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STUDY OF GROUNDWATER FLOW PATTERNS IN CARBONIFEROUS SEDIMENTS OF ATLANTIC CANADA FREDERICTON SUBBASIN

Water Management Services Limited.
and
3-D Geoconsultants Limited
J.A. Leslie and Associates Ltd

Earth Physics Branch Open File Number 84-11
Dossier public de la Direction de la Physique du Globe No. 84-11

Department of Energy, Mines &
Resources Canada
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Ministere de L'Energie, des
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Abstract

The Fredericton sedimentary sub-basin forms the westernmost section of the St. Lawrence Plains. The sediments of the sub-basin range in age from Pennsylvanian to Mississippian. The principal structural feature is the Fredericton Graben, a down-faulted block that occupies the northwest quadrant of the basin. The sub-basin displays no large identifiable aquifers. On a large scale, however, the series of sediments that are of limited areal extent display hydraulic continuity. Within the sub-basin groundwater flow occurs in two major directions, northeastwards and eastwards. Known water yields in the upper 200 m vary from 0.076 L/s to 38.0 L/s. Potential aquifers lie at depth, likely in Lower Pennsylvanian and Upper Mississippian sediments. Flows are expected to be in the range 38 to 76 L/s.

Résumé

Le bassin sédimentaire de Fredericton forme la partie la plus à l'ouest des Plaines du St. Laurent. Les sédiments du bassin s'étendent en âge du Pennsylvanien jusqu'au Mississippien. Le Fossé Fredericton, le trait structural majeur, est un bloc abaissé par failles qui occupe le quadrant nord-ouest du bassin. On ne peut pas identifier des acquifères étendues au bassin sédimentaire; cependant, sur une grande échelle, les ensembles de couches limitées en aire exposent une continuité hydraulique. A l'intérieur du bassin, l'écoulement souterrain se produit en deux directions principales: est et nord-est. Les rendements d'eaux connus dans les 200 m de dessus varient entre 0.076 et 38.0 L/s. Les acquifères potentiels reposeront à des profondeurs de sédiments Pennsylvaniens inférieurs et Mississippiens supérieurs. On présume que les écoulements souterrains seront classés de 38 à 76 L/s.

STUDY OF GROUNDWATER FLOW PATTERNS IN CARBONIFEROUS SEDIMENTS OF ATLANTIC CANADA FREDERICTON SUBBASIN

BY

WATER MANAGEMENT SERVICES LIMITED

AND

3-D GEOCONSULTANTS LIMITED

J. A. LESLIE AND ASSOCIATES LTD.

UNDER

DSS CONTRACT NO. OSQ83-00189

FOR

ENERGY MINES AND RESOURCES

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EXECUTIVE SUMMARY

The sedimentary subbasin forms the westernmost section of the St. Lawrence Plains (New Brunswick Lowlands) physiographic division in New Brunswick. Elevations vary from 5 m to 200 m although they are generally less than 125 m. The topography is gentle with few rapid changes in elevation. The centre of the subbasin is a wide low flood plain flanked by steeply rising ground at the northern and southern basin borders.

The greater part of the basin is drained by the Oromocto River, which flows eastwards to enter the St. John River. The Oromocto River rises from two main branches, the North Oromocto and the South Oromocto which confluence east of the Village of Fredericton Junction.

The climate is humid continental, characterized by long cold winters, cool summers and no dry season. Annual mean precipitation varies from 1059 mm to 1148 mm with a total mean snowfall accumulation of 255 cm per year.

The Carboniferous sediments of the subbasin range in age from Pennsylvanian to Mississippian. The Mississippian sediments parallel the southern contact of the Pennsylvanian rocks and are separated from them by an intervening discontinuous narrow belt of Mississippian volcanics. The northern and western contacts of the subbasin are essentially fault controlled, whereas the southern contact is one of structural unconformity.

The structural regime results from movement in the pre-Carboniferous basement. The principal structural feature is the Fredericton Graben, a down faulted block which occupies the northwest quadrant of the basin. Local faulting is also present.

Mississippian sediments are composed of poorly indurated arenaceous and argillaceous sediments such as mudstones, conglomerates and sandstones. The Pennsylvanian sediments are composed of similar rock types and include quartzose pebble conglomerates, sandstones, shales, siltstones and coal seams.

The subbasin displays no large identificable aquifers. On a large scale however, the series of sediments which are of limited areal extent, display hydraulic continuity. This is caused by extensive fracturing and faulting within the rocks. The result is the realization of a composite aquifer relying on interconnecting fracture permeability rather than on intraformational permeability. Known water yields throughout the subbasin in the upper 200 m vary from 0.076 L/s to 38.0 L/s.

Water level data indicates the overall generalized flow system to be from recharge at the head and along the flanks of the basin to discharge along the lower basin boundary at the St. John River. Within the subbasin groundwater flow occurs in two major directions, northeastwards and eastwards. The two systems are each bounded by the basin edge and are separated by the apparent downfaulted contact at the southern boundary of the graben.

Flow through the northern system is considered to be relatively rapid while that in the southern flow system is considered too slow. This may be due to deeper penetration of waters and the presence of basement highs at the lower end of the subbasin which may serve to restrict discharge of groundwater. Flow in both systems is complicated by the many faults that cross the subbasin and by the basement topography.

Total discharge across the lower basin boundary is estimated to be 4.5×10^6 m^3/day or 9.0 m^3/day/metre of boundary from 8 percent of precipitation which is believed to form permanent groundwater recharge. Only 60% of this discharge can be accounted for by assuming generalized flow gradients and permeabilities and an aquifer thickness of 300 m. The remainder therefore may leave the subbasin through flow at depths greater than this. Unfortunately definitive flow or permeability data for deep strata within the subbasin is not available. Flow is considered to be almost solely intraformational and fracture controlled. Permeability testing of 42 exploration core samples give intrinsic permeabilities no higher than 9.82 millidarcies, while the highest porosity was 13.0%.

The two flow systems are reflected in distinctive water chemistries. The northern system is characterized by low conductivity waters at depth, while the southern system demonstrates low conductivity water at the head of the basin which grades to waters with a high conductivity and total dissolved solids prior to discharge. Waters in the southern system are assumed to have risen from depth in the central part of the subbasin prior to discharge.

Aeromagnetic and gravity surveys together with paleogeothermal evidence from coal rank data indicate that potential heat sources may lie at depth beneath the basin. Gradients measured to depths of 300 m are recorded at 25 to 27^{o} C/km within the subbasin while gradients in Mississippian basins to the south and in the Silurian slates situated to the north have gradients less than 20^{o} C/km.

The study concludes that potential heat sources are likely to lie beneath the basin and that potential aquifers lie at depth likely in Lower Pennsylvanian and/or Upper Mississippian sediments. Flows are expected to be in the range of 38 to 76 L/s and 60^{o} C water is expected to lie approximately 2 kilometres below the surface. This depth may be much less if hotter waters rise from the basin depths to discharge in the southern half of the subbasin.

From the study data two areas are targeted for further exploration. Both demonstrate nearby potential users and the necessary geothermal potential to encourage more work. These areas lie in Fredericton and at Oromocto.

Résumé exécutif

Les bassins sédimentaires forment la partie la plus à l'ouest des Plaines du St-Laurent (New Brunswick Lowlands) de la région géographique à climat et structure homogènes au Nouveau-Brunswick. Les élévations du terrain varient entre 5 et 200 mètres (m), la moyenne étant établie à environ 125 m ou moins. La topographie est douce et on note aucun changement d'élévation rapide. La partie centrale du bassin sédimentaire consiste d'un périmètre d'inondation large et bas et elle est encadrée par une topographie escarpée aux limites nord et sud du bassin.

La rivière Oromocto draine la majeure partie du bassin et elle s'écoule vers l'est pour aboutir à la rivière Saint-Jean. De plus, la rivière Oromocto prend sa source de deux branches principales: la Oromocto Nord et la Oromocto Sud, où leur confluent se trouve à l'est du village de Fredericton Junction.

Le bassin a un climat continental humide, caractérisé de longs hivers froids, d'étés fraîches mais non de saison sèche. La précipitation moyenne annuelle varie entre 1 059 et 1 148 mm, et les accumulations moyennes de chute de neige totales sont de 255 cm par année.

Les sédiments carbonifères du bassin sédimentaire s'étendent en âge du Pennsylvanien jusqu'au Mississipien. Ceux de la période Mississipienne s'étendent parallèlement à la surface de contact sud de la roche Pennsylvanienne et ces sédiments sont interposés par une étroite zone discontinuée de roches volcaniques Mississipiennes. Les surfaces de contact au nord et à l'ouest du bassin sédimentaire sont essentiellement réglées par failles, tandis que la surface de contact au sud est de discordance angulaire.

Le régime structural provient du mouvement du socle métamorphique pré-carbonifère. Le Fossé Fredericton, le trait structural majeur, est un bloc abaissé par failles qui occupe le quadrant nord-ouest du bassin. On trouve également la formation de failles locales, à cet endroit.

Les sédiments Mississipiens sont composés de sédiments indurés arénacés et argileux médiocres tels que schistes argileux, conglomérats et grès. Les sédiments Pennsylvaniens, eux, sont composés de types de roches similaires et comprennent des conglomérats de galets quartzeux, grès, schistes argileux, leuronites et couches de carbon.

On ne peut pas identifier des acquifères étendues au bassin sédimentaire; cependant, sur une grande échelle, les ensembles de couches limitées en aire exposent une continuité hydraulique. Ceci est le résultat de vastes formations de fissures et de failles à l'intérieur des roches qui mènent finalement à la création de composites acquifères reposant sur la perméabilité de fracture connectée plutôt que sur la perméabilité intraformationelle. Les rendements d'eaux connus à travers le bassin dans les 200 m de dessus varient entre 0,076 et 38,0 L/s.

Les données des niveaux statiques indiquent que le réseau d'écoulement souterrain se dirige vers la rivière Saint-Jean en partant d'abord de l'alimentation de la nappe située à la partie amont et aux flancs du bassin, pour finalement aboutir au débit au long de la limite inférieure du bassin sédimentaire de la rivière Saint-Jean. À l'intérieur du bassin, l'écoulement souterrain se produit en deux directions principales: est et nord-est. Ces deux réseaux sont bornés par les limites du bassin et séparés par l'apparente surface de contact abaissée par failles à la limite sud du Graben.

L'écoulement souterrain du réseau nord-est semble relativement rapide lorsque celui du réseau semble trop lent. Ceci peut être la cause d'une profonde alimentation des eaux et la présence des hauteurs de soubassement à l'extrémité basse du bassin sédimentaire qui servent probablement à restreindre le débit d'eaux souterraines. L'écoulement à travers les deux réseaux est compliqué par plusieurs failles traversant le bassin et par le soubassement topographique.

Le débit total à travers la limite inférieure du bassin sédimentaire est estimé à $4,5 \times 10^6$ m^3 par jour par mètre (m^3/jour/m) ou 9,4 m^3/jour/m de limite à partir de 8 pourcent de précipitation croyant à former une alimentation d'eau souterraine permanente. On ne peut seulement justifier que 60 pourcent de ce débit, tenant compte des gradients hydrauliques généralisés et des perméabilités et même d'une épaisseur d'acquifère de 300 mètres. Le 40 pourcent de reste peut alors s'échapper du bassin sédimentaire par l'écoulement souterrain à de plus grandes profondeurs.

Les données de perméabilité et de l'écoulement défini pour les couches géologiques à l'intérieur du bassin ne sont malheureusement pas disponibles. L'écoulement souterrain est considéré comme étant presque entièrement intraformationel et controllé par failles. Les analyses de perméabilité sur 42 échantillons de carottes de soudage de recherches démontrent des perméabilités intrinsèques moins élevées que 9,82 millidarcies, avec une porosité supérieure de 13,0 pourcent.

Les deux réseaux d'écoulement souterrain sont identifiés à des chimies d'eau distinctes. Le réseau nord est caractéristique d'une basse conductivité d'eau à profondeur, tandis que le réseau du sud démontre une basse conductivité à la partie amont du bassin. Cette basse conductivité gradue aux eaux avec haute conductivité et à la quantité totale de matériaux dissous avant le débit. Les eaux dans le réseau du sud ont probablement été élevées de la profondeur de la partie centrale du bassin sédimentaire avant le débit.

Les levés gravimétriques et magnétiques aéroportées ajoutés à l'évidence paléogéothermique des données de catégories de charbon indiquent que les sources de chaleurs potentielles pourraient reposer à une profondeur sous le bassin. Les gradients mesurés à des profondeurs de 300 m sont classës de 25° à 27°C/km à l'intérieur du bassin, tandis que ceux du bassin Mississipien au sud et dans les ardoises de période Silurienne au nord sont des gradients classés à moins de 20°C/km.

L'étude détermine que les sources de chaleurs potentielles reposeront probablement sous le bassin et que les acquifères potentiels reposeront à des profondeurs de sédiments Pennsylvaniens inférieurs et/ou Mississipiens supérieurs. On présume que les écoulements souterrains seront classés de 38 à 76 L/s et les eaux de 60°C reposeront probablement à 2 km de la surface. Cette profondeur peut être diminuée si les eaux plus chaudes s'élèvent des profondeurs du bassin pour aboutir à la moitié de la partie sud du bassin sédimentaire.

On peut entendre par les données de cette étude que deux endroits seront choisis pour des recherches supplémentaires. Ces deux endroits démontrent des usagers potentiels géothermiques nécessaires pour encourager d'autres enquêtes. Ces endroits sont à Fredericton et à Oromocto.

1.0 INTRODUCTION

The Department of Energy, Mines and Resources has, since 1980, been evaluating the geothermal potential of the Carboniferous Sedimentary Basins in Atlantic Canada[1,2]. This study, under Contract No. 0SQ283-00189, complements previous geothermal energy resource investigations through evaluation of the groundwater regime in a selected Carboniferous subbasin at Fredericton. Objectives of the study are to determine flow patterns, define recharge and discharge areas, evaluate the geochemistry of the waters and locate high yield aquifers with geothermal potential.

2.0 PHYSIOGRAPHY AND DRAINAGE

The sedimentary subbasin forms the westernmost section of the St. Lawrence Plains (New Brunswick Lowlands) physiographic division in New Brunswick.

Elevations vary from extremes of 5 m to 200 m although elevations are generally less than 125 m. In general the topography is gentle with few rapid changes in elevation. The subbasin centre is a wide low floodplain flanked by steeply rising ground at the northern and southern basin borders where elevations reach 200 m or greater.

The greater part of the subbasin is drained by the Oromocto River which flows eastwards to enter the St. John River, the latter forming the easternmost boundary of the basin (Figure 1). The Oromocto River rises from two main branches, the North Oromocto and South Oromocto, which confluence just east of the Village of Fredericton Junction.

The North Oromocto rises from Oromocto Lake which is located at the head of the subbasin at an elevation of 116 m. Several major tributaries join the north branch prior to its confluence with the South Oromocto. The north branch drains the subbasin west of the Village of Tracy.

The South Oromocto rises from South Oromocto Lake which is located outside the subbasin boundary on Devonian and older igneous and metamorphic rocks. The river crosses the basin boundary south of the Village of Fredericton Junction.

The shallow floor of the basin is characterized by wet and swampy areas, lakes and ponds, slow moving meandering rivers and streams, and periodic flooding during periods of snowmelt and heavy runoff.

3.0 CLIMATE

The climate can be described as humid continental, characterized by long cold winters and cool summers with no dry season. Temperature variations over the region range from a mean annual temperature of 6^{o} C at Gagetown to 5^{o} C at Harvey Station. July and August are the warmest months in the region, while January and February are the coldest. The extreme annual maximum temperature varies from 37^{o} C to 39^{o} C, and the extreme annual minimum ranges from -37^{o} C to -40^{o} C.

The annual mean total precipitation varies from 1059 mm to 1148 mm with total mean snowfall accumulations of 255 cm per year. Approximately 40% of the total annual precipitation may be expected in the form of snow, although this percentage varies somewhat across the basin.

The summer season is approximately 4 months in duration (June to September) with these months specified as being frost free. An average of approximately 185 days of frost characterizes the remaining 8 months of the year.

Mean annual values of climatological data at selected meteorological stations in the subbasin are presented in Table 1.

4.0 DEMOGRAPHY

There is one city (Fredericton), a town (Oromocto) and three villages, (Tracy, Fredericton Junction and Gagetown) located within the subbasin.

The City of Fredericton, being the capital of the Province of New Brunswick, plays a significant role as the major employment centre within the region. It is the major urban centre and by virtue of containing the University of New Brunswick and St. Thomas University, it is the major educational centre. The

TABLE 1

CARBONIFEROUS SUB-BASIN

CLIMATOLOGICAL DATA

STATION	ANNUAL TEMP. MEAN oC	ANNUAL TEMP. MAX oC	ANNUAL TEMP. MIN oC	EXTREME ANNUAL TEMP. MAX oC	EXTREME ANNUAL TEMP. MIN oC	No. of Days WITH FROST	MEAM RAIN-FALL mm	MEAM SNOW-FALL cm	MEAN TOTAL PRECIP. mm
Fredericton A	5.5	11.1	-0.2	36.7	-37.2	177	785.	280.	1060.
Fredericton CDA	5.3	10.9	-0.3	38.9	-38.9	178	840.	243.	1084.
Fredericton UNB	5.6	11.3	0.0	38.3	-37.2	177	878.	245.	1124.
Gagetown	6.1	11.2	0.9	37.2	-37.8	161	809.	250.	1059.
Harvey Station	5.0	10.3	-0.3	37.2	-37.8	178	825.	265.	1090.
Oromocto	5.4	10.9	-0.2	37.2	-37.8	175	783.	230.	1014.
McAdam	4.9	10.8	-1.0	37.8	-40.6	183	876.	272.	1148.

city has experienced significant growth in population in recent years mainly due to amalgamation of satellite communities. The greater Fredericton area, which includes the districts of Silverwood, Marysville, Nashwaaksis, Barkers Point and Lower Maugerville, has a population of 48,262 (1976 census). This is a notable rise from 15,404 recorded in 1971 census.

The Town of Oromocto is situated centrally at the eastern end of the basin, 19 km southeast of Fredericton and 92 km north of Saint John. The town lies at the intersection of the Oromocto and the Saint John Rivers and provides living areas for civilians and military personnel associated with the Canadian Armed Forces Base CFB Gagetown. The 1976 census population for the Town of Oromocto was recorded at 10,377.

The Village of Tracy is located at the mouth of Porcupine Brook along the middle reach of the Oromocto River. The population of Tracy was 662 people in 1976. This population is compared to that of Fredericton Junction of 630. Both of these villages are situated centrally in the subbasin.

The Village of Gagetown located in the south east corner of the basin, 36 km south east of Oromocto has a population of 655 persons.

The total basin population was 67,039 in 1976. Of this, approximately 11% live outside of incorporated areas and appear spread evenly throughout the basin where access is good.

The area supports a variety of industries, the major of which are farming and logging. Dairy and beef herds are found together with market fruits such as apples, strawberries and blueberries. The City of Fredericton being the seat of government and learning in the Province supports the majority of its population through the civil and academic industries. The federal civil service is also represented through the airport at Fredericton and regional federal offices.

The Town of Oromocto derives much of its economic base from the Canadian armed forces stationed at CFB Gagetown.

5.0 GEOLOGY

5.1 General

The Carboniferous sediments of the subbasin consist primarily of rocks which range in age from Pennsylvanian (Namurian to Stephanian) to Mississippian (Tournasian to Visean). The latter sediments parallel the southern contact of the Pennsylvanian rocks and are separated from them by an intervening discontinuous narrow belt of mafic volcanics. Minor fault bounded "wedges" of Mississippian sediments are found along the northwest and western contacts of the Pennsylvanian strata (Figure 1) (after 3-D Geoconsultants).

The northern and western contacts are essentially fault controlled whereas the southern contact is one of structural unconformity. The rock units occuring along the boundary of the subbasin consist of Mississippian felsic volcanics and Siluro-Devonian metasediments.

The structural regime which has affected both the stratigraphic and structural history of the Carboniferous sediments of the New Brunswick Platform was in place in the Late Devonian. Carboniferous structures are mainly the result of dislocation in the pre-Carboniferous basement. The principal structural feature in the study area is the Fredericton Graben, a down-faulted block which occupies the northwest quadrant of the area. Local faulting, likely associated with the regional structural regime, which controls both the northwest contact of the Platform and the Fredericton Graben, is known to exist in areas where detailed geological studies have been undertaken. In addition to high angle faulting, broad open folds complete the structural features affecting the Carboniferous sediments on the Platform.

5.2 Surficial Geology

The Quaternary deposits and features of the area are related to continental glaciation of the Late Wisconsian. No evidence of glacial events older than Wisconsian are present. Although most of the surficial materials were deposited during deglaciation, ice was responsible for their transport.

No evidence of glacial events older than Wisconsian are present in the subbasin. All features related to continental glaciation are assumed to be of Wisconsian and are probably Late Wisconsian in age.

Striations with fluted or streamlined features, such as drumlins, indicate three principal ice flow directions eastwards, southwards and southeastwards.

Subsequent to the striation of the bedrock a veneer of basal till was deposited over large parts of the area. This till sheet is discontinuous, thin over bedrock and from 1 to 3 metres thick in till plains.

The ablation and retreat of the ice sheet took place alternating with periods of relative ice margin stability. During these periods morainic ridges and major outwash complexes were formed.

Seaman and Thibault (1981)[3] suggest the following deglaciation history for the area. Climatic amelioration resulted in downwasting of the ice and ice front retreat. Ice contact and outwash deposits were formed and ablation till was deposited where the ice wasted away on the upland surfaces. Ice lobes remained in the major valleys and kame terraces were formed. The ice retreated upvalley, possibly under the influence of transgressing marine waters which rose up to 90 metres above present mean sea level, creating a subaqueous depositional environment. Outwash deltas formed and some deeper water silt and clay beds were deposited. Due to isostatic uplift, sea level fell and shallow marine deposits and shoreline features were formed. Fluvial action reworked part of the previously deposited materials. Rivers incised during continuing uplift resulted in the present alluvial system. During early postglacial time, dunes, approximately 20 metres high, were formed between the confluence of the Oromocto and Saint John Rivers and Lincoln.

The subbasin is characterized by surficial units consisting of tills, moraines, ice contact and outwash meterial. Surficial sediments deposited under water influence include glaciolacustrine, marine shore and alluvial deposits. Over the more impermeable areas or areas of high water table peatlands have formed.

Many of the surficial deposits demonstrate local importance as unconsolidated aquifers. These include the outwash, kame and morainic deposits. The southwest margins of the subbasin are overlain by more granular glacial deposits while, in contrast, the northwest and southeast margins of the area are quite sparsely covered by surficial material. The central portions of the study area, west of the Oromocto River, exhibit a random scattering of occurrences of morainic ice contact drift and outwash deposits. The area to the east of the Oromocto River is rather sparsely covered except for a large deposit of moraines in an area between Burton, Geary and Upper Gagetown.

5.3 Bedrock Geology

The bulk of the Carboniferous sediments exposed on the New Brunswick Platform southwest of the Saint John River consist of Pennsylvanian rocks (Figure 1). The Mississippian sediments exposed are restricted to a narrow band along the southern contact of the subbasin and to minor fault bounded "wedges" along the northwest and western contacts of the Pennsylvanian rocks. The Mississippian-Pennsylvanian contact along the southern boundary of the study area is delineated, to a limited extent, by narrow bands of mafic volcanics. Lower-Middle Mississippian felsic volcanics effectively mark the contact of the Carboniferous sediments and the pre-Carboniferous metasediments along the southern margin of the study area. Equivalent felsic volcanics are found along the northwest boundary of the subbasin in the vicinity of the Village of Harvey.

Along the margins of the New Brunswick Platform the Pennsylvanian strata dip from 5^{o} to 8^{o} towards the centre, where bedding becomes essentially horizontal. These sediments form a bowl, open to the northeast. This configuration is further accentuated by the relative positioning of the Mississippian rock units "around" the margins of the Platform and by the delineation of crescent shaped interdigitating lithofacies units within the Pennsylvanian strata[4]. A general younging trend across the Platform to the northeast has been established in the Pennsylvanian sediments[5]. Structural disruption, however, of this rather simple configuration has been documented by LeGallais[4] in the Fredericton area.

The Mississippian sediments consist of poorly indurated, reddish brown, cobble to boulder conglomerates of the Piskahegan Group and greyish red and olive grey to black mudstones and sandstones of the Parleeville Formation and undivided gray sandstones and mudstones. The Piskahegan Group is the chronostratigraphic equivalent of the Moncton Group of rocks located in the Moncton sub-basin. The Parleeville Formation represents the entire exposed thickness of Windsor Group rocks in the subbasin. They lie stratigraphically between the lower group (Piskahegan) and the upper undifferentiated Mississippian clastics. The Piskahegan Group includes the felsic volcanics which in part form the boundaries of the subbasin.

The Hopewell Group, which is intermediate to the Mississippian and Pennsylvanian rock units, consists of coarse and fine-grained facies. The former consists of reddish brown conglomerates, conglomeratic sandstones and minor mudstones while the latter of reddish brown sandstones and mudstones with some conglomerates and minor greenish grey mudstones and sandstones. The mafic volcanics found along the southern contact of the Pennsylvanian sediments are included in the Hopewell Group.

The Pennsylvanian sediments consist of the Boss Point Formation, an unnamed lower Pictou rock unit and the Pictou Group. The Boss Point Formation is composed of grey quartzose to lithic sandtone, quartz pebble to cobble conglomerates and minor grey-green to buff shales and siltstones. The lower Pictou rock unit consists of grey granular to cobble polymictic conglomerates and minor grey medium grained lithic sandstones. A succession of grey coarse-grained sandstones and conglomerates, in part coal-bearing and red fine-grained sandstones, siltstones and shales make up the Pictou Group.

Two major lithofacies, grey coarse-grained and red fine-grained facies, although subject to variations in colour and grain size association, describe and Pictou Group.

Cyclic accumulations of the above assemblages record co-existing fluvial channel and floodplain depositional systems. The coarse-grained facies represent channel lag deposits while the fine-grained facies represent overbank deposits. Coal horizons were formed in paludal environments found on the alluvial plains which were subject to seasonal flooding and drying. Detailed core drilling and geophysical borehole logging in the Fredericton area has allowed the delineation of several of these cyclic interdigitating lithofacies units within the Pictou Group in the western half of the study area[4].

5.4 Basin Structure

During the Late Devonian, following the Acadian Orogeny, uplift and erosion created a set of tectonic elements that prevailed into the Permian. The New Brunswick Platform formed one of several of those elements and was in fact a stable area of uplift which accumulated a relatively thin and undeformed cover of Carboniferous rocks.

The regional tectonic framework resulted in a number of northeast trending normal faults affecting the pre-Carboniferous basement rocks of the Platform. Offset northeast trending and randomly crosscutting normal faults completed structural elements within the framework. This tectonic framework, which remained in place through the Carboniferous, resulted in recurrent activation upon pre-Carboniferous planes of movement. The Carboniferous rocks of the subbasin have been affected by this faulting.

The noted consistence in depositional environments through the Pennsylvanian and into the Permian has resulted in marked similarity in lithology regardless of age. This coupled with lack of exposure, has made detailed delineation of faulting in the Pennsylvanian rocks difficult and dependent to a large degree upon palynological, geophysical and remote sensing data. The result is that very few of the faults delineated in the Pictou Group have in fact been observed in the field. For these reasons discrepancies exist as to the number, location and degree of faulting which has been delineated in the subbasin. The term degree is used in the sense of has been delineated in the subbasin. The term degree is used in the sense of referring to the "severity" of the fault in question; whether or not it is associated with a major regional fault or is simply a local feature. Regional faults are associated with reactivated pre-Carboniferous fault planes whereas local faults are those thought to be simply local readjustments necessitated by the regional movements.

The northwestern contact of the Carboniferous rocks is essentially fault controlled (Fredericton Fault). This is in contrast to the western and southern contacts which, although not conformable, are not faulted. Regional interpretation of geophysical and remote sensing data has delineated a number of major normal faults in the subbasin[6]. Of particular importance to this study are those faults referred to as the Fredericton, Oromocto and Tracy Faults since they outline a downfaulted block which includes the northwestern quadrant of the subbasin.

The western half of the study area has been the centre of an intensive stratigraphic and sedimentological study resulting from the recent uranium exploration activity in the area. As a result of this activity delineation of numerous faults has been possible. The existence of the down faulted block previously referred to has been substantiated but the exact location of its southerwestern boundary (Tracy Fault) has been brought into question. In addition, the configuration of the previously recognized Fredericton Graben has been altered somewhat[7].

The Tracy fault, referred to by LeGallais[4] as the Tracy Fault System has, for the purposes of this study, been delineated at what is likely the most possible westerly location (Figure 1). Within the downfaulted block and occupying the northern portion of the study area is the Fredericton Graben. This structure, previously thought to be a simple downfaulted block appears to be somewhat more complicated. Although its northwest boundary remains unchanged, as defined by the Fredericton Fault, its southern boundary appears to be "stepped" as opposed to being controlled by a single fault plane. At least two and possibly three west-northwesterly trending normal faults control the Graben's southern margin. North-south cross-cutting fault(s), although of lesser magitude, have also been delineated.

6.0 HYDROLOGY

The topographic differences throughout the drainage basin of the Oromocto River are great. The Northwest Oromocto River drains a high plateau above Fredericton Junction. From that point downstream, the river is slow moving with substantial meandering. The South Oromocto River enters the north branch at Blissville after passing through a break in the southern subbasin boundary south of Fredericton Junction.

Storage in the upper reaches of both branches of the Oromocto River is afforded by lakes which to some degree are supplemented by wet and swampy areas distributed throughout middle and lower reaches of the river proper. There is a hydrometric station in the drainage basin at Tracy which serves a drainage area of 557 km^2 and has eighteen years of records available.

Maximum extreme daily flow was recorded at 456 m^3/s in February 4th, 1970 while the extreme minimum reached 0.01 m^3/s on September 11th, 1971. Monthly means flows vary from a low of 2.92 m^3/s recorded in September to a high of 34 m^3/s in April. Approximately 45% of the flow occurs during the spring months of March, April and May while from July to September 6% of the total flow leaves the basin[8].

Monthly and annual mean flows, together with annual extreme discharges, are presented in Table 2. A flow duration curve is also presented for the Oromocto River at Tracy (Figure 2). Reference to the curve indicates that the river experiences rapid runoff with relatively little storage, a condition explainable by the physical characteristics of a basin with high basin edges and low central flood plain.

Several low lying locations within the basin are flood prone. The cause of flooding is normally any combination of the following factors; excessive precipitation, high snowmelt, ice jams and/or debris jams. Most of the flooding events occur during the months of March, April and May at a time of high snowmelt, ice jams and occasional heavy rainstorms. Flooding may also occur at other times mainly due to heavy rainstorms. Small strips of marshy interval land

TABLE 2

OROMOCTO RIVER - DISCHARGE DATA

NORTHWEST OROMOCTO RIVER AT TRACY - STATION NO. 01AM001

MONTHLY AND ANNUAL MEAN DISCHARGES IN CUBIC METRES PER SECOND FOR THE PERIOD OF RECORD

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN	YEAR
1962	---	---	---	---	---	---	---	---	---	8.06	28.5	9.07	---	1962
1963	6.14	7.30	6.67	34.9	31.9	4.70	3.80	7.39	7.65	16.6	37.6	14.7	14.9	1963
1964	3.88	4.23	9.72	37.2	9.99	2.98	1.57	1.35	1.35	2.99	6.47	18.7	8.35	1964
1965	9.38	5.33	14.4	24.5	12.4	3.50	0.668	1.78	1.33	1.25	10.5	8.11	7.75	1965
1966	4.29	5.27	21.1	19.2	7.65	3.04	1.47	0.588	0.304	2.08	13.0	9.56	7.30	1966
1967	6.81	2.49	2.40	18.6	39.9	13.0	4.63	1.22	3.42	5.68	13.9	18.6	10.9	1967
1968	7.56	14.6	13.9	32.5	6.69	3.22	1.55	0.169	0.044	0.939	9.54	18.6	9.05	1968
1969	6.16	3.93	6.29	37.2	12.4	4.07	5.01	3.27	8.65	3.79	17.0	28.3	11.3	1969
1970	7.71	33.0	7.07	28.6	22.9	12.0	16.1	11.9	9.38	12.7	9.36	7.19	14.7	1970
1971	6.20	22.5	12.0	44.9	24.3	4.34	2.09	0.984	0.595	2.49	4.26	5.69	10.7	1971
1972	6.72	2.37	9.12	25.4	51.1	16.8	4.84	1.78	1.51	9.77	22.6	18.3	14.2	1972
1973	16.1	16.7	29.5	43.3	24.3	6.69	3.12	14.6	3.89	2.09	7.02	29.8	16.4	1973
1974	8.03	7.68	19.3	30.1	26.5	10.6	4.51	0.906	1.11	3.48	3.60	19.2	11.3	1974
1975	4.33	2.93	9.56	31.6	21.8	11.9	1.58	0.515	0.442	2.73	18.9	14.2	10.0	1975
1976	12.0	24.3	22.5	36.9	19.7	3.66	6.99	3.62	1.76	12.9	7.54	14.6	13.8	1976
1977	11.9	3.68	10.4	53.1	14.3	24.5	2.98	1.16	1.25	18.3	8.48	5.67	13.0	1977
1978	18.1	12.7	8.19	43.6	15.6	4.50	0.817	0.437	0.449	6.12	3.87	2.80	9.70	1978
1979	24.4	11.8	52.4	36.1	33.7	12.9	2.18	5.80	6.45	17.1	21.5	11.4	19.7	1979
MEAN	9.39	10.6	15.0	34.0	22.1	8.38	3.76	3.38	2.92	7.17	13.5	14.1	11.9	MEAN

LOCATION - LAT 45 40 25 N, LONG 66 40 58 W

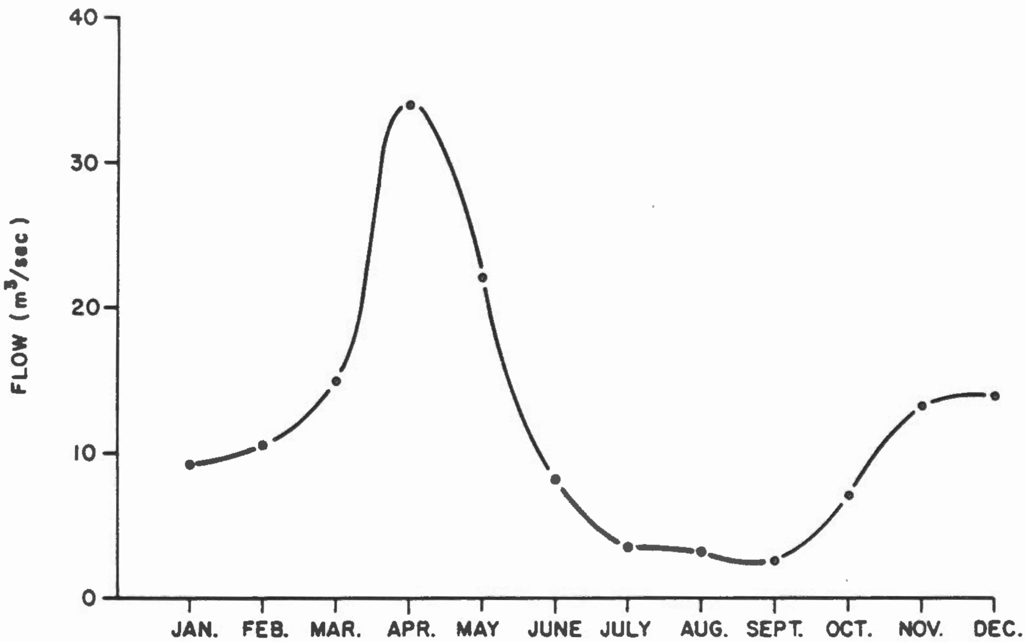
DRAINAGE AREA, 557 km²
NATURAL FLOW

NORTHWEST OROMOCTO RIVER AT TRACY - STATION NO. 01AM001

ANNUAL EXTREMES OF DISCHARGE AND ANNUAL TOTAL DISCHARGE FOR THE PERIOD OF RECORD

YEAR	MAXIMUM INSTANTANEOUS DISCHARGE (m^3/s)	MAXIMUM DAILY DISCHARGE (m^3/s)	MINIMUM DAILY DISCHARGE (m^3/s)	TOTAL DISCHARGE (dam^3)	YEAR
1962	---	---	---	---	1962
1963	170 AT 20:00 AST ON MAY 1	127 ON MAY 2	1.19 ON AUG 4	472 000	1963
1964	181 AT 21:00 AST ON APR 15	144 ON APR 15	0.459 ON OCT 8	264 000	1964
1965	84.4 AT 03:00 AST ON APR 17	78.4 ON APR 17	0.207 ON AUG 8	244 000	1965
1966	92.6 AT 10:00 AST ON NOV 4	75.6 ON NOV 4	0.173 ON SEP 12	230 000	1966
1967	143 AT 01:00 AST ON MAY 13	107 ON MAY 10	0.538 ON SEP 22	345 000	1967
1968	104 AT 04:00 AST ON DEC 16	88.6 ON DEC 16	0.027 ON SEP 25	286 000	1968
1969	135 AT 02:00 AST ON DEC 12	106 ON DEC 12	0.680 ON SEP 6	357 000	1969
1970	776 B AT 11:45 AST ON FEB 4 *	456 B ON FEB 4 *	2.63 B ON MAR 15	463 000	1970
1971	110 AT 03:50 AST ON APR 15	100 ON APR 15	0.013 ON SEP 11 *	338 000	1971
1972	202 AT 19:55 AST ON MAY 4	142 ON MAY 4	0.513 ON SEP 26	450 000	1972
1973	416 AT 07:57 AST ON APR 29	289 ON APR 29	1.17 ON JUL 29	518 000	1973
1974	131 B AT 00:40 AST ON DEC 10	85.0B ON DEC 10	0.331 ON AUG 29	356 000	1974
1975	154 AT 11:43 AST ON NOV 14	118 ON NOV 14	0.176 ON SEP 3	316 000	1975
1976	123 AT 22:22 AST ON APR 3	101 ON APR 4	0.748 ON OCT 6	437 000	1976
1977	---	85.0B ON APR 2	0.433 ON SEP 13	409 000	1977
1978	96.6 AT 20:50 AST ON APR 21	90.3 ON APR 21	0.891 ON SEP 3	306 000	1978
1979	385 A ON MAR 26	343 A ON MAR 26	0.999 ON AUG 12	621 000	1979
MEAN				377 000	MEAN

A - MANUAL GAUGE (SEE REFERENCE INDEX) B - ICE CONDITIONS * - EXTREME RECORDED FOR THE PERIOD OF RECORD



GAUGING STATION

LATITUDE 45 40 25 N

LONGITUDE 66 40 58 W

DRAINAGE AREA 557km²

PERIOD OF RECORD 18 YEARS

MEAN FLOW 11.9m³/sec.

FLOW DISCHARGE CURVE
NORTHWEST OROMOCTO RIVER

FIGURE 2

Water Management Services Limited

near Fredericton Junction and Tracy often flood due to rising spring melt waters. Flooding at Blissville however is caused by ice jams at the confluence of Black Creek and the South Oromocto River. Flooding there can be severe with several feet of water crossing the highway. Many of the lakeshores and marshy areas adjacent to the river near the confluence of the Oromocto and St. John Rivers flood through normal spring runoff. Flood damage tends to be light as much of the land is agricultural.

Surface water quality measuring several parameters, is available for the Oromocto River, French and Yoho Lakes (Table 3). The value of pH ranges widely from 4.2 to 7.6, the lowest pH being found at the boat club at the mouth of the Oromocto River. Values tend to be higher than this over the rest of the watercourses and lakes. Water temperature varied considerably from lows of 4.9^{0} C at Yoho Lake to a high of 26.0^{0} C in the Oromocto River at Rusagonish. Average ranges were from 10.2 to 22.5^{0} C. Specific conductance in micromhos per centimetre gives high values at the mouth of the Oromocto River and in the Oromocto River at Snake Creek. These values can likely be attributed to groundwater discharge of more comparatively saline water.[8]

7.0 HYDROGEOLOGY

7.1 General

The basin displays no large distinct and identifiable aquifers, but is rather composed of a series of sandstones, siltstones and conglomerates of restricted areal occurence and thickness and which display, on a large scale, hydraulic continuity. The rocks of the basin vary both laterally and vertically often passing from one species to another over short distances. These continual and noticeable facies changes give the basin, in cross section, a lensic appearance. The deposition of sediments in rapidly changing alluvial, fluvial and deltaic continental conditions have resulted in the gross heterogeneity present throughout the subbasin. The lack of resulting areally extensive lithologic units with good water bearing capacities is compensated by extensive fracturing and faulting within the rocks. These faults and fractures may not be continuous over large distances but of themselves may connect to other fractures. The result of this is the realization of a

TABLE 3 PHYSICAL PARAMETERS, SURFACE WATERS, 1980*

Watercourse	Total Hardness (mg/l)	Total Dissolved Solids	pH	Dissolved Oxygen (mg/l)	Temperature (oC)	Specific Conductance (µmhos/cm)
Yoho Lake	6.0	-	6.2-6.8	0.4-12.0	4.9-24.0	23.
Oromocto River at Snake Creek	8.0	161.	6.0-6.7	7.0-10.2	8.0-20.0	100.
Oromocto Lake	-	-	6.4-6.7	8.9-11.6	10.-18.	23.
N. Rusagonis River	25.0	280.	6.6-7.6	9.0-13.0	10.5-21.0	80.
Oromocto River at Route 101	17.0	-	6.0-7.4	5.5-10.5	11.0-23.1	40.
Oromocto River at Fredericton Junction	14.0	-	5.9-7.2	4.8-11.4	12.0-22.9	34.
French Lake	9.0	-	5.9-6.7	8.5-13.2	7.0-24.9	35.
Oromocto River at Rusagonis	20.	-	6.2-7.8	7.0-12.0	16.0-26.0	43.
Oromocto River at Boat Club	12.4	-	4.2-6.7	6.0-9.2	12.0-22.5	160.

*Department of Environment, New Brunswick composite aquifer or aquifer complex relying more on interconnecting fracture permeability than on interformational permeability.

The sediments of the basin are surrounded and underlain by older metasediments and igneous rocks which generally exhibit lower permeabilties.

Water yields throughout the subbasin vary considerably from as little as 0.076 L/s to as much as 38 L/s. Domestic, industrial and municipal water development generally takes place in the upper 100 m of the bedrock or in the glacial and alluvial sands and gravels which spordically overlie the bedrock.

Data concerning water occurence and quality at depth (>500 m) is sparse and little detailed water levels information from specific depths is available. The Carboniferous Drilling Project however, together with geologic data from mineral exploration holes provided sufficient data to allow general determination of the operative flow systems, identification of major directions of flow, and recharge and discharge areas affecting the subbasin.

7.2 Flow Systems

It is usual to determine directions of flow by assessing and interpreting different water pressure heads in the bedrock formations throughout the subbasin and the basin edges. Gross data shows water levels in the metasediments and granites along the basin edges to lie from 150 m to 100 m geodetic while groundwater levels in the basin centre may occur at depths of 25 to 5 m geodetic. Water level data, to define in more detail the operative flow directions, is not available as habitation is sparse and widely distributed throughout the basin. Consequently few deep domestic wells exist while unfortunately, deep exploration holes provide little water information. What data is available, is generally applicable to depths of less than 100 m below ground surface. The definition of flow directions therefore has been obtained through interpretation of hydrochemical data.

Factors controlling the amount of dissolved solids content of ground water include physical controls such as the permeability and porosity of the rocks through which flow occurs and the dominant flow path. Chemical factors are the original chemical characteristics of the recharged water and the distribution, solubility and absorption capacity of the minerals within the rocks.

On the basis of the assumption that chemical equilibrium has not been attained between the water and the minerals and that an excess of soluble material is available, the dissolved solids content of the water increases and the chemical system tends to move closer to equilibrium as the flow path lengthens. A constant volume of water and a decrease in grain size of soluble material will result in a higher dissolved solids content along a particular flow path. An increase in concentration due to smaller grain size results from two different effects: (1) the smaller grains of any soluble material will go into solution more readily than coarse grains of the same material, and (2) the smaller grain size causes a decrease in permeability that requires a longer residence time to traverse the same flow distance. Therefore, in an area of fine-grained material containing abundant soluble minerals, we would expect the water to have higher dissolved-solids content closer to the recharge area than it would have in an area of coarser sediments containing less soluble material.[9]

Grain size does not vary substantially over the subbasin such that fine grained sediments predominate in recharge areas while coarser sediments occur in the discharge areas. Rather, throughout the basin both fine and coarse grained sediments occur interfingered, discontinuous and generally of limited areal extent. For the purposes of factors affecting the dissolved solids content of groundwaters the subbasin may be considered as an entire unit which on a gross scale has similar grain size distribution; is covered by similar overburden types; and displays similar permeability coefficients.

Furthermore, the fracturing and faulting creates a condition closer to an overall coarse grained condition than a fine grained condition.

Waters present in recharge areas therefore are likely to be low in dissolved solids while those towards or beneath discharge areas are likely to display higher dissolved solids.

The holes drilled for the Carboniferous Drilling Project provided sufficient data to enable a hydrochemical facies evaluation to be performed and to determine patterns of flow. Table 4 presents the chemical data used for this evaluation. A three dimensional construction of the subbasin has been drawn to show conductivity values, in micromhos per centimetre, and their spatial variation (Figure 3). Isoconcentration lines of 500, 1000 2000 are 3000 micromhos per centimetre were extrapolated. Low conductivity water is apparent throughout the basin; in the upper 60 m (200 feet); to depth at the head of the basin; and to depths along the northern basin edge. In the centre of the basin and beneath the St. John River conductivity values are much greater. The figure indicates therefore that generalized flow is from the west (head of the subbasin) to east (St. John River). Within the subbasin groundwater flow occurs in two major directions northeastwards and eastwards.

7.2.1 Northern Flow System

Water recharged along the northern basin boundary, and a portion of the water recharged at the head of the basin together with that recharged over the northern basin section, flow initially downwards, then eastwards to apparent discharge in the Fredericton area. Flow occurs through a zone which approximately parallels the northern subbasin edge and is bounded on the north by the Fredericton fault and on the south by the apparent down faulted contact of a graben (Figure 3). This latter boundary runs from just east of Oromocto Lake to an area south of Fredericton, and is defined by gravity differentials and lines of isoconcentration (Figure 4). The southern graben boundary appears to restrict the flow of groundwater and prevent easy passage across the boundary. This is shown by conductivity and hence total dissolved solids (TDS) values which are considerably different on either side of the apparent boundary. It is also possible that geological facies differences exist across the boundary due to the down faulting and that these exert influences on the conductivity of the groundwaters through the presence of higher proportions of soluable minerals.

The occurence of artesian conditions along the graben boundary

TABLE 4

WATER QUALITY ANALYSES OF TEST HOLES - COAL EXPLORATION PROGRAMME

THNO	DEPT	COND	PH	ALK	F	CL	K	NA	MN	CAD	MGO	SO4
268	200	160	8.7	64	0.32	17.0	12.00	28.0	0.21	8.2	1.20	6.6
268	400	2400	7.8	63	1.20	800.0	1.30	400.0	0.21	99.0	1.40	N.O
270	200	250	9.3	130	0.43	5.3	8.40	59.0	0.08	3.2	1.10	11.0
270	385	240	9.3	130	0.43	2.8	1.70	59.0	0.04	3.5	0.52	9.0
282	200	90	7.8	18	0.10	7.3	2.70	4.5	0.35	8.1	1.90	9.0
282	401	150	7.8	34	0.34	12.0	4.90	19.0	0.28	7.7	1.70	21.0
283	200	1000	8.9	120	0.88	420.0	7.80	220.0	0.25	5.5	0.35	21.0
283	400	6200	7.8	48	0.74	2800.0	14.00	1200.0	0.68	240.0	7.50	4.1
284	200	330	8.8	140	0.62	14.0	2.00	84.0	0.07	5.1	0.23	29.0
284	400	1000	8.4	120	0.66	270.0	0.62	180.0	0.18	47.0	0.67	26.0
285	200	530	8.5	220	0.19	31.0	1.30	120.0	0.07	9.2	1.40	18.0
285	400	2400	8.2	100	1.30	1200.0	1.40	450.0	0.19	35.0	0.86	4.2
286	200	650	9.0	150	5.00	120.0	25.00	150.0	0.20	6.2	0.29	85.0
286	400	670	8.9	140	4.60	110.0	5.70	150.0	0.08	4.0	0.25	42.0
287	200	230	8.6	130	0.32	16.0	10.00	44.0	1.60	29.0	1.00	22.0
287	400	210	8.5	100	0.64	32.0	2.60	45.0	1.10	21.0	0.81	19.0
293	200	2600	8.1	130	0.32	140.0	1.40	9.8	0.77	41.0	5.50	15.0
293	400	290	8.2	130	0.26	12.0	1.80	34.0	0.41	30.0	3.00	21.0
294	200	2000	8.4	100	2.10	870.0	7.20	430.0	0.28	17.0	1.40	220.0
294	400	3200	8.4	82	2.00	1200.0	5.40	720.0	0.14	29.0	2.10	470.0
296	200	290	9.2	110	1.20	22.0	26.00	58.0	0.41	5.9	0.64	36.0
296	400	1000	8.9	100	1.60	240.0	2.60	210.0	0.06	9.9	0.33	30.0
297	200	550	8.3	110	0.26	98.0	1.30	97.0	0.19	19.0	0.66	26.0
297	375	590	8.3	110	0.30	130.0	1.10	100.0	0.17	19.0	0.65	32.0
298	200	190	9.0	110	0.58	31.0	25.00	38.0	1.10	17.0	0.78	24.0
298	400	200	8.7	79	1.50	88.0	3.60	130.0	0.31	12.0	0.32	130.0
299	200	310	8.7	120	0.36	4.8	13.00	71.0	0.18	5.1	0.46	35.0
299	400	320	8.3	120	0.80	9.8	0.71	57.0	0.13	13.0	1.10	37.0
300	200	61	6.2	15	0.10	7.6	1.40	5.8	0.16	5.2	0.99	6.0
300	400	87	6.3	29	0.10	7.8	1.70	6.3	0.73	15.0	0.96	4.0
303	200	460	8.8	120	2.00	19.0	15.00	82.0	0.80	17.0	0.86	140.0
303	400	900	8.4	70	1.90	320.0	8.00	170.0	0.11	22.0	1.00	270.0
305	200	180	8.5	86	0.17	6.2	1.60	15.0	0.09	24.0	1.50	8.0
305	400	200	8.4	88	1.30	9.8	2.00	31.0	0.06	13.0	0.73	13.0
306	200	260	9.0	110	0.13	4.0	7.60	67.0	0.16	2.5	0.26	42.0
306	372	260	8.4	110	0.26	8.3	0.68	54.0	0.10	14.0	0.90	33.0

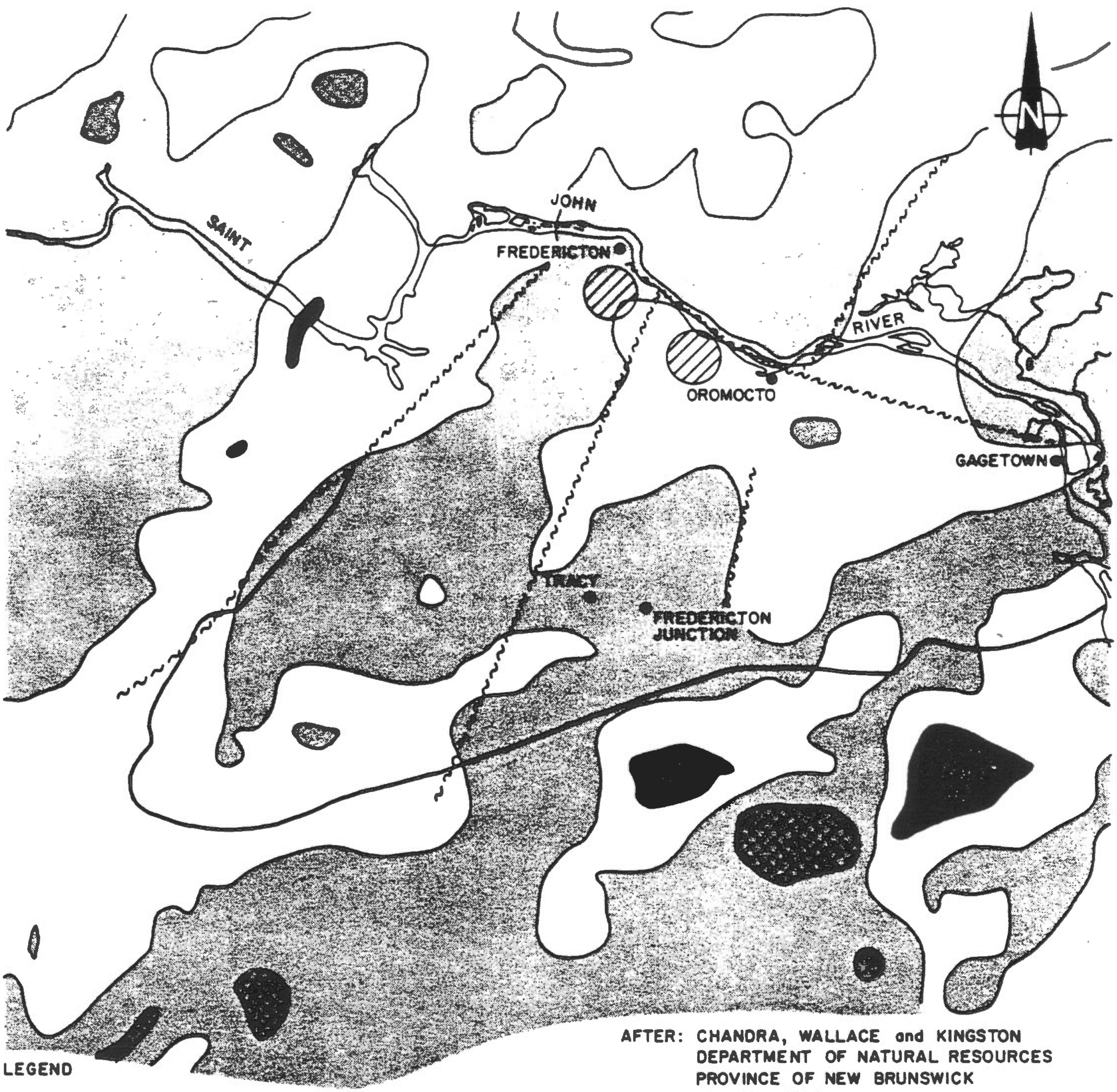
TABLE 4
CON'T

THNO	DEPT	COND	PH	ALK	F	CL	K	NA	MN	CAD	MGO	SO4
307	200	250	8.1	86	0.88	27.0	1.60	42.0	0.10	13.0	1.10	10.0
307	400	480	8.4	130	2.20	69.0	1.80	89.0	0.10	14.0	0.98	10.0
308	200	210	8.4	100	0.32	17.0	28.00	14.0	2.20	33.0	3.70	18.0
308	341	130	8.1	63	0.10	1.4	1.20	4.6	0.46	20.0	2.30	6.0
309	50											
309	200	120	8.2	70	0.10	1.8	0.85	8.8	0.20	22.0	2.00	12.0
309	304	140	7.7	66	0.10	2.8	0.77	8.3	0.21	21.0	1.80	11.0
1269	200	300	7.8	94	0.12	37.0	0.96	24.0	0.13	42.0	0.50	13.0
1269	200											
1269	200											
1269	400	440	7.7	100	0.12	87.0	0.92	27.0	0.24	65.0	4.90	13.0
1269	400											
1269	400											
1269	600	200	8.2	86	0.20	8.1	0.91	23.0	0.06	24.0	9.70	13.0
1269	600											
1269	600											
1269	800	350	7.8	96	0.25	78.0	2.00	33.0	0.17	50.0	2.40	14.0
1269	800											
1269	1000	480	7.9	31	0.26	110.0	1.20	52.0	0.14	51.0	0.50	13.0
1269	1000											
1304	600											
1304	750	1500	8.0	120	0.76	390.0	5.60	240.0	0.13	8.1	1.80	64.0
1304	800											
1304	800											
1304	850	1500	8.0	120	0.82	370.0	7.30	230.0	0.13	60.0	1.20	55.0
1304	950											
1304	966	1600	7.7	95	0.84	420.0	5.50	280.0	0.18	88.0	2.40	50.0

THNO - TEST HOLE NUMBER
DEPT - DEPTH
COND - CONDUCTIVITY
PH - PH
ALK - ALKALINITY
F - FLORIDE

CL - Chloride
K - POTASIUM
NA - SODIUM
MN - MANGANESE
CAO - CALCIUM
MGO - MAGNESIUM
SO4 - SULPHATE

All analyses are in MG/L except conductivity in microhms/ centimetre and PH in whole units.



AFTER: CHANDRA, WALLACE and KINGSTON
DEPARTMENT OF NATURAL RESOURCES
PROVINCE OF NEW BRUNSWICK
JANUARY 1980
PLATE 80-42

LEGEND

SCALE 1:500,000

APPROXIMATE CARBONIFEROUS SUBBASIN BOUNDARY

APPROXIMATE GRABEN BOUNDARY

-10 -5 0 5 10

Milligals

POTENTIAL TARGET AREAS FOR DEVELOPMENT

RESIDUAL GRAVITY
OF CARBONIFEROUS SUBBASIN

FIGURE 4

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further indicates a change in hydrogeologic conditions.

Vertical flow within the northern zone appears to be high as conductivities to a depth of 122 m (400 feet) in the Carboniferous Drilling Project boreholes, remained less than 260 micromhos per centimetre. The deep borehole at Fredericton, BH 1269, demonstrated conductivity to vary from 300 micromhos per centimetre at 61 m (200 ft) to a maximum of 400 micromhos per centimetre at 305 m (1000 ft.). From the chemical values available there does not appear to be a distinguishable and separate shallow and deep flow system. It is possible that deep waters in the northern zone are subjected to relatively rapid discharge through the basin, (along the graben fault or basement valley) thus inducing replacement water to penetrate to depth and preventing layering of water within the northern portion of the subbasin.

7.2.2 Southern Flow System

Recharge originating at the head of the basin and on the southern flanks follows a general path of flow eastwards towards the St. John River Valley. Geochemical data indicates a distinct transition with depth along the flow path, from waters having low conductivities in the upper parts of the basin to waters reaching conductivities of 5000 micromhos per centimetre and greater. Two flow systems within the northern basin zone are apparent, an upper or shallow system and a deeper or lower system.

The lower conductivities of the shallow system we considered to be influenced by two processes, continual recharge across and within the basin and relatively rapid flow through the upper bedrock zones. (Figure 3)

The deeper flow system appears characterized by relatively slow groundwater movement; penetration of recharge water to great depth; and apparent lack of easy discharge.

A portion of the water recharged at the head of the basin will descend only a short distance into the bedrock, less than 90 m (300 ft.), before flowing outwards. This shallow flow system is maintained across the basin to the apparent discharge in the area of St. John River. Additional recharge is received along the flow path through downward percolation of precipitation. The shallow flow system demonstrates low total dissolved solids and conductivities as much of the available soluble minerals have already been dissolved and groundwater flow is relatively rapid. The latter reduces groundwater residence time and hence contact time between the water and soluble minerals. Recharge to the deeper flow system is received at the head of the subbasin by continual descent of recharge water to depths greater than 90 m (300 ft.) and through downward migration of lower waters from the shallow flow system across the basin. Recharge to the subbasin will also result from deeper waters passing at depth from the adjacent metasediments and granites into subbasin.

A review of the conductivities shown in Figure 3 and the magnetic basement surface in Figure 5 demonstrates that basement surface highs are located beneath conductivity highs at the lower end of the basin, while the basement lows at the head of the basin correspond with conductivity lows. This structure is interpreted to indicate that recharge water descends, at the head of the basin, into the basement valley (low) where groundwater movement is slow, residence time is long and mineral-water equilibria occur. The resulting groundwater, comparatively higher in conductivity and hence TDS, is gradually pushed outwards towards the lower end of the basin by further recharging waters which themselves in turn become mineralised. These deep groundwaters cannot flow at depth through the basin due to comparatively impermeable basement rocks which rise steeply beneath the central part of the basin and present a barrier to flow. Consequently the mineralised waters appear to rise and overtop the basement high. This results in highly mineralised waters ascending and contaminating the lower portion of the shallow flow system beneath the lower basin.

This picture is further complicated by the many faults that cross the subbasin and by the basement topography. The most dominant feature of the basement topography is the northeast trending low (valley) which closely approximates the southern graben boundary. Smaller depressions in the basement surface are apparent in the central portion of the basin.

7.3 Recharge - Discharge Area

Recharging waters enter the basin via three pathways; recharge of precipitation fallen over the basin and seepage from influent surface waters; recharge of precipitation falling on the high ground surrounding the basin; and subsurface entry of groundwater from outside the basin.

No data are available on estimates of recharge occurring over the subbasin. Data are equally as sparse over the remainder of the larger central basin on the New Brunswick Platform. Well hydrographs from the flatter northern and eastern sections of the Pennsylvanian basin of the Province indicates that between 10 to 15 percent of total precipitation becomes permanent groundwater recharge. There, however, the bedrock is close to the ground surface and is highly weathered. Recharge therefore would likely be greater due to the lack of surface runoff and ease of penetration to the permanent groundwater table. This however, is not the case in the subbasin. For the subbasin a recharge of 8 percent of total precipitation is considered applicable. This figure gives a groundwater recharge quantity of $1.904 \times 10^9 m^3/yr$ or 4.52×10^6 m^3/day. This can also be taken as the discharge quantity across the St. John River boundary, a length 50 kilometres, if all groundwater discharge leave the subbasin by this route. Discharge therefore, is equivalent to 9.04 m^3/day per metre of lower basin boundary.

Using the Darcy formula Q=kIA, a permeability (k) of 7.5×10^{-2} cm/sec (100 gal/day/ft^2), a basin groundwater gradient (I) of 0.0035 and a unit aquifer thickness (A) of 305 m (1000 ft), a discharge (Q) of 5.22 m^3/day per metre of discharge boundary results. The difference in discharge quantities could be reflected in; greater thickness of bedrock through which discharge takes place; permeability differences with area and depth; steeper groundwater gradients; or loss of some discharging water through the southern basin boundary at depth and not through the lower basin boundary.

These numbers may also be interpreted to mean that a substantial amount of discharge takes place at depths greater than 305 m (1000 ft), thus indicating the potential for deep aquifers.

Discharge takes place from the shallow flow systems to adjacent surface waters. Some of the water in the shallow systems will penetrate deeper to join other recharged waters in intermediate and deep flow systems. These deeper systems flow under the influence of the regional hydraulic gradient towards discharge, a considerable distance from the point of recharge.

In the subbasin, intermediate and deep flow systems at the head of the basin receive waters from both downwards percolation of recharge waters, from high ground surrounding the basin and from transboundary waters at depth which pass from the Lower Paleozoic metasediments and granites into the Pennsylvanian sandstones, conglomerates and siltstones of the basin. These waters flow towards points at the lower end of the basin through initial vertical and later horizontal movement along flow paths operative in the deeper Pennsylvanian and Mississippian sediments. Geochemical facies analysis may indicate water descending deep into the basin +920 m (+3000 ft) in the area of Oromocto Lake may be forced back towards the surface closer to the point of discharge (ie high conductivities at shallow depths). Above these deeper waters pass the discharge waters of the intermediate flow systems. It is possible that rising deep waters will enter and mix with waters at shallow depths. The apparent basement highs aeromagnetically evidenced in the lower parts of the basin appear to contribute to the rise of deeper waters.

Actual discharge of these waters may not physically take place into surface waters but would more likely be discharged into adjacent basin(s) to join southward flowing systems which end with discharge to the sea in the Bay of Fundy.

7.4 Aquifer Definition

Permeabilities characteristic of the upper bedrock zones are likely to vary from 1.0 cm/sec (10^4 gal/day/ft^2) where faulting is extensive to 10^{-5} cm/sec (0.75 gal/day/ft^2) where small fractures and joints provide the main permeability. Permeabilities at depth are not known. Existing data is sparse and for the most part can only be inferred from geological evidence. Borehole cores from exploration holes, drilled at the head of the basin, into Mississippian sediments, indicate, through the high degree of apparent fracturing and disintegration of core, that permeabilities in the underlying Mississippian may be high ($>k=10^{-2}$ cm/sec (100 gal/day/ft^2). Some support is offered by experience in the Mississippian sediments of the salt subbasins presently being developed for potash. Flows of up to 150 L/s (2000 gal/min) have been recorded to depths of 610 m (2000 ft.) in fracture zones as wide as 330 ft (100 m). In these subbasins much of the fracturing is considered to be related to faulting activity in the area and post depositional salt tectonics. Although salt in abundant quantity is not expected to lie beneath the subbasin, faulting in both the Pennsylvanian and Mississippian sediments is evident. This faulting activity is related to the horst-graben structures apparent in the area, (Figures 3 and 4). These structures have been defined using gravity and aeromagnetic surveys on a large scale[10,11]. Few boreholes and little exploration data does not allow anything more than the major structures to be defined. Where additional geological information is available, as in the northern portion of the basin around Fredericton, more detailed fault definition has been attempted. It is likely that additional faults also exist in other basin areas, but are as yet undefined.

Aquifers, as defined, are strata containing exploitable quantities of water. To be exploitable the water must be extractable. Water can be contained within the rock itself or in the fractures penetrating the rock. Porous rocks such as sandstones and conglomerates often contain water within the rock in both primary spaces and in secondary spaces developed through solutioning. In order to assess the intrinsic permeability of the deep bedrock in the subbasin a number of samples taken from exploration borehole core were submitted to gas permeability analysis. The results of the analysis are presented in Table 5 while their stratigraphic relationship is given in Figure 6. In addition, a description of the samples is presented in Appendix 1. Of the forty two (42) samples tested only seven (7) gave permeabilities greater than 0.14 millidarcies (md). The highest values were recorded on core samples from Cominco #5 drilled in the Hopewell Group, west of Oromocto Lake. These values of 9.82 and 5.14 md were obtained from a subrounded to subangular pebble conglomerate. Porosity varied from 0.01% to the highest

TABLE 5

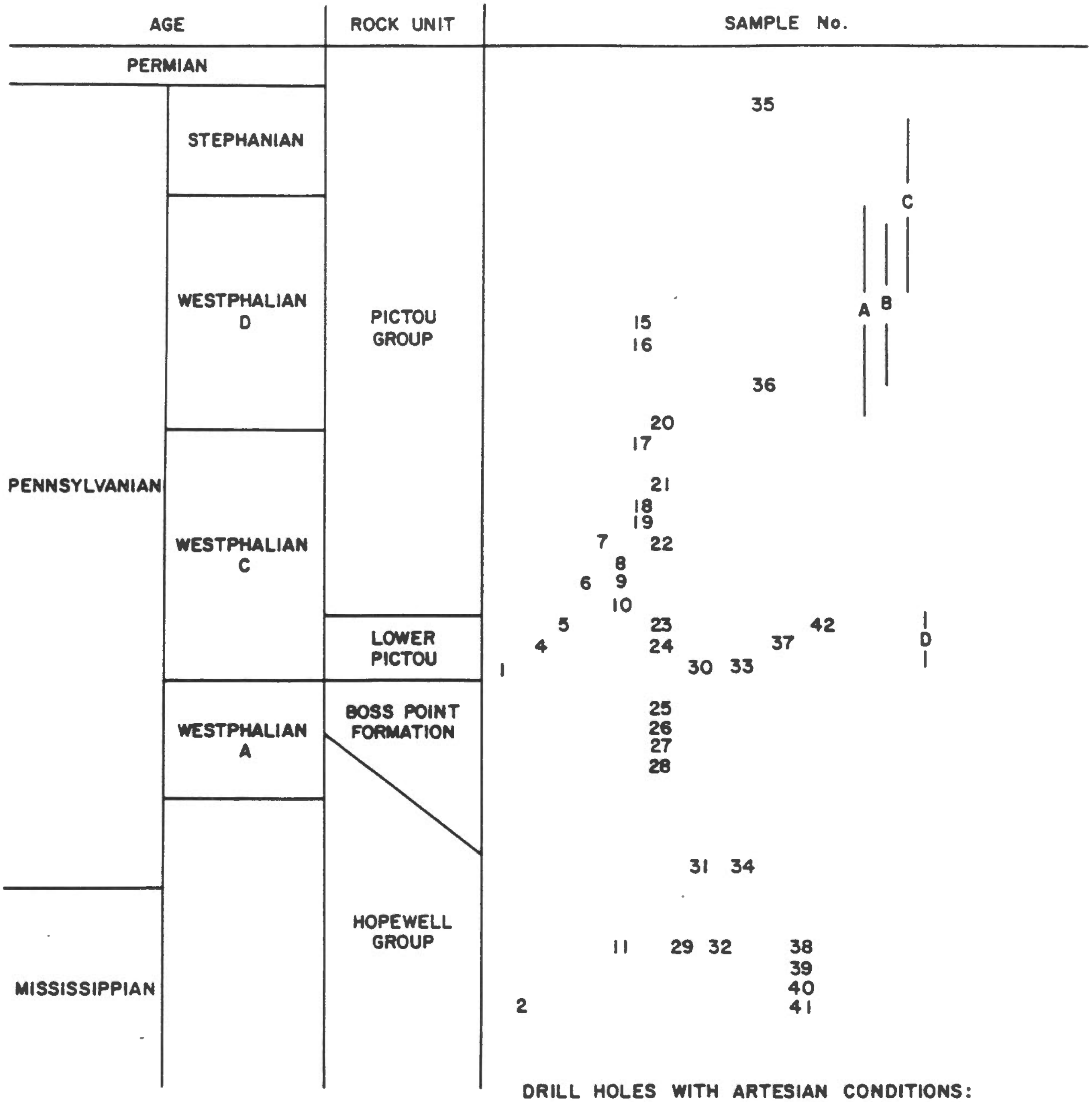
PERMEABILITY AND POROSITY OF SELECTED OUTCROP AND ROCK CORE SAMPLES

OUTCROP SAMPLES	PERMEABILITY TO AIR (md)	POROSITY (%)	GRAIN DENSITY (gm/cc)
1	0.01	3.7	2.69
2	N.P.A.	9.3	2.84
4	0.02	1.4	2.70
5	0.78	6.6	2.67
6	0.14	5.2	2.65
7	0.01	7.0	2.68
8	1.79	5.1	2.69
9	0.05	13.0	2.79
11	0.03	6.8	2.71
SERU-NUCLEAR S-1			
15	0.01	3.0	2.68
16	0.03	2.6	2.72
17	0.07	2.5	2.66
18	0.01	2.2	2.70
19	0.04	2.9	2.68
SERU-NUCLEAR S-2			
20	0.07	2.4	2.68
21	0.03	2.5	2.68
22	0.11	2.5	2.69
23	0.05	1.9	2.69
24	0.06	1.7	2.69
25	0.01	1.6	2.68
26	0.05	3.9	2.65
27	0.47	6.5	2.64
28	0.11	3.8	2.65
MARYSVILLE K-2			
35	0.08	4.4	2.66
36	0.04	3.7	2.66
IMPERIAL 1-3			
29	0.01	1.8	2.68
IMPERIAL 1-4			
30 GW	0.01	1.7	2.65
30 SS	0.01	2.1	2.70
31	2.64	6.1	2.69

TABLE 5
CON'T

	PERMEABILITY TO AIR (md)	POROSITY (%)	GRAIN DENSITY (gm/cc)
IMPERIAL 1-7			
32	0.01	1.2	2.64
33	1.79	4.5	2.69
34	0.02	3.0	2.64
COMINCO OL C-2			
37	0.02	2.2	2.67
COMINCO OL C-5			
38	9.82	5.6	2.66
39	5.14	5.3	2.66
COMINCO OL C-8			
40	0.01	0.9	2.71
41	0.01	1.1	2.71
COMINCO OL C-12			
42	0.01	2.5	2.72

N.P.A. - no permeability measurement was possible due to fractured nature of sample



DRILL HOLES WITH ARTESIAN CONDITIONS:

A SERU NUCLEAIRE S-3
B SERU NUCLEAIRE S-4
C SERU NUCLEAIRE S-5
D COMINCO C-1

RELATIVE STRATIGRAPHIC AGE
OF OUTCROP AND BOREHOLE SAMPLES

FIGURE 6

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value of 13.0% with an average of 3.4%. High porosities and permeabilities did not however correspond, thus indicating that pores within the rocks samples are not generally connected. This may indicate little post depositional rock alteration such as solution effects.

The analysis of random Pennsylvanian and Mississippian strata indicates intrinsic permeability to be negligible for the purposes of locating geothermal water sources.

In the remainder of the central Carboniferous basin, which covers much of the eastern part of the Province, secondary (fracture) permeability is the major reason for high permeability coefficients. Little data is available for the subbasin due to the lack of major water supply development. It is expected however, that fracturing and faulting is equally as common in the subbasin sediments as in the remainder of the basin.

Inspection of exploration borehole cores from the Oromocto Lake area drilled in Mississippian sediments indicated the presence of extensive fracturing in red shales and siltstones at depths greater than 100 m. The zones over which fracturing occured were greater than 10 m in length.

The quantities of discharging groundwater estimated for the subbasin could not pass through the bedrock with the intrinsic permeabilities found for the rock samples tested. Permeabilities in the range of 10^{-2} cm/sec (100 gal/day/ft^2) are necessary to allow the discharges calculated.

Storage coefficients in the subbasin are expected to vary from 0.001 to 0.1. Although no direct evidence is available for these numbers, comparison of the rock types and fracturing in the subbasin to the main basin provides a basis of estimation.

8.0 HYDROGEOCHEMISTRY

The chemistry of the groundwaters in the subbasin is only known with any degree of understanding for depths up to 120 m (400 ft). The 23 holes drilled for the Carboniferous Coal Exploration Programme in the subbasin provided data on water quality at 61 m (200 ft) and the 122 m (400 ft) depths. Two holes drilled to 305 m (1000 ft) at Fredericton and Tracy provide additional data for deeper water quality. It was hoped to obtain additional water quality data from depths greater than 300 m in the Seru Nuclear exploration borehole on Hanwell Road. Two attempts were made to obtain water samples from depth, however blockages in the borehole prevented this.

Hydrochemically the subbasin can be divided into two areas each with distinct chemical characteristics. These two divisions correspond to the area north of the southernmost boundary of the Fredericton graben and the area south of the same boundary. Conductivity values in the northern section range from 61 to 600 micromhos/centimetre with an average value of 234.5 micromhos/centimetre. The average in the southern section is 1312 micromhos/centimetre with a range of 90 to 6200 micromhos/centimetre (Table 5). pH values throughout the basin indicated the groundwaters to be strongly alkaline with an average value of 8.46. The highest value recorded was in borehole 270 at 9.3 while the lowest was 6.2 found in borehole 300. This was the only well to demonstrate a value less then 7.7. Little fluctuation was demonstrated by magnesium which gave a total range of 0.26 to 9.7 mg/L, attesting to the lack of magnesium bearing sedimentary rocks in the subbasin. Calcium, unlike magnesium ranged from 2.5 to 240.0 mg/L. Higher values for calcium tended to be located in boreholes in the southern section of the basin. The other major cations, sodium and potassium, also demonstrated considerable fluctuation for groundwaters. Sodium ranged from 4.5 to 1200 mg/L; again the higher values tending to be found in the southern section of the basin. Potassium however demonstrated high values in both sections, (Borehole 308 - 28.0 mg/L and borehole 296 - 26 mg/L) the total range being 0.62 to 28.00 mg/L.

Of the anions the greatest variance was demonstrated by chloride (1.4 to 2800 mg/L). Sulphate however, generally showed a less range of values. Three boreholes, 294, 298 and 303 gave values greater than 100 mg/L while the range in the remaining 18 boreholes was 6.0 to 85.0 mg/L.

The remaining parameters tested, fluoride and manganese, gave ranges of 0.1 to 5.0 mg/L and 0.04 to 2.1 mg/L respectively. These values are considered normal for the subbasin and general groundwaters across the main sedimentary basin.

Two 303 m holes (1000 ft) were drilled in the basin and thus allow some insight into chemical composition of water at deeper horizons. Water at depth in borehole 1269 was relatively low in dissolved solids. Conductivities ranged from 200 micromhos/centimetre at 61 m (200 ft) to 480 micromhos/centimetre at 303 m (1000 ft). All major ions also reflect low values. In comparison borehole 1304 demonstrates waters at depth much higher in total dissolved solids and hence conductivity. It is interesting to note that the approximate boundary of the Fredericton graben appears to seperate these two holes.

Unfortunately no chemical data is available for deep waters (>400 m) within the basin. The chemical characteristics of those waters however, may be to some degree inferred from shallow data. It is expected the deep waters would be characterized by high conductivity (>7,500 micromhos/centimetre) while chloride and sodium values are likely to be greater than 3000 and 1500 mg/L respectively.

9.0 GEOTHERMAL POTENTIAL

The basin structure demonstrates it to be steep sided containing several thousand metres both of coarse and fine grained sediments in near horizontally bedded sedimentary strata, which within parts of the major basin are highly permeable and flanked by potentially heat generating rock species.

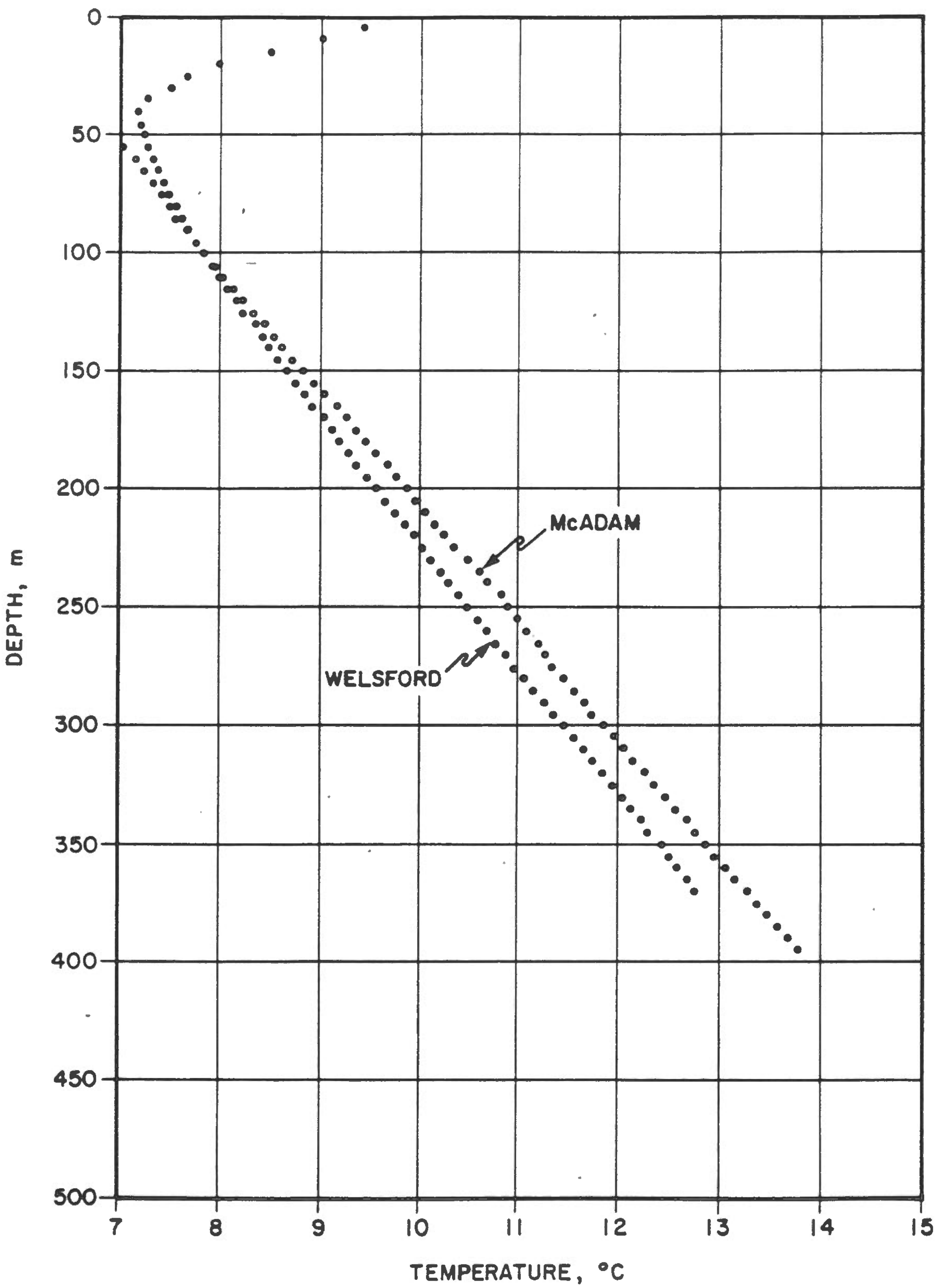
The energy tapped through geothermal development is produced in the main by the decay of various radioactive elements contained within intrusive rocks and to some degree through heat provided by conduction from greater depths.

The subbasin is downfaulted in multiphase acidic intrusions which may range in age from Devonian to Carboniferous. To the north of the basin lies the Pokiok batholith while the St. George granite mass flanks the basin to the south. Aeromagnetic and gravity surveys have indicated that intrusive rocks lie beneath and in the central part of the subbasin. This may mean that the two granite masses are connected beneath the basin. These together with extrusive Mississippian rocks seen at the basin edges and intrusives expected at depth, may provide the required source of heat.

In the fall of 1982 a deep hole was drilled in both flanking granite masses. The temperature gradients measured at McAdam in the Pokiok granite was 18° C while in the St. George granite at Welsford a similar gradient was found (Figure 7). These low gradients may be explained by a general lack of radioactive minerals, possibly leached out to depth, within the granite masses or the presence of relatively small amounts of such minerals as a veneer over the granite masses. While gradients in the granites are low, those obtained from three deep holes in the subbasin at Tracy, Fredericton and Hanwell Road suggest higher gradients are available in the adjacent subbasin (Figure 8).

All gradients measured fluctuated strongly at near surface depths reflecting the movement of recharging waters and seasonal climatic changes. At depths of 75 m and greater, gradients appear to increase more gradually. Boreholes at Tracy and Fredericton each gave an average gradient of 26.5° C/km while the Seru Nuclear exploration hole recently logged on the Hanwell Road gave a gradient that measured 25°C/km to a depth of approximately 200 m and 27° C/km to the lowest logging point at 300 m. This is the deepest hole to be logged in the subbasin so it is possible that deeper flow systems bearing hotter waters (27° C/km) are present at depth and are separated by confining layers from shallow systems (25° C/km). This change in gradient may also be explained by the possible upward mobilization of deeper waters under high hydrostatic head. The total depth of the exploration hole was 800 m. Unfortunately due to a blockage, the hole could not be logged beyond 300 m. This blockage may not however have prevented deeper waters from moving up the hole from the depth.

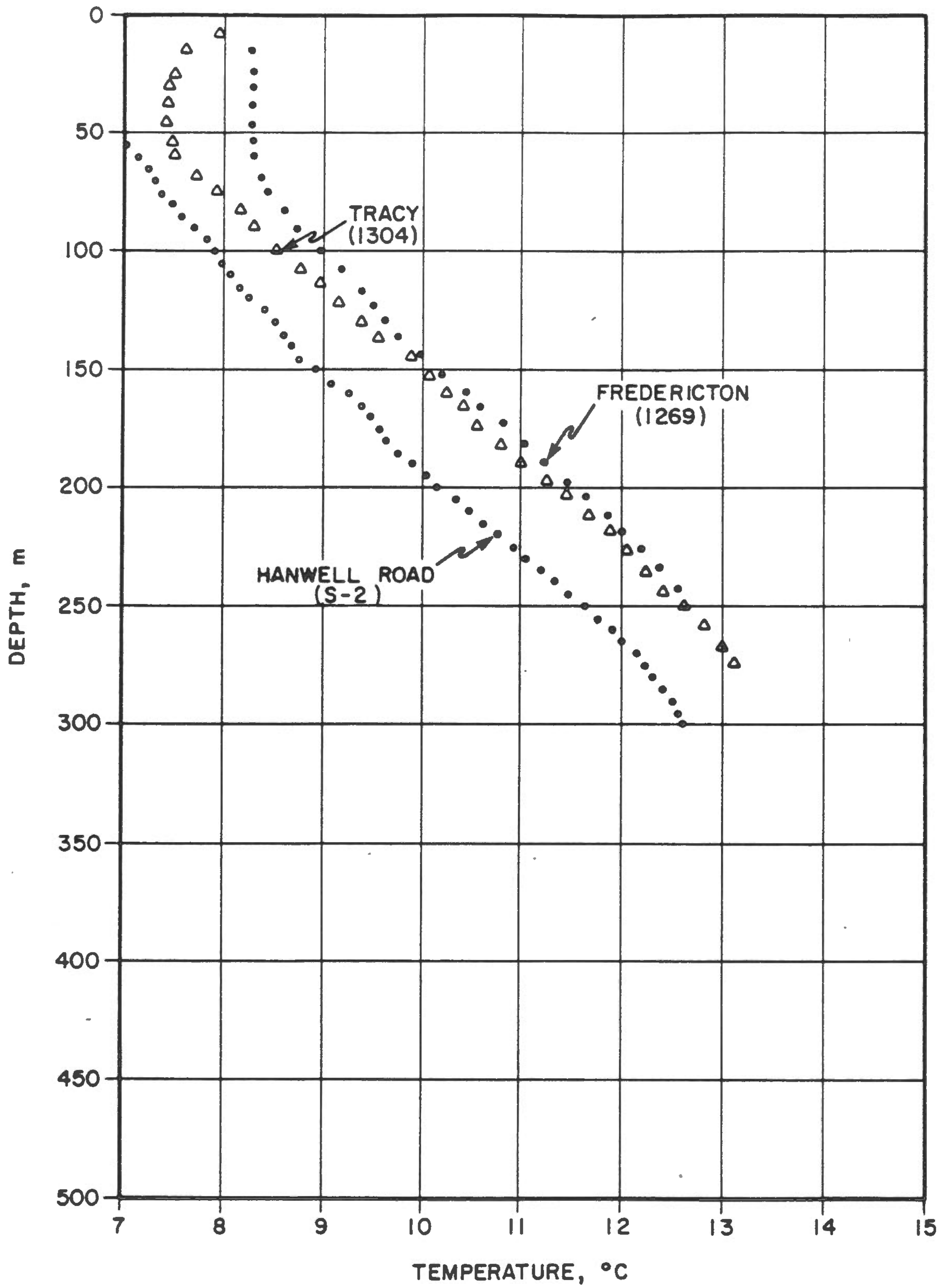
Further evidence of a potential heat source is given by coal rank data available for the entire basin. Investigations on several European coal basins has demonstrated that in bituminous coals the increase in rank is the result



TEMPERATURE LOGS
OF BOREHOLES AT
McADAM AND WELSFORD

FIGURE 7

Water Management Services Limited



TEMPERATURE LOGS OF BOREHOLES AT FREDERICTON, TRACY AND HANWELL ROAD

FIGURE 8

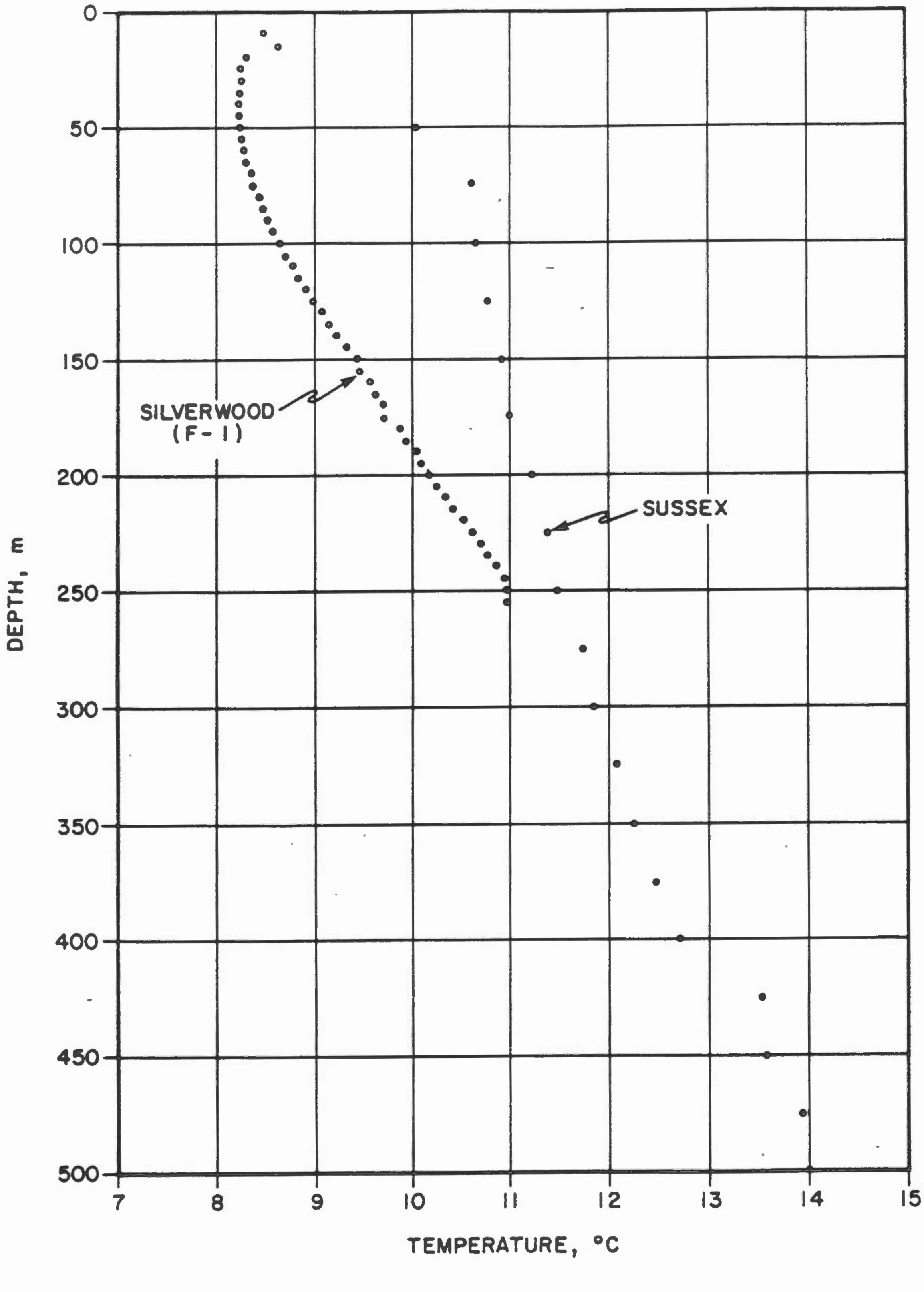
Water Management Services Limited

of increasing rock temperatures and other factors rather than solely through pressure caused by tectonic disturbance or overburden loading[12]. These changes in rank are related to heat transfer through the rock and may be related to heat sources that are no longer active.

Across the Carboniferous basin computer drawn vitrinite isoreflectance contours indicate a general increase in rank from high volatile bituminous coals at the coast to anthracites in the west. Hacquebard and Avery further suggest that the increase in rank from Minto to the apex of the basin (Oromocto Lake) cannot simply be explained by corresponding rock age and hence progressive depth of burial but must rely on other factors to produce such increases. They suggest that this rank increase can be explained by the presence at depth, within the basin, of intrusive hot rocks, although some coalification effects would have resulted from tectonic stress generated by movement along the Hanwell fault. It is interesting to note that the highest gradient (27^{0} C/km) is recorded in the same hole (Seru Nucleaire) from which the coal specimens came.

Although these rank charges reflect old (poleo) heat source they can be used to produce a paleogeothermal gradient. Hacquebard and Donaldson gave several deduced gradients for the Atlantic region[13]. These range from 22^{0} C/km from Stellarton coals to 25.6^{0} C/km at Bouctouche, and 29.4^{0} C/km at Marysville, which lies just east of Fredericton.

Temperature logging was also undertaken on a 250 m hole at Silverwood located just west of Fredericton (Figure 9). The hole is drilled in Silurian Ordovician slates, approximately a mile outside of the subbasin. Additionally, a temperature log of a borehole drilled in sediments of the Mississippian subbasin, south of the main basin, is also given. The gradient recorded at Silverwood was 16^{0} C/km, while in the Mississippian sediments was 8^{0} C/km to a depth of 400 m and 16^{0} C/km to 475 m. These two temperature logs serve to indicate the localized nature of the heat source beneath and in the basin.



TEMPERATURE LOGS
OF BOREHOLES AT
SILVERWOOD AND SUSSEX, N.B.

FIGURE 9

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10.0 POTENTIAL AQUIFERS AND DRILL SITES FOR DEVELOPMENT

Consideration of the evidence obtained from hydrogeological and hydrogeochemical assessment indicates that potential target aquifers are likely to be found at depth in the subbasin. With geothermal gradients of 26 to 27^{0} C/km, a depth of approximately 2.5 kilometres would be necessary for 60^{0} or greater temperature water. Such depths may intersect Lower Pennsylvanian or Mississippian sediments or basement, depending upon the location. Yields of up to 40 L/s could be expected in these sediments. Flow would be predominantly in fractures and faults and possibly produce artesian flows at the surface. The depth to obtain 60^{0} C water could be shallower than 2.5 kilometres should it be possible to intersect faults or fractures which are connected at depth, due to the presence of the graben feature or major faults in the basin. Gradients may also be higher at shallower depths than presently apparent.

Thermal gradients across the basin are not well defined as two of the holes temperature logged lie in the Fredericton area while the other is found at Tracy. These three holes appear to lie close to the approximate location of the southern boundary of the Fredericton graben, although at opposite ends of the structure. No other data is available for the subbasin.

Potential recommended drill sites are shown on Figure 5. These have been chosen with regard to several assumptions and the data presented in the report.

- Aeromagnetic data indicates projected basement depth is shallow at the lower end of the basin.

- Geochemical data indicates that hotter water from the deeper parts of the basin appears to rise at the lower end of the basin to discharge over the basement high in that same area.

Areas within the basin demonstrating geothermal anomalies cannot be interpolated from these existing data excepting that area encompassing the

Fredericton graben. We have therefore recommended potential drill sites that will; allow a more accurate definition of subbasin thermal gradient anomalies; allow a more knowledgeable decision on the commencement and location of a deep (>1.5 km) hole; and confirm the potential of deeper sediments to provide the necessary water flows for geothermal development. Such drilling would also allow the water chemistry from depth to be determined.

Two drill holes are recommended, each 500 m deep, situated at either side of the graben boundary. The first target area is located at Fredericton, close to several potential users, such as the new Federal-Provincial Ranger School, new RCMP "J" Division Headquarters, Regent Mall and City of Fredericton service garage and depot. Present indications are that water with low T.D.S. is present to a depth of 300 m. Should this be present to greater depths and the gradient be confirmed or shown to be higher, then the site would have high potential for future development.

The second target area is at Oromocto where CFB Gagetown, Fredericton airport and the Town of Oromocto could be classed as potential users. A hole in this area will allow the possibility of the rise of deeper hotter water over the basement high present at the lower end of the basin, to be assessed. Such a potential raises the prospect of a shallow production well to obtain the high temperature water required.

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APPENDIX I

GEOLOGICAL DESCRIPTION OF OUTCROP AND BOREHOLE CORE SAMPLES

Outcrop Samples:

#1 Route 3, Longs Creek to Harvey
- green medium grained sandstone; platey fracture (1-3" plates)

#2 Route 3, Harvey to York Mills
- maroon polymictic pebble to cobble conglomerate

#4 Tweedside
- polymictic pebble conglomerate, quartz rich, tight, hard, green matrix

#5 Route 640, Hurley Corner
- polymictic pebble conglomerate
- paleochannel deposit as evidenced by presence of coalified plant fragments, some replaced by pyrite

#6 Little Lake Road
- interbedded green coarse grained sandstone and polymictic conglomerate; portions with increased quartz content

#7 Blissville-Mt. Pleasant Road
- medium grained green lithic sandstone

#8 Route 7, Geary-Petersville Hill
- polymictic pebble conglomerate, grey matrix interbedded with tight medium grained grey sandstone; 20 centimetre thick beds
- primary permeability likely poor; secondary permeability likely much better given bedding related fractures

#9 Route 7, Geary-Petersville Hill
- very coarse grained sandstone to polymictic conglomerate
- apparent primary porosity given penetration of weathering effect into the outcrop

#10 Route 7, Geary-Petersville Hill
- underlies #9
- interbedded very coarse grained sandstone and conglomerate
- portions exhibit pronounced decomposition due to compositional based preferential weathering

#11 Route 7, Geary-Petersville Hill
- red fine to medium grained cross-bedded sandstone lenses with red shale and fine grained sandstone; cross-beds approximately 0.3-0.5 metres in section

Diamond Drill Core Samples:

#15 Seru Nuclear Fred. #1 (S-1)
461.4-461.5 metres
- pebble conglomerate

#16 Seru Nuclear Fred. #1 (S-1)
480.4-480.52 metres
- very coarse grained sandstone to pebble conglomerate

#17 Seru Nuclear Fred. #1 (S-1)
662.2-662.3 metres
- light red very coarse grained sandstone

#18 Seru Nuclear Fred. #1 (S-1)
785.82-785.92 metres
- dark red to brown very coarse grained sandstone

#19 Seru Nuclear Fred. #1 (S-1)
799.4-799.5 metres
- grey very coarse grained sandstone to conglomerate

#20 Seru Nuclear Fred. #2 (S-2)
599.8-599.9 metres
- light red conglomerate

#21 Seru Nuclear Fred. #2 (S-2)
708.7-708.75 metres
- light red coarse to very coarse grained sandstone

#22 Seru Nuclear Fred. #2 (S-2)
809.95-810.05 metres
- light red conglomerate

#23 Seru Nuclear Fred. #2 (S-2)
928.6-928.7 metres
- light grey conglomerate

#24 Seru Nuclear Fred. #2 (S-2)
986.45-986.55 metres
- light grey coarse to very coarse grained sandstone
- banding expressed as fine grained beds (≅0.25 cm)

#25 Seru Nuclear Fred. #2 (S-2)
1062.8-1062.9 metres
- very light grey to white medium to coarse grained quartzose sandstone

#26 Seru Nuclear Fred. #2 (S-2)
1080.1-1080.2 metres
- white coarse grained quartzose sandstone

#27 Seru Nuclear Fred. #2 (S-2)
1081.5-1081.6 metres
- white very coarse grained quartzose sandstone

#28 Seru Nuclear Fred. #2 (S-2)
1099.95-1100.0 metres
- white medium to coarse grained quartzose sandstone

#29 Imperial Frog Lake #3 (I-3)
59.89-60.05 metres
- mottled red and light grey conglomerate

#30 Imperial Frog Lake #4 (I-4)
35.20-35.36 metres
- medium grained grey sandstone

#31 Imperial Frog Lake #4 (I-4)
115.47-115.6 metres
- mottled red and white conglomerate

#32 Imperial Frog Lake #5 (I-5)
39.32-39.47 metres
- white, medium to coarse grained sandstone

#33 Imperial Frog Lake #7 (I-7)
110.00-110.15 metres
- white, medium to coarse grained sandstone

#34 Imperial Frog Lake #7 (I-7)
119.18-119.33 metres
- conglomerate

#35 Killarney Gas and Oil Marysville #2 (K-2)
628.65-628.50 metres
- fine to medium grained grey sandstone

#36 Killarney Gas and Oil Marysville #2 (K-2)
635.51-635.66 metres
- fine to medium grained white sandstone

#37 Cominco Oromocto Lake #2 (C-2)
57 metres
- light grey to white medium to coarse grained sandstone

#38 Cominco Oromocto Lake #5 (C-5)
21.60-21.65 metres
- red and white conglomerate; red colouration due to red shale fragments

#39 Cominco Oromocto Lake #5 (C-5)
41.8 metres
- as #38

#40 Cominco Oromocto Lake #8 (C-8)
56.5 metres
- light red fine to medium grained sandstone

#41 Cominco Oromocto Lake #8 (C-8)
38.0 metres
- light red and white conglomerate

#42 Cominco Oromocto Lake #12 (C-12)
16.75 metres
- grey medium grained sandstone