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Evaluation of the Petroleum Potential of the Trenton Group, St. Lawrence Lowlands, Quebec.

Geology

Masters of Science

Abstract

The limestones of the Trenton Group were evaluated for suitable petroleum reservoirs by means of petrography, porosity and permeability measurements, hydrocarbon analysis, and stratigraphic analysis.

The Trenton is predominantly non-porous, impermeable micritic limestone except for the crinoidal calcarenites in the Deschambault Formation near the base of the succession. The Deschambault calcarenites partially cemented early by precipitation of calcite, and the final infilling of the voids took place by means of pressure solution resulting in the formation of stylolites.

Petroleum fluids,possibly generated by the basinward black shale facies, migrated into the Deschambault limestones prior to the formation of stylolites. The hydrocarbon now present in the Deschambault limestones appears to represent the residue left after the expulsion of all fluids by stylolitization.

The Trenton ranges in thickness from 225 feet to 1000 feet, thickening towards the southeast,with black shale displacing the limestone southward. The depth of burial and the geothermal gradient are suitable for the generation and accumulation of both oil and gas, however, no suitable porous and permeable horizons occur, and no suitable stratigraphic or structural traps exsist.

EVALUATION OF THE PETROLEUM POTENTIAL OF THE TRENTON GROUP, QUEBEC

L. CURRIE

EVALUATION OF THE PETROLEUM POTENTIAL OF THE TRENTON GROUP, ST. LAWRENCE LOWLANDS, QUEBEC

by

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CHAPTER I

Introduction

The St. Lawrence Lowlands of Quebec refer to the large triangular segment of relatively unfolded sedimentary rocks that straddle the St. Lawrence River between Montreal and Quebec City. Physiographically it is a low lying plain bounded on the northwest by the Laurentian Mountains of the Canadian Shield, the Appalachian highland on the southeast, and the Adirondack massif on the south (Figures 1 and 2).

The sedimentary rocks of the St. Lawrence Lowlands vary from Upper Cambrian to Upper Ordovician, and are arranged in a general synclinal structure,the axis of which, trends northeasterly and lies southeast of the St. Lawrence River.

The first commercial drilling for gas in the St. Lawrence Lowlands began in the 1880's. These met with limited success producing gas for a time from the glacial drift. Gas seeps have been known to exist over the entire region. Many shallow wells have produced (for over a century) small amounts of natural gas from the overburden for domestic purposes.

In 1955 an important discovery was made at Pointe-du-Lac, near Three Rivers,where a reservoir of gas was found in the glacial drift.

Most of the natural gas found in the overburden is considered to have originated in the underlying Paleozoic rocks,however, to date commercial quantities have not been found in these underlying sediments. Of the more than 100 wells drilled into the bedrock only a few can be considered to have tested all potential oil and gas horizons. Prior to 1950 few of the deep wells were located by sound geological or geophysical principles. This, plus the proximity to market, points out the need for a detailed investigation to evaluate the underlying sedimentary rocks.

Scope and Objectives

The petroliferous nature of the Trenton Group has often led to the idea that these rocks acted as a possible source for the abundant gas seeps in the glacial drift, or as being reservoir rocks for gas and petroleum (Belyea, 1952; Clark, 1956; Jones, 1962; Maughan, 1964).

This study has been undertaken in order to evaluate the petroleum potential of the Trenton Group. The main objectives of this research were to:

1) determine if the rocks are capable of forming reservoirs
2) make a stratigraphic analysis using structure, facies, and isopach maps
3) analyze the hydrocarbon content
4) study the diagenetic history of the rocks

The reservoir potential was evaluated by porosity and permeability measurements and petrography. Facies, isopach, and structural maps were prepared with the aid of cores, rotary chip samples, and published reports and maps. The hydrocarbon content of the rocks was analyzed using Philippi's (1957) method, which indicates whether the hydrocarbon is indigenous or allochthonous.

Previous work

Prior to the work of Logan (1849, 1863) little had been done other than to assign all of the Ordovician rocks of the St. Lawrence Lowlands to the Secondary Series. Logan (1863) in Geology of Canada divided this succession into five mappable rock units, one of which was the Trenton. Logan did not attempt to separate these units into formations, however, his descriptions can be related to the present formations.

The Trenton was not separated into workable formations until Johnson (1914) and Raymond (1914) proposed their respective classifications of the Trenton successions in Ontario and New York. Johnson subdivided the rocks on the basis of their faunal content, but Raymond named them after geographical areas.

For the past twenty-five years T.H.Clark has studied, mapped,and logged all of the rocks and most of the wells in the St. Lawrence Lowlands. From his studies it became apparent that the Trenton of the St. Lawrence Lowlands, unlike the underlying Black River and the overlying Utica, was somewhat unique to this area. Although most of the results of his mapping remain unpublished ,Clark (1959) published a summary of the stratigraphy of the Trenton Group in the St. Lawrence Lowlands, Quebec.

Husain (1955) studied the bryozoan fauna of the Deschambault Formation of the Trenton Group. Young (1964) made a detailed petrographic study of the Deschambault Formation, which includes many stratigraphic sections not studied in this investigation.

An outline of the history of the natural gas industry in Quebec, and a list of the principle wells drilled for gas was published by Parks (1930, 1931). A study of some wells in the St. Lawrence Lowlands was made by Belyea (1952). A compilation of wells drilled in the St. Lawrence Lowlands was made by DeBlois and Simard (1958), and later revised by Houde (1964).

Location

The area studied was the St. Lawrence Lowlands between Montreal and Three Rivers (Figures 1 and 2).

Method of Study

Well cuttings and drill core of the Trenton Group were studied with the aid of a binocular microscope at the Quebec Department of Natural Resources. Detailed geologic well logs that included the Trenton were also examined.

Major field outcrops of the Trenton rocks were visited, and stratigraphic sections were measured and described along the Ouareau River and at Neuville.

Five shallow drill holes were made in the Deschambault Formation along the Ouareau River to obtain unweathered cores suitable for porosity and permeability measurements.

The following laboratory studies were carried out to further this study:

1) Porosity and permeability measurements
2) Hydrocarbon analysis
3) Petrography

Acknowledgements

The author wishes to express his appreciation to Professor

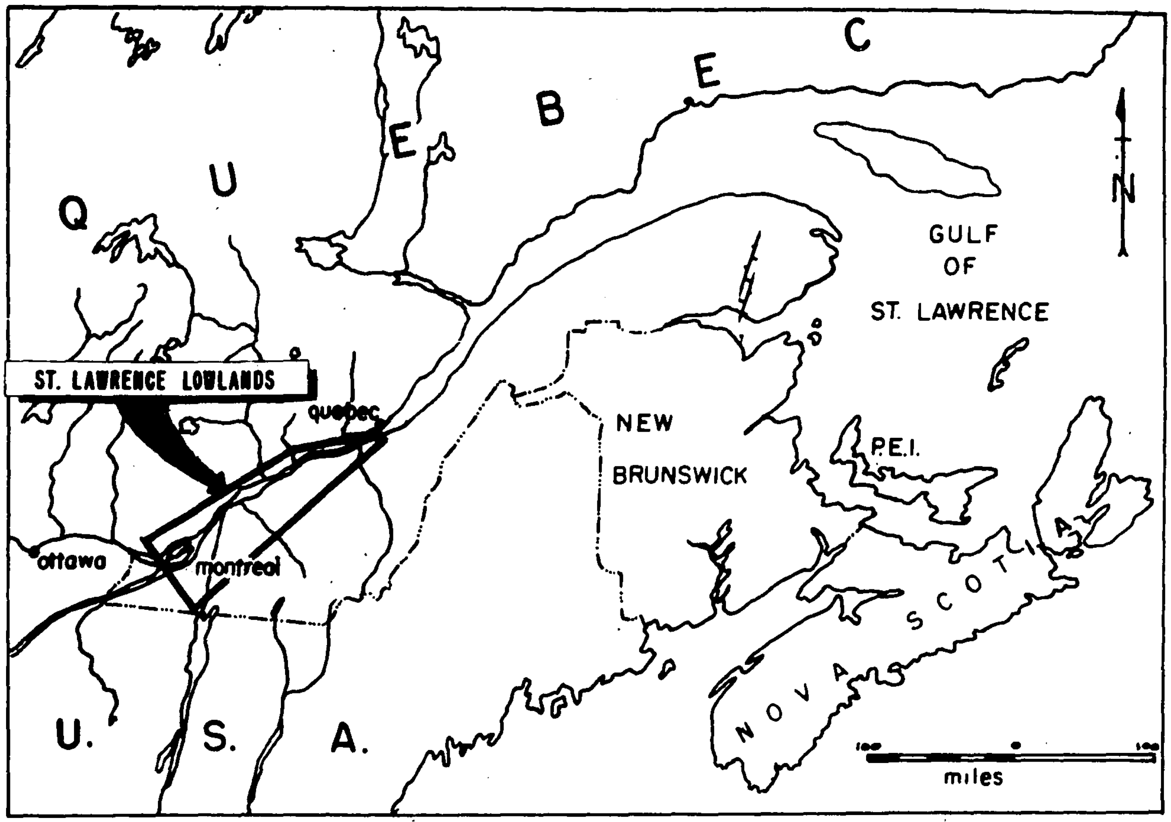


Figure 1 Location of the St. Lawrence Lowlands, Quebec.

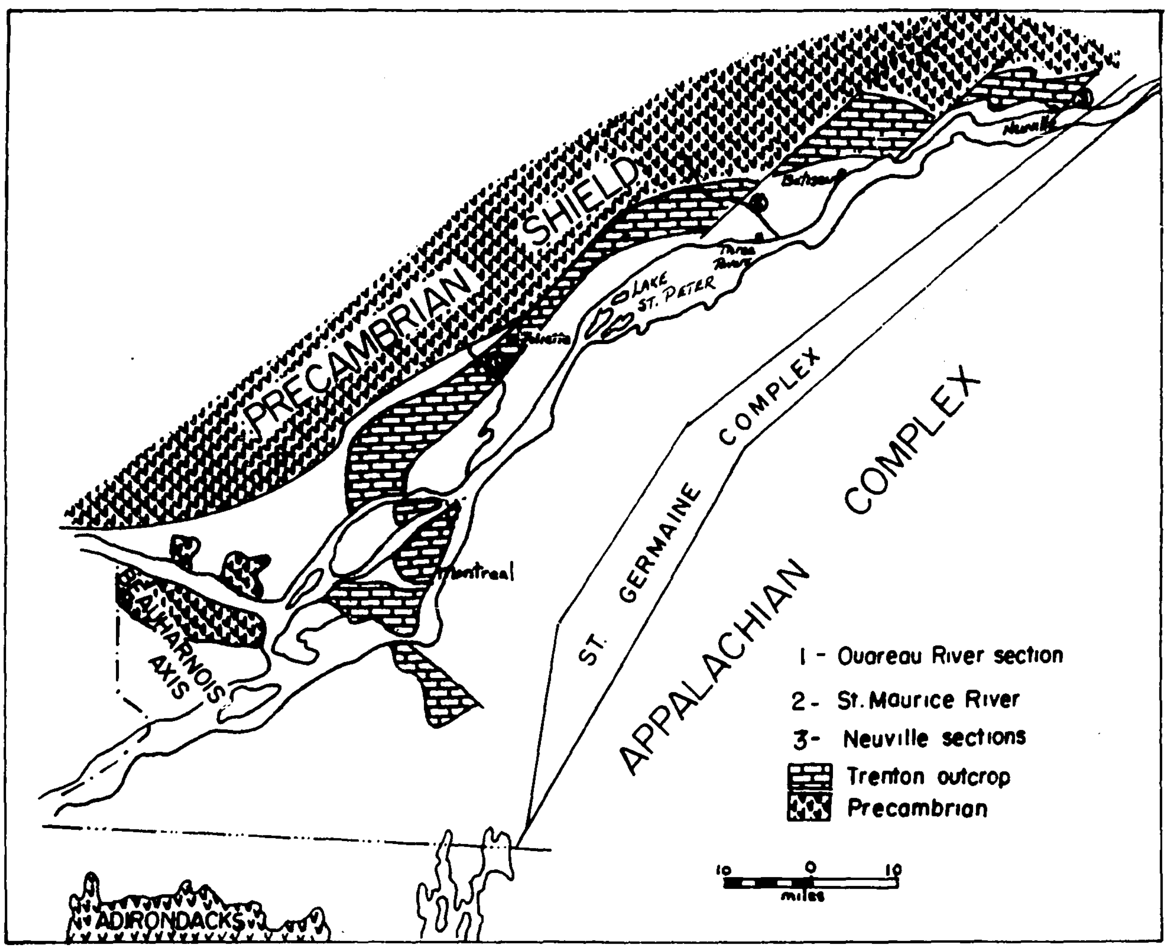


Figure 2 The St. Lawrence Lowlands, Quebec

E.W. Mountjoy, of McGill University, who suggested the problem, and supervised and directed the work. For his assistance, suggestions, and critical reading of the manuscript the writer extends his sincere thanks. Dr. T.H. Clark showed the author many of the more important Trenton outcrops in the St. Lawrence Lowlands, and provided much useful information.

Special thanks are extended to Dr.Brian Skidmore, Paul Simard, and other officers of the Quebec Department of Natural Resources, who made facilities available for the examination of government held drill core, provided copies of geologic well logs, defrayed all field expenses, and provided employment from May to September, 1967.

Gratitude is extended to Mr.John Cookson and Mr. Butler of Donald Inspection Company, Montreal, who provided the drilling equipment and made useful suggestions regarding the permeability tests.

The diverse stimulation and assistance of staff members and fellow students at McGill is acknowledged here. To my father, Mr. Gerald Currie,who assisted with the drilling, and to my wife Susan,who assisted with the typescript, the writer expresses his thanks.

CHAPTER II

General Geology

Structural Geology

The dominant structural feature of the St. Lawrence Lowlands is the Chambly-Fortierville syncline, (Clark,1947) a doubly plunging fold,the axis of which, trends northeasterly and lies southeast of the St. Lawrence River (Figure 3). The beds on the northwest limb of the fold dip relatively uniformly towards the axis, and are generally less than 5 degrees. The southeast limb in contrast, is tightly folded and overturned towards the northwest, and the beds dip up to 45 degrees (Clark, 1956).

Bounding the southeast limb of the Chambly-Fortierville syncline, and separting the relatively flat lying rocks of the St. Lawrence Lowlands and Logan's Line, is a zone of highly deformed rocks known as the St. Germain Complex (Clark, 1964,p.4). Logan's Line, a great thrust fault, separates the St. Germain Complex from the Appalchian thrust slices to the east.

A few normal faults occur along the contact between the Paleozoic sedimentary rocks of the St. Lawrence Lowlands and the Precambrian Shield. These faults strike northeast and offset the Paleozoic - Precambrian contact (Figure 3).

Stratigraphy

The Trenton limestone was defined by Vanuxem (1842) as the 300 feet of beds lying between the Black River limestone and the overlying Utica shale. Subsequent authors have held

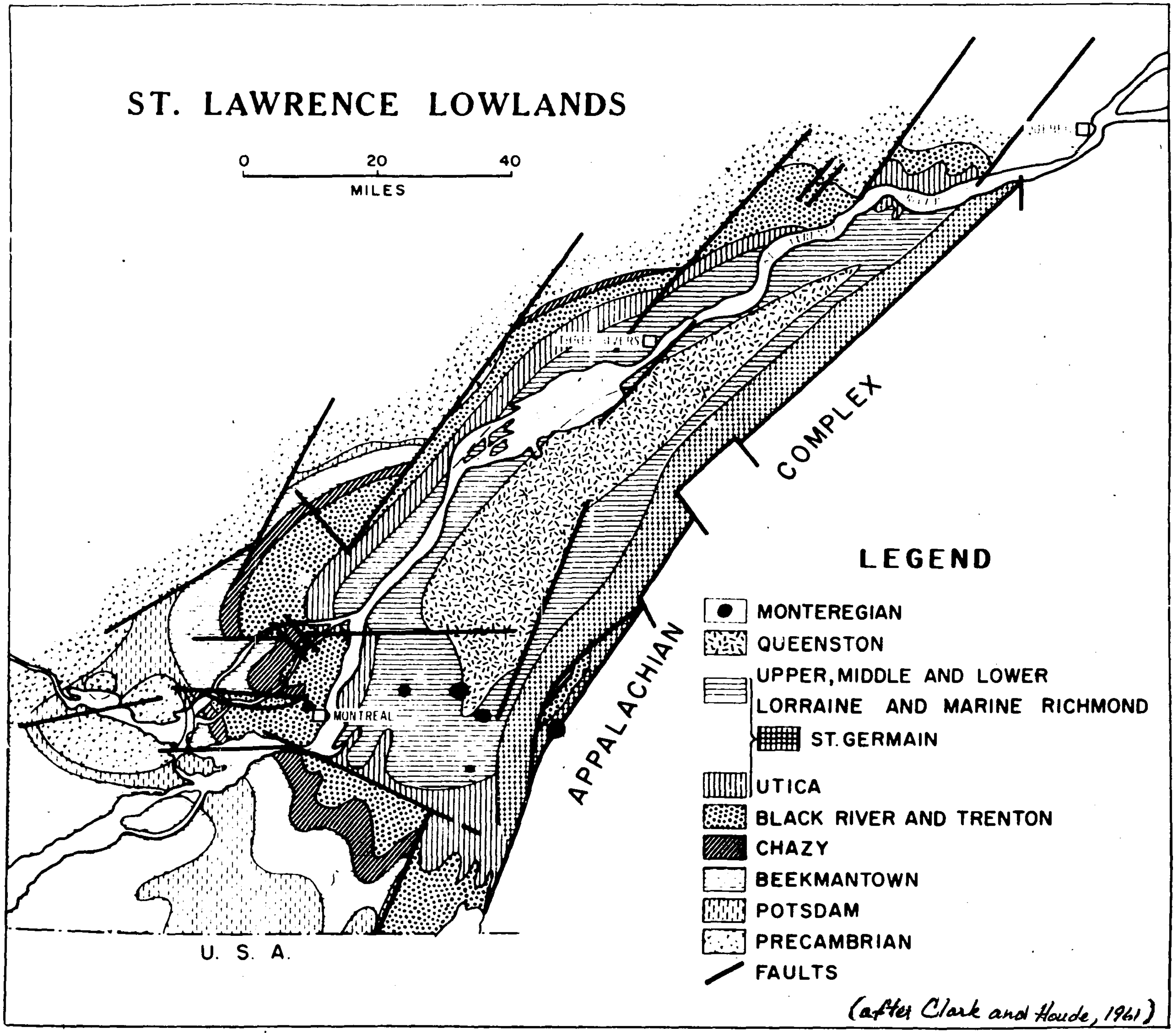


Figure 3 Geological map of the St. Lawrence Lowlands, Quebec

to that definition, although there has been considerable elaboration of the description and several formations are now recognized within the Trenton Group.

The underlying Black River formations, Pamelia, Lowville, and Leray, are lithologically similar in Ontario, New York, and Quebec, and much the same can be said of most of the overlying Utica (Clark,1959). The Trenton of Quebec is somewhat unique possibly due to the elevated extensions of the Precambrian Shield, known as the Frontenac Axis, the Adirondack massif, and the Beauharnois Anticline (Figure 2), restricting the basin during Trenton deposition.

The contact between the Black River and the Trenton Groups in the St. Lawrence Lowlands is represented by a distinct faunal break (Clark, 1959). On the northwest side of the St. Lawrence River there is little trouble in separating the Utica and Trenton on lithologic grounds. Towards the southeast the upper part of the Trenton Group is almost all shale (Figures 8 and 9), and the boundary becomes difficult to recognize.

The stratigraphy of the Trenton Group in Quebec has been reviewed by Clark (1952; 1959),and much of the following stratigraphic information is a brief summary taken from his published reports.

The Ouareau, Fontaine, St. Alban, and Pont Rouge Formations are rather thin and of local extent. All carry Trenton faunas, with slight Black River affinities. They consist of several limestone types which are generally dark, dense, and micro-crystalline. Local warpings are inferred to have isolated or restricted accumulations of different lithic types. The thickness and occurrence of these formations in the St. Lawrence Lowlands are as follows:

1) The Ouareau Formation, extending from Montreal to the Yamachiche River, is less than 20 feet thick.

2) The Fontaine Formation is found in the vicinity of the St. Maurice River and is 8 feet thick.

3) The St. Alban Formation, present in the area of the Ste. Anne River, is 5 feet thick.

4) The Pont Rouge Formation outcrops along the Jacques Cartier River, and has a thickness of 32 feet.

Overlying these formations in the St. Lawrence Lowlands is the persistent Deschambault Formation (Clark,1959). It commonly overlies the Ouareau, Fontaine, St. Alban, and Pont Rouge Formations along paraconformable surfaces with thin zones of limestone conglomerate locally developed near the contact (Young,1964).

The Deschambault Formation as proposed by Clark (1959) is essentially a biostratigraphic unit, however, it has distinctive and persistent lithologic characteristics. The Deschambault consists almost wholly of a pure, light gray crossbedded calcarenite composed of current transported fossil fragments, mostly echinoderms. A thin bryozoan phase, consisting of mats of bryozoa set in a shaly, limestone matrix persist throughout the formation southwest of the St. Maurice River.

The Deschambault varies in thickness from about 25 feet near Montreal to over 200 feet at the south end of Lake St. Peter (Young, 1964). Typically the Deschambault is 80 to 90 feet thick.

		ST. LAWRENCE LOWLANDS – QUEBEC (CLARK 1959)	
		MONTREAL – ST. MAURICE RIVER	ST. MAURICE RIVER – QUEBEC CITY
MOHAWKIAN SERIES	TRENTON GROUP	TETREAUVILLE with the Terrebonne	NEUVILLE
		MONTREAL	
		DESCHAMBAULT	ST. CASIMIR
			DESCHAMBAULT
		OUAREAU	FONTAINE, ST. ALBAN, PONT ROUGE
	BLACK RIVER GROUP	LERAY	LERAY
		LOWVILLE	LOWVILLE
		PAMELIA	PAMELIA

Figure 4 Mohawkian Stratigraphy, St. Lawrence Lowlands

Northeast of the Ste. Anne River the Deschambault Formation is overlain by the St. Casimir Formation (Clark, 1959). The St. Casimir is made up of a great variety of lithologic types, varying from medium to coarse grained limestones to fine, almost lithographic limestones. The St. Casimir is possibly equivalent, southeast of the Ste. Anne River, to the upper part of the Deschambault Formation (Clark, 1959). The St. Casimir is typically 180 to 190 feet thick.

The Montreal Formation succeeds the Deschambault Formation southeast of the Ste. Anne River. The thickness of this formation is variable, ranging from 100 to 300 feet thick between Montreal and Three Rivers, and 50 to 310 feet thick further northeast.

Lithologically the Montreal Formation is characterized by a great irregularity of sedimentation, and varied proportions of shale and limestone (Clark, 1959,p.18).

The Montreal Formation is overlain by the Tetreauville Formation southwest of the St. Maurice River. The Tetreauville Formation consists of dark, dense limestone alternating regularly with black shale.

Within the Tetreauville Formation there is a thick lens of limestone lithologically and faunally similar to the Tetreauville, but lacking definite bedding. This lens is found at the top or entirely within the Tetreauville. Clark (1959, p.18) termed this stratigraphically variable unit the Terrebonne Member.

The limestone between the St. Casimir and Utica Formations can rarely be separated by lithology (Clark, 1959, p.18). The entire thickness, 470 feet along the Neuville shore, is lithologically the same as the Tetreauville Formation, however, the proportion of black shale interbeds is lower. Clark (1959, p.19) proposed that this entire lithologic unit be called the Neuville Formation.

The Utica Formation was deposited over the Tetreauville and Neuville Formations.

Southeast of the St. Lawrence River all the Trenton formations become thicker, and the proportion of shale becomes greater, especially in the upper Trenton (Figures 8, 9, and 14). The corresponding sections of Utica and Lorraine also show a thickening southeast of the St. Lawrence River. Clark (1959, Figure 1) proposed that a shelf - miogeosynclinal hinge line exists southeast of the St. Lawrence River, with greater subsidence to the southeast relative to the stable shelf to the northwest.

Along the St. Maurice River there probably was a low Precambrian positive element that controlled sedimentation to some extent (Clark, 1959,p.19), as indicated by the occurrence of Trenton resting on Precambrian basement in well number 33 (Figure 16).

CHAPTER III

Petrography

A petrographic examination of the Trenton Group was made using acetate peels and some thin sections. Three stratigraphic sections were measured, described, and sampled (Appendix C). Also, seven bore hole cores of the Trenton were examined and described with the aid of a binocular microscope and a few acetate peels.

Classification

The limestone classification of Folk (1962) was used in conjunction with the textural classification of Folk (1959). A modification using Dunham's textural terms was employed to distinguish between sparse mud-supported biomicrite and packed grain-supported biomicrite.

The carbonate grain size and sorting are classified according to Folk (1962). Where bedding is referred to, it is classified according to Dunbar and Ridgers (1957,p.97), modified after McKee and Weir (1953).

Special Terms

Some of the terms used in describing the limestones may have uncertain meanings and are defined as follows:

1) Micrite - calcite of crystal size less than 5 microns.

2) Microspar- calcite of crystal size between 5 and 63 microns.

3) Spar - calcite of crystal size greater than 63 microns.

4) Pellets - rounded, spherical to elliptical or ovoid aggregates of micrite,devoid of any internal structure, well sorted, and with an upper size limit of 0.15 millimeters (Folk,1962,p.64). Similar particles coarser than this are classified as intraclasts.

Figure 5 Limestone classifications

Volumetric Allochem Composition			Limestones, Partly Dolomitized Limestones, and Primary Dolomites (see Notes 1 to 6)					Replacement Dolomites[7] (V)	
			>10% Allochems Allochemical Rocks (I and II)		<10% Allochems Microcrystalline Rocks (III)				
			Sparry Calcite Cement > Microcrystalline Ooze Matrix	Microcrystalline Ooze Matrix > Sparry Calcite Cement	1–10% Allochems	<1% Allochems	Undisturbed Bioherm Rocks (IV)	Allochem Ghosts	No Allochem Ghosts
			Sparry Allochemical Rocks (I)	Microcrystalline Allochemical Rocks (II)	Most Abundant Allochem			Evident Allochem	
>25% Intraclasts (i)			Intrasparrudite (Ii:Lr) Intrasparite (Ii:La)	Intramicrudite* (IIi:Lr) Intramicrite* (IIi:La)	Intraclasts: Intraclast-bearing Micrite* (IIIi:Lr or La)	Micrite (IIIm:L); if disturbed, Dismicrite (IIImX:L); if primary dolomite, Dolomicrite (IIIm:D)	Biolithite (IV:L)	Finely Crystalline Intraclastic Dolomite (Vi:D3) etc.	Medium Crystalline Dolomite (V:D4)
<25% Intraclasts	>25% Oölites (o)		Oösparrudite (Io:Lr) Oösparite (Io:La)	Oömicrudite* (IIo:Lr) Oömicrite* (IIo:La)	Oölites: Oölite-bearing Micrite* (IIIo:Lr or La)			Coarsely Crystalline Oölitic Dolomite (Vo:D5) etc.	Finely Crystalline Dolomite (V:D3)
	<25% Oölites, Volume Ratio of Fossils to Pellets	>3:1 (b)	Biosparrudite (Ib:Lr) Biosparite (Ib:La)	Biomicrudite (IIb:Lr) Biomicrite (IIb:La)	Fossils: Fossiliferous Micrite (IIIb: Lr, La, or Ll)			Aphanocrystalline Biogenic Dolomite (Vb:D1) etc.	
		3:1–1:3 (bp)	Biopelsparite (Ibp:La)	Biopelmicrite (IIbp:La)	Pellets: Pelletiferous Micrite (IIIp:La)			Very Finely Crystalline Pellet Dolomite (Vp:D2) etc.	etc.
		<1:3 (p)	Pelsparite (Ip:La)	Pelmicrite (IIp:La)					

(Folk, 1962)

Textural Classification of Limestones

Micrite / Spar 2:1				Micrite & Spar Subequal	Spar / Micrite 2:1		
Percent Allochems					Poor Sorting	Good Sorting, Ang.	Rounded
0 - 1	1 - 10	10	10				
MUD SUPPORTED*			GRAIN SUPPORTED*				
Micrite	Fossilferous Micrite	Sparse Biomicrite	Packed Biomicrite	Poor-Washed Biosparite	Unsorted Biosparite	Sorted Biosparite	Rounded Biosparite

(Folk, 1959) *Dunham (1962)

Lower Trenton

A. Ouareau Formation

Limestones of the Ouareau Formation are medium dark gray in colour, medium bedded, and are interbedded with black, calcareous shale, ½ inch to 1 inch thick (Plate 1, Figure 2).

Micrite predominates with scattered patches of microspar present in some samples (Plate 8, Figure 1). Argillaceous matter is present throughout the formation, however, it rarely exceeds 10 per cent of the rock. Gastropods are the most abundant fossil type, consistuting between 2 and 5 per cent of the rock, with some brachiopod fragments present.

In general, the limestones are argillaceous, gastropod micrites.

B. Deschambault Formation

The Deschambault limestones are light to medium gray-brown in colour, fine to very coarse grained, and medium to thick bedded. Black bituminous shale occurs in stylolites that are especially abundant in the coarser grained limestones.

Only a general petrographic study of the Deschambault limestones was made to examine and verify the limestone types established in the detailed and comprehensive study of Young (1964). A brief review of the data in Young (1964, pp. 13-45) follows.

The Deschambault Formation consists mainly of packed calcarenites with crinoids, the predominant and ever present grain type.

Brachiopods are generally well preserved, and are present in varying amounts. Bryozoan, of several types, are commonly associated with crinoids and brachiopods, and are especially abundant in the bryozoan reef unit (Husain, 1955) near the top of the Deschambault Formation. Ostracods are common in the finer calcarenites, and trilobite fragments are found in the microspar-rich sediments. Up to 5 per cent pellets occur in many of the fine grained calcarenites.

Except for rare micrite, microspar, presumably slightly recrystallized micrite, forms the matrix in the packed biomicrites and poorly washed calcarenites. Sparite cements the coarser crinoid calcarenites and calcirudites, and also occurs as void filling in microspar-rich limestones.

The three main limestone types comprising the Deschambault Formation are (Young, 1964) :

Type I	Fossiliferous calcilutite with microspar matrix.
Type II	Sorted pellet or bioclastic calcisiltite with microspar matrix.
Type III	Crinoidal calcarenite and intraclastic calcirudite with calcite spar cement.

The crinoidal calcarenite is the most abundant limestone type. The finer grained sediments, Types I and II, occur at the base of the Deschambault, in the chert rich unit in the middle of the stratigraphic section, and in parts of the bryozoan reef unit (see Appendix C).

C. St. Casimir Formation

The St. Casimir Formation is a mixture of medium dark gray, thin bedded, fine grained limestone, and thick bedded coarse grained limestone (Plate 4, Figures 1 and 2). The first occurrence of light yellow-brown weathering, fine grained limestone marks the base of the St. Casimir Formation (Clark, personal communication). The light gray-brown, coarse grained calcarenite, the same as the underlying Deschambault, decreases in abundance upwards. Minor calcareous, dark gray shale ($\frac{1}{4}$ inch to $\frac{1}{2}$ inch thick) interbeds occur, especially in the thin bedded, fine grained limestones.

The two main types of St. Casimir limestones are:

Type I Argillaceous micrite.

Type II Unsorted crinoidal calcarenite, medium to very coarse grained.

Middle Trenton

A. Montreal Formation

The limestones of the Montreal Formation are medium dark gray, very fine grained, thin to medium bedded with black calcareous shale interbeds ($\frac{1}{2}$ inch to 2 inches thick), and occurs in non-resistant rubbly outcrops (Plate 5, Figures 1 and 2). Crinoids are the predominant fossil type, less than 5 per cent, present in both the limestone and shale. Thin lenses of fine to medium grained crinoidal calcarenite occur scattered throughout. Near the Deschambault Formation these crinoidal calcarenites occur as beds and constitute up to 30 per cent of the strata.

The main limestone types of the Montreal Formation are;

Type I Argillaceous crinoid micrite.

Type II Crinoidal calcarenite, with brachiopods, fine to medium grained with sparite cement, and occurring in lenses and beds.

Upper Trenton

A. Tetreauville Formation

The Tetreauville Formation consists of dark gray, medium bedded, very fine grained limestone, interbedded with black calcareous shale (Plate 6, Figures 1 and 2). Fossil fragments are mainly crinoids and brachiopods, and rarely exceed 5 per cent of the rock.

The Terrebonne Member lacks definite bedding, and consists of an agglomeration of very fine grained limestone, dark gray in colour (60 per cent) and black, calcareous shale (40 per cent) with crinoid and brachiopod fragments found in both the limestone and the shale.

The limestone type of the Tetreauville Formation (Terrebonne Member) is argillaceous micrite to argillaceous crinoid, brachiopod micrite.

Middle and Upper Trenton

A. Neuville Formation

The Neuville Formation consists of dark gray to medium dark gray, medium bedded, very fine grained limestone interbedded with black,calcareous shale (¼ inch to 1 inch thick) (Plate 7, Figure 1). Crinoids, brachiopods, bryozoan, trilobites, and cephalopods are all well preserved, however, the fossil content rarely exceeds 5 per cent, except in local accumulations along the bedding planes. Argillaceous matter is common throughout the formation, and silt size quartz fragments, less than 5 per cent, occur in some beds (Plate 12, Figure 2).

The limestones of the Neuville Formation are argillaceous micrite to argillaceous fossiliferous micrite.

Summary

The Trenton Group, which ranges in thickness from 225 feet to 1100 feet, and is typically 700 feet thick (Figure 10), is predominantly micritic limestone, sparsely fossiliferous, interbedded with black, calcareous shale, except for the limestones of the Deschambault Formation, which are typically 80 to 90 feet thick (Young, 1964). These limestones are medium to coarse grained calcarenites with spar cement, and some finer grained calcarenites and calcilutites. The limestones of the Deschambault would be the most suitable lithic type in the Trenton Group to act as a reservoir rock for petroleum fluids if porosity and permeability were present (see Chapter V).

Mode of Occurrence of Bituminous Matter and Oil in the Deschambault Formation

Bituminous matter commonly occurs as finely disseminated material that is closely associated with the argillaceous fraction. Bitumen is very abundant along stylolites, and forms asphaltic weathering surfaces in the bryozoan reef unit (Plate 3, Figure 2). Oil droplets have been found in isolated vugs in a few localities, a very minor amount of oil was produced for a time in 1966 from the Louvicourt-Metal-L'Assomption Number 8 well, and black bituminous matter occurs in the pores and chambers of crinoids and bryozoan fragments. Black bituminous material occurs in small, isolated, irregular blebs, with sharp outlines within the microspar matrix of the fine grained limestones (Plate 10, Figure 1).

CHAPTER IV

Lithification of the Deschambault Formation

A study of the nature and character of the crystalline calcite in these carbonate rocks, which can form in several stages by different processes, is important to an under - standing of the stages of cementation of the sediment. The amount and stages of cementation, which govern the porosity, provides some indication of the time and duration of petroleum migration.

Forms of Crystalline Calcite

Crystalline calcite can be of two major genetic types; i) that formed by precipitation in water filled voids, and ii) that formed by 'neomorphism' (Folk, 1965).

Neomorphism includes inversion (aragonite to calcite), aggrading and degrading recrystallization (calcite to calcite), and strain recrystallization (strained calcite to unstrained calcite). In many cases it is difficult to tell from an examination of the physical properties and textures of the crystalline calcite whether inversion, recrystallization, or strain recrystallization was the operating process. Neomorphism is a convenient term when the processes that initiate and perpetuate changes in the crystalline calcite are unknown.

A. Precipitated calcite cement

Sparry calcite is associated with light gray-brown crinoidal calcarenites and calcirudites. Two forms of precipitated calcite can be recognized in the Deschambault Formation (young, 1964); i)'granular' or 'void-filling' calcite having the characteristic properties found by Bathurst (1958), Harbaugh (1961) and Chilingar et al (1967a), and ii) 'rim cement' (Bathurst, 1958) or 'calcite overgrowth' (Folk, 1965) of the crinoid fragments (Plate 9, Figures 1 and 2).

Young (1964) found that the texture of the granular cement is controlled by the type of grain that it is in contact with. Brachiopods have strongly developed, small elongate crystals perpendicular to the margins. Away from the margins these crystals become progressively larger and irregular in shape with sharp, planar to slightly curved boundaries (Plate 9, Figure 1). Ostracods, trilobites, and pellets have poorly developed radial growth of sparite, but the sparite still maintains the other characteristics of precipitated void filling cement.

Crinoid fragments, in the calcarenites are found to be in optical continuity with a rim of sparry calcite. The boundaries between the rim cemented fragments are usually planar to slightly curved (Plate 9, Figure 2).

B. Neomorphic crystalline calcite

Microspar forms the matrix in the fine grained calcarenites and poorly washed biomicrites. The microspar forms characteristic mosaics of equant, uniform size crystals that have curved to conserted boundaries (Plate 8, Figure 2). Young (1964, p.52) found that where crinoids occur in a microspar matrix, 'syntaxial rims' (Bathurst, 1958) form around the crinoid fragments. These syntaxial rims differ from the precipitated calcite overgrowths in that the outer boundaries are usually irregular, and are in contact with microspar or other syntaxial rims that have irregular shaped boundaries.

C. Summary

The coarser calcarenites of the Deschambault Formation were completely cemented by precipitated void filling cement and calcite overgrowths. The finer grained sediments have a microspar matrix formed by the neomorphism of lime mud and degrading neomorphism of crinoid fragments.

Lithification

A. Sparite cemented calcarenites

Recent research on cementation has shown that the majority of cementation does not take place in the marine environment. The number of reported submarine occurrences of cementation is, however, steadily increasing. The process of cementation in limestones is poorly understood so that the writer does not wish to infer that all limestones are cemented subaerially.

Cementation can occur where fresh water lenses float over and mix with marine water, with the fresh water inducing the precipitation of calcium carbonate, suitable for cement, from the brine (Matthews, 1967). In this situation, Kay and Colbert (1965) place the northern limit of Trenton deposition less than 25 miles northwest of the St. Lawrence Lowlands, so that cementation by this process is possible. Cementation takes place, however, largely within a fresh water vadose zone by solution of the metastable aragonite and high Mg calcite, and reprecipitation as low Mg calcite (Matthews,1967; Land,1967). Land (1967) showed that aragonite could also invert to low Mg calcite by isolated isochemical reaction, however, fresh water catalizes the reaction. It has also been found that subaerial exposure of a carbonate sand accelerates the inversion of aragonite and high Mg calcite to calcite cement by solution and reprecipitation (Ginsburg,1957; Beales,1965; Land,1967).

The time that elapses between the deposition and the elimination of the primary aragonite and high Mg calcite, leaving only low Mg calcite, appears to be relatively short, and elapses while the rock is not too far removed from the environment of deposition (Land,1967).

The crinoid calcarenites were probably deposited on shoals in the wave action (Young,1964,p.72). Finer grained sediments, with laminations, and fine crossbedding, and erosional disconformities suggest a quiet, near shore environment of deposition (Young,1964,p.73). The erosional surfaces have abrupt pits several inches wide with overhanging walls, overlain by intraformational limestone conglomerate, which suggests partial, early cementation of the eroded bed. The shallow broad shelf and near shore environment of deposition, and subaerial exposure at times, probably enhanced early, partial cementation perhaps by the processes outlined above, or by the development of beach rock (Stoddart, 1965).

The overall granular and rim character of the spar cement suggests that precipitation in voids, probably from the solution of aragonite and high Mg calcite, was the predominant process, however, the extent of lithification is not known.

Stylolites, sub-parallel to the bedding, are exceedingly common in the Deschambault, occurring on macroscopic and microscopic scales (Plate 10,Figure 2). There are two well substantiated schools of thought on the origin of stylolites.

One advocates a pre-lithification origin, whereas the other proposes a post-lithification origin (Park and Schot,1968). The horizontal, sutured character of the stylolites in the Deschambault Formation suggest that they were formed sometime after burial by increasing overburden pressure causing pressure solution of one or both sides of the stylolite. The insoluble, black bituminous residue associated with the argillaceous material within the stylolite seam indicates that pressure solution must have acted during and after petroleum migration. Since the sediment was partially cemented prior to burial, stylolitization occurred after partial lithification and before complete lithification.

The pressure solution involves the solution transfer of carbonate from around points or surfaces of contact, where the solubility is enhanced by overburden pressure, and the redeposition in regions of lower pressure or lower concentration. The formation of stylolites probably ceased during the final stages of pressure solution cementation, because pressure solution in carbonate rocks is not active after the complete reduction of pore space and expulsion of fluids (Bathurst,1958).

B. Fine grained limestones with microspar

The microspar matrix of the finer grained limestones of the Deschambault Formation was probably formed by neomorphism of micrite. The lithification of carbonate mud involves the change of all aragonite mud and any larger aragonite grains or fossil detritus to calcite (Folk,1965,p.36). During this process the sediment remains porous with large amounts of interstitial fluids, however, the resulting micritic limestone is nearly non-porous (Folk,1965,p.36). Further neomorphism of the micrite, less than 5μ, incorporates the small micrite crystals with any larger grains or fossil fragments into a larger microspar mosaic (Folk,1965,p.40; Matthews,1967).

In general the age relations of neomorphism cannot be defined,as these processes could have taken place any time after deposition (Harbaugh, 1961,p.98). The change of all aragonite to calcite was probably relatively early before substantial burial,as is common in recent and Pleistocene situations. Land (1967) stated that Pleistocene aragonite is known to have inverted in 10^5 years, while he found that it would take about 10^7 years for the inversion of skeletal aragonite in water. The change, therefore, of all aragonite to calcite probably occurred relatively early and before substantial burial. The presence of disseminated blebs of bituminous matter suggests that complete lithification did not occur until petroleum migration, unless small pores existed or were formed by solution after lithification.

Petroleum Migration

Partial cementation of the limestones of the Deschambault Formation appears to have occurred relatively early with some porosity remaining during the development of stylolites. Some petroleum migrated into the Deschambault before complete cementation, and after sufficient burial. This is suggested by the isolated and disseminated character of the oil and bituminous matter in the rock.

Dunnington (1954) considered that stylolite formation has been of fundamental importance, in some areas, in causing and controlling petroleum migration and accumulations in calcareous sediments. Dunnington (1954) suggested that where a thick shale sequence in a subsiding basin passes laterally into widely extensive thinner platform type, porous limestones, as was the case in the Deschambault Formation prior to stylolite formation, and where subsequent deposition continues to be thicker in the basin than on the shelf (see Chapter VII, Figures 8,9,and 10), fluid migration will be controlled by the compaction of the shales under load. Most of the contained fluids, including petroleum, will be squeezed out of the shale and will pass into the porous limestones, where further concentration of petroleum will be dictated by stratal gradients and intrinsic porosity (Dunnington, 1954, p.47). Since the rate of compaction in the basin is relatively slow, there would not be sufficient fluid flow to dislodge petroleum from the first encountered porous zones unless a high basinward dip is present. If no trapping structures develop, as is the case in the St. Lawrence Lowlands, petroleum will remain in this zone until the overburden increases to the critical pressure for stylolite development, whereupon the expulsion of all fluids from water-wet pores in the limestone will commence. The fluids will pass outwards and updip from the zone of initial accumulation to zones of lower overburden pressure, where stylolitization cannot occur (Dunnington, 1954, p.47).

Pore filling, pressure solution transfer will eventually infill the void spaces and incorporate any unexpelled petroleum residue. If there is sufficient oil accumulation in any area to produce oil wetting of the void surfaces, precipitation of calcite cement will be inhibited by the inaccessibility of crystal nuclei on which to crystallize (Dunnington, 1954,p.48).

Should oil accumulate to the exclusion of water, stylolite development will be prevented by the lack of solutions to act in pressure solution transfer.

Where oil droplets and thin oil horizons occur in the Deschambault Formation pressure solution cementation was probably prevented by oil saturation of the pores prior to stylolitization. For the most part the Deschambault has abundant stylolites, and was tightly cemented, hence, any petroleum that did accumulate within the rock was expelled updip during stylolitization, except for the bituminous residues along the stylolites and disseminated in the grains and matrix, to areas of less overburden pressure. These areas, if they did exist, have since been eroded.

CHAPTER V

Porosity and Permeability

Porosity and permeability are the two most important properties in the evaluation of potential reservoir formations. They determine the rate of fluid movement, the storage capacity, and the ultimate production from the rock. When a formation lacks zones of suitable porosity and permeability production of petroleum is impossible.

Cores and rotary chip samples, stored at the Department of Natural Resources, Quebec City, formed the basis of this study. Outcrop samples, and small cores obtained by drilling the Deschambault Formation along the Ouareau River were also utilized (Plate 1, Figure 1).

All the rotary drill cuttings and core were examined with the aid of a binocular microscope, noting lithology, grain size, grain type, and visible porosity. The following is a list of those wells from which cores of the Trenton Group were examined :

TABLE I Trenton core examined

Number (Houde,1964)	Name of Well	Trenton Cored Interval	Trenton Total
9	Bald Mountain Cap Santé No.1	330'-840'	510'
12	Bald Mountain Louiseville No.1	261'-711'	450'
14	Bald Mountain St. Roch No. 1	2010'-2565'	553'
15	Bald Mountain Portneuf No. 1	725'-1322'	597'
88	Oil Selections No.6	1000'-1557'	557'
102	Oil Selections No.36	756'-1321'	565'
58	Quonto Mascouche No. 1	150'-833'	683'

The petrographic study of the Tetreauville, Montreal, Neuville, and Ouareau Formations reveals that the limestones are predominantly dense micrite with shale occurring as partings or thin interbeds (see Chapter III). Some isolated lenses of fine to medium grained biosparite occur in the Montreal Formation.

Throughout the Tetreauville, Neuville, and Ouareau Formations and most of the Montreal Formation there is no evidence of primary porosity or solution except for a few isolated, calcite lined vugs of whole fossils. Although some primary porosity occurs in micritic limestones, the pores are generally so small as to be imperceptible, and the permeability so low that limestones with this texture can be excluded as commercial petroleum reservoir rocks (Chilingar et al, 1967a, p.357). Scattered pinpoint vugs occur in several coarser grained lenses of the Montreal Formation, however, these amount to less than 2 per cent of the rock.

In the cores studied several reported gas occurrences (Houde, 1964) were found to correspond to small fractures in the rock.

The Deschambault Formation is a pure, light gray, fine to coarse grained biosparite with thick to massive bedding. Examination of the Deschambault for visible porosity in the available core is summarized as follows:

TABLE II

Summary of visible porosity in cores penetrating the Deschambault Formation

Well	Cored Interval	Occurrence of porosity	Description
Bald Mountain Cap Santé No.1	740	745'	1/8 inch isolated vug and scattered pin-point vugs
		754'	Few 1/8 inch isolated vugs
	to	763'-764'	1 inch of 1/8 inch vugs in a network - 15% porosity
		777'	Few 1/16 inch vugs isolated
	840	800'	2 large ¼ inch isolated vugs
Bald Mountain Louiseville No.1	471 - 696	632'-638'	Scattered pin-point vugs porosity less than 1%
Bald Mountain St, Roch No. 1	2445-2565	----	No porosity visible
Bald Mountain Portneuf No.1	1224	1237'	2 inches of vuggy porosity vugs 1/16-1/8 inch
	to	1260.5'	Few vugs, very small and isolated
	1320	1296'	Fracture ¼" wide, with asphaltic lining
Oil Selections No.6	1450-1532	----	No porosity visible
Oil Selections No. 32	1264-1321	----	No porosity visible
Quonto Mascouche No. 1	734-833	----	No porosity visible

Seven samples of the Deschambault, obtained by drilling the outcrop, to obtain relatively unweathered specimens, were tested for permeability using a Soiltest Model K-670 Miniature

Permeameter (Appendix A).

All the samples yielded a negligible amount of water after 24 hours at a pressure of 4 atmospheres, and hence, are impermeable.

Two samples were sent to the Core Laboratory, Calgary for porosity and permeability measurements. The two samples were coarse grained calcarenites. Both samples were impermeable, having permeabilities of less than 0.01 millidarcy, and had very low porosities of 0.57 and 0.62 per cent.

The porosity in the Deschambault Formation occurs in isolated zones 1 to 2 inches thick that are too thin to be of commercial value. For the most part the Deschambault examined in the field and in the cores is not porous and is impermeable.

CHAPTER VI

Chemical Analysis of the Hydrocarbon Content

The presence of bituminous matter, droplets of oil in isolated vugs, black asphaltic material on the weathered surface of the bryozoan reef unit, and an overall fetid odour suggest that the Deschambault Formation may be petroliferous. The black shales of the Utica Formation and the upper Trenton may be a possible lateral source rock for petroleum.

The limestones and shales of the Trenton and Utica were analyzed to determine if their hydrocarbon content was indigenous or allochthonous. The principle of the oil source rock identification method used by Philippi (1957) is summarized as follows.

"In oil source rocks, small amounts of indigenous petroleum are practically universally present, even after the release of oil to reservoirs, and the amount of petroleum present is proportional to the much larger quantity of non-petroliferous indigenous organic matter called kerogen. In reservoir rocks the amount of oil present is determined by porosity, permeability, and trap conditions, and is in no way related to the content of indigenous organic matter" (Philippi, 1957,p.30).

There have been several studies of the extraction of hydrocarbons from the sediments, most notable are Hunt and Jamieson (1956) and Ferguson (1962), however, the procedure used by Philippi (1957) eliminates the time-consuming chromatography, and was used in this study because of its simplicity (Appendix B)

In order to isolate the small amount of hydrocarbon present the rocks are pulverized, and subsequently extracted with two organic solvents, diisopropyl, a hexane isomer C_6H_{14}, and diethylether, $C_4H_{10}O$.

Diisopropyl extracts the bulk of the monoaromatic and sturated hydrocarbons, paraffins and naphthenes, as well as free sulphur if present. The second solvent, diethylether, extracts mainly polyaromatic hydrocarbon molecules and complex oxygen, nitrogen, and sulphur compounds (Philippi,1957,p.27). Since the polyaromatic hydrocarbons are not normally a major constituent of petroleum, the diisopropyl extracts the bulk of the petroleum hydrocarbons present in the rock. The diethylether is used to effect a more complete extraction of the hydrocarbons, and to give some insight into the nature of the hydrocarbons present (Philippi, 1957,p.28).

Noncarbonate carbon is determined by dry combustion of the practically hydrocarbon free rock powder. Although the noncarbonate carbon and the content of insoluble organic kerogen are not identical, the kerogen being 1.2 to 1.5 times greater, it is assumed for simplicity to be equal to the noncarbonate carbon value (Philippi, 1957, p.30).

The insoluble organic matter should form the bulk of the total organic matter in a source rock, with the corresponding indigenous petroleum amounting to less than 10 per cent of the totla organic matter in the rock (Philippi, 1957,p.28). The kerogen probably represents some parent substance of petroleum formed from the original organic compounds deposited with the sediment (Nagy and Columbo, 1967).

To establish whether the petroleum extracted from the rocks is indigenous or allochthonous, the chemical data from several samples is plotted against their location in the stratigraphic section (Figure 6). If a correlation exists between the maxima and minima of the kerogen and the maxima and minima of the petroleum content, and the kerogen forms the bulk of the total organic matter, the rocks acted as an oil source and the petroleum is indigenous. If there is no correlation between the maxima and minima of the kerogen content and the maxima and minima of the petroleum content, and the kerogen does not form the bulk of the total organic matter in the rocks, the petroleum has probably migrated into the rocks.

Deschambault Formation

There is no genetic relationship between the petroleum content and the insoluble kerogen because the maxima and minima of the petroleum content and the kerogen do not correlate (Figure 6) in the manner shown by Philippi (1957, Figure 3). The kerogen also does not form the bulk of the total organic matter present in the Deschambault Formation.

Comparison of the graphs obtained by Philippi (1957) analyzing the reservoir and source rocks of the Pembina Field, Alberta (Figure 7b), and the reservoir rocks of the Mission Canyon and Lodgepole Formations in southern Saskatchewan (Figure 7c), with that obtained by analyzing the Deschambault Formation (Figure 7a) indicates that the Deschambault plots in a zone of reservoir rocks. This zone is characterized by a high amount of petroleum and a very low amount of insoluble kerogen.

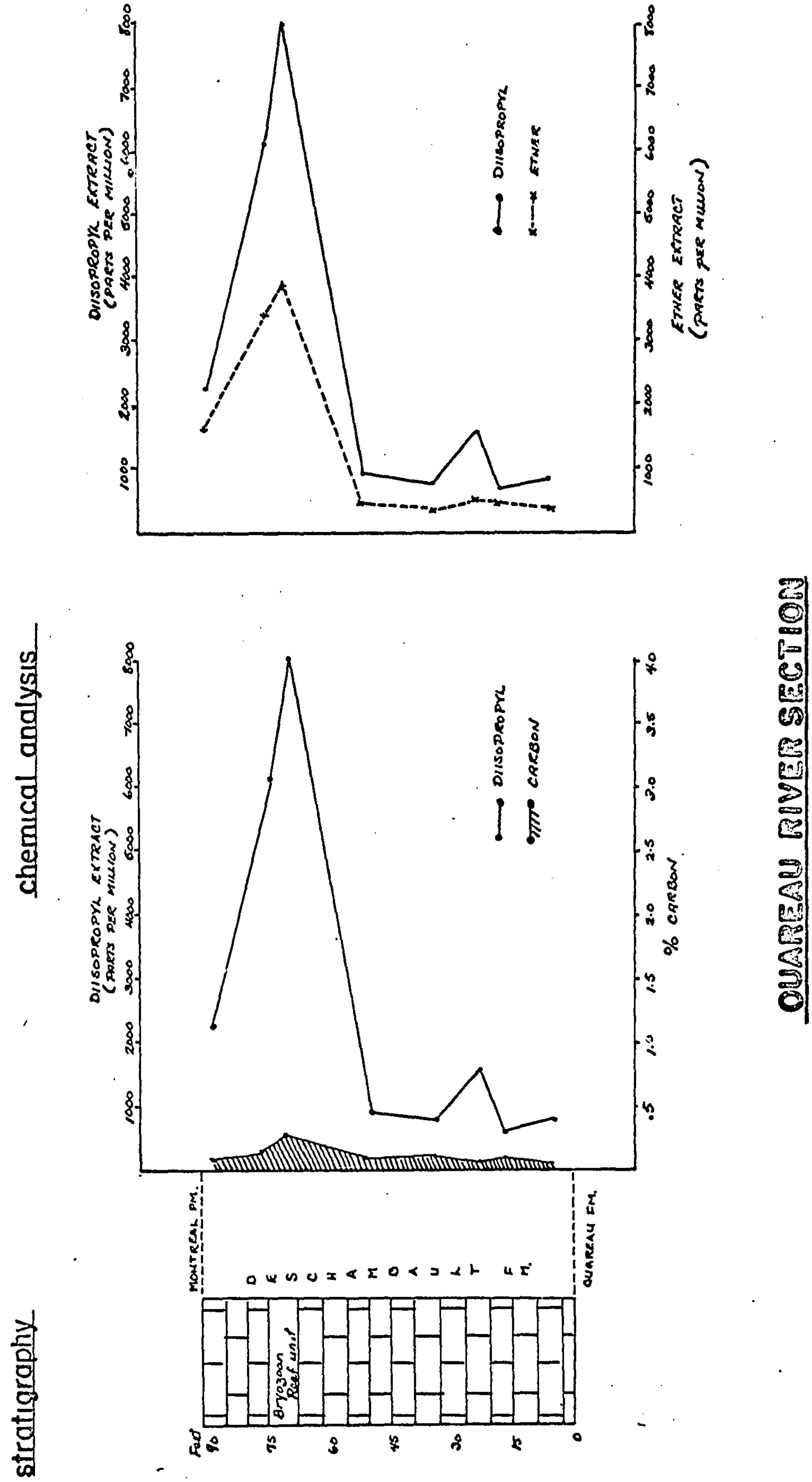
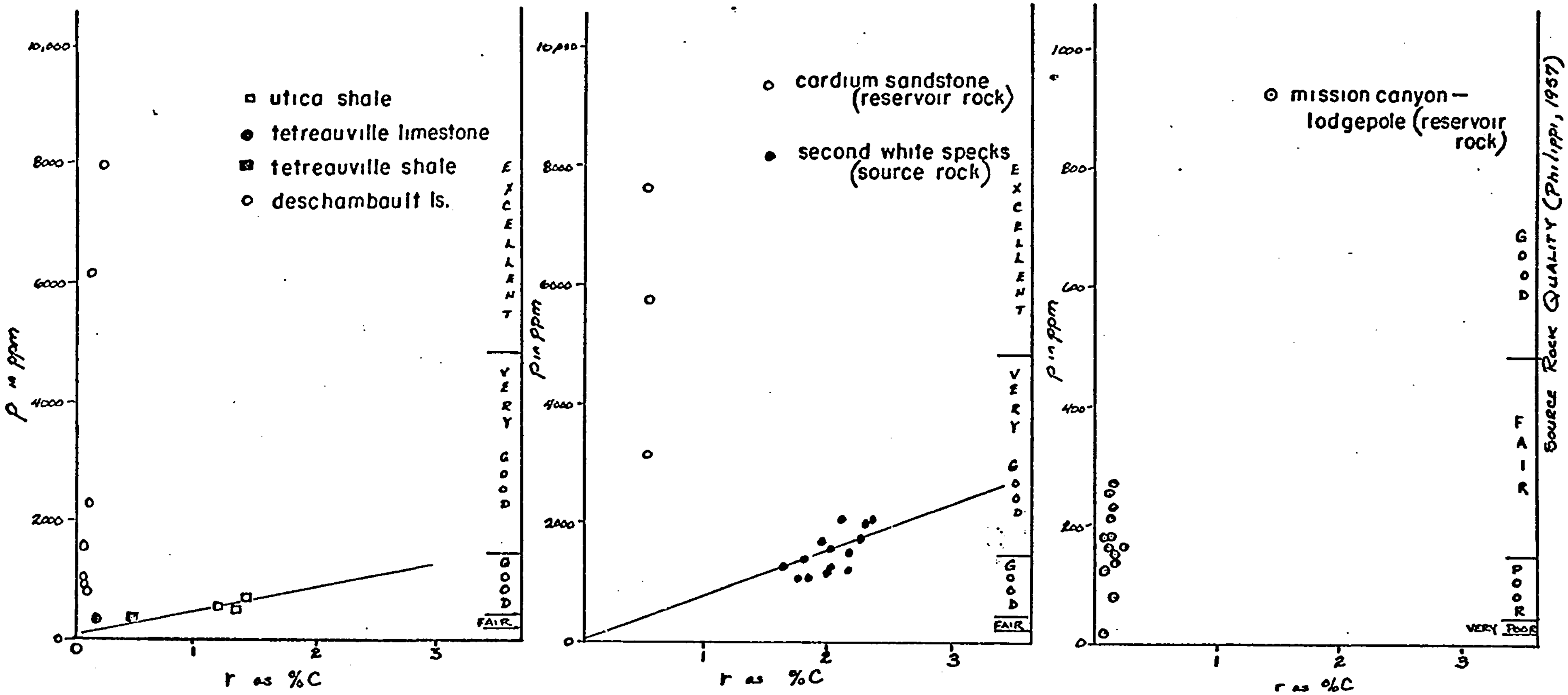


Figure 6 Chemical Analysis, Ouareau River

Figure 7

RELATIONSHIP BETWEEN PETROLEUM HYDROCARBONS AND RESIDUAL ORGANIC CONTENT OF THE SOURCE AND RESERVOIR ROCKS OF TWO OIL FIELDS, AND THE TRENTON – UTICA ROCKS.



a) TRENTON GROUP and UTICA, ST. LAWRENCE LOWLANDS

b) PEMBINA FIELD, ALBERTA (Philippi, 1957)

c) SOUTHERN SASKATCHEWAN FIELD (Philippi, 1957)

The petroleum present in the Deschambault is not indigenous and amounts to 3.5 to 12 barrels per acre foot* average, with up to 120 barrels per acre foot in the bryozoan unit.

The hydrocarbons present in the rocks have a greater amount of diisopropyl extractables than ether extractables (Figure 6) indicating that the petroleum has a high oil content and a low resin content.

Tetreauville and Utica Formations

The hydrocarbon content and the insoluble organic content of three samples of Utica shale, one sample of Tetreauville shale, and one sample of Tetreauville micritic limestone were analyzed. The samples all contained low amounts of petroleum hydrocarbons, ranging from 400 to 650 parts per million, and relatively higher amounts of insoluble kerogen, 0.4 to 1.4 per cent. The insoluble kerogen forms the bulk of the total oganic matter in the Utica and Tetreauville shales and limestones, amounting to 80 to 95 per cent, hence, the petroleum is indigenous.

A comparison of the data and characteristics, low petroleum content and high organic content, of the source rocks for the petroleum in the Pembina Field, Alberta (Figure 7b) with the data and characteristics of the rocks of the Utica and Tetreauville Formations indicates that the shale may have contained hydrocarbons or other materials which acted as a source for petroleum.

*In the conversion of parts per million into barrels per acre foot, the hydrocarbon density is assumed to be 0.9, and the rock density 2.7 (Philippi,1957,p.33).

CHAPTER VII

Stratigraphic Analysis

A stratigraphic analysis of an area, such as the St. Lawrence Lowlands, involves the use of several kinds of subsurface geologic maps based on borehole data. The location of wells referred to by number in the text is shown on Figure 16. Isopach, lithofacies, shale-limestone ratio, and structure maps each contribute an essential facet to an understanding of the geology of an area, however, the maps are necessarily incomplete because of widely spaced well control.

Trenton-Utica Contact Relationship

In general, the Utica, or Canajoharie, shale can be thought of as a widespread mud deposit which progressively encroached northwestward and displaced the Trenton upwards. The Trenton disappears toward the center of the Appalachian geosyncline, hence, the upper part of the Trenton and the lower part of the Utica are essentially contemporaneous (Clark, 1952,1959).

There is,as a rule, little trouble in determining the boundary between the Utica and Trenton on the northwest side of the St. Lawrence River where an abrupt lithologic change from limestone to black shale occurs. On the southeast side of the St. Lawrence River this boundary is gradational. Black shale with some limestone is the predominant lithology in the upper part of the Trenton (Figures 8 and 9).

In the Senigon well, 40 miles south of Montreal near the International Boundary, black shale predominates down to 2090 feet and is followed by 206 feet of Trenton limestone

(Clark and Strachan, 1955). The Trenton - Utica boundary, located by graptolites and other fossils, occurs mid-way in the shales, and the limestone is correlated with the Deschambault Formation (Clark and Strachan, 1955).

Belyea (1952) placed the base of the Utica Formation at the highest occurrence of limestone followed by black shale. In this study lithologic boundaries and rock stratigraphic units were used due to the limited paleontological data. Quite possibly in the deeper parts of the basin part of the black shale assigned to the Utica may have been deposited at the same time as the Trenton in the northwest part of the basin, as in the Senigon well south of Montreal. Since this contact is a facies change (Figure 8), and because little faunal control is available it is impossible to determine time lines in this part of the sequence and divide the Utica and Trenton into chronostratigraphic units, as is desired in the construction of isopach and lithofacies maps.

Lithifacies, Shale-Limestone Ratio, and Isopach Maps

Northwestward and upwards in the succession, shale gradually displaces the limestone (Figures 12,13 and 14). During the deposition of the lower Trenton **sediments** shales were deposited in a small northwestward embayment south of Lake St. Peter (Figure 12). During the upper Trenton, shale deposition had encompassed most of the southeast side of the St. Lawrence River (Figure 14). A shale-limestone facies change occurs southeast of the St. Lawrence River (Figure 11).

An anomalous calcarenite facies resulted when a shale-limestone boundary for the Utica- Trenton contact was selected

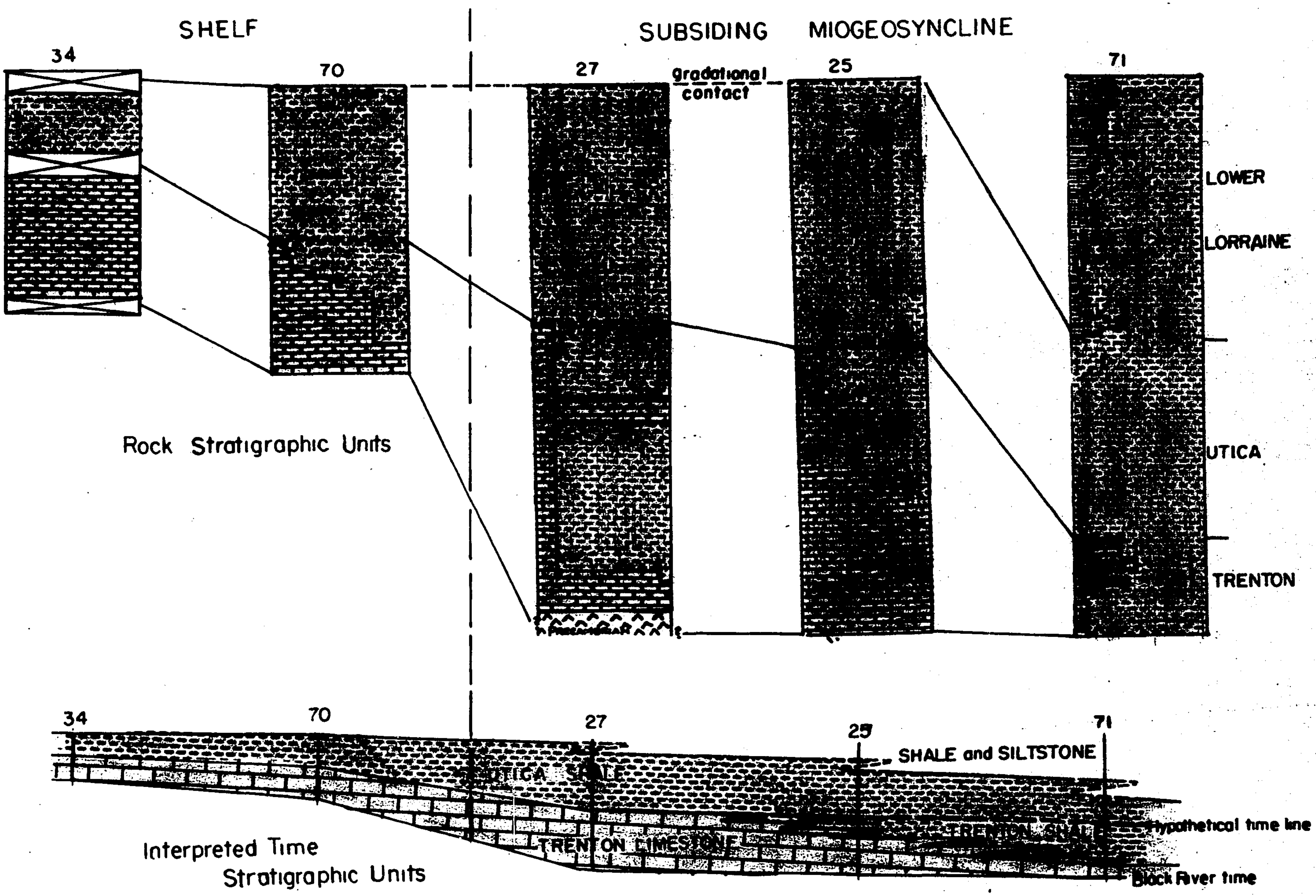
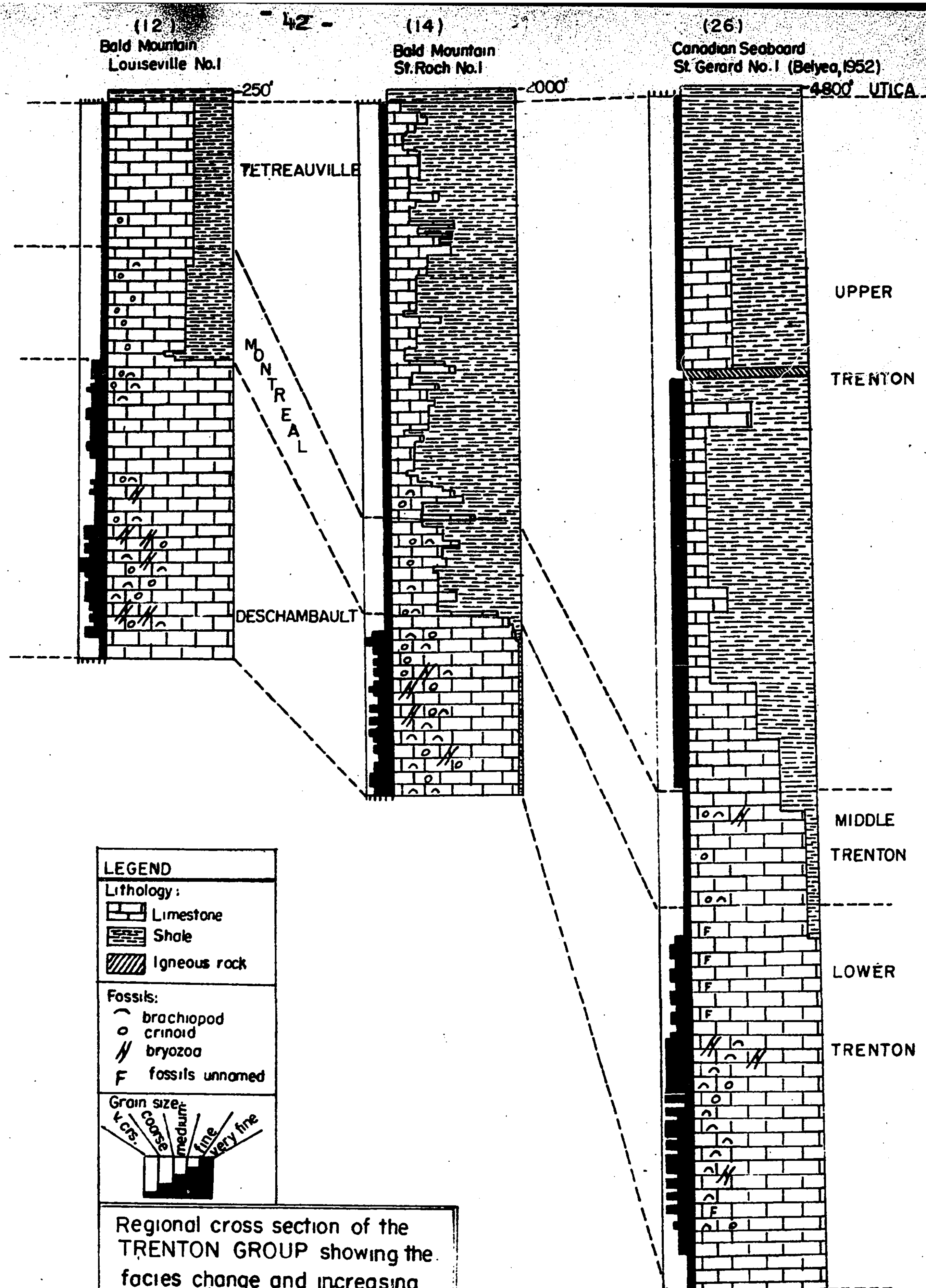


Figure 8 Regional Cross Section of the Trenton Group



Regional cross section of the TRENTON GROUP showing the facies change and increasing thickness southward.

May 1968 L. Currie

Figure 9

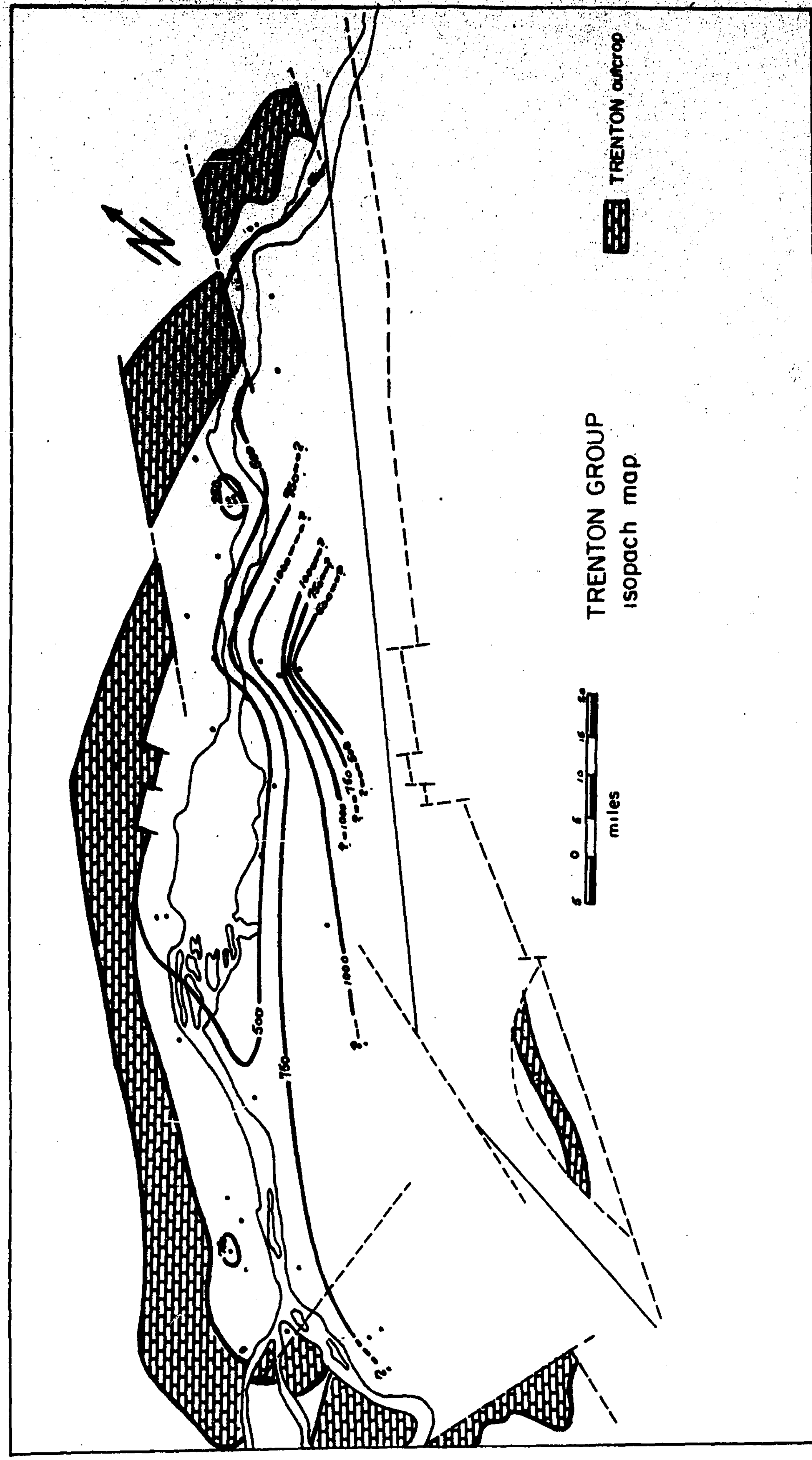


Figure 10 Trenton isopach map

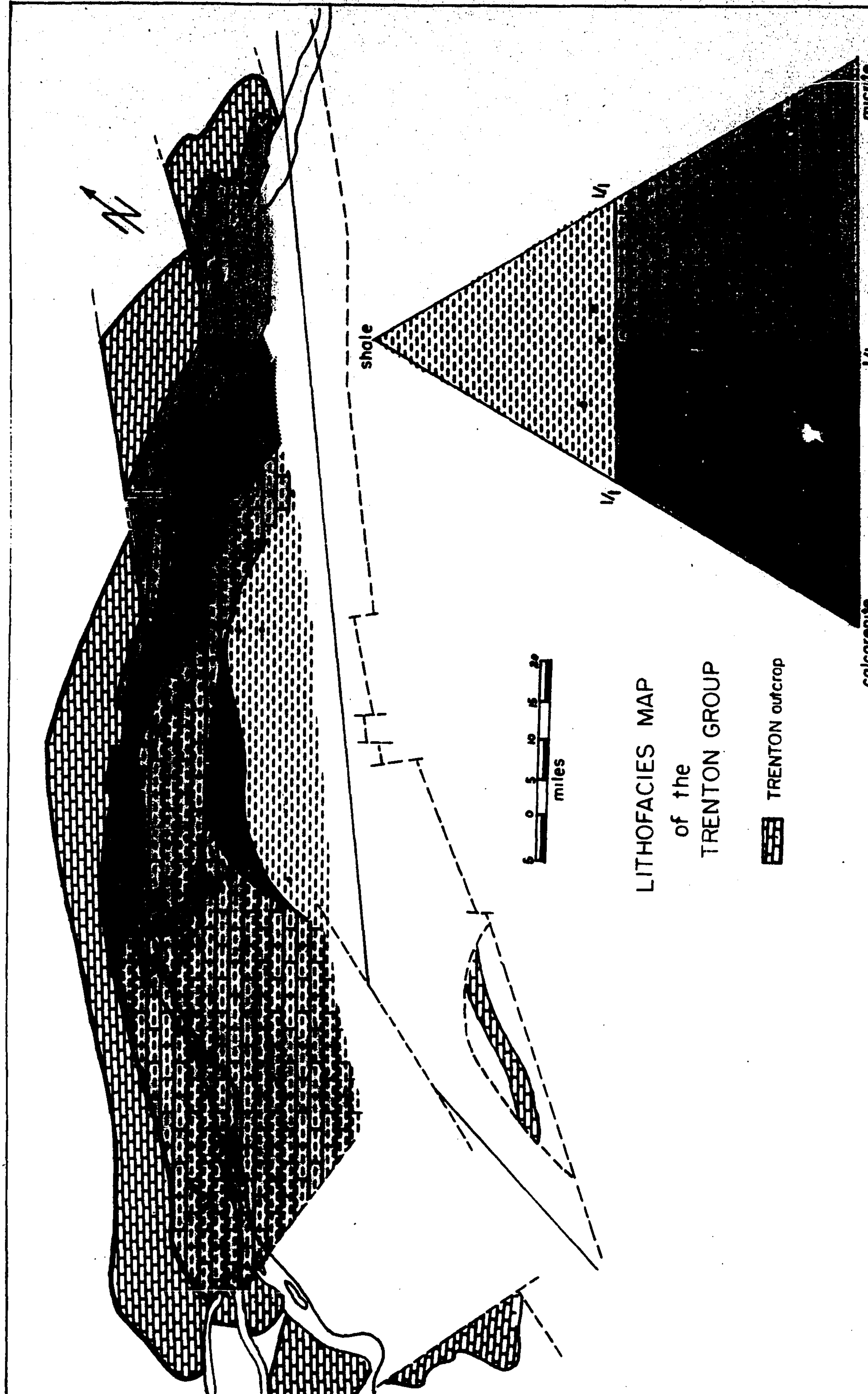


Figure 11 Trenton lithofacies map

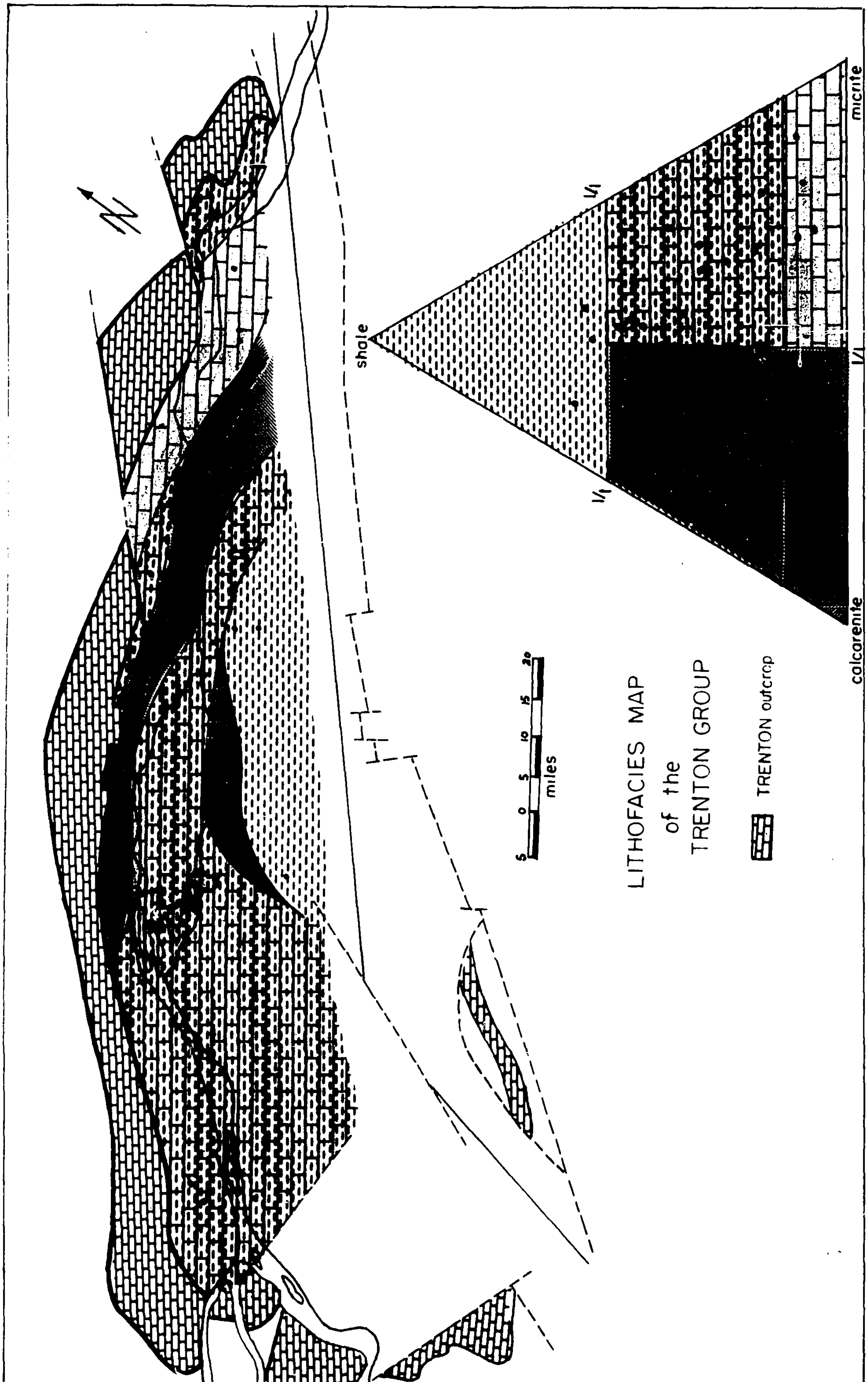


Figure 11 Trenton lithofacies map

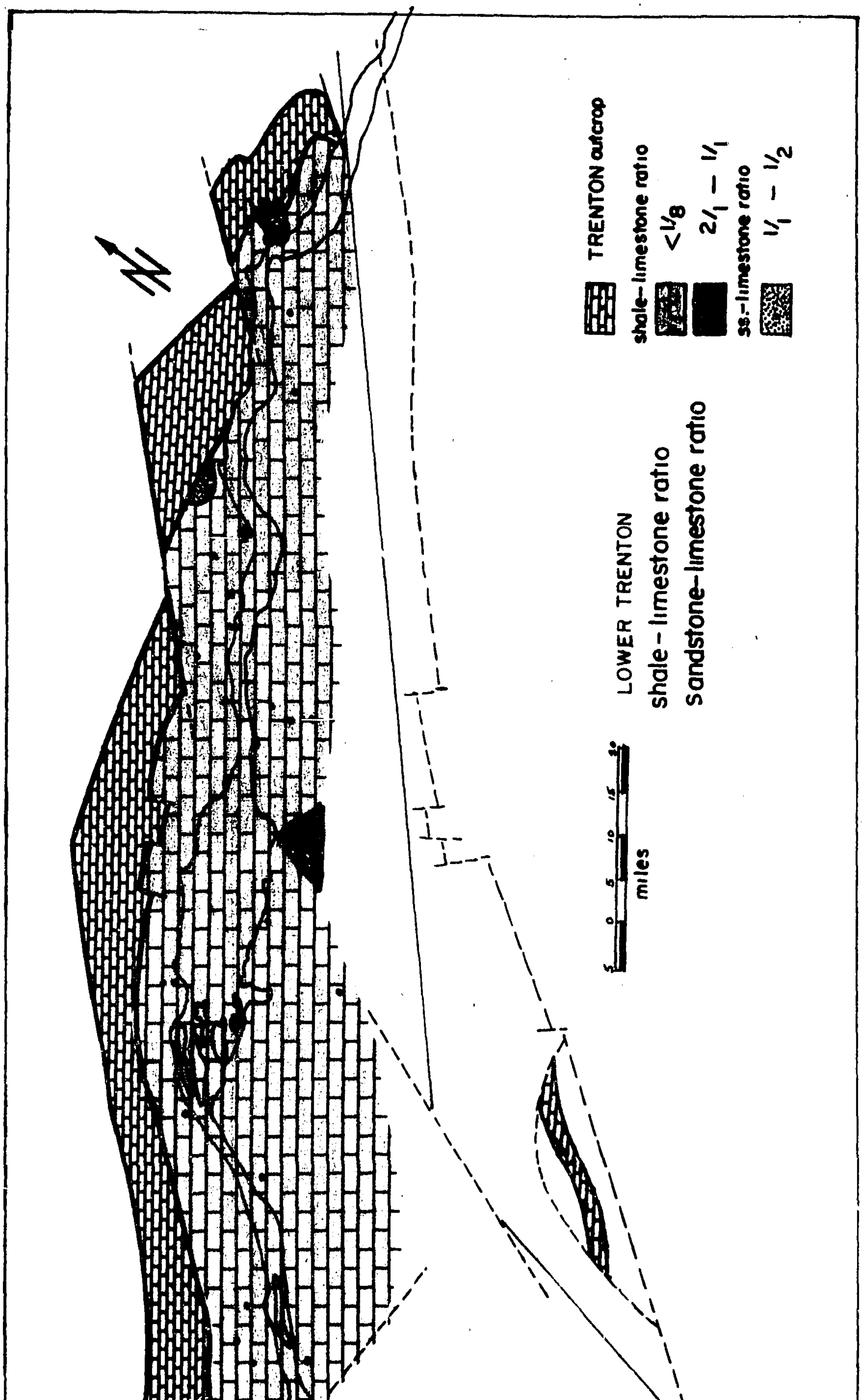


Figure 12 Lower Trenton shale-limestone ratio map

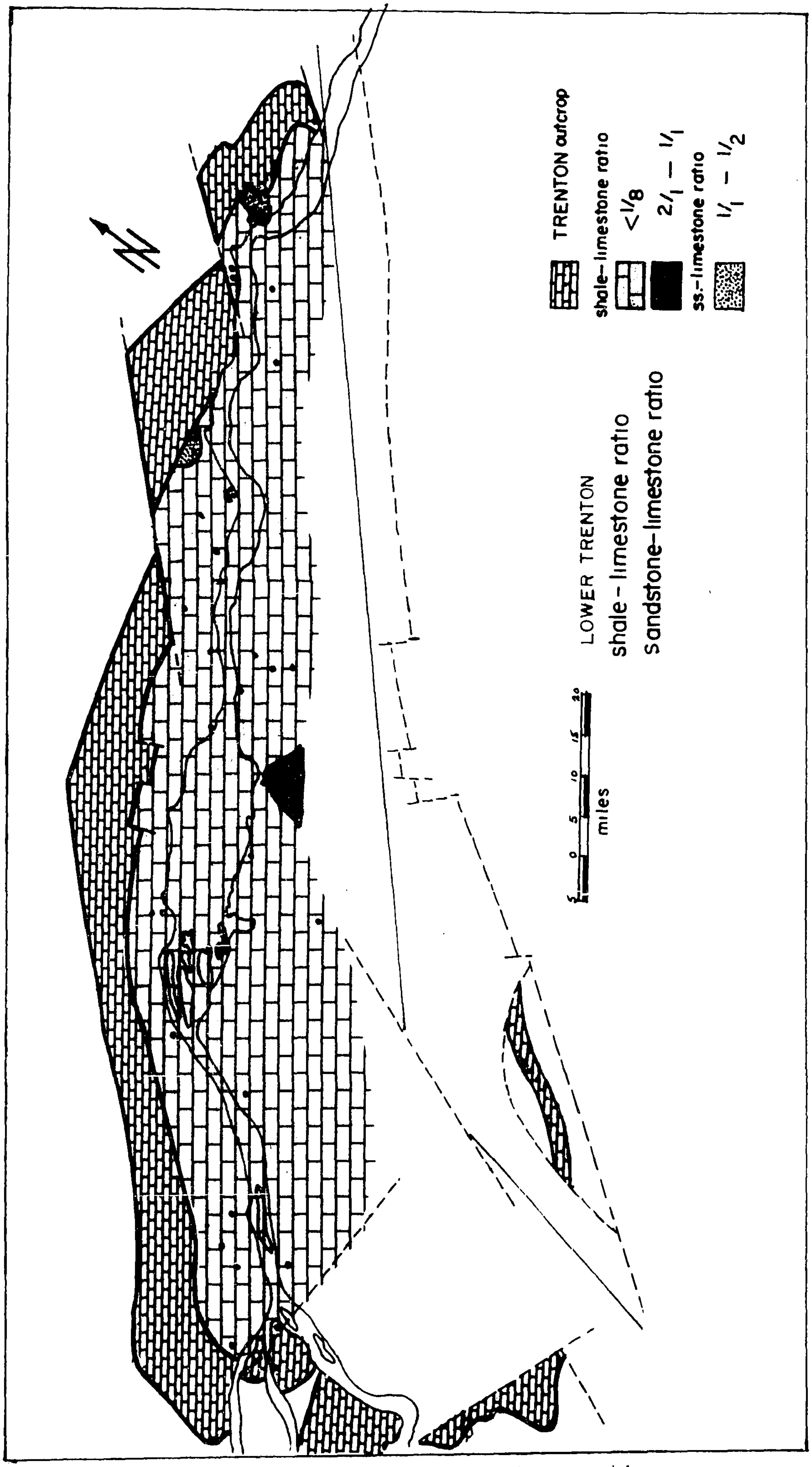


Figure 12 Lower Trenton shale-limestone ratio map

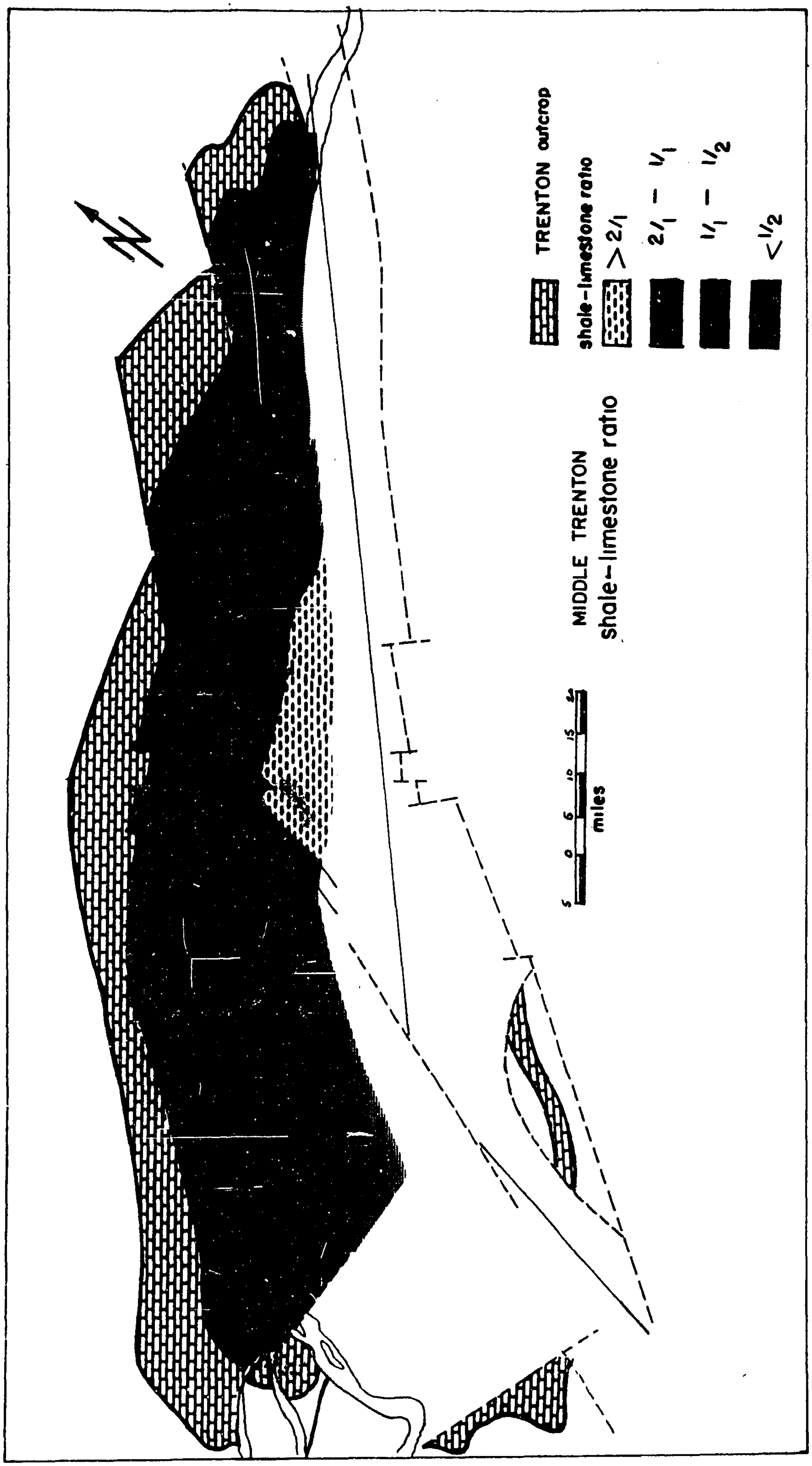


Figure 13 Middle Trenton shale-limstone ratio map

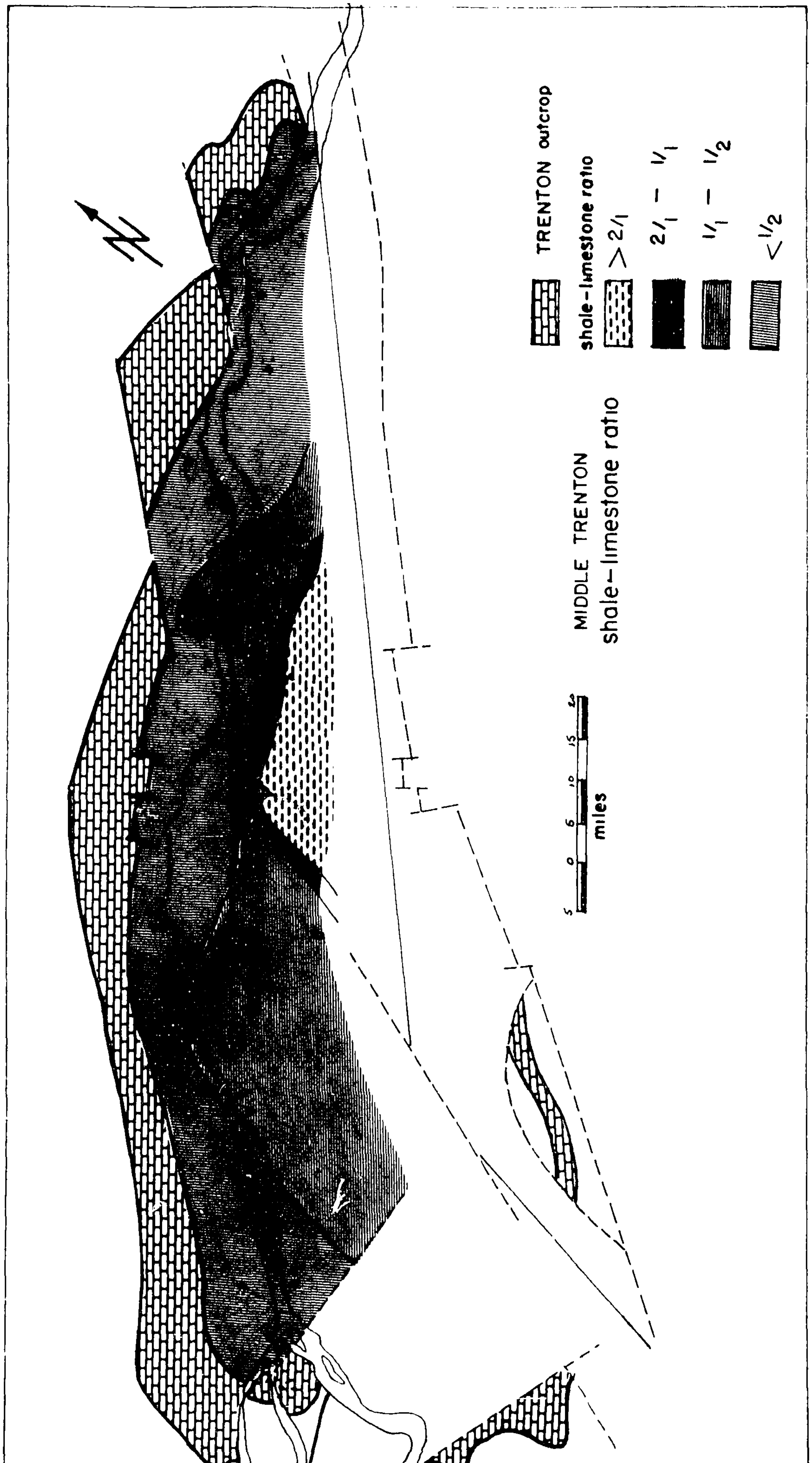


Figure 13 Middle Trenton shale-limestone ratio map

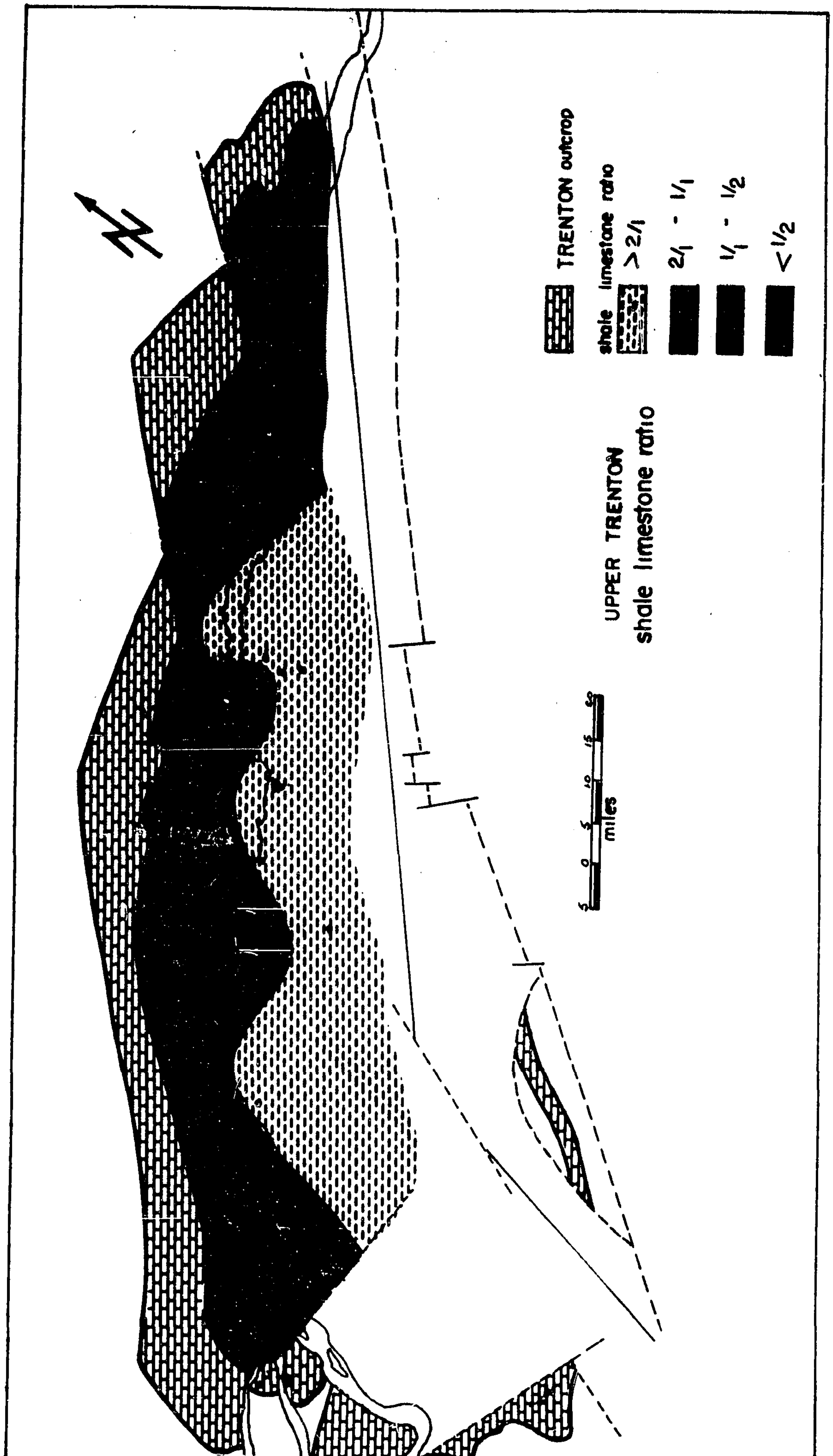


Figure 14 Upper Trenton shale-limestone ratio map

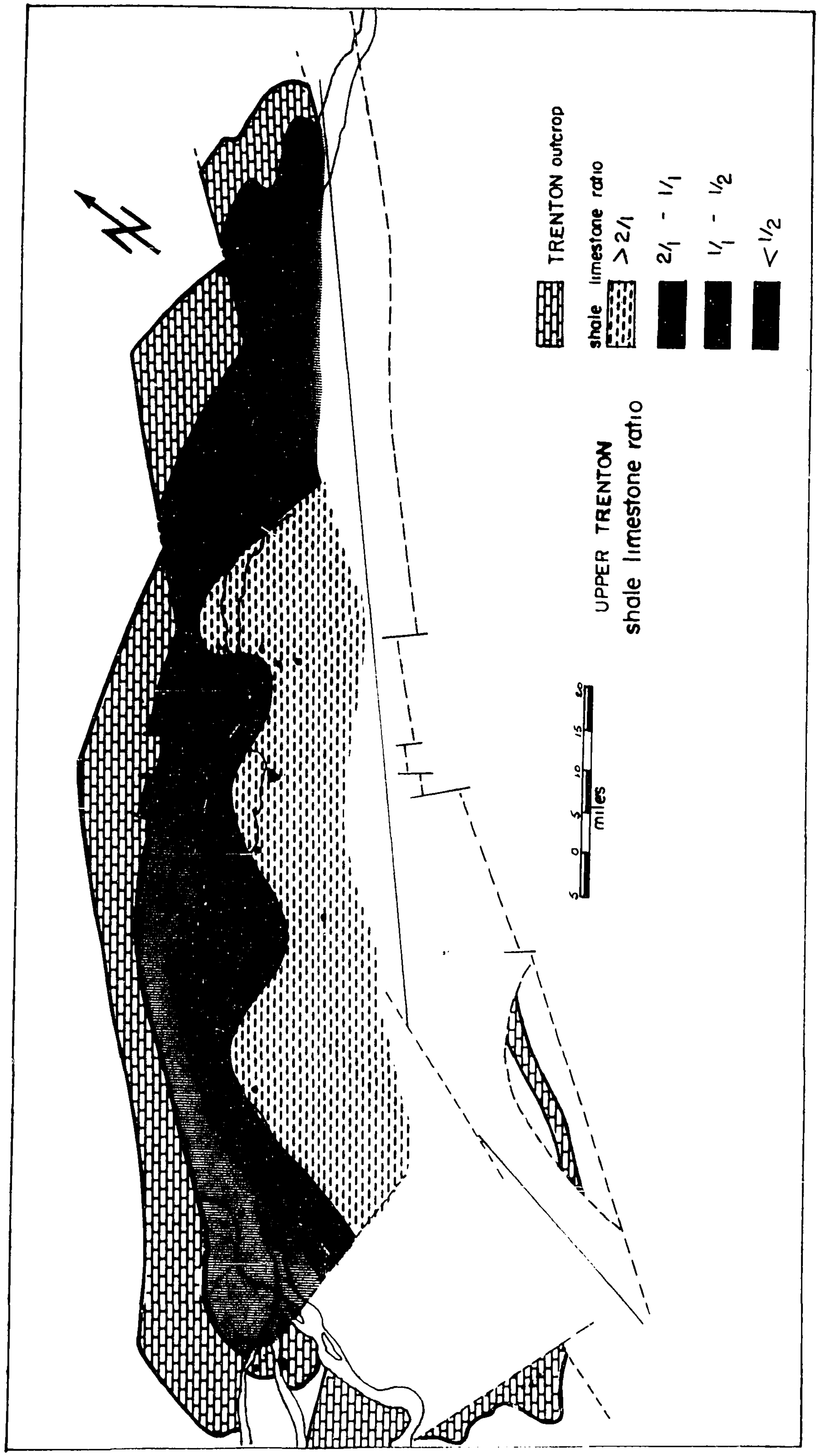


Figure 14 Upper Trenton shale-limestone ratio map

in well 71. Riva (personal communication,1968) stated that the thinning of the Trenton between wells 25 and 71 (Figure 8) is remarkable, but is not uncommon southeastward where the Trenton disappears and is replaced by Utica shale. In the construction of the lithofacies map (Figure 11) a portion of the Utica in well 71 was therefore assumed to have been deposited during the same time as the Trenton limestones.

The shale-limestone ratio is much lower throughout the Trenton on the nortwest side of the St. Lawrence River (Figures 12,13,and 14). The lower Trenton also contains abundant sandstone in wells number 11 and 16, where the Deschambault rests on the Precambrian basement.

The Trenton Group ranges in thickness from 225 feet to 1000feet, with a thickening towards the southeast (Figure 10). A uniform and thinner section occurs on the northwest side of the St. Lawrence River. The greatest thickness,1100 feet occurs in well number 27, southeast of Three Rivers, and a very thin section of Trenton was intersected in wells 4, 5, 6, and 7, east of Three Rivers.

The Trenton thins abruptly in well number 71, but as previously mentioned, a portion of the overlying black shale may belong to the Trenton, however, paleontological evidence to support this hypothesis is at present lacking (Figure 8), although elsewhere, as in the Senigon well, this situation does occur.

A southeast source for the black shales is indicated by the presence of relatively clear limestones in the northwest part of the basin and the increase of shale content in the upper in well 71. Riva (personal communication,1968) stated that the thinning of the Trenton between wells 25 and 71 (Figure 8) is remarkable, but is not uncommon southeastward where the Trenton disappears and is replaced by Utica shale. In the construction of the lithofacies map (Figure 11) a portion of the Utica in well 71 was therefore assumed to have been deposited during the same time as the Trenton limestones.

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A southeast source for the black shales is indicated by the presence of relatively clear limestones in the northwest part of the basin and the increase of shale content in the upper part of the Trenton which gradually shifted northwest with time. This interfingering of shales and limestones would provide suitable pathways for fluids, possibly petroleum bearing, compacted from the black shales provided the limestones contained some permeable zones and were not completely cemented at an early stage.

Table III
List of wells drilled to the Trenton Group, St.Lawrence Lowlands

Well Number (Houde,1964) Spudded	Well Name	Cored	Rotary
3 (1956)	Bald Mountain Batiscan No. 1		X
4 (1957)	Bald Mountain Batiscan No. 2		X
5 (1957)	Bald Mountain Batiscan No. 3		X
6 (1957)	Bald Mountain Batiscan No. 4		X
7 (1957)	Bald Mountain Batiscan No. 5		X
8 (1956)	Bald Mountain Berthierville No.1		X
9 (1957)	Bald Mountain Cap Santé No.1	X	
10 (1958)	Bald Mountain Cap Santé No.2		X
11 (1957)	Bald Mountain La Pérade No.2		X
12 (1957)	Bald Mountain Louiseville No.1	X	
13 (1957)	Bald Mountain Louiseville No.2		X
14 (1957)	Bald Mountain St. Roch No.1	X	
15 (1957)	Bald Mountain Portneuf No.1	X	
16 (1957)	Bald Mountain Portneuf No.2		X
17 (1958)	Bald Mountain Ste.Geneviève No.1		X
25 (1934)	Canadian Seaboard St. Grégoire No.1		X
26 (1931)	Canadian Seaboard St.Gérard No.1		X
27 (1933)	Canadian Seaboard Ste.Angèle No.1		X
28 (1957)	Canso St.Maurice-St.Léon No.1		X

Table III(continued)

Well Number	Well Name	Cored	Rotary
29 (1959)	Caprive No.2 Trois Rivières		X
30 (1962)	Caprive No.3 Trois Rivières		X
31 (1934)	Cartier Natural Gas No. 5		X
33 (1956)	Madeleine No. 1	X	
34 (1956)	Madeleine No. 2	X	
46 (1929)	L'Assomption Experimental Farm Well		X
56 (1911)	Longueuil Military Barracks Well		X
58 (1957)	Quonto International Mascouche No.1	X	
60 (1957)	Canso-St.Maurice-Pointe-du-Lac No.1B		X
62 (1958)	Laduboro No.2 La Baie-Yamaska	X	
63 (1959)	Laduboro No.3 La Baie-Yamaska		X
64 (1959)	Laduboro No.4 La Baie-Yamaska		X
65 (1962)	Laduboro No.5 La Baie-Yamaska		X
69 (1956)	Imperial Lowlands No.1 (Lotbinière)		X
70 (1956)	Imperial Lowlands No.2 (Nicolet)		X
71 (1956)	Imperial Lowlands No.3 (Nicolet)		X
72 (1957)	Imperial Lowlands No.4 (Lotbinière)		X
74 (1959)	Imperial Lowlands Seaway No.1		X
75 (1957)	Imperial Lowlands Verchères No.1		X
80 (1934)	Mohr No.1		X
84 (1956)	Okalta-Oilmont No. 1		X
85 (1956)	Okalta-Oilmont No.2	X	X
86 (1956)	Oil Selections No.2		X
87 (1956)	Oil Selections No.5		X
88 (1956)	Oil Selections No.6	X	X
91 (1956)	Oil Selections No.9		X

Table III(continued)

Well Number	Well Name	Cored	Rotary
94 (1956)	Oil Selections No. 20		X
97 (1956)	Oil Selections No.23		X
98 (1956)	Oil Selections No.24		X
99 (1956)	Oil Selections No.29	X	X
100 (1956)	Oil Selections No.30		X
101 (1956)	Oil Selections No.31		X
102 (1956)	Oil Selections No.32	X	
103 (1957)	Oil Selections No.33		X
105 (1909)	Quebec Fuel No.2		X
106 (1909)	Quebec Fuel No.3		X
107 (1910)	Quebec Fuel No.4		X
109 (1931)	Richelieu Gas St. Denis Nos.1 and 2		X
111 (1947)	St.Johns Petroleum St.Hubert No.1		X
117 (1959)	Seaway-Almega No.9 St. Maurice		X

Structure

Structure contour maps of the top of the Trenton Group were constructed using data from Belyea (1952) and Houde(1964). Structure control on the southeast side of the St. Lawrence River is scattered and poor, especially in the vicinity of Montreal.

The Trenton dips uniformly southward towards the axis of the Chambly-Fortierville syncline (Figures 15,16, and 19). The spacing of the contours does not indicate a flattening of the regional dip or a change of dip direction.

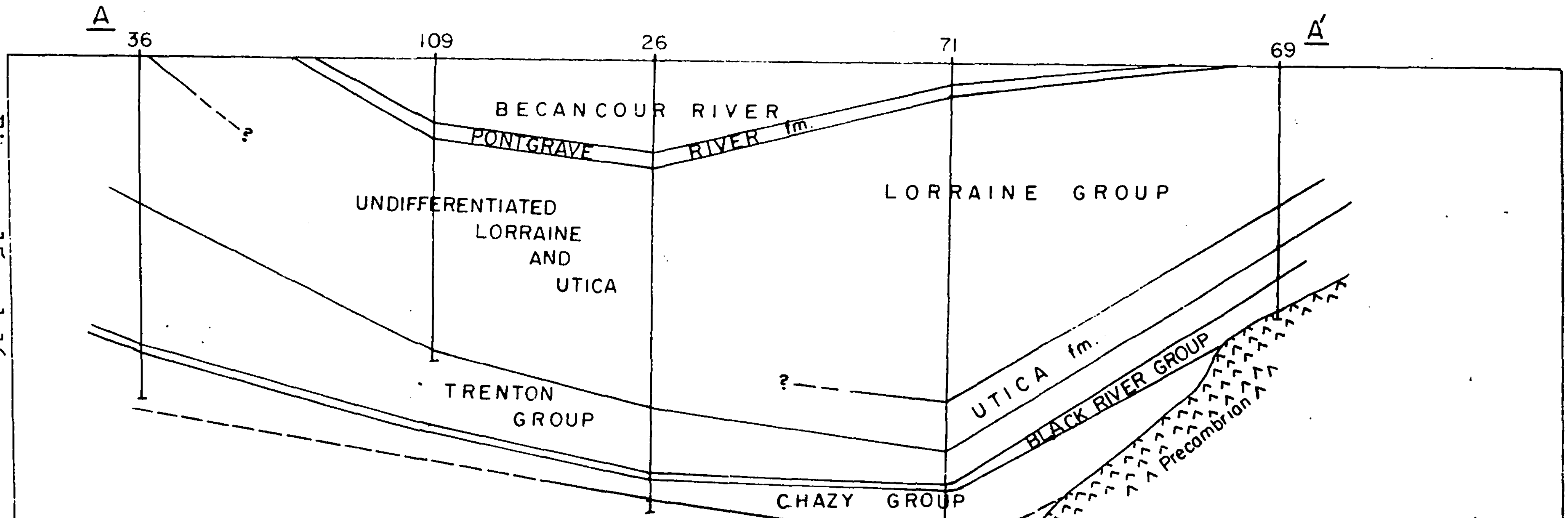


Figure 15 CROSS SECTION A-A' ALONG THE AXIS OF THE CHAMBLY-FORTIERVILLE SYNCLINE

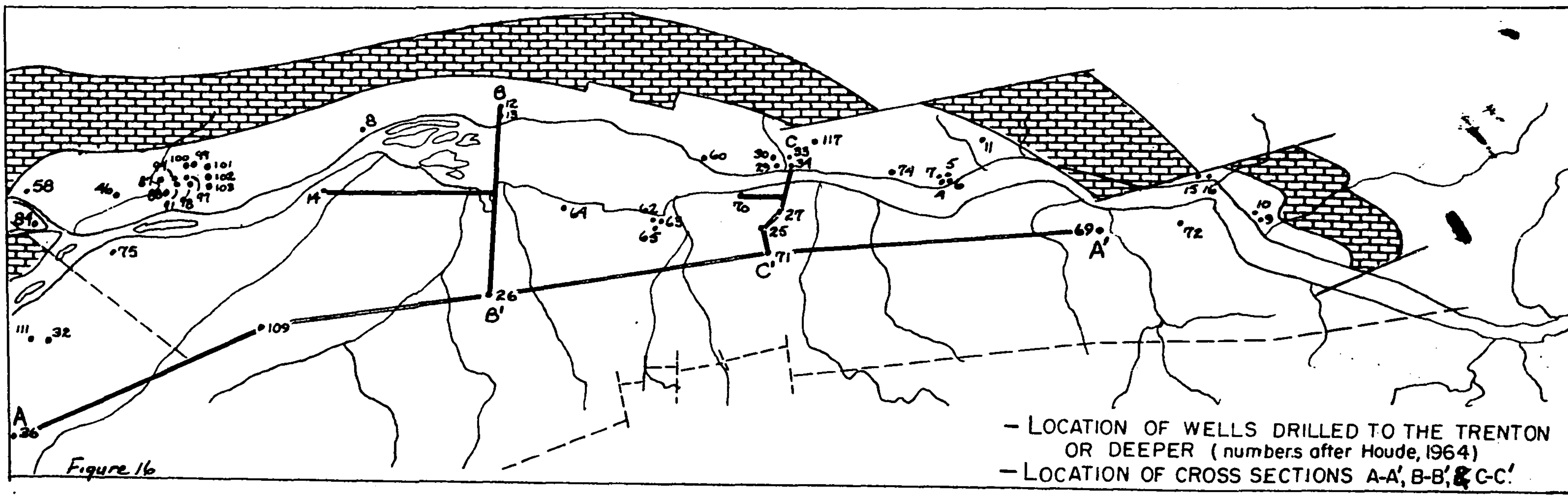
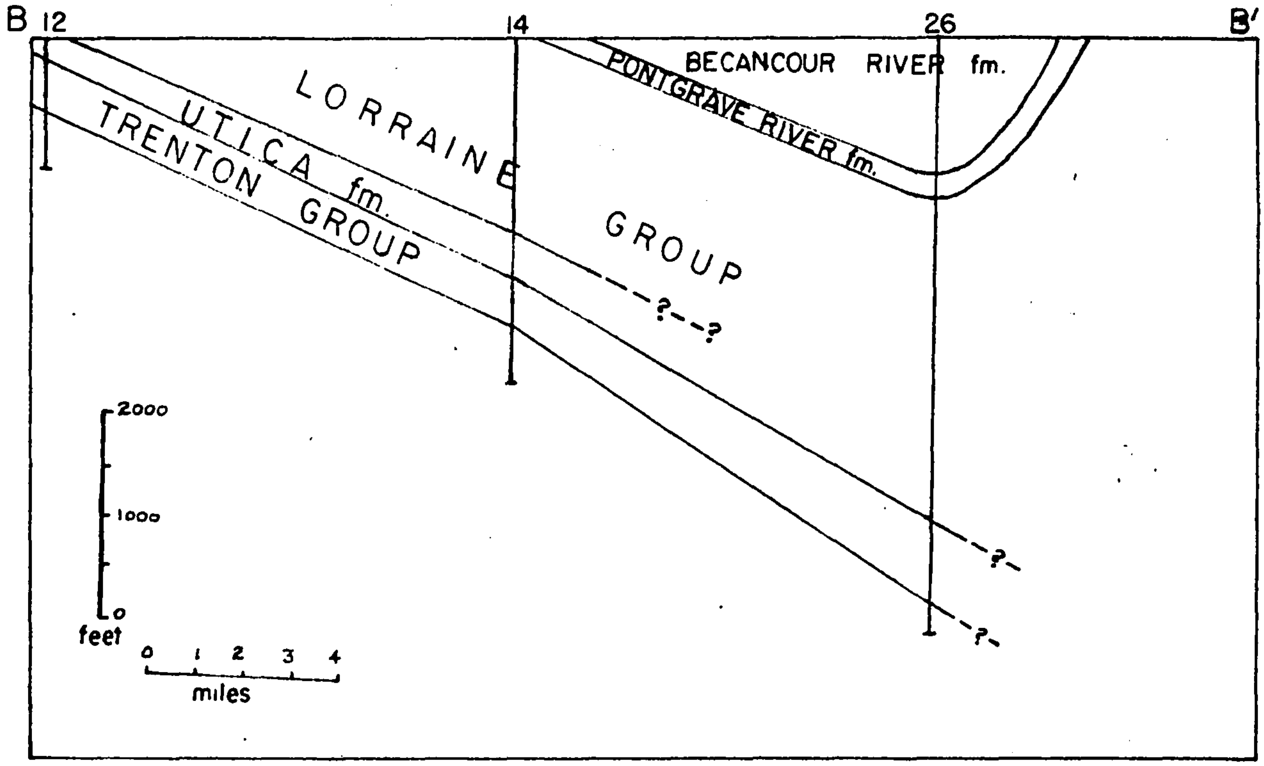


Figure 16



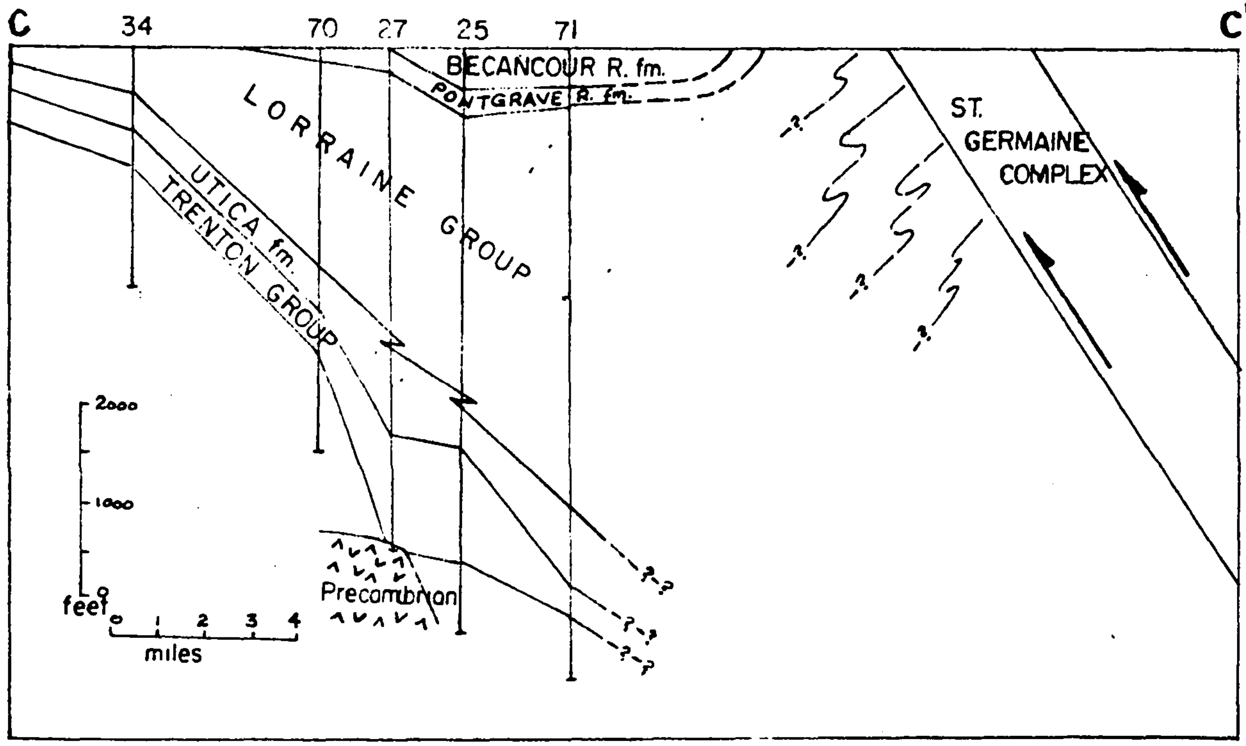
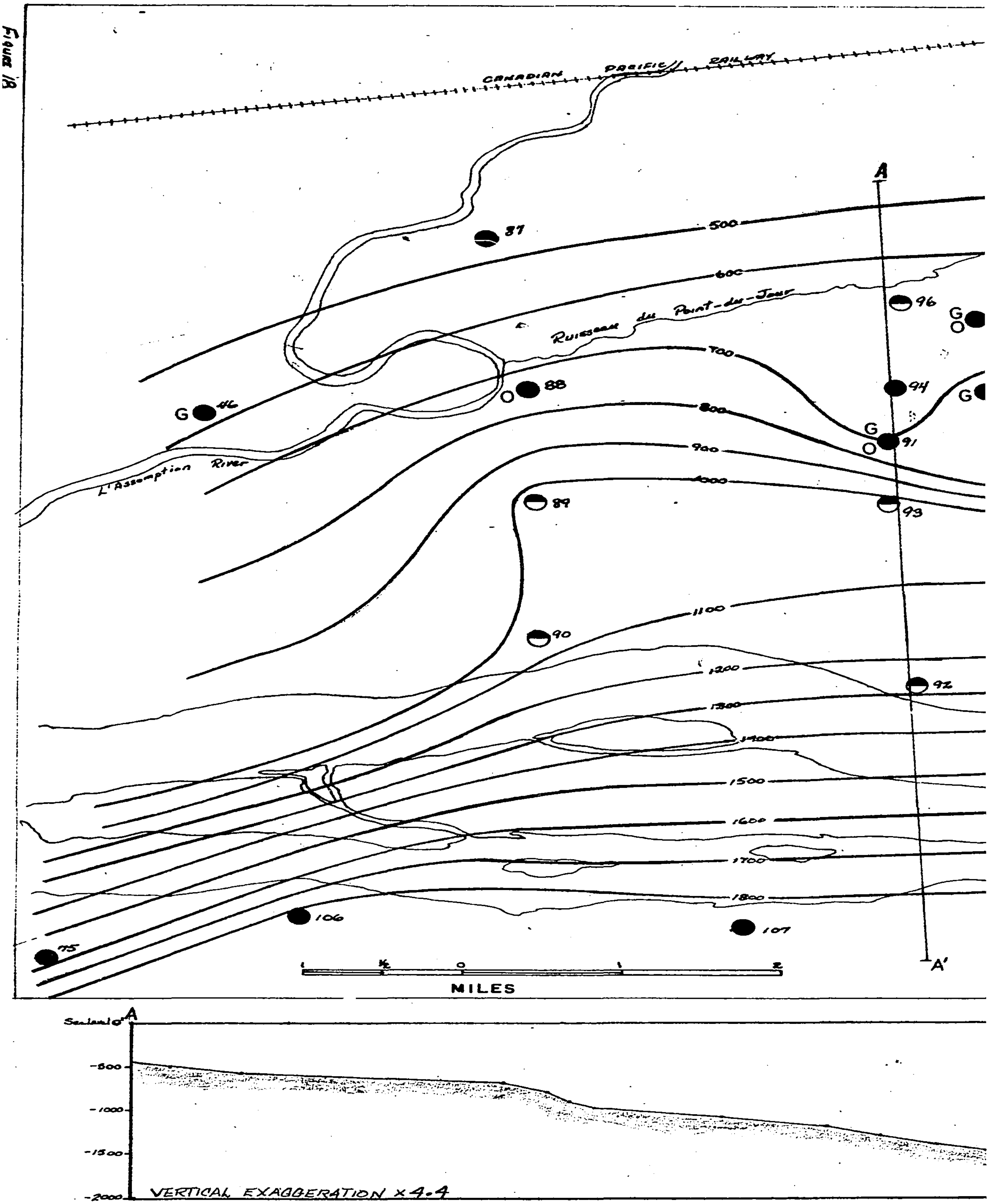


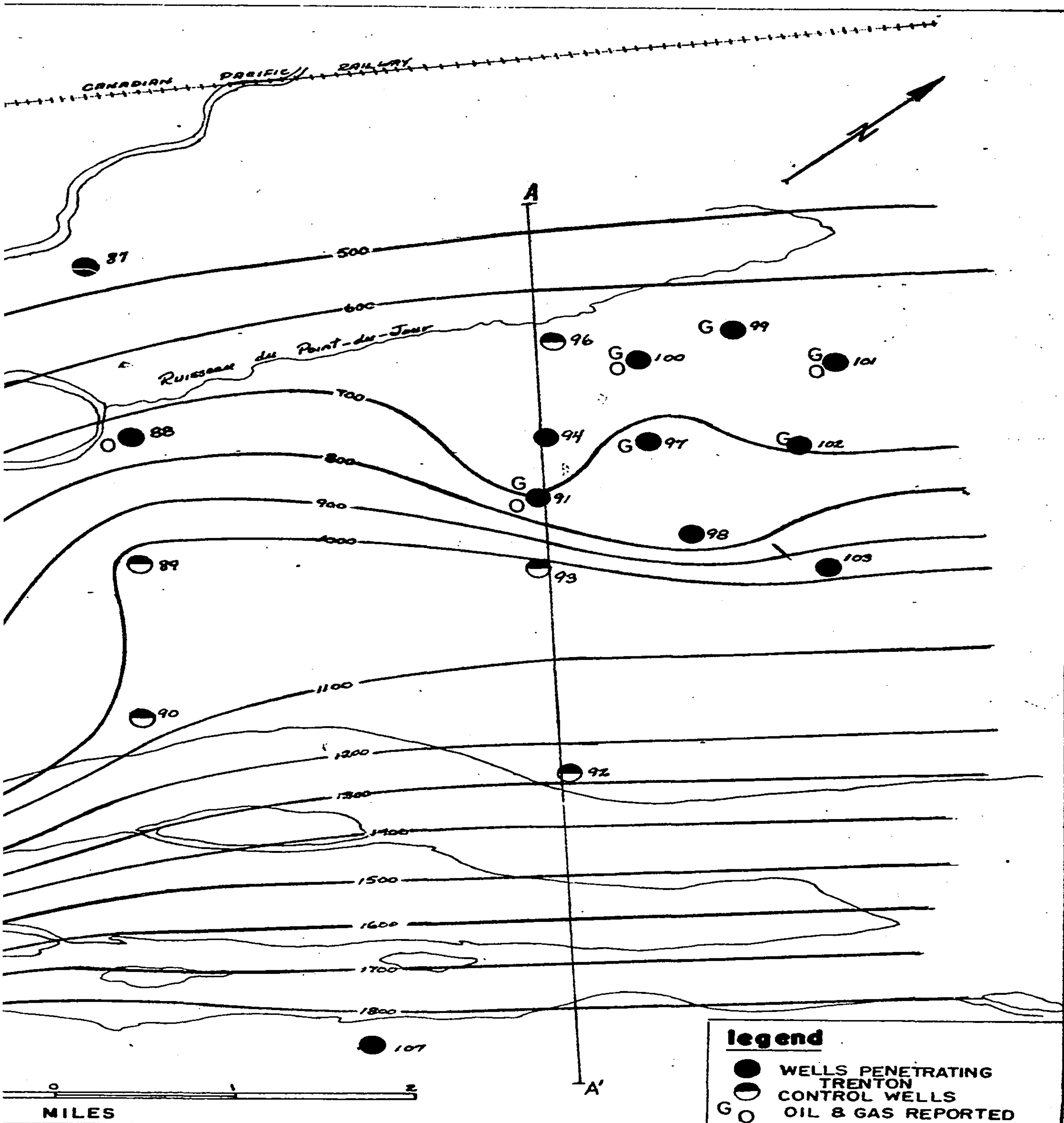
FIGURE 17 CROSS SECTIONS B-B' and C-C' (see Figure 16)

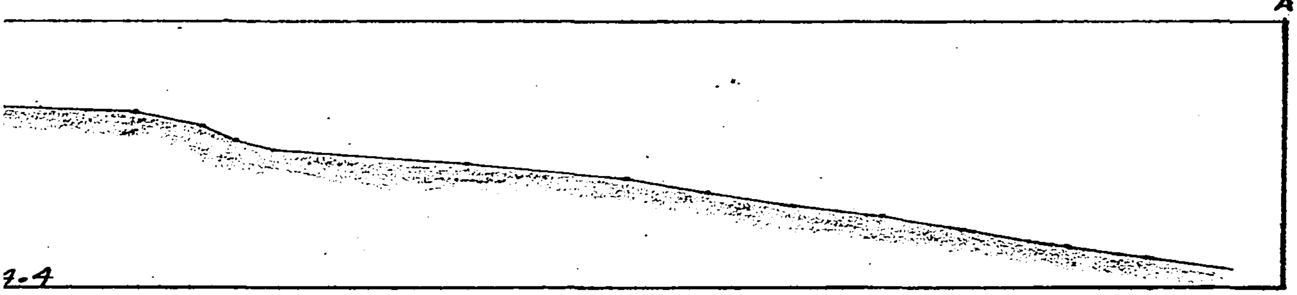


SECTION A-A' , TRENTON-UTICA CONTACT

Figure 18 **STRUCTURE OF THE TOP OF THE TRENTON G**

L'ASSOMPTION





?-4

SECTION A-A' , TRENTON-UTICA CONTACT

CTURE OF THE TOP OF THE TRENTON GROUP
L'ASSOMPTION

A detailed structure map of the L'Assomption area reveals the presence of a terrace. In wells located along this flattening in the otherwise uniformly dipping strata, several minor oil and gas occurrences have been reported (Houde,1964) (Figure 18). The isopach map is not detailed enough in this area (only three wells penetrate the complete Trenton section) to interpret this as a stratigraphic thickening. There are no obvious large scale structures or faults present in this area that may control such a feature. The terrace may, therefore, be either stratigraphically or structurally controlled.

Any petroleum present in the Trenton limestone would not be substantially trapped by the synclinal structure of the St. Lawrence Lowlands. Most of the Trenton limestone is nonporous and impermeable, micritic limestone and relatively early cemented calcarenites, with very thin isolated zones of porosity. The occurrence of petroleum would not be controlled by post-lithification faulting and where minor occurrences do occur in the Trenton they are controlled by fracturing or small isolated porous zones.

Geothermometry

The suggested relation between earth temperature, depth of burial, and hydrocarbon occurrence and density permits some insight into the type and occurrence of hydrocarbons present in prospective horizons.

The amount of heat flow is the product of the thermal gradient, over some distinct uniform section, and the average thermal conductivity for that section.

In the St. Lawrence Lowlands the average heat flow is

0.740 ± 0.044 μcalories/cm.^{2}/sec. (Doig,1961,p.64). Heat flow values of 0.82 ± 0.03 μcalories/cm.^{2}/sec. for two boreholes were reported by Beck (1967,p.134). Most of the results in the St. Lawrence Lowlands are left uncorrected for the unknown effect of the Pleistocene glaciation. This effect could e explain the low values obtained, and if corrected they would be near to the world average (Crain,1967). The heat flow may have been as high as 1.3 μcalories/cm.^{2}/sec. in geologic time, and at present, allowing for the glaciation, is about 1.0 μcalories/cm.^{2}/sec. (Doig, personal communication).

The average values of the thermal conductivity for the Lorraine Group (Doig,1961,p.56), and approximate values for the limestones, sandstones,and shales (Doig, personal communication) were used in conjunction with the corrected heat flow value for the St. Lawrence Lowlands.

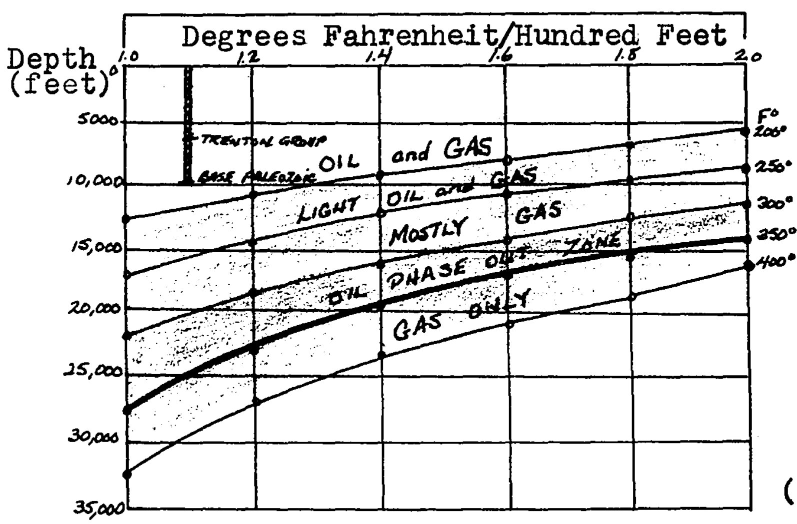
The Cretaceous igneous intrusives in the Montreal area are of very local extent, and probably did not effect the thermal gradient to any extent (Dr.A.R.Philpotts, personal communication, May,1968).

The approximate stratigraphic thicknesses of the rock units on the south side of the St. Lawrence River and their lithologies are as follows (Clark,1947; Belyea,1952;Roliff,1967):

Table IV

Stratigraphic Thicknesses and Lithologies				
Age	**Unit**	**Lithologies**	**Unit Thickness**	**Total Feet**
Devonian	Oriskany and Helderberg	limestone	unknown	9670+
Ordovician	Richmond Group	shale, siltstone	1500	9670
	Lorraine Group	sandstone shale, siltstone	3500	8170
	Utica Formation	black shale	800	4670
	Trenton Group	limestone	1000	3870
	Black River Group	dolomite limestone	70	2870
	Chazy Group	dolomite limestone	800	2800
	Beekmantown Group	dolomite	1200	2000
Cambrian	Potsdam Formation	sandstone	800+	800

Thus, a minimum of 10,000 feet of sediments were deposited in that part of the basin that subsided the most.



(from Landes,1967)

Figure 20 Earth temperature and the occurrence of oil and gas

The geothermal gradient in the St. Lawrence Lowlands is approximately 1.1 F°/100 feet, which does not appear to be abnormal (Levorsen,1954,p.403). The Trenton was probably buried to at least a depth of 6500 feet, and the base of the Paleozoic sediments to at least a depth of 10,000 feet. The depth of burial and the pressure and temperature conditions would have been suitable for the generation of both oil and gas in the St. Lawrence Lowlands (Figure 20) following the depth and temperature conditions summarized by Landes (1967).

CHAPTER VIII

Summary and Conclusions

1. Micritic limestones predominate in the Trenton Group, except for the crinoidal calcarenites of the Deschambault Formation. By virtue of being micrites, most of the Trenton limestones are non-porous and impermeable. The Deschambault calcarenites are tightly cemented, non-porous, and impermeable, except for thin, isolated zones.

2. The Deschambault calcarenites appear to have been lithified shortly after deposition. The final infilling of the void space was by pressure solution associated with the formation of the abundant stylolites.

3. The hydrocarbons present in the Deschambault limestones are not indigenous, they migrated into the limestone prior to stylolitization, and represent residues left after the expulsion of all fluids from the limestones during stylolitization. The hydrocarbons may have been derived from the compaction of the thick, basinward black shale facies of the Trenton and Utica which may have contained hydrocarbons or other material that acted as a source for petroleum.

4. The depth of burial of the Trenton Group and the geothermal gradient of the sedimentary basin are not abnormal. These conditions are suitable for the generation and accumulation of both oil and gas in the St. Lawrence Lowlands, however, no suitable porous or permeable horizons occur, and no suitable stratigraphic or structural traps are known. From the present known distribution of the Trenton Group it appears unlikely

that suitable traps will occur in the deeper parts of the basin or even in the thrust slices of the St. Germain Complex because of the rapid increase of shale content in this direction and the predominance of micrites in the Trenton Group.

BIBLIOGRAPHY

Ager, D. V., 1963, Principles of Paleocology; McGraw-Hill pub., New York, pp. 77-84.

Baker, D. R., 1962, Organic geochemistry of the Cherokee Groups in southeastern Kansas and northeastern Oklahoma; Bull. Am. Assoc. Pet. Geol., vol. 46, pp. 1621-1642.

Baker, E. G., 1960, A hypothesis concerning the accumulation of sediment hydrocarbons to form crude oil; Geochim. Cosmochim. Acta, vol. 19, pp. 309-317.

------- ,1962, Distribution of hydrocarbons in petroleum; Bull. Am. Assoc. Pet. Geol., vol. 46, pp. 76-84.

------- ,1967, A geochemical evolution of petroleum migration and accumulation; in Fundamental Aspects of Petroleum Geochemistry, pub. Elsevier, Amsterdam.

Bathurst, R. G. C., 1958, Diagenetic fabrics in some British Dination limestones; Lvpl. and Manch. Geol. Jour., vol, 2, pp. 11-36.

-------- , 1966, Boring algae, micrite envelopes, and lithification of molluscan biosparites; Geol. Jour., vol. 5, pp.15-30.

Beck, A, 1967, Heat flow; in Can. Upper Mantle Rpt., Geol. Surv. Canada, paper 67-41, pp. 133-147.

Belyea, H. R., 1952, Deep wells and subsurface stratigraphy of part of the St. Lawrence Lowlands, Quebec; Geol. Surv. Canada Bull. 22.

Bishop, S, 1960, Subsurface mapping; John Wiley and Sons Inc., New York.

Bray, E. E. and Evans, E. D., 1961, Distribution of n-paraffin as a clue to recognition of source beds; Geochim. Cosmochim. Acta, vol. 22, pp. 2-15.

Caley, J. F., and Liberty, B. A., 1957, The St. Lawrence and Hudson Bay lowlands and Paleozoic outliers; Geol. and Econ. Min. of Can., Geol. Surv. Canada, 4th ed., pp. 207-246.

Chilingar, G. V., Bissel, H. J., and Fairbridge, R. W., 1967a, Carbonate Rocks; in Developments in Sedimentology No. 9B, pub. Elsevier, Amsterdam.

Chilingar, G.V., Wolf, K. H., and Bissell, H. J., 1967b, Diagenesis of Carbonate Rocks; in Diagenesis of Sediments, Developments in Sedimentology No. 8, pub. Elsevier, Amsterdam.

Clark, T. H., 1944, Structure and stratigraphy in the vicinity of Montreal; Trans. Royal Soc. Can., vol. 38, sec IV, pp. 23-33.

------ , 1947, Summary report on the St. Lawrence Lowlands south of the St. Lawrence River; Quebec Dept. of Mines Prelim. Rept. 204.

------ , 1952, Montreal and area, Laval and Lachine map areas; Quebec Dept. of Mines, Geol. Rept. 46, 159pp..

------ , 1956, Oil and gas in the St. Lawrence Lowlands, Quebec; Trans. Can. Inst. Mining and Met., vol. LIX, pp. 278- 282.

------ , 1959, Stratigraphy of the Trenton Group, St. Lawrence Lowlands, Quebec; Proc. Geol. Assoc. Can., vol. 11, pp.13-21.

------ , in press,a, Grondines map area MS., Quebec Dept. Nat. Resources.

------ , in press, b ,Portneuf map area MS., Quebec Dept. Nat. Resources.

------ , in press, c, Sorel map area MS., Quebec Dept. Nat. Resources.

------ , in press, d, Three Rivers map area MS., Quebec Dept. Nat. Resources.

------ , in press, e, Verchères map area MS., Quebec Dept. Nat. Resources.

------ , in press, f, Laurentide map area MS., Quebec Dept. Nat. Resources.

------ , 1964, Geology of Yamaska- Aston; Quebec Dept. Nat. Resources Geol. Rept. 102.

------ , and Houde, M., 1961, Geological map of the St. Lawrence Lowlands, Quebec; Quebec Dept. Nat. Resources No. 1407.

------ , and Strachan I., 1955, Log of the Senigon well, southern Quebec; Bull. Geol. Soc. Amer., vol. 60, pp. 685-698.

Crain, I. K., 1967, The influence of post-Wisconsin climatic changes in the St. Lawrence Lowlands; unpubl. M.Sc. thesis, McGill University, Montreal, Quebec.

DeBlois, R., and Simard, P., 1959, Data on wells drilled for gas and petroleum in the St. Lawrence Lowlands area; Quebec Dept. Mines Rept. S-49.

Dickson, J. A. D., 1966, Carbonate identification and genesis as revealed by staining; Jour. Sed. Pet., vol. 36, pp. 491-505.

Doity, R. P., 1961, A further study of terrestrial heat flow in the St. Lawrence Lowlands of Quebec; unpubl. M.Sc thesis, McGill University, Montreal, Quebec.

Dresser, J. A., and Denis, T. C.,1944, The Geology of Quebec, vol. II, Descriptive Geology; Quebec Dept. Mines, Geol. Rept. 20. pp. 250-291.

Dunbar, C. O.,and Rodgers, J., 1957, Principles of Stratigraphy; John Wiley and Sons, Inc., New York, 356 pp..

Dunham, R. J., 1962, Classification of carbonate rocks according to depositional textures; Am. Assoc. Pet. Geol., Mem. 1, pp. 108-121.

Dunnington, H.V., 1954, Stylolite development post-dates rock induration; Jour. Sed. Pet., vol. 24, pp. 27-49.

Ferguson, W. S.,1962, Analytical problems in determining hydrocarbons in sediments; Bull. Am. Assoc. Pet. Geol., vol. 46, pp. 1613-1620.

Fettke, C. R., 1948, Subsurface Trenton and sub-Trenton rocks in Ohio, New York, Pennsylvania, and West Virginia; Bull. Am. Assoc. Pet. Geol., vol. 32, pp. 1457-1492.

Folk, R. L., 1959, Practical petrographic classification of limestones; Bull. Am. Assoc. Pet. Geol., vol. 43, pp. 1-38.

------ , 1962, Spectral subdivision of limestone types; Am. Assoc. Pet. Geol., Mem . 1 , pp. 62-84.

------ , 1965, Recrystallization in ancient limestones; in Dolomitization and Limestone Diagenesis, Soc. Econ. Paleontologist Mineralogists Spec.Pub. 13.

Friedman, G. M., 1965, Terminology of recrystalline textures of fabrics in sedimentary rocks; Jour.Sed. Pet., vol. 35, pp.643-655.

Ginsburg, R. N., 1957, Early diagenesis and lithification of shallow water carbonate sediments in southern Florida; in Regional Aspects of Carbonate Diagenesis, Soc. Econ. Paleontologists Mineralogists Spec. Pub. 5, pp. 80-100.

Goudge, M. F., 1935, Limestones of Canada, their occurrence and characteristics; Part III, Quebec, Canada Dept. of Mines Branch No. 755.

Gusson, W. C., 1955, Time of migration of oil and gas; Am. Assoc. Pet. Geol., vol. 39, pp. 547-573.

Harbaugh, J. W., 1961, Relative ages of visibly crystalline calcite in late Paleozoic limestones; Bull. State Geol. Surv. Kansas, vol. 152, part 4, pp. 91-126.

Hedberg, H.D., 1964, Geologic aspects of the origin of petroleum; Am. Assoc. Pet. Geol., vol. 48, pp. 1755-1803.

Houde, M., 1964, Data on wells drilled for gas and petroleum in the St. Lawrence Lowlands area, Part II; Quebec Dept. Nat. Resources Rept. S-75.

Hume, G. S., 1932, Oil and gas in Eastern Canada; Geol. Surv. Canada, Econ. Geol. Ser. 9.

Hunt, J.M., 1961, Distribution of hydrocarbons in sedimentary rocks; Geochim. Cosomochim, Acta, vol.22,pp.37-49.

------ , and Jamieson, G. W., 1956, Oil and organic matter in source rocks of petroleum; Bull. Am. Assoc. Pet. Geol., vol. 40, pp. 477-488.

Husain, B. R., 1955, Semi-microfossils of the Black River and Trenton Groups in Quebec; unpubl. Ph.D. thesis, McGill University, Montreal, Quebec.

Johnston, W. A., 1914, Geology of Lake Simcoe area, Ontario; Geol.Surv.Canada Summ. Rept.1912, pp.294-300.

Jones, I. W., 1941, Possible future oil provinces of Eastern Canada; Bull. Am.Assoc. Pet. Geol.,vol.25, pp.1157-

----- , 1962, Sedimentary basins and petroleum possibilities of Quebec; Proc. Geol. Assoc. Can.,vol.14, pp.43-58.

Kay, G. M., 1937, Stratigraphy of the Trenton Group; Bull. Geol. Soc. Amer., vol.48, pp.233-302.

------ , 1960, Classification of the Ordovician System in North America; International Geol. Congress, 21st. Session, Proc.sec.7, pp. 28-34.

------ , and Colbert,E. H., 1965, Stratigraphy and Life History; John Wiley and Sons, New York.

Land, L. S., 1967, Diagenesis of skeletal carbonates; Jour. Sed. Pet., vol.37, pp. 914 - 930.

Landes, K. K., 1967, Eometamorphism and oil and gas in time and space; Bull. Am. Assoc. Pet. Geol.,vol.51,pp828-841.

Levorsen, A. I., 1954, Geology of Petroleum; W. H. Freeman and Co., San Francisco.

Logan, W. E., 1848, Can. Geol. Surv. Rpt. of Progress for 1847 to 1848; pp. 10-14.

------ , 1863, Can. Geol. Surv. Rpt, of Progress to 1863.

Lucia, F. J., 1962, Diagenesis of a crinoidal sediment; Jour, Sed. Pet., vol. 32, pp. 848-865.

McKee, E. D., and Weir, G. W., 1953, Terminolgy for stratification and cross-stratification in sedimentary rocks; Bull. Geol. Soc. Amer.,vol.64, pp. 381-389.

Malcolm, W., 1915, The oil and gas fields of Ontario and Quebec; Geol. Surv. Can. Mem. 81.

Matthews, R. K., 1967, Diagenesis fabrics in biosparites from the Pleistocene of Barbados, West Indies; Jour. Sed. Pet.., vol. 37, pp. 1147- 1153.

Maugham, J. B., 1964, A general review of oil and gas developments in the province of Quebec; Can. Inst. Mining and Met., vol. 57, pp. 641-647.

Murray, R.C., 1960, Origin of porosity in carbonate rocks; Jour. Sed. Pet., vol. 30,pp.59-84.

Nagy, B., and Columbo, U.,1967, Fundamental Aspects of Petroleum Geochemistry; Elsevier pub., Amsterdam.

Park, W. C.,and Schot, E. H., 1968, Stylolites; their nature and origin; Jour, Sed. Pet., vol. 38, pp. 175- 191.

Parks, W. A., 1930, Report on the oil and gas resources of the Province of Quebec; Quebec Bur. Mines Ann. Rpt. 1929, Part B, pp. 1-126.

------ , 1931, Natural gas in the St. Lawrence Lowlands, Quebec; Quebec Bur. Mines Ann. Rpt. 1930, Part D , pp. 3- 98.

Pettijohn, F. J., 1957, Sedimentary Rocks; Harper and Row, New York, 2nd. ed..

Philippi, G. T., 1957, Identification of oil source beds by chemical means; Congreeso Geologico Internacional XX Sesion- Mexico, Seccion III Geologia del Petroleo, pp. 25-38.

------ , 1965, On the depth,time, and mechanism of petroleum generation; Geochim. Cosmochim. Acta, vol 29, pp.1020 - 1049.

Ramsden, R. N., 1952, Stylolites and oil migration; Bull. Am. Assoc. Pet. Geol., vol.36, pp.2185-2186.

Raymond, P. E., 1914, The Trenton Group in Ontario and Quebec; Geol. Surv. Can. Summ. Rpt. 1912, pp.342-350.

Riva, J., 1968, written communication, Univ. Laval, Dept. Geology, Quebec City, Quebec.

Robinson, R. B., 1967, Diagenesis and porosity development in Recent and Pleistocene oolites from southern Florida and the Bahamas; Jour. Sed. Pet.,vol. 37, pp. 355-364.

Roliff, W. A., 1955, Exploration for oil and gas in Eastern Canada; Proc. Geol. Assoc. Can., vol. 7, pp. 61-81.

------ , 1967, A stratigraphic analysis of the subsurface data relating to the Chazy Group in the St. Lawrence Lowlands of Eastern Canada; Can. Jour. Earth Sciences, vol. 4, pp. 579-595.

Shaub, B. M., 1953, Stylolites and oil migration; Jour. Sed. Pet., vol. 23, pp. 206-264.

Snider, L. C., and Farish, L. M., 1935, Natural gas in Quebec and the Maritime Provinces; in Geology of Natural Gas, Am. Assoc. Pet. Geol. pub..

Stoddart, D. R., and Cann, J. R., 1965, Nature and origin of beach rock; Jour. Sed. Pet., vol. 35, pp.243-247.

Usher, J. L., 1947, Geology of St. Pie Hill, St. Dominique County,Quebec; unpubl. thesis, McGill University, Montreal, Quebec.

Vanuxem, L., 1842, Geology of New York, Part III; Third Geol. District, New York.

Wardlaw, N. C., 1962, Aspects of diagenesis in some Irish Carboniferous limestones; Jour. Sed. Pet., vol. 32, pp. 776- 780.

Welte, D. H., 1965, Relation between petroleum and source r rock; Bull. Am. Assoc. Pet. Geol., vol. 49, pp. 2246 - 2268.

Weyl, P. K., 1959, Pressure solution and the force of crystallization -a phenomenological theory; Jour. Geophys. Research, vol. 64, pp. 2001- 2025.

Wilson, A. E., 1936, A synopsis of the Ordovician of Ontario and western Quebec and the related succession in New York; Geol. Surv. Can. Mem. 202,Part I.

Wilson, A. E., 1946, Geology of the Ottawa- St. Lawrence Lowlands; Geol. Surv. Can. Mem. 241.

Winder, C.G., 1960, Middle Ordovician in southern Ontario; International Geol. Congress 21st. Session, Proc. sec. 7, pp.18-27.

Wyatt, M., 1915, Oil and gas fields of Ontario and Quebec; Geol. Surv. Can. Mem. 81.

Young, F. G., 1964, Petrology of the Deschambault Formation, Trenton Group, St. Lawrence Lowlands of Quebec; unpubl. M.Sc. thesis, McGill University, Montreal, Quebec.

Plate I

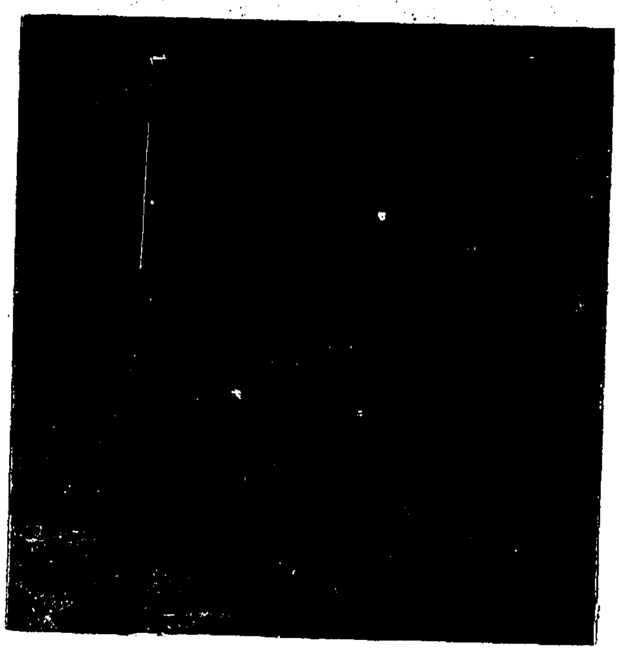


Figure 1. Drilling shallow bore holes to obtain unweathered core for permeability measurements, Deschambault Formation, Ouareau River.

Figure 2. Medium bedded limestones of the Ouareau Formation along the Ouareau River.

Plate I

Figure 1. Drilling shallow bore holes to obtain unweathered core for permeability measurements, Deschambault Formation, Ouareau River.

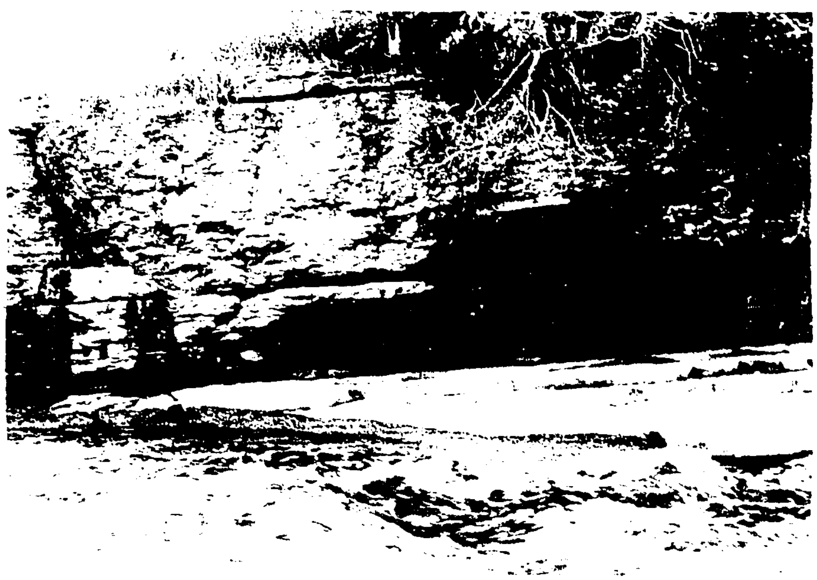


Figure 2. Medium bedded limestones of the Ouareau Formation along the Ouareau River.

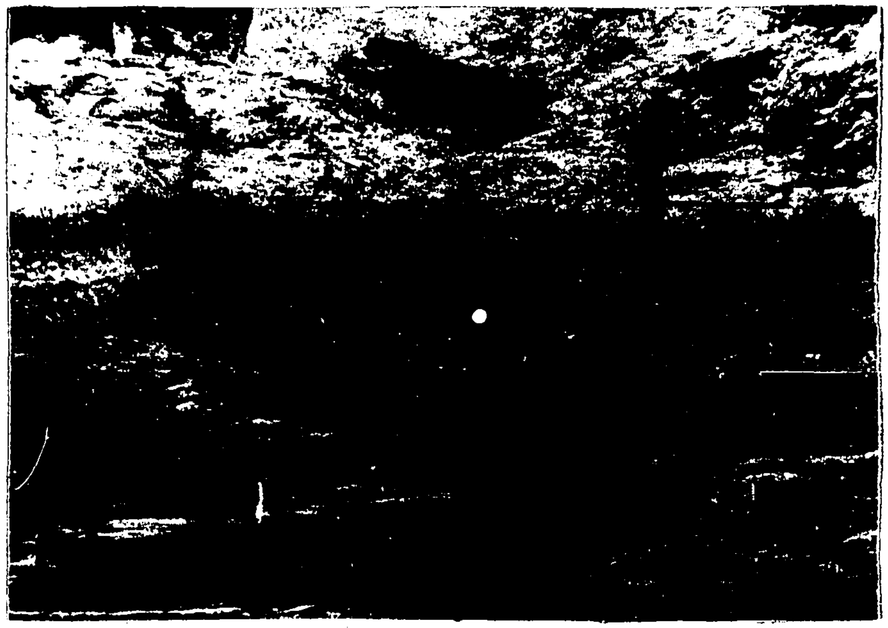


Figure 1. Irregular disconformable surface overlain by limestone conglomerate near the base of the Deschambault Formation, Ouareau River.

Figure 2. Closer view of the limestone conglomerate showing limestone pebbles up to four inches in diameter.

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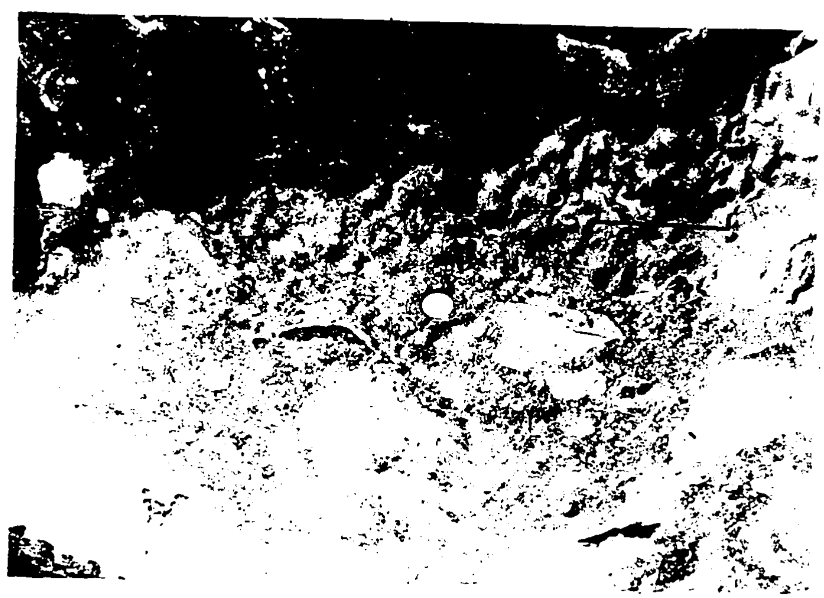


Figure 2. Closer view of the limestone conglomerate showing limestone pebbles up to four inches in diameter.

Plate 3

Figure 1. Very thick bedded,resistant calcarenites, three-quarters upsection in the Deschambault Formation,Ouareau River. Note that stylolites control the splitting within the beds.

Figure 2. Black, asphaltic bituminous material on the weathered bedding surface in the bryozoan reef unit, Ouareau River.

Plate 3

Figure 1. Very thick bedded,resistant calcarenites, three-quarters upsection in the Deschambault Formation,Ouareau River. Note that stylolites control the splitting within the beds.

Figure 2. Black, asphaltic bituminous material on the weathered bedding surface in the bryozoan reef unit, Ouareau River.

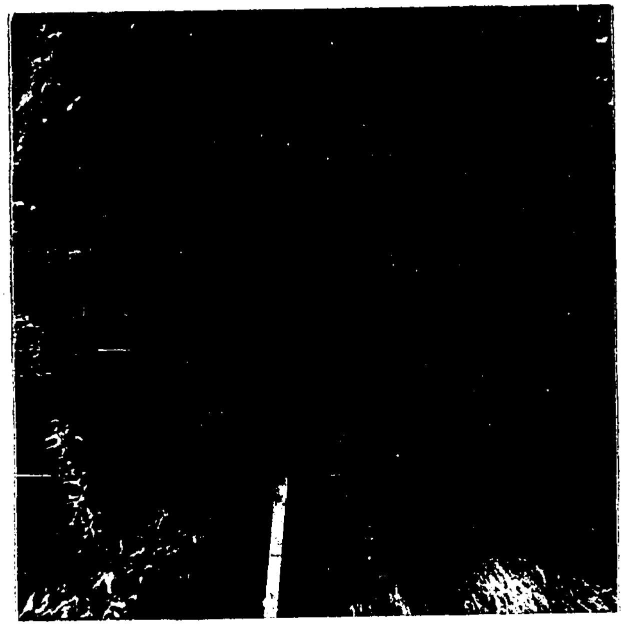


Figure 1. Medium to thick bedded crinoid calcarenites that are interbedded with thin bedded micites near the base of the St. Casimir Formation, Neuville Railroad Cut, Neuville.

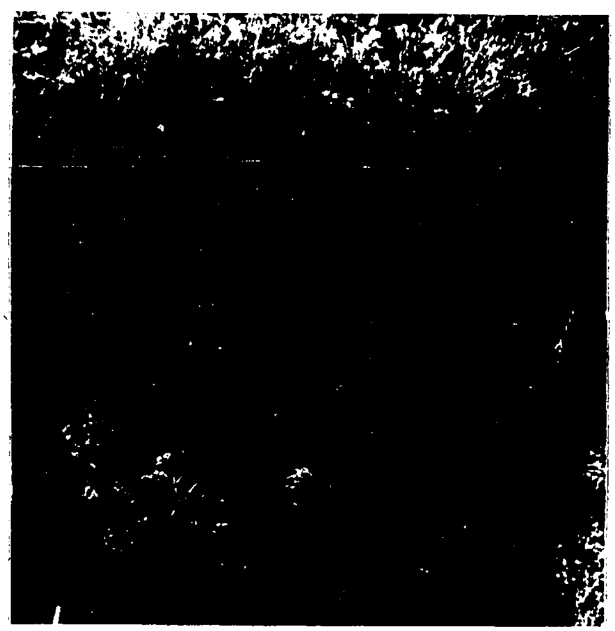


Figure 2. Pinch and swell, thin bedded micritic limestones with shale partings near the top of the St. Casimir Formation, Neuville Railroad Cut,Neuville.

Figure 1. Medium to thick bedded crinoid calcarenites that are interbedded with thin bedded micites near the base of the St. Casimir Formation, Neuville Railroad Cut, Neuville.

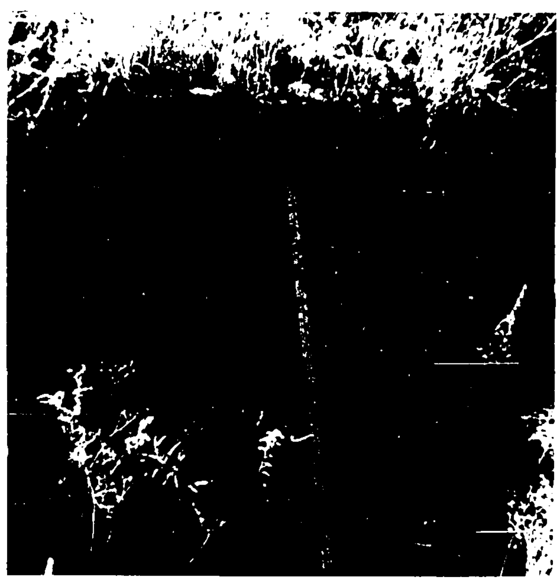


Figure 2. Pinch and swell, thin bedded micritic limestones with shale partings near the top of the St. Casimir Formation, Neuville Railroad Cut, Neuville.

Figure 1. Rubbly weathering limestones of the Montreal Formation, Ouareau River.

Figure 2. Non-resistant nature of the limestones of the Montreal Formation near the top of the Ouareau River section.

Figure 1. Rubbly weathering limestones of the Montreal Formation, Ouareau River.

Figure 2. Non-resistant nature of the limestones of the Montreal Formation near the top of the Ouareau River section.

Figure 1. Thin bedded limestones, with abundant shale, Tetreauville Formation, Ouareau River- Rivière Rouge.

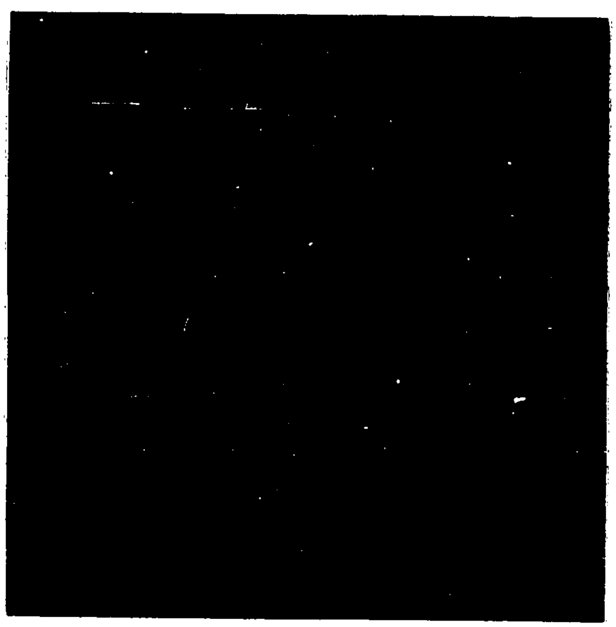


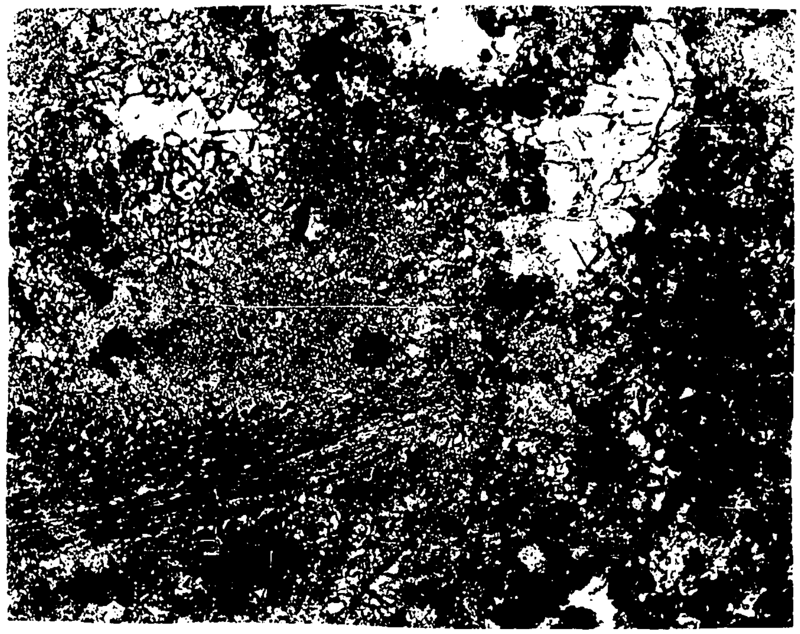
Figure 2. Medium bedded limestones with thin shale partings, Tetreauville Formation, L'Ephiphanie Quarry, L'Ephiphanie, Quebec.

Figure 1. Interbedded limestone and shale forming a small cliff midway upsection in the Neuville Formation, Neuville shore.

Figure 2. Abrupt Trenton limestone Utica shale contact, L'Achigan River, L'Ephiphanie, Quebec.

Figure 1 Micrite with patches of microspar and black argillaceous matter, Ouareau Formation.

Figure 2 Microspar matrix of a fine grained calcarenite, Deschambault Formation.



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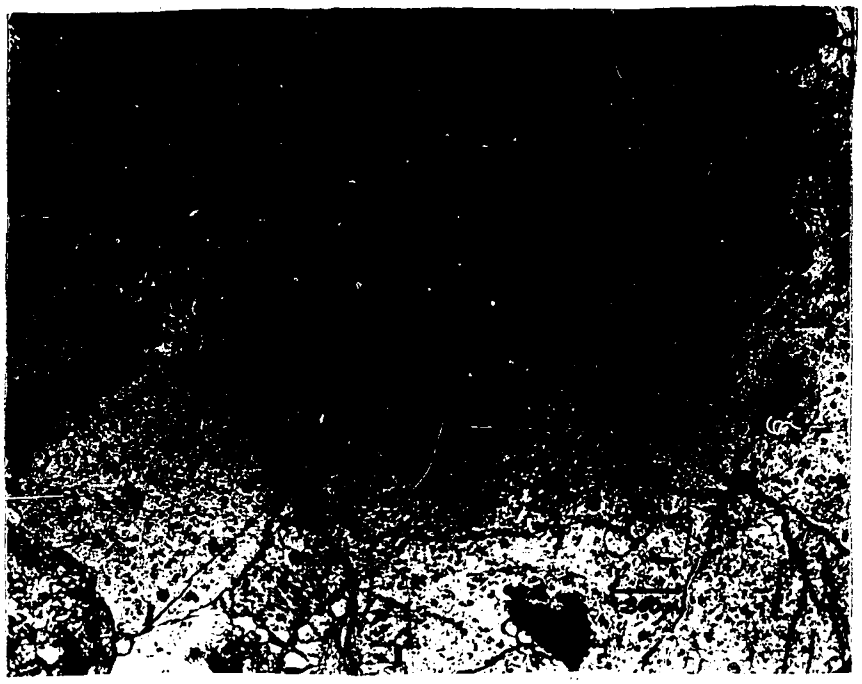


Figure 1 Granular, void filling cement with increasing crystal size away from the margins of the brachiopod fragments, in a crinoid calcarenite, Deschambault Formation.

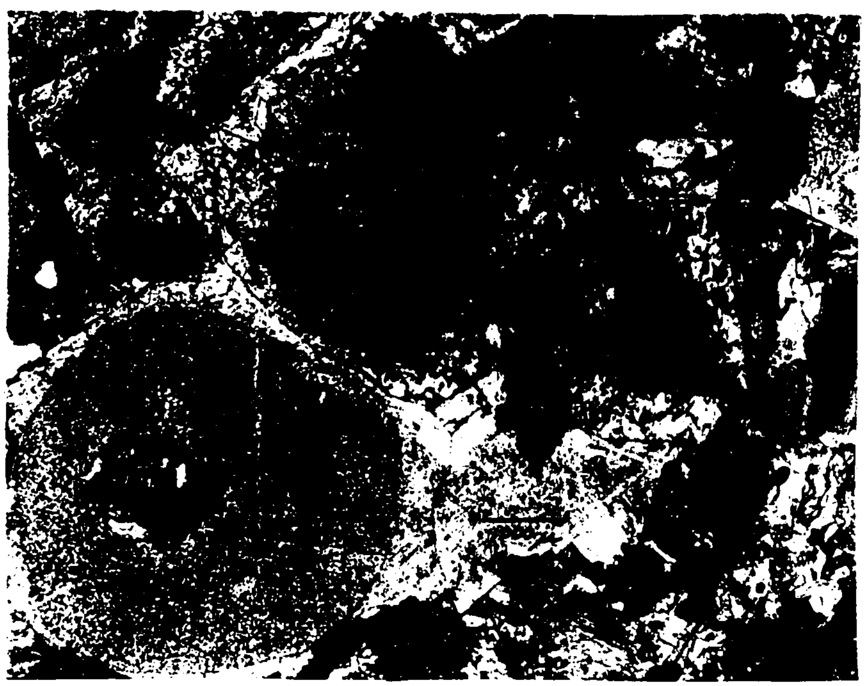
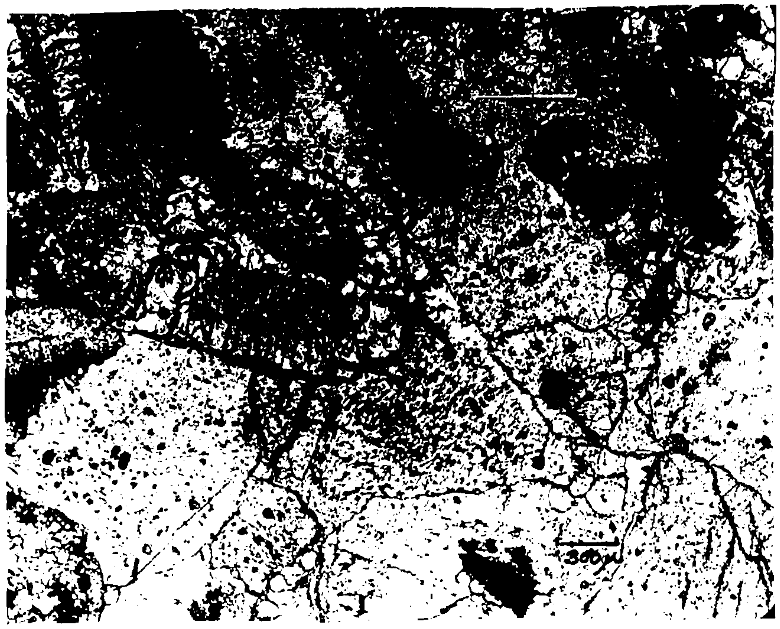


Figure 2 Rim cemented crinoid fragment in coarse grained calcarenite, Deschambault Formation.



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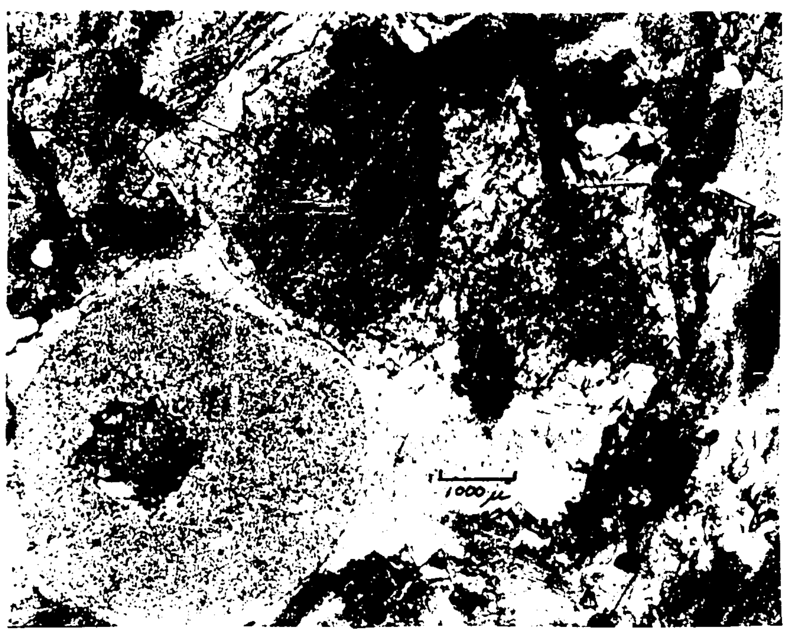

Figure 2 Rim cemented crinoid fragment in coarse grained calcarenite, Deschambault Formation.

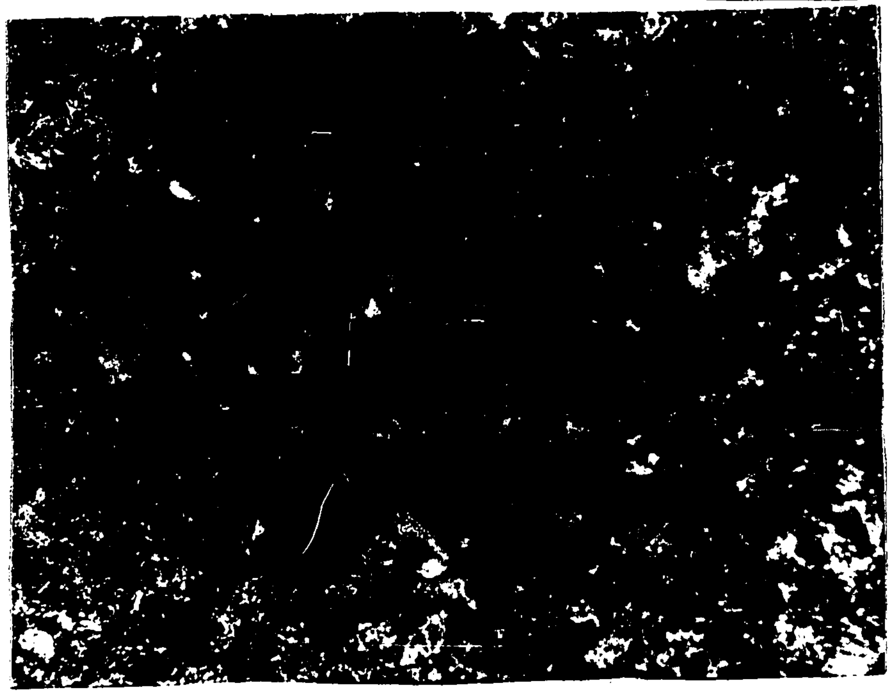

Figure 1 Small blebs of black bituminous matter in a fine grained calcarenite with a microspar matrix, Deschambault Formation.

Figure 2 Microstylolites with a bituminous argillaceous seam in a coarse grained calcarenite, Deschambault Formation.

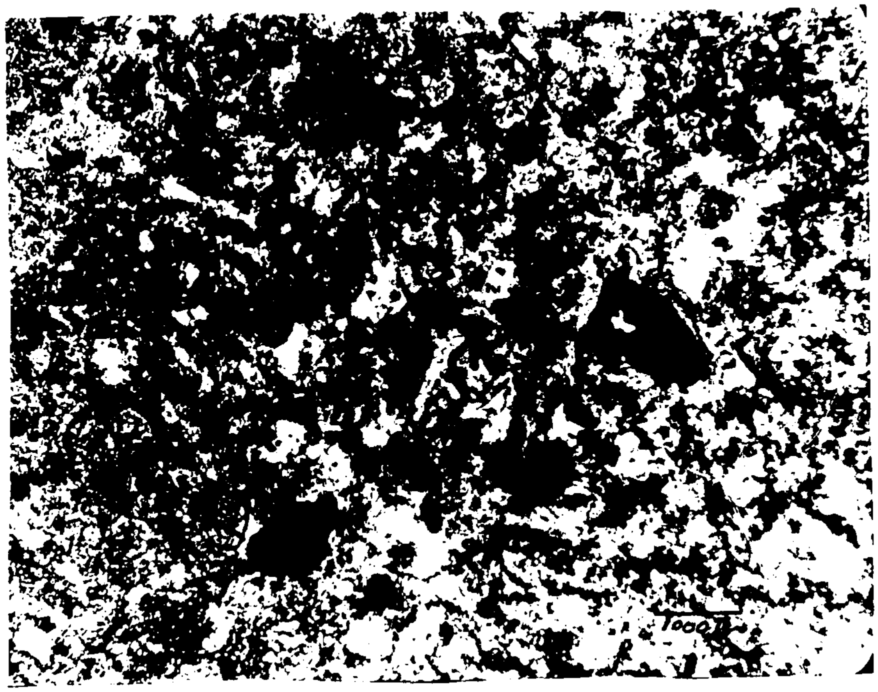

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Figure 1 Bryozoan mats with bryozoa set in a black bituminous shale, Bryozoan Reef unit, Deschambault Formation.

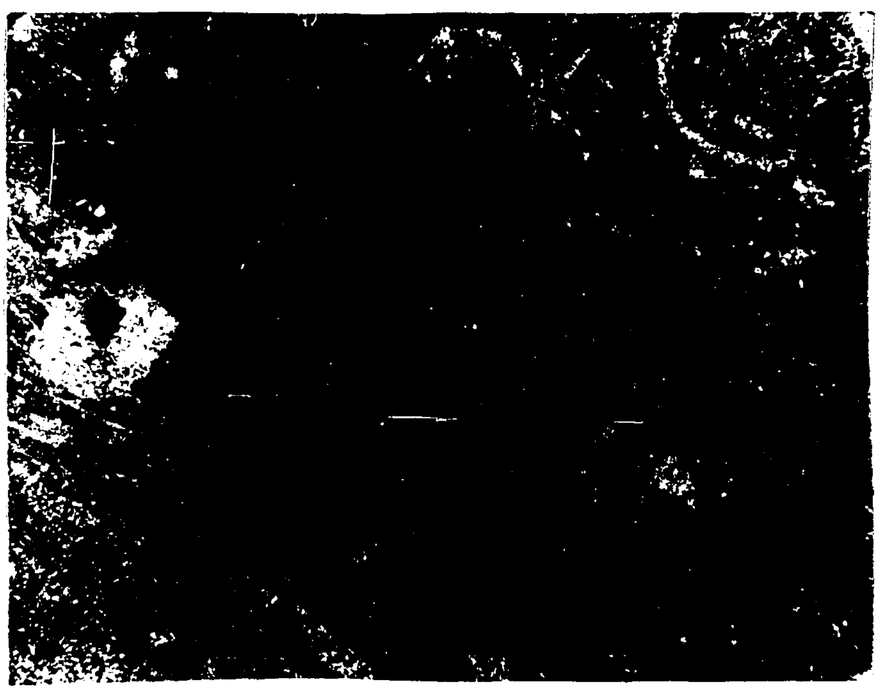

Figure 2 Sparse biomicrite in the Montreal Formation.

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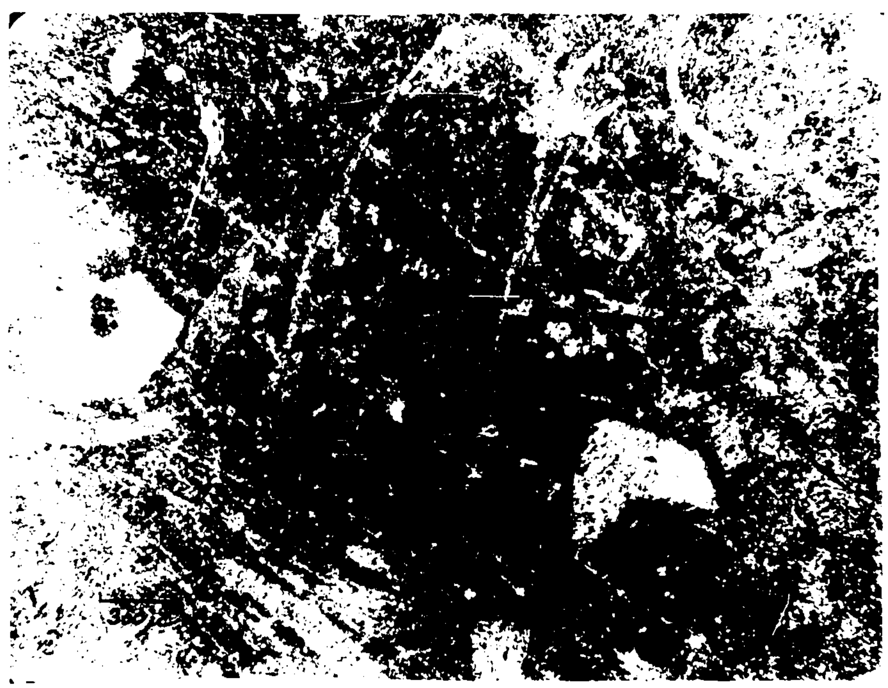


Figure 2 Sparse biomicrite in the Montreal Formation.

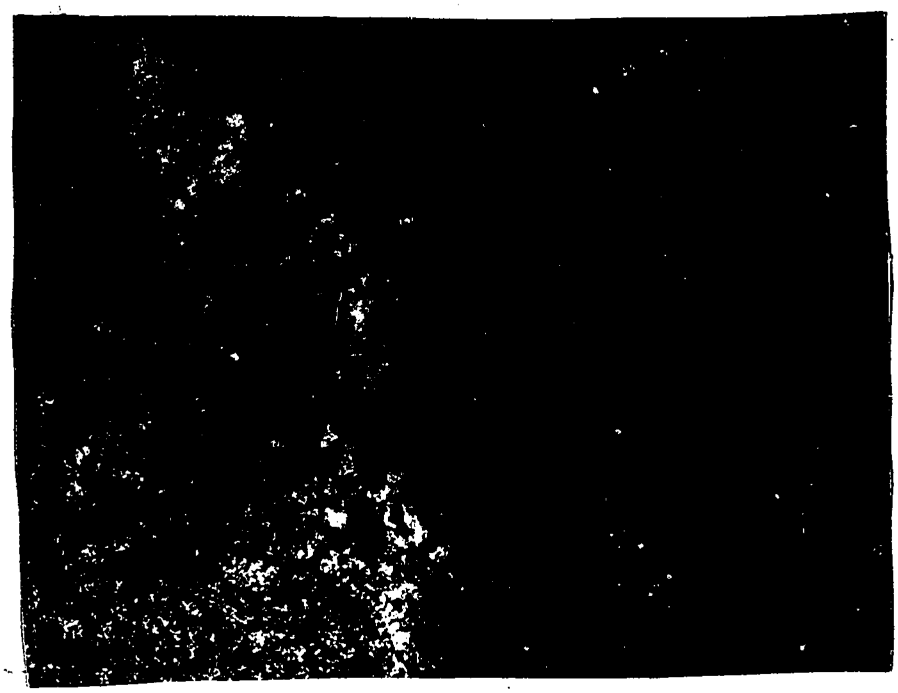


Figure 1 Black argillaceous matter in micrite of the Neuville Formation.

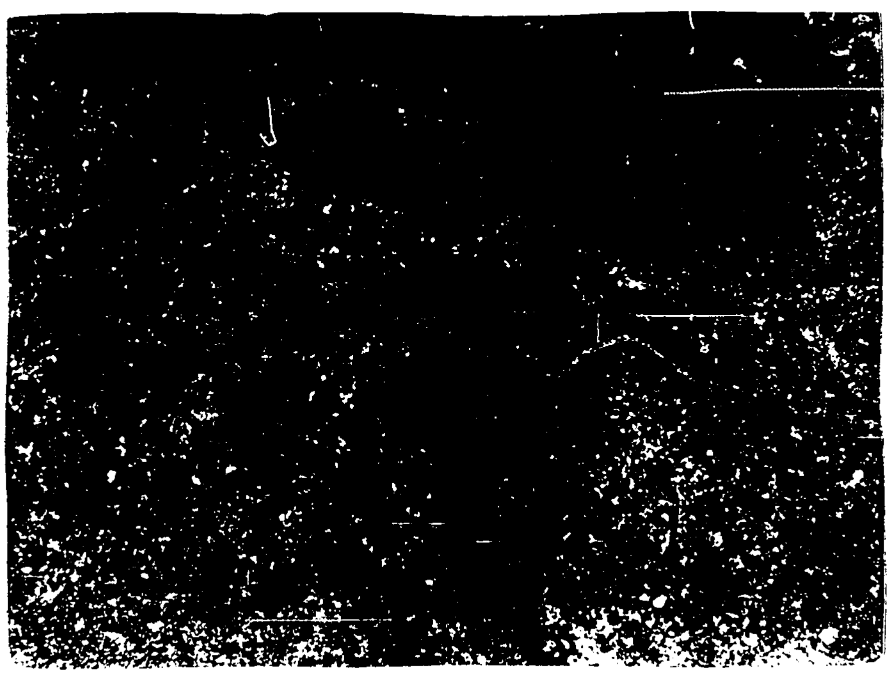
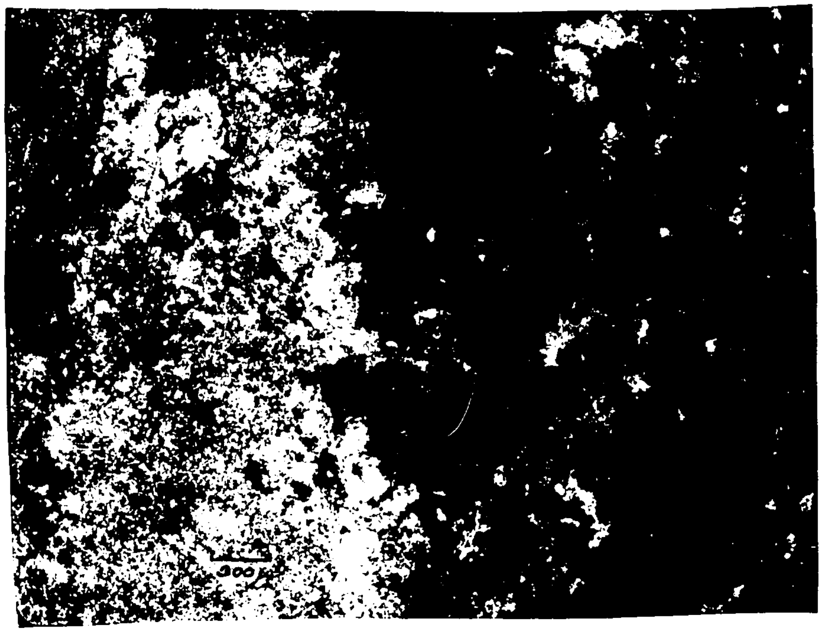


Figure 2 Silt size quartz grains in micrite of the Neuville Formation.



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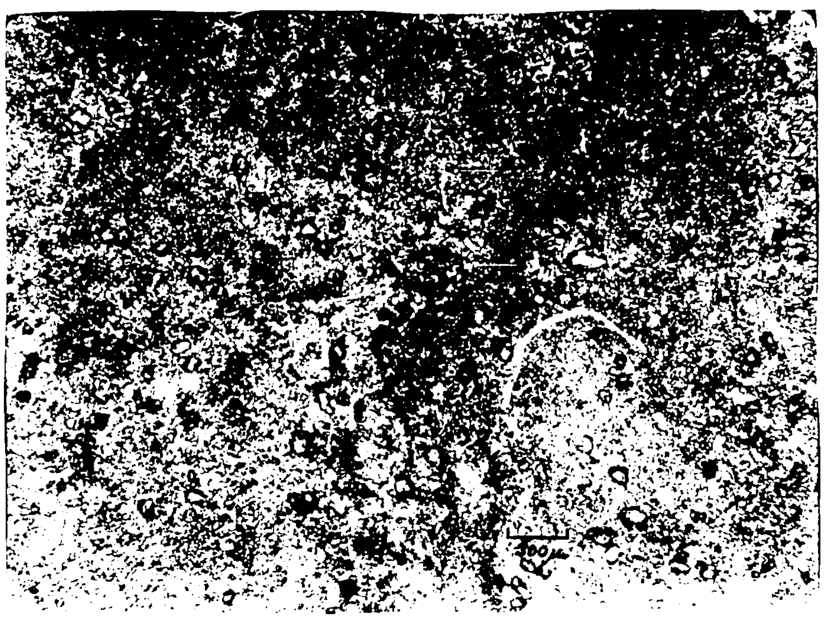


Figure 2 Silt size quartz grains in micrite of the Neuville Formation.

A P P E N D I X

APPENDIX A

Permeability Measurement

The core samples were tested with a Sioltest Model K-670 Miniature Permeameter. Although this apparatus is best suited for unconsolidated material or very permeable rock, slight modifications to the sample holder made it suitable for this study. A smaller sample holder was made so that a much smaller length of core could be used.

1. Preliminary Steps

The tank of the permeameter A is filled with about a pint of water. It was found that if water was left in the permeameter, as would be the case if the tank was filled with a large quantity of water, for more than two days, the water became extremely rusty and unsuitable for testing. Air is pumped into the tank through the valve C until a maximum of four atmospheres is reached. Tap B is opened until all the air is expelled from the line D.

2. Sealing the Sample in the Sample Holder

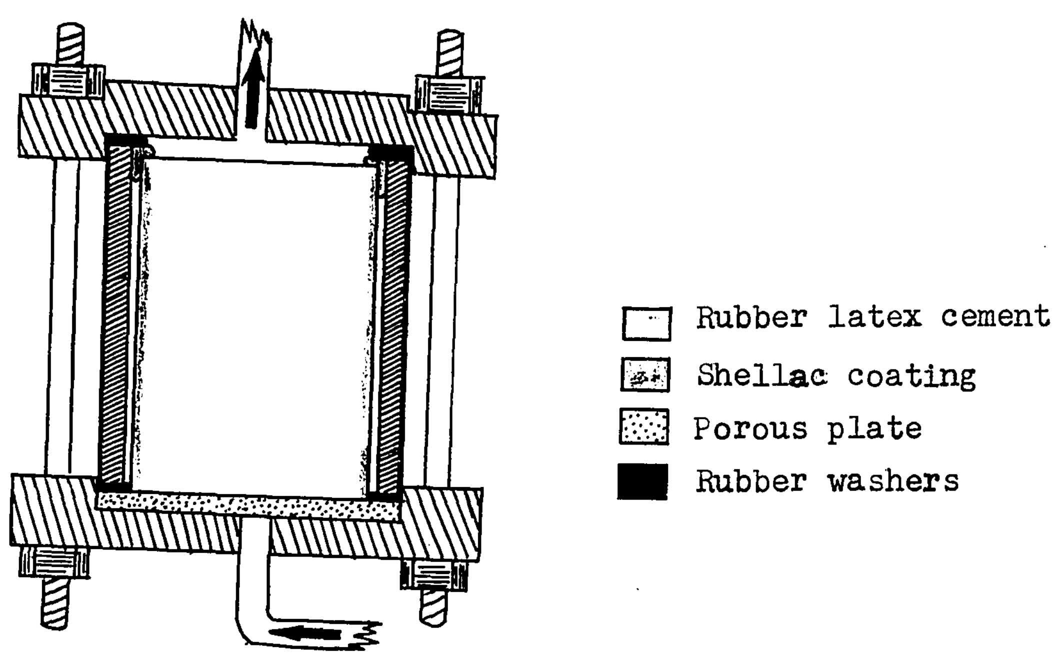


Figure 21 Sealing the Sample in the Sample Holder

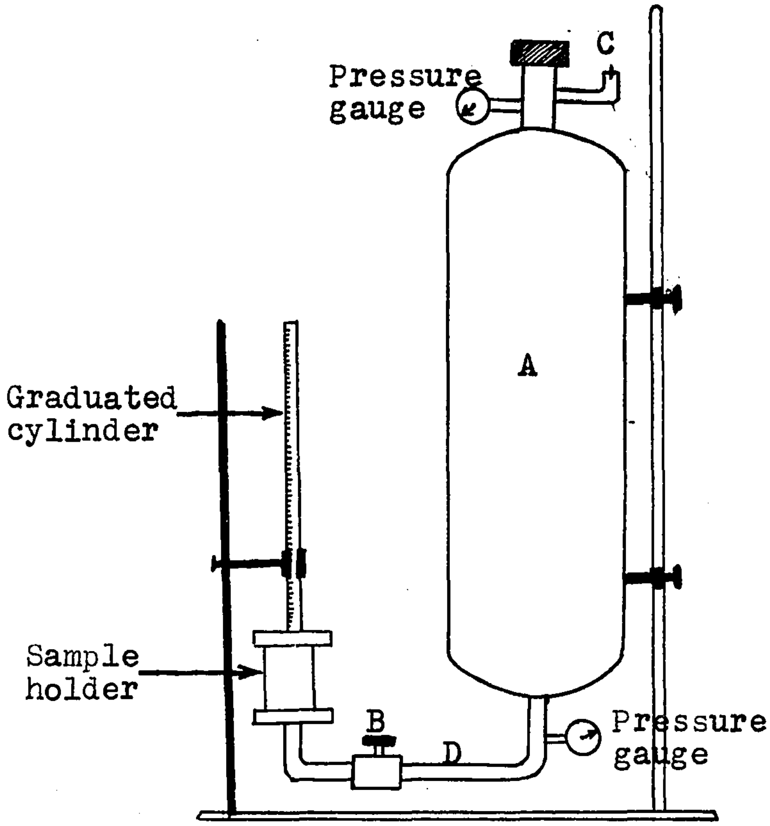


Figure 22 Schematic diagram of the permeameter

The core, cut to fit the sample holder, is twice coated with shellac around the sides and allowed to dry. The core is placed in the sample holder and the joint between the top of the core and the sample holder wall is sealed with rubber latex cement. After the rubber cement has set the cover is bolted into place.

3. <u>Operating the Permeameter</u>

Tap B is opened. When water reaches the level of the bottom of the glass cylinder, graduated in cubic centimeters, the time T_1 and level l_1 are recorded. Subsequent times T_2 and T_3 and levels l_2 and l_3 are also recorded.

4. <u>Calculations</u>

The rate of flow F(cubic centimeters per second) $= \dfrac{l_2 - l_1 \text{ (cc.)}}{T_2 - T_1 \text{ (sec.)}}$

$$P = \frac{FVL}{CD}$$

P - permeability (darcys)

F - rate of flow (cc./second)

V - viscosity (centipoises)

L - length of core (cm.)

D - cylindrical surface (πr^2) (cm^2.)

C - pressure (atmospheres)

APPENDIX B

Chemical Analysis of Hydrocarbons

Hydrocarbon Extraction

The general procedure for extracting hydrocarbons outlined by Philippi was used and is outlined here.

1. Sample Preparation

The fresh, unweathered samples are crushed in a jaw crusher, and then pulverized in a Braun disc pulverizer using ceramic plates.

2. Diisopropyl Extraction

50 grams of finely powdered rock is placed in the modified Soxhlett extractor A (Figure 23). The sample size used depends upon the amount of hydrocarbons present; the greater the amount the less sample is used. The sample is extracted with 300 cubic centimeters of diisopropyl, also called 2,3 dimethylbutane $(CH_3)_2CHCH(CH_3)$ by some chemical distributors, for 24 hours.

3. Isolating the Diisopropyl Extracted Hydrocarbons

The hydrocarbon extract, plus some diisopropyl collected in the concentrator B, is distilled, and then evaporated to remove all the diisopropyl. Evaporation should take place over very low heat to avoid boiling away any hydrocarbons. The remaining residue, a yellow amber, greasy substance is weighed.

4. Diethylether Extraction

After the diisopropyl has been completely removed from the sample, 300 cubic centimeters of diethylether are added to the sample in the Soxhlett extractor A. The hydrocarbons from the sample are extracted for 24 hours.

5. Isolating the Diethylether Extracted Hydrocarbons

As in step 3, the hydrocarbon content obtained by the diethylether is distilled and evaporated to remove any ether. It is not necessary to use heat to evaporate the ether. The residue, dark brown and black, is weighed. All the ether is removed from the sample, and the sample retained for dry combustion.

Per Cent Carbon Content

Many methods and forms of apparatus are in use for the determination of the total carbon content by dry combustion. The type employed in this study is that recommended by the Association for Standard Testing of Materials (No.E50-43T).

1. Sample Preparation

Each doubly treated sample is weighed. The carbonate is removed by HCl acid and the residue obtained by filtering, using a millipore vacuum filter and plastic filters. The plastic filter is used to avoid impregnating the filter with much of the extremely fine residue, as occurs with paper filters. The sample is dried.

2. Dry Combustion

The electric furnace is heated to 1100°C and oxygen is fed into the train at the rate of 2 bubbles per second passing through the KOH solution. The oxygen is passed through the system for 30 minutes to rid the system of any CO_2 present. The absorption bulb is weighed and replaced. The sample, in an alundum boat, is placed in the combustion tube of the electric furnace for 15 minutes. After 15 minutes the absorption tube is disconnected, and the sample removed. The absorption tube is weighed. The increase in weight is the amount of CO_2 evolved by the sample. Blank runs are made to correct for the slight amount of CO_2 introduced from the atmosphere into the system when the furnace is opened to place the sample in.

3. Calculations for the Per Cent Carbon

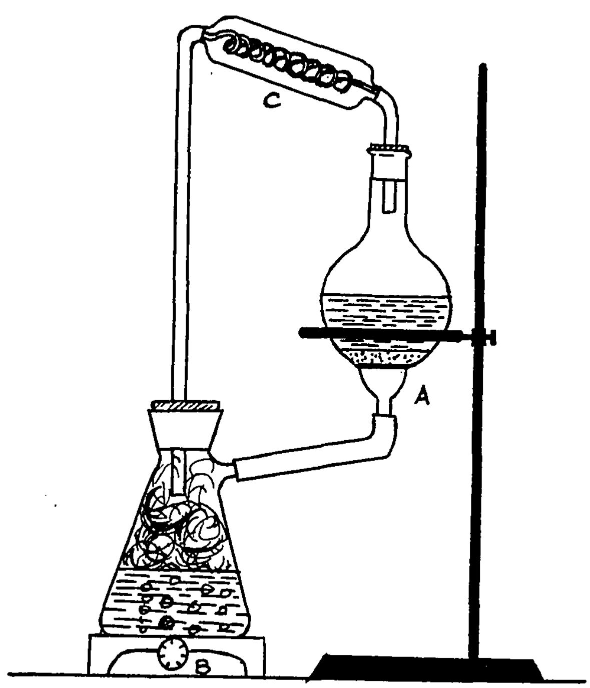
Weight of carbon in the amount of carbon dioxide obtained $= \frac{12.01}{12.01 \quad 32.00} = .27289$

$$\text{Carbon Per Cent} = \frac{A - B}{W} \times .27289 \times 100\%$$

A- weight of CO_2 in grams

B- blank correction in grams

W- weight of sample before acidizing



A- Soxhlett extractor with fritted glass filter

B- Concentrater

C- Condenser

Figure 23 Soxhlett extractor unit

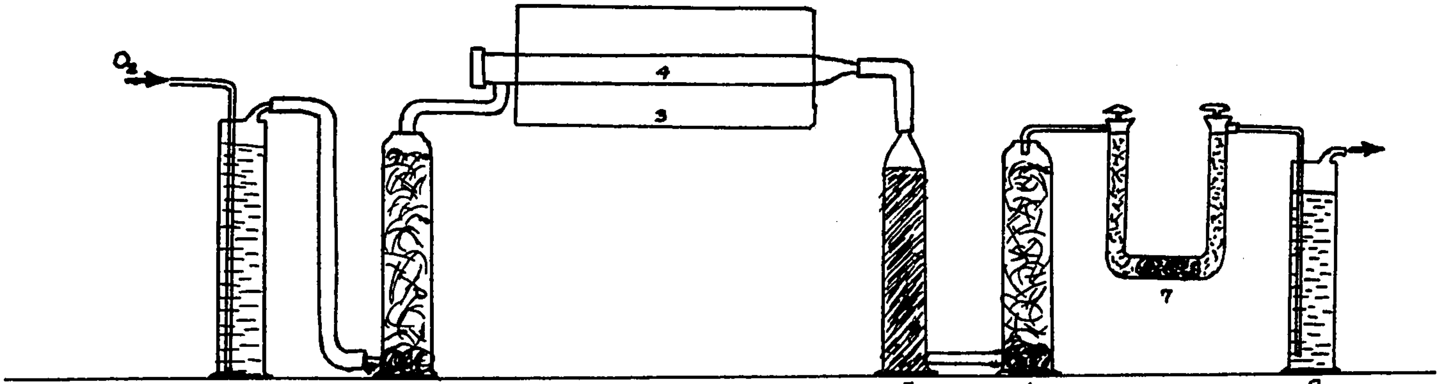


Figure 24 Carbon Dioxide Train

1. Potassium hydroxide solution, indicates the rate of flow of oxygen and absorbs carbon dioxide.

2. Tower containing $CaCl_2$ to absorb moisture.

3. Electric furnace

4. Combustion chamber

5. Zinc jar filled with 20 mesh granular zinc to absorb acids, sulphur, and chlorine.

6. Jar filled with $Mg(ClO_4)_2$ (anhydrone) to absorb water carried from the combustion tube.

7. Absorption tube. This is a two compartment tube, the left side for soda asbestos (ascarite) to absorb carbon dioxide, and the right side for $Mg(ClO_4)_2$ for absorbing water produced. One change will serve 70 determinations.

$$2NaOH + CO_2 \longrightarrow Na_2CO_3 + H_2O$$

8. Potassium hydroxide to seal the end of the train from the atmosphere.

APPENDIX C

Statigraphic Sections

Abbreviations

ls. - limestone

sh. - shale

cgl. - conglomerate

calc. - calcareous

v.f. - very fine

f. - fine

med. - medium

crs. - coarse

bddg. - bedding

interbdd. - interbedded

crossbdd. - crossbedded

lt. - light

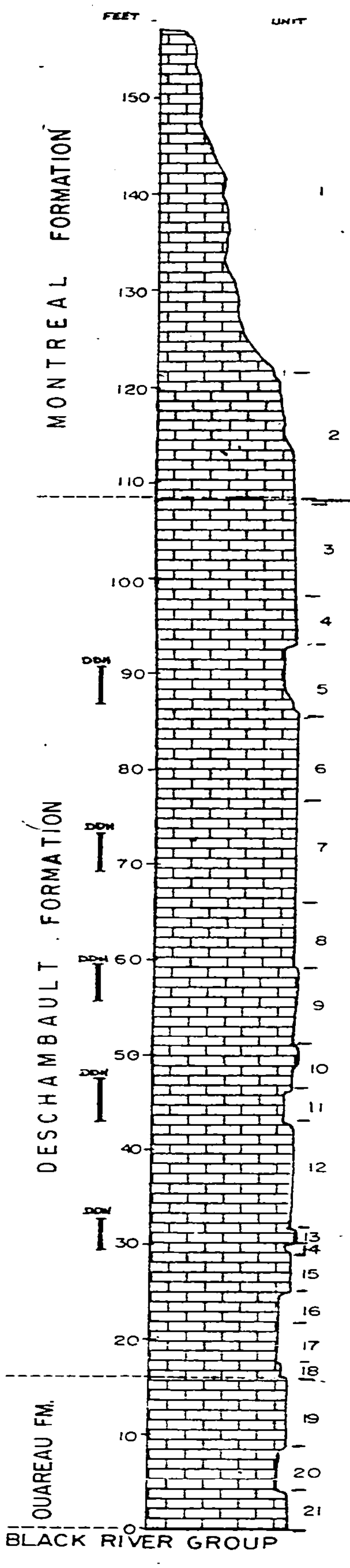
dk. - dark

yell. - yellow

brn. - brown

Quareau River Section

The section is well exposed along both sides of the Quareau River. The base of the section is under the highway bridge where Route 41 crosses the Oureau River. Outcrop is continuous for a mile downstream.



Ls., med.gray,f.grn. with some crs.calcarenite beds near the base,bddg.2"-5" with nodular irregular surface,interbdd.with black shale 1"-2".
Peels: Sparse argillaceous crinoid brachiopod biomicrite to crinoid biosparite.

Ls.,med.gray,f.grn.,bddg.2"-5" and crs.grn. ls., bddg.4"-6". Abundant crinoids and brachiopods in crs.grn beds.
Peels: i) Sorted crinoid brachiopod biosparite
ii) Sparse argillaceous crinoid brachiopod biomicrite.

Ls.,med.gray,med.-crs.grn.,calcarenite,bddg, 2"-4" with black bituminous partings.
Peel: Crinoid biosparite.

Ls.,lt.gray-brn.,f.grn.and crs.grn.,bddg.2"-4" with thin bituminous shale partings
Peel: Unsorted crinoid brachiopod bryozoa biosparite

Ls.,lt.gray-brn.,med.-crs.grn.calcarenite with black bituminous shale interbeds 1"-2". Ls.bddg.2"-5". Crinoids and bryozoa abundant,bryozoa in shale beds
Peel: Crinoid brachiopod bryozoa biosparite

Ls., lt.gray-brn.,med.-crs.grn.calcarenite,whole brachiopods common,bddg.12"-18",bituminous partings in upper part of unit.
Peel: Crinoid biosparite with brachiopods,bryozoa, trilobites .

Ls.,med.gray-brn.,f.,med.,and crs.grn.calcarenite,bddg. 12-18",black chert bands,1"-2",every 18",Rafinesquina common.
Peel: Unsorted crinoid brachiopod biosparite.

Ls.,med.gray-brn.,f.-med.grn.calcarenite,bddg.4"-8", black chert nods and lenses common,ls.cgl.at base.
Peel: Crinoidbrachiopod biosparite and biopelmicrosparite.

Ls.,lt.med,gray-brn.,crs.-v.crs grn.calcarenite,bddg. 8"-10".
Peel: Crinoid brachiopod biosparite.

Ls.,lt.gray,f.grn.and v.crs.grn.calcarenite,bddg.2"-5", crossbddg.
Peel: Crinoid brachiopod biosparite.

Ls.,med.gray-brn.,f.and crs.grn.,bddg.2"-4" interbdd. with black shale ½"-1".

Ls.,med.gray-brn,f.-crs.grn.calcarenite,crossbedd.in places,bddg.2"-5",thin shale partings.
Peels: Crinoid brachiopod biopelsparite and crinoid brachiopod biosparite

Ls.,v.dk.gray,f.grn.,bddg 9".Peel:Argillaceous microsparite

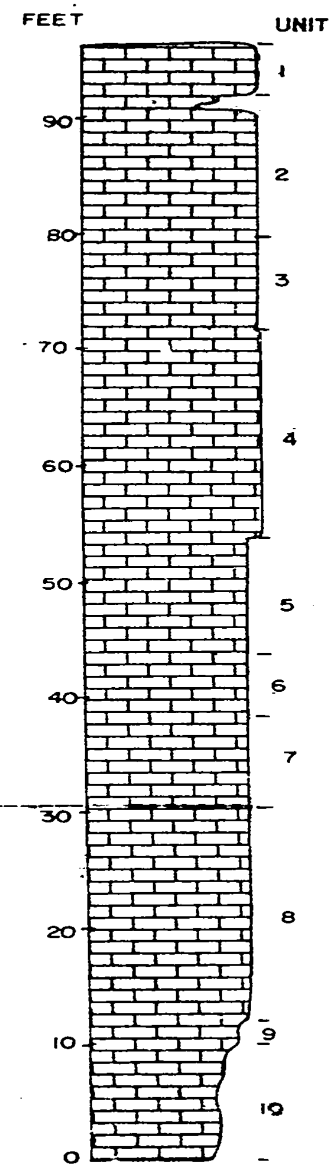
Ls.,v.dk.gray,f.grn.,bddg.1"-3".Peel:Biopelmicro-sparite
Ls., med.gray-brn.,med.-crs.grn.calcarenite,ls.cgl..
Peel: Crinoid brachiopod biosparite
Ls.,med.gray-brn.,med.grn.calcarenite,crossbdd,bddg. 4"-6". Peel: Biopelmicrosparite
Ls.,med,gray-brn.,med.grn.calcarenite,bddg.2"-4",ls.cgl.
Peel:Crinoid biopelmicrosparite.
Ls., med.dk.gray,v.f.grn.,laminated,ls.cgl..

Ls.,med.dk.gray,v.f.grn.,argillaceous,bddg.2"-7"with irregular pinch and swell,minor shale partings.
Peel:Very argillaceous micrite.

Ls.,med.dk.gray,v.f.grn.,gastropods abundant,bddg.5"-7", interbdded with b;ack shale ½"-1".
Peel: Argillaceous gastropod micrite.
Ls.,med.dk.gray,v.f.grn.,abundant near top of unit, bddg.2"-4",minor shale ¼"-½".
Peel: Argillaceous gastropod micrite with 10%microspar.

Neuville Railroad Cut Section

The section is located along the railroad cut at the eastern limit of the town of Neuville. Neuville is twenty-two miles west of Quebec City.



Ls.,med.dk.gray (weathering lt.yell.brn),f.grn.,bdding 2-3" with ¼" calc.sh.partings.

Ls.,70%-80% med.dk.gray (weathering lt.yell.brn.),f. grn.,laminated,bdding 1"-3" with ¼" calc.sh.partings, 30%-20% med.lt.gray,f.-med.grn.,bdding 2"-4".

Ls.,med.lt.gray,med.grn.,bdding 2"-3" interbdd with dk.gray,v.f.grn.ls.,bddg 1"-2",minor calc.sh.partings.

Ls.,med.dk.gray,fine grn.,bddg.1"-2" interbdd with ls., med.lt.gray,crs.-med.grn,fossiliferous,bddg 3"-5".Some ¼" calc.sh. partings.

Peels: a) Argillacepus micrite

b) Unsorted crinoid,brachiopod,biosparite containing some bryozoa.

Ls.,med.dk.grey,f.grn.,bddg.1"-2" with lenses of ls., crs.grn.,coquina.

Ls.,med.lt.gray,crs.grn coquina,abundant crinoids,bddg. 6"-8",cross-bddg.

Peel: Unsorted crinoid biosparite containing brachiopods and bryozoa.

Ls.,med.lt.gray,crs.grn.,bddg.4"-6",interbdd.with ls., med.dk.grey,(weathering lt.yell.brn.),v.f.grn.,bddg. 1"-2".

Peel: Unsorted crinoid,brachiopod biosparite.

Ls.,med lt.gray,crs.grn.,bddg.5"-10",crossbdd.,few f. grn.ls.lenses.

Peels : a)Unsorted crinoid,brachiopod,bryozoa biosparite.

b) Argillaceous micrite

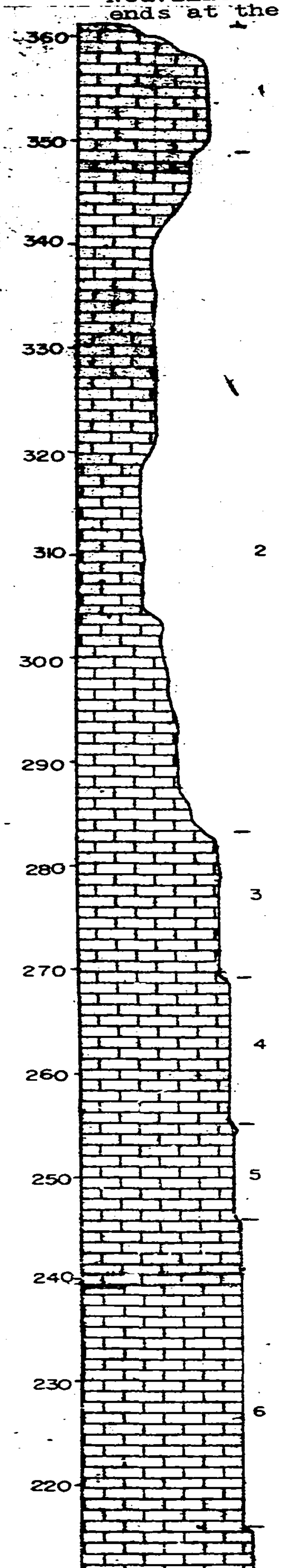
Ls.,dk.gray,f.grn.,bddg.1"-2",laminated.

Ls.,med.lt.gray,v.crs.grn.,crinoids,brachiopods,bryozoa abundant,bddg.4"-10",crossbdd.,

Peel: Unsorted crinoid,bryozoa,brachiopod biosparite.

Neuville Shore Section

A continucus section of Middle and Upper Trenton limestone is exposed along the Neuville shore. The section begins east of the Neuville wharf and continues westward for about a mile. The exposure ends at the base of the Utica. Neuville is 20 miles west of Quebec City.



1 Ls.,med.dk.gray,v.f.grn.,bddg.2"-5",rubbly weathered surface,sh.interbeds ½"-1". Cephalopods abundant on bedding planes
Peel: Micrite with 1-2% silt size quartz,rare brachiopods.

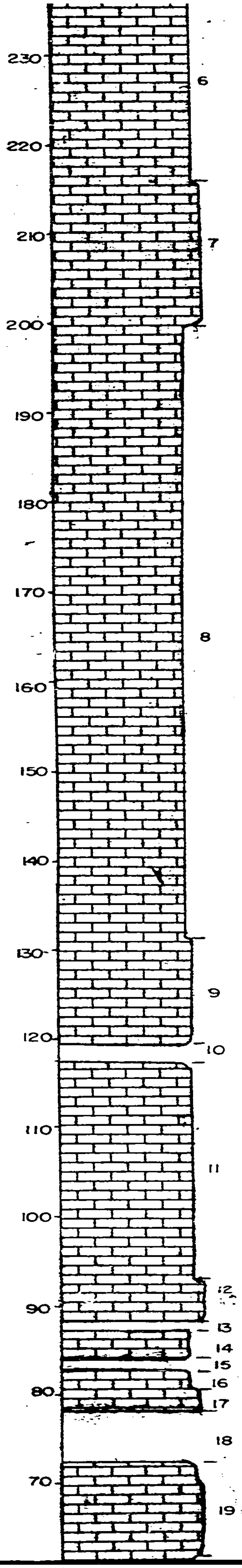
2 Ls.,med.dk.gray,v.f.grn.,bddg.2"-3",interbdd.with sh.½"-1".
Peel: Micrite with 5% silt size quartz,rare brachiopods.

3 Ls.,med.gray,v.f.grn.,bddg. 4"-6" with few 12"beds, rubbly weathering,minor shale partings.

4 Ls.,med.dk.gray,v.f.grn.,bddg.4"-[illegible] rubbly weathering minor shale partings.

5 Ls.,med.dk.gray,v.f.grn.,bddg.6"-8" interbdd.with shale ¼"-½".

6 Ls.,med.dk.gray,v.f.grn.,localized patches of fossil fragments on bddg.plane,bddg.2"-5" with some shale interbeds ½"-1".
Peel: Argillaceous micrite



fragments on bddg.plane,bddg.2"-5" with some shale interbeds ½"-1".
Peel: Argillaceous micrite

Ls.,med.dk.gray,v.f.grn.,bddg.3"-6",interbdd.with shale 1"-2", localized patches of fossil fragments on bddg. plane. Unit forms small cliff (Plate ,Figure).
Peel and thin section: Argillaceous micrite with up to 10% silt size quartz.

Ls.,med.dk.gray,v.f.grn,bddg.2"-4" with shale partings ½"-½", patches of very fossiliferous ls.(trilobotes, brachiopods,bulbous bryozoa,cephalopods).
Peels: Argillaceous micrite with 5% silt size quartz.

Ls.,med.dk.gray,v.f.grn.,bddg.2"-4" with a [illegible] 12" bed, shale interbeds ½".
Peel: Sparse crinoid brachiopod microsparite.

Covered interval

Ls.,dk.gray,f.grn.,bddg.1"-2" with shale interbeds ½", fossils abundant in patches on bddg.plane (crinoids, brachiopods, trilobites (Isotelus)).
Peel: Argillaceous micrite to Argillaceous fossiliferous micrite.

Ls.,dk.gray,f.grn.,bddg.6"-12",thin shale partings.
Peel: Argillaceous micrite to Argillaceous fossiliferous micrite.

Covered interval

Ls.,dk.gray,f.grn.,bddg.4"-6", few fossil fragments.

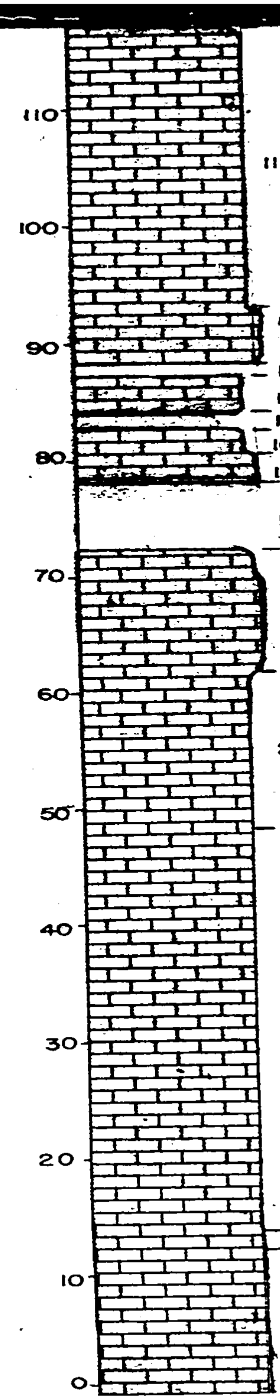
Covered interval

Ls.,dk.gray,f.grn.,bddg.4"-8" with 1"-[illegible]" black shale interbeds.

Ls., dk.gray, f.grn., bddg.4"-6", shale partings.

Covered interval

Ls.,dk.gray,f.grn,bddg,18-24".
Peel: Argillaceous micrite.



11 Ls.,dk.gray,f.grn.,bddg.1"-2" with shale interbeds ½", fossils abundant in patches on bddg.plane (crinoids, brachiopods, trilobites (Isotelus)).
Peel: Argillaceous micrite to Argillaceous fossiliferous micrite.

12 Ls.,dk.gray,f.grn.,bddg.6"-12",thin shale partings.
Peel: Argillaceous micrite to Argillaceous fossiliferous micrite.

13 Covered interval

14 Ls.,dk.gray,f.grn.,bddg.4"-6", few fossil fragments.

15 Covered interval

16 Ls.,dk.gray,f.grn.,bddg.4"8" with 1"-2" black shale interbeds.

17 Ls., dk.gray, f.grn., bddg.4"-6", shale partings.

18 Covered interval

19 Ls.,dk.gray,f.grn,bddg.18-24".
Peel: Argillaceous micrite.

20 Ls.,v.dk.gray,f.grn.,with abundant whole fossil fragments on bddg.plane (trilobites,brachiopods,bryozoa,and algal).

21 Ls.,v.dk.gray,f.grn.,bddg.,5"-8" with black shale interbed ½".
Peels: Argillaceous micrite with 1% silt size quartz.

22 Ls., dk.gray,f.grn.,fossilferous,bddg.5" with shale parting
Peel: Sparse brachiopod biomicrite with crinoid and bryozoa fragments.

23 Ls.,v.dk.gray,f.grn.,uncommon fossil fragments,bddg.4"-6", minor black shale partings,
Peel: Brachiopod micrite with argillaceous patches.

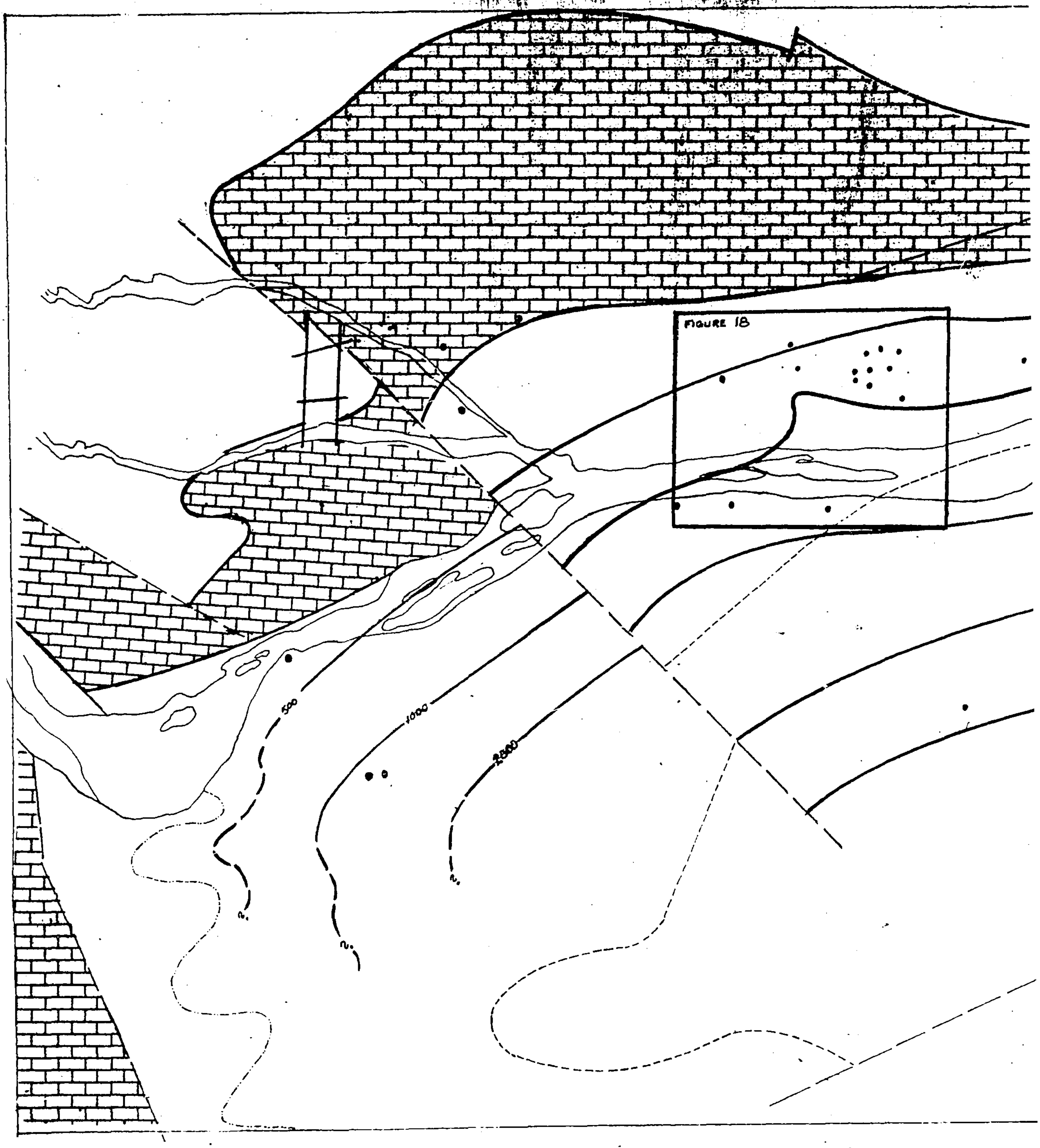


FIGURE 18
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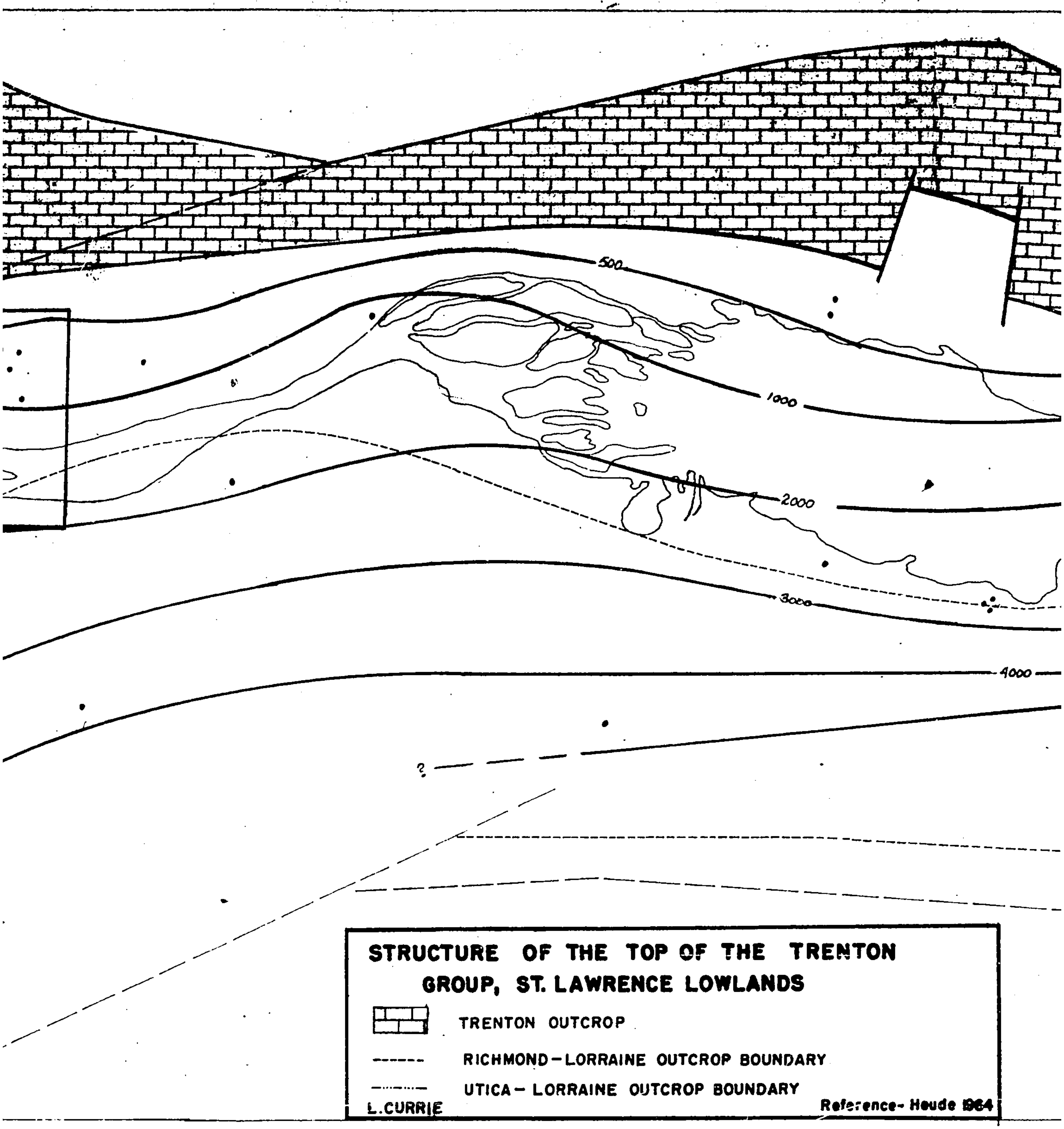
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STRUCTURE OF THE TOP OF THE TRENTON GROUP, ST. LAWRENCE LOWLANDS
TRENTON OUTCROP
RICHMOND–LORRAINE OUTCROP BOUNDARY
UTICA – LORRAINE OUTCROP BOUNDARY
L. CURRIE
Reference- Heude 1964

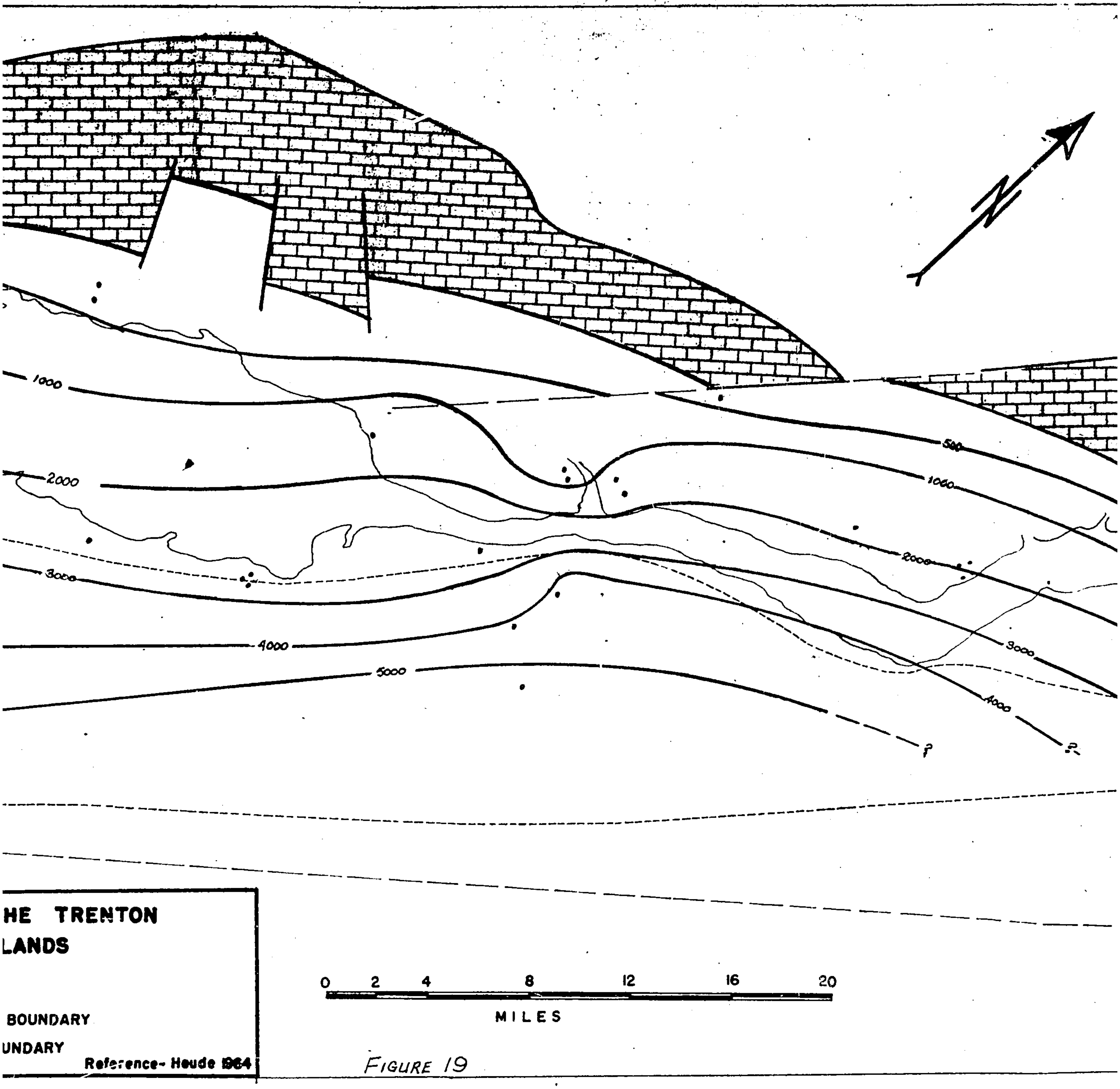
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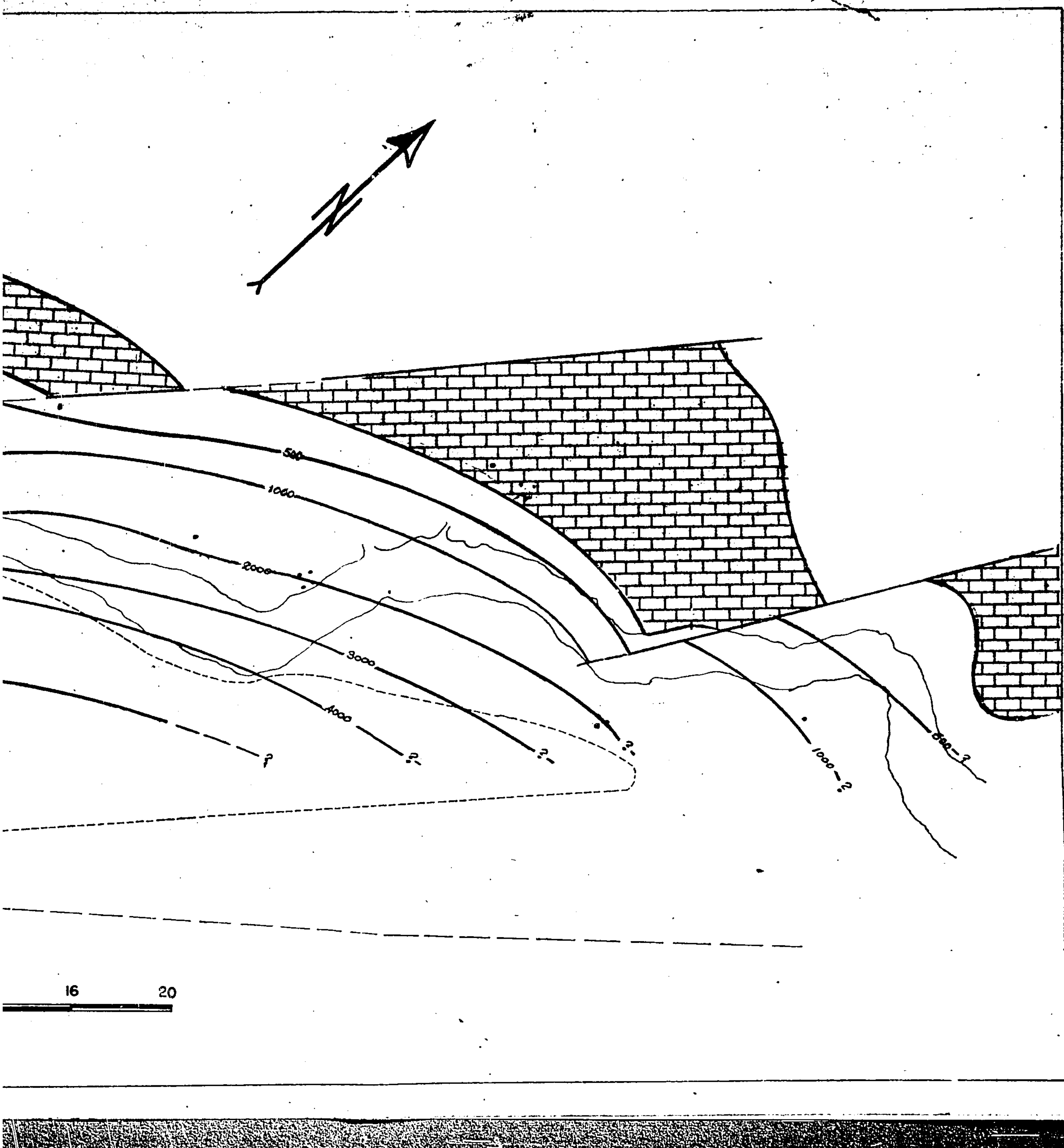
FIGURE 19



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