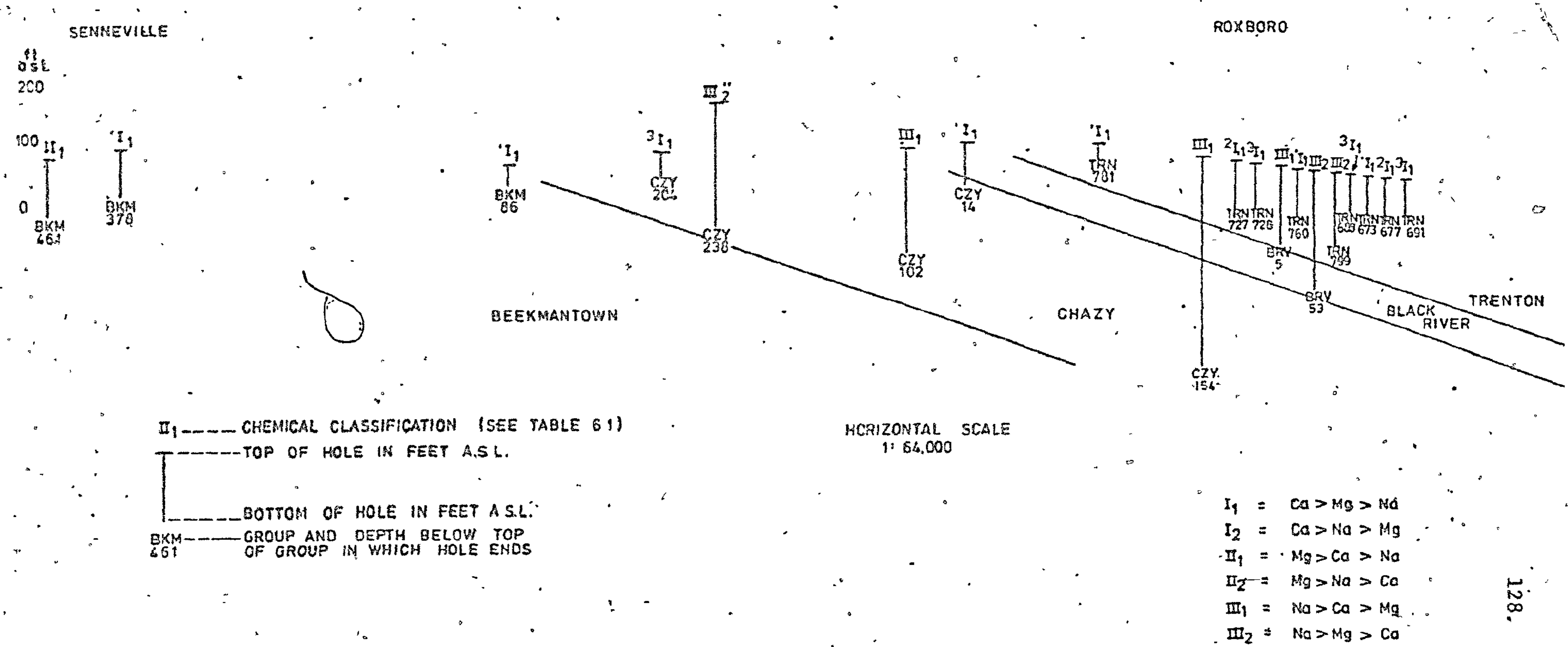
A_1 ---- CHEMICAL CLASSIFICATION (SEE TABLE 6.1)
---- TOP OF HOLE IN FEET A.S.L.
---- BOTTOM OF HOLE IN FEET A.S.L.
BKM 461 ---- GROUP & DEPTH BELOW TOP OF GROUP IN WHICH HOLE ENDS

SEE ALSO APPENDIX E

A_1 & A_2 = HCO_3^-
A_1' = $HCO_3^- + SO_4^{2-}$
A_2' = $HCO_3^- + Cl^-$
B_1 & B_2 = SO_4^{2-}
B_1' = $SO_4^{2-} + HCO_3$
B_2' = $SO_4^{2-} + Cl$
C_1 & C_2 = Cl^-
C_1' = $Cl^- + SO_4^{2-}$
C_2' = $Cl^- + HCO_3^-$

FIGURE 6.11

SECTION TO SHOW VERTICAL ZONATION OF PRINCIPAL CATIONS



6.6 Changes in Chemistry along Flow Lines

The calcium bicarbonate zone is characteristic of limestone water which is close to its source. It suggests that the recharge of Montreal takes place locally, resulting from precipitation in the form of rain and snow. It does not, however, eliminate the possibility of subsurface flow from outside the area contributing to recharge, an idea mooted by Cumming in 1915 to explain the local occurrence of high sodium values.

It is evident that the chemical composition of water in a ground water system is not static but evolves chemically. Firstly there is an increase in the T.D.S. by solution of the available minerals. This solution is greater as trajectory and time of contact are longer, as rate of flow is slower and as rock pores are smaller, ie. as a larger surface area is available for reaction. Generally the ratio of rSO_4 to rCl decreases down the flow line: as the speed at which a salt is dissolved is proportionate to the saturation deficit, chlorides are dissolved faster than alkali earth sulphates. If an aquifer is rich in sulphates, but poor in chlorides, the reverse happens until the water becomes saturated in SO_4^{2-}, after which the ratio declines (Schoeller, 1959, p.73).

Similarly the base exchange index tends to be negative in recharge areas since chloride concentrations tend to be low. The ratio becomes less negative down the flow line as more chloride is dissolved. The ratio rMg:rCa tends to diminish downstream. This is because the increase of calcium by dissolution of $CaCO_3$ declines rapidly, because the water becomes saturated in $CaCO_3$ quickly and subsequently $CaSO_4$ dissolves less rapidly than $MgSO_4$ and $MgCl_2$.

An idea of the flow pattern can in general be obtained by the relative abundance of different species and their relationships to each other, but it is necessary to appreciate that different mechanisms can lead to the same result. For example high sodium values in ground water can result from protracted solution of low concentrations of sodium minerals. Sodium minerals are very soluble and once they have been dissolved sodium ions tend to remain in solution. A relatively long flow line, often synonymous with depth, facilitates this chance for protracted solution. Alternatively high concentrations of sodium may occur naturally, such as in evaporite deposits or associated with igneous rocks. In these cases a short flow line is sufficient to result in high sodium values, as long as the flow line intercepts the sodium-rich environment. Thirdly a base exchange mechanism can occur when calcium or magnesium ions are lost from solution and are replaced in the water by sodium ions from, say, a marine clay or other sodium-rich source.

On the Island of Montreal all three mechanisms are represented. Sample no. 5321 is sodium rich 17.7 meq/1 (Table 6.3) and comes from a well with a depth of 325 feet (Fig 5.4). It is unlikely that any flow line originating on the Island would have had time

TABLE 6.3

CHEMICAL ANALYSES OF SAMPLE NOS. 5321, 5104, 5207 IN MEQ/L

Sample no.	Ca	Mg	Na	Cl	SO_4	HCO_3
5321	2.9	2.4	17.7	14.3	3.9	5.7
5104	2.2	2.9	5.0	1.1	4.7	4.6
5207	2.4	0.6	2.8	0.3	1.3	4.4

to reach the sodium concentration present. The sample is also rich in chloride, another indicator of a long flow line, and its base exchange index is only -0.25 ie. near equality between rNa and rCl. It is likely that water at this depth, here, has come from outside the Island, ie. it is a part of the regional flow, possibly originating in the Laurentians, and moving slowly through the St. Lawrence Lowlands. The water has been 'metamorphosed' into a long flow type water.

Sample no. 5104 is an example of simple solution from a sodium-rich sulphate mineral since the sulphate concentration is quite similar to that of sodium, 4.7 meq/l and 5.0 meq/l respectively (Table 6.3).

Sample no. 5207, probably represents base exchange augmentation of the sodium concentration of ground water. The base exchange index is strongly negative, -5.00, an excess of sodium over chloride. Only 15% of the samples are more negative than this. Sodium is the dominant cation with 2.8 meq/l, but calcium has 2.4 meq/l (Table 6.3). This suggests that a calcium-rich water has encountered a sodium clay. Adsorption of the divalent calcium ions (preferred to monovalent ones due to the higher charge) has occurred on to the clay, releasing the monovalent sodium ions into the ground water where they tend to remain. The sample was taken from a well only 58 feet deep which is too shallow for a sodium dominant water to occur from prolonged solution, unless the area is the discharge zone of a deep system.

Simple solution from a high sodium content source is not to be entertained because one would expect a similar meq/l value for the anion of the mineral.

CHAPTER 7 SUMMARY AND CONCLUSIONS

7.1 Introduction

The investigation has sought to delineate the chemical facies and zones of the ground water of Montreal Island, chiefly by the study of the chemical analyses of well waters. This knowledge has in turn permitted some understanding of the ground water flow pattern.

7.1.1. Ground Water Flow System

A simple ground water flow pattern has been derived from observations of water levels in wells, although the contributions from various aquifers could not be distinguished. The pattern consists of two more or less radial flows towards the boundaries of the Island, from Mount Royal, the major topographic high, and from a secondary area of high ground in the western part of the Island (Figs. 2.2 and 4.4).

7.1.2 Recharge

Recharge on the Island has been calculated to be in the order of 37 million gallons per day, by considering the area of outcrop and likely values of permeability of the different lithostratigraphical formations.

7.1.3 Discharge

Equilibrium of the system is achieved by pumpage from wells and by apparent discharge into the St. Lawrence River and Rivière des Prairies, which bound the Island. There is no official monitoring of the abstractions of private wells, so that no total is available. However, it appears that there has been a considerable decline in the use of ground water from the seven million gallons per day reported by Cumming in 1915, so that it is expected that most of the 37 mgd recharge is lost by subsurface flow from the Island.

7.2. General Properties of the Wells and Waters

7.2.1 Artesian and Sub-Artesian Wells

Although Cumming's report of 1915 was entitled 'The Artesian Wells of Montreal', he found only 12 flowing wells. It is not clear how many of the wells were sub-artesian, with their static levels controlled by the potentials intercepted at depth - potential greater than those in some of the aquifers at higher elevations. In contrast, Pollitt's data collected in 1951-53 contained no report of flowing wells.

7.2.2 Temperature of Ground Water

The temperature of well waters examined by Cumming varied between 48 and 52 degrees Fahrenheit. He deduced that as the mean temperature of Montreal is 41.5 degrees Fahrenheit that the waters were generally from depths between 300 and 500 feet. Temperatures of the waters from Pollitt's study were not recorded.

7.2.3 pH

The variation of pH in the underground waters as measured in the laboratory is from 6.8 to 8.7. The distribution on Figure 5.1 is difficult to interpret as while there is a trend from 8.0 in the central recharge area of the northern part of the Island, to 7.4 peripheral to this centre, a possible hypothesis of a lowering of pH towards discharge areas, results in some unexpected directional trends in the western part of the Island.

7.3 Hydrogeochemistry

The total dissolved solid content of the ground water of Montreal Island ranges from 161 mg/l to 2290 mg/l with an average, for bedrock aquifers, of 576 mg/l, and for surficial aquifers 550 mg/l. The waters are dilute solutions with a maximum calculated ionic strength of 4.597×10^{-2}, within the range of validity of permitting application of the law of mass action.

7.3.1 Depth and Dissolved Solids

The samples in this study were obtained from wells less than 919 feet deep, in which there is only a general relationship between depth and the total dissolved solids content (T.D.S.). The water from the 25 wells with depths greater than 300 feet were found to have contents averaging 718 mg/l, while the water from the 119 shallower wells averaged 553 mg/l. Furthermore, the data do not indicate from which aquifers individual components of a well water originated.

The ranges and averages of concentrations of the common ions are given in Table 5.4 in which it can be seen that the calcium and bicarbonate ions are dominant.

7.3.2 Chemical Zonation

The principal ground water facies is calcium bicarbonate, in contrast to Cumming's findings, confirmed in this study, for a smaller area of the Island, which was characterised by a preponderance of sodium carbonate (Cumming, 1915, p.5). There is a minor zone in the west of the Island, associated with the Beekmantown Dolomite group, where magnesium is the most significant cation, while a sodium rich zone is found in the north east.

Sub-zones have been defined by examination of the concentrations of the sulphate and chloride anions, and the calcium, magnesium, and sodium cations, against the ubiquitous background of bicarbonate. The analytical results have been plotted on Schoeller diagrams (Figs. 6.1 a,b,c and 6.2 a,b,c), that permit ready comparison of the relative abundance of individual ions and the recognition of the various facies (Table 6.1). The areal distribution of individual ions have been plotted and contoured. The contouring has been unavoidably subjective, influenced by tentative correlations of facies with geological features. The facies or classified types of ground water have been plotted, well by well, on sets of profiles that also show the stratigraphical units across the Island. As already intimated, the value of such profiles is preliminary where wells intercept several aquifers, and the nature of the individual waters is concealed by mixing. Nevertheless the classification in Table 6.1 probably provides a reasonable indication of characteristics of the waters from shallow aquifers, while apparent classes of waters from deep holes are mixtures of unknown proportions.

7.4 Interpretation of Areal Distribution and Sources of Ions

The first part of the interpretation has consisted of the identification and understanding of the general geochemical processes, and of the possible sources from where the various ions were introduced into the ground waters.

The bicarbonate ion is ubiquitous with a minimum value equal to the average of the second most common anion, sulphate, and so the bicarbonate ion concentrations do not assist much in the delineation of the system. Sulphate concentrations are localised and result from either the solution of sulphate minerals or the oxidation of sulphide to sulphate. It is not unusual for Mg SO_4 to be found in limestones. Since both high magnesium and high sulphate concentrations are found in the same area it is possible that they result from solution of $MgSO_4$. The first process can be recognised in restricted areas eg. to the west of Mount Royal, where above-average sulphate values are associated with higher magnesium values. To the east of the mountain there is a slightly ragged zone with higher sulphate, that may indicate oxidation of disseminated sulphides known to be present as pyrite in Trenton formations. No determinations of iron were available.

Bicarbonate and sulphate, A_1', zones are found near the mountain. They result from the localised sulphate concentrations, just discussed, superimposed on the general bicarbonate background. The distribution of sulphate concentration shown on Fig 5.6, appears to be influenced by the White Horse Rapids fault, which could allow upward migration of comparatively sulphate-rich water from depth. Other isolated occurrences of the bi-carbonate and sulphate, A_1', group probably result from local solution of sulphate minerals.

Solution and the length and time of travel paths are functions affecting the chloride content. The limited data of the study did show that the chloride dominant water was found generally in the deeper wells, averaging 212 feet in depth. The highest values originated adjacent to the White Horse Rapids fault (Fig. 5.5), and in a three mile wide strip adjacent to the St. Lawrence River. In these cases, the chloride would have been acquired anywhere along the path and so is not specific to particular horizons. However in the last example, adjacent to the St. Lawrence River, chloride could have been derived from the marine clays, although their present chloride content is not known.

The cation distribution shows greater variety than the anions, and so may have a greater diagnostic value, even though calcium is by far the most dominant cation. Maximum calcium values of 140 mg/l (7 meq/l) were found in undifferentiated Trenton limestones on the axis of the Villeray anticline, near the northern tip of the Island, and to the south of the White Horse Rapids fault in the centre of the Island, and along the contact with the Utica shale (Fig. 5.2). This propinquity of the shale contact is perhaps fortuitous, as to the north of the Rapids fault; minimum calcium values were found near the shale boundary, as well as along the axis of the Ahuntsic syncline. There is also a pronounced decreasing trend in calcium values from the maximun values in the centre, towards the west tip of the Island in the direction moving updip of the Beekmantown Dolomite. To summarise, the higher calcium values were found in limestone areas often associated with gentle folding or faulting.

The higher concentrations of magnesium (Fig. 5.3) appeared to be associated with magnesium-rich lithologies, both dolomite to the west of the Island, and in limestones to the west and the east of Mount Royal, where there is a maximum of dykes and sills. The high along the axis of the Villeray anticline, also a high for calcium, may indicate the effect of geology at depth.

The sodium occurrence (Fig. 5.4) is concentrated in the northern half of the Island on both sides of the White Horse Rapids fault, which appears to be a significant control. Other concentrations were found along the Villeray anticline axis further to the north from the fault, and in the northeastern shore belt where chloride concentrations were also above average (Fig. 5.5). The major source of sodium is presumably sodic feldspar of the Monteregian intrusives, whilst there may be some contribution from the Champlain marine clays, for which no local chemical analyses were available, and perhaps from the shales.

The areal classification of Cumming (1915, p.8-9) applied to wells within the limits of the City of Montreal at the time of his report, and which were deeper in average than the wells of the early 1950s. There were 151 operating wells deeper than 300 feet in 1915, and 25 in 1951. Therefore it is not surprising that the dominant facies of his study was sodium carbonate, rather than calcium bicarbonate of the present study. Both studies noted the importance of local lithology, the carbonate sedimentary rocks and the igneous intrusions, whilst with the benefit of Clark's mapping (1952 and 1972), above average concentrations of several ions can be tentatively correlated with the possibly higher than normal permeabilities of the White Horse Rapids fault and the Villeray anticline.

7.5 Changes in Ground Water Chemistry along Flow Lines

A simple example of the metamorphism of ground water (Chebotarev, 1955) was demonstrated by the selection of analyses from three wells on a line trending northwest from Mount Royal to the Rivière des Prairies (Fig. 4.4). The waters were found to be bicarbonate, sulphate, and chloride respectively in the direction of flow. However a fuller examination of results shows a more complex picture particularly when the facies profile diagrams were examined.

The minimum concentrations of sulphate and chloride ions were found in the southern part of the Island (Figs. 5.5 and 5.6), with the maximum concentrations close to the eastern part of the White Horse Rapids fault. This suggested discharge up the fault zone as well as general ground water flow towards the north. The distribution of sulphate/chloride ratios (Fig. 6.5), with maximum values in both the centre portions in the west and north of the Island, confirmed recharge in these areas, and the high values in the central part several miles to the west of Mount Royal suggested recharge there too.

The base exchange index quantifying the relationship between sodium and chloride was found to be negative in all but a few isolated localities (Fig. 6.4). Values more negative than -1.0, considered to be especially indicative of recharge, were widely scattered possibly suggesting that areas of recharge were more extensive than deduced from generalised data on surficial deposits due to variations in rock lithologies.

The ratio of calcium and magnesium equivalents in the west appears to be controlled lithologically thereby obscuring indication of ground water flow directions. However, in the north and centre some areas of low values, indicative of magnesium contact of the waters, suggests upward water flow along fold and fault zones. The locations of 10 samples unsaturated in $CaCO_3$, appear to correspond to calcium-magnesium equivalent ratios below 2.0, the limiting criterion selected as for dolomitic sources.

It was thought that the distribution of ground water facies plotted on the sections (Fig. 6.10) would demonstrate flow zones, and possibly the metamorphism sequence of Chebatorev, 1955, but this has not been the case generally, probably due to the non-selective samples in individual wells. Nevertheless, some confirmation has been noted. Water from wells less than 100 feet deep was found usually to be bicarbonate, regardless of geographical location. This is indicative of local recharge and short flow paths. The deepest wells, those of over 500 feet depth, produced sulphate dominant waters in the area to the east of Mount Royal, and in a restricted area five miles to the north of the mountain. However sulphate was found as the second anion in water from wells of many depths, and at many widespread locations, thereby its presence fails to provide clearcut evidence for an evolution of facies. Chloride dominant waters were encountered in medium depth (212 feet) wells, generally away from the principal recharge areas, but the occurrences were so scattered, and since there was the possibility of the marine clay as a source, a progressive evolution was again not proven.

The distribution of cations on the profiles do show very definitely a general trend from magnesium dominant to sodium dominant waters, a trend which results from lithological control.

7.6 Conclusions

The water level data indicated that the ground water flow of the Island is radially outwards from its two topographically high areas (Fig 4.4). The most important of these is in the central and northern part, associated with Mount Royal.

The ground water of Montreal has a variety of chemical compositions, and chemical trends emerged to confirm the flow patterns deduced from hydraulic evidence (Section 6.4). The chemical trends were not as clear as they might have been which was possibly due to the limited area of the study, preventing sufficient development of distinct patterns. There might also have been a masking of minor chemical changes by the widespread occurrence of calcium bicarbonate. This was found in 63% of the samples. This correlates with the Palaeozoic limestones found extensively on the Island. Two other minor hydrochemical zones are superimposed on the main calcium bicarbonate one. One is magnesium-rich, in the west of the Island, and is asociated with the Beekmantown Dolomite. The other is sodium-rich and occurs east and north of Mount Royal. It appears to be associated with this, and minor intrusions, rather than Quaternary marine clays. Bicarbonate is by far the most important anion, whilst sulphate and chloride achieve significant concentrations locally.

Essentially therefore a single ground water system is present within the limestones of the Island. The variations that occur are mainly due to secondary modifications of the original composition eg. by base exchange or the occasional minor mixing with other ground water systems, such as that associated with the igneous areas, or from outside the Island.

7.7 The Future

More precise interpretation will require sampling from specific horizons within wells. This would permit and justify more comprehensive chemical analysis, and calculation of degrees of saturation of salts in addition to calcium bicarbonate. Only then could the ground water and hydrogeological structure of Montreal Island be utilised in optimum fashion. There might be selective use of either the predominant calcium bicarbonate water, or the localised sodium and magnesium sulphate and bicarbonate waters for drinking, processing and cooling. Also unusable aquifers might be satisfactory for the safe disposal of unwanted liquids.

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Report 2

APPENDIX A . DATA HANDLING

The data used in this investigation were those compiled by Pollitt in 1951-3. As previously mentioned, the data comprised of two types, chemical and lithological. The chemical information was very reliable judging by the close meq/l balance obtained by comparing the concentration of the cations with that of the anions. Where the balance was poorer than 10%, the analyses were not used. No field water temperature or pH values were recorded. The lithological data, however, was less comprehensive. The type of rock from which the water came was given, but in most cases this was simply 'limestone', without any indication of which limestone formation it was. Similarly the depth from which each sample was obtained was omitted. This in turn prevented any specific lithological horizon from being associated with any specific chemical analysis. The total depth of each hole was, however, available and thus, in order to obtain some correlation of geology with chemistry it was assumed that, lacking information about depths of casing, there was ground water contribution from the whole depth of the hole. In fissured rocks such as limestones, water in a borehole is usually derived from several fissures or fissure zones, each of which can contribute different proportions of the total flow as the head of water fluctuates.

It was not feasible to make special chemical analyses of the local rocks, and no typical analyses can be presented. Data were processed by means of two programmes UPDATE and PLAN, developed by the Department of Geological Sciences and run on the McGill IBM 360/75 computer. Major information for each well was recorded on a Master form (Table A.1), (Grice, 1971). Coding of nomenclature eg. TRV = Tetreauville, was based on the methods outlined by Robinson in 1966. Chemical analyses of water samples from wells were recorded on the Water Quality Form (Table A.2). This is basically the same as that used by the Quebec Government, in an attempt to achieve some measure of standardisation, but it has been modified slightly in order to dovetail with the existing departmental programme procedures.

The data were punched on to cards and stored on tape using the UPDATE programme. The input card decks were arranged in a sandwich, with each punched card of Master Form data for each hole followed by all the Water Quality data cards for that hole, in turn followed by the Master Form and Water Quality cards for the next hole (Fig. A.1).

UPDATE stored the data in a geographical sequence, starting at the west of the Island, and enabled individual card records to be added, replaced, deleted or changed without having to resubmit entire card decks.

The retrieval programme, PLAN, provides a map of the location of wells in any specified area (Appendix E). The PLAN request consists of five cards (Fig. A.2). The first two are used for the title. The third is used for project location and

TABLE A.1

MASTER FORM (Form No. 1) Revised Oct. 1970

PROJECT NAME ______ Form filled by ______ Date ______

CARD NO. [ ][ ] (1 2) — HOLE OR LOCATION NO. [ ][ ][ ][ ] (3 4 5 6) — PROJECT NO. [ ][ ] (7 8)

Enter 01 for 1st card, then 21, 41, ... A1, ...M1 for continuation cards

Location may be start point of a traverse, whose orientation is given in columns 29-33.

If depth is greater than 99 feet, enter '1', '2', etc. in column 79. Start new form for each 'hundred'.

LOCATION by UTM GRID — LETTER INDEX [ ][ ] (9 10) — EASTING [ ][ ][ ][ ][ ][ ] (11 12 13 14 15 16) — NORTHING [ ][ ][ ][ ][ ][ ] (17 18 19 20 21 22)

HOLE TRAVERSE DATA — ELEVATION [ ][ ][ ][ ][ ].[ ] (23 24 25 26 27 28)

Enter 'X' in column 23 if elevation is approximate

DIP — INCLINATION [ ][ ] (29 30) — AZIMUTH [ ][ ][ ] (31 32 33)

DATE — MONTH [ ][ ] (34 35) — DECADE [ ] (36) — YEAR [ ] (37)

HOLE SIZE eg. AX or TRAVERSE WIDTH [ ][ ] (FT) (38 39) — enter 1/2 traverse width

STRATIGRAPHICAL NAME OF TOP ROCK OR SOIL UNIT [ ][ ][ ] (40 41 42)

LITHOLOGICAL OR STRAT UNIT [ ][ ] (43 44) — DEPTH OR DISTANCE TO TOP OR START OF UNIT (FEET) [ ][ ].[ ] (45 46 47)

ROCK UNIT [ ][ ] (48 49) — DEPTH OR DISTANCE (FEET) [ ][ ].[ ] (50 51 52)

ROCK UNIT [ ][ ] (53 54) — DEPTH OR DISTANCE (FEET) [ ][ ].[ ] (55 56 57)

ROCK UNIT [ ][ ] (58 59) — DEPTH OR DISTANCE (FEET) [ ][ ].[ ] (60 61 62)

TOTAL LENGTH OF HOLE OR TRAVERSE (FEET) [ ][ ][ ].[ ] (63 64 65 66)

Enter length on final form only if continuations are used.

DEPTH TO WATER TABLE (FEET) see below [ ][ ][ ] (67 68 69) — equilibrium after completion of hole

DRILLING WATER LOSSES

DEPTH (FEET) [ ][ ] (70 71) — LOSS [ ]0% (72) — DEPTH (FEET) [ ][ ] (73 74) — LOSS [ ]0% (75) — DEPTH (FEET) [ ][ ] (76 77) — LOSS [ ]0% (78)

If water loss is partial & % not known, enter '5', if loss is complete, enter '9'.

[ ] (79) If depth is greater than 99 feet, enter '1', '2', etc. in column 79

Additional detailed data may be recorded on the following –

Drilling operations	Form No. 16A
Water level observations	Form No. 15
Lithology	Form No. 38

Engineering Geology
Department of Geological Sciences
McGill University, Montreal

Form 22 parts 1&2 — TABLE A.2 — June 1971

WATER QUALITY

PROJECT NAME — PROJECT NO — HOLE NO

CARD No [1 | 2] ANALYST [3 | 4 | 5 | 6] [7 | 8 | 9]

NAME of AQUIFER or SOURCE [10 | 11 | 12] DATE OF SAMPLING [DAY 13 | 14 | MTH 15 | 16 | YR 17 | 18]

PART 1		PART 2		
FOR THIS PART OF THE FORM PUT BA - BF, B2 - BØ IN COLUMNS 1-2 ABOVE		FOR THIS PART OF THE FORM PUT CA - CF, C2 - CØ IN COLUMNS 1-2 ABOVE		
Depth of sample	19 20 21 22		19 20 21 / 22	
No aménagement	23	Couleur	23 24 25 / 26	
Depth of aquifer	24 25 26 27	R secs	27 28 29 / 30	Dry residue
Mode échantillonnage	28	SiO_2	31 32 33 / 34	
Code unité	29	Alcal	35 36 37 / 38	$CaCO_3$ (MgO)
pH	30 31 32 33 34	NO_3	39 40 41 / 42	
Fe	35 36 37 / 38	Mn	43 44 45 / 46	
Dureté totale	39 40 41 / 42	F	47 48 49 / 50	
" non perm	43 44 45 / 46	B	51 52 53 / 54	
Ca	47 48 49 / 50	Field K	55 56 57 / 58	(µmhos/cm)
Mg	51 52 53 / 54	Total solids	59 60 61 / 62	
Na	55 56 57 / 58	C granulo	63	
K	59 60 61 / 62	D90	64 65 66 / 67	Granulometric analysis
HCO_3	63 64 65 / 66	Temp °C	68 69 70 71	
CO_3	67 68 69 / 70	K (µ mhos / cm)	72 73 / 74	
SO_4	71 72 73 / 74	Storage	75 76 / 77	days
Cl	75 76 77 / 78		78 79 80	
	79 80			

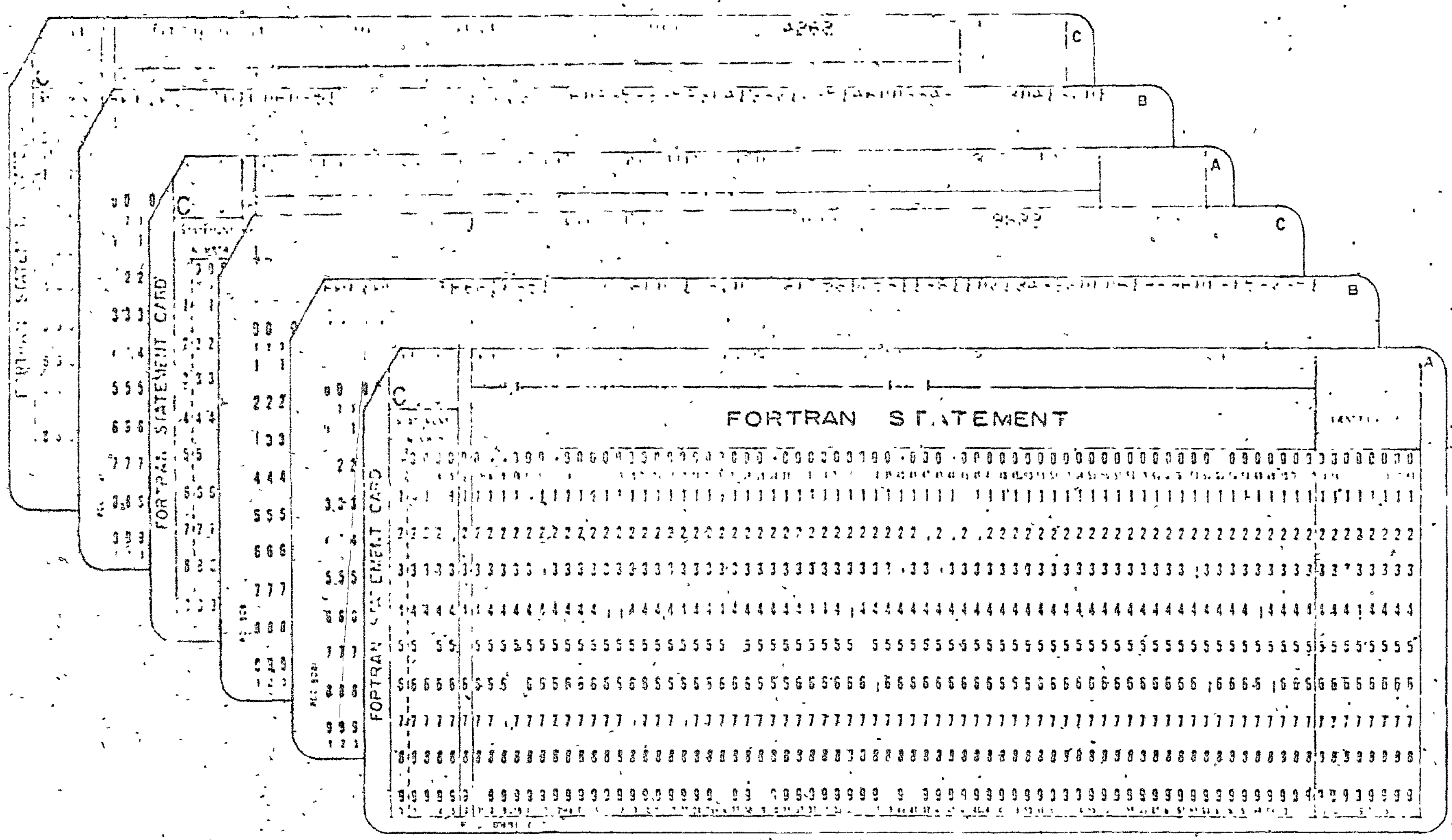
Mode échantillonnage — échantillonneur (1) clapet (2) seau (3) pompe (4) autre (9) inconnu (0)

Code unité — (0) en 1/100 de millième d'epm excepté • en 1/100 de ppm

(1) en 1/100 de ppm

FIGURE A 1

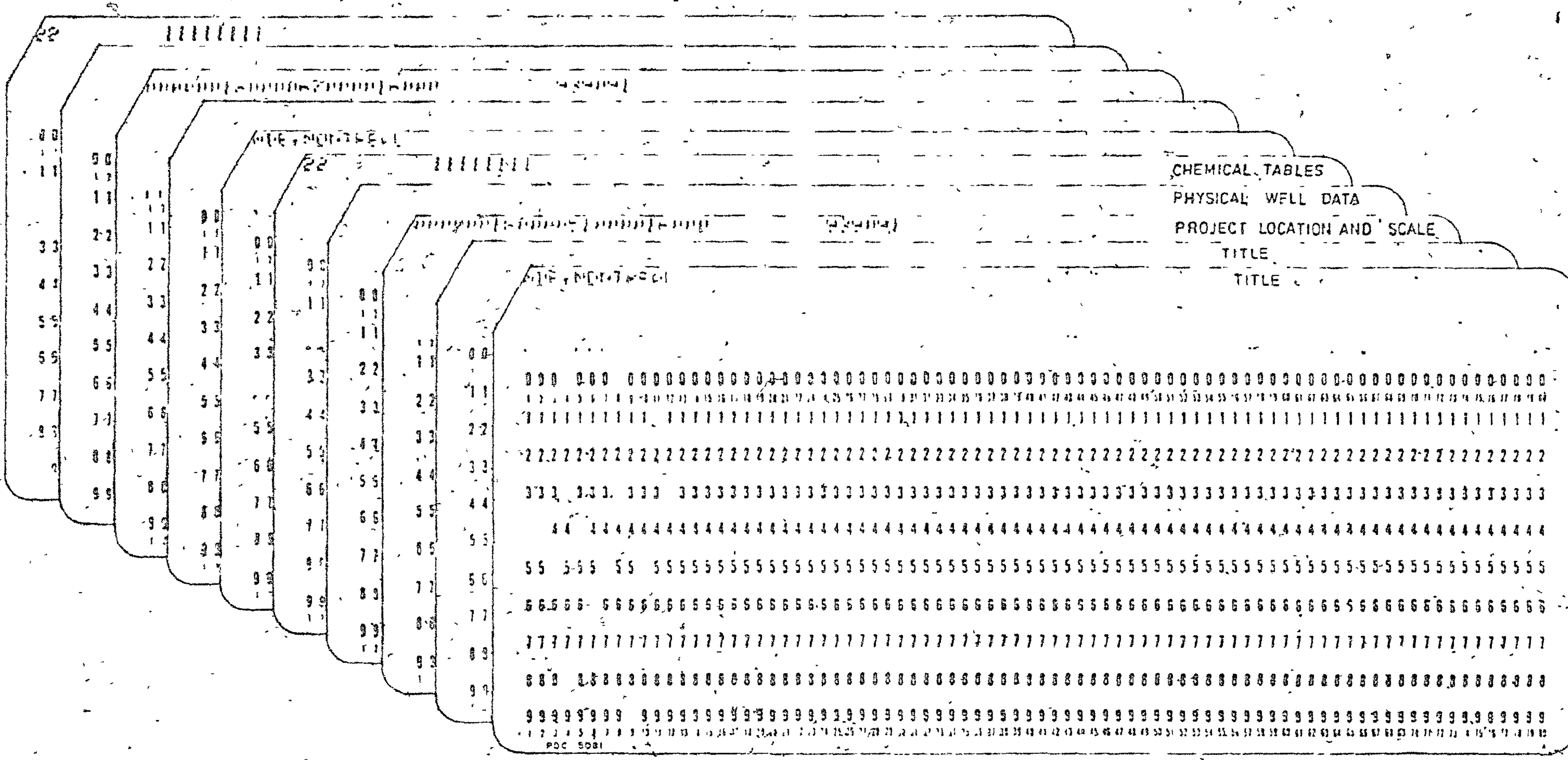
UPDATE REQUEST CARD DECK



A = MASTER FORM DATA CARD
B = WATER QUALITY DATA CARD
C = WATER QUALITY DATA CONTINUATION CARD

FIGURE A 2

PLAN REQUEST CARD DECK



scale, by stating the northerly and southerly bounding UTM co-ordinates of the plan and the northing of the centre line of the PLAN. The fourth specifies the required physical well characteristics to be printed out below the asterisk representing the well site, and includes elevation of ground surface; depth of hole, lithological codings and elevations, and water table elevation. The fifth card is used to specify the type of chemical data to be printed in table form. This card also is used if the calculated chemical data is required to be punched directly onto cards for use in the RAX system. The seven available tables deal with general well data, primary chemical data (eg. concentrations in mg/l) and calculated chemical data such as the meq/l totals for the cations and anions, the meq/l balance, meq/l ratios between specific ions and the percentage of each cation or anion of the respective meq/l total (Appendix E). Any combination of tables can be requested.

PLAN was used most extensively, because with convenient 'dummy' well sites representing easily recognisable points on both the periphery and within the Island, selected data eg. water levels, ionic contents, could be plotted quickly and accurately on maps of any desired scale. The 'located' data were then contoured by hand in order to produce iso-ionic maps such as Figures 5.3, 5.4 etc. These were redrawn for incorporation in this thesis.

APPENDIX B - CALCULATION OF THE TOTAL ANNUAL RECHARGE OF THE ISLAND OF MONTREAL

Because of the lack of hydrometric data for Montreal itself, a figure of five inches is taken for effective recharge from Freeze's work immediately to the south of the river (1964, p. 8).

The area of the Island of Montreal is 192 mi^2 ∴ the volume of recharge is

$$192 \times 5280^2 \times \frac{5}{12} \; ft^3$$

There are 7.481 U.S. gallons/ft^3 ∴ volume in U.S. gallons per year is

$$192 \times 5280^2 \times \frac{5}{12} \times 7.481$$

$$= 16,790 \text{ million gallons}$$

The recharge per day is thus

$$\frac{16,790}{365} = 46 \text{ mgd}$$

This is also equivalent to

$$0.24 \text{ mgd/mi}^2$$

and 167 gpm/mi^2

However much of Montreal has been paved thus preventing natural recharge. If it is assumed that only 80% of the surface can be recharged then the actual recharge becomes only 37 mgd.

Recharge and permeability

The most impermeable surficial material of Montreal is clay whose permeability (K) is between 10^{-5} cm/sec and 10^{-7} cm/sec.

It can be calculated how much water can infiltrate through the clay per year.

There are 3.1536×10^7 secs/yr.

For a 1 cm high column of water to infiltrate it takes 10^6 secs if $K = 10^{-6}$ cm/sec.

In a year a column of water

$$\frac{3.1536 \times 10^7}{10^6} = 31.536 \text{ cm}$$

can infiltrate.

Since 5" = 12.70 cm it is physically possible for the calculated effective recharge to infiltrate.

APPENDIX C SATURATION INDICES AND OTHER GEOCHEMICAL PARAMETERS OF MONTREAL GROUND WATERS

The degree of saturation and other geochemical parameters for Montreal ground water have been calculated by Hoag (1976) using his programme (1975, p. 201-227). This programme supplied the activities of the constituents following Debye-Hückel theory, assuming ion pairing and employing a method of successive approximations to calculate ionic strength and activities. As field temperatures were not recorded, a temperature of 10°C was assumed, the average of the values found by Cumming (1915, p. 4).

The results in this appendix comprise the saturation indices of $CaCO_3$ and $CaSO_4$, and pCO_2 values which are of major significance in the present study, as well as other parameters considered in Hoag's original work.

Although only a saturation index of 0.00 indicates true saturation equilibrium, Hoag (1976) considers that values of 0.00 ± 0.20 are probably indicative of saturation equilibrium and values as high as 0.50 may not demonstrate significant saturation, particularly as some laboratory pH values may be in the order of 0.5 greater than field values. Nevertheless, as few pCO_2 values approach the atmospheric value of $10^{-3.5}$ atmospheres, CO_2 losses between sampling and testing may be generally insignificant.

TABLE C 1

SATURATION INDICES AND OTHER GEOCHEMICAL PARAMETERS OF MONTREAL GROUND WATERS (HOAG, 1976)

		SATURATION INDEX							
SAMP	DATE	CACO3	FECO3	MGCO3	DOLOMITE	ZNCO3	MNCO3	CASO4	MALACHITE
5345	160753	0.280	200.000	-0.586	0.652	200.000	200.000	-2.113	200.000
5323	130653	0.535	200.000	-0.092	0.440	200.000	200.000	-1.650	200.000
5337	300753	0.533	-0.667	0.236	0.603	200.000	200.000	-1.573	200.000
5247	120651	0.749	200.000	-0.339	0.434	200.000	200.000	-1.734	200.000
5245	110651	0.531	200.000	-0.315	0.327	200.000	200.000	-1.656	200.000
5344	170753	0.790	200.000	-0.344	0.445	200.000	200.000	-1.628	200.000
5341	250753	0.836	-1.002	-0.107	0.583	200.000	200.000	-0.918	200.000
5342	40653	0.658	-1.044	-0.301	0.397	200.000	200.000	-1.078	200.000
5322	20952	0.543	200.000	-0.069	0.606	200.000	200.000	-1.461	200.000
5339	30853	0.368	-0.947	-0.294	0.256	200.000	200.000	-1.794	200.000
5336	120653	0.432	-1.171	-0.550	0.160	200.000	200.000	-1.264	200.000
5321	260952	0.369	200.000	-0.246	0.280	200.000	200.000	-1.551	200.000
5244	50651	0.227	200.000	-0.864	-0.100	200.000	200.000	-1.333	200.000
5319	100653	0.409	200.000	-0.593	0.127	200.000	200.000	-1.799	200.000
5320	300952	0.462	200.000	-0.541	0.189	200.000	200.000	-1.225	200.000
5318	41052	0.595	200.000	-0.023	0.505	200.000	200.000	-2.016	200.000
5315	161052	0.764	200.000	-0.073	0.564	200.000	200.000	-1.859	200.000
5316	190852	0.156	200.000	-0.247	0.173	200.000	200.000	-2.497	200.000
5317	91052	0.356	200.000	-0.055	0.369	200.000	200.000	-2.182	200.000
5311	250853	0.409	200.000	-0.593	0.127	200.000	200.000	-1.799	200.000
5312	200753	0.975	200.000	-0.209	0.601	200.000	200.000	-1.727	200.000
5313	160653	0.584	200.000	-0.449	0.286	200.000	200.000	-1.857	200.000
5314	90953	0.642	200.000	-0.208	0.435	200.000	200.000	-1.618	200.000

200 = INCOMPLETE INFORMATION TO PERFORM THE CALCULATION

EQUILIBRIUM PE

SAMP	DATE	FE(OH)3	FE2O3	FES2	ZNS	CUFES2	PPCO2	ERROR	I.STR.
5345	160753	200.000	200.000	200.000	200.000	200.000	-2.594	68.225	0.03065
5323	130653	200.000	200.000	200.000	200.000	200.000	-2.899	-2.720	0.01057
5337	300753	0.306	-4.529	-4.137	200.000	200.000	-3.180	-0.592	0.01151
5247	120651	200.000	200.000	200.000	200.000	200.000	-2.480	5.393	0.01079
5245	110651	200.000	200.000	200.000	200.000	200.000	-2.290	-2.247	0.01050
5244	170753	200.000	200.000	200.000	200.000	200.000	-2.433	0.037	0.01110
5341	250753	2.367	-2.469	-3.337	200.000	200.000	-2.153	0.200	0.02032
5342	40853	2.046	-2.769	-3.456	200.000	200.000	-2.416	0.999	0.01495
5322	20952	200.000	200.000	200.000	200.000	200.000	-2.338	1.152	0.01406
5339	30953	1.698	-3.117	-3.621	200.000	200.000	-2.567	1.297	0.00924
5336	120853	2.318	-2.517	-3.756	200.000	200.000	-2.371	1.923	0.01220
5321	260952	200.000	200.000	200.000	200.000	200.000	-2.498	-0.084	0.02702
5244	90651	200.000	200.000	200.000	200.000	200.000	-1.849	-1.763	0.01253
5319	100653	200.000	200.000	200.000	200.000	200.000	-2.177	1.043	0.00991
5320	300952	200.000	200.000	200.000	200.000	200.000	-1.857	0.629	0.01546
5318	41052	200.000	200.000	200.000	200.000	200.000	-2.495	0.447	0.01133
5315	161052	200.000	200.000	200.000	200.000	200.000	-2.580	1.519	0.01012
5316	190953	200.000	200.000	200.000	200.000	200.000	-2.956	1.606	0.01563
5317	91053	200.000	200.000	200.000	200.000	200.000	-2.032	-0.899	0.01313
5311	250853	200.000	200.000	200.000	200.000	200.000	-2.177	1.045	0.00991
5312	200753	200.000	200.000	200.000	200.000	200.000	-2.194	0.865	0.01427
5313	160653	200.000	200.000	200.000	200.000	200.000	-2.396	1.491	0.00947
5314	90953	200.000	200.000	200.000	200.000	200.000	-2.496	-0.674	0.01127

200 = INCOMPLETE INFORMATION TO PERFORM THE CALCULATION

SATURATION INDEX

SAMP	DATE	CACO3	FECO3	MGCO3	DOLOMITE	ZNCO3	MNCO3	CASO4	MALACHITE
5243	70651	1.500	200.000	0.339	1.188	200.000	200.000	-1.600	200.000
5340	280953	0.077	-1.174	-0.464	0.035	200.000	200.000	-1.841	200.000
5310	250953	0.493	200.000	-0.670	0.130	200.000	200.000	-1.502	200.000
5272	250953	0.220	200.000	-1.033	-0.191	200.000	200.000	-1.351	200.000
5361	190551	0.604	-1.029	-0.537	0.252	200.000	200.000	-1.480	200.000
5107	190551	-0.152	-2.245	-1.009	-0.362	200.000	200.000	-0.973	200.000
5134	70951	0.253	-1.025	-0.328	0.181	200.000	200.000	-1.472	200.000
5106	70951	-0.101	-2.125	-1.182	-0.423	200.000	200.000	-1.129	200.000
5105	190751	-0.130	-1.674	-0.916	-0.304	200.000	200.000	-1.424	200.000
5334	290552	0.729	200.000	-0.179	0.493	200.000	200.000	-1.331	200.000
5123	190751	0.500	-0.907	-0.299	0.319	200.000	200.000	-1.357	200.000
5333	280552	0.727	200.000	0.302	0.766	200.000	200.000	-1.106	200.000
5332	220951	0.648	200.000	-0.171	0.457	200.000	200.000	-1.208	200.000
5104	180751	0.306	-1.225	-0.117	0.313	200.000	200.000	-1.484	200.000
5307	10653	0.476	200.000	-0.175	0.469	200.000	200.000	-1.309	200.000
5335	290552	0.436	-0.920	-0.036	0.449	200.000	200.000	-1.528	200.000
5103	190751	-0.102	-2.351	-0.732	-0.198	200.000	200.000	-1.083	200.000
5132	170751	0.060	-0.965	-0.017	0.243	200.000	200.000	-1.484	200.000
5238	150651	0.615	200.000	-0.605	0.223	200.000	200.000	-1.417	200.000
5237	140651	1.029	200.000	0.107	0.832	200.000	200.000	-1.475	200.000
5101	180751	-0.423	-1.850	-0.886	-0.436	200.000	200.000	-0.927	200.000
5306	10653	0.378	200.000	-0.637	0.104	200.000	200.000	-1.236	200.000
5305	10653	0.332	200.000	-0.190	0.275	200.000	200.000	-1.277	200.000

200 = INCOMPLETE INFORMATION TO PERFORM THE CALCULATION

EQUILIBRIUM PE

SAMP	DATE	FE(OH)3	FECO3	FES2	ZNS	CUFES2	PPCO2	ERROR	I.STR.
5243	70651	200.000	200.000	200.000	200.000	200.000	-3.259	2.279	0.01110
5340	280853	2.582	-2.253	-3.280	200.000	200.000	-2.210	1.939	0.00968
5310	290853	200.000	200.000	200.000	200.000	200.000	-1.970	3.221	0.01303
5372	250953	200.000	200.000	200.000	200.000	200.000	-1.702	-0.025	0.01374
5361	190551	2.299	-2.536	-3.393	200.000	200.000	-2.248	-0.450	0.01149
5107	190551	5.359	0.524	-2.317	200.000	200.000	-1.374	0.459	0.01989
5134	70951	2.740	-2.095	-3.124	200.000	200.000	-2.003	-0.819	0.01412
5106	70951	5.018	0.183	-2.461	200.000	200.000	-1.424	0.238	0.01530
5105	190751	4.405	-0.439	-2.572	200.000	200.000	-1.487	1.206	0.01440
5334	290552	200.000	200.000	200.000	200.000	200.000	-2.319	1.129	0.01400
5133	190751	2.445	-2.390	-3.249	200.000	200.000	-2.080	-0.388	0.01454
5333	280552	200.000	200.000	200.000	200.000	200.000	-2.549	0.618	0.01823
5332	220951	200.000	200.000	200.000	200.000	200.000	-2.208	1.122	0.01538
5104	180751	1.763	-3.072	-3.696	200.000	200.000	-2.690	-0.241	0.01375
5307	10653	200.000	200.000	200.000	200.000	200.000	-2.546	3.792	0.01548
5335	290552	1.731	-3.104	-3.595	200.000	200.000	-2.507	0.395	0.01328
5103	180751	5.054	0.219	-2.441	200.000	200.000	-1.315	-0.317	0.02052
5132	190751	2.481	-2.354	-3.204	200.000	200.000	-2.122	0.580	0.01793
5238	150651	200.000	200.000	200.000	200.000	200.000	-2.080	-0.861	0.01684
5237	160651	200.000	200.000	200.000	200.000	200.000	-2.896	0.789	0.01139
5101	180751	4.632	-0.263	-2.347	200.000	200.000	-1.576	-0.126	0.02403
5306	10653	200.000	200.000	200.000	200.000	200.000	-1.906	0.875	0.01493
5305	10653	200.000	200.000	200.000	200.000	200.000	-2.018	1.261	0.01644

200 = INCOMPLETE INFORMATION TO PERFORM THE CALCULATION

SATURATION INDEX

SAMP	DATE	CACO3	FECO3	MGCO3	DOLOMITE	ZNCO3	MNCO3	CASO4	MALACHITE
5135	60951	0.539	-1.047	-0.196	0.390	200.000	200.000	-0.931	200.000
5102	190751	-0.216	-1.859	-0.887	-0.333	200.000	200.000	-1.596	200.000
5362	180753	0.496	-1.076	-0.329	0.302	200.000	200.000	-1.409	200.000
5308	30653	0.663	200.000	-0.436	0.332	200.000	200.000	-1.150	200.000
5303	190653	0.254	-1.236	-0.766	-0.037	200.000	200.000	-1.174	200.000
5301	100653	0.216	-1.267	-0.525	-0.086	200.000	200.000	-1.377	200.000
5301	50653	0.426	-1.217	-0.561	0.151	200.000	200.000	-1.381	200.000
5129	190951	0.435	-1.153	-0.214	0.329	200.000	200.000	-1.689	200.000
5374	70852	0.621	-1.035	-0.334	0.362	200.000	200.000	-1.303	200.000
5110	180851	0.205	-1.834	-0.999	-0.178	200.000	200.000	-1.123	200.000
5111	100851	0.318	-1.380	-0.766	-0.005	200.000	200.000	-1.121	200.000
5136	20851	0.732	-0.377	0.212	0.690	200.000	200.000	-1.837	200.000
5302	190653	0.161	-0.987	-0.603	-0.003	200.000	200.000	-1.942	200.000
5120	200751	0.003	-1.224	-0.766	-0.163	200.000	200.000	-1.510	200.000
5113	200751	-0.183	-1.598	-0.633	-0.280	200.000	200.000	-1.787	200.000
5373	210951	0.403	200.000	-0.625	0.107	200.000	200.000	-1.242	200.000
5376	31051	0.376	200.000	-0.233	0.290	200.000	200.000	-1.570	200.000
5112	120751	0.091	-1.803	-0.979	-0.235	200.000	200.000	-0.964	200.000
5303	180653	0.518	-1.791	-0.483	0.236	200.000	200.000	-0.624	200.000
5114	200751	0.197	-1.670	-0.569	0.033	200.000	200.000	-1.352	200.000
5363	120953	0.621	200.000	-0.292	0.388	200.000	200.000	-1.764	200.000
5117	150951	0.060	-2.409	-1.112	-0.307	200.000	200.000	-0.138	200.000
5364	30851	-0.147	-1.285	-1.117	-0.414	200.000	200.000	-2.309	200.000

200 = INCOMPLETE INFORMATION TO PERFORM THE CALCULATION

EQUILIBRIUM PE

SAMP	DATE	FE(OH)3	FE2O3	FES2	ZNS	CUFES2	PPCO2	ERROR	I.STR.
5135	60951	2.791	-2.044	-3.087	200.000	200.000	-1.974	2.062	0.02039
5102	180751	3.478	-1.357	-3.048	200.000	200.000	-2.199	0.263	0.00861
5362	180753	2.310	-2.525	-3.373	200.000	200.000	-2.283	0.728	0.01226
5308	30653	-200.000	200.000	200.000	200.000	200.000	-2.250	0.407	0.01452
5303	190653	3.040	-1.795	-2.997	200.000	200.000	-2.014	0.666	0.01354
5301	180653	3.038	-1.797	-2.997	200.000	200.000	-2.047	0.253	0.01317
5301	50653	2.904	-1.931	-3.151	200.000	200.000	-2.031	2.271	0.01298
5129	130951	1.723	-3.112	-3.736	200.000	200.000	-2.648	-0.117	0.01050
5371	70852	2.318	-2.517	-3.369	200.000	200.000	-2.235	0.012	0.01339
5110	180851	3.819	-1.016	-2.920	200.000	200.000	-1.934	-0.298	0.01457
5111	100851	3.222	-1.613	-3.006	200.000	200.000	-1.977	-0.280	0.01419
5136	20851	0.092	-4.743	-4.176	200.000	200.000	-3.103	3.773	0.00895
5302	190653	2.089	-2.746	-3.404	200.000	200.000	-2.416	0.736	0.00747
5120	200751	2.723	-2.112	-3.123	200.000	200.000	-2.219	-0.001	0.01102
5113	200751	2.289	-2.546	-3.502	200.000	200.000	-2.727	2.372	0.00757
5373	280953	200.000	200.000	200.000	200.000	200.000	-1.854	-0.531	0.01979
5376	91053	200.000	200.000	200.000	200.000	200.000	-2.437	0.666	0.01070
5112	120951	2.968	-1.867	-3.216	200.000	200.000	-2.453	2.202	0.01536
5303	180653	4.505	-0.330	-2.652	200.000	200.000	-1.404	-1.634	0.03052
5114	200751	3.214	-1.621	-3.151	200.000	200.000	-2.134	0.450	0.01299
5363	120953	200.000	200.000	200.000	200.000	200.000	-3.440	0.512	0.00637
5117	150951	4.025	-0.810	-2.826	200.000	200.000	-2.302	-0.175	0.04597
5364	30851	1.644	-3.191	-3.673	200.000	200.000	-2.959	0.529	0.00427

200 = INCOMPLETE INFORMATION TO PERFORM THE CALCULATION

SATURATION INDEX

SAMP	DATE	CACO3	FECO3	MGCO3	DOLOMITE	ZNCO3	MNCO3	CASO4	MALACHITE
5118	240751	-0.362	200.000	-0.932	-0.429	200.000	200.000	-1.544	200.000
5143	90851	0.491	-1.526	-0.561	0.184	200.000	200.000	-1.016	200.000
5142	250751	0.289	-1.543	-0.681	0.022	200.000	200.000	-1.401	200.000
5119	240751	-0.348	200.000	-0.829	-0.370	200.000	200.000	-1.209	200.000
5140	10351	0.657	-1.119	-0.177	0.459	200.000	200.000	-1.720	200.000
5137	170851	-0.017	-1.861	-0.830	-0.209	200.000	200.000	-1.321	200.000
5144	20851	-0.116	-1.176	-0.770	-0.275	200.000	200.000	-2.340	200.000
5108	60851	-0.337	-1.202	-0.570	-0.235	200.000	200.000	-2.430	200.000
5141	20351	0.264	-1.781	[illegible]	-0.068	200.000	200.000	-1.046	200.000
5366	300751	0.765	-0.989	0.014	0.608	200.000	200.000	-1.021	200.000
5365	60951	0.350	-1.529	-0.658	0.065	200.000	200.000	-0.736	200.000
5139	60951	0.595	-1.147	0.048	0.540	200.000	200.000	-1.672	200.000
5121	160951	0.060	-1.650	-0.995	-0.204	200.000	200.000	-0.642	200.000
5146	150851	-0.094	-1.523	-0.571	-0.114	200.000	200.000	-1.454	200.000
5145	280951	-0.181	-1.659	-0.765	-0.255	200.000	200.000	-1.533	200.000
5116	230751	0.067	-1.455	-0.640	-0.072	200.000	200.000	-1.499	200.000
5115	230751	0.200	-1.563	-0.766	-0.064	200.000	200.000	-0.974	200.000
5375	110653	0.306	200.000	-0.679	0.022	200.000	200.000	-1.670	200.000
5369	20853	0.060	200.000	-0.289	0.104	200.000	200.000	-3.030	200.000
5374	110653	0.263	200.000	-0.697	0.002	200.000	200.000	-1.341	200.000
5130	270851	0.505	-1.205	0.105	0.524	200.000	200.000	-1.332	200.000
5209	220752	-0.201	200.000	-0.489	0.077	200.000	200.000	-3.247	200.000
5368	270853	-0.132	-1.519	-0.868	-0.281	200.000	200.000	-1.649	200.000

200.= INCOMPLETE INFORMATION TO PERFORM THE CALCULATION

EQUILIBRIUM PE

SAMP	DATE	FE(OH)3	FE2O3	FES2	ZNS	CUFES2	PPCO2	ERROR	I.STR.
5119	240751	200.000	200.000	200.000	200.000	200.000	-1.627	1.172	0.01470
5143	90851	2.649	-2.186	-3.356	200.000	200.000	-2.395	-0.842	0.01540
5142	250751	2.607	-2.229	-3.398	200.000	200.000	-2.454	-0.447	0.01193
5119	240751	200.000	200.000	200.000	200.000	200.000	-1.980	1.219	0.01743
5140	10951	1.417	-3.418	-3.882	200.000	200.000	-2.821	2.956	0.00936
5137	170851	3.809	-1.026	-2.921	200.000	200.000	-1.970	0.414	0.01287
5144	20851	2.000	-2.835	-3.641	200.000	200.000	-2.494	-1.608	0.00931
5108	60851	3.290	-1.544	-2.976	200.000	200.000	-1.830	0.320	0.01023
5141	20851	3.835	-1.000	-2.908	200.000	200.000	-1.864	-1.625	0.01641
5366	300751	0.910	-3.925	-3.894	200.000	200.000	-2.997	0.039	0.01783
5365	60951	3.584	-1.251	-2.867	200.000	200.000	-1.863	0.042	0.02543
5139	60951	1.732	-3.103	-3.755	200.000	200.000	-2.633	1.853	0.01331
5121	170851	4.622	-0.213	-2.331	200.000	200.000	-1.386	0.016	0.02646
5146	150851	3.002	-1.833	-3.220	200.000	200.000	-2.149	-1.915	0.02599
5145	280951	3.302	-1.533	-3.127	200.000	200.000	-2.116	-1.192	0.03169
5116	230751	3.510	-1.325	-2.909	200.000	200.000	-1.860	2.177	0.01493
5115	230751	3.844	-0.991	-2.764	200.000	200.000	-1.736	-0.371	0.01795
5375	110651	200.000	200.000	200.000	200.000	200.000	-2.239	0.759	0.00362
5369	20851	200.000	200.000	200.000	200.000	200.000	-2.771	-0.027	0.02307
5374	110651	200.000	200.000	200.000	200.000	200.000	-1.258	0.245	0.01773
5130	270851	1.781	-3.053	-3.695	200.000	200.000	-2.642	-0.290	0.01816
5209	220751	200.000	200.000	200.000	200.000	200.000	-2.611	1.738	0.01138
5368	270851	3.475	-1.360	-2.926	200.000	200.000	-1.961	1.111	0.00948

200 = INCOMPLETE INFORMATION TO PERFORM THE CALCULATION

SATURATION INDEX

SAMP	DATE	CACO3	FECO3	MGCO3	DOLOMITE	ZNCO3	MNCO3	CASO4	MALACHITE
5210	230752	-0.176	200.000	-1.432	-0.585	200.000	200.000	-1.870	200.000
5211	240752	0.428	200.000	0.421	0.643	200.000	200.000	-3.456	200.000
5131	220751	0.316	200.000	-0.330	0.211	200.000	200.000	-1.199	200.000
5214	210752	0.515	200.000	-0.466	0.264	200.000	200.000	-1.914	200.000
5212	250752	0.454	200.000	-0.628	0.132	200.000	200.000	-1.875	200.000
5215	260752	0.130	200.000	-0.779	-0.106	200.000	200.000	-1.723	200.000
5127	270651	0.076	-1.295	-0.352	0.080	200.000	200.000	-1.792	200.000
5216	40252	0.620	200.000	-0.478	0.290	200.000	200.000	-1.581	200.000
5221	60852	0.065	200.000	-1.311	-0.405	200.000	200.000	-1.513	200.000
5217	40852	0.209	200.000	-0.708	0.019	200.000	200.000	-1.644	200.000
5218	250852	0.227	200.000	-0.879	-0.107	200.000	200.000	-1.733	200.000
5219	170852	0.389	200.000	-0.158	0.577	200.000	200.000	-1.918	200.000
5220	50852	0.208	200.000	-1.165	-0.230	200.000	200.000	-1.487	200.000
5208	220652	0.439	200.000	-0.851	0.013	200.000	200.000	-1.593	200.000
5222	50952	0.050	200.000	-0.833	-0.175	200.000	200.000	-1.799	200.000
5207	140652	0.213	200.000	-0.333	-0.161	200.000	200.000	-1.869	[illegible]
5213	250752	0.192	200.000	-0.421	0.104	200.000	200.000	-2.412	[illegible]
5223	20752	-0.187	200.000	-0.811	-0.280	200.000	200.000	-1.[illegible]	200.000
5109	100951	-0.006	-1.746	-1.096	-0.338	200.000	200.000	-1.053	200.000
5225	40752	0.204	200.000	-0.378	0.132	200.000	200.000	-2.[illegible]	200.000
5224	220852	0.322	200.000	-0.111	-0.625	200.000	200.000	-1.724	200.000
5206	140652	0.601	200.000	-0.277	0.381	200.000	200.000	-2.121	200.000
5124	220851	0.481	200.000	0.117	0.518	200.000	200.000	-1.959	200.000

200 = INCOMPLETE INFORMATION TO PERFORM THE CALCULATION

EQUILIBRIUM PE

SAMP	DATE	FE(OH)3	FE2O3	FES2	ZNS	CUFES2	PPCO2	ERROR	I.STR.
5210	220752	200.000	200.000	200.000	200.000	200.000	-2.194	-1.924	0.01145
5211	240752	200.000	200.000	200.000	200.000	200.000	-3.030	1.920	0.00704
5131	230751	200.000	200.000	200.000	200.000	200.000	-2.507	-0.310	0.02132
5214	210752	200.000	200.000	200.000	200.000	200.000	-1.843	-2.033	0.01858
5212	250752	200.000	200.000	200.000	200.000	200.000	-2.436	-0.694	0.00850
5215	260752	200.000	200.000	200.000	200.000	200.000	-1.965	-1.718	0.01030
5127	270851	2.632	-2.203	-3.376	200.000	200.000	-2.191	1.665	0.01445
5216	40352	200.000	200.000	200.000	200.000	200.000	-2.709	-0.928	0.00370
5221	60852	200.000	200.000	200.000	200.000	200.000	-1.799	2.549	0.01082
5217	40952	200.000	200.000	200.000	200.000	200.000	-1.681	-0.997	0.01726
5218	252852	200.000	200.000	200.000	200.000	200.000	-1.942	-3.076	0.00935
5219	170752	200.000	200.000	200.000	200.000	200.000	-1.918	-0.722	0.02259
5220	50852	200.000	200.000	200.000	200.000	200.000	-1.860	-2.393	0.01101
5208	230652	200.000	200.000	200.000	200.000	200.000	-2.190	-0.106	0.01015
5222	50652	200.000	200.000	200.000	200.000	200.000	-2.060	-0.660	0.01009
5207	140652	200.000	200.000	200.000	200.000	200.000	-2.474	-2.298	0.00776
5213	250752	200.000	200.000	200.000	200.000	200.000	-2.259	-0.460	0.00747
5223	20752	200.000	200.000	200.000	200.000	200.000	-2.068	0.134	0.00834
5109	100851	4.427	-0.468	-2.545	200.000	200.000	-1.537	0.111	0.01601
5225	40752	200.000	200.000	200.000	200.000	200.000	-2.563	-0.285	0.01415
5224	230852	200.000	200.000	200.000	200.000	200.000	-2.332	0.142	0.00814
5206	140652	200.000	200.000	200.000	200.000	200.000	-3.329	-0.016	0.01345
5124	230851	200.000	200.000	200.000	200.000	200.000	-2.849	1.465	0.01976

200 = INCOMPLETE INFORMATION TO PERFORM THE CALCULATION

SATURATION INDEX

SAMP	DATE	CACO3	FECO3	MGCO3	DOLOMITE	ZNCO3	MNCO3	CASO4	MALACHITE
5204	100652	0.173	200.000	-0.230	0.190	200.000	200.000	-0.928	200.000
5201	103652	0.929	200.000	0.450	0.908	200.000	200.000	-2.291	200.000
5236	200952	0.413	200.000	-0.608	0.121	200.000	200.000	-0.926	200.000
5126	210651	-0.146	-1.438	-0.567	-0.138	200.000	200.000	-1.846	200.000
5125	210851	0.085	-0.357	-0.332	0.096	200.000	200.000	-2.085	200.000
5276	80852	0.326	200.000	-0.416	0.173	200.000	200.000	-1.778	200.000
5203	240652	0.157	200.000	-0.932	-0.171	200.000	200.000	-1.090	200.000
5227	80852	0.408	200.000	-0.374	0.335	200.000	200.000	-1.737	200.000
5367	61052	0.139	200.000	-0.098	0.239	200.000	200.000	-1.937	200.000
5228	80852	0.117	200.000	-0.463	0.046	200.000	200.000	-2.097	200.000
5123	200951	0.111	-1.664	-0.854	-0.153	200.000	200.000	-0.778	200.000
5120	220851	0.523	0.063	0.065	0.613	200.000	200.000	-2.344	200.000
5205	130652	0.549	200.000	-0.572	0.207	200.000	200.000	-1.101	200.000
5370	240853	-0.591	-0.559	-0.831	-0.493	200.000	200.000	-2.864	200.000
5233	140852	0.434	200.000	-0.107	0.382	200.000	200.000	-3.513	200.000
5232	180352	-0.376	200.000	-1.577	-0.758	200.000	200.000	-1.737	200.000
5147	41051	-0.769	200.000	-0.780	-0.556	200.000	200.000	-4.096	200.000
5235	150652	0.416	200.000	-0.407	0.223	200.000	200.000	-1.417	200.000
5234	10852	-0.728	200.000	-1.716	-1.004	200.000	200.000	-2.294	200.000
5229	120652	0.038	200.000	-0.525	-0.035	200.000	200.000	-1.489	200.000
5230	150752	0.176	200.000	-0.527	0.042	200.000	200.000	-1.703	200.000
5231	130852	-1.150	200.000	-1.780	-1.244	200.000	200.000	-1.789	200.000

200 = INCOMPLETE INFORMATION TO PERFORM THE CALCULATION .

EQUILIBRIUM OF

SAMP	DATE	FE(OH)3	FE2O3	FES2	ZNS	CUFES2	PPCO2	ERROR	I.STR.
5204	100652	200.000	200.000	200.000	200.000	200.000	-1.503	-1.825	0.02932
5201	103652	200.000	200.000	200.000	200.000	200.000	-3.051	3.867	0.01051
5236	200952	200.000	200.000	200.000	200.000	200.000	-1.913	-0.014	0.01703
5126	210951	2.919	-1.916	-3.257	200.000	200.000	-2.138	0.167	0.01254
5125	210951	1.781	-3.954	-3.702	200.000	200.000	-2.335	0.260	0.01873
5226	80852	200.000	200.000	200.000	200.000	200.000	-2.156	-0.856	0.01029
5203	240652	200.000	200.000	200.000	200.000	200.000	-2.090	3.608	0.01521
5227	80852	200.000	200.000	200.000	200.000	200.000	-2.366	-1.436	0.00994
5367	61052	200.000	200.000	200.000	200.000	200.000	-2.834	0.187	0.02672
5228	80852	200.000	200.000	200.000	200.000	200.000	-2.136	-0.302	0.00930
5123	200851	4.604	-0.231	-2.405	200.000	200.000	-1.378	-0.146	0.02740
5128	220951	-0.408	-5.243	-4.378	200.000	200.000	-2.363	5.840	0.01596
5205	130652	200.000	200.000	200.000	200.000	200.000	-2.500	-0.742	0.01385
5370	240853	1.166	-3.669	-3.805	200.000	200.000	-2.511	-0.426	0.01453
5233	140952	200.000	200.000	200.000	200.000	200.000	-3.070	5.014	0.01597
5232	180952	200.000	200.000	200.000	200.000	200.000	-1.680	-1.057	0.00807
5147	41051	200.000	200.000	200.000	200.000	200.000	-2.020	1.178	0.02167
5235	190652	200.000	200.000	200.000	200.000	200.000	-2.149	-0.691	0.01347
5234	10852	200.000	200.000	200.000	200.000	200.000	-2.348	-2.490	0.00426
5229	120652	200.000	200.000	200.000	200.000	200.000	-2.033	-0.196	0.01615
5230	150752	200.000	200.000	200.000	200.000	200.000	-1.734	1.269	0.01972
5231	130852	200.000	200.000	200.000	200.000	200.000	-1.571	-0.427	0.00889

200 = INCOMPLETE INFORMATION TO PERFORM THE CALCULATION

SATURATION INDEX

SAMP	DATE	CACO3	FECO3	MGCO3	DOLOMITE	ZNCO3	MNCO3	CASO4	MALACHITE
5329	250952	0.914	200.000	0.368	0.810	200.000	200.000	-1.586	200.000
5328	250952	0.831	200.000	0.112	0.690	200.000	200.000	-1.789	200.000
5360	240653	0.564	-0.577	0.267	0.834	200.000	200.000	-1.610	200.000
5359	150653	0.306	200.000	-0.057	0.343	200.000	200.000	-1.844	200.000
5358	150653	0.478	-0.809	-0.115	0.400	200.000	200.000	-1.706	200.000
5357	250753	0.665	-0.929	-0.061	0.520	200.000	200.000	-1.496	200.000
5356	80753	0.503	200.000	0.123	0.731	200.000	200.000	-1.836	200.000
5355	60753	0.690	-0.947	0.122	0.624	200.000	200.000	-1.518	200.000
5327	160952	0.587	200.000	-0.161	0.432	200.000	200.000	-1.896	200.000
5354	230653	0.661	-0.525	0.188	0.743	200.000	200.000	-1.712	200.000
5353	150753	0.672	-0.770	-0.052	0.529	200.000	200.000	-1.598	200.000
5352	290753	0.280	200.000	0.034	0.376	200.000	200.000	-1.877	200.000
5351	290653	0.785	-0.741	0.025	0.624	200.000	200.000	-1.743	200.000
5349	170853	0.024	-0.811	-0.022	0.219	200.000	200.000	-2.362	200.000
5348	170753	0.678	200.000	-0.055	0.530	200.000	200.000	-1.639	200.000
5347	753	0.695	-1.301	-0.223	0.459	200.000	200.000	-1.683	200.000
5326	160952	0.561	200.000	-0.565	0.217	200.000	200.000	-2.028	200.000
5350	270753	0.756	-0.693	0.085	0.659	200.000	200.000	-1.760	200.000
5346	130753	0.810	-1.149	-0.039	0.804	200.000	200.000	-1.498	200.000
5246	130653	1.126	200.000	0.023	1.053	200.000	200.000	-1.774	200.000
5338	300752	0.756	-0.942	0.202	0.718	200.000	200.000	-1.529	200.000
5331	111052	0.407	200.000	-0.113	0.366	200.000	200.000	-1.770	200.000
5325	80952	0.558	200.000	-0.128	0.423	200.000	200.000	-1.359	200.000

200 = INCOMPLETE INFORMATION TO PERFORM THE CALCULATION

EQUILIBRIUM PE

SITE	DATE	FE(OH)3	FE2O3	FES2	ZNS	CUFES2	PCO2	ERROR	I.STR.
5329	250952	200.000	200.000	200.000	200.000	200.000	-3.096	3.759	0.00551
5328	250952	200.000	200.000	200.000	200.000	200.000	-2.520	4.908	0.01205
5360	240653	0.556	-4.237	-4.060	200.000	200.000	-2.937	0.303	0.01101
5359	150653	200.000	200.000	200.000	200.000	200.000	-2.855	-0.298	0.00801
5358	150653	1.655	-3.137	-3.627	200.000	200.000	-2.529	0.247	0.00962
5357	250753	2.016	-2.819	-3.502	200.000	200.000	-2.330	0.163	0.01330
5356	80753	200.000	200.000	200.000	200.000	200.000	-2.954	-0.034	0.00871
5355	60753	0.835	-4.000	-4.118	200.000	200.000	-3.031	-0.539	0.00771
5327	160952	200.000	200.000	200.000	200.000	200.000	-2.652	0.321	0.00846
5354	230653	1.135	-3.700	-3.995	200.000	200.000	-2.608	-0.119	0.01011
5353	150753	1.356	-3.439	-[illegible].763	200.000	200.000	-2.552	0.469	0.00913
5352	290753	200.000	200.000	200.000	200.000	200.000	-3.216	-0.634	0.00756
5351	250653	1.412	-3.423	-3.757	200.000	200.000	-2.547	0.252	0.01091
5349	170853	0.520	-4.315	-4.085	200.000	200.000	-3.209	-1.071	0.00569
5348	170753	200.000	200.000	200.000	200.000	200.000	-2.459	0.290	0.01125
5347	753	2.907	-1.928	-3.334	200.000	200.000	-2.011	0.173	0.01900
5326	160952	200.000	200.000	200.000	200.000	200.000	-2.556	0.282	0.00772
5350	270753	1.121	-3.714	-3.668	200.000	200.000	-2.689	4.536	0.01052
5340	120753	2.322	-2.513	-3.533	200.000	200.000	-2.246	0.669	0.01465
5248	130653	200.000	200.000	200.000	200.000	200.000	-3.169	6.272	0.01171
5338	300753	1.419	-2.416	-3.506	200.000	200.000	-2.641	3.095	0.01055
5331	111052	200.000	200.000	200.000	200.000	200.000	-2.382	1.303	0.01047
5325	80953	200.000	200.000	200.000	200.000	200.000	-3.237	-0.888	0.02871

200 = INCOMPLETE INFORMATION TO PERFORM THE CALCULATION

APPENDIX D PRINT-OUT OF SELECTED DATA FROM THE PLAN REQUEST.

TABLE D.1

LISTING OF INPUT DATA

```
MUL,MONTREAL

     80350      30500     27000     43000      16000             1          0
01933193WF  8030003050000A 0000000000           0000   0000   0000   0000000000000000000000
     80500      31900     27000     43000      16000             1          0
01933293WF  8050003180000A 0000000000           0000   0000   0000   0000000000000000000000
     81100      32200     27000     43000      16000             1          0
01532990WF  81100032200DAP0095090000   3PA18KMDM0170   0000   0000   0000096002100000000000
     81100      32200     27000     43000      16000           121          2
BADIAL   WF  811000322000H      MKM250352        40 1 8.4      28822262513138912521510026824300521135A1
     81100      32200     27000     43000      16000           136          2
CADIAL   WF  811000322000H      MKM250352        40     16412272 800                 3612        631
     81700      32500     27000     43000      16000             1          0
01532990WF  81700032500DAP0103090000   4961BKMDM0420   0000   0000   0000066002100000000000
     81700      32500     27000     43000      16000           121          2
BADIAL   WF  81700032500309     BKM090653        38 1 8.0      3912323293213841200142003942        50611751
     81700      32500     27000     43000      16000           136          2
CADIAL   WF  817000325000H      MKM090653        40     11513/321600                 4312        761
     82030      28000     27000     43000      16000             1          0
01533493WF  82000028000304 0300000000           0000   0000   0000   0000000000000000000000
     82000      33000     27300     43000      16000             1          0
01533193WF  8200003300000A 0000000000           0000   0000   0000   0000000000000000000000
     82230      34200     27000     43000      16000             1          0
01732393WF  8220003420000A 0000000000           0000   0000   0000   0000000000000000000000
     82700      33100     27000     43000      16000             1          0
01733093WF  8270003310000A 0300000000           0000   0000   0000   0000000000000000000000
     83000      33500     27000     43000      16000             1          0
01932993WF  8300003350000A 0000000000           0000   0000   0000   0000000000000000000000
     83500      28500     27000     43000      16000             1          0
01537093WF  83500028500DAP0100090000   4961BKMDM0070   0000   0000   0000046001A00000000000
     83500      28500     27000     43000      16000           121          2
FACIAL   WF  83500028500309     AKP240653        18 1 8.3      40351725428261353112113580310Z        84212721
     83500      28500     27000     43000      16000           136          2
CADIAL   WF  835000285000H      BKM240653        20     14612542  .         100       4122        661
     83500      28700     27000     43000      16000             1          0
01535790WF  83600028700DAP0103090000   4761BKMDM0160   0000   0000   0000041000600000000000
     83600      28700     27300     43000      16000           121          2
BADIAL   WF  83600028700009     BKM150653         7 1 8.4      24921702308134617500160D2072        87515800
     83600      28700     27000     43000      15000           136          2
CADIAL   WF  836000287000H      BKM240653        00     13811702             50       2052        481
     83900      28600     27000     43000      16000             1          0
01535890WF  83900028600DAP0099090000   5361BKMDM0450   0000   0000   0000065000900000000000
     83900      28600     27000     43000      16000           121          2
BADIAL   WF  83900028600009     BKM150653        28 1 7.9      40304225226411350130712800307Z        69813600
     83900      28600     27000     43000      16000           136          2
CADIAL   WF  839000286000H      BKM150653        00     15012522            100       3532        571
     84000      36000     27000     43000      16000             1          0
01932793WF  8400003600000A 0000000000           0000   0000   0000   0000000000000000000000
     84500      28100     27000     43000      16000             1          0
01933493WF  8450002810000A 0000000000           0000   0000   0000   0000000000000000000000
     84900      29200     27000     43000      16000             1          0
01535790WF  84900029200DAP0121090000   5161BKMDM0100   0000   0000   0000038001500000000000
     84900      29200     27000     43000      16000           121          2
BADIAL   WF  84900029200009     BKM250753        15 1 7.8      40438232121085242518700160039Z2        95512541
     84900      29200     27000     43000      16000           136          2
CADIAL   WF  849000292000H      BKM250753        00     12913212                     4852        791
     85000      34500     27000     43000      16000             1          0
01932693WF  8500003450000A 0000000000           0000   0000   0000   0000000000000000000000
     85100      29500     27000     43000      16000             1          0
01535490WF  85100029500DAP0129090000   5261BKMDM0160   0000   0000   000004500ZC00000000000
     85100      29500     27000     43000      16000           121          2
BADIAL   WF  85100029500309     BKM090753        29 1 8.3      28022402708125018200130019Z2        51613500
     85100      29500     27000     43000      16000           136          2
```

TABLE D.2

LISTING OF DATA POINT DESIGNATIONS

AND

COMPUTER-DRAWN MAP OF DATA POINT LOCATIONS

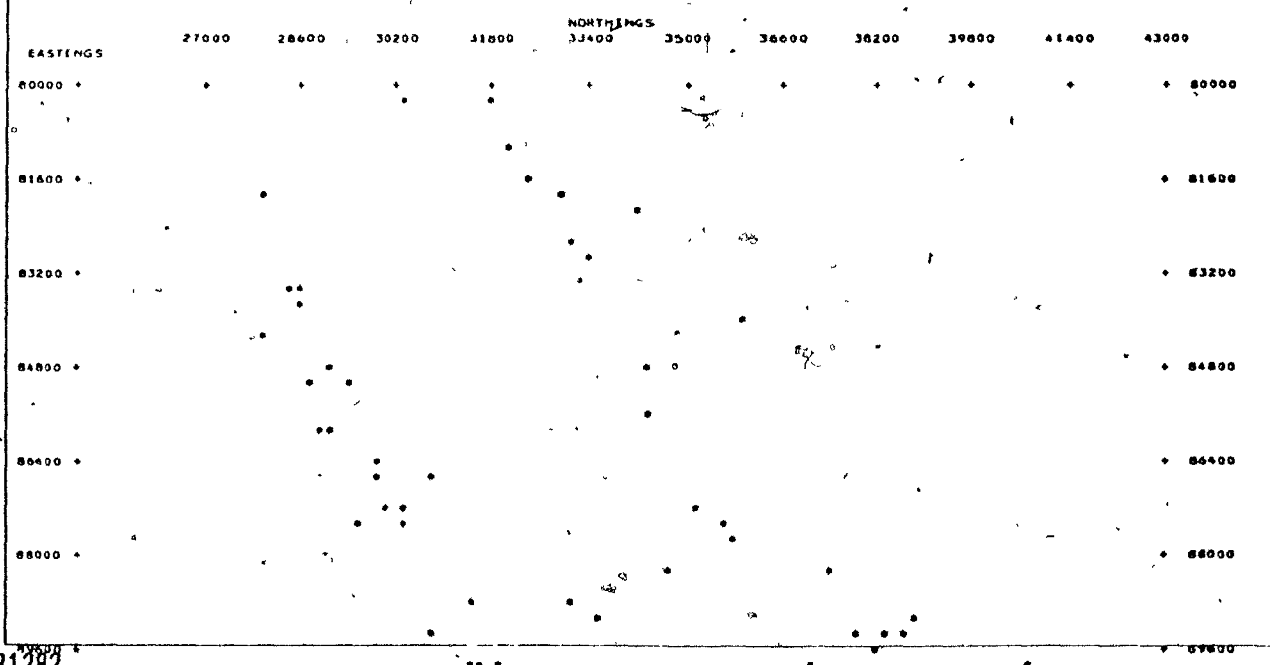
14 SEP 72   REQUEST NO. MOE.

GEOTECHNICAL DATA ON FILE FOR THE AREA WITHIN 8000 METRES
OF THE LINE BETWEEN UTM GRID COORDINATES 800000 350000 AND 999990 350000
GENERAL VICINITY OF MONTREAL

DRILL HOLES AND OTHER DATA POINTS IN AREA

93/ 9333	93/ 9332	90/ 5329	90/ 5328	93/ 9334	93/ 9331	93/ 9328	93/ 9330	93/ 9329	90/ 5360	90/ 5359	90/ 5358	93/ 9327
93/ 9335	90/ 5357	93/ 9326	90/ 5356	90/ 5355	90/ 5327	93/ 9336	90/ 5354	90/ 5353	90/ 5352	90/ 5351	90/ 5349	90/ 5348
90/ 5347	90/ 5326	90/ 5350	93/ 9325	93/ 9344	90/ 5346	91/ 9120	90/ 5248	93/ 9324	90/ 5338	90/ 5331	93/ 9322	91/ 9117
90/ 5325	90/ 5345	93/ 9323	90/ 5323	91/ 9121	90/ 5337	90/ 5247	93/ 9321	91/ 9118	90/ 5245	93/ 9337	91/ 9119	90/ 5344
90/ 5341	90/ 5342	90/ 5322	90/ 5339	93/ 9345	91/ 9122	93/ 9338	91/ 9124	90/ 5336	93/ 9346	90/ 5321	90/ 5244	91/ 9123
90/ 5319	90/ 5320	90/ 5318	90/ 5315	93/ 9347	90/ 5316	90/ 5317	93/ 9339	90/ 5311	90/ 5312	90/ 5313	90/ 5314	93/ 9348
93/ 9340	93/ 9320	91/ 9125	93/ 9341	90/ 5243	93/ 9342	90/ 5340	91/ 9126	91/ 9127	93/ 9319	93/ 9343	93/ 9301	91/ 9128
90/ 5310	90/ 5372											

REPRESENTATIVE FRACTION 1:64000



2581282

TABLE D.3

GENERAL WELL DATA

GENERAL WELL DATA

LOCATION GRID SQ	PROJ NO	WELL NO	OBSVN NO	ELVN	FIRST BED-ROCK NAME	FIRST BED-ROCK LITH	OVER-BURDEN THICK-NESS	SURFACE DIAM OF WELL CASING	DEPTH OF WELL	DEPTH TO WATER TABLE	DEPTH TO SOURCE OF WATER (AQUIFER)	LITHOL OF SOURCE OF WATER (AQUIFER)	NAME OF SOURCE OF WATER (AQUIFER)	DATE COMPLETED
WFA132	90	5329	01AL	95.0	BKM	DM	17	61	96.0	021	40			38
WF3132	90	5328	01AL	103.0	PKM	DM	42	61	66.0	021	38			49
WF8328	90	5360	01AL	100.0	BKM	DM	07	61	46.0	018	18			49
WF8328	90	5359	01AL	103.0	PKM	DM	16	61	41.0	006	7			47
WFA328	90	5358	01AL	99.0	PKM	DM	[illegible]	61	65.0	009	28			53
WFA429	90	5357	01AL	121.0	PKM	DM	10	61	38.0	015	15			51
WF[illegible]529	90	5356	01AL	129.0	BKM	DM	1[illegible]	61	45.0	020	29			52
WF[illegible]29	90	5355	01AL	87.0	BKM	DM	20	61	52.0	015	42			53
WF[illegible]34	90	5327	01AL	77.0	PKM	DM	18	61	33.0	000	33			25
WF[illegible]2[illegible]	90	5334	01AL	91.0	PKM	DM	48	61	[illegible]5.0	003	12			53
WF[illegible]29	90	5353	01AL	11[illegible].0	LKM	DM	14	61	6[illegible].0	023	66			52
WF8630	90	5352	01AL	107.0	BKM	DM	25	61	75.0	013	35			48
WF[illegible]29	90	5351	01AL	104.0	PKM	DM	00	61	75.0	010	75			50
WF[illegible]730	90	5349	01AL	97.0	PKM	DM	10	61	50.0	015	40			52
WF8730	90	5346	01AL	107.0	EKM	DM	20	61	45.0	008	33			51
WF6730	90	5347	01AL	105.0	PKM	DM	21	61	29.0	005	18			49
WF[illegible]735	90	5326	01AL	70.0	CZY	LS	14	61	14.0	000	14			48
WF9729	90	5350	01AL	91.0	PKM	DM	32	61	40.0	002	25			51
WF[illegible]710	90	5310	01AL	97.0	CKM	DM	00	61	[illegible]35.0	006	5			52
WF[illegible]534	90	5248	01AL	182.0	CZY	LS	35	61	210.0	030	100			49
WF[illegible]831	90	5333	01AL	12[illegible].0	CZY	LS	01	61	54.0	010	25			47
WF[illegible]933	90	5331	01AL	161.0	BRV	LS	15	61	103.0	017	27			
WF8937	90	5325	01AL	77.0	PRV	LS	04	61	109.0	006	50			53
WF8930	90	5365	01AL	93.0	CZY	LS	35	61	102.0	018	18			50
WF8938	90	5323	01AL	72.0	BRV	LS	00	61	13.0	004	12			
WF[illegible]931	90	5337	01AL	109.0	BRV	LS	35	61	50.0	010	40			50
WF9032	90	5247	01AL	167.0	BRV	LS	20	61	45.0	010	45			21
WF9037	90	5245	01AL	116.0	ERV	LS	0[illegible]	61	62.0	010	30			31
WF9031	90	5344	01AL	82.0	CZY	LS	15	61	42.0	008	42			36
WF9031	90	5341	01AL	85.0	CZY	LS	38	61	59.0	010	65			45
WF9031	90	5342	01AL	87.0	CZY	LS	20	61	30.0	010	13			53
WF9139	90	5322	01AL	48.0	TRN	LS	18	61	49.0	005	33			43
WF9131	90	5339	01AL	89.0	CZY	LS	18	61	75.0	010	75			52
WF9331	90	5336	01AL	89.0	CZY	LS	23	61	39.0	009	24			51
WF9240	90	5321	01AL	79.0	TRN	LS	07	61	325.0	035	325			48
WF9239	90	5244	01AL	89.0	TRN	LS	20	61	20.0	006	20			41
WF9239	90	5319	01AL	79.0	TRN	LS	14	61	46.0	003	14			53
WF9239	90	5320	01AL	81.0	TRN	LS	14	61	52.0	006	30			52
WF9240	90	5318	01AL	76.0	TRN	LS	01	61	129.0	020	128			51

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TABLE D.4

GENERAL SAMPLE DATA

GENERAL SAMPLE DATA

LOCATION GRID NO.	PROJ NO	OBSVR NO	SAMPLE NO.	DATE OF SAMPLE	SAMPLE TYPE	SAMPLE DPTH	SAMPLE POINT TEMP	PH AT ANALYSIS TIME	K AT ANALYSIS TIME	TOTAL DISS. SOLIDS	HARDNESS TOTAL	HARDNESS TEMP (ALKNTY)	STOR AGE DAYS	COLIF
[illegible]	90	01AL	5329HA	250952			*****	8.4	630.00	361.00	288.00	276.00		4
WF8132	90	01AL	5328FA	090953			*****	8.0	760.00	431.00	391.00	323.00		4
WF8[?]28	90	01AL	5360FA	240053			*****	8.3	680.00	412.00	351.00	254.00		2
WF8378	90	01AL	5359[?]A	150653			*****	8.1	480.00	295.00	249.00	170.00		0
WF9325	90	01AL	5358FA	130653			*****	7.9	570.00	353.00	304.00	252.00		0
[illegible]	90	01AL	5357FA	250753			*****	7.8	790.00	485.00	438.00	321.00		0
[illegible]	90	01AL	5356FA	090753			*****	8.3	520.00	320.00	280.00	240.00		0
[illegible]	90	01AL	[illegible]	260753			*****	8.3	460.00	279.00	247.00	200.00		0
[illegible]	90	01AL	5[?]27FA	160[?]52			*****	8.0	310.00	[illegible]	273.00	237.00		4
[illegible]	[illegible]	01AL	5254[?]A	270[?]1			*****	8.2	600.00	370.00	320.00	218.00		0
[illegible]	90	01AL	5353HA	150753			*****	8.0	540.00	326.00	297.00	274.00		
[illegible]	90	01AL	5352UA	290753			*****	8.3	460.00	280.00	230.00	130.00		
[illegible]	90	01AL	5351HA	250653			*****	8.0	660.00	394.00	353.00	307.00		0
[illegible]	90	01AL	5349HA	170453			*****	8.3	350.00	212.00	164.00	110.00		0
WF8739	90	01AL	5348HA	170753			*****	7.9	670.00	410.00	366.00	298.00		0
[illegible]	90	01AL	[?]367 A	000753			*****	7.6	920.00	546.00	483.00	422.00		
WF8735	90	01AL	[illegible]	1[?]0952			*****	7.9	470.00	290.00	240.00	[illegible]		
[illegible]	90	01AL	5359[?]A	270753			*****	8.1	610.00	372.00	328.00	27[?].00		2
[illegible]	90	01AL	536[?] A	130753			*****	7.8	890.00	554.00	459.00	[illegible]		2
[illegible]	90	01AL	526[?]DA	1[?]0951			*****	8.[?]	760.00	446.00	283.00	280.00		[illegible]
[illegible]	90	01AL	533[?]HA	[?]00753			*****	8.1	620.00	391.00	329.00	312.00		4
WF7933	90	01AL	5331HA	111052			*****	7.8	640.00	391.00	322.00	281.00		4
WF8937	90	01AL	5325HA	080953			*****	8.2	2400.00	1360.00	516.00	107.00		
WF1930	90	01AL	5345HA	160753			*****	7.8	570.00	340.00	310.00	249.00		0
WF8939	90	01AL	5323HA	130653			*****	8.1	700.00	446.00	263.00	211.00		0
WF8931	90	01AL	5337HA	230753			*****	8.4	740.00	497.00	252.00	185.00		[illegible]
WF9032	90	01AL	5247[?]A	120951			*****	7.9	720.00	431.00	358.00	202.00		0
WF9037	90	01AL	5265HA	110651			*****	7.8	670.00	402.00	310.00	241.00		0
WF9031	90	01AL	5344[?]A	170753			*****	7.9	670.00	419.00	345.00	314.00		2
WF9031	90	01AL	5341HA	250753			*****	7.2	1200.00	802.00	662.00	392.00		2
WF9931	90	01AL	5342EA	040853			*****	7.8	920.00	592.00	471.00	264.00		4
WF9139	90	01AL	5[?]728A	020952			*****	7.9	920.00	549.00	423.00	347.00		4
WF9131	90	01AL	5339FA	030853			*****	7.9	610.00	377.00	260.00	229.00		0
WF9231	90	01AL	5335HA	170953			*****	7.7	740.00	481.00	372.00	229.00		4
WF9240	90	01AL	5121HA	260952			*****	7.9	2300.00	1400.00	260.00	200.00		4
WF9239	90	01AL	5244HA	030651			*****	7.3	770.00	471.00	405.00	302.00		2
WF9233	90	01AL	5319HA	100653			*****	7.6	590.00	366.00	323.00	280.00		4
WF9234	90	01AL	5320HA	300952			*****	7.4	920.00	584.00	509.00	379.00		4
WF9240	90	01AL	5318HA	041052			*****	8.0	820.00	497.00	233.00	233.00		4

2581286

TABLE D.5

PRIMARY CHEMICAL DATA-1

PRIMARY CHEMICAL DATA

LOCATION GRID 50	PROJ NO	OBSV NO	SAMPLE NO.	DATE OF SAMPLE	CATIONS CA	MG	PPM NA	K	ANIONS HCO3	CO3	SO4	CL
WF8132	90	01AL	53294A	230952	51.30	38.90	25.20	4.10	266.00	6.10	52.10	35.40
WF8132	90	01AL	53288A	090653	93.20	35.60	20.00	4.20	394.00	0.0	50.60	17.50
WF8726	90	01AL	53600A	240653	62.60	35.30	12.10	[illegible]	310.00	0.0	64.20	27.20
WF8328	90	01AL	53591A	150553	30.80	36.40	7.50	[illegible]	207.00	0.0	97.50	5.80
WF8328	90	01AL	[illegible]	150653	64.10	35.00	10.70	[illegible]	307.00	0.0	49.80	3.60
WF8429	90	01AL	[illegible]	250753	105.00	47.50	8.70	[illegible]	392.00	0.0	95.50	25.40
WF8529	90	01AL	53565A	080753	70.80	25.00	9.20	1.30	293.00	0.0	51.00	3.80
WF8528	90	01AL	53558A	160753	50.90	29.20	6.20	2.20	244.00	0.0	56.40	2.80
WF8536	90	01AL	53270A	110952	66.90	25.60	6.30	4.60	289.00	0.0	46.50	1.60
[illegible]	90	01AL	53548A	230653	75.10	34.10	7.00	2.10	327.00	0.0	60.80	5.00
[illegible]	90	01AL	53538A	150753	71.10	26.90	8.20	1.30	334.00	0.0	35.80	1.60
WF8630	90	01AL	53578A	290753	31.20	37.00	7.10	1.00	159.00	0.0	102.00	10.10
WF8629	90	01AL	53511A	250653	65.70	32.50	11.40	3.30	374.00	0.0	57.60	7.70
WF8730	90	01AL	53498A	170453	15.90	30.10	10.50	3.70	159.00	0.0	56.80	4.00
WF8730	90	01AL	53488A	170753	80.60	35.30	8.70	1.40	364.00	0.0	73.30	7.30
WF8730	90	01AL	53470A	000753	135.00	35.80	17.60	1.60	515.00	0.0	51.90	33.10
WF8735	90	01AL	53260A	160952	77.60	12.50	7.90	1.60	283.00	0.0	20.00	1.60
WF8729	90	01AL	53500A	270753	77.80	32.40	10.10	27.00	340.00	0.0	60.70	7.50
WF8730	90	01AL	53468A	130753	122.00	37.60	27.00	1.90	478.00	0.0	83.70	24.80
[illegible]	90	01AL	[illegible]	110651	53.60	35.60	87.00	4.80	357.00	15.10	89.70	17.20
[illegible]	90	01AL	[illegible]	300753	61.10	37.90	22.80	5.30	381.00	0.0	46.00	1.60
[illegible]	90	01AL	53318A	111052	62.40	40.50	10.90	5.30	343.00	0.0	73.50	7.60
[illegible]	90	01AL	51259A	080457	121.00	51.30	290.00	11.00	131.00	0.0	153.00	651.00
[illegible]	90	01AL	53451A	160753	73.50	300.00	6.60	1.90	304.00	0.0	59.10	6.70
WF8938	90	01AL	53236A	130653	57.70	28.80	50.90	2.30	257.00	0.0	104.00	54.80
WF8931	90	01AL	53378A	300753	36.90	38.00	70.00	4.00	221.00	2.40	211.00	8.50
WF9032	90	01AL	52470A	120651	112.00	18.80	10.60	4.20	344.00	0.0	45.30	13.00
WF9037	90	01AL	52450A	110651	82.50	25.30	22.50	2.40	343.00	0.0	72.00	15.40
WF9031	90	01AL	53448A	170753	109.00	17.00	20.00	1.50	363.00	0.0	39.90	7.70
WF9031	90	01AL	53478A	250753	189.00	46.20	22.10	2.40	470.00	0.0	262.00	32.10
WF9031	90	01AL	53428A	040853	136.00	31.70	18.40	2.00	322.00	0.0	210.00	20.60
WF9139	90	01AL	53227A	020952	118.00	31.20	32.70	9.90	423.00	0.0	92.00	37.10
WF9131	90	01AL	53390A	030853	94.30	25.20	43.60	4.20	278.00	0.0	73.90	18.30
WF9231	90	01AL	53368A	170853	109.00	24.10	20.30	4.20	270.00	0.0	150.00	20.20
WF9240	90	01AL	53218A	260952	58.50	29.70	407.00	13.00	349.00	0.0	188.00	505.00
WF9239	90	01AL	52440A	090651	126.00	22.00	5.00	1.20	368.00	0.0	111.00	10.00
WF9239	90	01AL	53198A	100653	95.30	20.50	6.80	2.70	342.00	0.0	43.60	5.60
WF9239	90	01AL	53200A	300952	152.00	31.30	9.80	2.80	462.00	0.0	133.00	0.90
WF9240	90	01AL	53108A	041052	50.00	26.10	97.00	7.60	420.00	0.0	50.60	37.10

TABLE D.6

PRIMARY CHEMICAL DATA-2

PRIMARY CHEMICAL DATA

LOCATION GRID SQ	PROJ NO	OBSVN NO	SAMPLE NO.	DATE OF SAMPLE	MINOR CONSTITUENTS PPM F	NO3	FE	SIO2	FIELD K
WFF132	90	01AL	5324BA	250952	0.0	0.60	0.0	16.40	********
WFF132	90	01AL	5328BA	090653	0.0	1.60	0.0	11.50	********
WFR324	90	01AL	5363CA	240653	0.10	0.0	0.04	14.60	********
WFR32[illegible]	90	01AL	5359HA	150653	0.05	0.0	0.0	13.80	********
WF8324	90	01AL	5358DA	150653	0.10	0.0	0.04	15.60	********
[illegible]	90	01AL	5357HA	250753	0.0	0.0	0.04	12.90	********
WF8520	90	01AL	5356DA	080753	0.10	0.45	0.0	14.00	********
WF8578	90	01AL	5355HA	060753	0.10	0.40	0.02	12.20	********
WF8534	90	01AL	5327HA	160952	0.0	0.20	0.0	22.90	********
WF8 29	90	01AL	5354HA	230553	0.10	0.20	0.02	13.40	********
[illegible]	90	01AL	5353HA	[illegible]	0.0	0.60	0.04	16.30	********
WF8730	90	01AL	5352BA	260753	0.0	0.70	0.0	12.90	********
WF8720	90	01AL	5351HA	250653	0.0	0.20	0.06	10.60	********
WF8733	90	01AL	5349BA	170853	0.10	0.60	0.04	12.30	********
WF8730	90	01AL	5340DA	170753	0.0	0.40	0.0	15.60	********
WF8730	90	01AL	5347BA	000753	0.0	0.60	0.02	17.30	********
WF8739	90	01AL	5326BA	160952	0.0	0.60	0.0	19.90	********
WF8729	90	01AL	5350HA	270753	0.0	0.20	0.04	13.20	********
WF873C	90	01AL	5346HA	130753	0.0	0.08	0.02	13.60	********
[illegible]	90	01AL	[illegible]	130751	0.0	1.60	0.0	15.30	********
[illegible]	90	01AL	5339HA	100753	0.0	2.40	0.02	18.20	********
[illegible]	90	01AL	5331HA	111052	0.0	0.40	0.0	19.90	********
[illegible]	90	01AL	[illegible]	040957	0.02	1.60	0.0	17.20	********
WF8330	90	01AL	5345DA	160753	0.0	0.20	0.0	11.80	********
WF8930	90	01AL	5323HA	130553	0.30	0.40	0.0	20.00	********
WF8931	90	01AL	5337HA	300753	0.0	1.60	0.06	15.80	********
WF9032	90	01AL	5247HA	120551	0.0	46.00	0.0	8.60	********
WF6037	90	01AL	5245HA	110651	0.0	3.20	0.0	9.60	********
WF6031	90	01AL	5344BA	170753	0.0	0.20	0.0	15.10	********
WF9031	90	01AL	5341FA	250753	0.0	0.40	0.04	12.30	********
WF9031	90	01AL	5342BA	040853	0.0	0.40	0.04	14.30	********
WF9139	90	01AL	5322FA	020952	0.10	0.40	0.0	15.20	********
WF9131	90	01AL	5339BA	030853	0.0	0.0	0.06	20.00	********
WF9231	90	01AL	5336CA	120853	0.0	2.40	0.04	13.20	********
WF9240	90	01AL	5321BA	260952	0.80	0.0	0.0	21.30	********
WF9239	90	01AL	5244HA	090651	0.0	2.40	0.0	11.30	********
WF9239	90	01AL	5319BA	100653	0.0	12.00	0.0	15.60	********
WF9230	90	01AL	5320DA	300952	0.0	6.00	0.0	16.70	********
WF9240	90	01AL	5318BA	041052	0.60	0.40	0.0	20.60	********

TABLE D.7

CALCULATED CHEMICAL DATA-1

CALCULATED CHEMICAL DATA

LOCATION GRID SQ	PROJ NO	OBSVR NO	SAMPLE NO.	DATE OF SAMPLE	CATIONS CA	MG	EPM NA	K	ANIONS HCO3	CO3	SO4	CL
WF0132	90	01AL	53790A	250952	2.6 36%	3.2 45%	1.1 15%	0.1 1%	4.4 66%	0.1 2%	1.1 16%	1.0 15%
WF0132	90	01AL	53780A	090653	4.7 52%	3.2 35%	0.9 9%	0.1 1%	6.5 80%	0.0 0%	1.1 13%	0.5 6%
WF0328	90	01AL	53608A	240653	4.1 53%	2.9 37%	0.5 6%	0.1 1%	5.1 66%	0.0 0%	1.8 23%	0.8 10%
WF 320	90	01AL	53590A	150653	2.0 37%	3.0 55%	0.3 6%	0.0 0%	3.4 63%	0.0 0%	1.8 33%	0.2 3%
WF0320	90	01AL	53580A	150653	3.2 48%	2.9 43%	0.5 7%	0.1 1%	5.0 76%	0.0 0%	1.5 22%	0.1 1%
WF0420	90	01AL	53578A	250753	5.2 57%	3.5 38%	0.4 4%	0.0 0%	5.4 70%	0.0 0%	2.0 23%	0.7 7%
WF0520	90	01AL	53560A	080753	3.5 59%	2.1 34%	0.4 5%	0.0 0%	4.8 80%	0.0 0%	1.1 17%	0.1 1%
WF0[illegible]	90	01AL	53558A	060753	2.5 48%	2.4 46%	0.2 3%	0.1 1%	4.0 76%	0.0 0%	1.2 22%	0.1 1%
WF0514	90	01AL	53770A	160952	3.3 57%	2.1 36%	0.3 4%	0.1 1%	4.7 82%	0.0 0%	1.0 16%	0.0 0%
WF0721	90	01AL	53548A	230653	3.7 54%	2.6 40%	0.3 4%	0.1 0%	5.4 77%	0.0 0%	1.5 20%	0.1 2%
[illegible] 723	90	01AL	53530A	150753	3.5 56%	2.4 37%	0.4 5%	0.0 0%	5.5 87%	0.0 0%	0.7 11%	0.0 0%
[illegible] 730	90	01AL	53520A	290753	1.6 31%	3.0 61%	0.3 6%	0.0 0%	2.6 51%	0.0 0%	2.1 42%	0.3 5%
[illegible] 723	90	01AL	53510A	250[illegible]53	4.3 57%	2.7 35%	0.5 6%	0.1 1%	6.1 81%	0.0 0	1.2 15%	0.2 2%
WF0730	90	01AL	53490A	170653	6.4 [illegible]	2.5 6[illegible]%	0.5 11[illegible]	0.1 2%	2.6 66%	0.0 0%	1.2 30%	0.1 2%
WF0730	90	01AL	53480A	170753	4.4 57[illegible]	2.9 37%	0.4 4%	0. 0%	6.0 77%	0.0 0%	1.5 19%	0.2 2%
WF0730	90	01AL	53470A	080753	[illegible]	2.9 20%	0.8 7%	[illegible] 0%	8.4 80%	0.0 0%	1.1 10%	0.9 8%
WF0729	90	01AL	53260A	160952	3.6 7[illegible]	1.0 19%	0.3 6%	0.0 0%	4.8 87%	0.0 0%	0.6 11%	0.0 0%
WF0729	90	01AL	53500A	270753	3.9 56%	2.7 34%	0.6 5%	0.7 6%	5.6 79%	0.0 0%	1.3 17%	0.2 2%
WF0730	90	01AL	53460A	130753	6.1 [illegible]	3.1 29%	1.2 11%	0.0 0%	7.8 75%	0.0 0%	1.7 16%	0.7 6%
WF 134	90	01AL	52440A	130651	2.7 28%	2.9 30%	3.8 39%	0.1 1%	5.2 67%	0.5 5%	1.9 21%	0.5 5%
WF[illegible]31	90	01AL	53340A	300753	5.6 44%	3.1 40%	1.0 12%	0.1 1%	6.2 85%	0.0 0%	1.0 13%	0.0 0%
WF[illegible]3[illegible]	90	01AL	53310A	111052	3.1 42%	3.3 44%	0.8 11%	0.1 1%	5.6 77%	0.0 0%	1.5 21%	0.1 1%
WF0937	90	01AL	53250A	090453	6.1 26%	4.2 18%	12.6 54%	0.3 1%	2.1 9%	0.0 0%	3.2 13%	18.4 77%
WF 930	90	01AL	53450A	160753	3.7 12%	25.2 86%	0.3 1%	0.0 0%	5.0 77%	0.0 0%	1.2 19%	0.2 2%
WF4938	90	01AL	53238A	130653	2.9 36%	2.6 31%	2.2 27%	0.1 0%	4.2 53%	0.0 0%	2.2 27%	1.5 19%
WF9131	90	01AL	53370A	300753	1.8 22%	3.2 39%	3.0 37%	0.1 1%	3.6 43%	0.1 0%	4.4 52%	0.2 2%
WF9032	90	01AL	52470A	120651	5.6 72%	1.5 20%	0.5 5%	0.1 1%	5.6 73%	0.0 0%	0.9 12%	0.4 4%
WF9037	90	01AL	52650A	110651	4.1 56%	2.1 28%	1.0 13%	0.1 0%	5.6 73%	0.0 0%	1.5 19%	0.4 5%
WF9031	90	01AL	53440A	170753	5.4 70%	1.4 18%	0.9 11%	0.0 0%	6.3 81%	0.0 0%	1.2 16%	0.2 2%
WF0031	90	01AL	53410A	250753	9.4 66%	3.8 26%	1.0 6%	0.1 0%	7.0 55%	0.0 0%	5.5 39%	0.9 6%
WF9031	90	01AL	53420A	040853	6.8 66%	2.6 25%	0.8 7%	0.1 0%	5.3 51%	0.0 0%	4.4 42%	0.6 5%
WF9130	90	01AL	53228A	020952	5.9 55%	2.6 25%	1.4 13%	0.3 2%	6.9 70%	0.0 0%	1.9 19%	1.0 10%
WF9131	90	01AL	53307A	030853	2.7 39%	2.1 30%	1.9 27%	0.1 1%	4.6 68%	0.0 0%	1.5 23%	0.5 7%
WF0231	90	01AL	51360A	120653	5.4 64%	2.0 23%	0.9 10%	0.1 1%	4.6 55%	0.0 0%	3.1 37%	0.6 6%
WF9240	90	01AL	53210A	260252	2.9 12%	2.4 10%	17.7 75%	0.3 1%	5.7 23%	0.0 0%	3.9 16%	14.2 59%
WF9239	90	01AL	52480A	050651	6.3 75%	1.8 21%	0.2 2%	0.0 0%	6.0 69%	0.0 0%	2.3 26%	0.3 3%
WF9239	90	01AL	53190A	100653	4.8 69%	1.7 24%	0.3 4%	0.1 1%	5.6 81%	0.0 0%	0.9 13%	0.2 2%
WF9239	90	01AL	53208A	300952	7.6 71%	2.6 24%	0.4 3%	0.1 0%	7.6 71%	0.0 0%	2.8 26%	0.2 1%
WF9240	90	01AL	53180A	041052	2.5 27%	2.1 23%	4.2 48%	0.2 2%	6.9 76%	0.0 0%	1.1 11%	1.0 11%

TABLE D.8

CALCULATED CHEMICAL DATA-2

CALCULATED CHEMICAL DATA

LOCATION GRID NO	PROJ NO	DISVD NO	SAMPLE NO.	DATE OF SAMPLE	PRINCIPAL CATION	PRINCIPAL ANION	TOTAL CATIONS (EPM)	TOTAL ANIONS (EPM)	EPM % DIFF
WF8132	90	01AL	5329PA	250952	MG	HCO3	6.98	6.60	5.85
WF8132	90	01AL	5328BA	090653	CA	HCO3	8.79	8.03	9.40
WF8328	90	01AL	5360DA	240853	CA	HCO3	7.64	7.60	0.52
WF8328	90	01AL	5359BA	150453	MG	HCO3	5.35	5.38	0.59
WF8328	90	01AL	5358BA	150453	CA	HCO3	6.61	6.59	0.41
WF8429	90	01AL	5357BA	290753	CA	HCO3	9.15	9.13	0.26
WF8529	90	01AL	5356[illegible]	080753	CA	HCO3	5.98	5.99	0.20
WF8628	90	01AL	5355[illegible]	060753	CA	HCO3	5.20	5.26	1.10
WF8534	90	01AL	5327[illegible]A	110952	CA	HCO3	5.78	5.75	0.53
WF8628	90	01AL	5354BA	230653	CA	HCO3	6.96	6.98	0.31
WF8729	90	01AL	5353DA	150753	CA	HCO3	6.31	6.27	0.70
WF8630	90	01AL	5352DA	220753	MG	HCO3	4.95	5.02	1.28
WF8629	90	01AL	5351DA	250653	CA	HCO3	7.58	7.55	0.39
WF8730	90	01AL	5349BA	170653	MG	HCO3	3.82	3.91	2.39
WF8730	90	01AL	5348DA	170753	CA	HCO3	7.74	7.70	0.44
WF8770	90	01AL	5347MA	000753	CA	HCO3	10.49	10.44	0.21
WF8735	90	01AL	5326MA	160952	CA	HCO3	5.29	5.28	0.28
WF8735	90	01AL	5350MA	270753	CA	HCO3	7.08	7.05	0.86
WF8730	90	01AL	5348FA	130753	CA	HCO3	10.40	10.41	0.03
WF8934	90	01AL	5248HA	110651	NA	HCO3	9.51	8.73	8.87
WF8931	90	01AL	5339EA	300753	CA	HCO3	7.68	7.29	5.44
WF8931	90	01AL	5331HA	111052	MG	HCO3	7.40	7.23	2.34
WF8937	90	01AL	5125BA	080953	NA	CL	23.25	23.71	2.00
WF8930	90	01AL	5345PA	160753	MG	HCO3	29.17	6.41	355.36
WF8935	90	01AL	5323BA	130453	CA	HCO3	7.52	7.03	5.45
WF8931	90	01AL	5437[illegible]	303753	MG	SO4	6.19	6.36	2.13
WF9032	90	01AL	5247BA	120651	CA	HCO3	7.70	7.72	0.25
WF9037	90	01AL	5245BA	110651	CA	HCO3	7.24	7.61	5.11
WF9031	90	01AL	5344DA	170753	CA	HCO3	7.75	7.75	0.00
WF9031	90	01AL	5361BA	250753	CA	HCO3	14.25	14.22	0.25
WF9031	90	01AL	5342DA	040853	CA	HCO3	10.24	10.24	0.01
WF9139	90	01AL	5322BA	020952	CA	HCO3	10.11	9.90	2.08
WF9131	90	01AL	5339DA	030853	CA	HCO3	6.79	6.63	2.38
WF9231	90	01AL	5336DA	120853	CA	HCO3	8.41	8.30	1.29
WF9240	90	01AL	5321BA	260952	NA	CL	23.30	23.87	2.06
WF9239	90	01AL	5244BA	090651	CA	HCO3	8.34	8.66	3.82
WF9239	90	01AL	5319BA	100653	CA	HCO3	6.81	6.86	0.86
WF9239	90	01AL	5320BA	300952	CA	HCO3	10.68	10.63	0.22
WF9240	90	01AL	5318BA	041052	NA	HCO3	9.05	8.99	0.70

TABLE D.9

CALCULATED CHEMICAL DATA-3

CALCULATED CHEMICAL DATA

LOCATION WELL NO	PROJ NO	DRAWN NO	SAMPLE NO.	DATE OF SAMPLE	RATIOS EPM CA/MG	CA/NA	CA/K	MG/NA	MG/K	NA/K	HCO3/CO3	HCO3/SO4	HCO3/CL	CO3/SO4	CO3/CL	SO4/CL
WF0132	90	01AL	5329BA	250952	0.80	7.34	19.43	2.92	24.53	8.40	30.42	4.02	4.37	0.13	0.1[illegible]	1.09
WF0132	90	01AL	5328LA	090453	1.47	5.35	43.30	3.63	29.40	8.10	******	6.13	13.09	0.00	0.00	2.[illegible]
WF0298	90	01AL	5360BA	240453	1.42	7.83	46.05	5.52	32.43	5.88	******	2.90	6.63	0.00	0.00	2.29
WF0328	90	01AL	5359BA	150653	0.66	6.09	40.53	9.18	73.15	7.97	******	1.86	20.79	0.00	0.00	11.[illegible]
WF0328	90	01AL	5358BA	150653	1.11	6.88	44.67	6.19	40.19	6.50	******	3.46	49.58	0.00	0.00	14.37
WF0429	90	01AL	5357BA	250753	1.50	13.85	128.06	9.24	85.41	9.26	******	3.23	8.97	0.00	0.00	2.78
WF0529	90	01AL	5356BA	080753	1.72	9.91	106.26	5.77	61.84	10.72	******	4.47	44.83	0.00	0.00	17.93
WF0575	90	01AL	5355BA	0?0753	1.07	12.70	45.14	12.01	42.68	3.55	******	3.41	50.66	0.00	0.00	14.[illegible]
WF0538	90	01AL	5327BA	140952	1.59	12.19	50.20	7.69	31.68	4.12	******	6.89	105.01	0.00	0.00	21.[illegible]
WF0629	90	01AL	5354BA	230553	1.34	11.34	69.77	8.49	52.21	6.15	******	3.64	38.02	0.00	0.00	16.31
WF0627	90	01AL	5353BA	150753	1.49	9.95	109.71	6.67	71.68	10.72	******	7.39	121.36	0.00	0.00	16.43
WF0730	90	01AL	535?BA	270753	0.51	5.04	23.42	9.86	46.10	4.71	******	1.23	9.15	0.00	0.00	7.46
WF0729	90	01AL	5731BA	250653	1.62	8.73	51.26	5.39	31.67	5.87	******	5.11	26.24	0.00	0.00	5.52
WF0710	90	01AL	5349BA	170353	0.32	1.74	8.30	5.42	26.16	4.82	******	2.20	23.11	0.00	0.00	10.43
WF0730	90	01AL	5348BA	170753	1.52	11.69	123.48	7.67	81.08	10.56	******	3.91	20.99	0.00	0.00	7.42
WF0730	90	01AL	5347BA	080753	2.29	8.80	164.62	3.85	71.95	18.70	******	7.81	9.05	0.00	0.00	1.16
WF0735	90	01AL	5326BA	140952	3.76	11.30	94.87	2.99	25.12	8.39	******	7.96	102.83	0.00	0.00	12.92
WF0??	90	01AL	5350BA	270753	1.47	8.44	5.62	6.07	3.86	8.64	******	4.41	26.36	0.00	0.00	5.24
WF0730	90	01AL	534?BA	130753	1.97	5.19	125.28	2.63	63.63	24.15	******	4.80	11.21	0.00	0.00	7.49
WF0834	90	01AL	5248BA	110651	0.91	0.71	21.79	0.77	23.85	30.81	11.63	7.13	12.97	0.27	1.04	3.45
WF0931	90	01AL	5338BA	300753	1.11	3.41	25.46	3.17	22.99	7.25	******	6.52	130.44	0.00	0.30	21.[illegible]
WF0937	90	01AL	5131IA	111052	0.93	3.79	22.97	4.05	24.57	6.06	******	3.67	76.70	0.00	0.00	20.48
WF0927	90	01AL	5125BA	080953	1.45	0.49	21.82	0.33	15.00	44.82	******	0.67	0.12	0.00	0.00	[illegible].17
WF0930	90	01AL	5345BA	160753	0.15	12.78	75.40	87.69	517.50	5.91	******	4.05	2?.38	0.00	0.00	6.52
WF0930	90	01AL	5323BA	130653	1.22	1.30	48.95	1.07	40.26	37.62	******	1.93	2.73	0.00	0.00	1.40
WF0931	90	01AL	5337BA	200753	0.58	0.61	18.00	1.05	31.27	29.75	45.28	0.82	15.12	0.02	0.33	13.33
WF9037	90	01AL	5247BA	120651	3.61	12.13	52.03	3.35	14.39	4.20	******	5.98	15.38	0.00	0.00	2.57
WF8037	90	01AL	5245BA	110651	1.98	4.21	67.07	2.13	33.90	15.94	******	3.75	12.95	0.00	0.00	3.45
WF9031	90	01AL	5344BA	170753	3.09	6.25	141.70	1.01	30.46	22.67	******	5.03	20.92	0.00	0.00	5.74
WF?031	90	01AL	5341BA	250753	2.40	9.62	153.65	3.95	61.90	15.65	******	1.44	8.60	0.00	0.00	6.03
WF9031	90	01AL	5342BA	040653	2.60	6.40	132.67	3.26	50.96	15.64	******	1.21	9.00	0.00	0.00	7.45
WF0139	90	01AL	5322BA	070952	2.29	4.21	23.26	1.83	10.13	5.53	******	3.62	6.63	0.00	0.00	1.63
WF0131	90	01AL	5339BA	030653	1.31	1.43	25.22	1.09	19.29	17.65	******	2.97	8.86	0.00	0.00	2.98
WF0231	90	01AL	5336BA	120553	2.74	6.16	50.64	2.25	18.45	8.22	******	1.46	8.03	0.00	0.00	5.40
WF0240	90	01AL	5321BA	260952	1.20	0.16	8.70	0.14	7.35	53.22	******	1.46	0.40	0.00	0.00	0.27
WF0239	90	01AL	5244BA	090651	3.46	20.92	204.87	8.32	58.95	7.08	******	2.61	21.39	0.00	0.00	8.29
WF0239	90	01AL	5319BA	100653	2.82	16.05	68.87	5.70	24.41	4.28	******	6.18	35.51	0.00	0.00	5.75
WF0239	90	01AL	5320BA	300952	2.95	17.80	105.92	6.04	35.94	5.95	******	2.73	30.93	0.00	0.00	14.23
WF0240	90	01AL	5318BA	041052	1.18	0.59	12.86	0.51	11.04	21.70	******	6.53	6.58	0.00	0.00	1.07

APPENDIX E GROUND WATER ZONATION

E.1 Introduction

The purpose of the investigation was to ascertain whether specific geological horizons had control over the chemistry of the water passing through them and as such whether they led to the production of any zonation. Thus it was necessary to deduce the geological horizon from which a sample was taken. Unfortunately, this was not possible in absolute terms since there was no record of the sampling depth of individual samples, or of casing depths, so it was necessary to use other guides. These are discussed in Appendix G.

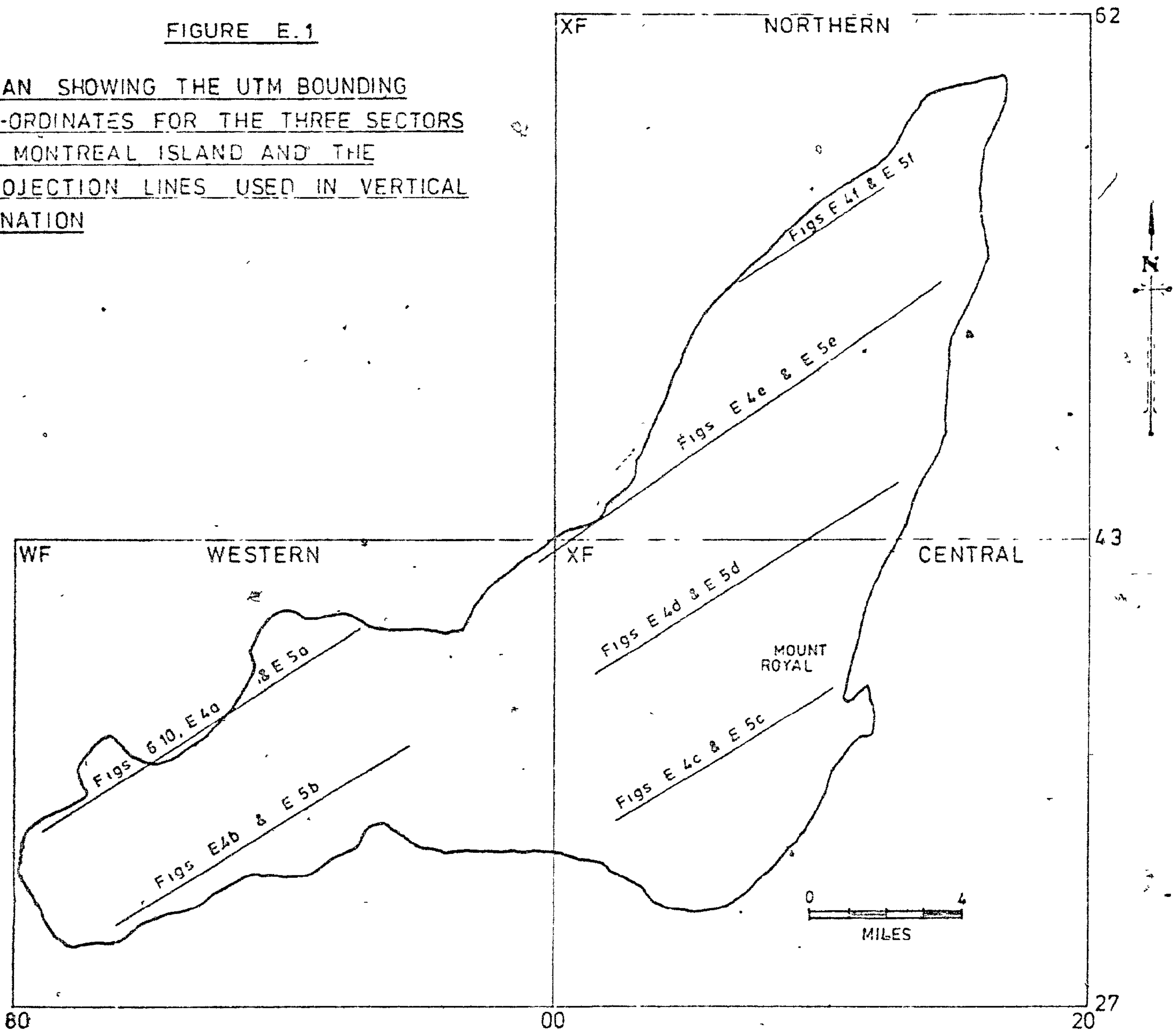
For the study of possible hydrogeochemical zonation, the Island was divided into three sectors. These western, central and northern sectors each contain different geology. By a coincidence the computer retrieval of the data was printed-out in three UTM sectors conforming quite closely to the geological zones (Fig. E.1).

Since zonation is three dimensional, the distribution of ions was examined in both horizontal and vertical planes. A brief summary of the chemical sub-groups is supplied for each sector with reference to both chemical and spatial considerations, and a short description of the important features is given.

An integrated review has been presented in section 6.5. A

FIGURE E.1

PLAN SHOWING THE UTM BOUNDING CO-ORDINATES FOR THE THREE SECTORS OF MONTREAL ISLAND AND THE PROJECTION LINES USED IN VERTICAL ZONATION



correlation of chemical facies with the depth of the source has been given in Table 6.2.

E.2 Horizontal Zonation of Anions

E.2.1 Western Sector - 46 analyses (Figure E.2)

37 HCO_3^-	36 A_1 and 1 A_2	For coding see Table E.1
5 $HCO_3^- + SO_4^{2-}$	5 A'_1	
1 $HCO_3^- + Cl^-$	1 A'_2	
1 $SO_4^{2-} + HCO_3^-$	1 B'_1	
2 Cl^-	1 C_1 and 1 C_2	

Bicarbonate predominates in the western sector and except for five A'_1 and one B'_1, sample the entire area west of Pointe Claire is of bicarbonate type. The only B'_1 sample ($SO_4^{2-} + HCO_3^-$) was close to the Black River/Chazy contact, and perhaps marks a sulphate rich layer (magnesium is also quite common at this point (Fig. E.2).

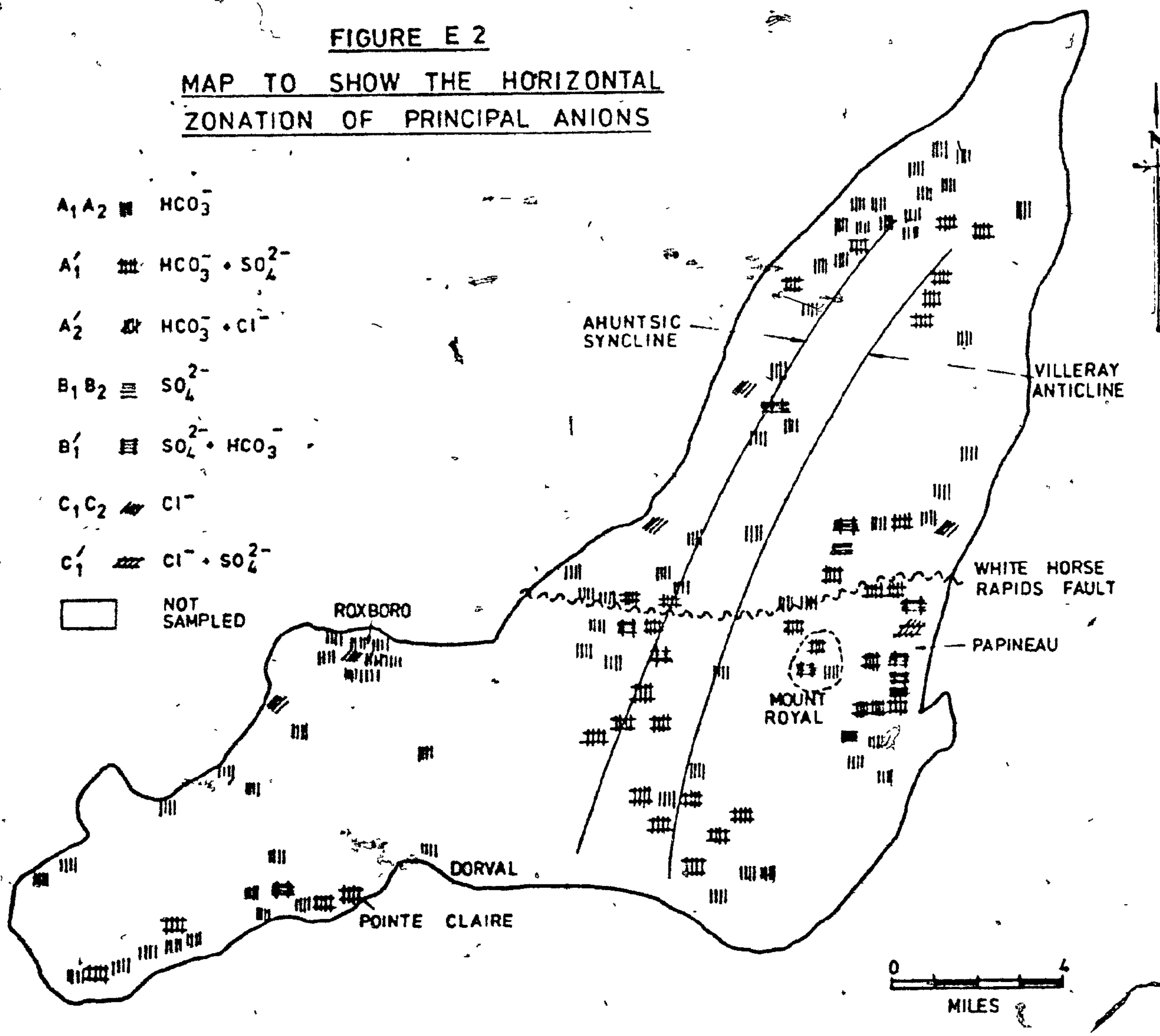
In Roxboro (Fig. 2.1 no. 17) there is a chloride water (sample no. 5321) and two samples with chloride secondary to bicarbonate (sample no. 5316 and 5317) in an otherwise purely bicarbonate area.

E.2.2 Central Sector - 44 analyses (Figure E.2)

14 HCO_3^-	12 A_1 and 2 A_2
21 $HCO_3^- + SO_4^{2-}$	20 A'_1 and 1 A''_1
1 $HCO_3^- + Cl^-$	1 A'_2
2 SO_4^{2-}	2 B_1

FIGURE E 2

MAP TO SHOW THE HORIZONTAL ZONATION OF PRINCIPAL ANIONS



CATIONS

GROUP	I		II		III	
subgroup	I_1	I_2	II_1	II_2	III_1	III_2
in meq/l	Ca>Mg>Na	Ca>Na>Mg	Mg>Ca>Na	Mg>Na>Ca	Na>Ca>Mg	Na>Mg>Ca

Prefix of [1] to cation in subgroup I_1A_1 = $rCa:rMg<2.0$
Prefix of [2] to cation in subgroup I_1A_1 = $rCa:rMg$ 2.0-3.0
Prefix of [3] to cation in subgroup I_1A_1 = $rCa/rMg>3.0$

Suffix of ' to anion group means r ratio between the two main anions is <2.0
Suffix of '' to anion group means r ratio between all the anions is <2.0
Suffix of '' to cation group means r ratio between all the cations is <1.5

r denotes values in meq/l

<u>Example</u> (no. 5214) $^{2}I_1A_1'$

	meq/l		
Ca	8.5	Ca>Mg>Na	Group I, subgroup 1 = I_1
Mg	3.2		
Na	1.1		
HCO_3	7.9	$HCO_3>SO_4>Cl$	Group A, subgroup 1 = A_1
SO_4	4.5	$rCa:rMg = 2.67$	[2]prefix to cation in subgroup I_1A_1 = $^{2}I_1$
Cl	0.9	$rHCO_3:rSO_4 = 1.75$	'suffix to anion group = A_1'; whole = $^{2}I_1A_1'$

ANIONS

Group	Subgroup (in meq/l)	
A	A_1	$HCO_3>SO_4>Cl$
A	A_2	$HCO_3>Cl>SO_4$
B	B_1	$SO_4>HCO_3>Cl$
B	B_2	$SO_4>Cl>HCO_3$
C	C_1	$Cl>SO_4>HCO_3$
C	C_2	$Cl>HCO_3>SO_4$

TABLE E.1

CODING OF CHEMICAL GROUPING

5 $SO_4^{2-} + HCO_3^-$	5 B_1'	For coding see Table E.1
1 $Cl^- + SO_4^{2-}$	1 C_1'	

The bicarbonate radical, by itself, is secondary to the A_1', $(HCO_3^- + SO_4^{2-})$, type, and there is not any single location in this area where bicarbonate alone has a continuous coverage. Its greatest frequency of occurrence is to the northwest of the mountain. An $HCO_3^- + SO_4^{2-}$ zone is found about three miles west of Mount Royal, thence continuing in an arc to the southeast for about four miles (Fig. E.2). East of the mountain is the highest number of B_1', $(SO_4^{2-} + HCO_3^-)$, species found in one area and they stretch for about two miles south southwest from the vicinity of Papineau (Fig. 2.1, no.18) between Sherbrooke (Fig. 2.1 and no. 19) and Notre Dame (Fig. 2.1 no. 20). The samples do not come from a single horizon, but the proximity of the Utica Shale is significant (Fig. 3.1). This is because shale has more sulphide, in the form of pyrite, than does limestone, and oxidation of the pyrite, would produce sulphate, thus giving a higher sulphate content in this kind of lithology. The Upper Trenton has a moderate abundance of shale layers which could contribute to the sulphate concentration. It is possible that the sulphate is an intermediate stage in a flow line originating on the mountain, and ending near the periphery of the Island, since chloride waters appear further along the line. This, however, is unlikely because the distances involved are too small for a natural development by gradual solution.

E.2.3 Northern Sector - 53 analyses (Figure E.2)

36 HCO_3^-	32 A_1 and 4 A_2	For coding see Table E.1
11 $HCO_3^- + SO_4^{2-}$	9 A_1' and 2 A_1''	
2 $SO_4^{2-} + HCO_3^-$	1 B_1' and 1 B_1''	
1 SO_4^{2-}	1 B_2	
1 $Cl^- + SO_4^{2-}$	1 C_1''	
2 Cl^-	1 C_1 and 1 C_2	

Bicarbonate is the most abundant ion here and forms an extensive zone to the northwest of this sector. In the middle part of this sector, on the Villeray anticline (Fig. 3.1), there is an $HCO_3^- + SO_4^{2-}$ zone associated with the Trenton. There is no chloride however, which may indicate that the folding was sufficiently gentle to preclude fractures from connecting with water at depth. The only chloride which does occur is on the periphery of the Island at various depths. Though the distances are again small, they could represent the chloride stage of a flow line which may or may not have originated on the Island.

E.3 Horizontal Zonation of Cations

E.3.1 Western Sector - 46 analyses (Figure E.3)

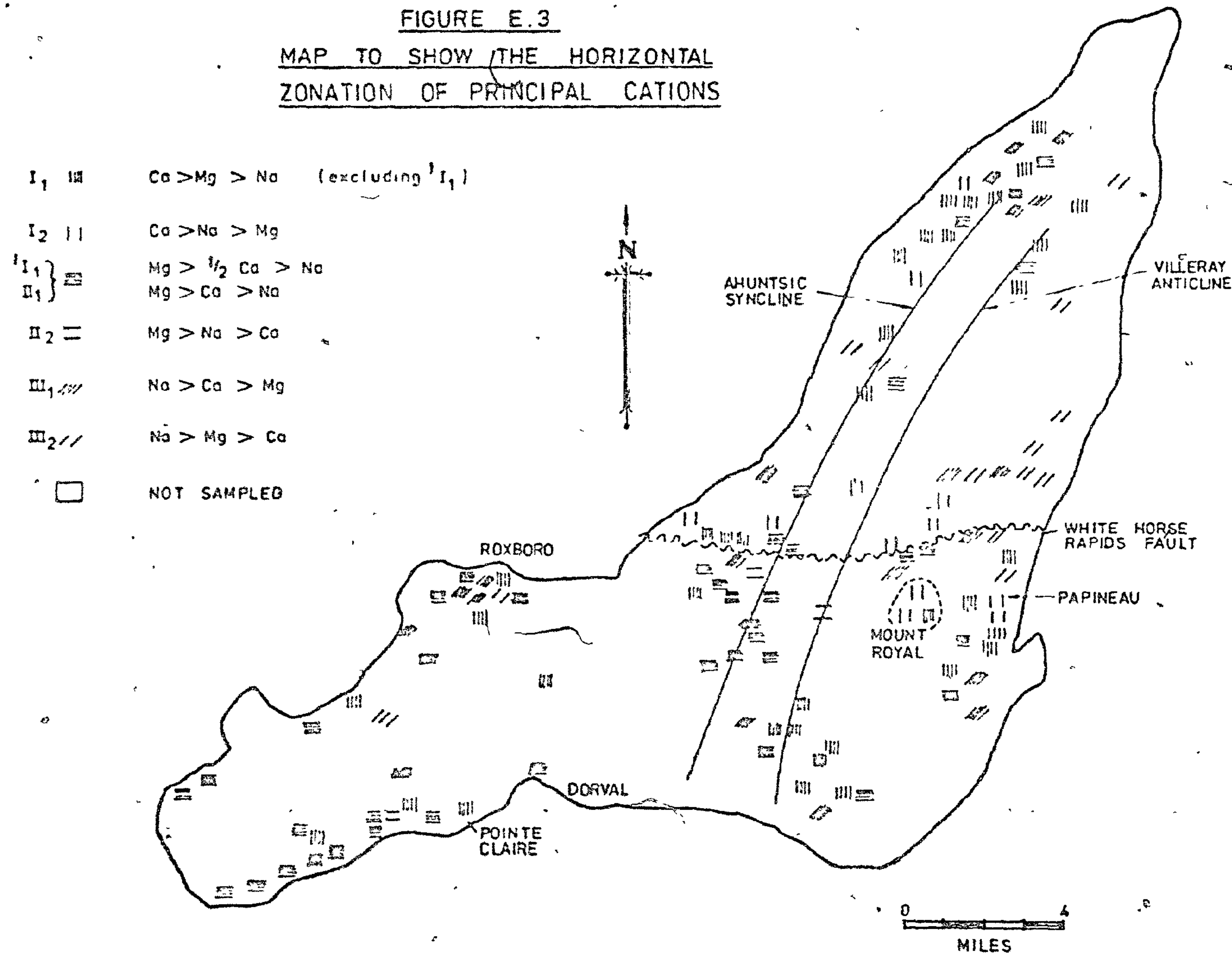
33 I	$18^1 I_1$	Ca > Mg > Na
	$2^1 I_1'$	
	$6^2 I_1$	
	$7^3 I_1$	
7 II	6 II_1	Mg > Ca > Na
	1 II_2	Mg > Na > Ca
6 III	4 III	Na > Ca > Mg
	1 III_2	Na > Mg > Ca
	1 III_2'	

For coding see Table E.1

The most noticeable feature here is that in the Beekmantown outcrop area (Fig. 3.1) all samples except one have an rCa:rMg ratio of less than 2.0, and no sample is sodium-rich (Fig. E.3). This shows a convincing geological control over water quality. Even the Pointe Claire fault fails to produce any sodium water on the south side, but further north close to the Black River/ Chazy contact two such samples are found. Sodium-rich water occurs in the vicinity of Roxboro, at about 150 feet depth, and underlies a shallow calcium (bicarbonate) zone. It is caused either by solution of sodium minerals, or by base exchange of the overlying calcium ions with sodium ions left after marine inundation, or introduced from depth by virtue of the Ile Bizard fault.

FIGURE E.3

MAP TO SHOW THE HORIZONTAL ZONATION OF PRINCIPAL CATIONS



More comprehensive sampling would be useful.

E.3.2 Central sector - 44 analyses (Figure E.3)

29 I	4 I_1	Ca > Mg > Na	
	$10^1 I_1$		
	$6^2 I_1$		
	$5^3 I_1$		
	4 I_2	Ca > Na > Mg	
6 II	3 II_1	Mg > Ca > Na	For coding see Table E.1
	1 II_1''		
	1 II_2	Mg > Na > Ca	
	1 II_2''		
9 III	6 III_1	Na > Ca > Mg	
	3 III_2	Na > Mg > Ca	

The notable feature of this sector is that sodium becomes more abundant than in the western sector. This is shown by the increase in number of samples from the I_2 and III groups. Water from these groups was obtained from the northeast part of this sector, in the area near Mount Royal (Fig. E.3). Although magnesium is not as common overall as in the western sector, it is still prominent in a zone about three miles west southwest of Mount Royal (the associated anion group tends to be $HCO_3^- + SO_4^{2-}$, the A'_1 group). With the decline of magnesium there is also an increase in the number of samples where calcium is the only main cation, represented by groups I_1, $^2I_1$, $^3I_1$ and I_2. Calcium is found throughout this sector, but there is a relatively unbroken zone to the southwest of Mount Royal.

E.3.3 Northern Sector - 53 analyses (Figure E.3)

33 I	7 $^1I_1$		
	1 $^1I_1''$		
	8 $^2I_1$	Ca > Mg > Na	For coding see Table E.1
	10 $^3I_1$		
	7 I_2	Ca > Na > Mg	
1 II	1 II_1	Mg > Ca > Na	
19 III	7 III_1	Na > Ca > Mg	
	2 III_1''		
	10 III_2	Na > Mg > Ca	

The trend of an increase in sodium which was outlined in the previous sector, continues here. Samples with sodium as the main cation account for 19 of the 53 samples ie. 36% as against 13% and 20% for the western and central sectors respectively. They were obtained essentially from two areas. The larger of the two is on the eastern side of the Island running from the north and east of Mount Royal to Pointe-aux-Trembles (Fig. E.3). It is characteristic of this sodium area that magnesium exceeds calcium as the no. 2 cation in most cases, ie. the III_2 group. The second zone is in the north of the Island, due west of Pointe-aux-Trembles. Here calcium is the no. 2 cation, the III_1 group, though there are two samples at the eastern margin of the zone where the ratio between calcium and magnesium is less than 2.0, which might show a transition between the two zones.

Magnesium is of little importance in this sector as illustrated by the paucity of samples from the II group and $^1I_1$ subgroup, only 17% of the total. This is explicable if one considers that the Beekmantown is now about 1000 feet below ground level, and that other sources of magnesium, eg. the Pamelia, are about 700 feet below the surface, so that any water moving upward from depth into the Trenton rocks of this sector has a chemistry reflecting both the upper calcareous horizons and the increasingly abundant shale intercalations which contribute to the sodium content.

E.4 Vertical Zonation of Anions

Vertical zonation is possible due to the relatively low rate of vertical movement. Vertical permeability is generally poorer than horizontal permeability. This leads to a low rate of vertical movement of water through a rock unit, so that distinct chemical zones, related to the enclosing medium, have a chance to form without allochthonous water mixing and causing indefinite or blurred boundaries to occur. In this study, since the exact sample depth was unknown it was assumed that contributions to the sampled bore hole could occur throughout its length. This automatically detracted from exact zoning, but nevertheless enabled an approach to be made, see Appendix G.

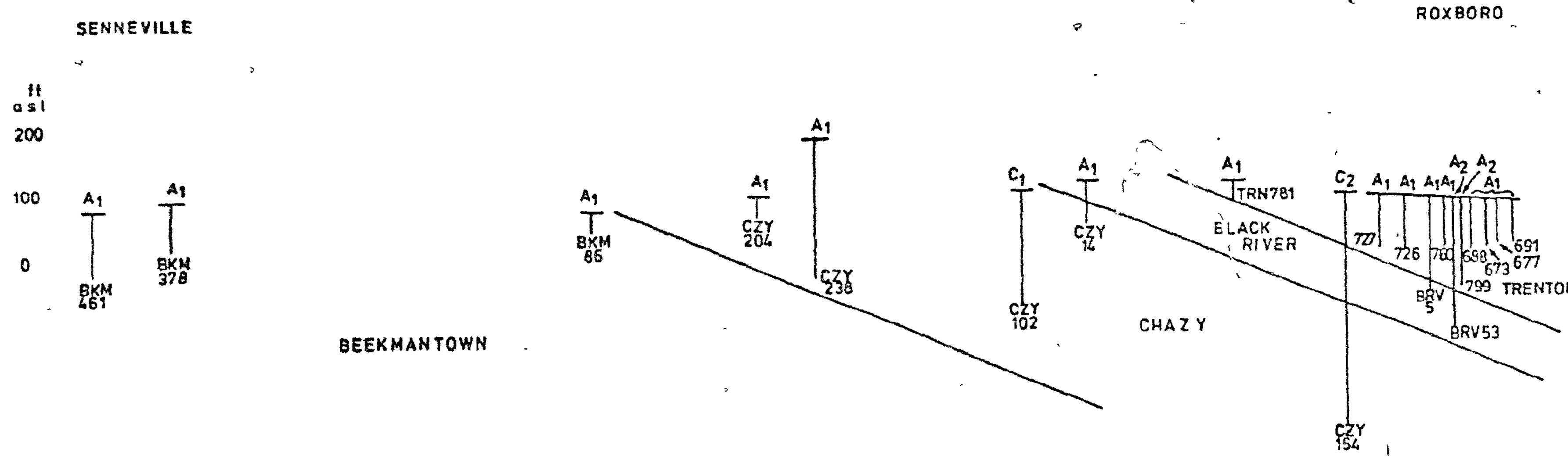
E.4.1 Western sector - 45 analyses (Figures E.4 a and b)

36 HCO_3^-	35 A_1 and 1 A_2	For coding see Table E.1
5 $HCO_3^- + SO_4^{2-}$	5 A'_1	
1 $HCO_3^- + Cl^-$	1 A'_2	
1 $SO_4^{2-} + HCO_3^-$	1 B'_1	
2 Cl^-	1 C_1 and 1 C_2	

Bicarbonate, as the HCO_3^-, A_1 group, predominates in the western part of this sector, but especially so in the Beekmantown and lowest 100 feet of the Chazy, where in only two samples out of 21 is sulphate at all important as the $HCO_3^- + SO_4^{2-}$, A'_1, group. Both of these are associated with magnesium.

In the Roxboro area (Fig. 2.1 no. 17) the basic unbroken bicarbonate zone is located by relatively shallow holes less than 100 feet deep, tapping the lowest 150 feet of the Trenton, but it overlies a deeper chloride zone represented by samples no. 5316 (A'_2), 5317 (A_2) and 5321 (C_2), from depths of 189 feet, 138 feet and 325 feet respectively. All three samples are sodium-rich. The

FIGURE E.4a
SECTION TO SHOW VERTICAL ZONATION OF PRINCIPAL ANIONS



HORIZONTAL SCALE 1 / 64,000

A_1 ---- CHEMICAL CLASSIFICATION (SEE TABLE 6.1)

---- TOP OF HOLE IN FEET ASL.

---- BOTTOM OF HOLE IN FEET ASL.

BKM 461 ---- GROUP & DEPTH BELOW TOP OF GROUP IN WHICH HOLE ENDS

SEE ALSO APPENDIX E

A_1 & A_2 = HCO_3^-

A_1' = HCO_3^- + SO_4^{2-}

A_2' = HCO_3^- + Cl^-

B_1 & B_2 = SO_4^{2-}

B_1' = SO_4^{2-} + HCO_3

B_2' = SO_4^{2-} + Cl

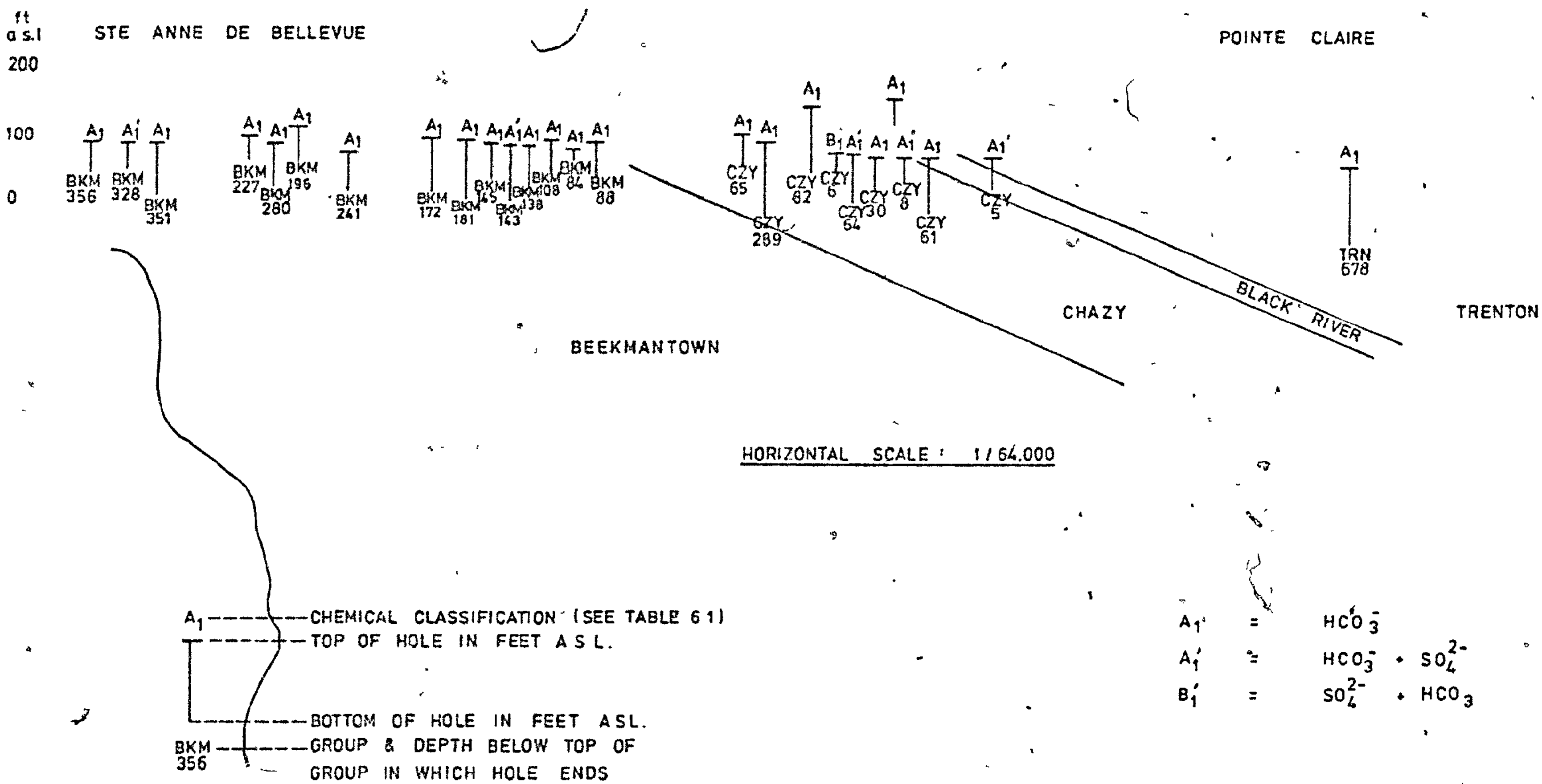
C_1 & C_2 = Cl^-

C_1' = Cl^- + SO_4^{2-}

C_2' = Cl^- + HCO_3^-

FIGURE E 4b

SECTION TO SHOW VERTICAL ZONATION OF PRINCIPAL ANIONS



Ile Bizard fault runs just to the south of this area, so it is possible that sodium chloride water from depth is afforded a passage towards the surface. Sample no. 5321 is the deepest and has most chloride. Sample no. 5316 is the next deepest with the second value for chloride while sample no. 5317 is the shallowest and has least chloride, though still significant. The respective $rHCO_3:rCl$ values are 0.40, 1.00, and 2.54, which shows the lessening effect of upward seepage from the fault towards the surface.

The contact of the Black River and Chazy Groups is marked by three samples of the $HCO_3^- + SO_4^{2-}$, A'_-, type, and one of the $SO_4^{2-} + HCO_3^-$, B'_1, type (Fig. E.4b). This shows the presence of a sulphate rich horizon.

E.4.2 <u>Central Sector - 39 analyses</u> (Figures E.4 c and d)

11 HCO_3^-	10 A_1 and 1 A_2	
20 $HCO_3^- + SO_4^{2-}$	19 A'_1 and 1 A''_1	
2 SO_4^{2-}	2 B_1	For coding
5 $SO_4^{2-} + HCO_3^-$	5 B'_1	see Table E.1
1 $Cl^- + SO_4^{2-}$	1 C'_1	

The number of samples in which bicarbonate is the single main anion, HCO_3^-, A_1 group, diminishes towards the east. Instead the sulphate content of the ground water increases as shown by the number of samples from the A'_1 and B groups, due to the increasing influence of

FIGURE E 4c

SECTION TO SHOW VERTICAL ZONATION OF PRINCIPAL ANIONS

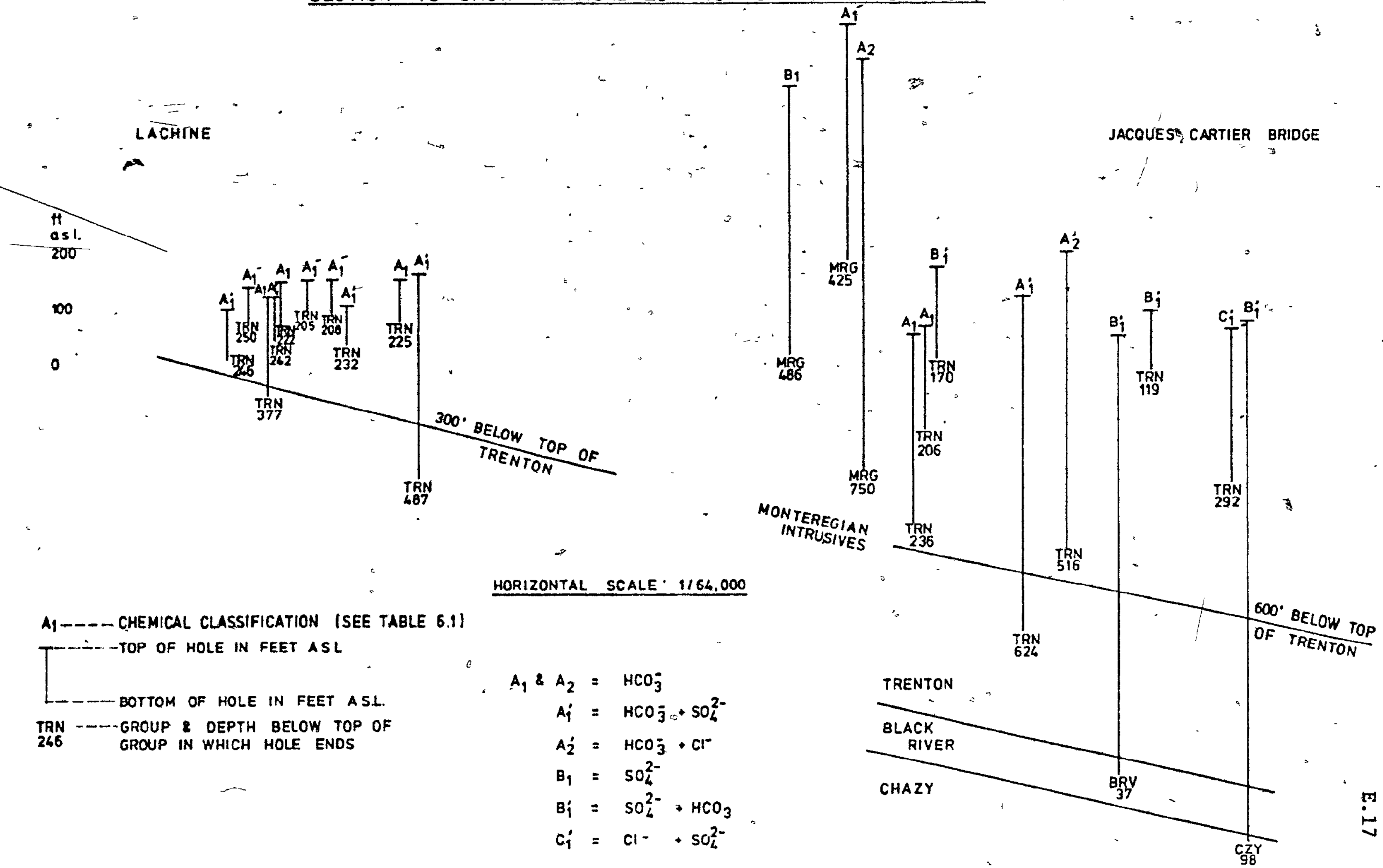
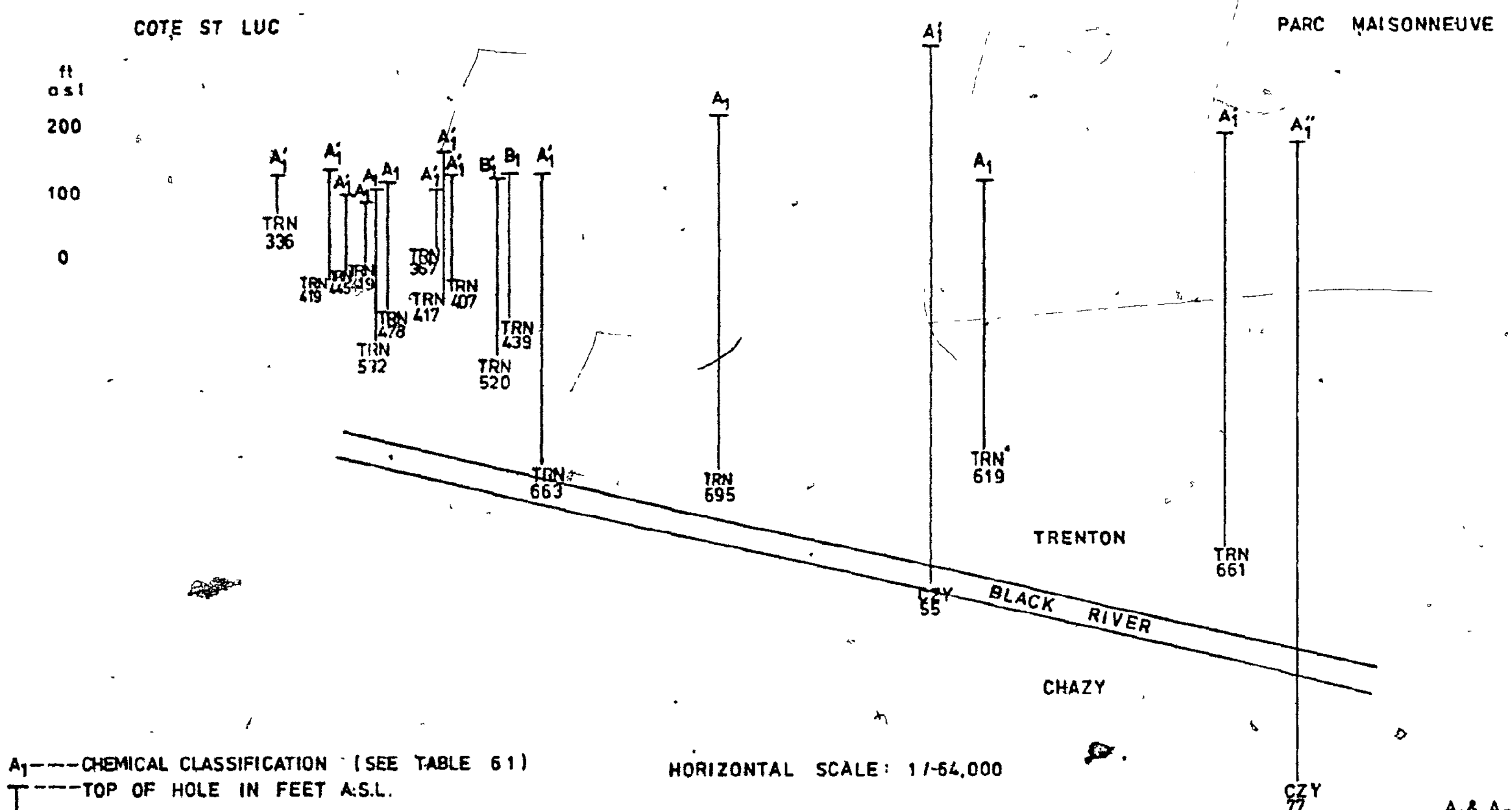


FIGURE E 4d.

SECTION TO SHOW VERTICAL ZONATION OF PRINCIPAL ANIONS



A_1 ---- CHEMICAL CLASSIFICATION (SEE TABLE 61)

---- TOP OF HOLE IN FEET A.S.L.

---- BOTTOM OF HOLE IN FEET A.S.L.

TRN 336 ---- GROUP & DEPTH BELOW TOP OF GROUP IN WHICH HOLE ENDS

HORIZONTAL SCALE: 1/64,000

A_1 & A_2	=	HCO_3^-
A_1'	=	$HCO_3^- + SO_4^{2-}$
B_1 & B_2	=	SO_4^{2-}
B_2'	=	$SO_4^{2-} + HCO_3$

the sulphide-containing Trenton and Utica (see Section 6.5).

Fig. E.4c has 22 samples of which only five are of the HCO_3^-, A group. All are in the top half of the Trenton, and four of the five are between 206 feet and 236 feet below the top of the Trenton. There are zones rich in sulphate both above and below, so it might be that this horizon has less shale in it. All the remaining samples of this figure are relatively rich in sulphate, without comprising any specific zone.

Fig. E.4d shows much the same as above. It only has five samples of the HCO_3^-, A, group, but 10 of the HCO_3^- + SO_4^{2-}, A_1', group, and two of the B_1 group, again showing the importance of sulphate. The Trenton has an A_1' zone from about 330 feet to 450 feet below its top. There are only three samples from the Chazy, all from between 50 feet and 100 feet below its top, and all are sulphate-rich.

There is only one sample of water which has chloride as the dominant ion, no. 5146. This is found about 292 feet below the top of the Trenton in a hole 270 feet deep.

E.4.3 Northern Sector - 53 analyses (Figure E.4e and f)

36 HCO_3^-	32 A_1 and 4 A_2
11 $HCO_3^- + SO_4^{2-}$	9 A'_1 and 2 A''_1
1 SO_4^{2-}	1 B_2
2 $SO_4^{2-} + HCO_3^-$	1 B'_1 and 1 B''_1
1 Cl^-	1 C''_1
2 Cl^-	1C1 and 1C_2

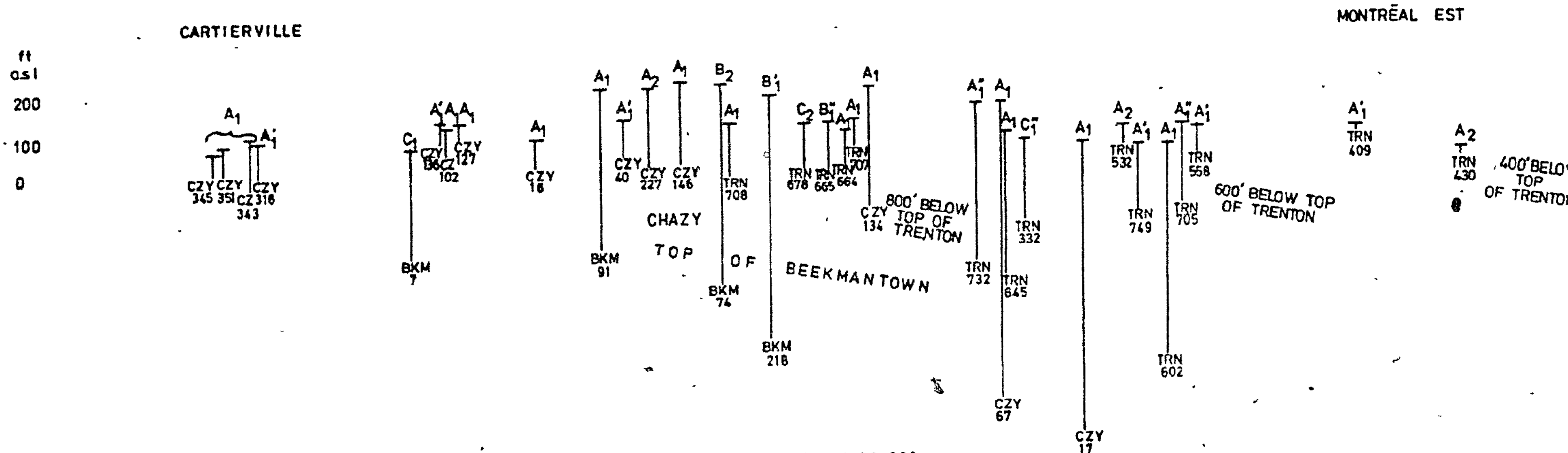
For coding see Table E.1

Bicarbonate is as ubiquitous as ever, and it can be seen from Figure E.4e that there is an A_1 zone at 100 feet ± 50 feet below the top of the Chazy, and also from 600 ± 100 feet below the top of the Trenton. Immediately below the A_1 zone in the Trenton is an A'_1 zone. Figure E.4f shows the same zonation as above and extends the A_1 zone to the 400 foot level of the Trenton.

Analyses in which chloride is important are rare, though three are present but with no horizontal or vertical correlation. However, since they tend to be peripheral to the area, they may represent the distal end of a flow line.

FIGURE E 4e

SECTION TO SHOW VERTICAL ZONATION OF PRINCIPAL ANIONS



HORIZONTAL SCALE 1/96,000

A_1 ----- CHEMICAL CLASSIFICATION (SEE TABLE 61)

----- TOP OF HOLE IN FEET A.S.L.

----- BOTTOM OF HOLE IN FEET A.S.L.

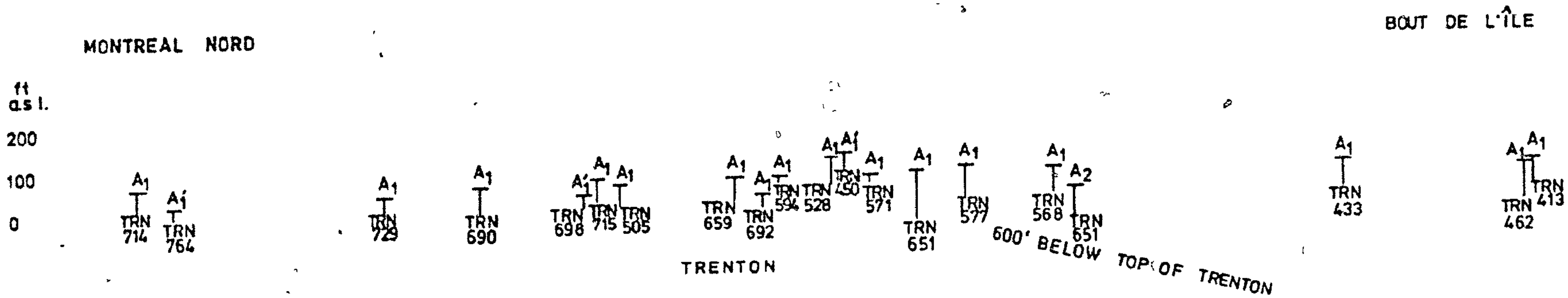
CZY 345 ----- GROUP AND DEPTH BELOW TOP OF GROUP IN WHICH HOLE ENDS

NOTE ANY APPARENT STRATIGRAPHICAL INCONSISTENCIES ARE DUE TO THE EFFECT OF FOLDING NOT CATERED FOR IN THIS METHOD OF PLOTTING

A_1 & A_2	=	HCO_3^-
A_1'	=	$HCO_3^- + SO_4^{2-}$
A_2'	=	$HCO_3^- + Cl^-$
B_1 & B_2	=	SO_4^{2-}
B_1'	=	$SO_4^{2-} + HCO_3$
B_2'	=	$SO_4^{2-} + Cl$
C_1 & C_2	=	Cl^-
C_1'	=	$Cl^- + SO_4^{2-}$
C_2'	=	$Cl^- + HCO_3^-$

FIGURE E 4f

SECTION TO SHOW VERTICAL ZONATION OF PRINCIPAL ANIONS



HORIZONTAL SCALE 1 / 24,000

A_1 ------ CHEMICAL CLASSIFICATION (SEE TABLE 6.1)
T ------ TOP OF HOLE IN FEET A S L
⌊ ------ BOTTOM OF HOLE IN FEET A.S.L.
TRN 714 ------ GROUP AND DEPTH BELOW TOP OF GROUP IN WHICH HOLE ENDS

A_1 & A_2 = HCO_3^-

A_1' = $HCO_3^- + SO_4^{2-}$

E.5 Vertical Zonation of Cations

E.5.1 Western Sector - 45 analyses (Figures E.5a and b)

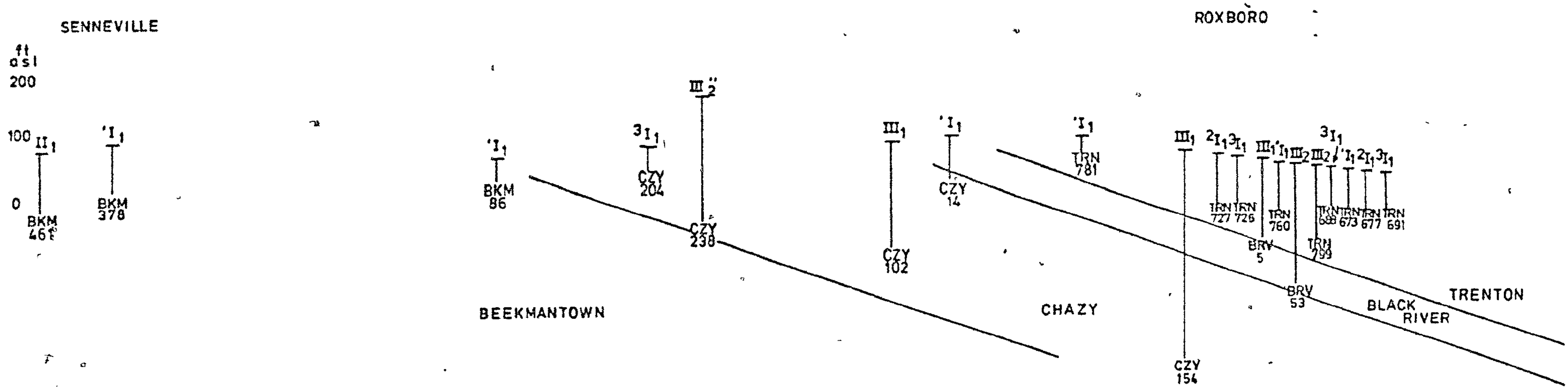
32 I	18 $^{1}I_{1}$	$Ca > Mg > Na$	For coding see Table E.1
	2 $^{1}I_{1}''$	$Ca > Mg > Na$	
	6 $^{2}I_{1}$	$Ca > Mg > Na$	
	6 $^{3}I_{1}$	$Ca > Mg > Na$	
7 II	6 II_{1}	$Mg > Ca > Na$	
	1 II_{2}	$Mg > Na > Ca$	
6 III	3 III_{1}	$Na > Ca > Mg$	
	2 III_{2}	$Na > Mg > Ca$	
	1 III_{2}''	$Na > Mg > Ca$	

Magnesium is very important in the western part of this area, and within the Beekmantown only one sample - of the $^{2}I_{1}$ group - does not have a 'dolomitic' rCa:rMg ratio of less than 2.0 ie. all samples except one are of the $^{1}I_{1}$ group. Magnesium-rich layers are apparent, especially from 320 feet to 370 feet and from 130 feet to 200 feet below the top of the Beekmantown, but also the rest of the samples outside these specific horizons, ranging from 86 feet to 461 feet below the top of the Beekmantown, are all magnesium-rich.

The Chazy in the northern part of the area has the first examples of a sodium-rich water, from horizons 102 feet

FIGURE E 5a

SECTION TO SHOW VERTICAL ZONATION OF PRINCIPAL CATIONS



II_1 —— CHEMICAL CLASSIFICATION (SEE TABLE 6 1)

—— TOP OF HOLE IN FEET A S L

—— BOTTOM OF HOLE IN FEET A S L

BKM 461 —— GROUP AND DEPTH BELOW TOP OF GROUP IN WHICH HOLE ENDS

HORIZONTAL SCALE
1 64,000

I_1 = Ca > Mg > Na

I_2 = Ca > Na > Mg

II_1 = Mg > Ca > Na

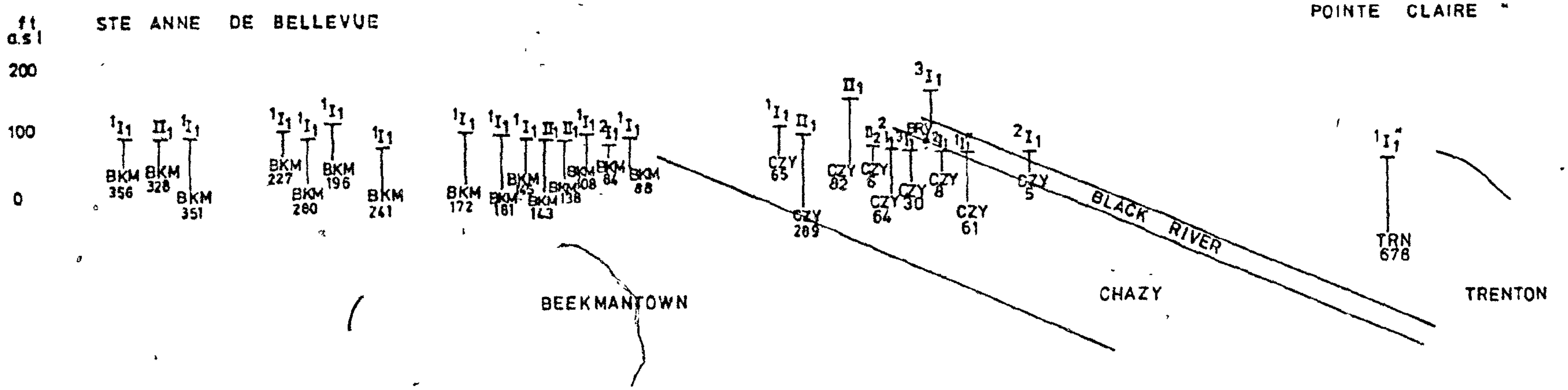
II_2 = Mg > Na > Ca

III_1 = Na > Ca > Mg

III_2 = Na > Mg > Ca

FIGURE E 5b

SECTION TO SHOW VERTICAL ZONATION OF PRINCIPAL CATIONS



$^1I_1$ — CHEMICAL CLASSIFICATION (SEE TABLE 61)

TOP OF HOLE IN FEET A.S.L

BKM 356 — BOTTOM OF HOLE IN FEET A.S.L; GROUP AND DEPTH BELOW TOP OF GROUP IN WHICH HOLE ENDS

HORIZONTAL SCALE 1 : 64,000

I_1	=	Ca > Mg > Na
I_2	=	Ca > Na > Mg
II_1	=	Mg > Ca > Na
II_2	=	Mg > Na > Ca
III_1	=	Na > Ca > Mg
III_2	=	Na > Mg > Ca

and 154 feet below its top (samples no. 5325 and 5321 respectively, both associated with chloride), with other examples at the contact of the Trenton and Black River Groups. These appear to form a sodium zone about 150 feet below ground, which underlies a calcium-rich one. The Chazy to the south of this area is less calcium-rich than one might expect from a limestone, but it may be affected by magnesium from the Beekmantown below, and the Pamelia formation (at the base of the Black River Group) above, with ground water movement helped by the Pointe Claire fault. Generally, however, the proportion of magnesium begins to wane in favour of calcium further up the succession, a trend which continues eastward.

E.5.2 <u>Central Sector - 39 analyses</u> (Figures E.5c and d)

26 I	3 I_1	Ca > Mg > Na	
	9 $^{1}I_1$		
	5 $^{2}I_1$		
	5 $^{3}I_1$		
	4 I_2	Ca > Na > Mg	For coding
6 II	3 II_1	Mg > Ca > Na	see Table E.1
	1 II_1''		
	1 II_2	Mg > Na > Ca	
	1 II_2''		
7 III	4 III_1	Na > Ca > Mg	
	3 III_2	Na > Mg > Ca	

FIGURE E 5c

SECTION TO SHOW VERTICAL ZONATION OF PRINCIPAL CATIONS

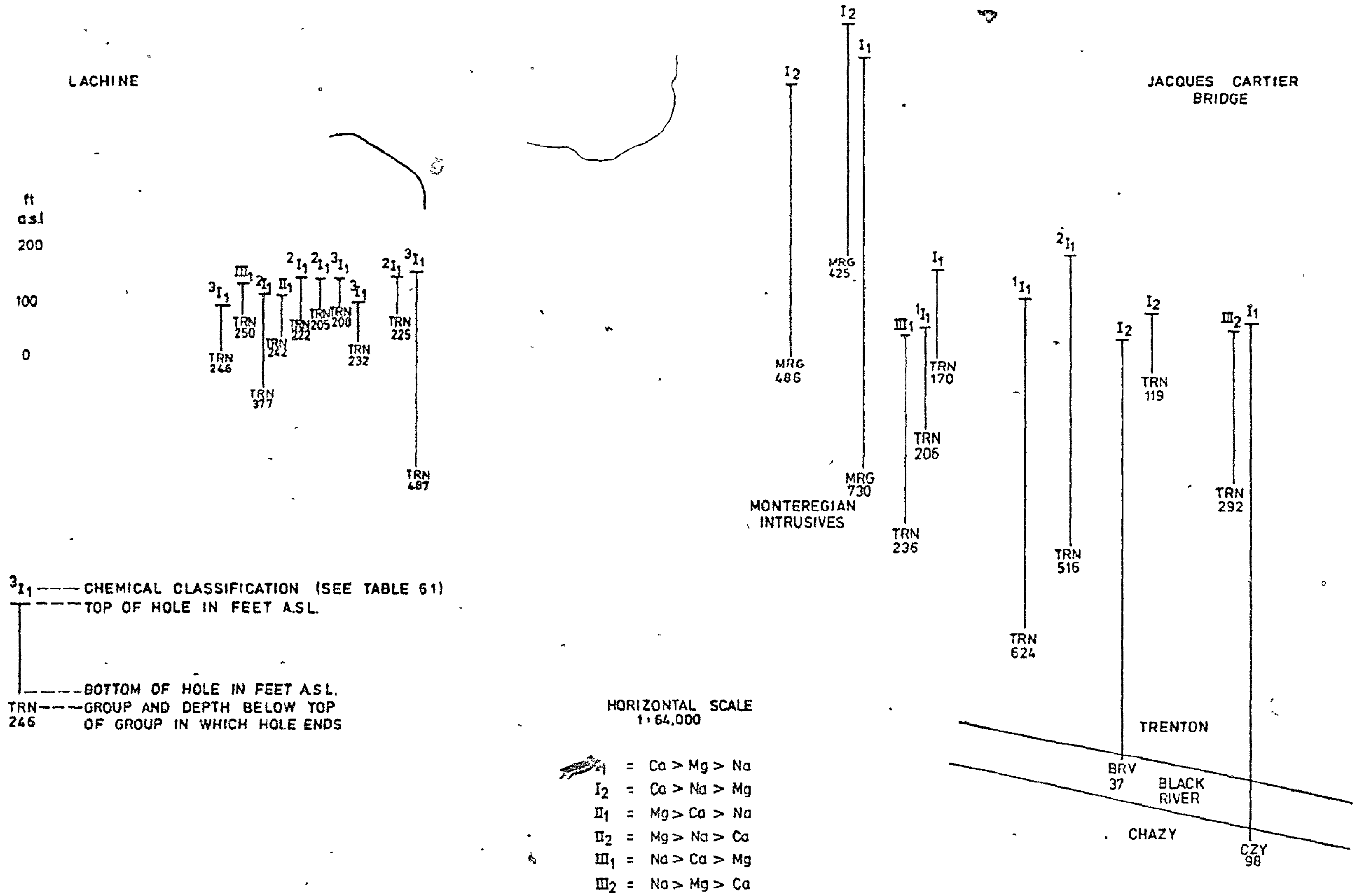
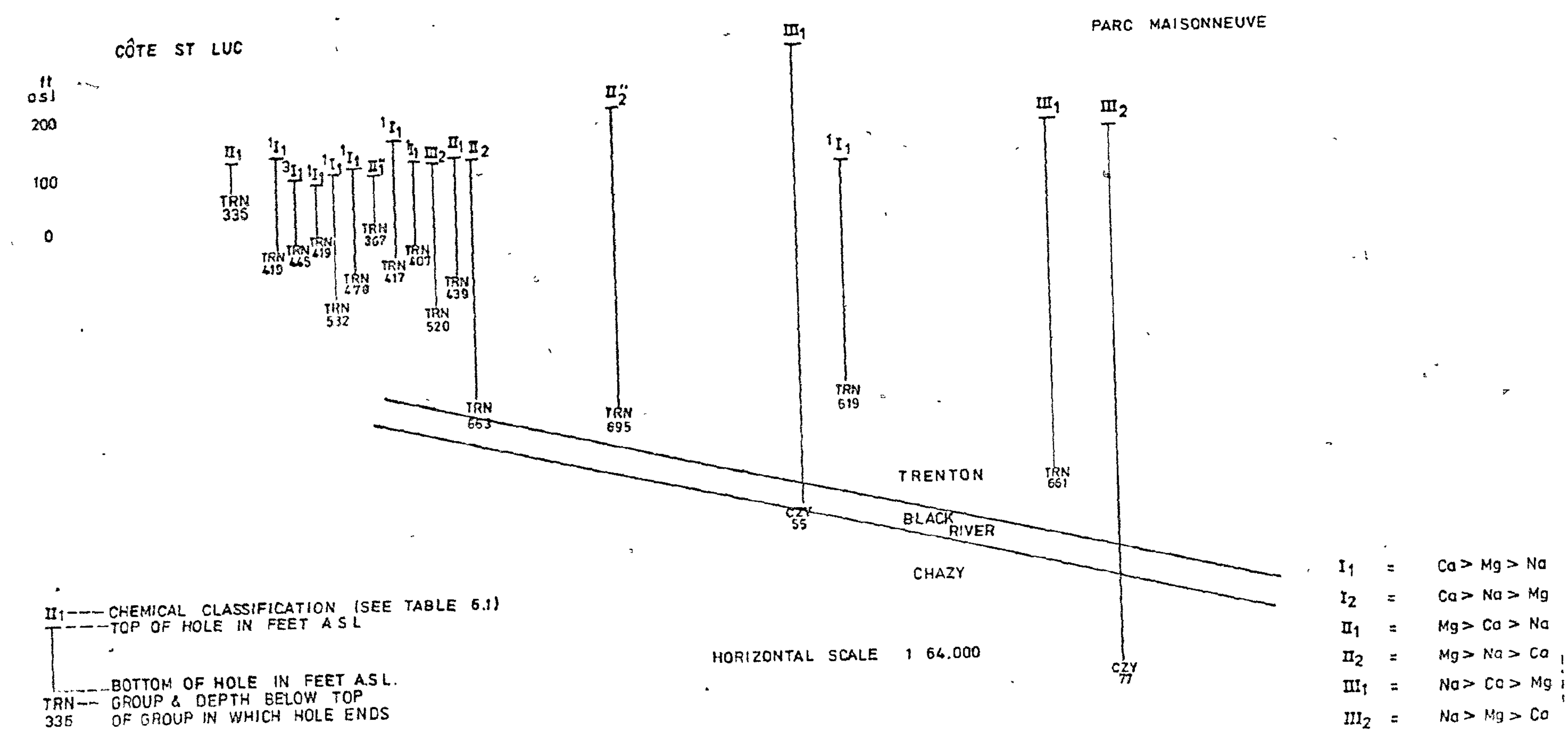


FIGURE E 5d

SECTION TO SHOW VERTICAL ZONATION OF PRINCIPAL CATIONS



Magnesium is not as consistently abundant here as in the western sector, but it is still important. The main zone is west southwest of Mount Royal at depths corresponding to the top 40 feet and bottom 60 feet of the Rosemount formation of the Trenton (Rosemount = from 400 feet to 675 feet of the Trenton).

There are more sodium-rich samples in this sector than in the western one, mainly to the north and east of, and associated with, Mount Royal. Horizons which are sodium-rich are the 230 feet to 290 feet below the top of the Trenton, and the top 80 feet of the Chazy.

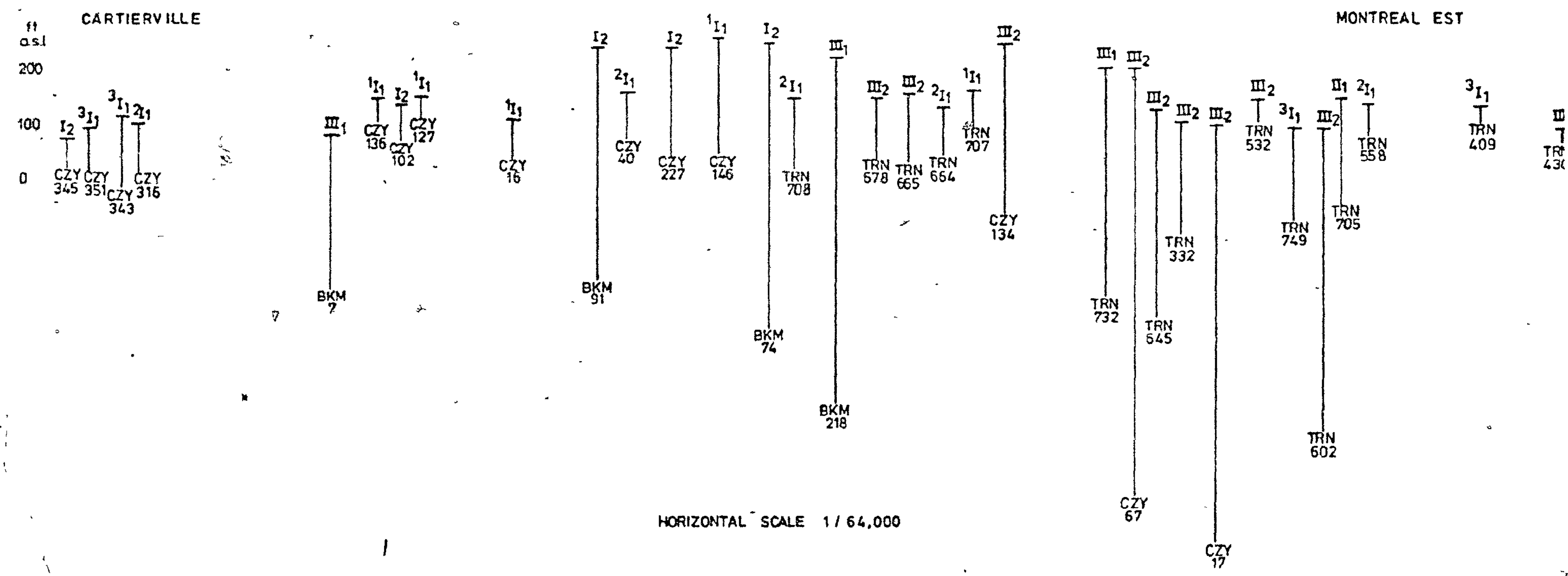
Calcium is found mainly to the southwest of the mountain from 200 feet to 250 feet, and from 370 feet to 490 feet below the top of the Trenton.

E.5.3 Northern Sector - 53 analyses (Figures E.5e and f)

33 I	7 $^{1}I_{1}$	Ca > Mg > Na
	1 $^{1}I'_{1}$	Ca > Mg > Na
	8 $^{2}I_{1}$	Ca > Mg > Na
	10 $^{3}I_{1}$	Ca > Mg > Na
	7 I_{2}	Ca > Na > Mg
1 II	1 II_{1}	Mg > Ca > Na
19 III	7 III_{1}	Na > Ca > Mg
	2 III''_{1}	Na > Ca > Mg
	10 III_{2}	Na > Mg > Ca

For coding see Table E.1

FIGURE E 5e
SECTION TO SHOW VERTICAL ZONATION
OF PRINCIPAL CATIONS



HORIZONTAL SCALE 1 / 64,000

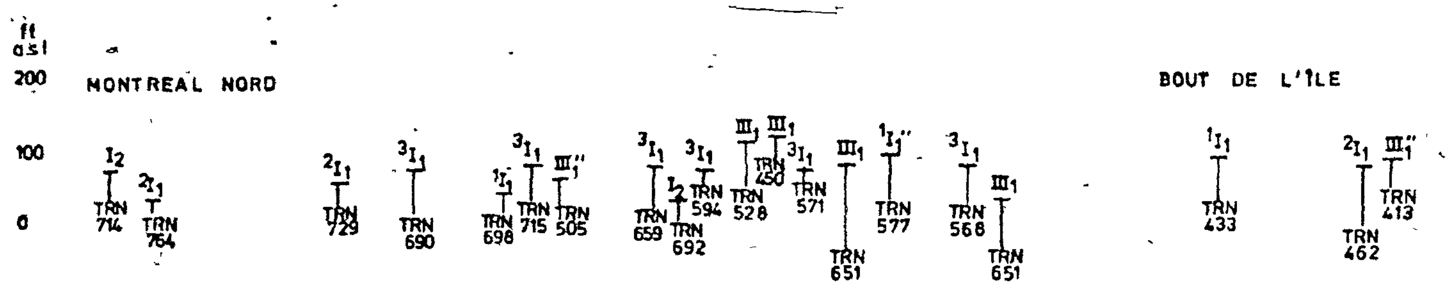
I_2 ---- CHEMICAL CLASSIFICATION (SEE TABLE 6.1)
---- TOP OF HOLE IN FEET A.S.L
---- BOTTOM OF HOLE IN FEET A.S.L
CZY 345 ---- GROUP AND DEPTH BELOW TOP OF GROUP IN WHICH HOLE ENDS

I_1 = Ca > Mg > Na
I_2 = Ca > Na > Mg
II_1 = Mg > Ca > Na
II_2 = Mg > Na > Ca
III_1 = Na > Ca > Mg
III_2 = Na > Mg > Ca

NOTE :- ANY APPARENT STRATIGRAPHICAL INCONSISTENCIES ARE DUE TO THE EFFECT OF FOLDING NOT CATERED FOR IN THIS METHOD OF PLOTTING

FIGURE E 5 f

SECTION TO SHOW VERTICAL ZONATION OF PRINCIPAL CATIONS



HORIZONTAL SCALE 1/32,000

I_2 — CHEMICAL CLASSIFICATION (SEE TABLE 6 1)
— TOP OF HOLE IN FEET A.S.L.
— BOTTOM OF HOLE IN FEET A.S.L.
TRN 714 — GROUP AND DEPTH BELOW TOP OF GROUP IN WHICH HOLE ENDS

I_1	=	Ca > Mg > Na
I_2	=	Ca > Na > Mg
II_1	=	Mg > Ca > Na
II_2	=	Mg > Na > Ca
III_1	=	Na > Ca > Mg
III_2	=	Na > Mg > Ca

NOTE:- ANY APPARENT STRATIGRAPHICAL INCONSISTENCIES ARE DUE TO THE EFFECT OF FOLDING NOT CATERED FOR IN THIS METHOD OF PLOTTING

The continuing trend of decrease in the importance of magnesium is again seen, and only nine magnesium-rich samples (the II_1 and $^1I_1$ groups) are found. They do however indicate two zones. One is in the top 150 feet of the Chazy while the other is about 700 feet below the top of the Trenton.

Sodium now achieves its greatest importance, and it is dominant in 19 samples. It forms a minor zone to the southwest of this sector, at the base of the Chazy and top of the Beekmantown. This is located by deep holes with water of the III_1 and I_2 groups (Fig. E.5e). In both these groups magnesium is the no. 3 cation, so it appears that there is little upward ground water movement, or else the magnesium of the Beekmantown would have had an influence. There are two other sodium zones the major one is to the east and northeast of the area, the other is to the northwest. Both are found in the middle and lower Trenton, roughly corresponding to the Rosemount. The northereastern zone is of the III_2 group, the northwestern one is of the III_1 group.

The northwestern sodium zone and northern part of the eastern zone show up in shallow wells, less than 100 feet deep, while the southern part of the eastern one derives from a source always deeper than 195 feet and on average 490 feet deep. All the samples involved have a base exchange index more negative than - 1.0, which tends to preclude the possibility of either a connate or deep brine source, since otherwise the concentrations of chloride and sodium would have been similar, and hence the base exchange index closer to a balance at zero. The alternatives are base exchange or simple solution from a sodium source. There is not a significantly large concentration of any anion, such as sulphate, which might be expected if specific solution of a sodium mineral, such as $CaSO_4$ had occurred. Base exchange is the more likely. Limestone is far more abundant in the area than dolomitic rocks, so the status of calcium as the No. 2 cation is not surprising within the northwestern group, despite the inference that calcium ions must be removed from solution to cause the release of sodium. In the east the wells are deeper, so sodium has had more time to replace the calcium ions by base exchange. The replacement has been such that calcium is reduced to the no. 3 ion. Doubtless some magnesium is exchanged by sodium as well, but since it has a larger hydrated ion the exchange process would be slower. This can explain the III_2 group of the east as against the III_1 of the west.

Calcium is found in the northwest, in a zone in the lowest 100 feet of the Trenton. This is beneath the sodium zone with the transition from one to the other marked by samples of the I_2 group. There is another horizon at the 550 feet to 600 feet below the top of the Trenton. In the southwest of the area, Cartierville has a calcium-rich zone about 100 feet below ground at the base of the Chazy.

There is a slight interdigitation of the calcium and sodium zones, and this is probably due to the variation in shale content of the rocks.

From the foregoing discussions of the distributions of cations, both vertically and horizontally, one may get the impression that calcium is not particularly important since little emphasis or comment is attached to its occurrence. This is not so however and it is only because calcium is so widespread that attention must be paid to secondary trends. It is more enlightening to discuss why a sample is not calcium-rich rather than simply to state that it is calcium-rich.

An integrated review has been presented in section 6.5.

APPENDIX F RECOMMENDATIONS FOR AQUIFER MANAGEMENT

Cumming found 12 artesian wells in his investigation in 1915, but Pollitt did not report any in his study during the 1950's. The lowering of ground water levels by reduced recharge would be rectified by constructing recharge bore holes with the necessary pollutant traps, and would be worthwhile because ground water, in the long term, is cheaper than surface water, especially with the new water rates. However the initial capital expenditure to exploit ground water is often high, and not always guaranteed to provide the yield required. For current satisfied users of ground water these restraints are probably welcome, because it means their supply is not jeopardized. However, if more people decide to invest in ground water, some form of check must be introduced so that the quantities of water removed can be estimated, and if necessary restricted, so that annual recharge can make good the abstractions. If the water were allowed to be mined locally, ground water level could fall to such an extent that infiltration from the river might occur and contaminate borehole supplies already in use. This has happened extensively in London, England, where saline intrusion from the tidal reaches of the Thames has occurred along both banks of the river, and the aquifer has been contaminated as a result. Now no further abstractions are permitted, but the legislation was much too late. Artificial recharge is a solution to the mining of ground water, but problems can arise with clogging, either by bacteria or by suspended solids. Also the compatibility of the recharge water with that already in the aquifer must be considered, so careful planning must precede any recharge scheme.

Ground water in Montreal has an average temperature of 50°F (10°C), which remains constant throughout the year. Thus it is useful for air conditioners during the summer, and also for heating systems during the winter. It is also of a good quality for domestic consumption. Full utilization depends upon detailed knowledge of the aquifer characteristics and the local hydrological budget. The aquifer characteristics can best be obtained by means of specially controlled pumping tests using main abstraction boreholes and, if necessary, purpose made observation holes. The tests should be for as long as economically possible to get a true picture of the aquifers capabilities in terms of transmissivity and storativity. There can then be treatment by 35% hydrochloric acid and further pumping tests made, to ascertain whether acidisation improves the yield significantly. Before any pumping test, a survey of other ground water users within a mile radius of the proposed test should be made, so that any resulting derogation of their supplies can be remedied. During any pumping test the quality of water should be monitored to ascertain if there is any change with time, which might indicate induced recharge from a nearby river or interception of a stagnant area, which in either case may make the water unsuitable for the purpose originally intended. Similarly, full hydrometric data such as ground water level fluctuations, rainfall, evapotranspiration rate, stream flow, base flow and soil moisture deficits should be obtained in order to calculate the hydrologic budget. Also extensive permeability tests could be made to enable more accurate figures for recharge, and lateral flow rates to be calculated, and hence a more precise delineation of recharge areas could be made. This is necessary to determine how much water should be allowed to be abstracted without altering the balance between recharge and discharge.

In Montreal it is clear that ground water of a quality suitable for all domestic uses is available at depths of less than 100 feet throughout most of the Island. This water is of a calcium bicarbonate type. There are other types of water such as those rich in sodium. These would be more useful to industry since they are softer and would not cause scaling if used in cooling processes. Although not as widespread, zones of softer water are present and are not so deep as to preclude exploitation, eg. the north eastern sodium zone has an average depth of 418 feet. Thus there is ground water satisfactory for most needs, but in order to manage it both quantitatively and qualitatively, more data of the type outlined above are required. These could be obtained from a network of small diameter observation wells, especially important in areas without reliable coverage at present, and from stream gauging. Moreover these data should be obtained if a valuable resource is not to be wasted.

APPENDIX G - VERTICAL ZONATION

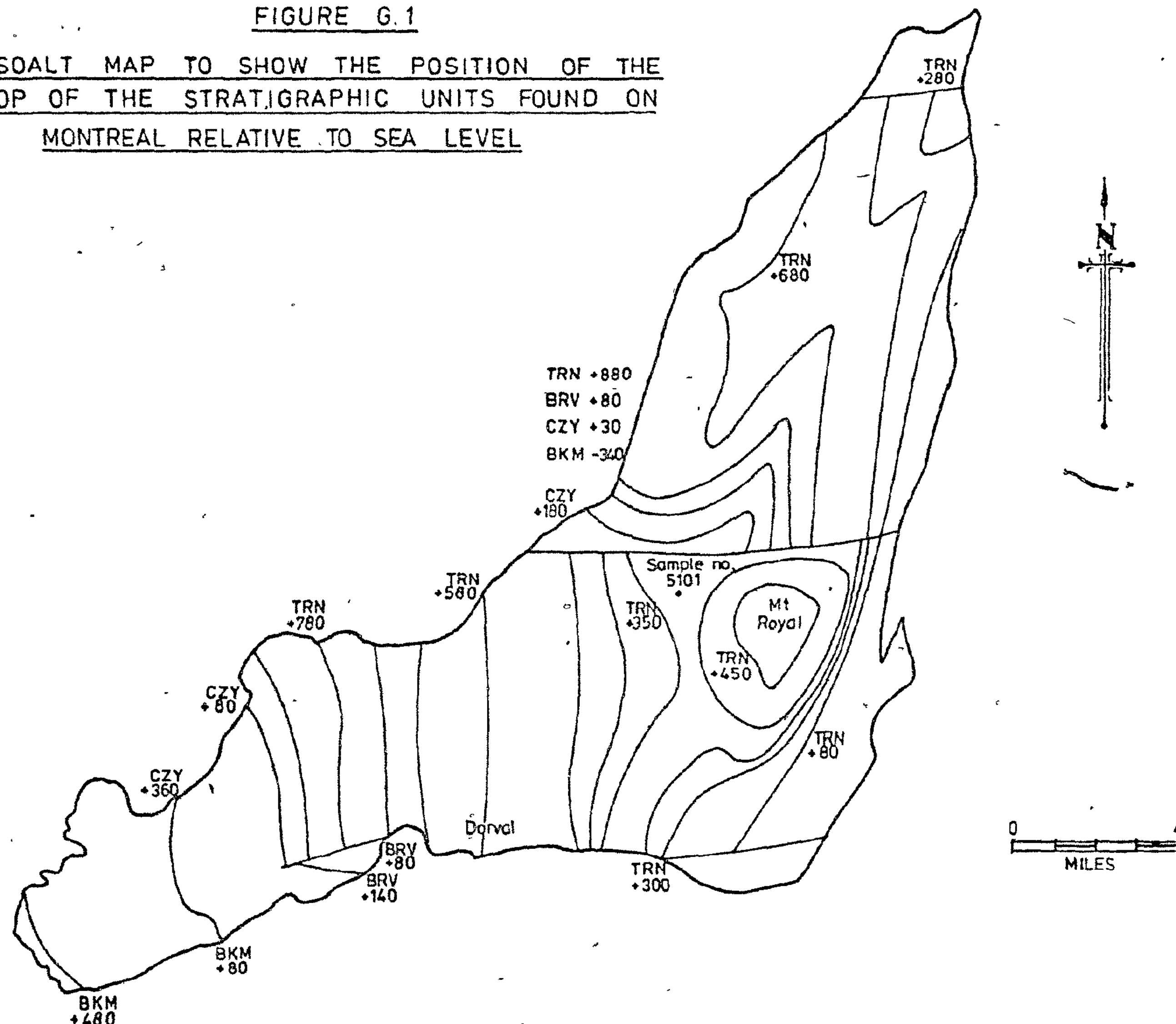
Ground water flow in limestones such as those found on Montreal Island is through fissures, so any borehole will have water contributed by a number of discrete horizons. The depth of the main contributory fissures is likely to affect the chemistry of the water in any given borehole, because of the varying lengths of the flow lines intercepted at different depths and changes of mineralogy with depth due to alteration of sedimentary processes at time of deposition.

However the data available in this study have no reference to the depth from which samples were obtained. There was no information as to casing depths, as to the level at which water was first struck, or as to the depth of the pump in any pumped samples. Consequently the rough guide that was used was that the bottom of the hole was taken to represent the contributing horizons.

It was decided to try to ascertain whether these horizons correlated with specific geological formations or groups. To help deduce quickly which geological horizon was being tapped, an 'isoalt' map of the Island was drawn using the PLAN programme (see Appendix A). This showed the height of the top of each geological group found on Montreal Island relative to mean sea level (Fig. G.1). Each sampling point

FIGURE G.1

ISOALT MAP TO SHOW THE POSITION OF THE TOP OF THE STRATIGRAPHIC UNITS FOUND ON MONTREAL RELATIVE TO SEA LEVEL



was plotted on the map and its position relative to the top of a geological group found by associating it with the appropriate isoalt.

To find out how far below the top of a group a sample was taken the topographic elevation and depth of the well were needed. So

$G_h = T - (I + D_w)$ where G_h = horizon of group

T = topographic elevation

I = isoalt

D_w = depth of well

Consider sampling point 5101 (Fig. G.2).

Its isoalt contour is 374 feet ie. at that point the top of the Trenton is theoretically 374 feet above sea level. Its own topographic height is 135 feet above datum and the depth of the well is 200 feet thus

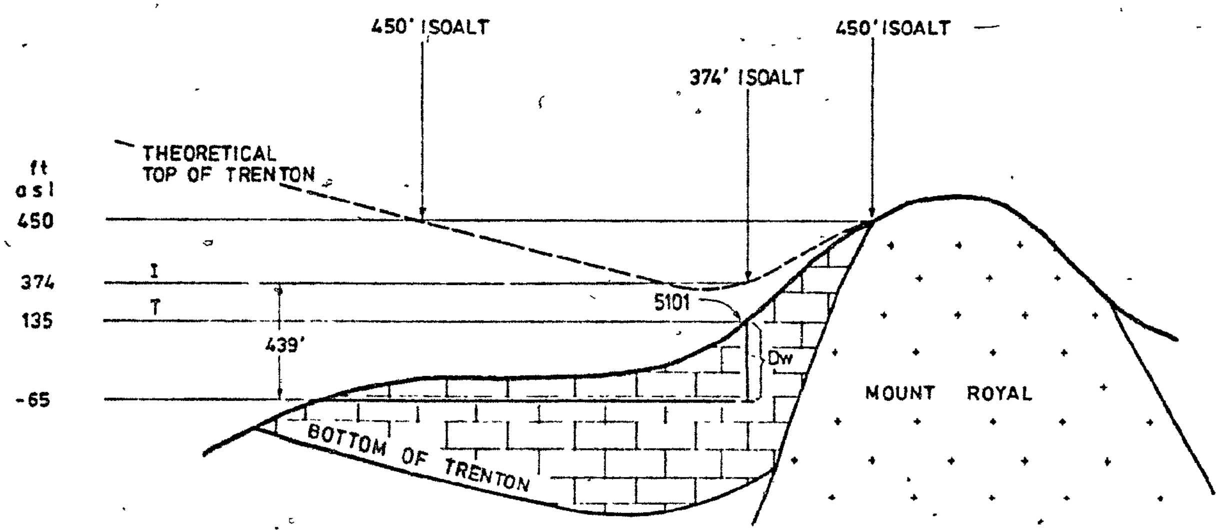
$$G_h = 135 - (374 + 200)$$
$$= 135 - 574$$
$$= -439$$

ie. the sample came from 439 below the top of the Trenton Group.

If the depth below the top of the group exceeds the thickness of the group then the excess is the depth below the top of the underlying group.

FIGURE G 2.

DIAGRAM TO SHOW USE OF ISOALTS



This method is not intended to be absolute but rather to give a general guide to the horizons encountered, anything more would be outside the scope of this thesis in terms of the structural considerations.