Geological Survey of Canada
Commission géologique du Canada

BULLETIN 380

UPPER PALEOZOIC EVAPORITES OF SOUTHEASTERN CANADA

Robert D. Howie

Canada

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Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

Available in Canada through

authorized bookstore agents and other bookstores

or by mail from

Canadian Government Publishing Centre
Supply and Services Canada
Ottawa, Canada K1A 0S9

and from

Geological Survey of Canada offices:

601 Booth Street
Ottawa, Canada K1A 0E8

3303-33rd Street N.W
Calgary, Alberta T2L 2A7

A deposit copy of this publication is also available
for reference in public libraries across Canada

Cat. No. M42-380E — Canada: $8.00
ISBN 0-660-12777-6 — Other countries: $9.00
Price subject to change without notice

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Original manuscript submitted — 1986-05
Final version approved for publication — 1987-07.

Preface

The evaporite deposits of Atlantic Canada have been known for many years and have been mined for both salt and potash. The evaporites were deposited on folded and faulted Lower Paleozoic rocks in a series of basins during two extended intervals of Late Paleozoic time.

This report presents the results of a study undertaken to help assess the feasibility of mining some of the undeveloped deposits and also to evaluate their potential for underground storage of hydrocarbons or industrial wastes. The author provides a regional synthesis of the deposits, describing 28 areas by means of text, cross-sections, and geological and geophysical maps. The bulletin concludes with a breif description of the mechanics of salt flow with reference to the salt of the Windsor Group of Atlantic Canada.

R.A. Price
Assistant Deputy Minister
Geological Survey of Canada

Préface

Les gisements d'évaporites de l'Atlantique canadien sont connus depuis plusieurs années et ont été exploités pour le sel et la potasse qu'ils contiennent. Les évaporites ont été déposées sur des formations plissées et faillées du Paléozoïque inférieur dans une série de bassins au cours de deux intervalles étendus qui se situent chronologiquement à la fin du Paléozoïque.

Ce travail de recherche présente les résultats d'une étude entreprise dans le but d'aider à l'exploitation minière de gisements pas encore suffisamment exploités et aussi pour l'évaluation du potentiel de stockage souterrain d'hydrocarbures ou de déchets industriels. L'auteur fait une synthèse régionale des gisements, il décrit vingt-huit régions au moyen du texte, de coupes et de cartes géologiques et géophysiques. Cet ouvrage se termine avec une brève description de la mécanique d'écoulement du sel en se référant au sel du groupe de Windsor de l'Atlantique canadien.

R.A. Price, sous-ministre adjoint
Commission géologique du Canada

CONTENTS

UPPER PALEOZOIC EVAPORITES OF SOUTHEASTERN CANADA

Abstract

The Paleozoic fold belt in Atlantic Canada forms the northeastern part of the Appalachian region of North America. During the waning stages of the Middle Paleozoic Acadian orogeny, folding, faulting, uplift and granitic intrusion occurred. The highly fractured basement subsided forming a complex series of northeast-trending horst and graben structures. In this area of regional downwarp, evaporite deposits of two ages were deposited. Minor salt deposits containing glauberite accumulated locally and are preserved as part of continental sequences in Horton Group rocks of late Tournaisian to possibly early Viséan age. The overlying Windsor Group (middle to late Viséan age) contains thick deposits of salt, and is the only Late Paleozoic marine sequence in southeastern Canada.

The Horton Group evaporites are interpreted as local playa lake deposits. Exploratory drilling has confirmed the occurrence of these evaporites in four different areas, but the deposits are not considered to be of economic importance.

Temporary tectonic stability, abnormally high temperatures, a nearly land- locked marine setting and semiarid conditions resulted in the rhythmic deposition of Windsor Group evaporites over a wide area. The Windsor Group evaporites, preserved as outliers in New Brunswick and Nova Scotia and in a northeast- trending basin beneath the Gulf of St. Lawrence, are erosional remnants of a much larger evaporite basin. The salt occurs as bedded deposits or within flow structures that vary in thickness from a few centimetres to over 4573 m in structurally thickened sections. The variation in local thickness of these rocks is a function of both environment of deposition and tectonism. In some areas the salt is pure enough to be mined and, locally, contains significant amounts of potash. Some of these mines have the potential for development of underground storage sites for hydrocarbons and industrial waste.

Résumé

La zone orogénique du Paléozoïque de l'Atlantique au Canada forme la partie nord-est de la région des Appalaches en Amérique du Nord. Pendant les derniers stades de l'orogenèse acadienne du Paléozoïque moyen, il s'est produit des plissements, des failles, des soulèvements et des intrusions granitiques. Le socle très fracturé s'est enfoncé en formant une série complexe de structures en horst et graben orientées vers le nord-est. Dans cette zone de fléchissement régional, se sont déposés des gisements d'évaporites des deux âges. De petits gisements de sel contenant de la glaubérite se sont accumulés localement et ont été préservés en tant que partie de successions continentales dans les roches du groupe de Horton du Tournaisien supérieur jusqu'à probablement le Viséen inférieur. Le groupe de Windsor (du Viséen moyen à supérieur) qui les recouvre, contient d'épais gisements de sel et c'est la seule succession marine du Paléozoïque supérieur dans le sud-est du Canada.

Les évaporites du groupe de Horton seraient des gisements locaux de lacs temporaires. Un forage d'exploration a confirmé la présence de ces évaporites dans quatre régions différentes, mais les gisements ne sont pas considérés comme rentables.

Une stabilité tectonique temporaire, des températures anormalement élevées, une configuration semblable à celle d'une mer intérieure et des conditions semi-arides ont eu pour résultat le dépôt rythmique des évaporites du groupe de Windsor sur une vaste région. Les évaporites du groupe de Windsor, conservées sous forme de lambeaux de recouvrement au Nouveau-Brunswick et en Nouvelle-Écosse et dans un bassin orienté vers le nord-est au-dessous du golfe Saint-Laurent sont des restes d'érosion d'un bassin d'évaporites beaucoup plus grand. Le sel se présente sous forme de dépôts lités ou dans des structures d'écoulement dont l'épaisseur varie de quelques centimètres à plus de 4 573 m dans les sections épaissies structuralement. La variation de l'épaisseur locale de ces roches dépend à la fois de l'environnement du gisement et du tectonisme. Par endroits, le sel est suffisamment pur pour être exploité localement et contient des quantités importantes de potasse. Quelques-unes de ces mines pourraient servir de sites de stockage souterrains pour des hydrocarbures et des déchets industriels.

SUMMARY

Near the close of Horton sedimentation, late Tournaisian age salt was deposited as part of a playa lake sequence in at least two locations in New Brunswick, one in Nova Scotia and one in Prince Edward Island. Although not confirmed, Horton Group salt may also be present in the deepest part of the Gulf of St. Lawrence, east of the Îles de la Madeleine.

Viséan age Windsor Group salt is preserved in the Atlantic Provinces, Gulf of St. Lawrence and on the continental shelf off Newfoundland.

In the Plumweseep-Penobsquis and Salt Springs area of southern New Brunswick, commercial amounts of sylvite are known to be present.

Exploratory drilling in the Lower Millstream-Apohaqui area also indicates the presence of probable commercial amounts of potash.

The Riverside-Shepody Bay area is underlain by the western extension of the Marangouin-Minudie anticline which contains domal to diapiric salt structures in Nova Scotia.

Exploratory drilling on the Dorchester gravity low intersected diapiric salt. Although other gravity lows in the area at Sackville, Aulac, Baie Verte and Johnson Creek have not been drilled, they also may contain salt.

The Cumberland subbasin of Nova Scotia is underlain by the northeast- trending Minudie and Malagash anticlines which contain thick deposits of Windsor Group evaporites. Salt is presently been mined in this area at Pugwash and extracted as a brine from wells near Amherst.

The Shubenacadie-Stewiacke area contains the most complete and least deformed Windsor Group evaporite section observed to date in Atlantic Canada. This near-horizontal bedded deposit, 56 km long, 11 km wide and up to 300 m thick, is about 450 m below the surface.

In the Antigonish subbasin salt is known to be present near Ohio, James River, Antigonish, Southside Antigonish Harbour and Pomquet Forks. In the Pomquet area gravity surveys and exploratory drilling suggest the area is underlain by a large salt body, about 300 m below the surface.

The Mabou subbasin, characterized by a highly faulted basement overlain by a thick section of Horton and Windsor group rocks, contains a considerable volume of domal to diapiric salt.

At Kingsville exploratory drilling has indicated that the area is underlain by a south plunging partly diapiric anticline containing salt with a 60% grade.

The entire Windsor Group at McIntyre lake is dominated by salt with dips ranging from 20 to 70°. In this area salt may also be present in the overlying Canso Group.

SOMMAIRE

Vers la fin de la sédimentation de Horton, du sel du Tournaisien supérieur a été déposé dans une succession de lac temporaire à deux endroits au moins au Nouveau-Brunswick, à un endroit en Nouvelle-Écosse et à un autre dans l'Île-du-Prince-Édouard. Bien que non confirmé, il est possible que du sel du groupe de Horton soit aussi présent dans la partie la plus profonde du golfe Saint-Laurent, à l'est des Îles-de-la-Madeleine.

Du sel viséen du groupe de Windsor est conservé dans les provinces de l'Atlantique, dans le golfe Saint-Laurent et sur la plate-forme continentale au large de Terre-Neuve.

Dans la région de Plumweseep-Penobsquis et de Salt Springs, dans le sud du Nouveau-Brunswick, on a relevé des quantités commerciales de sylvite.

Des forages d'exploration dans la région de Lower Millstream-Apohaqui ont aussi indiqué la présence de quantités commerciales probables de potasse.

La région de Riverside-Shepody Bay repose sur le prolongement occidental de l'anticlinal Marangouin-Minudie qui contient des structures salifères en forme de dôme ou de diapir en Nouvelle-Écosse.

Des forages d'exploration sur le minimum gravimétrique de Dorchester ont traversé du sel diapirique. Bien que d'autres minimums gravimétriques dans la région, à Sackville, à Aulac, à la Baie-Verte et à Johnson Creek n'aient pas été explorés par forage, il est possible qu'ils contiennent aussi du sel.

Le sous-bassin de Cumberland de Nouvelle-Écosse repose sur les anticlinaux orientés vers le nord-est de Minudie et de Malagash qui contiennent d'épais gisements d'évaporites du groupe de Windsor. Actuellement, du sel est extrait dans la région de Pugwash et en saumure de puits près d'Amherst.

La région de Shubenacadie-Stewiacke contient la section d'évaporites du groupe de Windsor la plus complète et la moins déformée qui ait été observée jusqu'à nos jours dans la région canadienne de l'Atlantique. Le gisement lité presque horizontal, de 56 km de long, 11 km de large et jusqu'à 300 m d'épaisseur se trouve à environ 450 m sous terre.

Dans le sous-bassin d'Antigonish, on sait qu'il y a du sel près de Ohio, de James River, d'Antigonish, de Southside Antigonish Harbour et de Pomquet Forks. Dans la région de Pomquet, des levés gravimétriques et des forages d'exploration ont indiqué que la région recèle une grosse masse de sel, à environ 300 m de profondeur.

Le sous-bassin de Mabou, caractérisé par un socle très faillé, est recouvert par une épaisse section de roches des groupes de Horton et de Windsor, et contient un volume considérable de sel provenant de dômes ou de diapirs.

À Kingsville, des forages d'exploration ont indiqué que la région repose sur un anticlinal en partie diapirique plongeant vers le sud et titrant 60 % de sel.

Au lac McIntyre, le groupe de Windsor contient surtout du sel ayant un pendage de 20 à 70°. Dans cette zone, il est possible que du sel soit présent dans le groupe de Canso sus-jacent.

Exploratory drilling at Inhabitants Harbour indicates the large gravity anomaly which underlies the area can be attributed to an extensive domal or diapiric salt mass. As a large part of this salt structure is beneath Inhabitants Harbour, it is probably less attractive economically than a similar structure would it be if located entirely on land.

The sedimentary section penetrated by exploratory holes at Cleveland, Seaview and St. Peters, could not account for the observed gravity lows. Although the results from these boreholes were somewhat inconclusive as to the thickness of the evaporite section, salt was intersected at each location.

At Malagawatch exploratory drilling indicated Windsor Group evaporites are folded into a northeast-trending anticline overturned to the north. The thick section of salt observed in Windsor Group, subzone A, in some areas also contains one or two potash zones. The lowest and main potash zone varies in thickness from 2.6 to 9.2 m and has an average K_2O content of 12 to 40%. In subzone B, salt usually represents more than 60% of the section with sylvite grades of less than 20% and the average K_20 content less than 15%. Although the subzone C evaporite section contains salt, potassium salts appear to be absent.

The Ashfield-Orangedale area appears to be a poorly defined syncline or half graben downdropped to the north which contains a thick sequence of Windsor Group rocks overturned to the southwest. Four of the five holes drilled in the area intersected salt and two also intersected potash. One of the holes intersected two potash zones in subzone A. The main potash zone in subzone A, with a true thickness of 3 m, was approximately 50% sylvite. The other zone in this hole was 1 m thick and contained only 25% sylvite and carnallite. A second well intersected a 3-m zone of potash in subzone B. The sylvite and carnallite content of this zone contained about 30% KCL.

Salt in the McIvor Point hole was about 774 m thick and contained some low grade carnallite (10-20%). The lower or main potash zone as observed in subzone A at Malagawatch was not encountered in this well.

The Estmere hole spudded in the lower part of subzone C, was abandoned in salt in the upper part of subzone A above the projected depth of the main potash zone. Massive salt was encountered in subzone B but it did not contain potash as observed in the Malagawatch and Orangedale drill sites.

The Kempt Head hole, near the southern end of Boularderie Island, intersected 400 m of salt and two minor potash zones. The presence of salt in this hole indicates the distribution of Windsor Group evaporites is far more widespread than previously realized.

Des forages d'exploration à Inhabitants Harbour ont indiqué que l'importante anomalie gravimétrique sous la région, peut être attribuée à une grosse masse salifère dans une structure en dôme ou diapirique. Comme une grande partie de cette structure salifère se trouve sous Inhabitants Harbour, elle est probablement moins intéressante sur le plan économique qu'une structure semblable qui se trouverait entièrement en surface.

La section sédimentaire traversée par des forages d'exploration à Cleveland, Seaview et St. Peters ne fait pas partie des minimums gravimétriques observés. Bien que les résultats de ces forages ne permettent pas de tirer des conclusions quant à l'épaisseur de la section d'évaporites, du sel a été traversé à chaque endroit.

À Malagawatch, des forages d'exploration ont indiqué que les évaporites du groupe de Windsor sont plissées dans un anticlinal orienté vers le nord-est et renversé vers le nord. L'épaisse section de sel observée dans la sous-zone A du groupe de Windsor contient aussi par endroits une ou deux zones de potasse. L'épaisseur de la zone principale inférieure de potasse varie de 2,6 à 9,2 m, et sa teneur moyenne en K_2O est de 12 à 40 %. Dans la sous-zone B, le sel représente habituellement plus de 60 % de la section avec des teneurs en sylvite de moins de 20 % et une teneur moyenne en K_2O inférieure à 15 %. Bien que la section d'évaporites de la sous-zone C contienne du sel, elle ne semble pas renfermer de sels de potassium.

La région d'Ashfield-Orangedale semble être un synclinal mal défini, ou un demi-graben basculé vers le nord, qui contient une succession épaisse de roches du groupe de Windsor déversées vers le sud-ouest. Quatre des cinq trous forés dans la zone ont recoupé du sel et deux aussi, de la potasse. Un des forages a recoupé deux zones de potasse dans la sous-zone A. La principale zone de potasse de la sous-zone A, qui a une épaisseur vraie de 3 m contient approximativement 50 % de sylvite. Dans ce forage, l'autre zone a 1 m d'épaisseur et contient seulement 25 % de sylvite et de carnallite. Un second puits a recoupé une zone de 3 m de potasse dans la sous-zone B. La sylvite et la carnallite de cette zone titraient environ 30 % de KC1.

Le sel dans le trou de McIvor Point avait environ 774 m d'épaisseur et contenait de la carnallite à faible teneur (10-20 %). La zone inférieure ou principale de potasse, observée dans la sous-zone A à Malagawatch, n'a pas été recoupée dans ce puits.

Le trou d'Estmere foré dans la partie inférieure de la sous-zone C a été abandonné dans la couche de sel de la partie supérieure de la sous-zone A, au-dessus de la profondeur projetée de la principale zone de potasse. Dans la sous-zone B, on a rencontré du sel massif, mais il ne contenait pas de potasse comme on l'avait observé dans les forages de Malagawatch et d'Orangedale.

Le forage de Kempt Head près de l'extrémité sud de l'île de Boularderie a recoupé 400 m de sel et de petites zones de potasse. La présence de sel dans ce trou indique que la distribution des évaporites du groupe de Windsor est bien plus étendue que prévu.

Dans la partie sud du golfe Saint-Laurent, des forages d'exploration et un certain nombre de coupes transversales à travers les Îles-de-la-Madeleine indiquent que la région repose sur une épaisse succession salifère en dôme à diapirique. L'épaisseur totale de la section carbonifère dans cette zone dépasse probablement 12 km.

In the southern part of the Gulf of St. Lawrence exploratory drilling and a number of cross-sections through the Îles de la Madeleine indicates the area is underlain by a thick sequence of domal to diapiric salt. The total thickness of the Carboniferous section in this area probably exceeds 12 km.

In the St. George's Bay area of western Newfoundland the Codroy Group (Windsor Group) is partly marine and locally contains evaporites in drill-holes at Fischells Brook, Robinsons and St. Fintan's. At Fischells Brook 743 m of salt was penetrated, containing some potash over a 40 m section near the top of the deposit. Sylvite concentrations from 20 to 25 % were recorded from 376-378 m and 10 % from 378-384 m.

At Robinsons approximately 240 m of salt contains 14 potash-bearing zones 1 to 8.7 m thick scattered throughout the deposit with K_2O values that vary from 2.7 to 6.3 %.

At St. Fintan's about 90 m of salt was intersected containing 11 potassium- bearing zones from 0.5 to 6 m thick with 3.5 to 9 % K_2O.

On the Grand Banks south of the Avalon Peninsula, Newfoundland, 616 m of salt was penetrated in an exploratory well. This occurrence is considered to represent an erosional remnant of a much larger Windsor Group salt deposit.

The St. Anthony Basin north of Newfoundland contains breached Mississippian diapirs that are considered to have been caused by salt erosion.

In the East Newfoundland Basin seismic structures that appear to relate to salt may be of Carboniferous age.

Dans la région de la baie St-Georges, dans l'ouest de Terre-neuve, le groupe de Codroy (groupe de Windsor) est en partie marin et contient localement des évaporites comme l'ont révélé les forages de Fischells Brook, de Robinsons et de St. Fintan's. À Fischells Brook, on a traversé 743 m de sel contenant un peu de potasse dans une section de 40 m près du sommet du gisement. Les concentrations de sylvite allaient de 20 à 25 % entre 376 et 378 m et étaient de 10 % de 378 à 384 m.

À Robinsons, dans environ 240 m de sel, on a trouvé 14 zones contenant de la potasse de 1 à 8,7 m d'épaisseur, dispersées dans le gisement avec des teneurs en K_2O qui varient de 2,7 à 6,3 %.

À St. Fintan's, dans les 90 m de sel recoupés, on a trouvé 11 zones de potasse ayant de 0,5 à 6 m d'épaisseur et des teneurs de 3,5 à 9 % en K_2O.

Sur les Grands Bancs au sud de la péninsule d'Avalon, à Terre-Neuve, un puits d'exploration a été creusé dans 616 m de sel. Cette manifestation est considérée comme un vestige d'érosion d'un gisement de sel bien plus important du groupe de Windsor.

La bassin de St. Anthony au nord de Terre-neuve contient des diapirs à coeur érodé du Mississippien qui auraient été causés par l'érosion du sel.

Dans le bassin d'East Newfoundland, il est possible que les structures sismiques qui semblent reliées au sel soient du Carbonifère.

INTRODUCTION

Salt springs have long been known in the Atlantic Provinces and were documented by the early settlers. In 1912, rock salt from the Windsor Group was discovered 26 m below the surface in a well drilled for water at Malagash, Nova Scotia. Since then Windsor Group salt has been found at various other locations in the Atlantic Provinces, Îles de la Madeleine, Gulf of St. Lawrence, and on the Grand Banks south of Newfoundland. It is also believed to be present in the offshore St. Anthony Basin area, northeast of the Newfoundland central highlands. The distribution of upper Paleozoic rocks within Phanerozoic rocks of eastern Canada and adjacent areas is shown in Figure 1. The study area includes land portions in the Atlantic Provinces and Quebec, the southern part of the Gulf of St. Lawrence and part of the continental shelf off Newfoundland.

Data obtained from geological maps, well samples, chemical analyses and geophysical surveys have been compiled and interpreted to delineate many of the known evaporite deposits. This work was undertaken to help assess the feasibility of mining some of the presently undeveloped Windsor Group salt deposits, or using the deposits for underground storage. Three modes of investigation have been employed: (1) construction of maps and cross-sections to illustrate the present distribution, thickness and structural configuration of the various salt deposits; (2) construction of a depositional model; and (3) construction of paleogeographic and facies maps to illustrate the regional depositional setting.

Within the Carboniferous of the study area, the present size and configuration of the salt deposits is a function of the environment of deposition, nature of deformation and degree of preservation. Furthermore, no two occurrences are exactly alike and the amount of information varies from area to area, so that the description of each salt body may be governed more by the availability of data than by the geological complexity of the deposit.

This study of salt deposits from Horton, Windsor and Canso group rocks in the Atlantic Provinces, Gulf of St. Lawrence and offshore areas adjacent to Newfoundland is a regional synthesis. The listing of the salt deposits under 28 headings is arbitrary because in some locations a number of structures have been included under one area. This is particularly true for the Gulf of St. Lawrence area, or for the Malagawatch- Ashfield-Orangedale area, which also includes Bucklaw and McIvor Point. Detailed reports for each area are listed in the bibliography. Additional information is also available from company reports on file with Provincial or Federal agencies. Production figures for salt and potash or current and proposed mine development or expansion have not been included, partly because it would

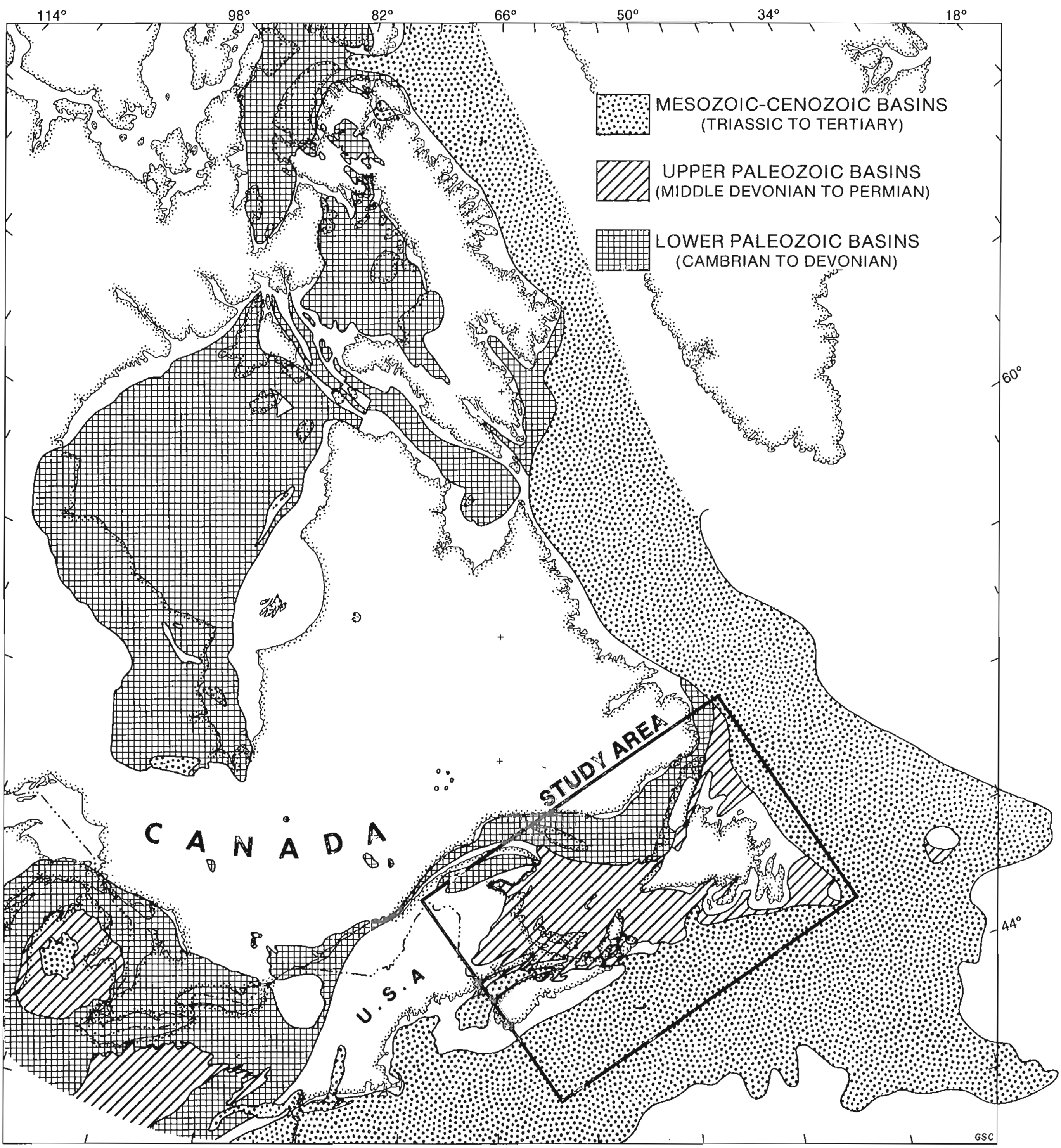


Figure 1. Phanerozoic rocks in eastern Canada and adjacent areas.

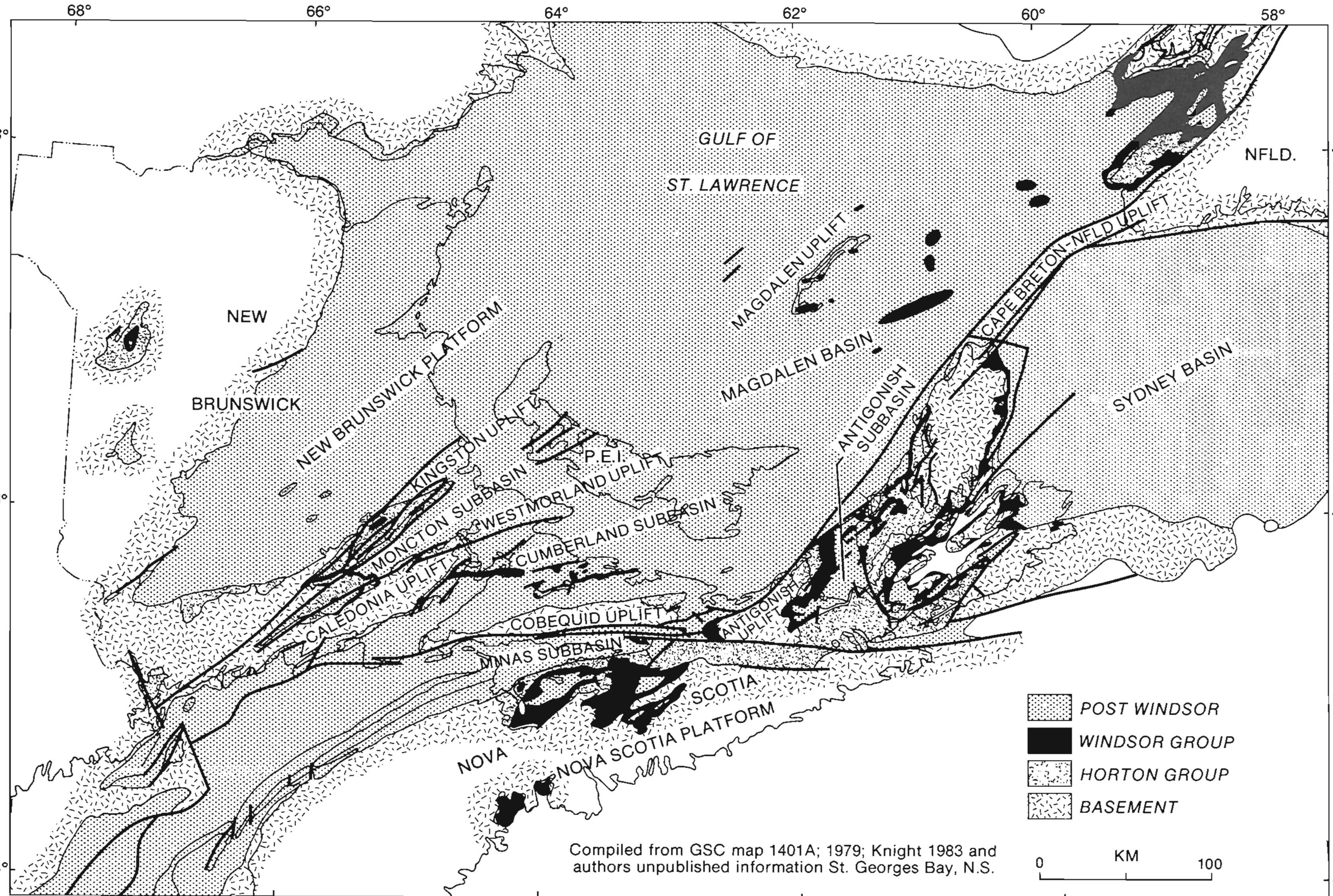


Figure 2. Distribution of Horton and Windsor group rocks, Gulf of St. Lawrence area of Atlantic Canada.

distract from the regional geology of the paper and partly because this information which is subject to change can be obtained annually from company and/or government reports.

ACKNOWLEDGMENTS

The author is particularly grateful for information provided by P.S. Giles and R.C. Boehner of the Nova Scotia Department of Mines and Energy; D.E.T. Bidgood and K. Howells of the Nova Scotia Research Foundation; D.E. Barnett of the New Brunswick Department of Natural Resources and Energy; and P.W.E. Kingston (formerly with the New Brunswick Department of Natural Resources); G. McArthur and I. Knight of the Department of Mines and Energy, Government of Newfoundland and Labrador; G. Karg of the Canada Oil and Gas Lands Administration, Department of Energy, Mines and Resources; and the following companies: Anschutz (Canada) Exploration Ltd., Bowman Developments Ltd., Getty Oil (Canada Operations) Ltd., Gulf Oil Canada Ltd., Hudson's Bay Oil and Gas Company Ltd., Lacana Mining Corporation, Murphy Oil Company, Pan American Petroleum Corporation (Amoco), Scurry-Rainbow Oil Ltd., Shell Canada, Soquem, Soquip and Texaco Exploration Canada Limited. Special thanks are also extended to Geological Survey colleague B.V. Sanford and D. Umpleby (formerly with the Geological Survey of Canada) for assistance and advice, to G.L. Cook and G.H. McFall for drafting of illustrations and to N. Koziel for typing the manuscript. The author also wishes to thank the following critical readers: R.C. Boehner, I. Knight, T.C. Webb of the New Brunswick Department of Natural Resources and Energy, and H.H.J. Geldsetzer of the Geological Survey of Canada.

REGIONAL GEOLOGICAL SETTING

The Atlantic region of Canada includes the northeastern part of the Appalachian fold belt of North America and was affected by the Acadian orogeny (390 Ma) in late Early Devonian time (Reynolds et al., 1973; Faul and Lyons, 1970) when it experienced folding, faulting, metamorphism and granitic intrusion. Subsequent fragmentation of the Acadian orogen during Late Devonian time involved the evolution of a complex series of northeast-trending faults and numerous horsts and grabens (Howie and Cumming, 1963; Howie and Barss, 1975a).

Some of the mechanisms considered responsible for the Acadian orogeny include: tension movements that began in the Late Devonian and concluded in the Late Triassic (Bullard and Uchupi, 1972; Belt, 1968b); isostatic adjustments following plate collision and subduction of oceanic crust (Dewey and Burke, 1973); basins formed as pull-aparts (Keppie, 1977, 1982; Mann et al., 1983; Bradley, 1984); rift tectonics reflected by block faulting (McCutcheon, 1978; McLeod and Ruitenberg, 1978; McLeod, 1979; Ruitenberg and McCutcheon, 1982).

Paleomagnetic data indicate that most orogenies are the result of colliding plates (Irving, 1983). The subduction of the large Siluro-Devonian ocean below the North American plate is responsible for the mid-Devonian Acadian orogeny (Van der Voo, 1983). According to Fyffe (1982) Acadian tectonism was controlled by transform movement which represents the late phase continental convergence following the closing of the Iapetus Ocean during the Taconian orogeny. Paleomagnetic data from Devonian or lower Carboniferous stratified rocks in Newfoundland suggest a left-lateral displacement of the Avalon Platform in respect to cratonic North America (Kent, 1982), and Irving (1977) and Morel and Irving (1978, 1981) argue that the continents underwent large relative motions from mid-Carboniferous to mid-Jurassic.

However, recent paleomagnetic data from eastern and western Newfoundland indicate that large strike-slip faulting did not occur during the Carboniferous (Irving and Strong, 1984). This paleomagnetic data is apparently due to magnetic overprinting during the Kiaman interval (late Carboniferous and Permian) when magnetization was reset in Newfoundland, and in some cratonic rocks that were originally assumed to reflect Early Carboniferous magnetization. Thus, the northward 1500 to 2000 km Carboniferous transcurrent motion of most of Maritime Canada relative to cratonic North America as proposed by Kent and Opdyke (1978), Van der Voo and Scotese (1981), Lefort and Van der Voo (1981) from limited paleomagnetic data, probably did not exist. This conclusion does not affect the hypothesis of smaller-scale Late Paleozoic strike-slip faulting as proposed by Arthaud and Matte (1977), or earlier large-scale mid-Devonian left lateral displacements as suggested by Morris (1976). A general synthesis of the Appalachian area has been prepared by Schenk (1978) and Williams and Hatcher (1982).

Uplift and erosion of the newly accreted Acadian orogen created a new set of tectonic elements that persisted into the Permian period. This late phase tectonism of the Acadian orogeny in eastern Canada is known as the Maritime Disturbance (Poole, 1967), and correlates with the Hercynian-Variscan diastrophism in Europe. Most of the tectonism appears to have been confined to the narrow northeast-trending Magdalen Basin that extends from the Bay of Fundy to western Newfoundland (Fig. 2; Wade et al., 1977). This lens-shaped belt also designated as the Fundy Epieugeosyncline by Kelley (1970) and Fundy Basin by Belt (1968a, 1968b) is bounded on the northwest by the New Brunswick platform and on the east by the Nova Scotia and Newfoundland platforms. In southern New Brunswick and mainland Nova Scotia, the Kingston, Caledonia, Westmorland and Cobequid uplifts are basement highs within the Magdalen Basin that have separated the southern part of the Magdalen Basin into the Moncton, Cumberland and Minas subbasins. In western Newfoundland the mobile belt is restricted to a narrow zone extending from the Gulf of St. Lawrence to the St. Anthony Basin on the east side of the Long Range Uplift (Fig. 3). Although the Magdalen Basin was underlain by a very unstable, highly deformed basement, the influence of this disturbance is nonexistent on adjacent platforms or appears to have been limited to broad open folds and local faults (Howie and Barss, 1975b).

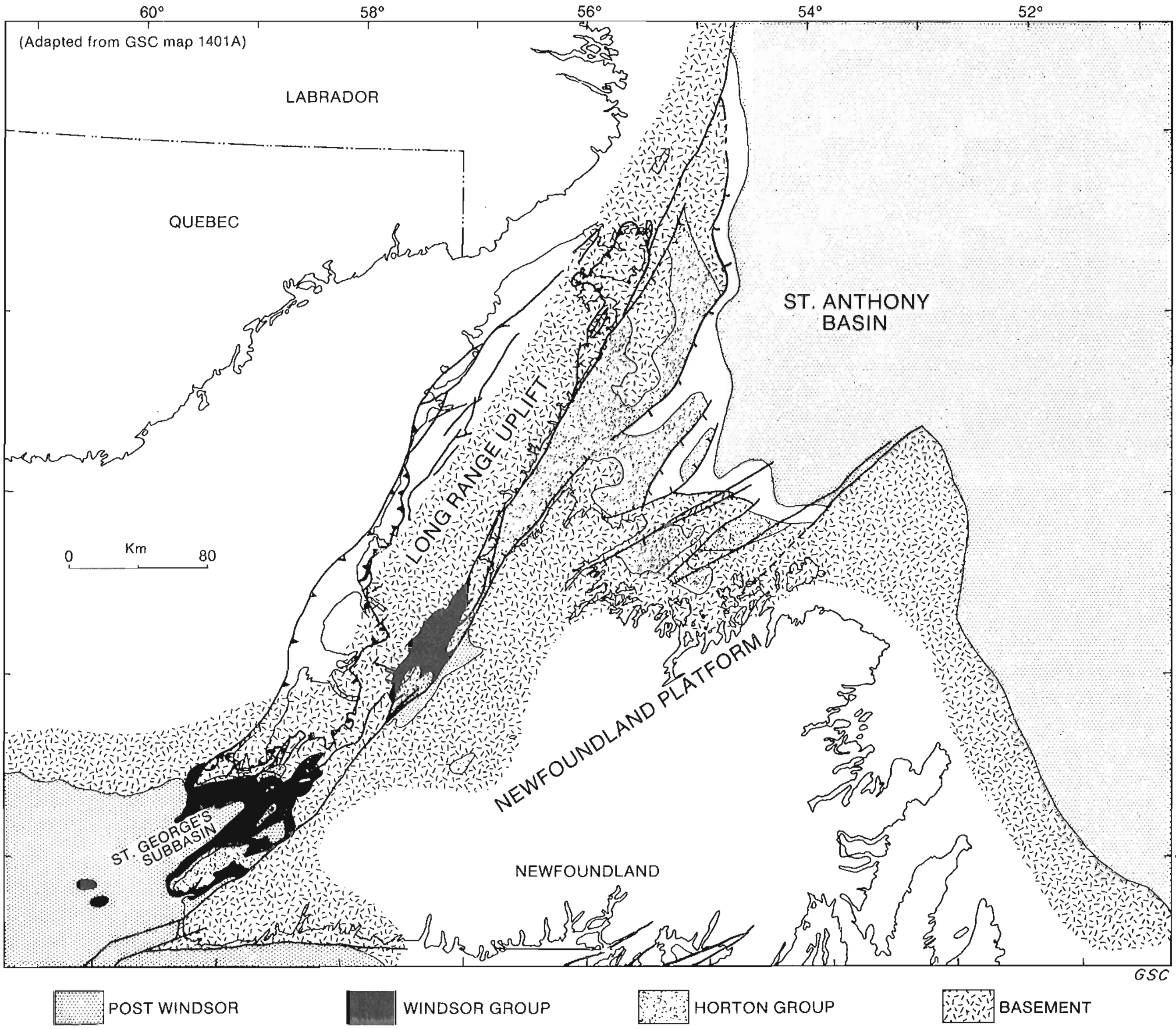


Figure 3. Distribution of Horton and Windsor group rocks, Newfoundland.

Rocks ranging in age from Precambrian to Devonian that have undergone regional metamorphism, granitization, intrusion or intense deformation during or prior to the Acadian orogeny are considered as basement. Biostratigraphic data from the Upper Paleozoic rocks in eastern Canada show that these cover rocks range in age from Middle Devonian to Early Permian.

The oldest rock unit in the Upper Paleozoic section is the Horton Group, defined by Bell (1929) from exposures at Horton Bluff near Windsor, Nova Scotia where it consists of two formations which in ascending order were designated the Horton Bluff and Cheverie formations of Tournaisian age. Although this section indicates the general depositional environment of the Horton Group, time equivalent successions outside of the type area may vary from place to place due to the influence of local provenance areas (Howie and Barss, 1975a).

Kelley (1967b) removed the Tournaisian time restriction of Bell (1929) and redefined the Horton Group as a rock stratigraphic unit. In 1970, Kelley described the typical Horton Group section as: "red to red and grey sandstone and conglomerate, succeeded by grey siltstone, sandstone and shale, then by red to red and grey sandstone, siltstone and conglomerate". Locally, the grey sequence may also contain salt (Howie and Barss, 1975a). Using this broader definition, the Horton Group embraces a continental sequence of sedimentary rocks that rests unconformably on the eroded Acadian orogen and is overlain conformably, disconformably and rarely unconformably by Windsor Group or younger rocks. Volcanic rocks known locally in Cape Breton as the Fissett Brook Formation are also included in this group (Kelley and MacKasey, 1965). Based on paleontological evidence and stratigraphic position, these redefined Horton Group sediments are considered to range in age from Eifelian to Early Viséan (Howie and Barss, 1975b).

In the Middle Devonian, piedmont and fluviatile clastic sediments of the Horton Group were deposited in low-lying terrain, with each successive rock unit overlapping the basement. As the area of deposition expanded, many local provenance areas were buried. Considerable variance in rock fragments from local provenance areas during the deposition of Upper Paleozoic rocks has resulted in the introduction of a number of formational names. They are listed in a correlation chart of the Horton to Pictou Group rocks that extend from the New Brunswick platform (northwestern New Brunswick) to the Grand Banks off Newfoundland (Fig. 4).

A composite stratigraphic section (Fig. 5), prepared to show the general sequence and lithology of the Upper Paleozoic rocks that represent about 7600 to 9100 m of strata, shows salt to be present in both Horton and Windsor Group rocks. Minor amounts of salt have also been observed locally in the Canso Group (Boehner, 1986), although it is not shown on this figure.

Regionally, the Windsor Group (Middle to Late Viséan age) contains the only marine sequence in the Upper Paleozoic rocks of southeastern Canada. It conformably to nonconformably overlies the Horton Group and the pre-Carboniferous basement. At the type section in the Avon River area, Windsor, Nova Scotia (Bell, 1929), the Windsor Group is composed of red sandstone, red and minor grey siltstone, limestone, minor dolomite and gypsum. Based on stratigraphic succession and faunal evidence obtained primarily from carbonates, Bell divided the entire Windsor section into subzones A-E. The thickest evaporites were deposited in subzones A and B, whereas most of the limestone horizons occur in subzones C to E. Salt may not have been deposited in the type area or is absent, either because of erosion and/or dissolution subsequent to faulting. According to Bell (1929) the stratigraphic section along the Avon River is approximately 55 % sandstone and shale, 25 % carbonate and 20 % gypsum (anhydrite). The sandstoneshale content appears to be higher at this location than the average for the region, because the type section was adjacent to a large provenance area. Epeirogenic uplift and adjustment of fault blocks and/or a eustatic fall in sea level during the Viséan after the deposition of subzone E, expelled the Windsor sea and changed the depositional environment from marine through brackish into the fluvial and fluvial-lacustrine facies of the Canso and Riversdale groups.

In view of the overlap in age and problems in nomenclature as indicated by Belt (1964, 1965, 1968a, 1968b), Kelley (1967a, 1967b) and Howie and Barss (1975a), the Canso and Riversdale groups (late Viséan to Westphalian A age) are considered as a single unit on most geological maps in this paper.

The Canso Group (Bell, 1944, p. 5-6) consists of thinly laminated nonmarine red and green shale, sandstone and minor limestone that conformably overlie marine Windsor Group or nonmarine rocks of equivalent age and unconformably overlie older Carboniferous and pre-Carboniferous rocks. When fossiliferous, the Canso Group contains only Namurian-age fossils (Barss, personal communication). Outside the type area this rock sequence may also contain conglomerate, tuff, basic and acidic intrusives and extrusives (Poole et al., 1970). Minor intervals of salt are locally present on the Nova Scotia mainland and Cape Breton Island (Boehner, 1983).

The Riversdale Group (early Westphalian A age) at the type section (Bell, 1944, p. 12) consists of red and grey sandstone, siltstone and shale. The gradual change from a semiarid climate that prevailed during the deposition of the Canso Group to the warm temperate climate during the deposition of the Riversdale Group is indicated by the appearance of abundant plant remains and local coal seams (Howie and Barss, 1975a). The increase in plant remains was also accompanied by a gradation sediment-colour from mainly red to mainly grey. Outside the type area the Riversdale Group may consist of fine to coarse-grained sandstone, shale, siltstone, and conglomerate with a local basal quartz-pebble conglomerate (Kelley, 1970).

The Cumberland Group (Late Westphalian A to early Westphalian B) defined by Bell (1944) and described by Logan (1845), Copeland (1959), Hacquebard and Donaldson (1964), and Duff and Walton (1973), has not been recognized outside of the Cumberland subbasin. The Cumberland Group consists of nonmarine red and grey conglomerate, sandstone, shale and economic deposits of coal. It rests conformably, unconformably and disconformably on older Upper Paleozoic rocks and regionally overlaps the basement. This rock sequence was deposited in a rapidly subsiding and restricted fault-bounded subbasin in northwestern Nova Scotia. Based on spore assemblages (Howie and Barss, 1975a), the upper beds of the Cumberland Group are considered coeval with the lower beds of the Pictou Group.

The Pictou Group (Westphalian B to Wolfcampian age; Barss and Hacquebard, 1967) was originally defined by Bell (1944) from a type section in the Cumberland subbasin, Nova Scotia. It is a sequence of nonmarine, dark red sandstone, grey sandstone, arkosic grit, dark red shale, mudstone, grey shale and local economic deposits of coal. These rocks rest unconformably on older Paleozoic rocks, as well as the younger beds of the Cumberland Group and onlap the basement. As indicated by the correlation table (Fig. 4), the Morien Group, Inverness-Broad Cove formations and the Scotch Village Formation are correlatives of the Pictou Group.

DEPOSITIONAL SETTING OF EVAPORITE DEPOSITS

The Carboniferous rocks of southeastern Canada are largely nonmarine and were deposited in a series of connected intermontane basins or troughs within a complex rift valley system (Reading, 1980) or pull-apart basin (Keppie, 1982; Mann et al., 1983). Regional subsidence of the Magdalen Basin occurred at the same time as local source areas were uplifted. This interplay is documented by thousands of metres of coarse clastics and primary features in the lower part of the Horton Group. As the depositional area grew, many local provenance areas were buried, and the coarse clastics were largely replaced by thick sequences of siltstone

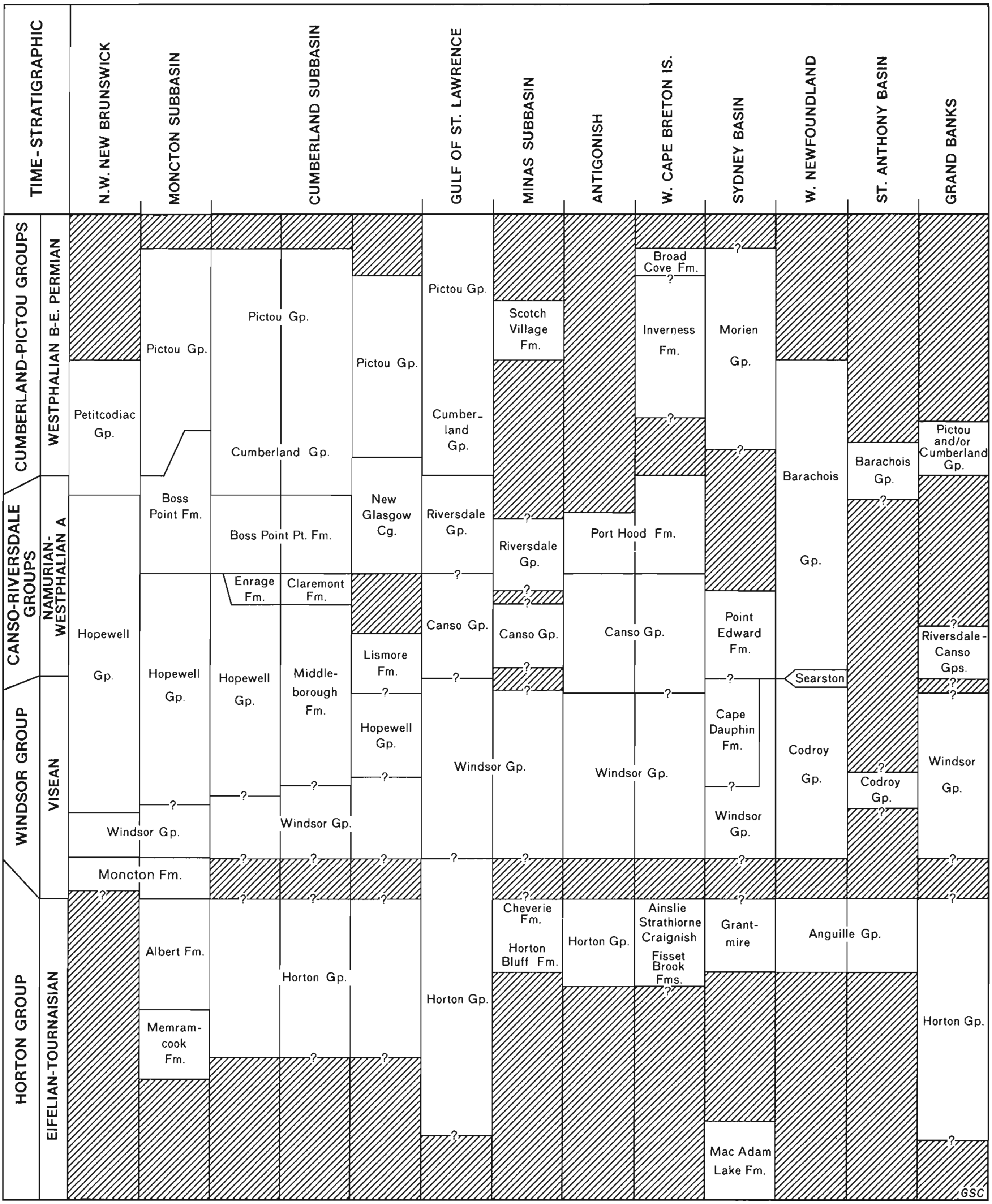


Figure 4. Correlation table, southeastern Canada.

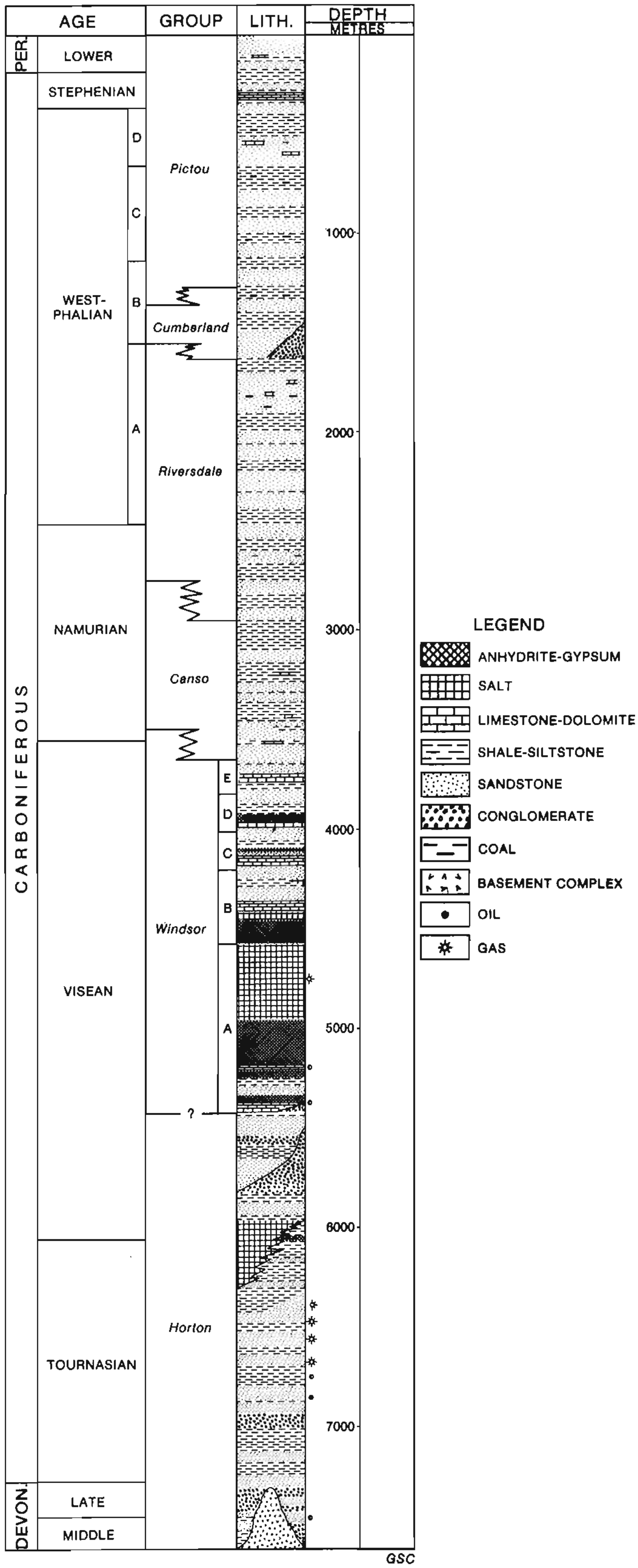


Figure 5. Generalized Stratigraphic Column, Upper Paleozoic rocks southeastern Canada.

and shale and in some areas by evaporites. Renewed uplift near the end of Horton Group sedimentation was followed by another period of regional subsidence, by a subsequent rise in sea level, and eventually by the deposition of Windsor Group evaporites.

Paleomagnetic data indicate that the study area was located on or near the equator from Middle Devonian to Early Permian (Irving, 1977). Windsor deposition began with a thin but widespread laminated limestone, the Macumber Formation, which may be of algal origin (Geldsetzer, 1977, 1978) and local bioherms fringing pre-Carboniferous basement highs (Giles et al., 1979). The nearly land-locked setting of the Windsor Sea, a semiarid climate, and a low clastic input due to temporary crustal stability led to increasingly restricted conditions which resulted in the accumulation of thick evaporites. Marine oscillations characterize deposition of the upper Windsor Group with a gradual decrease in marine encroachments on the platform areas and a gradual increase in clastics in part due to regional uplift (Mamet, 1970). Tectonism during and after the deposition of the evaporites resulted in flowage of salt into pillows, domes, diapirs and ridges (Howie and Barss, 1975a).

EIFELIAN TO EARLY VISÉAN HORTON GROUP

Introduction

The post-orogenic Horton Group is the oldest Upper Paleozoic sequence in the area. In 1929, when Bell published data on the Horton type section from Horton Bluff, Nova Scotia, fossil evidence indicated a Lower Mississippian (Tournaisian) age for the Horton Group. More recently, palynological studies from other stratigraphic sections, considered to be lithologically equivalent to the lower part of the Horton Group, provided a Middle Devonian or even possibly Lower Devonian age (Howie and Barss, 1975a). The type section now appears to contain the younger onlap units located on the flank of a marginal basin basement high adjacent to a larger basin that was already partly filled with Horton Group sediments. The upper limit of the group has also been extended from Tournaisian to early Viséan on the basis of paleontological data from the Moncton subbasin in New Brunswick (Howie and Barss, 1975a).

Distribution and thickness of the Horton Group

The Horton Group is exposed in numerous areas in the Atlantic Provinces and identified in boreholes on the continental shelf off Newfoundland (Fig. 2, 3). In western Newfoundland, the Anguille Group is considered to be the lateral equivalent of the Horton Group (Fig. 4). In measured sections, the Horton Group varies in thickness from a few metres to over 3200 m in western Cape Breton Island (Kelley, 1967a). In the Îles de la Madeleine area, Gulf of St. Lawrence, at least 4000 m of Horton Group rocks are considered to be present based on interpretations of various geophysical surveys (Goodacre et al., 1969; Hudson's Bay Oil and Gas Co., 1974). Similar thicknesses are believed to be present in the St. George subbasin of western Newfoundland (Knight, 1983). Obvious local variations in thickness reflect the instability of the underlying basement.

On the continental shelf south of Newfoundland, approximately 700 m of Horton Group rocks occur in the Amoco-Imperial Gannet O-54 well (Fig. 17). The presence of Horton Group rocks southeast of Newfoundland, originally postulated in an interpretation of seismic data by Grant (1972), has been confirmed by palynomorphs recovered from rock samples in the Pan Am 10C corehole (Howie and Barss, 1975a). In the St. Anthony Basin, east of the Long Range uplift off the north coast of Newfoundland, Horton Group rocks have been identified by Baird (1966). Grant (1972) also suggested the occurrence of Lower Carboniferous rocks in the St. Anthony Basin, based on seismic interpretation. It is therefore reasonable to assume that the Horton Group and younger Upper Paleozoic rocks underlie a large part of the offshore area of the continental shelf. Additional information on the distribution and thickness of the Horton Group in the area is outlined on an isopach map by Howie and Barss (1975a, Fig. 3).

Stratigraphy of the Horton Group

The Horton Group is a sedimentary sequence regionally represented by a number of laterally equivalent formations (Fig. 4). Basal grey and red conglomerate of piedmont origin, succeeded by fluviolacustrine sandstone, grey shale, black carbonaceous shale overlain by red shale, sandstone and minor conglomerate, comprise the major lithologies of the group. This transition from piedmont to a predominantly fluviolacustrine depositional environment was suggested by Bell (1929). His conclusions were based on the occurrence of angular quartz fragments, erect plant stems, freshwater ostracods, laminated shales with fish remains, and widespread black carbonaceous shale and coal. In some areas salt also forms part of the Horton Group, indicating periodic arid conditions. The upper facies of the Horton Group reverts to fluvial. It is predominantly red with a gradual upward increase in coarseness. This is interpreted to reflect deposition in a semiarid climate following an interval of renewed uplift.

In southern New Brunswick, Horton Group salt contains glauberite ($Na_2Ca(SO_4)_2$). Although salt is usually considered to be a marine deposit, Livingstone (1963) and Turekian (1969) indicate that a considerable volume of salt can be leached from continental deposits, as is evidenced from late Pleistocene lakes in the southwestern United States and western Canada (Shelton, 1966). Glauberite is not important in salts of marine origin (Braitsch, 1971), but is considered to have a higher concentration associated with salts indicative of a continental environment. The intermontane continental depositional environment that prevailed throughout Atlantic Canada during the late Tournaisian and early Viséan resulted in numerous playa-type deposits which contain salt in Nova Scotia and Prince Edward Island and salt with glauberite in New Brunswick.

HORTON GROUP EVAPORITES

Near the close of Horton sedimentation, salt was deposited in at least two locations in New Brunswick, one in Nova Scotia and one in Prince Edward Island (Fig. 6). Although not confirmed, Horton Group salt may also be present in the Gulf of St. Lawrence east of the Îles de la Madeleine because this is considered to have been the deepest part of the basin during the deposition of the upper part of the Horton Group.

Cornhill area, New Brunswick

The Cornhill area, about 30 km west of Moncton, is geologically part of the Kingston Uplift (Fig. 7). Salt spring seeps thought to have originated from the underlying Albert Formation in the Cornhill-Manhurst-Gordon Brook areas, were brought to the attention of the scientific community in 1930 (Hamilton, 1961b). Most springs are near faults, and at least one is reported to contain anomalous glauberite values.

Salt springs at Cornhill are about 1 km south of Cornhill East on Salt Springs Brook. In 1947, two vertical cable-tool holes were drilled by the New Brunswick government hoping to intersect salt. Hole no. 1 was drilled to 122 m and hole no. 2 was abandoned at 91 m due to drilling problems. Both holes were reported to have intersected siltstones of the Albert Formation and although each overflowed brackish water, rock salt was not encountered (Hamilton, 1961b).

A gravity survey conducted in southern New Brunswick (Chiasson, 1973) indicated a northeast-trending gravity low extending from Cornhill East to Gordon Brook. Local anomalies associated with this trend, shown on the Bouguer gravity anomaly map (Fig. 8), were attributed to Horton Group salt (Fig. 9). Based on these data, the Cornhill no. 3 hole was drilled by the New Brunswick government in 1973 to verify the interpretation. The hole penetrated 786 m of Albert Formation sandstone and siltstone, before encountering 108 m of salt, silty mud and breccia. From 786 to 894 m the salt content increased with depth, eventually comprising up to 75 % of the total section (Crosby, 1975b). From 894 m to the bottom of the hole at 944 m, the silty mudstone breccia zone generally contained less than 5 % salt, with a few horizons containing up to 40 % salt. Chemical analysis of the salt indicated up to 10 % concentrations of glauberite (New Brunswick Department of Natural Resources, 1978, p. 25).

In the Gordon Brook area, Wright (1944) attributed the bitter taste in one of the salt brine springs to glauberite. In 1947, the New Brunswick Department of Lands and Mines drilled a 70- m hole in the area but penetrated only Albert Formation shales. Interpretation of an anomalous gravity low in the Gordon Brook area by Chiasson (1973) indicated a possible salt structure could be intersected at a depth of about 488 m. This anomaly is located on a horst structure associated with the Kingston Uplift that extends from Cornhill on the west to Fawcett on the east. An aeromagnetic map of the same area (Fig. 10) indicates a slight magnetic high associated with the horst. Although at first glance the aeromagnetic and gravity maps seem to be contradictory, they are both accurately interpretating the geology of the area. The variance in the magnetics over the horst can probably be attributed to a shallower basement rather than a change in rock type. The gravity lows are outlining low density sediments (evaporites) on the horst.

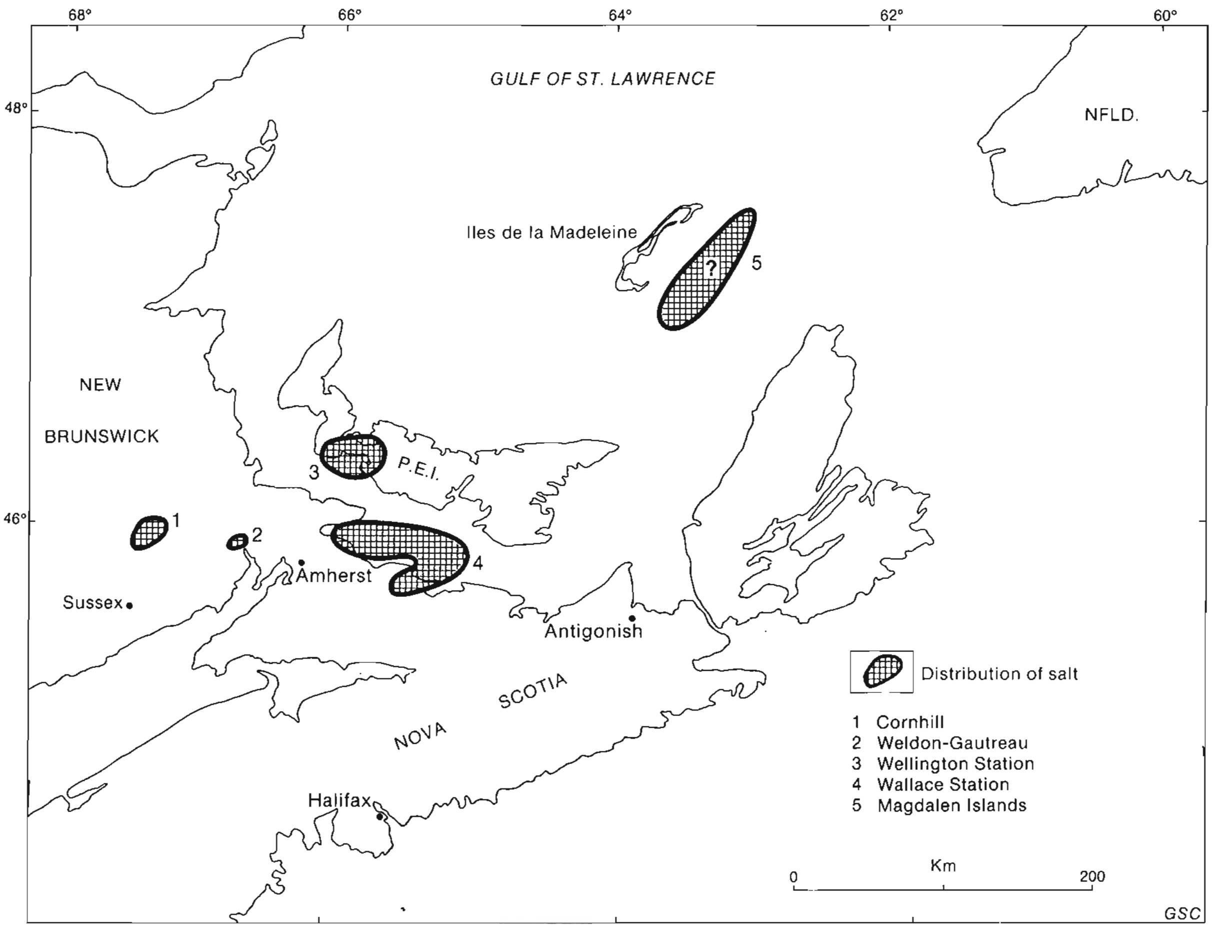


Figure 6. Present distribution of Horton Group salt, Atlantic Provinces and Gulf of St. Lawrence.

Weldon-Gautreau area, New Brunswick

In the Weldon-Gautreau area, salt springs have been known to occur for many years, but the source of the salt was not known until 1921 when the D'Arcy Exploration Co. encountered Albert Formation salt in a hole drilled in search of oil and natural gas. Additional drilling and geophysical surveys, spanning a thirty-year period after the initial discovery, have approximately defined the subsurface boundaries of the salt body.

This area is underlain by Carboniferous rocks of the Horton, Windsor, Canso and Riversdale groups (Fig. 11). Locally the Horton Group is represented by Memramcook, Albert and Moncton formations. The Memramcook Formation, composed of red and green conglomerate, sandstone, siltstone and shale, is the basal member of the Horton Group. Its lower contact is considered to be in angular unconformity with the pre-Carboniferous basement. Regionally the upper contact is generally gradational with the overlying Albert Formation, although in some areas it may be disconformable. The Memramcook-Albert contact is usually placed at the top of the uppermost red bed (Howie, 1980).

The Albert Formation at the Stony Creek field, located about 15 km south of Moncton, New Brunswick, is a deltaic lacustrine deposit (Howie, 1968, 1980) containing grey to black kerogenous to non-kerogenous shale, arkosic sandstone, siltstone and some sandy limestone. The formation is well known for its oil and gas zones which occur in six petroliferous groups: five sand and one kerogenous shale (Henderson, 1940). East and southeast of the Stony Creek area, where the sand- shale ratio is less than 10 %, the shale contains beds of gypsum, carbonate and a zone of salt. The upper contact of the Albert Formation is in most places conformable and gradational with the overlying red Moncton Formation (Pickerill et al., 1985) and is placed at the bottom of the lowest red bed or where the red beds become predominant.

The Monton Formation consists of a lower sequence red shale to siltstone, termed the Weldon Member, which is overlain by red conglomerate of the Hillsborough Member. Red conglomerate, shale, and sandstone of the Canso Group unconformably overlie these older Carboniferous rocks. The Riversdale Group, composed of grey sandstone, quartz-pebble conglomerate, red shale and siltstone, gradationally overlie Canso strata. In New Brunswick the Canso and Riversdale groups are known as the Hopewell Group and Boss Point Formation, respectively (Fig. 4).

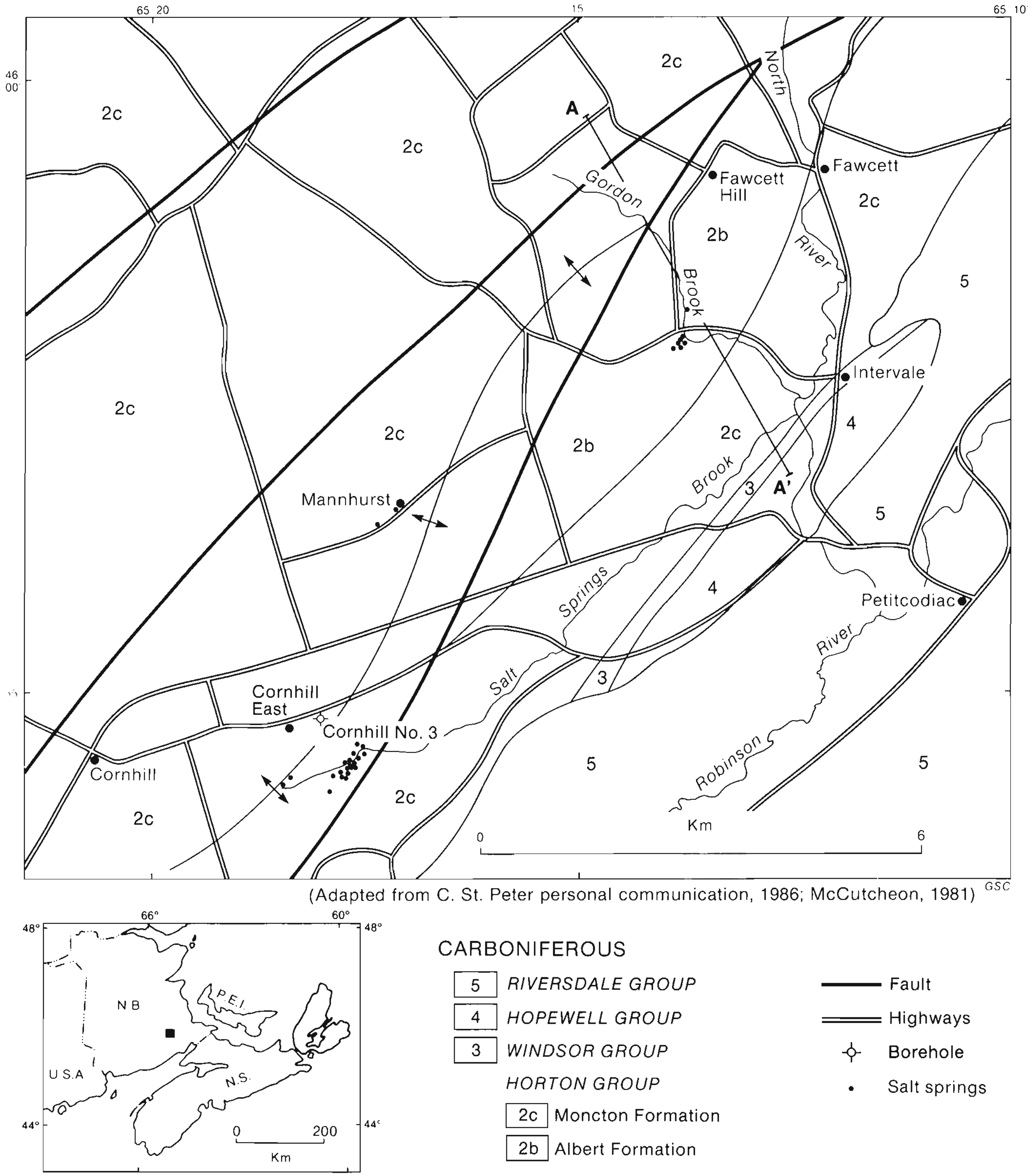


Figure 7. Geological map, Cornhill area, New Brunswick.

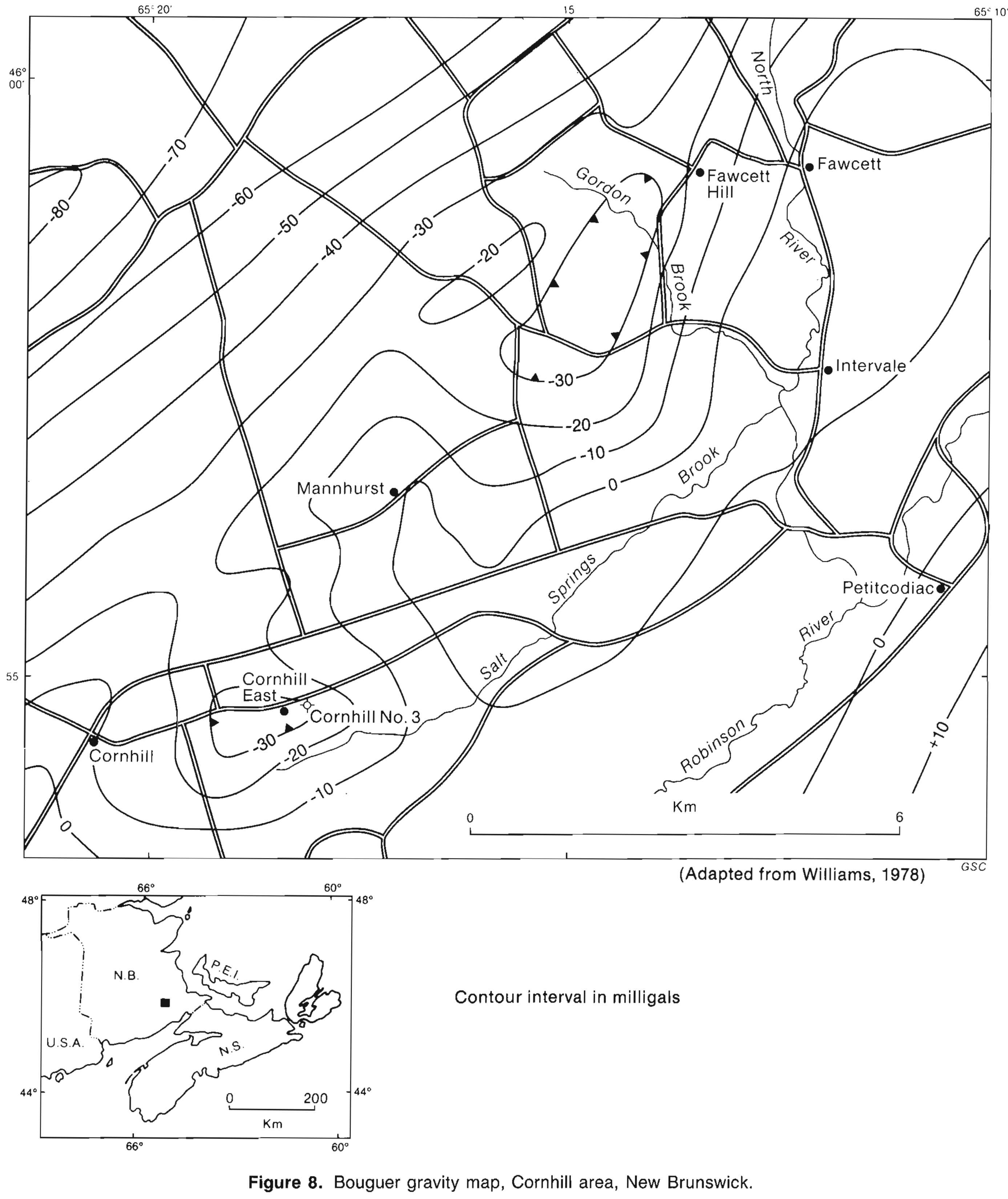
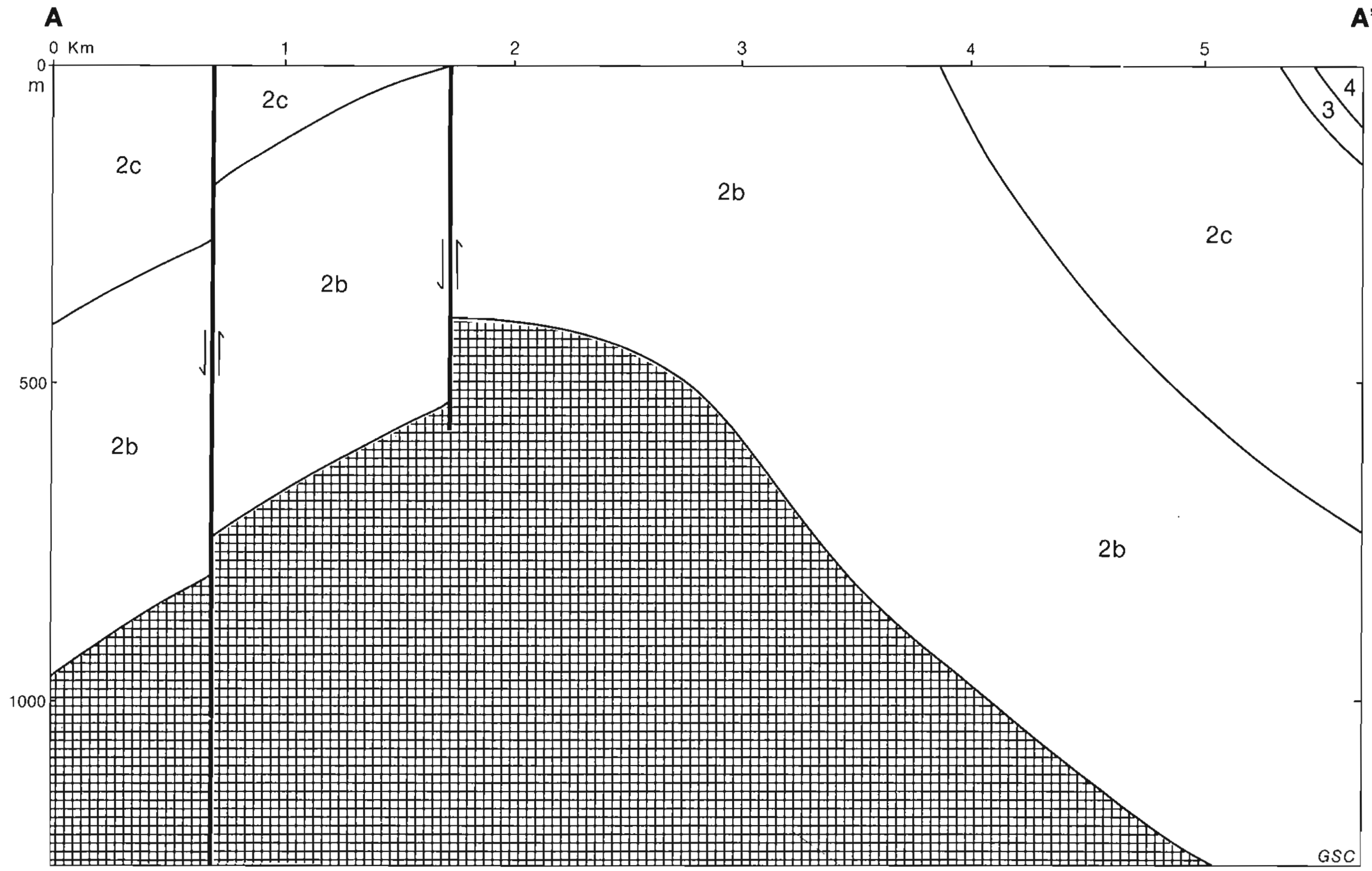


Figure 8. Bouguer gravity map, Cornhill area, New Brunswick.



(Adapted from N.B. Dept. Natural Resources, 1974, T.C. Webb, personal communication, 1986)

CARBONIFEROUS

HORTON GROUP

2c Moncton Formation

2b Albert Formation

Albert Formation (Salt)

4 Hopewell Group

3 Windsor Group

Figure 9. Schematic cross section from the Cornhill area, New Brunswick.

A Bouguer gravity map of the Weldon-Gautreau area (Williams, 1978), indicates an intense gravity low centred over the Petitcodiac River, which is attributed to subsurface low density sediments (Fig. 12). An aeromagnetic map of the same area indicates a magnetic low (Fig. 13). The low may be attributed to a change in the basement rock and/or masking of the basement complex by a fairly thick Carboniferous section. Exploratory drilling (Fig. 14) has outlined a subsurface salt body extending over 19.4 km^2. This northeast-trending structural basin bounded to the south by the Hillsborough fault (Hamilton, 1961b) does not seem to have been subjected to severe deformation. The Horton Group section appears to have been gently folded and contorted into a series of anticlines and synclines striking approximately northeast (Webb, 1977). This gentle warping, combined with probable salt migration, has resulted in a slightly domal evaporite sequence (Fig. 15). This interbedded sequence of salt, glauberite, anhydrite and shale is a lens-shaped deposit about 5.7 km long, 1 to 3 km wide, and up to 488 m thick. The top of the structure is 368 m below the surface. A 274 m contour line (Fig. 14) outlines the area of maximum salt. As indicated on the cross section, this salt deposit appears to be a lateral equivalent of deltaic sand zones I and II in Stony Creek field (Howie, 1980). Hamilton (1961b) estimated the deposit contained in excess of 1 million tons of low grade salt.

A significant intersection of glauberite $Na_2Ca(SO_4)_2$ has been confirmed by several drillholes (Fig. 14) in which glauberite was found interbedded with shale or claystone immediately on top of or isolated within the main salt mass (Webb, 1977). Drilling has delineated over 25 million tons of glauberite ore averaging 23 % Na_2SO_4 (Webb, 1977).

Wellington area, Prince Edward Island

The Wellington area of western Prince Edward Island, near the eastern limits of the Moncton subbasin (Fig. 2, 6), is underlain by Upper Paleozoic rocks of the Pictou Group

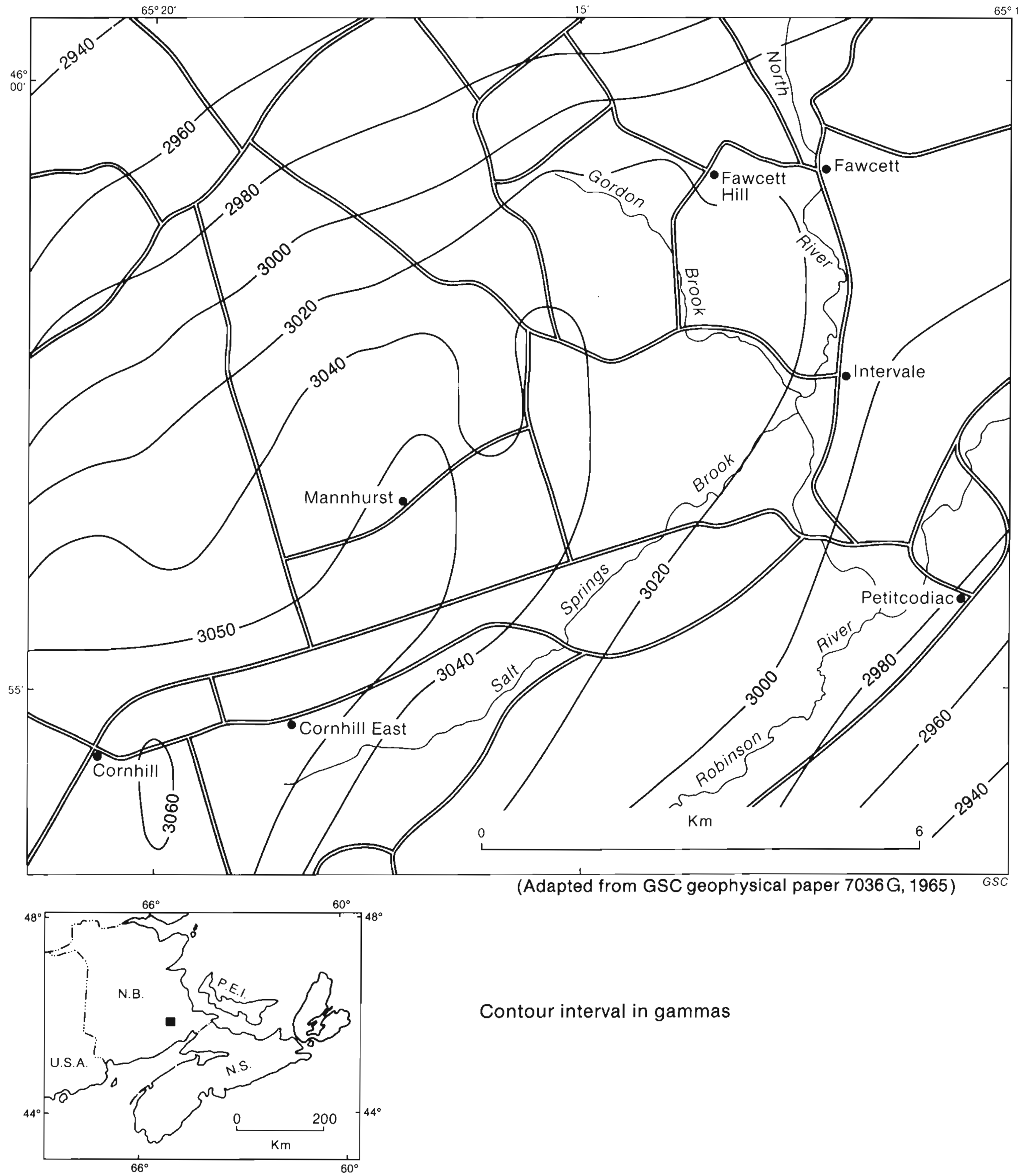


Figure 10. Aeromagnetic map, Cornhill area, New Brunswick.

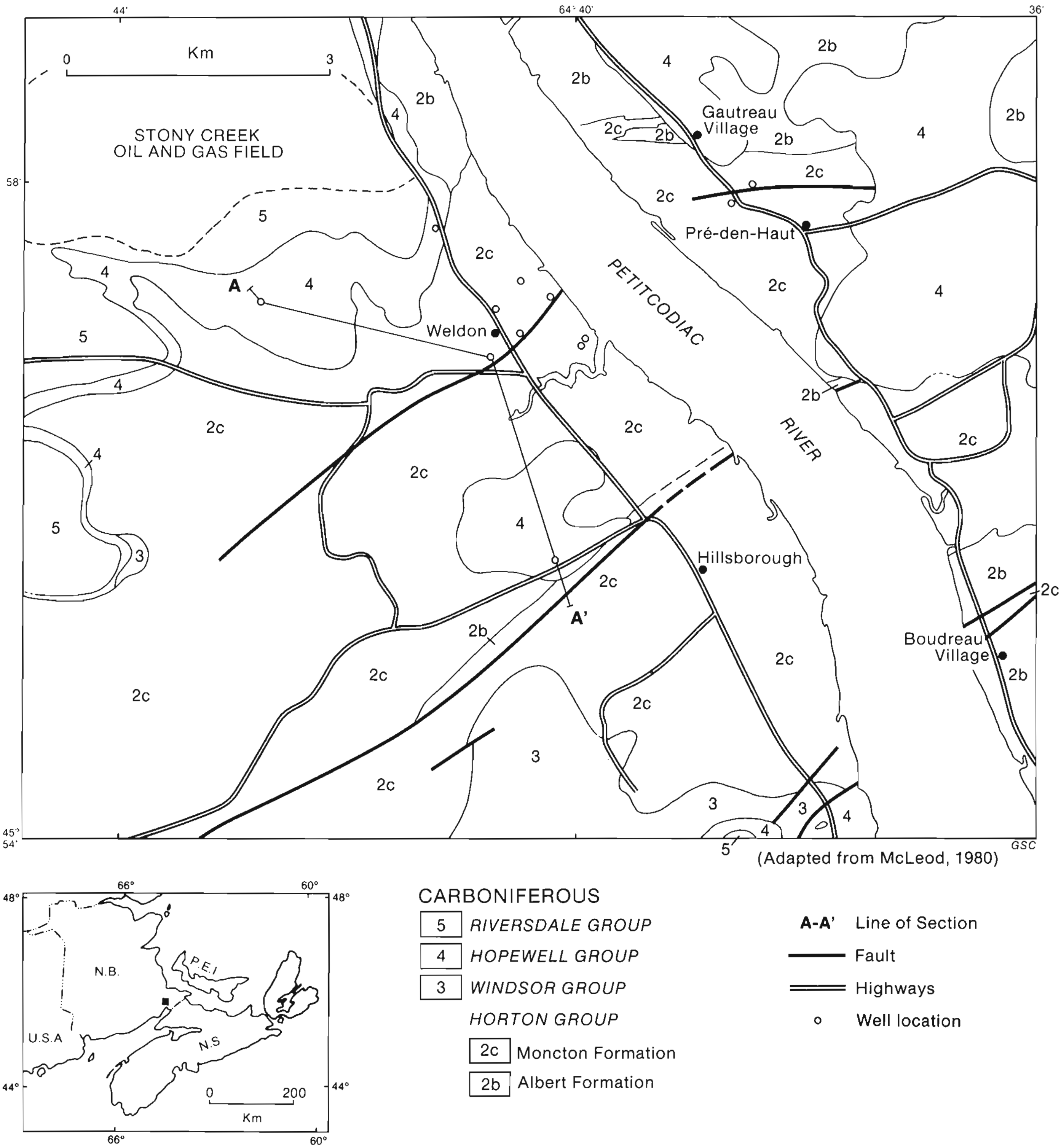


Figure 11. Geological map, Weldon — Gautreau area, New Brunswick.

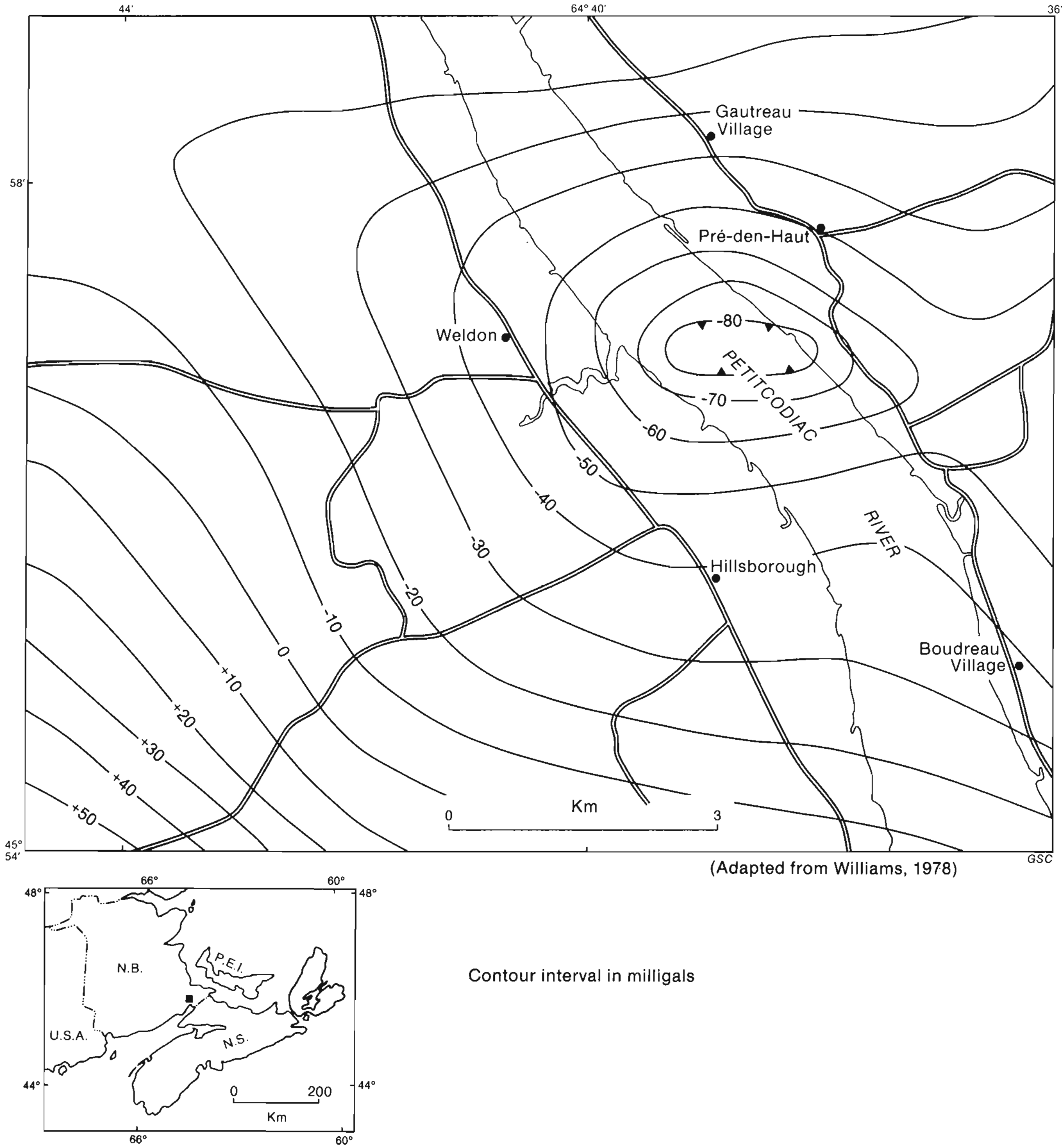


Figure 12. Bouguer gravity map, Weldon — Gautreau area, New Brunswick.

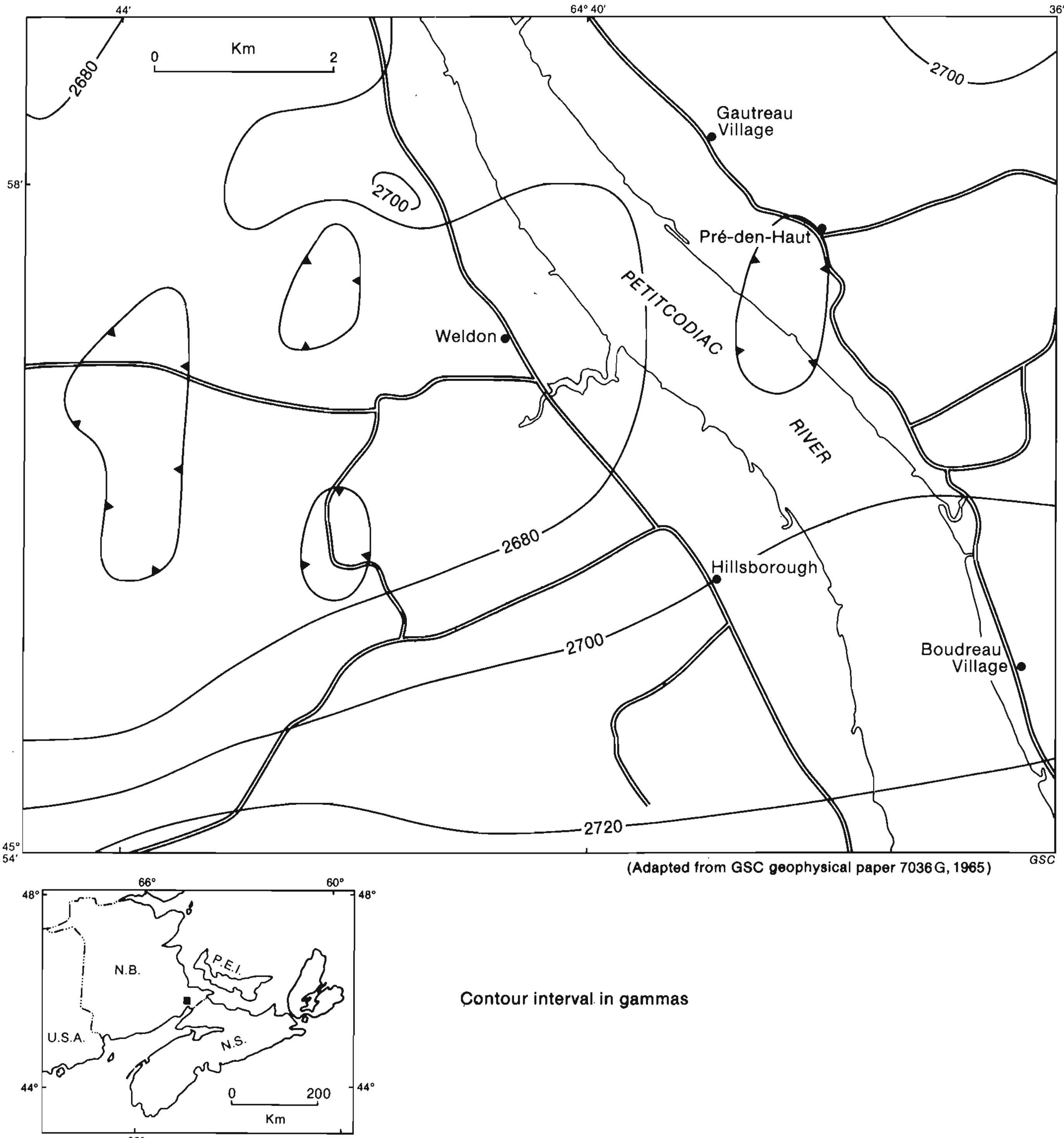
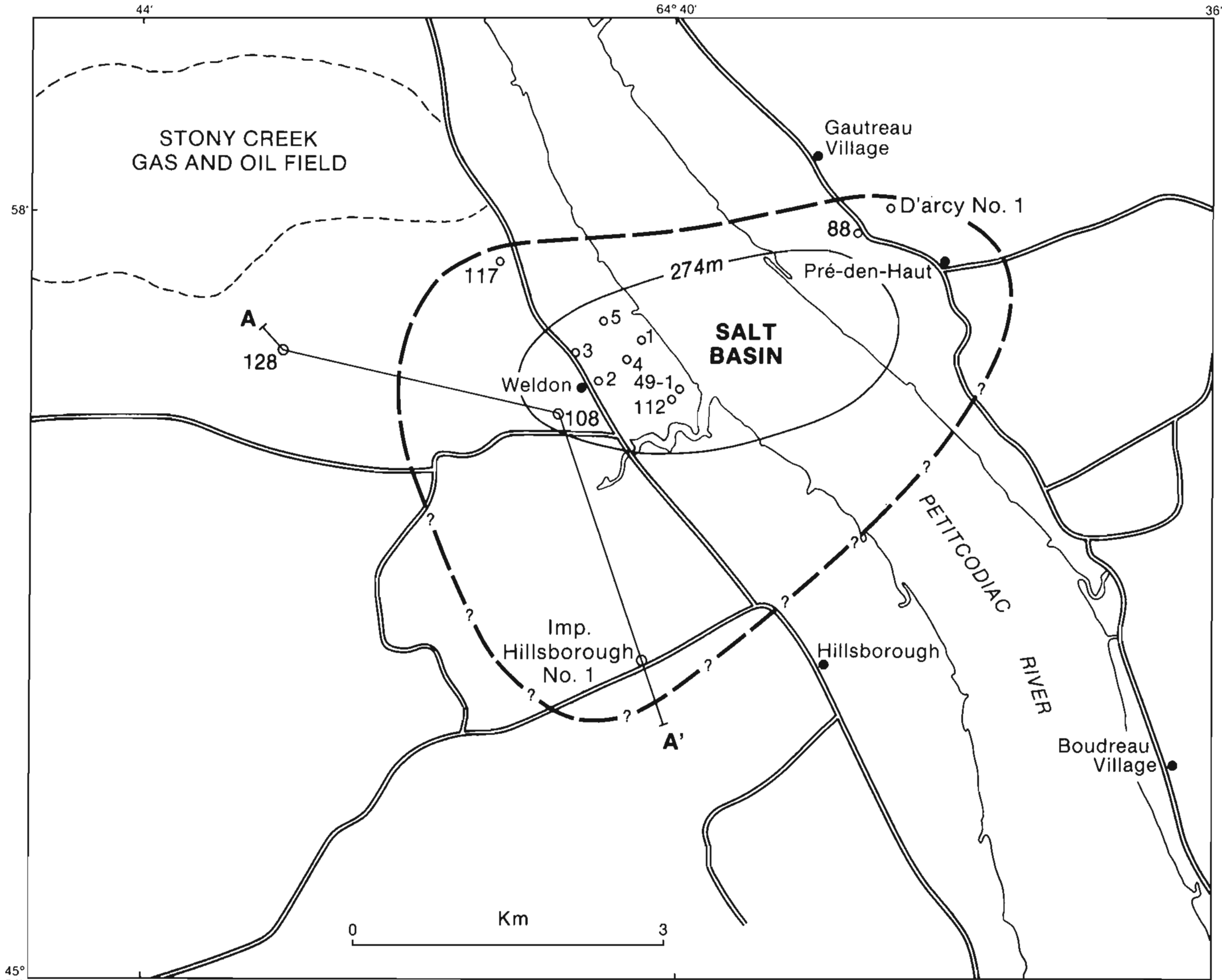
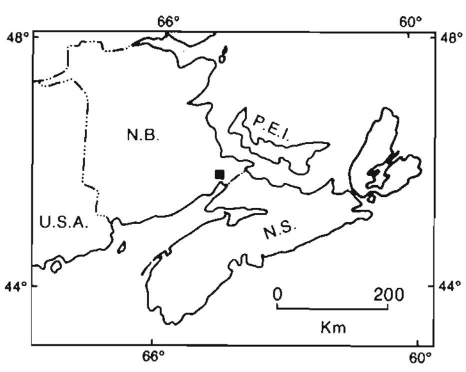


Figure 13. Aeromagnetic map, Weldon — Gautreau area, New Brunswick.



(Adapted from Howie 1968, reprinted by permission of American Association of Petroleum Geologists)



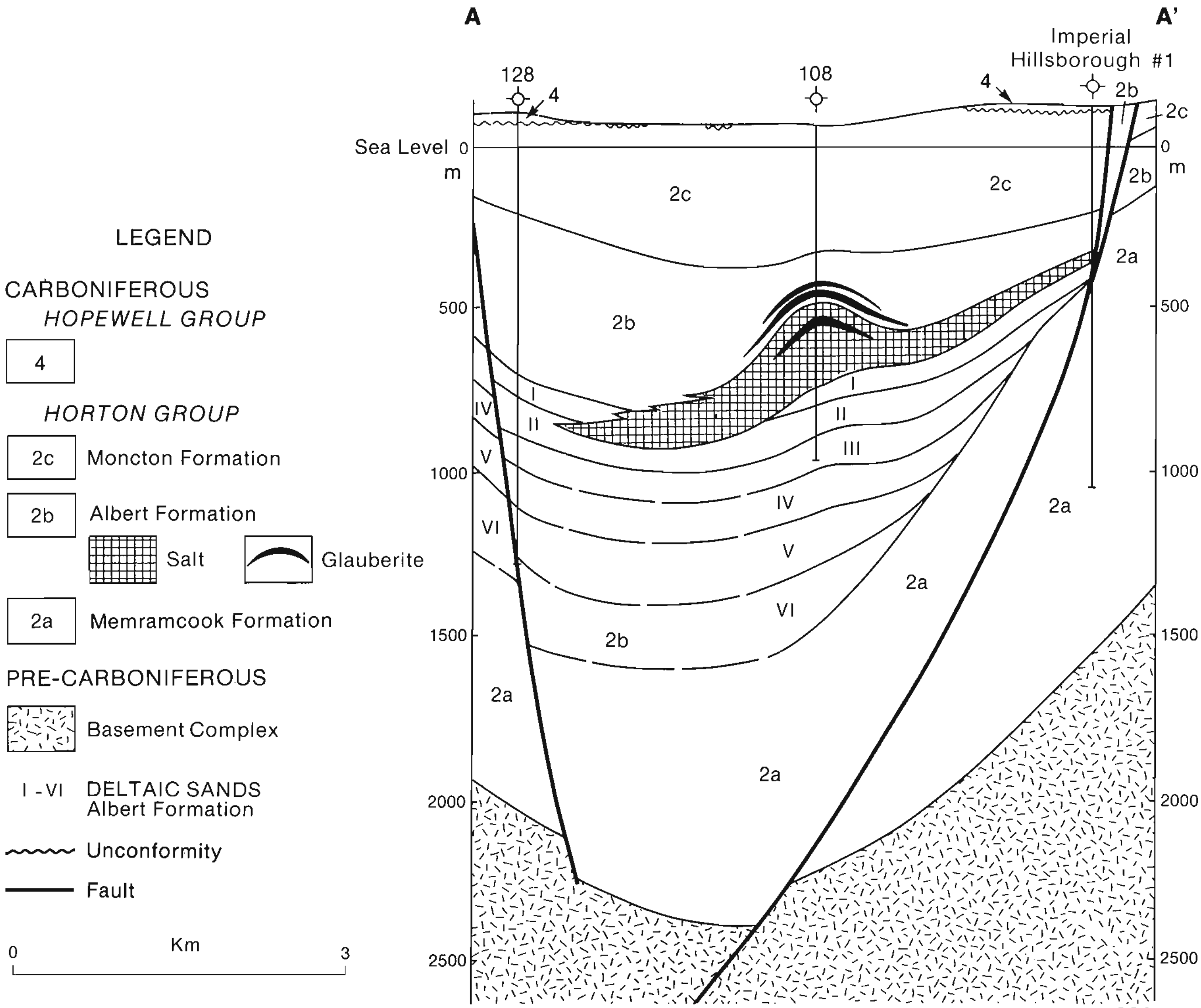
Stony Creek Gas and Oil Field boundary — — — — — — —

Borehole o

Isopach (defined, approximate) 274m

Salt facies boundary (approximate, indefinite) — — ? —

Figure 14. Distribution and thickness of the Albert Formation salt, Weldon — Gautreau area, New Brunswick.



(Adapted from Howie 1968, reprinted by permission of Association of American Petroleum Geologists

Figure 15. Stratigraphic cross section of the Albert Formation salt, Weldon — Gautreau area, New Brunswick.

ranging in age from Westphalian B to early Permian (Fig. 4). Although Horton to Riversdale group rocks are not exposed at the surface, they have been recorded in exploratory wells drilled for oil and gas. In this area, Imperial Oil Ltd. drilled the Wellington Station No. 1 well (Howie and Cumming, 1963). It was completed in Horton Group rocks at 2962 m. Salt was a minor constituent, interbedded with sandstone, shale and anhydrite over a 350- m interval from 2290 to 2640 m. This is the only well in Prince Edward Island known to have penetrated Horton Group salt.

Wallace Station area, Nova Scotia

Wallace Station occurs within the Cumberland subbasin, which extends from southeastern New Brunswick through northern Nova Scotia to Prince Edwards Island. The area is characterized by thick deposits of Upper Paleozoic rocks considered to be approximately 6100 m thick. On a geological map of the area, the Windsor Group is the oldest Carboniferous strata sequence exposed at surface (Fig. 43). It outcrops along the crest of the Minudie and Malagash anticlines and in three smaller structures in the intervening area between the two structures. Although Horton Group rocks, which underlie the Windsor Group and unconformably overlie the basement, are not exposed in the area, they have been identified in the subsurface. The Anschutz Wallace Station No. 1 well, located about 29 km east of Oxford on the Malagash anticline, intersected Horton Group rocks at 4196 m below sea level (Fig. 44, section C-C'). The lower part of this well penetrated 177 m of Horton Group siltstone and an underlying 92 m of salt-shale sequence before it was abandoned at 4538 m (Howie, 1985).

As the dip of the beds in this part of the well is relatively flat (5° to 28° dip with a mean reading of from 10° to 12°), the salt body is considered to be a bedded deposit. The total thickness and areal extent of this evaporite occurrence is unknown.

Gulf of St. Lawrence — east of Îles de la Madeleine

During Carboniferous time the central part of the Magdalen Basin was considered to have been an actively sinking part of the crust (Howie and Barss, 1975a). As this area was a considerable distance from any known provenance area the sedimentary sequence was probably dominated by mainly fine-grained clastic material. The presence in New Brunswick, Nova Scotia and Prince Edward Island of red beds and some playa lake salt deposited fairly late in Horton Group time suggests that an arid to semiarid climate extended over a fairly wide area. This hot, dry climate may have encouraged the deposition of Horton Group salt in one or more locations in the Magdalen Basin. The topographically lowest areas of many present deserts, probably similar to this area, are often close to the water table and may contain ephemeral saline lakes or playas (Reading, 1980; Shelton, 1966). As the Îles de la Madeleine-Gulf of St. Lawrence area is considered to have been the deepest part of this basin, it is unlikely that the Horton Group section will ever be intersected by drilling. However, from a geological point of view, it is interesting to speculate that some of the massive salt deposits in the Gulf of St. Lawrence that have been attributed to the Windsor Group may also contain Horton Group salt. Seismic records for this area indicate that the geology is too complex to determine if any of the evaporites can be attributed to the Horton Group.

PALEOGEOGRAPHY AND DEPOSITIONAL ENVIRONMENTS OF HORTON GROUP EVAPORITES

A paleogeographic reconstruction showing eastern Canada during the deposition of the Horton Group indicates the area was located a little south of the Equator (Drewry et al., 1974; Irving, 1977). Paleomagnetic studies conducted in New York and Pennsylvania suggests this area was also located slightly south of the Equator during this same period (Edmunds et al., 1979). An examination of the fossil flora from Pennsylvania and New York also indicates a mostly subtropical climate for the area. The continental aspects of the upper Devonian rocks in the northeastern United States and eastern Canada indicate the New England region was a provenance area shedding into both depositional areas throughout late Devonian and early Carboniferous time (Geldsetzer, 1978). Although the two regions may be different in their paleogeographic setting, they were affected by the same tectonic pulses.

Near the end of the period of crustal convergence that left the African plate in close proximity with the North American and European plates, a period of tension caused a readjustment of highly shattered basement in Atlantic Canada. The resultant horst and graben topography led to the accumulation of locally derived Horton Group sediments that range in age from Eifelian (Middle Devonian) to Tournaisian, and locally Early Viséan (Carr, 1968). Although northeast- trending basement blocks were uplifted, the thick sequence of nonmarine sediments now lying thousands of feet below sea level, indicates that crustal subsidence was the main tectonic movement. The presence of salt near the close of Horton sedimentation is indicative of a playa lake facies. Nonmarine evaporites in the Albert Formation of New Brunswick suggests the existence of a large basinal area with an interior drainage (Kirkham, 1978). Glauberite associated with salt in southern New Brunswick indicates that the salt brines were concentrated from the products of continental weathering in inland drainage basins (Webb, 1977).

A generalized paleogeography and facies map (Fig. 16) depicts the depositional environments of the Horton Group during the Late Tournaisian-early Viséan. Evidence of arid conditions with local deposition of salt near the close of Horton deposition is indicated by a large playa lake interpreted as covering part of southern New Brunswick, a small area of the northern Nova Scotia mainland, and part of western and central Prince Edward Island. The presence of unconfirmed salt is also suggested in the Gulf of St. Lawrence, east of the Îles de la Madeleine. As this area is considered to have been a major depocentre during Horton sedimentation, it seems logical to infer that it may contain some Horton salt. It should also be considered that a number of other playa-type deposits may have been present in local topographic depressions in the Magdalen Basin between southern New Brunswick and Îles de la Madeleine.

A few of the many basement highs that were probably exposed during this period are located on Prince Edward Island, in southern New Brunswick and northern Nova Scotia. Basement ridges to the south and east of the main depositional basin which extended from southern Nova Scotia to western Newfoundland preserved the intermontane character of the area, and influenced the distribution and nature of the younger sediments. Although Horton Group salt is of geologic interest, it is considered to be only of limited economic importance.

LATE VISÉAN TO EARLY NAMURIAN WINDSOR GROUP

Introduction

The Windsor Group is a partly or wholly marine sequence of strata that conformably to unconformably overlies the Horton Group and overlaps the pre- Carboniferous. It was first subdivided biostratigraphically by Bell (1929) on the Avon River near Windsor, Nova Scotia. Fossils used in this correlation were brachiopods and corals. The vertical changes in the fauna led to the recognition of five microfaunal subzones A to E (Fig. 18). Subzones A and B were attributed to the Lower Windsor and C to E to the Upper Windsor. These subzones or time stratigraphic units have been substantiated in the Antigonish area of Nova Scotia by Sage (1954) and in Cape Breton Island by Stacey (1953). In the St. George Bay area of western Newfoundland the mixed sequence of marine and nonmarine strata are known as the Codroy Group (Fig. 4).

The Middle to Late Viséan age, originally assigned by Bell (1929), has been revised by Mamet (1970) as Late Viséan to Early Namurian, based on foraminiferal assemblages. A palynological investigation of core samples from an undeformed section in the Stewiacke area of the Minas subbasin suggests three miospore zones may be recognized

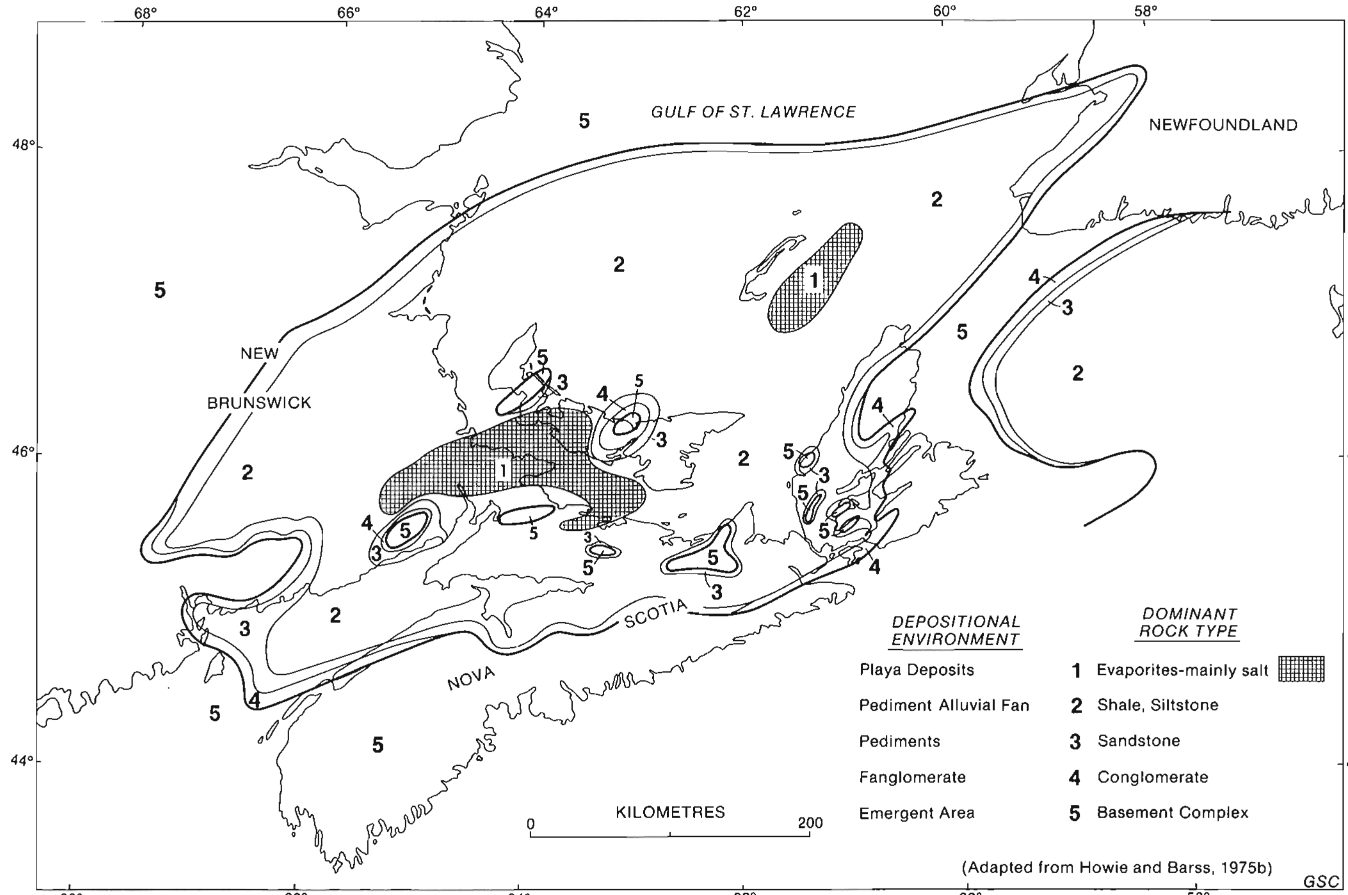


Figure 16. Late Horton Group paleogeography and depositional environments.

(Utting, 1980). This subdivision is only tentative because of the difficulty of recovering sufficient spore data from marine rocks. The Windsor Group has also been correlated with the Viséan of western Europe and approximately with the Meramecian and Chesterian of Mississippian sections in the United States (Bell, 1929).

This dominantly marine sequence, which was deposited in an interconnected graben-basin system, consists of cyclically repeated evaporites, maroon siltstone, limestone and dolomite. In an area where the present day average annual precipitation is 112 cm, the very nature of the lithology is not conducive to the preservation of good surface exposures. Groundwater action has removed some of the salt and converted some of the anhydrite to gypsum resulting in disruption of the original bedding. Tectonism in some areas has increased the effectiveness of the groundwater penetration and salt migration which has further disrupted the bedding.

In most areas, the Windsor Group rocks are poorly exposed. In recent years exploratory drilling for oil and gas, gypsum, salt, potash, lead and zinc have greatly increased our knowledge and understanding of the group.

Distribution and thickness of the Windsor Group

The Windsor Group is widely distributed throughout the Atlantic provinces and the southern part of the Gulf of St. Lawrence (Fig. 2, 3). Offshore on the continental shelf, south of Newfoundland, the Amoco-Imperial Gannet O-54 exploratory well encountered 412 m of Windsor Group strata (Howie and Barss, 1975a). The Elf Hermine E-94 exploratory well penetrated a 812-m-thick section before it was abandoned in Windsor Group salt (Fig. 17). Shallow drillholes on the northeast Newfoundland shelf have also encountered fossiliferous Windsor Group limestone (Jansa and Mamet, 1985). Reflection seismic profiles over the same area indicate limestones extend east of the drillholes and are underlain by higher order evaporites also considered to belong to subzone A or B or both of the Windsor Group (Cutt and Laving, 1977; Haworth, Grant et al., 1976).

The type section of the Windsor Group in Nova Scotia (Fig. 2) is in a highly disturbed area of the Minas subbasin where it was estimated by Bell (1929) to be at least 473 m thick. As the Minas subbasin is only a marginal part of the much deeper Magdalen Basin, the type section is inferred to be considerably less than the average thickness of the

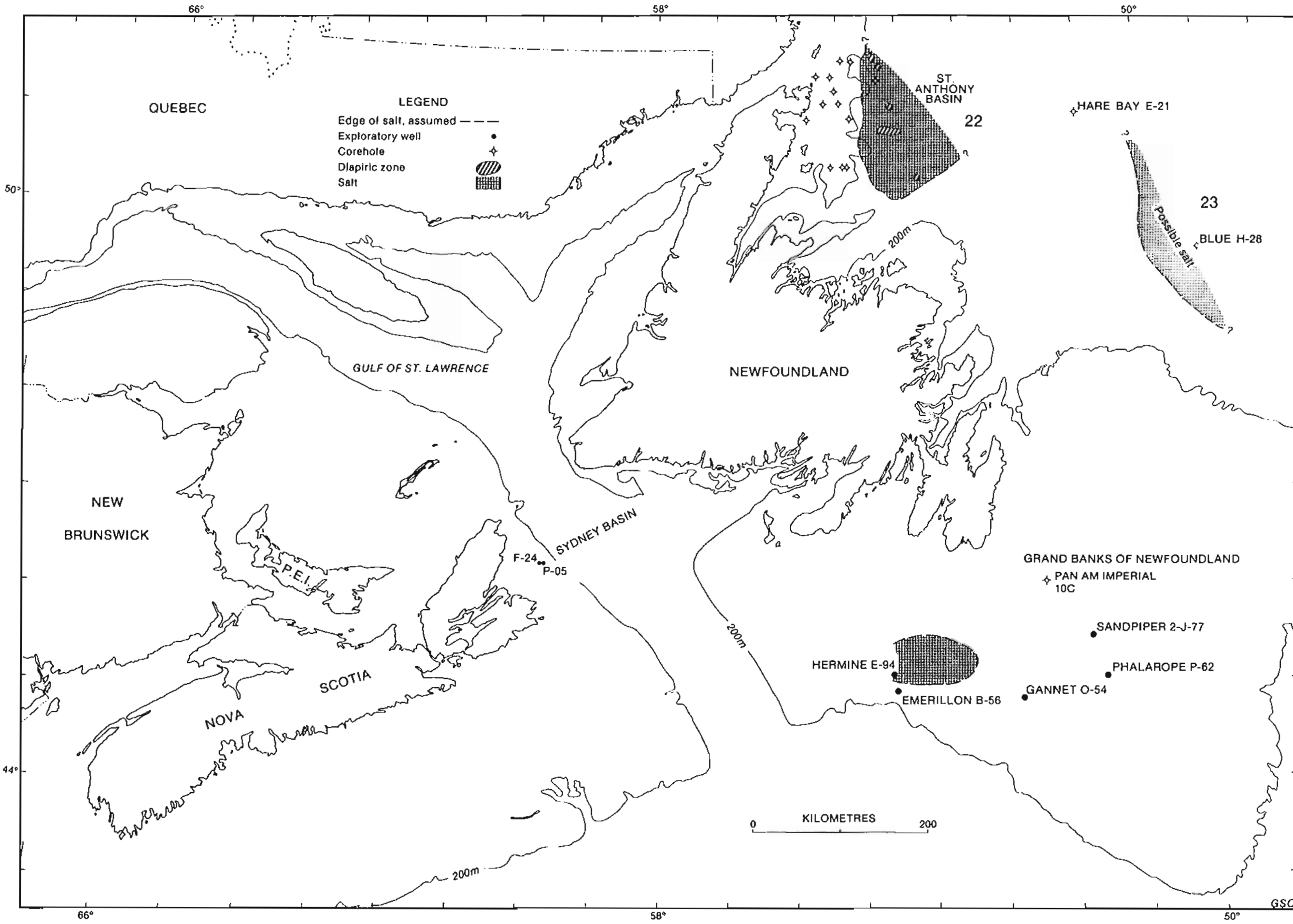


Figure 17. Present distribution of Windsor Group salt, Atlantic offshore.

Windsor Group throughout the Atlantic region. Farther to the east in the same subbasin where the group is virtually undeformed, Giles and Boehner (1979) estimated 760 m of Windsor section based on drillhole data.

Wells drilled on a variety of structures in the Gulf of St. Lawrence, Prince Edward Island, southern New Brunswick, west and south Cape Breton Island and northern Nova Scotia have penetrated as much as 2134 m of Windsor Group clastics and evaporites (Howie and Barss, 1975a). Seismic data from the Gulf of St. Lawrence indicate pillows, swells, ridges, domes and diapirs of Windsor salt, in some cases estimated to exceed a thickness of 4800 m. The thickest accumulation on land probably occurs in the Cumberland subbasin where over 6000 m of Windsor strata are believed to be present. The greatest cause of local variations in thickness is the halokinetic behavior of salt, brought about by post-depositional tectonism.

General stratigraphy of the Windsor Group

The stratigraphy of the Windsor Group was poorly understood until a fairly complete and virtually undeformed section was drilled in the Stewiacke area of the Minas subbasin, Nova Scotia. Based on lithostratigraphy and paleontological data, Giles (1981b) was able to recognize five major depositional cycles (Fig. 18). This broader perspective provided time-significant subdivisions for paleontological reconstructions, because the lower boundaries of the cycles coincided reasonably well with biostratigraphic boundaries as determined by independent studies (Adams, 1978; Bell, 1929; Globensky, 1967; Mamet, 1970; Moore, 1967; Moore and Ryan, 1976: Ryan, 1978; Sage, 1954; Stacey, 1953; Utting, 1978, 1980; von Bitter, 1976). These cycles have also been correlated with similar major transgressive-regressive cycles of the Dinantian in Britain, where they correspond approximately with recently defined stages (Giles, 1981b).

Windsor Group may be defined as a succession of marine to nonmarine strata bounded at the base by laminated carbonate or lateral equivalent carbonate, and at the top by the youngest marine limestone.

The first or lower cycle, as described by Giles (1981a) is an evaporite-dominated sequence up to 500 m thick. In ascending order it comprises a basal carbonate typified by its ubiquitous laminations and peloidal character that is

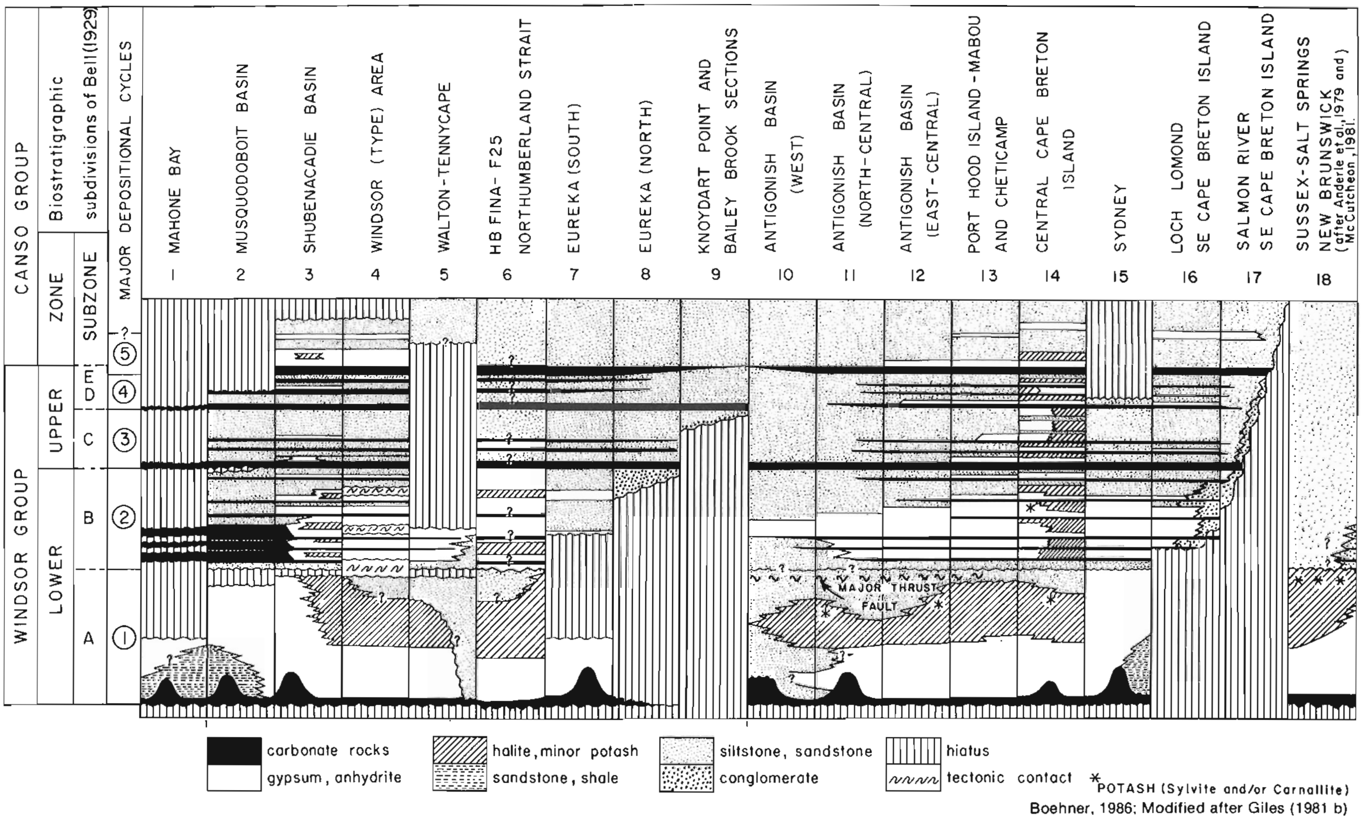


Figure 18. Lithostratigraphy and major cycles of the Windsor Group in Nova Scotia and southern New Brunswick.

generally about 6 m thick and may thicken to about 60 m as a biohermal facies (Giles and Boehner, 1979; Giles et al., 1979). The limestone is overlain by a 'basal anhydrite' locally up to 396 m thick. This anhydrite facies, which has a remarkably uniform lithology, contains minor intercalations of grey-green argillaceous dolostone and siltstone at irregular intervals. The anhydrite is overlain by salt with interbeds of anhydrite and siltstone. On the eastern end of the Minas subbasin a near-horizontal bedded salt section is approximately 305 m thick (Howie, 1985). This represents the most complete section of undeformed salt drilled to date (Fig. 18, area 3). In some areas the sequence contains potash. Regionally these rock units, which constitute cycle 1, reflect a trend towards increased salinity which in some areas may culminate in arid-flat sedimentation and subaerial exposure (Giles and Boehner, 1979). This cycle also approximately coincides with faunal subzone A of Bell (1929).

Cycle 2 is a complex succession of interbedded anhydrite, gypsum, salt, limestone, dolomite, siltstone and fine-grained sandstone up to 185 m thick. In this transgressive-regressive marine sequence, which has anhydrite as the dominant rock type, there is a gradual upward increase in the proportion of terrigenous rocks. The highly fossiliferous carbonates in the lower part of the cycle gradually give way to thinner and more marginal marine-type beds. The section may also contain two or three thin salt horizons (Fig. 18, area 3). According to Giles (1981b), cycle 2 approximately coincides with macrofaunal subzone B of Bell (1929).

Cycles 3, 4 and 5 disconformably overlie cycle 2 (Fig. 18, area 3). Although they resemble cycle 2, there is a gradual upward decrease in the proportion of evaporite and an increase in arenaceous and argillaceous material (Boehner 1986; Howie, 1986b). This transgressive- regressive succession of siltstone, carbonate and minor evaporite contains up to 9 mini cycles with a combined thickness of up to 160 m (Boehner, 1986). Cycles 3 and 4 are approximately equivalent to subzones C and D and the lower part of subzone E. Cycle 5 appears to be equivalent to the remainder of subzone E and extends up into the lower part of the Canso Group. In the Shubenacadie area some salt is present in cycle 5 which is part of the Canso Group.

Although the lithology of cycles 1 through 5 may represent a mainly marine sequence, the high arenaceous and argillaceous content reflects the proximity to a provenance area.

The paleontological reconstructions for the Windsor Group are based primarily on Nova Scotian stratigraphy because the province contains the original type section of Bell (1929) as well as the most complete section observed in drill core. The Windsor Group as described by Anderle et al. (1979), Gussow (1953), Hamilton (1961b), Kingston and Dickie (1979), McCutcheon (1981, 1983), Waugh and Urquhart (1983), and Webb (1977, 1984) for New Brunswick, by Brisebois (1981), Carbonneau (1977), Gagnon (1981), Gagnon et al. (1984) and Tiphone (1970) for the Îles de la Madeleine, by Bell (1948b), Fong (1974) and Knight (1983) for Newfoundland, will be discussed later.

WINDSOR GROUP EVAPORITES

In the Early to Middle Viséan the Windsor sea flooded the Magdalen Basin and adjacent low-lying areas of the present continental shelf, where restricted circulation and intense evaporation led to the deposition of evaporites over a wide area. The present distribution of Windsor salt is outlined in Figure 19. The shaded areas are salt domes, lenses, diapirs, anticlines or walls of salt. The numbers correspond to the areas being discussed in this report. As indicated, most of the salt is preserved in the Gulf of St. Lawrence in the northeast-trending Magdalen Basin that extends from northern Nova Scotia to western Newfoundland. The inferred present distribution of Windsor Group salt on the continental shelf south and northeast of Newfoundland is shown in Figure 17.

The onshore deposits, some of which are outliers due to post-depositional erosion, are considered to be remnants of a regionally more extensive evaporite sequence. Deposits in

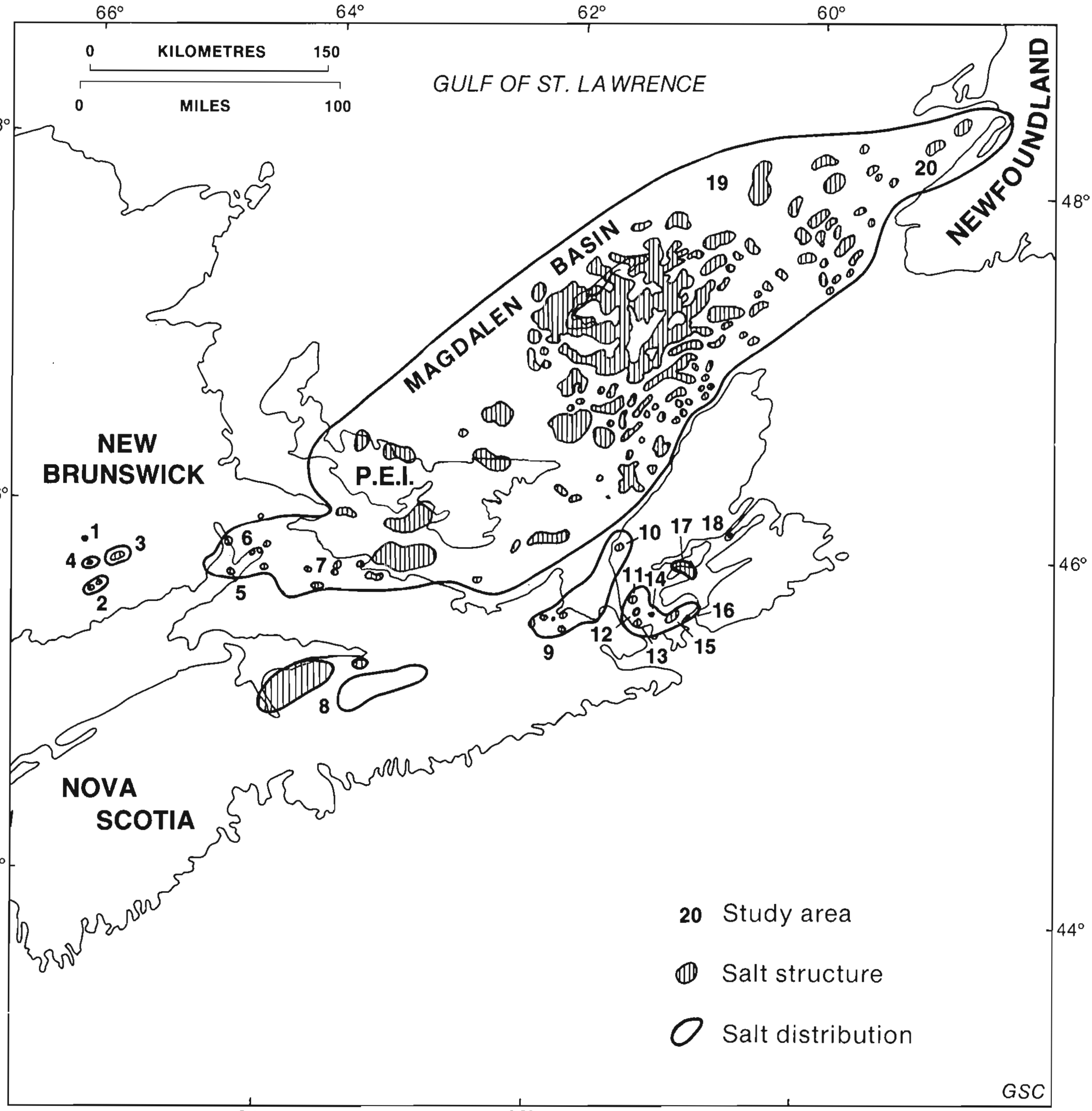


Figure 19. Present distribution of Windsor Group salt, Atlantic Provinces and Gulf of St. Lawrence.

southern New Brunswick, northern Nova Scotia, southern and western Cape Breton Island, Prince Edward Island and western Newfoundland appear to contain mainly deformed salt structures. In the eastern part of the Minas subbasin of Nova Scotia, salt and other evaporites are mainly bedded, undeformed deposits overlying a small segment of the stable Nova Scotia platform. The volume of data compiled for each area reflects the availability of information rather than the complexity of the occurrence.

1. Codys area, New Brunswick

Codys is on the New Brunswick Platform about 30 km northwest of Sussex (Fig. 19, 20). Although this is now outside of the area usually considered to contain Windsor Group salt, it has been included because it contains a number of gravity lows which in other areas often correspond to thick deposits of salt. This area is underlain by a pre-Carboniferous basement complex and Horton to

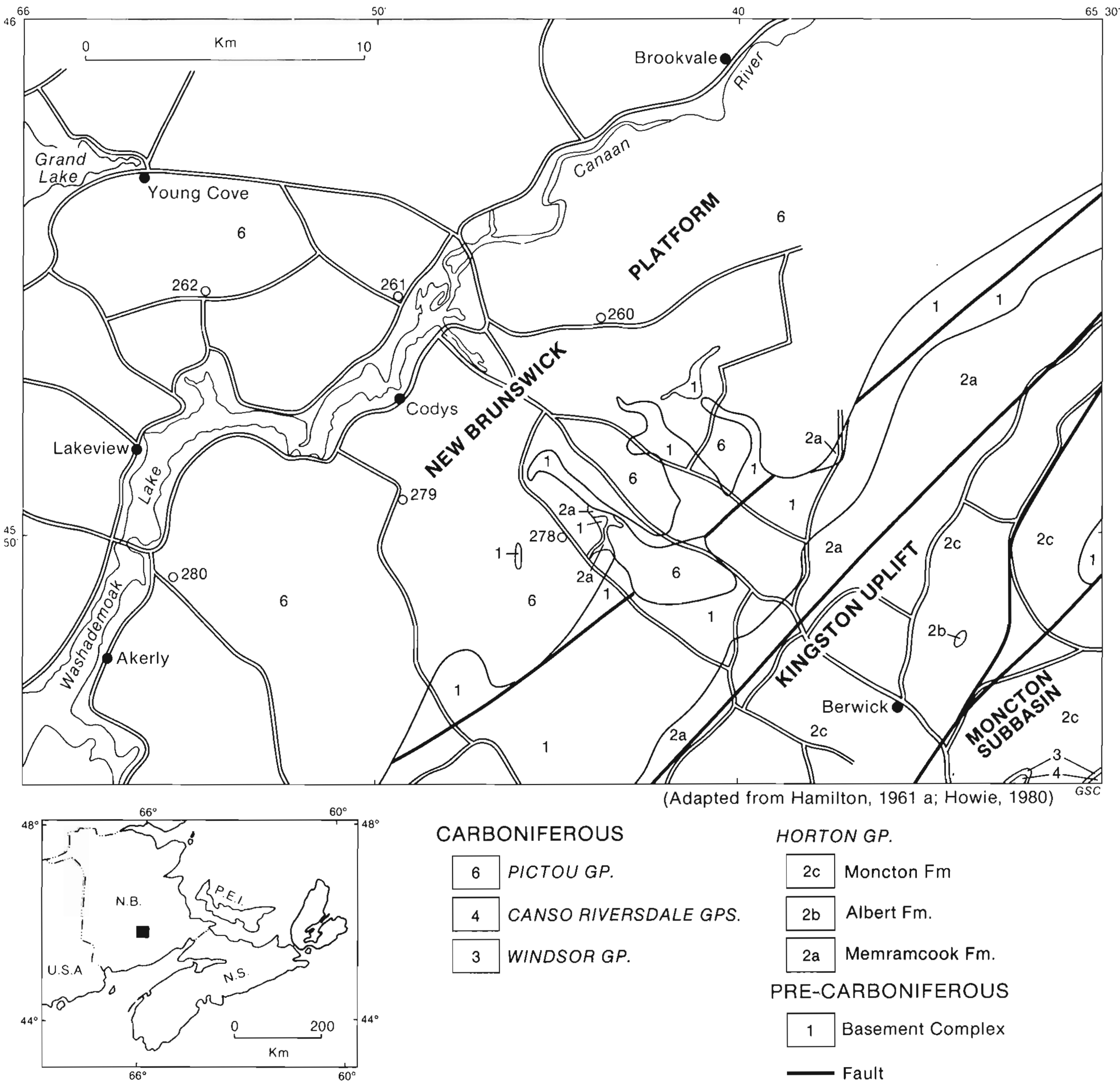


Figure 20. Geological map, Codys area, New Brunswick.

Pictou group Carboniferous rocks (Hamilton, 1961a). As indicated by the fault system, the structural trend is northeast. The Kingston Uplift is a fault- controlled structural high that separates the Moncton subbasin on the southeast from the New Brunswick Platform on the northwest. The post-tectonic erosional surface of the basement complex, exposed along the northwest side of the Kingston Uplift and to some extent on the adjacent New Brunswick Platform, undergoes a gradual decrease in elevation from uplift to platform. Outliers and extensions of the basement complex on the platform east of Codys indicate that this part of the platform is covered by only a relatively thin veneer of sediments.

Regional isopach maps of the Upper Paleozoic rocks in Atlantic Canada, prepared by Howie and Barss (1975a, Fig. 3-6), suggest that Pictou Group rocks on this part of the New Brunswick Platform directly overlie the pre-Carboniferous basement except near the southwestern corner of Codys map area where in the Lakeview-Ackerly district, varying amounts of Horton and Pictou group rocks may be present.

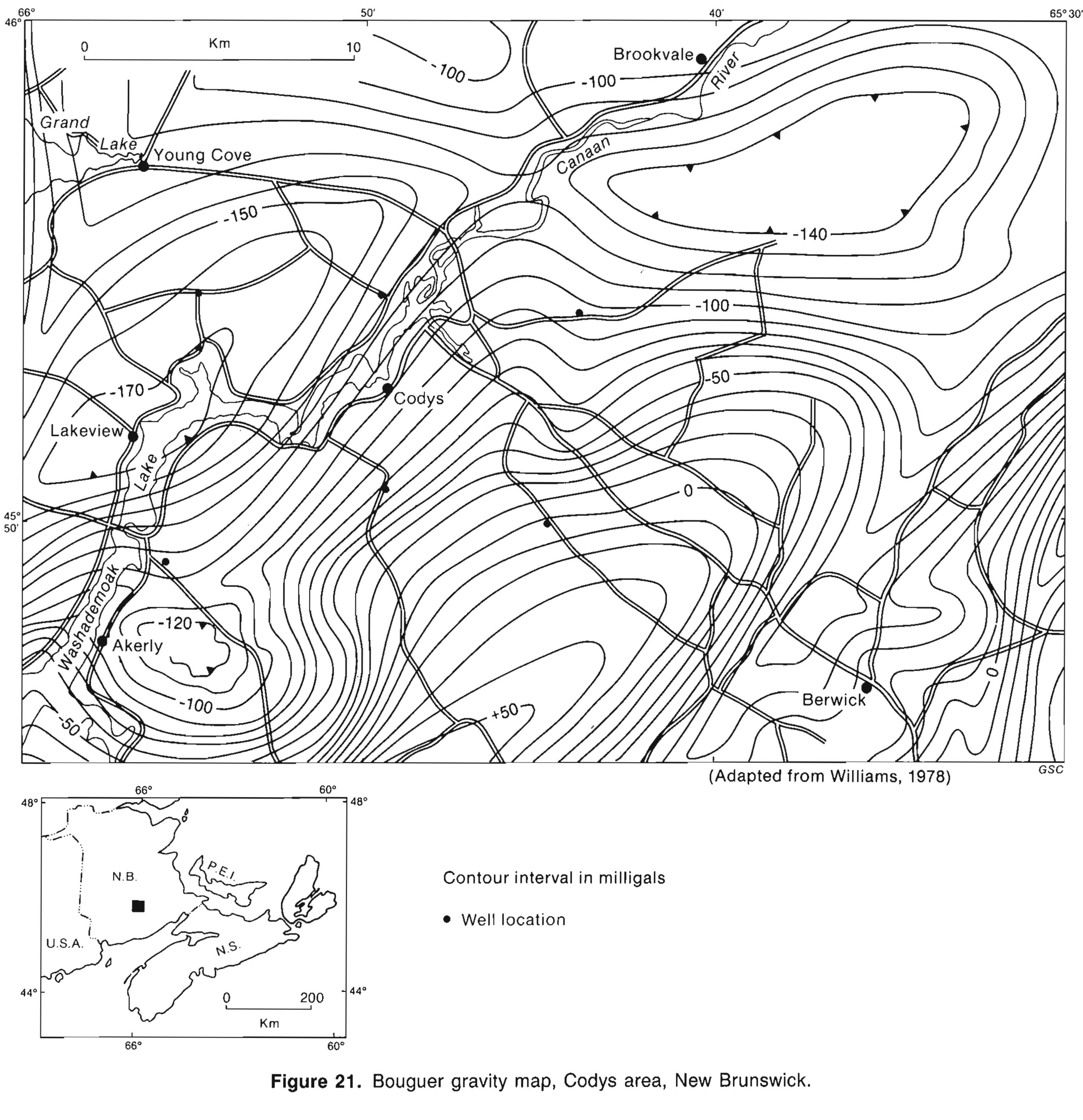
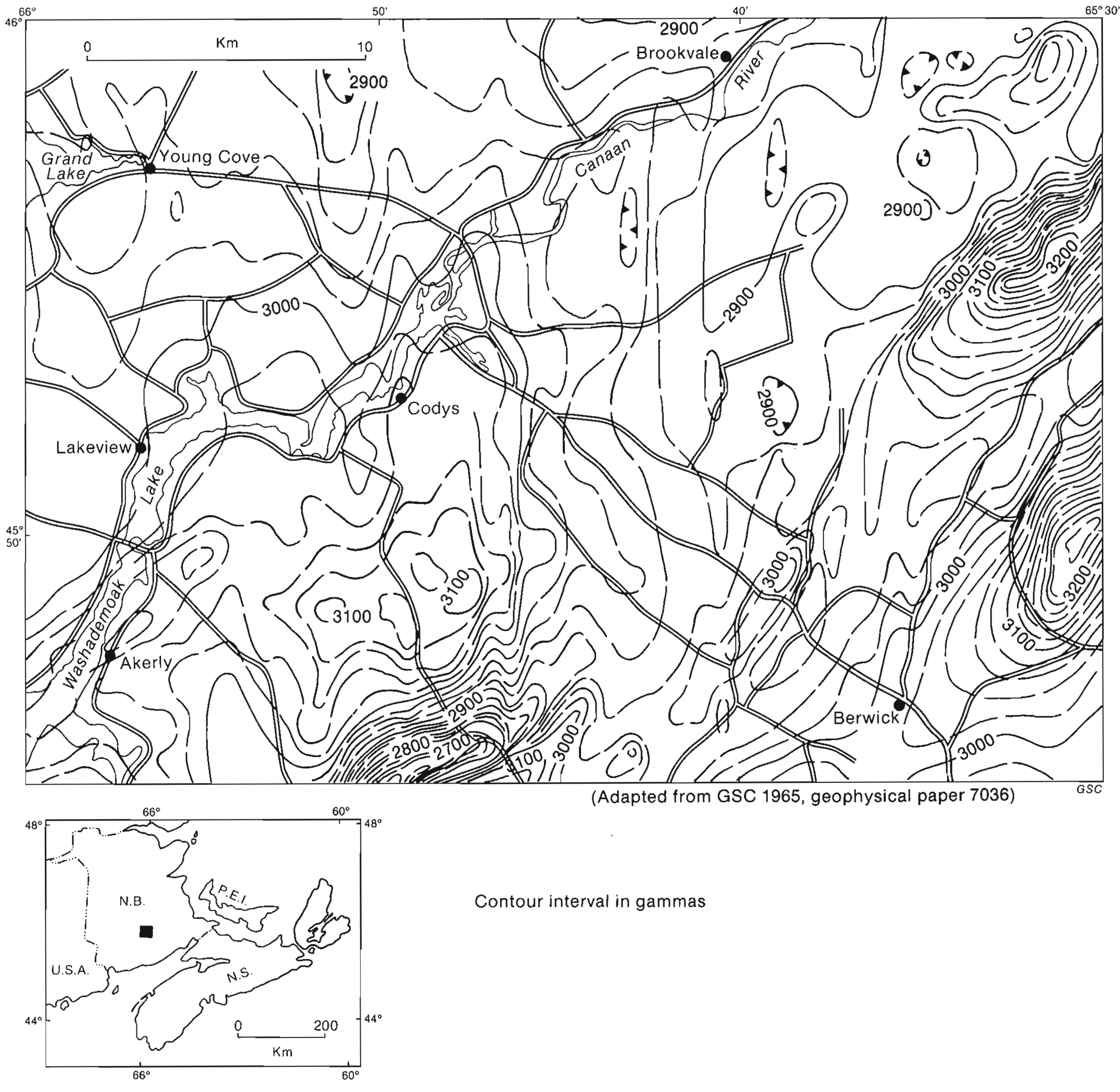


Figure 21. Bouguer gravity map, Codys area, New Brunswick.

McCutcheon (1983) also suggested that there may be some Windsor Group sediments in this district. Kingston and Dickie (1979) suggested that most of the platform area is overlain by the Windsor Group.

A Bouguer gravity map (Fig. 21) indicates a northeast-trending positive anomaly coincident with the basement zone exposed on the Kingston Uplift. The platform area adjacent to the northwest is dominated by three strong gravity lows: -140 milligals south of Brookvale, -120 milligals east of Ackerly, and -170 milligals at Lakeview (Williams, 1978). The range of values from the uplift to the platform exceeds 200 milligals. This is at least 10 times the magnitude of the anomaly observed over the Plumweseep-Penobsquis salt deposit in southern New Brunswick or over the Minudie-Malagash salt cored anticlines in the Amherst-Malagash area of northern Nova Scotia which contain approximately 2000 and 4000 m of Carboniferous sediments, respectively. It should be considered that these large gravity anomalies relate primarily to something other than salt. Gravity lows of this magnitude appear to coincide with the Middle Devonian granite (St. George intrusives), that



Contour interval in gammas

Figure 22. Aeromagnetic map, Codys area, New Brunswick.

outcrop in southern New Brunswick at Central Tower Hill, 3 km east of Rolling Dam Station and 3 km south of Oromocto Lake (Williams, 1978, Plate 78-42b; MacKenzie and Alcock, 1960). It is suggested that the three gravity lows in the Codys area may also be more closely related to anomalies within the basement than to a thick section of low-density Windsor Group evaporites. Although the gravity anomalies have not been drilled, four holes have penetrated to the base of the Carboniferous and two others have been completed in the Carboniferous (Fig. 20) as part of the regional study for coal and mineral potential in New Brunswick (Ball et al., 1981). Holes No. 260 and 278 were completed in the Canso-Riversdale groups at 100.6 and 73.2 m, respectively. Holes No. 261 and 279 were both completed in the Pictou Group at 109.8 and 91.4 m. Holes No. 262 and 280 were completed at 122.3 and 118 m in the Pictou Group without penetrating to the basement. About 5.5 km south of Akerly (just south of the southern limit of Fig. 20), hole No. 292 was spudded in the Pictou Group and completed in Canso-Riversdale group rocks at 54 m.

The data obtained from the drillholes indicate that much of the New Brunswick Platform in the Codys area is overlain by a fairly thin veneer of Carboniferous sediments. It therefore seems unlikely that part of the Brookvale, Lakeview and Akerly anomalies can be attributed to a thick section of Windsor Group evaporites unless there are a number of basement topographic lows due to local downwarping of the pre-Carboniferous basement and/or graben structures.

The aeromagnetic map (Fig. 22) includes three prominent anomalies associated with the Kingston Uplift. Peak values for these range from 2700 to 3200 gammas. Contours on the platform indicate a relatively smooth magnetic field. The magnetic differences between the two areas can probably be attibuted to a change in basement rock type rather than masking of the platform area by a thick section of Carboniferous rocks.

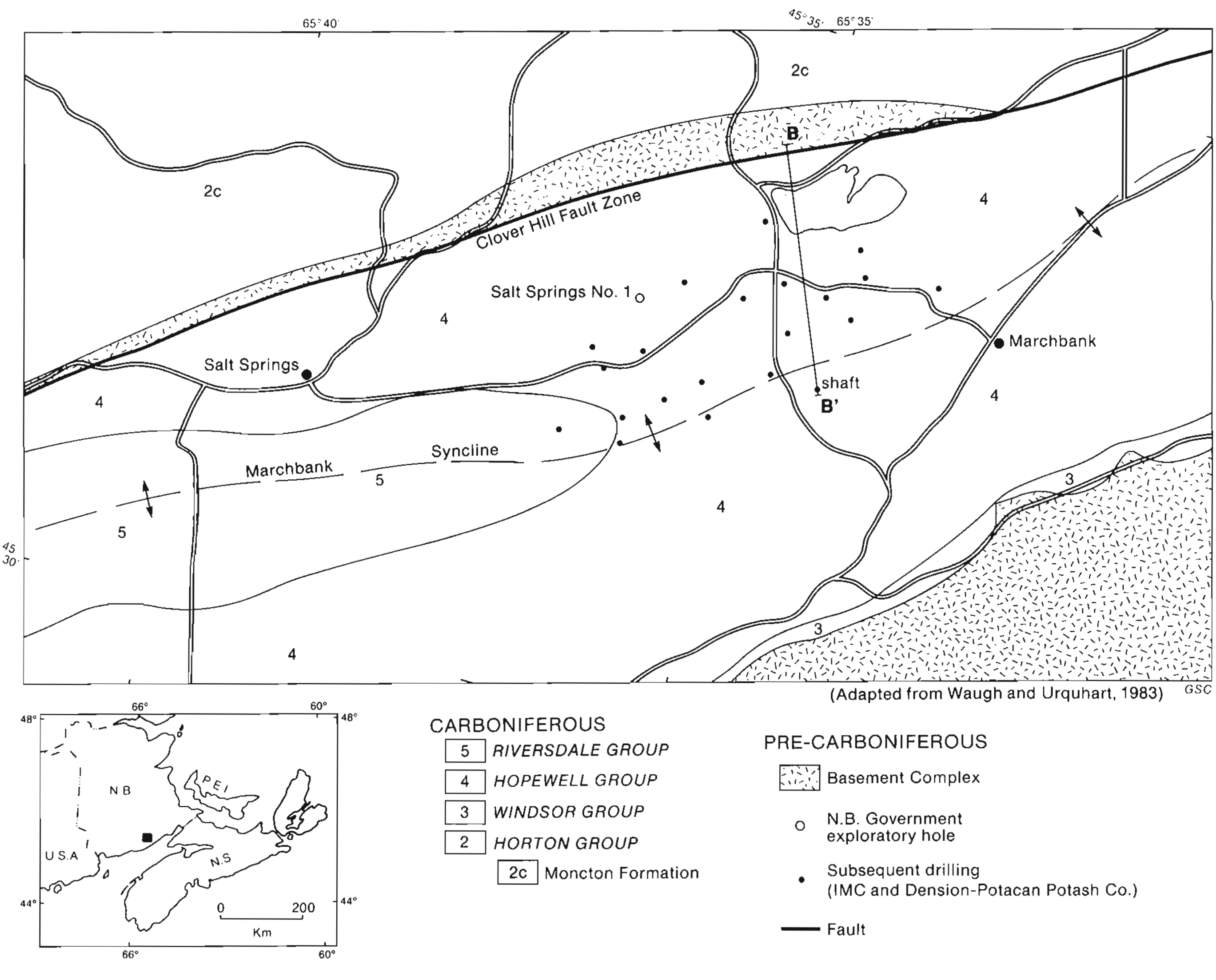


Figure 23. Geological map of the Salt Springs area, New Brunswick.

2. *Salt Springs area, New Brunswick*

The Salt Springs area, located in the Marchbank syncline about 19 km southwest of Sussex, was a source of salt from brine springs dating back to early settlement of the area (Dawson, 1868). Salt was reported to have been of excellent quality, but production was limited and often short lived, depending on the seasonal variations in the groundwater. In an effort to improve the quantity of the brine, a number of shallow holes were drilled around 1895. The deepest penetrated a near-vertical gypsum-sandstone sequence before it was completed at 100 m. Although the drillholes did not intersect salt, the abundance of gypsum observed in outcrop and in the subsurface, was considered to warrant some deeper drilling (Hamilton, 1961b).

A geological map of this area (Fig. 23) indicates the Marchbank syncline is underlain by Carboniferous rocks that range in age from the Horton Group to the Canso-Riversdale groups. This northeast-trending structure, bounded to the south by the Caledonian pre-Carboniferous complex, and to the north by the Clover Hill fault zone, has a maximum width of 7 km and can be traced for 38 km (Waugh and Urquhart, 1983).

The presence of a fairly extensive subsurface section of Carboniferous rocks thought to contain Windsor Group evaporites was interpreted for this area in a 1971-72 gravity survey (Chiasson, 1975). Figure 24 is from a Bouguer gravity anomaly map of southern New Brunswick adapted from Williams (1978). The area considered to contain a fairly thick sequence of relatively low density sediments is shown as a fairly large gravity low. An aeromagnetic map of the same area (Fig. 25) also indicates a small magentic anomaly in the same area, attributed to a slight variation in the basement complex or/and a fairly thick blanket of Carboniferous sediment.

The Salt Springs No. 1 well, jointly funded by the Federal Department of Regional Economic Expansion and the New Brunswick Department of Natural Resources, was drilled in 1973 in order to check the results of the previous

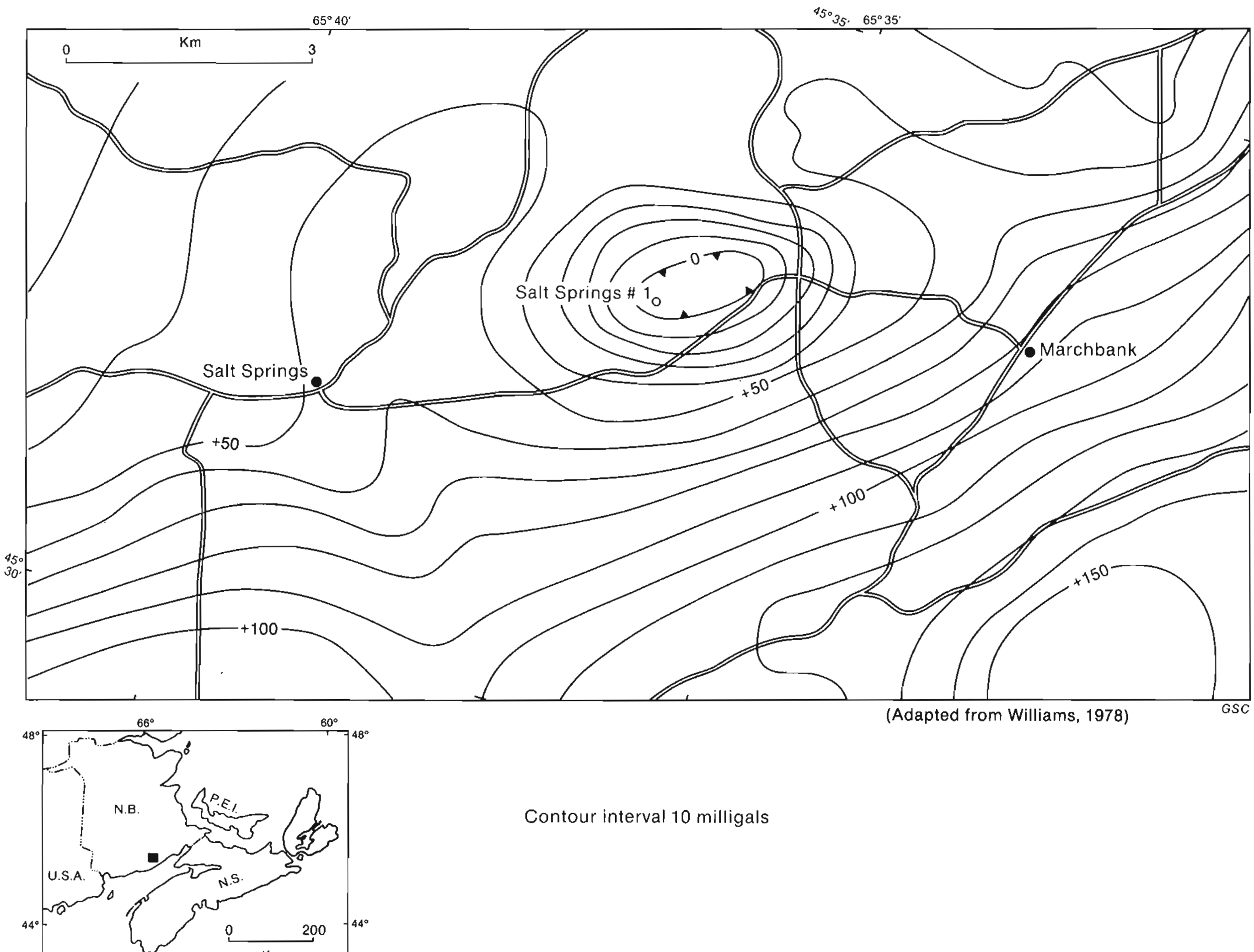


Figure 24. Bouguer gravity map, Salt Springs area, New Brunswick.

gravity survey (Crosby, 1975a). This drillhole intersected salt at 605.8 m and 15.5 m of potash averaging 31.6 % K_2O equivalent between 608 and 623 m. The hole was abandoned in Windsor Group salt at 914 m. The location of this well and subsequent exploratory drilling are as shown on Figure 23. The Salt Springs deposit is the host of New Brunswick's second potash mine operated by Denison Potacan Potash Company. Production at the mine began in 1985.

Drilling and geophysical reports on the Clover Hill property indicate the Marchbank syncline contains about 1800 m sediment of Carboniferous age. Figure 26 is a stratigraphic correlation of the Windsor Group in the Salt Springs and Plumweseep-Penobsquis area. Although not shown on this chart, regional mapping indicates the Windsor Group is paraconformably underlain by Horton Group rocks that lithologically vary from conglomerate to shale (Fig. 5).

The basal Windsor Group beds of the Macumber Formation (McCutcheon, 1981) consist of massive to bedded limestone which is overlain by the basal anhydrite of the Upperton Formation (Fig. 26). The combined thickness of the two members may exceed 240 m (Kingston and Dickie, 1979). The salt and sylvinite beds of the Cassidy Lake Formation, which conformably overlie the Upham Formation, have been divided into four members: Basal Halite, Middle Halite, Potash, and Upper Halite (Roulston and Waugh, 1983).

The Basal Halite member is generally light grey in colour to clear, with some interbeds of argillaceous clay that increases up section. Danburite nodules 2-5 mm have been observed near the base of the section (Waugh and Urquhart, 1983). Due to salt flowage this unit varies in thickness from about 1 m on the south flank of the deposit to over 150 m in the centre of the structure. The Middle Halite, which forms a gradational contact with the lower salt member, is represented by interbanded clean and argillaceous salt, which becomes entirely argillaceous in the upper part of the sequence. Some bedding planes have been slightly disrupted due to slumping. The thickness of this unit varies from 24 to 75 m.

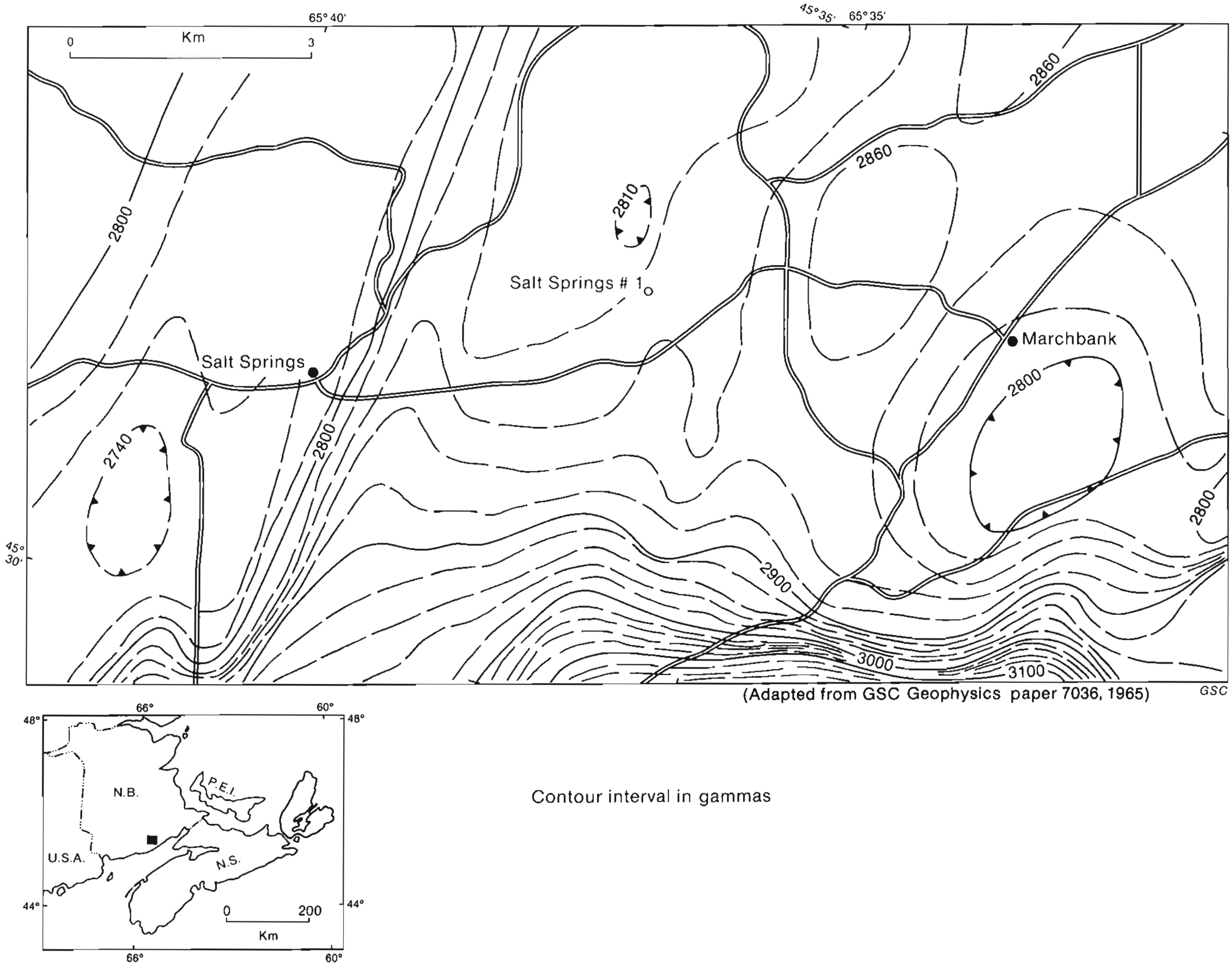


Figure 25. Aeromagnetic map, Salt Springs area, New Brunswick.

The Potash member, which represents the only major potassium-bearing salt unit in the Marchbank syncline, is up to 50 m thick. It has been divided into a lower gradational potash bed and a sylvinite bed. The lower gradational bed is composed of light brown to orange salt similar to the middle salt member, but it also contains randomly distributed clusters of sylvinite from 1 to 10 cm in diameter. These clusters increase in number up section but with some sporadic barren intervals. The actual potash content varies from less than 5 % to about 10 % K_2O equivalent in beds from 1 to 25 m thick.

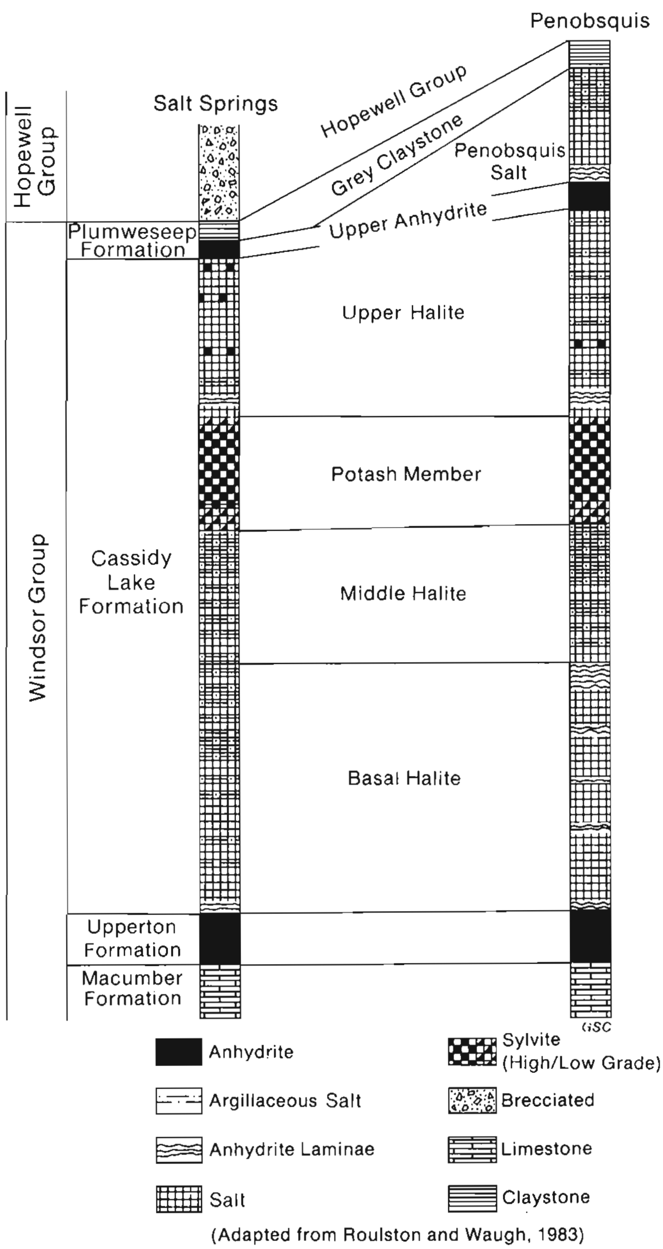


Figure 26. Stratigraphic correlation of Windsor Group salt in the Plumweseep — Penobsquis and Salt Springs area, New Brunswick.

The sylvinite bed is a homogenous interval composed almost entirely of sylvinite and salt crystals with only about 1 % disseminated clay. The sylvinite crystals range in size from 2 to 5 mm. The sylvinite bed has been subdivided from bottom to top into zones A to E, of which B and C are the main ore zones (Waugh and Urquhart, 1983) comprising a thickness of about 12 to 15 m.

The Upper Halite, a very distinct heterogeneous sequence, overlies the potash member. It is composed of orange and brown salt with interbeds of argillaceous salt, red sylvinite beds and laminae, and some claystone and anhydrite laminae. A distinctive borate mineral assemblage is also unique to this interval. Although the unit may be highly deformed with complex internal folding, the maximum thickness is estimated to be about 60 m.

The contact of the Upper Halite member of the Cassidy Lake Formation with the overlying upper anhydrite and grey claystone members of the Plumweseep Formation is a dissolution zone 0.5 to 1.5 m thick. This contact may vary from conformable to unconformable depending on the flowage of the Upper Halite member. The upper anhydrite and claystone as a bedded deposit varies in thickness from 7.5 to 13 m or as a collapse breccia composed of siltstone, claystone and anhydrite to 18.5 m (Waugh and Urquhart, 1983). The upper contact of the Plumweseep Formation with the Hopewell Group is a conformable gradational contact. The Hopewell Group, a lateral equivalent of the Canso Group, consisting of red-brown siltstone and sandstone in the Marchbank syncline is about 915 m thick.

Cross-section B-B' (Fig. 27) indicates the salt and potash deposit is part of a synclinal structure terminated to the northwest by the Clover Hill fault zone which has a vertical displacement of over 900 m (Anderle et al., 1979). The salt pinches out to the northeast and south and is undefined to the southwest. Post-Windsor movement along the fault zone has influenced the formation of some diapiric and overturned structures (Anderle et al., 1979). Although it is not obvious from the cross-section, the strike of the folded salt mass is northeast, which is approximately parallel to the regional trend for the Carboniferous rocks in the Moncton subbasin.

The Marchbank syncline appears to have been a topographic depression flooded by the Windsor sea and separated from other original depressions by extensive areas of shallow water (Roulston and Waugh, 1983). The thick succession of carbonate and sulphate beds, overlain by rock salt and in some cases potash, suggest fairly stable tectonic conditions. The relatively low content of terrigenous material associated with the salt suggests the depositional basin was protected or was a considerable distance from an active provenance area. The gradual increase in the anhydrite laminae in the younger beds of the upper salt, followed by the upper anhydrite indicates a gradual return to a normal marine environment. Salt has not been found above the upper anhydrite member in the Salt Springs area.

3. *Plumweseep-Penobsquis area, New Brunswick*

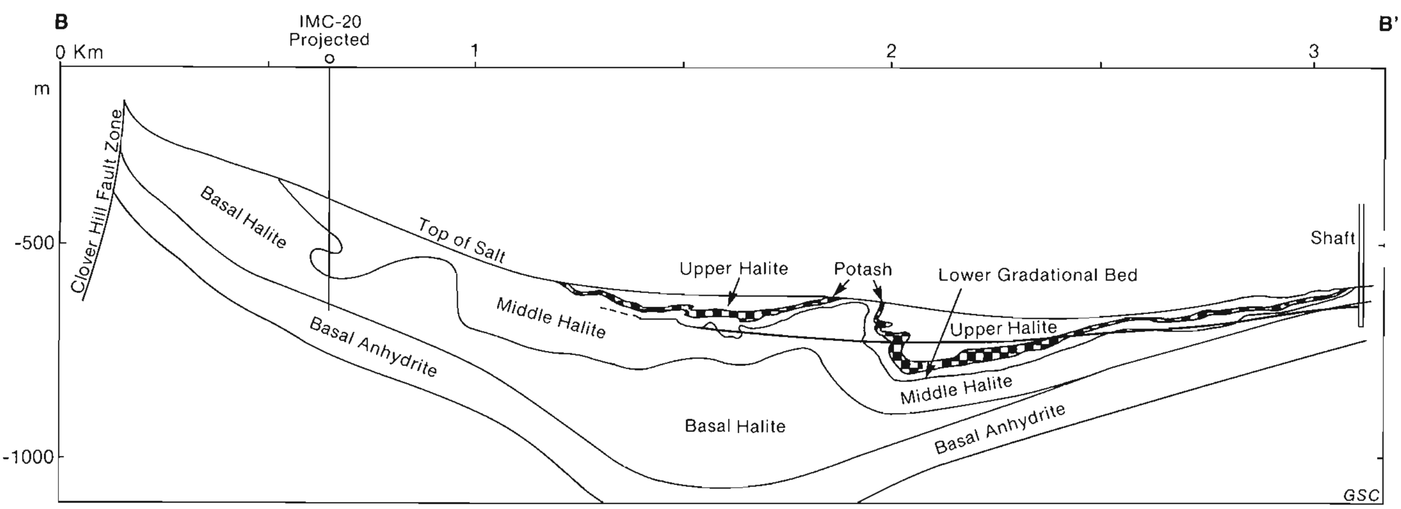
Well over 100 years ago, brine from salt springs in the Plumweseep area, 5 km east of Sussex, was evaporated as a source of salt for the local dairy industry. Production was sporadic and limited, but it continued until shortly after the turn of the century. From 1887 to 1945, five holes varying in depth up to 149 m were drilled in hope of locating the source of the brine. Unfortunately, none intersected salt. Shortly before World War I (1914-1918) another attempt was made to locate the salt by sinking a shaft, however it was abandoned at 12 m (Hamilton, 1961b).

The Plumweseep-Penobsquis salt deposits are near the western end of the northeast-trending Moncton subbasin (Fig. 28), in an area locally referred to as the Dunsinane synclinorium (Roulston and Waugh, 1983). This structure contains a thick succession of Carboniferous strata represented by the Horton, Windsor and Canso-Riversdale groups. A northeast-striking, salt-cored anticline known as the Anagance axis occurs near the middle of the syncline. This structureal feature, tracable for a strike length of at least 24 km, is considered to be the result of post-Windsor movement along the adjacent northeast-trending Kennebecasis Fault (Pickerill et al., 1985).

Gussow (1953) noted an intense elongated gravity minimum that was generally coincident with the anticlinal structure identified in the area (Fig. 29). He considered this to indicate an accumulation of low density material at relatively shallow depths. Numerous sinkholes and salt springs were used as additional evidence supporting the occurrence of subsurface evaporites. An aeromagnetic map of the same area indicates a relatively smooth magnetic field along the trend of the gravity low (Fig. 30). A prominant magnetic anomaly along the southeast corner of the map has a range of 2900 to 3100 gammas. The magnetic difference in the two areas is attributed to a change in the basement rock and/or masking of the basement complex by a fairly thick section of Carboniferous rocks.

In 1971 the New Brunswick Department of Natural Resources in conjunction with the Canadian Department of Regional Economic Expansion drilled two exploratory holes in the Plumweseep-Penobsquis anticlinal structure. Gravity reports by Konecny (1970) and Burke (1971) were used to position the Plumweseep No. 1 and the Penobsquis No. 1 holes on a gravity low along this structure. Plumweseep No. 1, drilled near the crest of the anticline, penetrated the entire Windsor evaporite section before it was completed in Horton Group rocks at 914 m. The hole was successful in intersecting a composite 21 m sylvinite zone from 277 to 305 m which was underlain by 491 m of massive salt, (Hamilton, 1971). The sylvinite with an average grade of 23.7 % K_2O equivalent, occurred in four beds varying in thickness from 2.7 to 10 m.

Although the second hole, Penobsquis No. 1 located about 7.5 km northeast of the Plumweseep hole did not encounter sylvinite, it did intersect 890 m of salt from 184 to 1074 m and was abandoned at 1172 m in Windsor Group limestone of the Macumber Formation. Salt grades in both holes assayed 96 to 99 % NaCl (Potter, 1980).



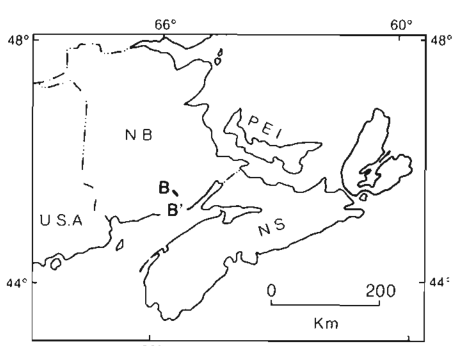


Figure 27. General northeast cross section through the Salt Springs Windsor Group salt deposit.

The Potash Company of America (PCA) obtained the potash rights to the Plumweseep-Penobsquis area from the New Brunswick government in 1973. This salt deposit is the site of New Brunswick's first potash mine which opened in 1983.

Cross-section A-A' (Fig. 31), compiled from data obtained from the exploratory holes, is located on the crest of the Anagance axis, northeast of the Plumweseep No. 1 hole. Top of salt is approximately 153 m below the surface at the shallowest point, and deepens to about 915 m down the flanks. The great thickness of the evaporites along the Anagance axis is attributed in part to salt flowage. An intraformational breccia (Unit 7, Fig. 31) on the crest of the anticline is interpreted to have been derived from the subsurface solution of salt and subsequent collapse of the overlying red beds onto the residual derived from the leached salt zone. This suberosion is considered to have removed over 150 m of salt and sylvinite (Kingston and Dickie, 1979). As a result sylvinite is now restricted to the anticlinal flanks in less leached areas. Throughout the Plumweseep-Penobsquis area, sylvinite has been intersected at depths ranging from 490 to 700 m below sea level (Webb, 1984a).

A generalized stratigraphic section of the Penobsquis Windsor Group evaporite section in conjunction with the Salt Springs section is shown in Figure 26. The basal unit is the Macumber Formation, composed of laminated to thinly bedded carbonates, which is in gradational contact with massive bedded anhydrite or claystone interbedded with anhydrite of the Upperton Formation. The complete section is in excess of 60 m (Roulston and Waugh, 1983).

The Upperton Formation is generally conformable with the Basal Halite member of the Cassidy Lake Formation.

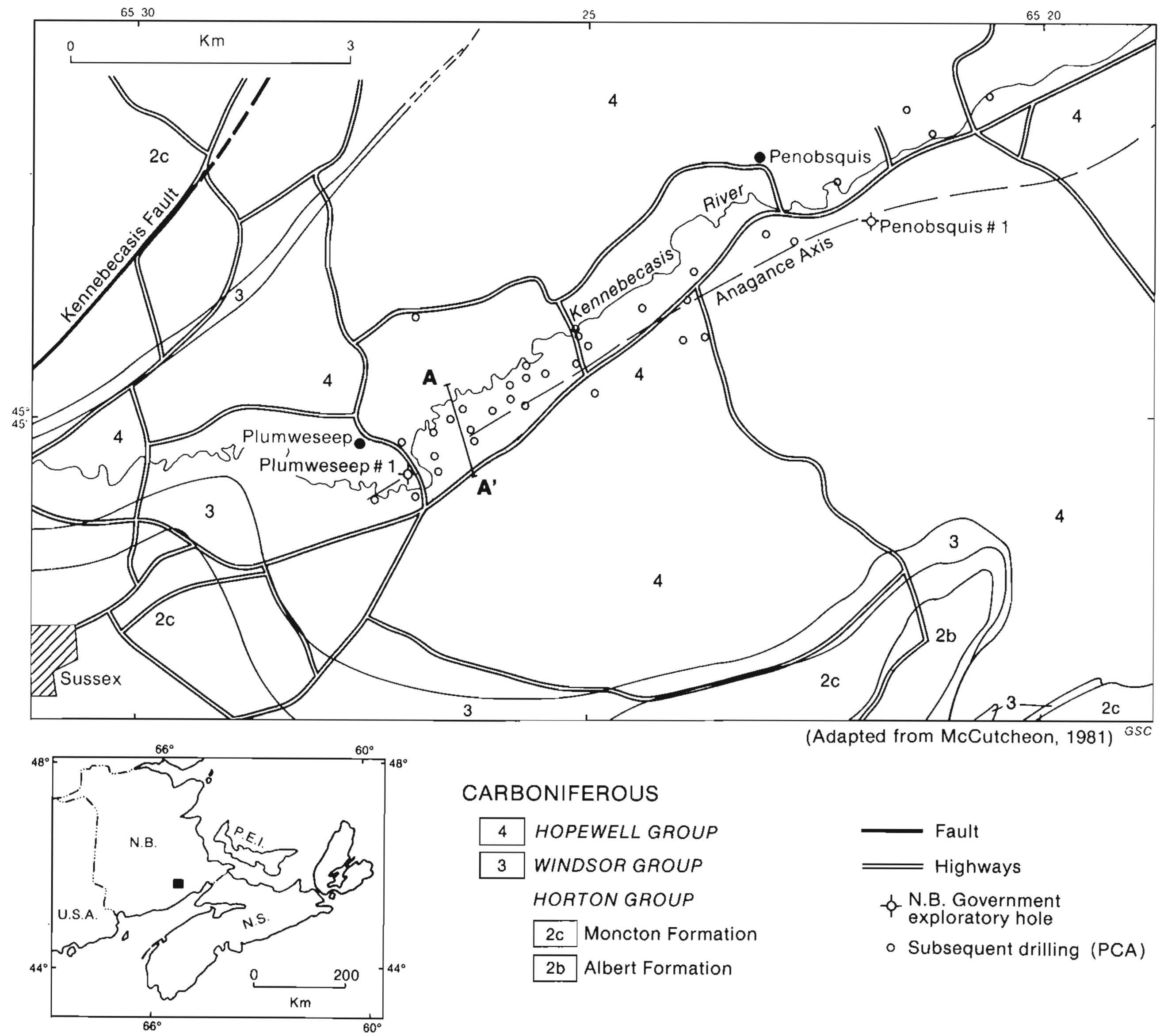


Figure 28. Geological map, Plumweseep — Penobsquis area, New Brunswick.

The contact between the salt and the anhydrite is quite distinct, although fine anhydrite laminae may extend 5 m up into the salt. The Basal Halite member is predominanatly clear salt with an average grade in excess of 98.5 % NaCl (Roulston and Waugh, 1983). The remainder of the unit comprises anhydrite laminae. The Basal Halite varies in thickness from 0 m on the margins of the basin to an estimated true thickness of around 200 m, and up to 1000 m due to flowage. A zone of interbedded anhydrite and clear salt is present at the contact with the Middle Halite.

The Middle Halite member consists of light red, brown to orange, medium- to fine-grained salt with 5 to 10 % interstitual and disseminated clay. The lower half of this member is represented by interbedded clean and argillaceous salt which gradually becomes entirely argillaceous over the upper half of the sequence. This member varies in thickness from less than 1 m to 60 m (Roulston and Waugh, 1983).

The Potash member overlies the Middle Halite member and includes gradational salt-sylvinite zones above and below the main ore zone. The overall thickness of the Potash member varies up to 50 m. This member has been divided into a Lower Gradational and the overlying Sylvinite bed which also includes low grade sylvinite beds above the main ore zone. The Lower Gradational bed is a distinctive stratigraphic layer up to 20 m thick, composed of light brown to orange salt with some red-rimmed, clear to white sylvinite crystals.

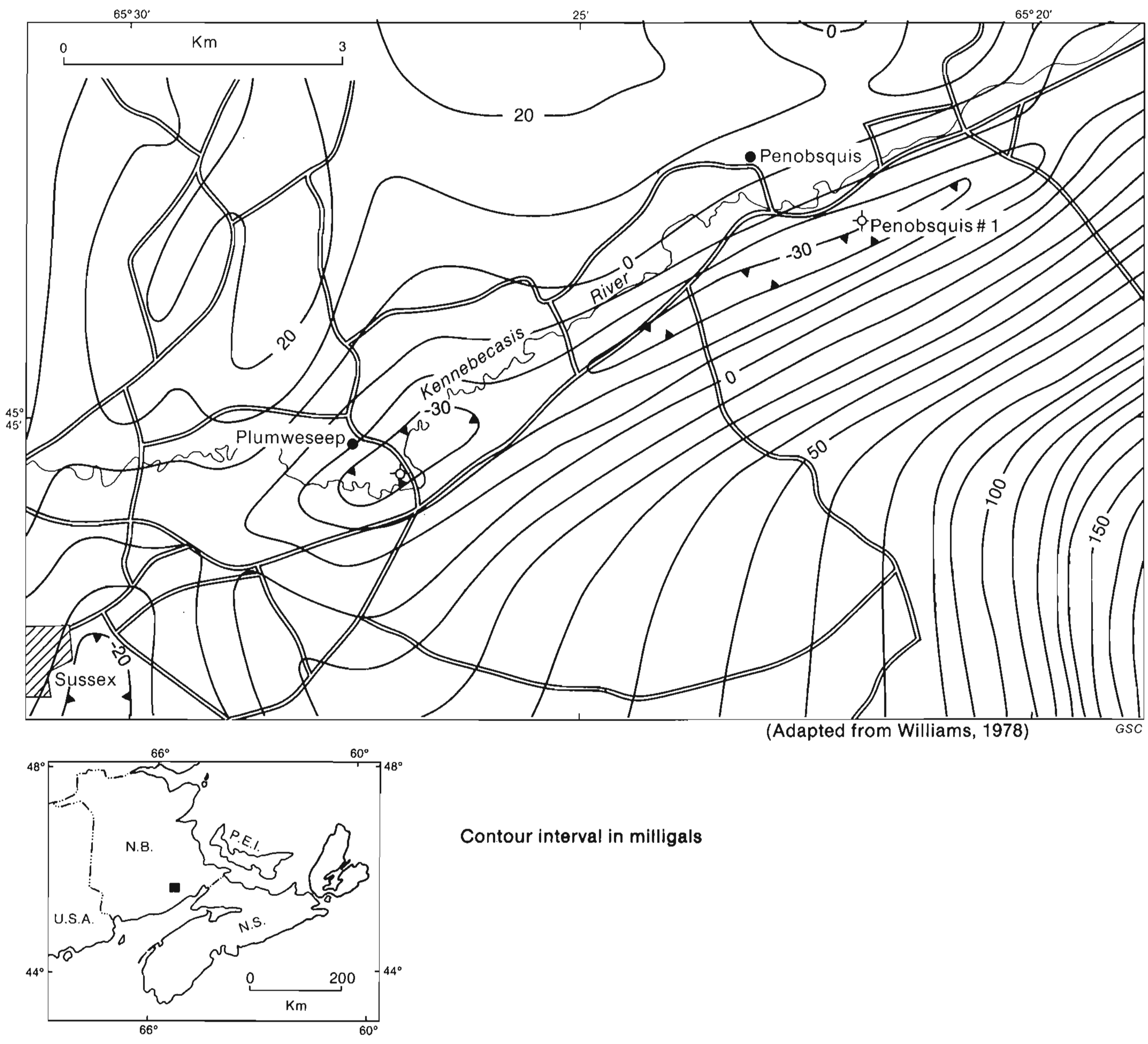


Figure 29. Bouguer gravity map, Plumweseep — Penobsquis area, New Brunswick.

The gradational contact between the Sylvinite bed and the Lower Gradational bed is usually less than 1 m. The sylvinite bed has been divided into zones A to D of which B and C are the main ore zones. The clay content varies from 0.5 to 4 % with an ore grade of 26 %, K_2O with an average thickness of 12 to 15 m (Roulston and Waugh, 1983). Interbedded sylvinite and barren salt form a gradational contact between the upper part of the Sylvinite bed and the overlying Upper Halite member.

The Upper Halite member is a heterogeneous interval composed of interbedded orange, brown and clear fine-grained salt to argillaceous salt, with some red fine-grained sylvinite claystone and grey anhydrite laminae. The estimated maximum thickness is about 70 m (Roulston and Waugh, 1983).

The contact of the Upper Halite member with the overlying Plumweseep Formation interpreted by Roulston and Waugh (1983) as a second evaporite cycle, is considered by T.C. Webb (personal communication, 1987) to be mostly recycled evaporites, due to an influx of freshwater into the basin. At the base of the formation the Upper Anhydrite consists of massive anhydrite with occasional thin argillaceous laminae (1 mm) areas of small scattered clear salt crystals. Although the Upper Anhydrite is at least 20 m thick

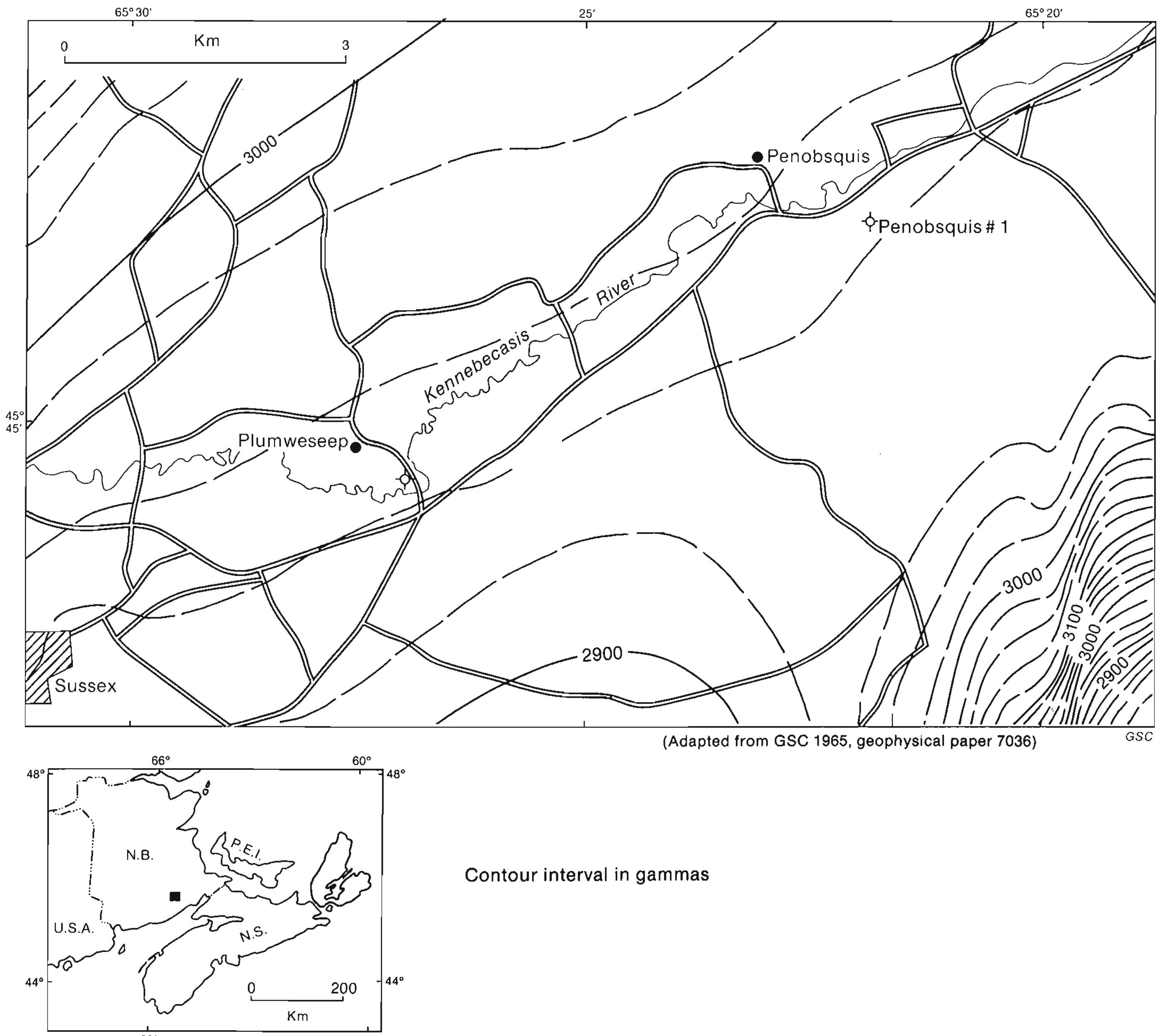


Figure 30. Aeromagnetic map, Plumweseep — Penobsquis area, New Brunswick.

at Penobsquis it thins outward from this area and does not seem to have been deposited over the western part of the basin (Roulston and Waugh, 1983).

The lower contact of the Penobsquis Salt member with the Upper Anhydrite is a 10- m gradational zone composed of light grey nodular anhydrite alternating with argillaceous salt. The ratio of anhydrite to salt in the eastern part of the deposit is about 70:30 and diminishes to about 10:90 in the west. Above the gradational zone the salt is coarse grained, clear to reddish brown with up to 30 % reddish brown clay fragments. The percentage of clay decreases slightly upward in favour of anhydrite. The upper contact is gradational over 10 m, consisting of finely laminated grey siltstone with scattered salt crystals and salt interbeds. Further up section the salt beds become increasingly argillaceous. The maximum measured thickness of the member is about 40 m (Roulston and Waugh, 1983).

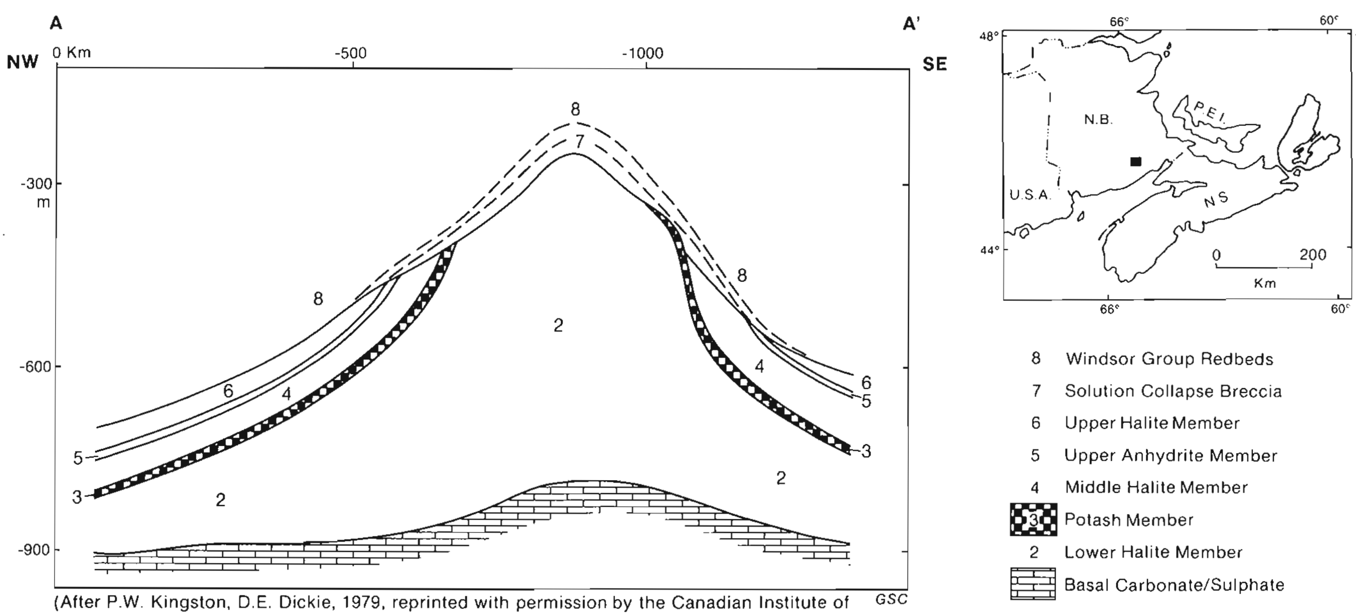
The Grey Claystone member in the upper part of the Plumweseep Formation is composed of finely laminated, greenish grey sandstone only a few metres thick. Minor internal breccias suggest post-depositional removal of salt. This claystone member in turn is overlain by red mudstone and minor gypsum and anhydrite of the Hopewell (Canso) Group.

Salt and potash deposits in the Plumweseep-Penobsquis and Salt Springs area (Fig. 26) display similar lithology, stratigraphic sequences, colour, texture and mineralogy (Kingston and Dickie, 1979), and are thought to have been synchronously deposited in separate restricted bays or lagoons in a highly saline lower Windsor sea (Anderle et al., 1979; Roulston and Waugh, 1983). The Plumweseep-Penobsquis area has three salt zones and the Salt Springs area has two, but this variance may be due to a slightly different post-depositional tectonic history. Both deposits contain a single, continuous, high grade sylvinite-bearing zone, and both contain boron minerals associated with potash in the Middle Halite member (Roulston and Waugh, 1981). In the upper part of the Windsor Group the stratigraphic section shown as the Plumweseep Formation is also the Clover Hill Formation of McCutcheon (1981).

4. Lower Millstream-Apohaqui area, New Brunswick

The Lower Millstream-Apohaqui area (Fig. 32), about 10 km south of Sussex is underlain by Horton to Hopewell Group rocks. The central part of this region is occupied by a dominant structural feature referred to as the Case Syncline. On the accompanying gravity map (Fig. 33) the southeastern part of this syncline corresponds to a 30 milligal negative Bouguer anomaly. The aeromagnetic map of the same area (Fig. 34) indicates that the steepest gradients also correspond fairly well to the western half of the Case Syncline. The steeper gradients are attributed to the basement offsets associated with the graben structure, as well as a possible variance within the basement rocks.

In 1973 an exploratory hole, Millstream No. 1, was initiated by the New Brunswick Department of Natural Resources in cooperation with the Canadian Department of Regional Economic Expansion. Although this hole intersected Windsor evaporites at 925 m, it was unfortunately abandoned at 938 m due to technical difficulties (Webb, 1984a). Results from subsequent gamma-ray logging and traces of potash recovered from the lower 12.8 m of the hole suggested the presence of some potash-bearing zones (New Brunswick Department of Natural Resources, 1980).



(After P.W. Kingston, D.E. Dickie, 1979, reprinted with permission by the Canadian Institute of Mining and Metallurgy)

Figure 31. Cross section in Windsor Group evaporites, Plumweseep area, New Brunswick.

The Lower Millstream-Apohaqui potash prospect has been in the exploration phase of development since it was acquired by BP Canada Inc.-Selco Division in January of 1981. Gravity and seismic surveys and subsequent drilling have been successful in intersecting several beds of potash at depths between 950 and 1050 m (Carroll, 1985).

5. Riverside-Shepody Bay area, New Brunswick

The Riverside-Shepody Bay map area, on the Bay of Fundy, includes a small part of Nova Scotia east of Shepody Bay (Fig. 35). The northeast-trending Harvey-Hopewell Fault (Gussow, 1953) is the approximate line of demarcation

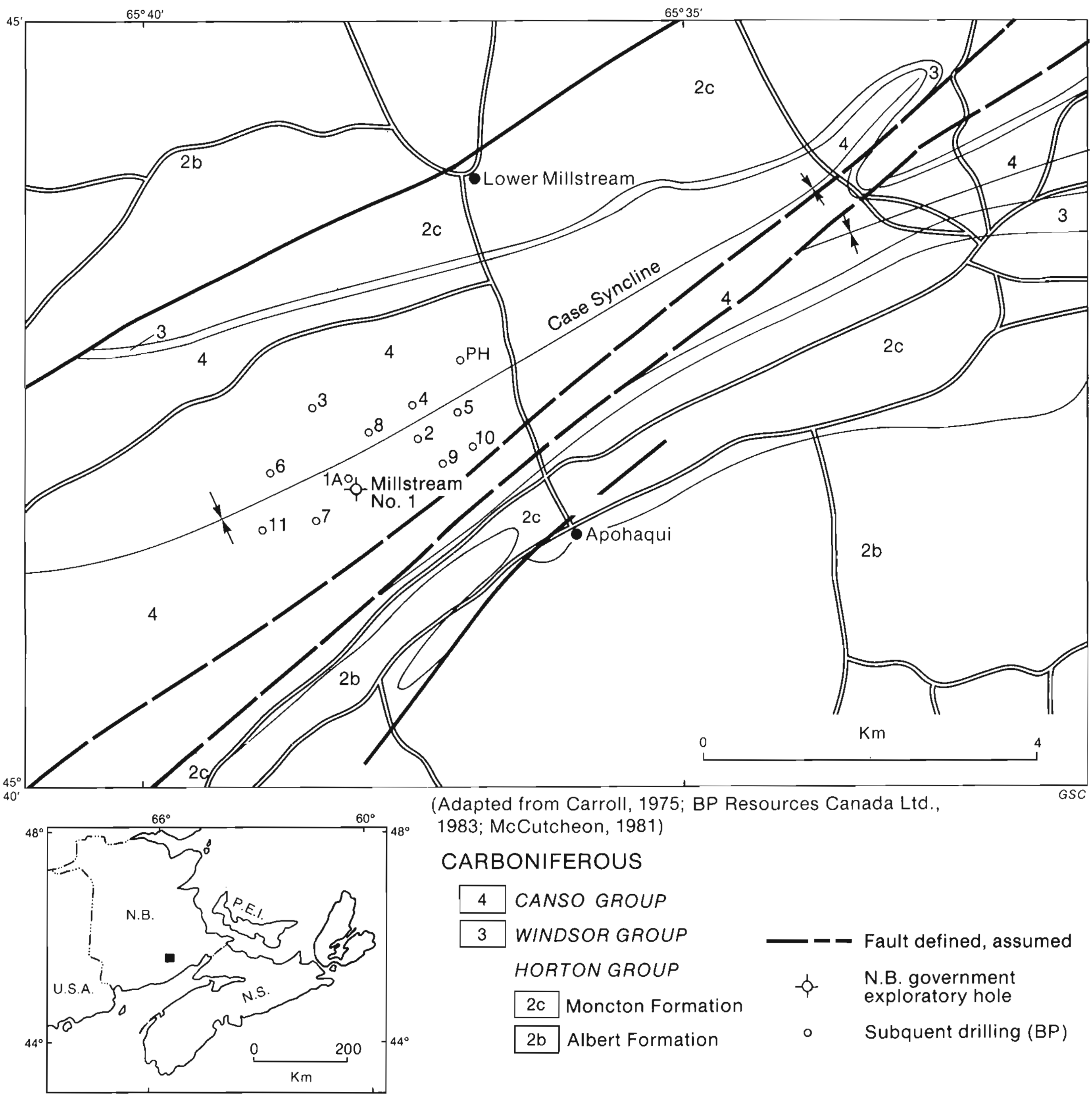


Figure 32. Geological map, Lower Millstream — Apohaqui area, New Brunswick.

between the uplifted Caledonian Mountain area and subsided Shepody Bay area. The Caledonian uplift is a pre-Carboniferous basement high, flanked by Hopewell and Riversdale group rocks. The basinal area to the southeast is underlain by a thick section of Horton to Pictou group Carboniferous rocks except for a narrow band of pre-Carboniferous rocks, exposed for almost 5 km along the east side of the Harvey-Hopewell fault.

South of the villages of Riverside and Shepody and east to Nova Scotia, Windsor Group rocks form the core of the Maringouin-Minudie anticline. A gravity map of this area (Fig. 36) indicates that the geological trace of the MaringouinMinudie anticline corresponds to an extensive gravity low, attributed to underlying low density Windsor Group evaporites. To the east in Nova Scotia, the Minudie anticline extends for approximately 80 km and is underlain by thick

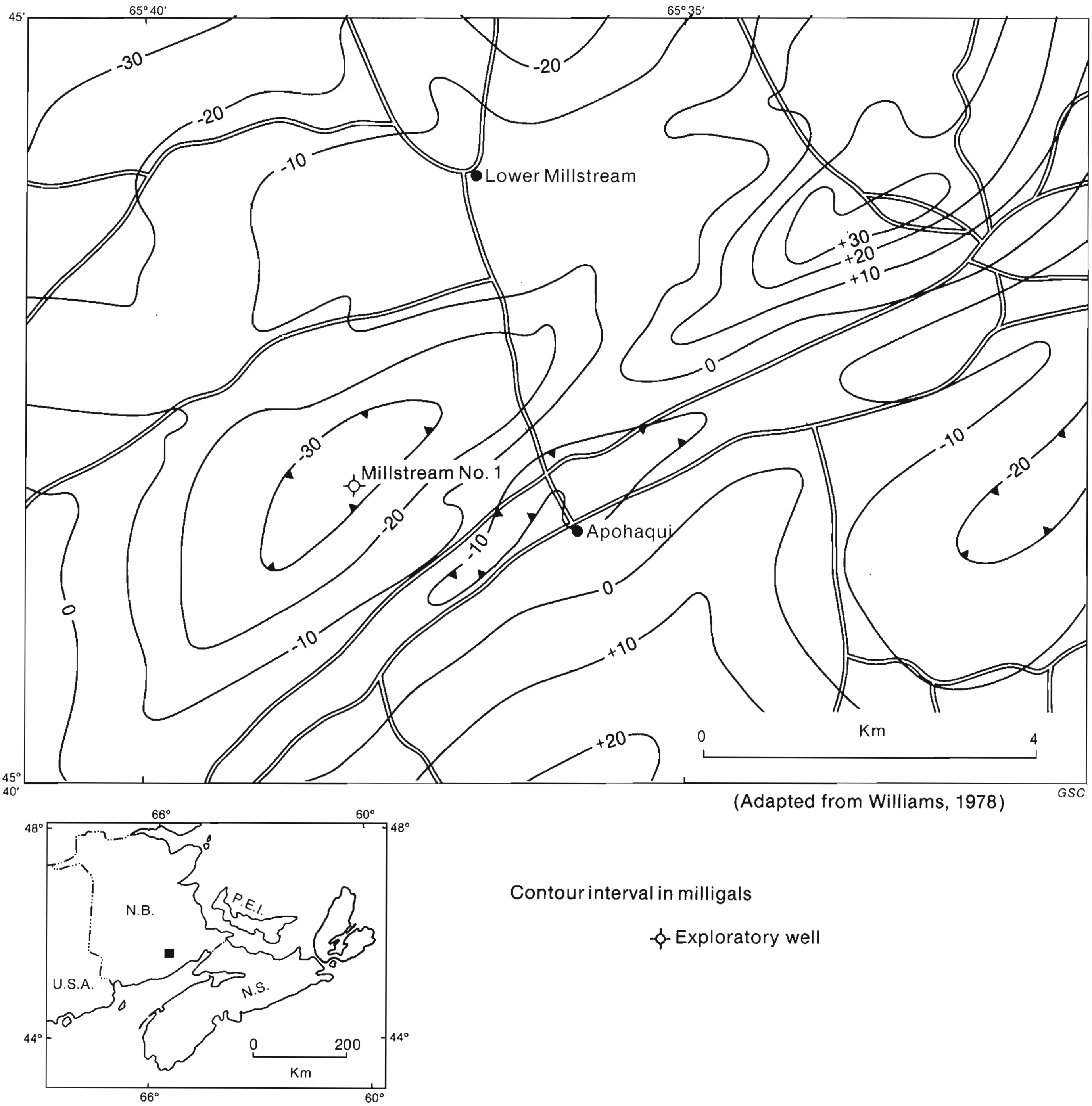


Figure 33. Bouguer gravity map, Lower Millstream — Apohaqui area, New Brunswick.

domal to diapiric accumulations of Windsor Group salt (Howie, 1986b). The aeromagnetic map (Fig. 37) indicates that the Caledonia Mountain basement complex is characterized by closely spaced gamma contours. The Shepody Bay area contains widely spaced gamma contours. Unless the Harvey-Hopewell fault is coincident with a substantial change in basement rock type, the Shepody Bay area is underlain by a thick sequence of Carboniferous sediments. This interpretation corresponds with the geological and gravity assessment of the area.

Chiasson (1973) published a preliminary report on the results of a gravimetric survey in southern New Brunswick. In this report he included a schematic cross-section (A to A[1]) through the Maringouin-Minudie anticline (Fig. 38) predicting Windsor Group salt at 640 m. To date this structure has not been verified by drilling.

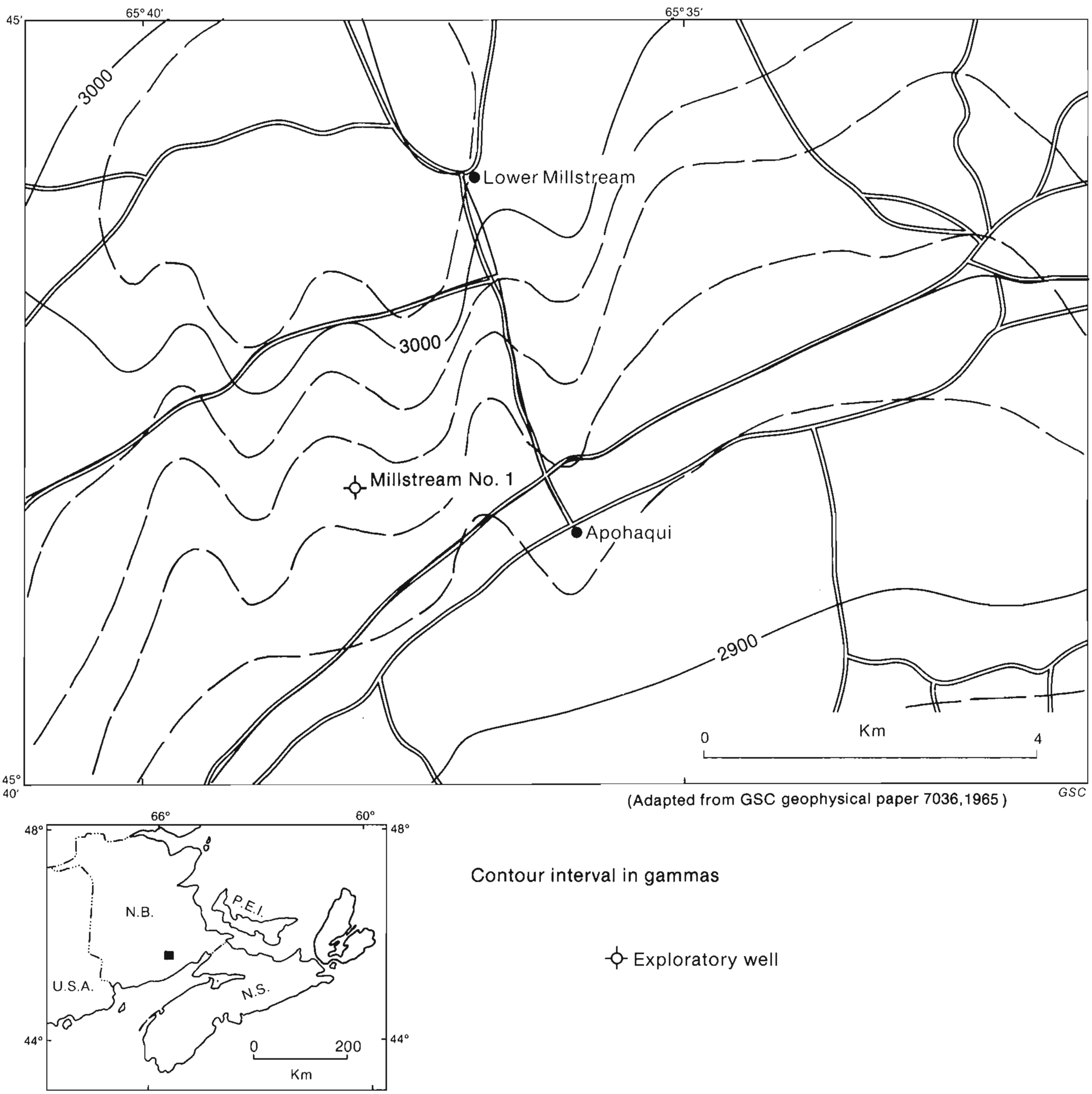


Figure 34. Aeromagnetic map, Lower Millstream — Apohaqui area, New Brunswick.

6. Dorchester area, New Brunswick

The Dorchester map area of southeastern New Brunswick is underlain by a folded complex of Mississippian and Pennsylvanian sedimentary rocks (Fig. 39). These Carboniferous sediments range from piedmont to fluviolacustrine rocks of the Horton Group to shallow marine evaporites and clastics of the Windsor Group to semiarid fluvial/terrestrial deposits of the Canso and Riversdale groups. Regional tectonism during the Maritime Disturbance reactivated some of the pre-Carboniferous faults and combined with salt migration to produce some broad folds and a number of additional faults in the region. Resulting

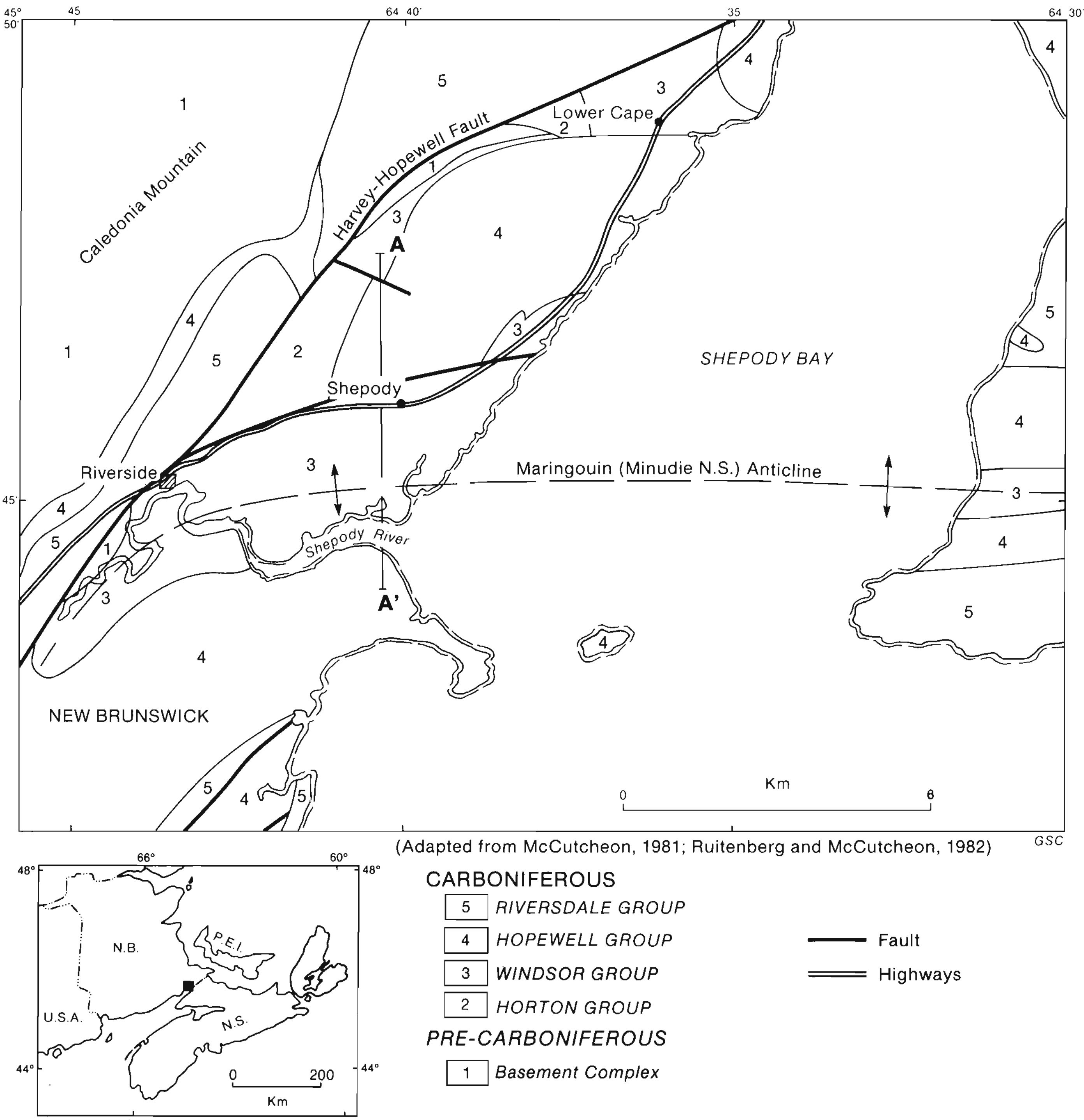


Figure 35. Geological map of the Riverside — Shepody Bay area, New Brunswick.

structures consisting of the Dorchester Fault, Dorchester anticline, Dorchester syncline and three folds adjacent to the Tantramar Fault, all trend northeast in accordance with the regional structural pattern for the region.

According to Gussow (1953), a large part of this area appears to be a structural basin centred over Sackville that plunges gently to the east. This basin has been considered a western extension of the Cumberland subbasin of Nova Scotia.

A gravity survey conducted by the Shell Oil Company in 1949 indicated a pronounced, elliptical-shaped, negative gravity anomaly over the western end of the Dorchester

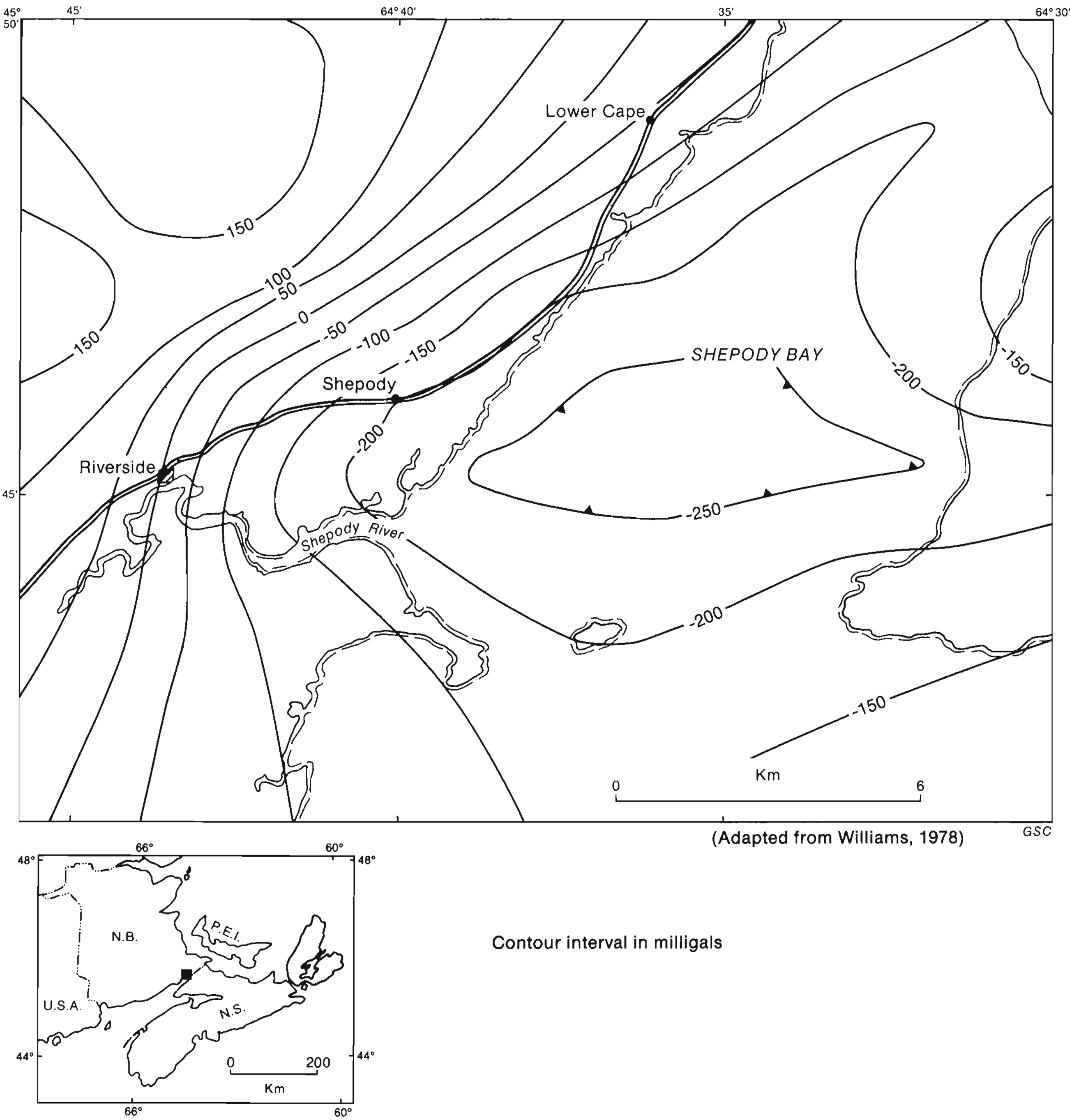
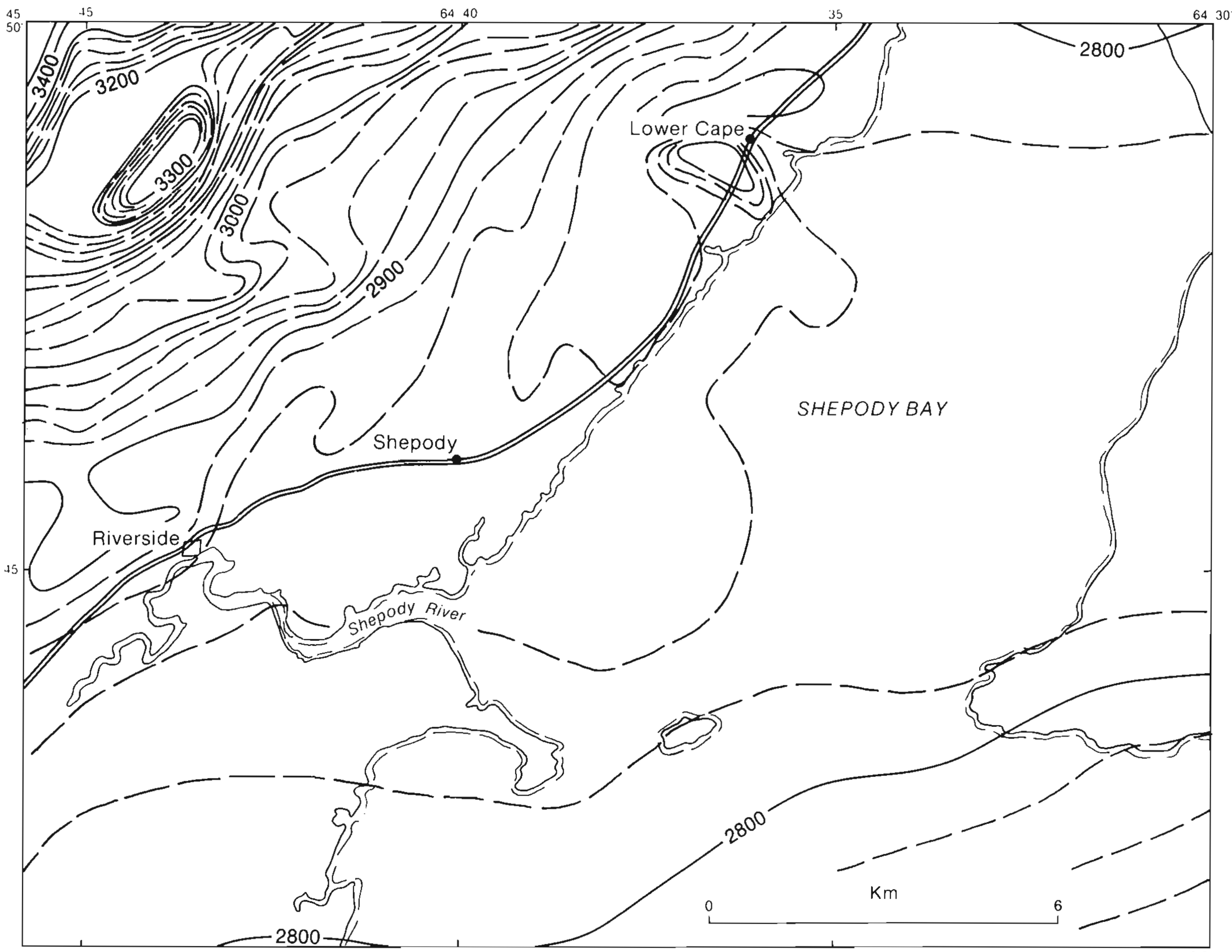
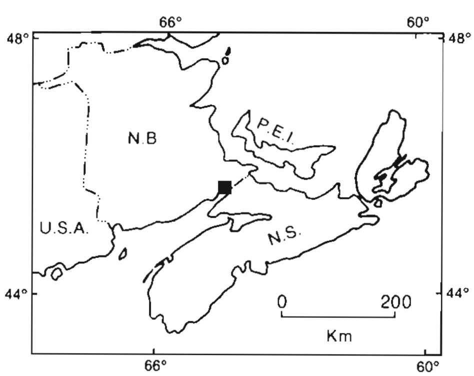


Figure 36. Bouguer gravity map, Riverside — Shepody Bay area, New Brunswick.

anticline (Gussow, 1953). The Shell Dorchester No. 1 well (Fig. 39, 40) encountered salt at this location before the gravity survey was compiled thereby indicating that the gravity low was a result of a thick deposit of salt (Webb, 1984b). The Shell well intersected Windsor Group salt between 350 and 1466 m and was completed at 2509 m in what has been interpreted as Horton Group strata. The salt in this well is capped by 230 m of gypsum and anhydrite, which in turn is overlain by 120 m of overburden. A second well, Imperial Dorchester No. 1, was drilled in 1960 approximately 3.2 km south of the Shell well. It intersected a thin zone of Windsor Group evaporites around 2100 m



(Adapted from GSC geophysical paper 7036, 1965)



Contour interval in gammas

Figure 37. Aeromagnetic map, Riverside — Shepoby Bay area, New Brunswick.

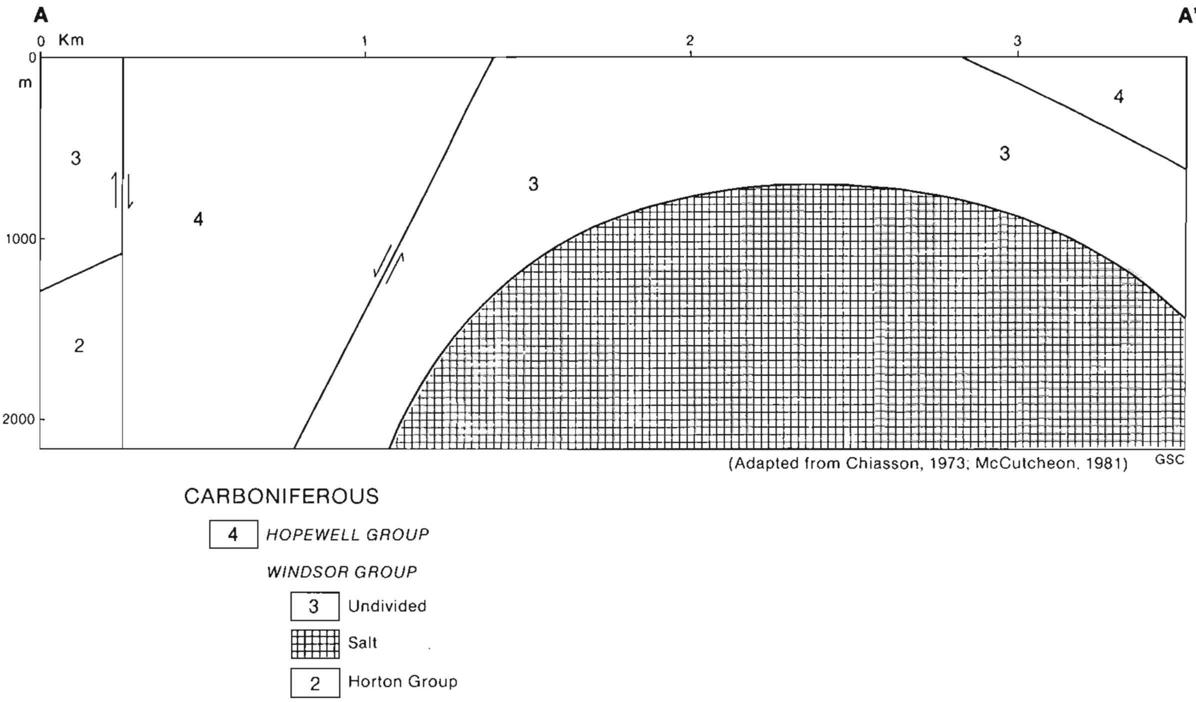


Figure 38. Schematic cross section in the Riverside — Shepoby Bay area, New Brunswick.

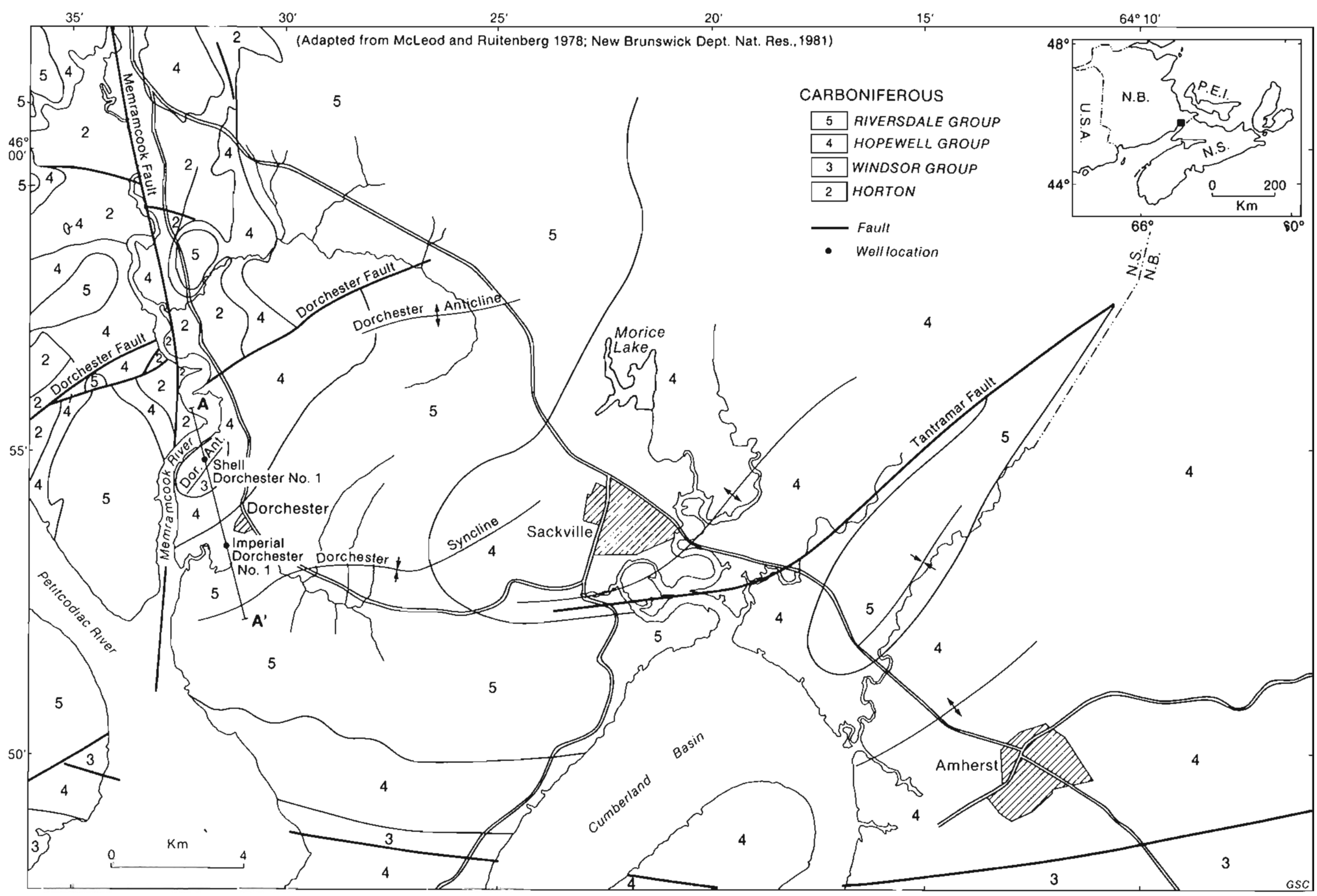


Figure 39. Geological map, Dorchester area, New Brunswick.

(New Brunswick Department of Natural Resources, 1981). As indicated on the cross-section, the Imperial Dorchester well was completed in Windsor Group sulphate (Upperton Formation, Fig. 26).

Cross-section A-A[1] (Fig. 40) indicates that the salt mass is diapiric. The Shell Dorchester No. 1 well, located near the crest of the Dorchester anticline, contained fairly pure salt except for varying amounts of gypsum and anhydrite scattered throughout. The Imperial Dorchester No. 1 well penetrated salt with a fairly high silt content. The silt is not considered to have been part of the original salt section, but was incorporated into the salt mass during the salt migration. In both the Shell Oil Company and Imperial wells there was no indication of potash mineralization.

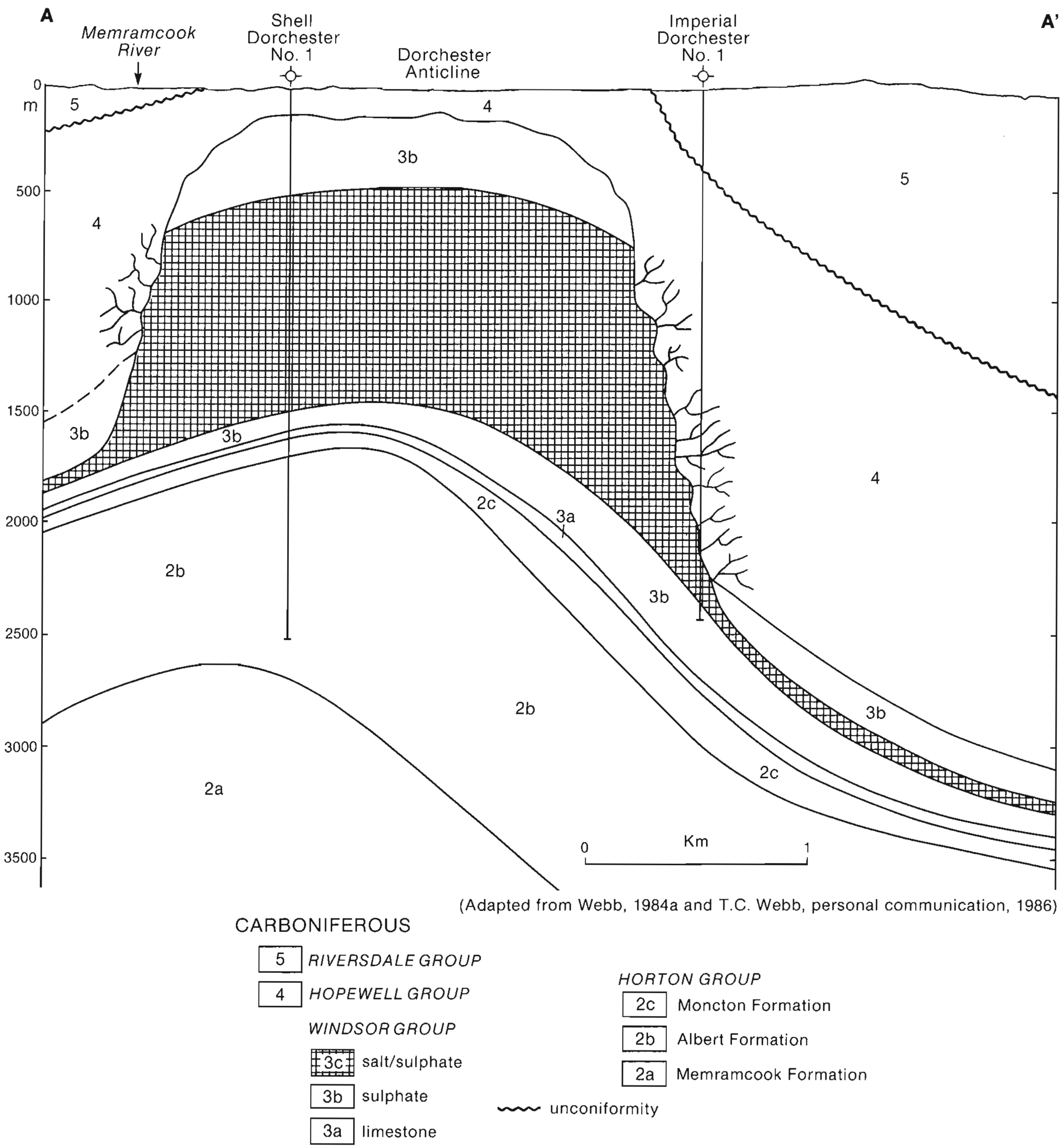


Figure 40. Geological cross section of the Dorchester area, New Brunswick.

Regional gravity coverage of the New Brunswick part of the Cumberland subbasin (Fig. 41), adapted from Williams (1978), outlines five local gravity anomalies. There is no doubt that this Dorchester anomaly (No. 1), as outlined by a 200 milligal contour is a result of a thick diapiric salt accumulation. A broad gravity low north of Sackville (No. 2) is outlined by the 240 milligal contour. Although located between the Dorchester anticline and the Dorchester syncline, the lack of a strong anomaly here as compared with Dorchester No. 1 could be due to the relative thinness and/or greater depth of burial of the presumed evaporite body. As the anomaly is coincident with Morice Lake, part of the anomaly could be due to a thick section of surficial material. Hamilton (1961b) reported 120 m of overburden in the Dorchester area. The Morice Lake anomaly has not been drilled.

In the Aulac area (No. 3) three gravity lows trend northeast along the Tantramar Fault. These anomalies are believed to be the result of salt anticlines closely associated with the Tantramar Fault. The magnitude of the anomalies, combined with the results of seismic surveys (New Brunswick Department of Natural Resources, Appendix B, p. 44, 1981) and the presence of sinkholes suggest that the postulated salt mass is at relatively shallow depths.

The Baie Verte anomaly (No. 4) is on strike with the eastern extension of the Tantramar Fault. If Windsor Group evaporites are present in this area, movement along the Tantramar Fault may also have weakened the overlying beds in this area, thus permitting the upward migration of salt.

The Johnson Creek (No. 5) anomaly may be coincident with the subsurface occurrence of Windsor Group evaporites. It is probably significant that the Johnson Creek, Aulac and Baie Verte anomalies form a northeast trend, parallel to the regional structure and coincident with the eastern part of the Tantramar Fault. This fault may be the local surface expression of a general zone of weakness and/or offset in the basement complex that permitted upwelling and intrusion of Windsor Group evaporites for a considerable distance along this zone.

The aeromagnetic map (Fig. 42) is dominated by broad general contours that indicate a magnetic high north of Sackville. Another magnetic high with more closely spaced contours southwest of Dorchester is related to the Caledonia Mountain basement high just west of the area. The prominent gravity anomalies at Dorchester and north of Sackville do not appear to have any expression on the aeromagnetic

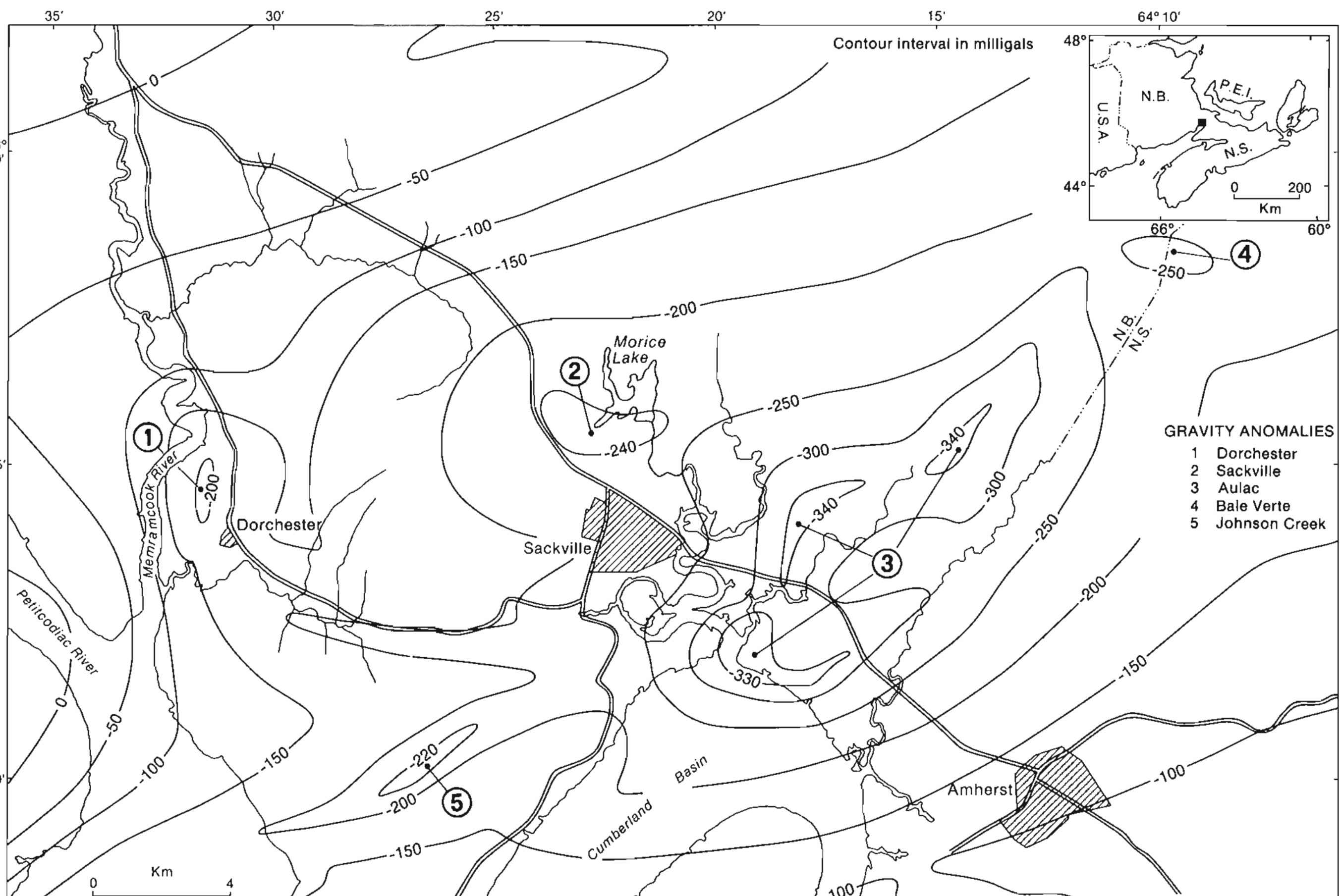


Figure 41. Bouguer gravity map, Dorchester area, New Brunswick.

map. The position of the contours on the aeromagnetic map in the Johnson Creek, Aulac and Baie Verte areas indicate a northeast trend, coincident with the gravity anomalies on the previous map (Fig. 41). This orientation of the aeromagnetic contours may indicate a change in the magnetic properties of the basement complex and/or an offset in the basement.

7. *Cumberland subbasin, Nova Scotia*

The Cumberland subbasin is a marginal embayment on the southern flank of the Magdalen Basin. The geological map (Fig. 43) indicates this east-west to northeast-trending subbasin contains Windsor to Pictou group rocks. Although the Horton Group, which usually underlies Windsor strata, is not shown on the map, borehole data indicate that it is present at depth. This Carboniferous sequence, which is considered to be up to 6100 m thick (Bell, 1958) is underlain by a highly fractured basement (Howie, 1986b).

The Windsor Group, which contains thick deposits of salt and anhydrite, is exposed at the surface along the Malagash and Minudie anticlines and in other smaller structures in the Spinghill Junction, Roslin and Pugwash Junction areas. In the Anschutz Wallace Station No. 1 drillhole (Fig. 46), 3567 m of Windsor Group strata were intersected. This does not represent the true thickness of the group because the section penetrated was highly contorted due to salt migration.

Five cross-sections have been prepared to show the effects of salt movement on the distribution and thickness of the Carboniferous rocks in the Cumberland subbasin (Fig. 44, 45). These sections are based on data collected from various deep wells and shallow boreholes, as well as limited seismic and gravity data. The operating salt mine at Pugwash was also a valuable source of information.

Section A to A' (Fig. 44) crosses the Amherst area. At the north end of this cross-section a sequence of gently dipping Horton to Pictou Group rocks overlie a pre-Tournaisian basement complex. Cross-section D-D' (Fig. 45) follows the Minudie anticline (Evans, 1970), an evaporite-cored structure that is traceable over a strike length of 80 km. Section D-D' is also coincident with a basement feature designated as the Hastings Uplift (Fig. 44, section C-C') (Howie, 1985). To the south, in the Athol syncline (Copeland, 1959), Horton Group to Cumberland Group rocks are present (Fig. 44, section A-A').

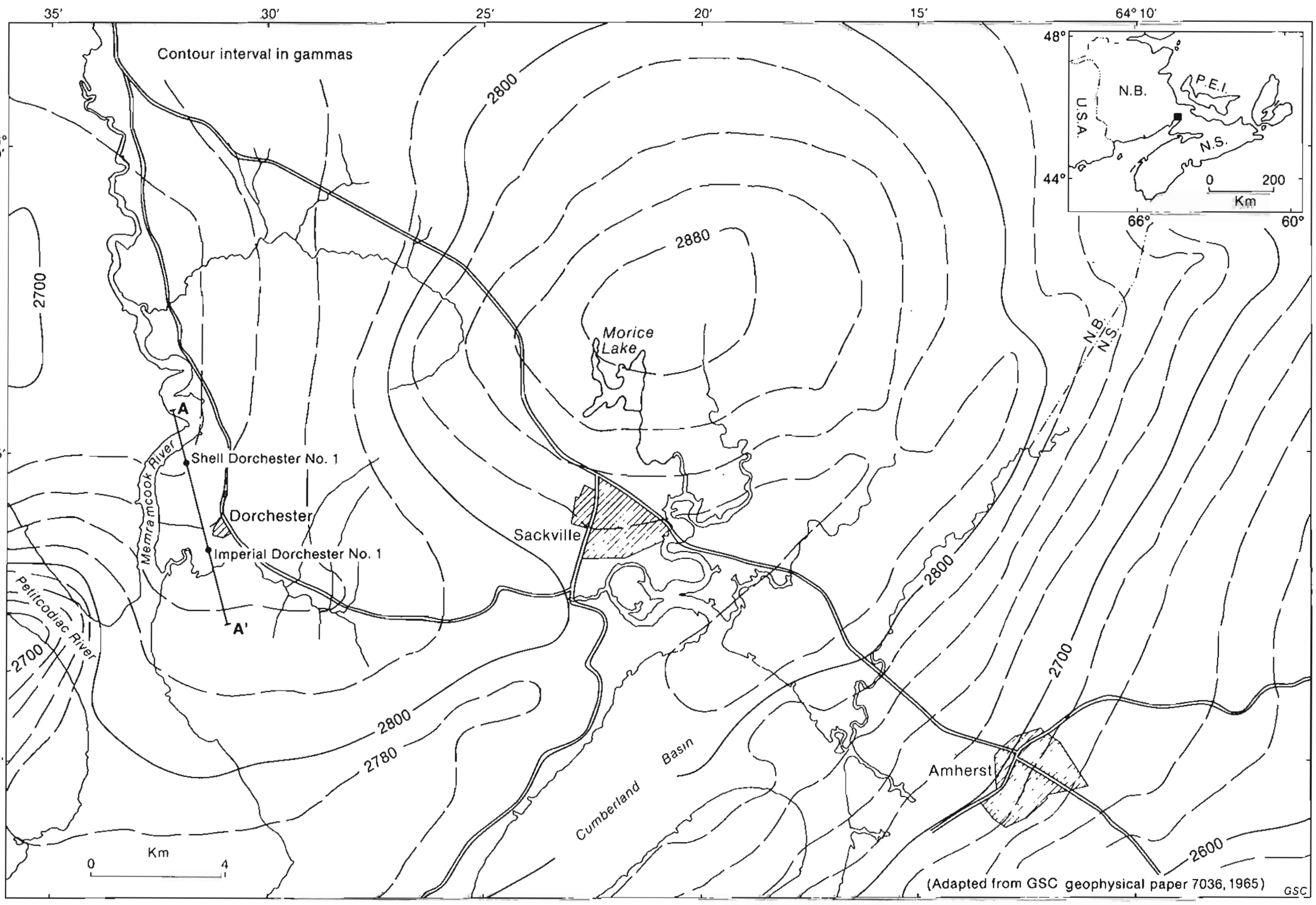


Figure 42. Aeromagnetic map, Dorchester area, New Brunswick.

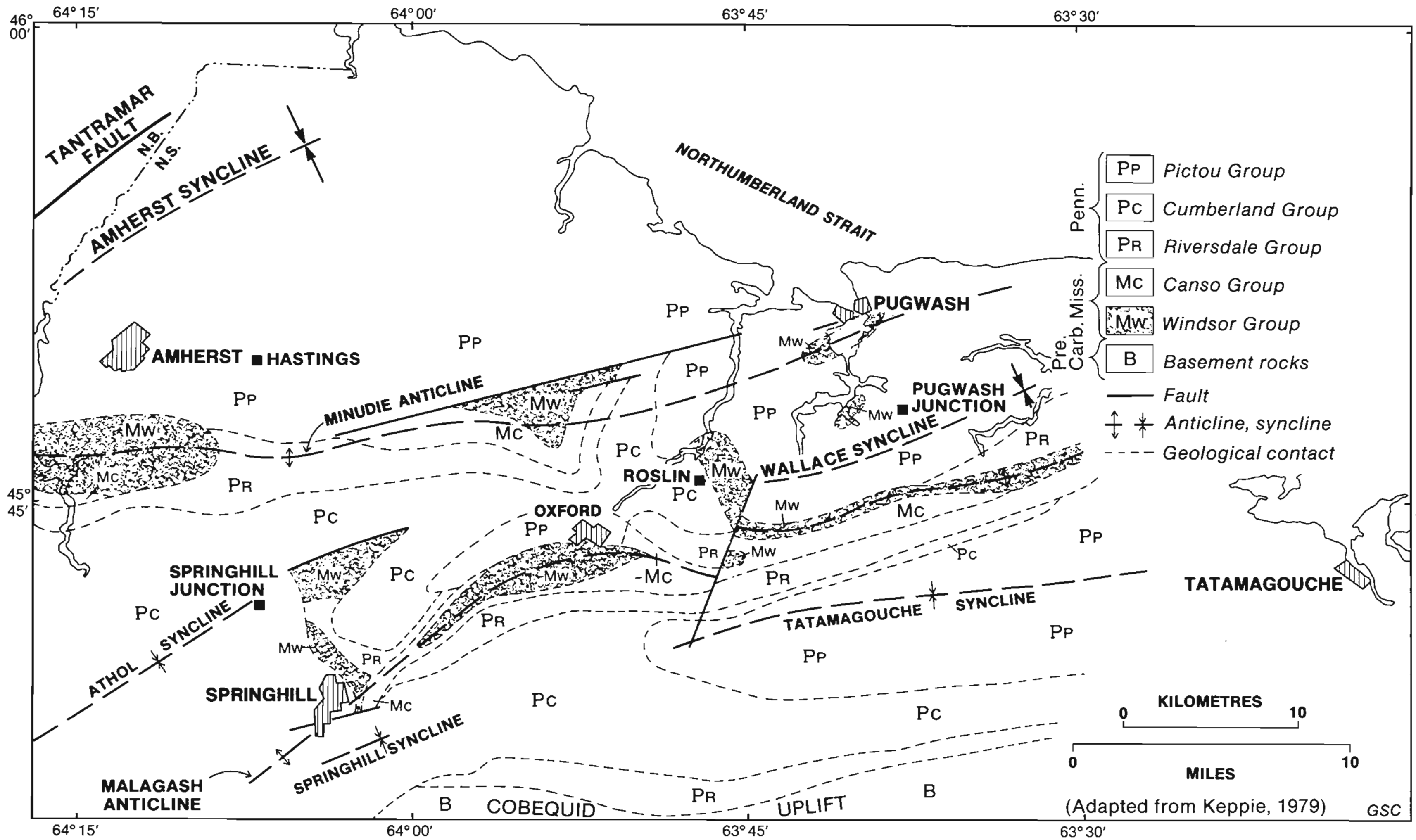


Figure 43. Geological map, Cumberland subbasin, Nova Scotia.

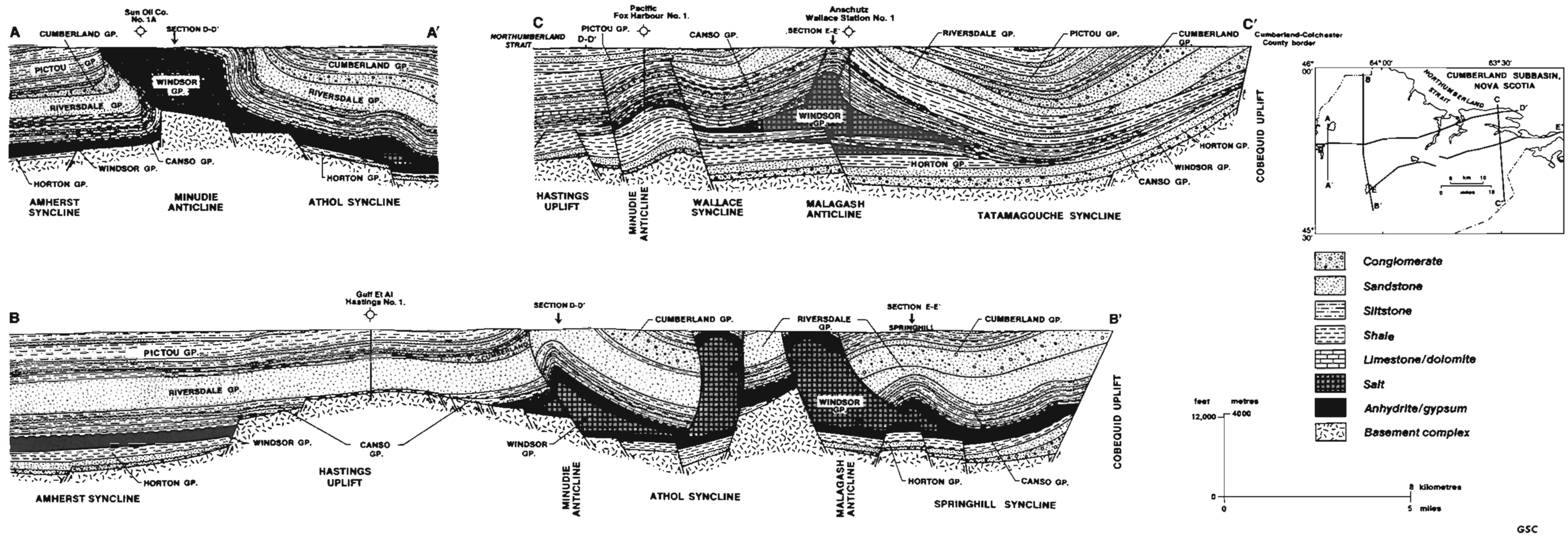


Figure 44. Cross sections A-A', B-B', and C-C', Cumberland subbasin, Nova Scotia.

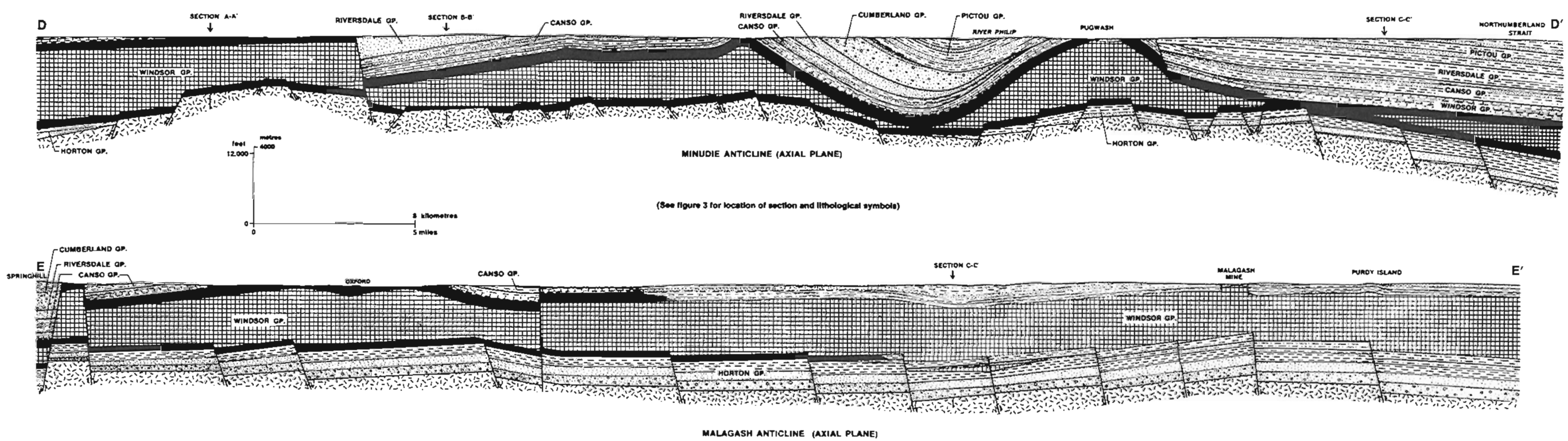


Figure 45. Cross sections D-D' and E-E', Cumberland subbasin, Nova Scotia.

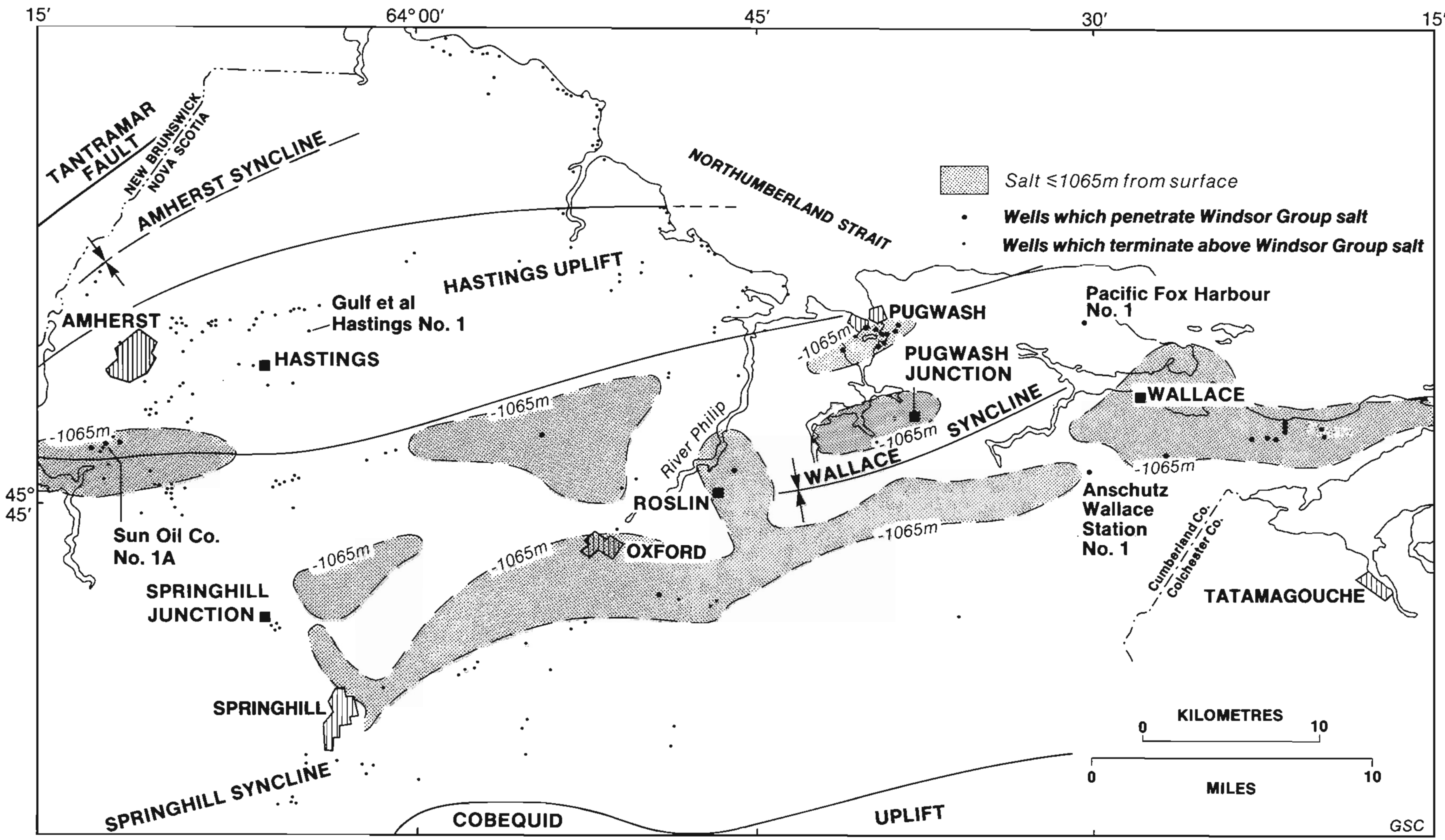


Figure 46. Borehole locations and distribution of Windsor Group salt, Cumberland subbasin, Nova Scotia.

It appears that much of the salt originally deposited in the Athol syncline has migrated up-dip along the Hastings Uplift basement ridge to form the diapiric Minudie salt structure. The upward movement of this salt diapir has overturned some of the younger Upper Paleozoic sediments. This is well documented in the Sun Oil Co. No. 1A well south of Amherst.

Section B-B' extends from the New Brunswick-Nova Scotia provincial border on the north flank of the Hastings Uplift to the Cobequid Uplift. In the Amherst syncline the gently dipping Horton to Riversdale and Pictou groups are present. The Cumberland Group was not included in this part of the stratigraphic section because it was not known to be present in the Gulf et al. Hastings No. 1 borehole. The Minudie anticline, Athol syncline and Malagash anticline are structurally very complex areas that contain thick accumulations of domal to diapiric salt (Evans, 1970). In both the Minudie and Malagash structures the salt appears to have migrated up-dip from south to north. In the Springhill syncline, Horton to Cumberland groups are present. The proposed thinning of the Riversdale Group in this area is attributed to local uplift and erosion due to salt migration during the Maritime Disturbance (Poole, 1967), which was prior to the deposition of the Cumberland Group.

Section C-C' extends from the southern flank of the Hastings Uplift to the Cobequid Uplift. Areas underlain by the Hastings Uplift and the Minudie anticline contain rocks of the Horton to Riversdale groups, which are unconformably overlain by rocks of the Pictou Group. As indicated on the cross- section, the Pacific Fox Harbour No. 1 well, located on the Minudie anticline, encountered only minor amounts of Windsor Group salt. To the south the term Wallace syncline is herein proposed for the downwarped zone between the Minudie and Malagash anticlines in the eastern part of the map area (Fig. 43). It contains Horton to Riversdale and Pictou group rocks. The Riversdale Group gradually thickens from north to south below an unconformity with the overlying Pictou Group. The Windsor Group evaporites also gradually thicken towards the central axis of the Malagash anticline.

In the Malagash anticline area both Horton and Windsor group evaporites are present. In the Anschutz Wallace Station No. 1 well Horton evaporites appear to be undeformed, bedded deposits, whereas those of the Windsor Group are highly contorted into a domal to partly diapiric structure.

South of the Malagash salt structure is the Tatamagouche syncline containing a thick section of Horton to Pictou group strata. The Cumberland Group is shown as a wedge of sediments thinning from south to north.

Cross-sections D-D' and E-E' (Fig. 45) trend in an easterly direction along the crest of the Minudie and Malagash anticlines, respectively. A highly faulted basement overlain by thick deposits of Windsor Group evaporites are the most dominant feature of both sections. East of Amherst on section D-D' the Windsor rocks are overlain by the Canso and Riversdale group strata. In the River Philip area a relatively thin section of Windsor Group evaporites is overlain by a thick sequence of Canso to Pictou group rocks. This area can be compared with the Tatamagouche syncline (Fig. 45, section C-C'), which also contains a thick section of post-Windsor Group sediments.

In the Pugwash area, Windsor Group rocks exposed at the surface form part of a large salt dome or diapir. The Canadian Salt Company Limited has been in production since 1959 at this site. Here underground workings are the main source of detailed information on structured salt in the Cumberland subbasin. Although the shaft entrances are on a peninsula in Pugwash Harbour, some of the workings are beneath the harbour. At this location, as well as in other occurrences in Atlantic Canada, the Windsor salt is protected by a siltstone- anhydrite-gypsum caprock (Howie, 1985).

Detailed mapping of the underground workings at Pugwash by Evans (1967), indicate the salt is severely deformed. Every transition from horizontal to vertical axes and planes have been observed in the mine. Fold amplitudes range in size from a few centimetres to 100 m and may be symmetrical, overturned or recumbent (Howie, 1986b, Fig. 8-12). Due to the unpredictable salt/anhydrite ratios that occur throughout the deposit, the salt is removed in a nonsymmetrical manner rather than by a regular room and pillar.

East of Pugwash, the Windsor Group evaporites appear to pinch out and then gradually thicken at the eastern end of section D-D'. This reduction in thickness was also observed in the Pacific Fox Harbour No. 1 well, in the same vicinity (Fig. 45, section C-C'). The well was completed in siltstone of the Windsor Group.

Section E-E' (Fig. 46), extends along the crest of the Malagash anticline, from the Springhill area to the northeast coast of Nova Scotia. In section D-D' a highly faulted basement is overlain by thick deposits of Windsor Group salt. Windsor Group rocks are exposed along the crest of the Malagash anticline except in the Springhill and Oxford areas. In the highly faulted area around Springhill at the western end of the section, the Windsor Group is overlain by rocks of the Canso, Riversdale and Cumberland groups. In a horst area east of Springhill, the Windsor is exposed at the surface. From the horst structure to a fault east of Oxford, the Windsor Group outcrops, except for a short distance at either end of the section that is overlain by the Canso Group.

A fault east of Oxford offsets the crest of the Malagash anticline by about 3 km (Fig. 44). East of this fault the crest of the anticline is displaced northwards relative to its axis west of the fault. In order to restore the crest of the anticline to the line of section, the apparent normal fault on the cross-section may actually represent a thrust or strike-slip fault.

Near the eastern end of section E-E' the old Malagash salt mine is shown as occupying a local horst structure. Drillholes in this area encountered Windsor salt within 26 m of the surface (Hayes, 1920; Cole, 1930).

An isopach map has been prepared to show the borehole locations and the distribution of salt encountered at depths equal to or more than 1065 m within the Cumberland subbasin (Fig. 46). The distribution of salt shown on this map corresponds very closely to the distribution of the Windsor Group shown by the geological map (Fig. 43), because of the steeply dipping salt-cored structures.

A regional gravity map has also been prepared for the same area (Fig. 47). The shaded area on the map is an overprint of Figure 46, showing the distribution of salt encountered at depths equal to or less than 1065 m. The intensity of the gravity lows correlate fairly well to the near-surface occurrence of low density salt. The insert on the upper left corner of the map is a detailed gravity map of the Roslin area. The Roslin No. 1 borehole, drilled near the centre of this gravity low, penetrated 114 m of siltstone-claystone-gypsum caprock and 192 m of salt with siltstone, before it was completed at 306 m.

The regional aeromagnetic map of the same area has smooth, widely-spaced contours, suggesting a thick sedimentary section (Fig. 48). The 2500 gamma closures, shown as patterned areas on the map, are considered to represent anomalies associated with minor structural highs within the basement. The apparent change of pattern inside the 2500 gamma closures south of Oxford is strictly an artifact due to the partial overlap of two adjacent surveys. The insert in the upper left corner of the figure gives details of a magnetic anomaly of a basement feature in the Roslin area. The shaded area on the regional map is an overprint showing the distribution of salt that is buried to depths equal to or less than 1065 m. The magnetic anomalies correspond fairly well to the distribution of the salt-cored structures.

The first underground salt mine in Canada was opened at Malagash in 1919. The Malagash Salt Company Limited operated this mine until 1959, when the company moved its mining operation to Pugwash and changed its name to the Canadian Salt Company Limited. A few kilometres south of Amherst, Domtar Chemicals Limited, Sifto Salt Division, have been producing salt from brine wells drilled near the Sunoco No. 1A well. Traces of potash mineralization have been reported from the old mine at Malagash, in two boreholes near Wallace, and from the salt mine at Pugwash (Barr, 1966; Bancroft, 1957; Boehner, 1981, 1983; Cameron, 1967; Evans, 1967, 1970; Nova Scotia Department of Mines, 1950; Shea, 1970) suggest that the area may have some potash potential.

8. Minas subbasin, Nova Scotia

The Minas subbasin, an isolated marginal depression or outlier of the Magdalen Carboniferous Basin, contains the original type section of the Windsor Group as described by Bell (1929, 1958). A regional geology map of the Windsor-Truro area of the Minas subbasin indicates that pre-Carboniferous basement rocks are overlain by a sequence of Upper Paleozoic to Mesozoic sediments (Fig. 49), ranging in age from Middle Devonian to Early Cretaceous (Howie, 1985; Howie and Barss, 1975a; Keppie, 1979).

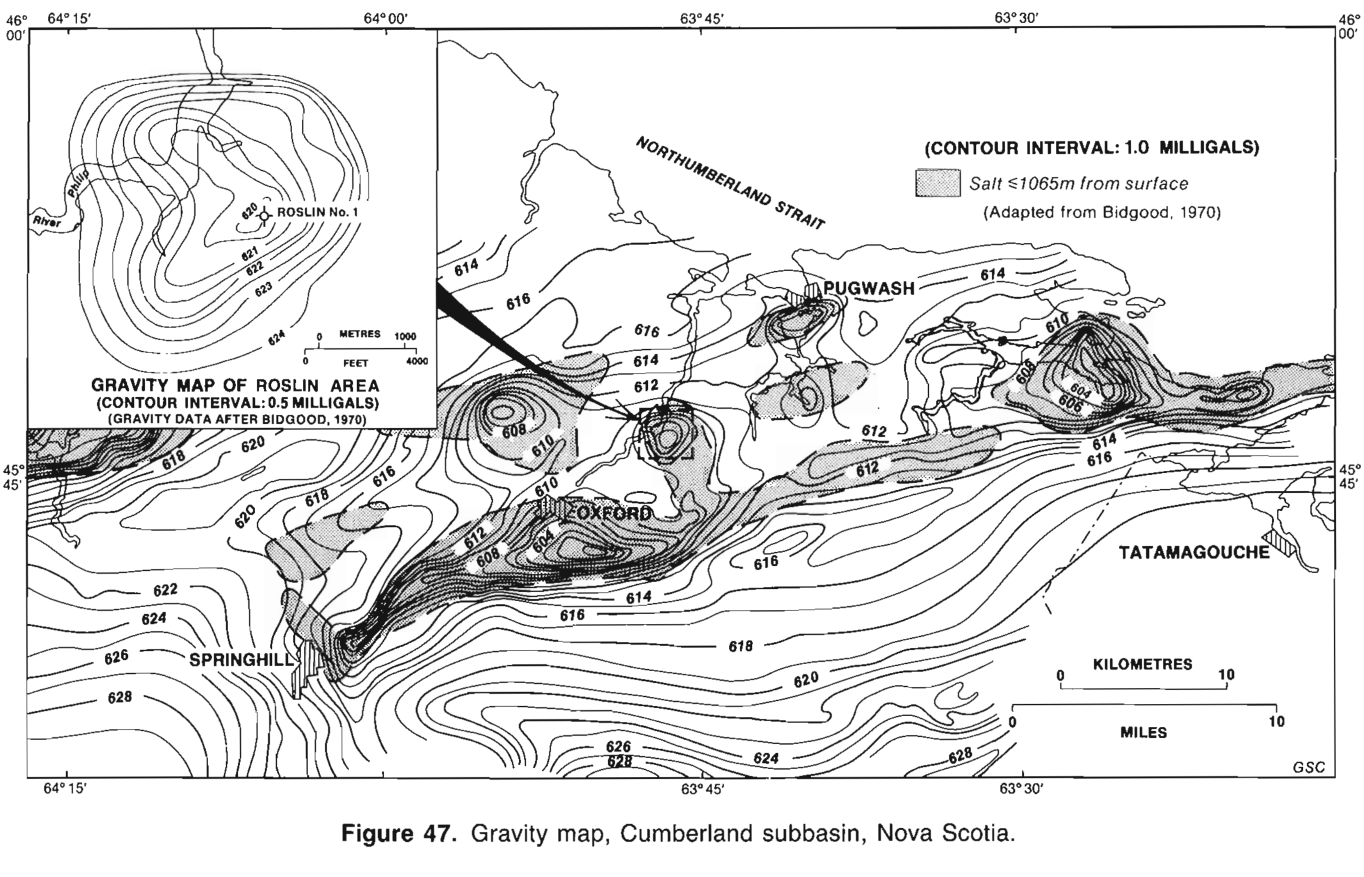


Figure 47. Gravity map, Cumberland subbasin, Nova Scotia.

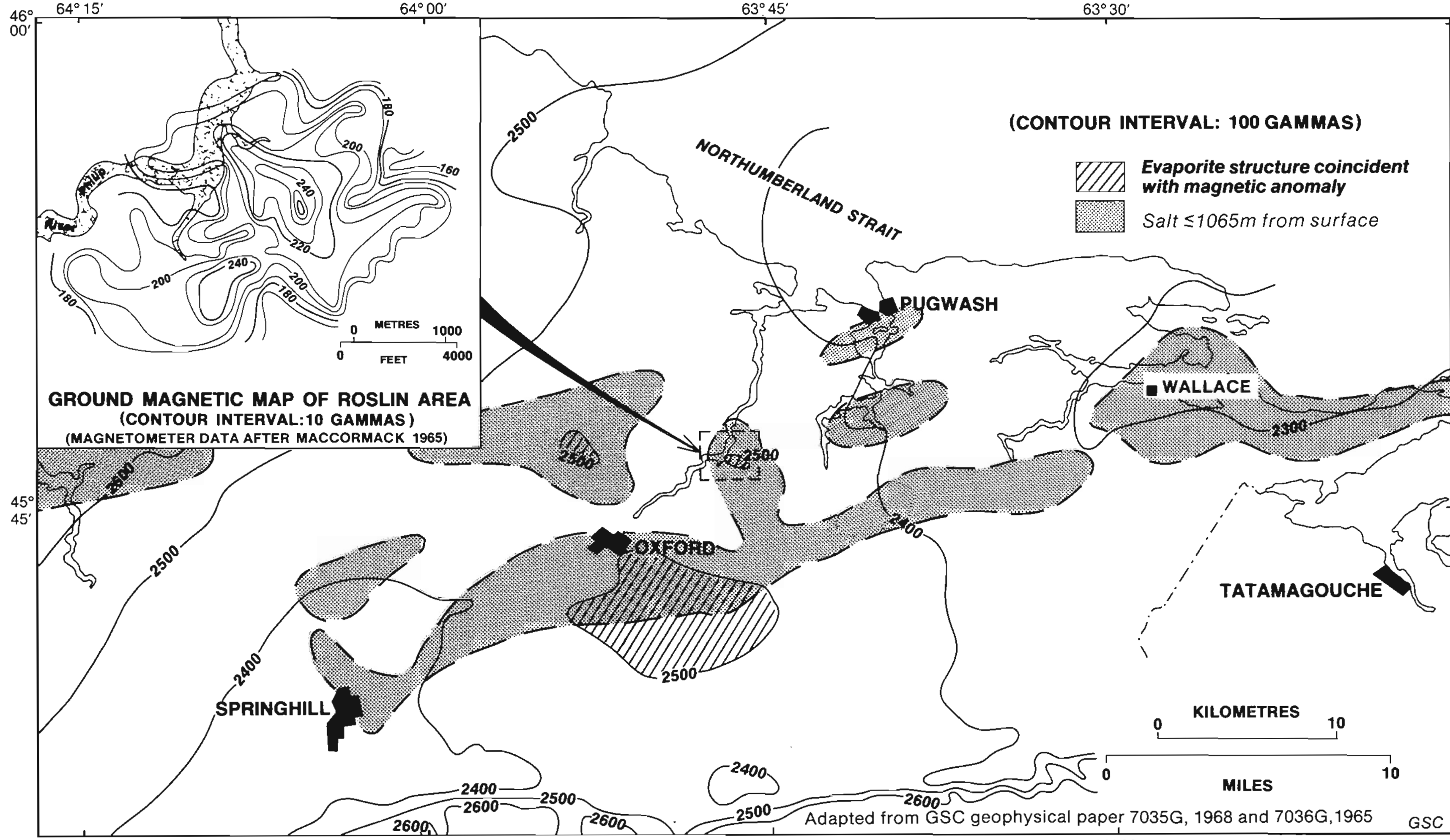


Figure 48. Aeromagnetic map, Cumberland subbasin, Nova Scotia.

Based on surface mapping and borehole data, Windsor Group evaporites in the Minas subbasin have been divided into two categories: 1) deformed salt located in the Windsor-Kennetcook and Beaver Brook areas, and 2) weakly deformed, bedded salt located in the Shubenacadie-Stewiacke area.

In the Windsor-Kennetcook and Beaver Brook areas, 13 boreholes have penetrated salt of the Windsor Group. Salt thickness in borehole locations 1, 4, 6 and 7 (Fig. 50) is not shown because the salt-bearing zone is a mixture of salt and anhydrite, salt and shale or salt and sandstone. Borehole data obtained from company logs for each well shown on this map indicates that the Windsor evaporites are highly deformed, making it very difficult to reconstruct a detailed stratigraphy for the area.

In 1985 the Nova Scotia Department of Mines and Energy drilled Riverside Corner 85-1 (Fig. 50) in order to examine the stratigraphy, structure and potash potential of the Clarksville area (Carter and Boehner, 1986). The hole was located on one of the largest (30 x 6 km) and virtually unexplored gravity lows in Nova Scotia (Boehner, 1984; Cominco Limited, 1981). This anomaly trends northeast parallel to the regional structure (Fig. 51).

The drill penetrated Canso Group bedrock at 52 m (Fig. 53), passed through a fault into steeply dipping Pictou Group rocks at 132 m and into the Windsor Group at 434 m. The basal carbonate of the Green Oaks Formation, Windsor Group, was intersected twice, 468-480 m and 486-495 m, both stratigraphically right-way-up separated by a small reverse fault (Carter and Boehner, 1986). The

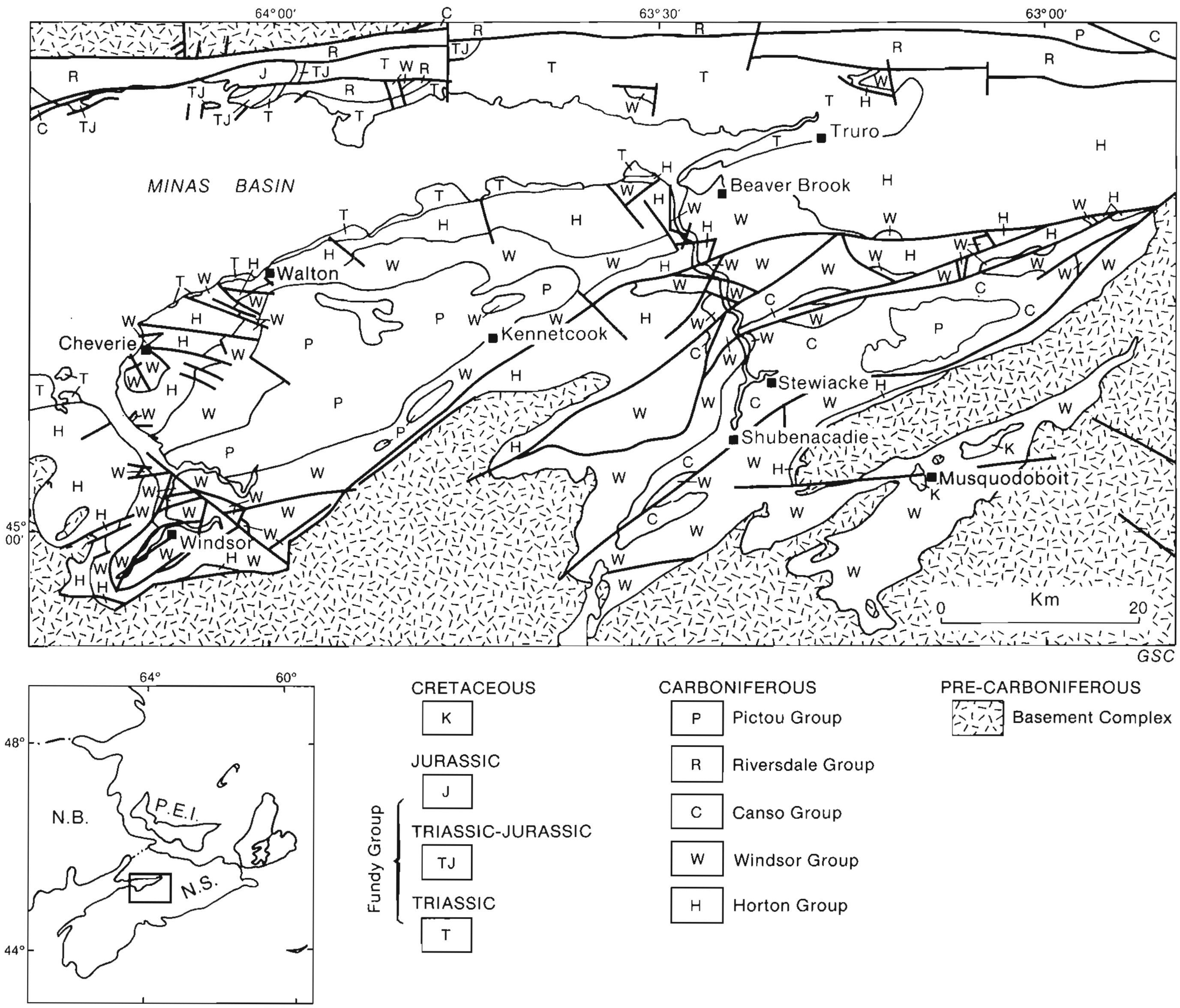


Figure 49. Geological map, Windsor — Truro area, Nova Scotia.

top of salt was intersected at 657 m. This evaporite section is complicated by at least six fold structures. The hole was abandoned at 1057.6 m in an overturned section of MacDonald Road Formation salt.

The structural complexity of the Carboniferous rocks in this part of the Minas subbasin was also observed by Boyle (1963) and is reflected on his map of the Walton-Cheverie area. If all the faults recorded on Boyle's map were transferred to the geological map (Fig. 49), their traces would obliterate almost all other information. If the remainder of the area from Windsor to Beaver Brook were mapped in the same detail as the Walton-Cheverie area, an equivalent number of faults would probably be recognized. The large number of faults that cut the Carboniferous rocks can be attributed to a highly shattered basement overlain by a fairly thin sedimentary cover through which many of the basement faults penetrate (Howie, 1985). The groundwater movement along these faults has also led to a significant solution of Windsor Group evaporites in the area, leaving behind an incomplete stratigraphic section.

The Shubenacadie-Stewiacke area contains the least deformed Windsor Group evaporite section observed to date in Nova Scotia. A geology map and a composite lithologic section compiled by Giles and Boehner (1979) and Boehner (1980b) indicate the distribution and general lithology of the various rock units (Fig. 52, 53) occurring in the area. The Stewiacke Formation is the main salt-bearing unit of the Windsor Group in the Minas subbasin (Fig. 53). At Stewiacke this sequence, with a regional dip less than 3°, forms a bedded deposit up to 300 m thick (Fig. 54), which is mainly confined to the shallow northeast-trending Stewiacke graben (Howie, 1986a). The salt varies in colour from grey through orange to translucent, and is often interbedded with anhydrite in the lower two-thirds of the

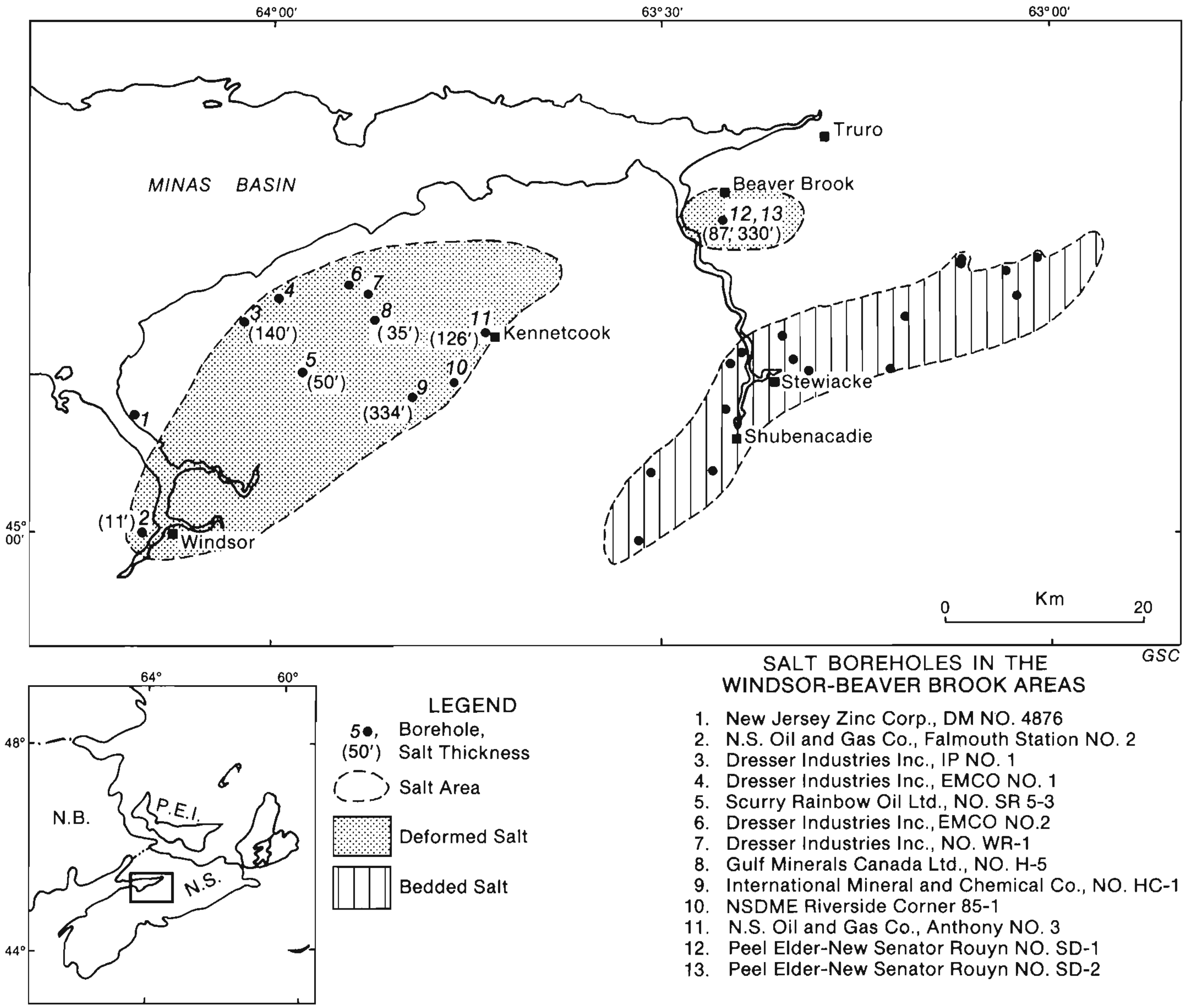


Figure 50. Distribution of Windsor Group salt in the Windsor — Truro area, Minas subbasin, Nova Scotia.

formation and green siltstone in the upper third. An interpreted area of erosion and possible dissolution around the perimeter of the deposit is indicated by the hachured lines on Figure 53. This zone contains a residual breccia composed of unleached material from the salt zone, and rock fragments from overlying or adjacent strata.

A comparison of the salt intersected in three boreholes in the area (Fig. 55) indicate that the lower 60 m of both the Stewiacke Borax No. 1 hole (SB-1) and the St. Joseph Explorations Limited 153-1 hole contain salt with purity of 93% NaCl (Giles and Boehner, 1979; Boehner, 1980b). The St. Joseph Explorations Limited 153-3 hole also contained some fairly pure salt zones. The upper 60 m of the St. Joseph Explorations Limited 153-1 hole contained fairly pure salt interbedded with anhydrite. If the anhydrite beds in this hole die out laterally, this horizon may also contain as much salt as the lower beds in the other two wells. Although the evaporite zone was tested for potash mineralization results were not encouraging (Boehner, 1980b).

The lithologic character and structural configuration of the rocks in this area is illustrated in two generalized cross-sections. Figure 56 is a northeast-trending section along the axis of the shallow Stewiacke graben. The southwest end of this section has been extended across a fault to include the southern flank of the basin. The salt at this end of the section is terminated by a breccia zone.

On the northeastern side of the section, the St. Joseph Explorations Limited 153-3 borehole penetrated salt associated with the Stewiacke, MacDonald Road and Watering Brook formations. The thin salt beds in the lower part of the Watering Brook Formation (Canso Group)

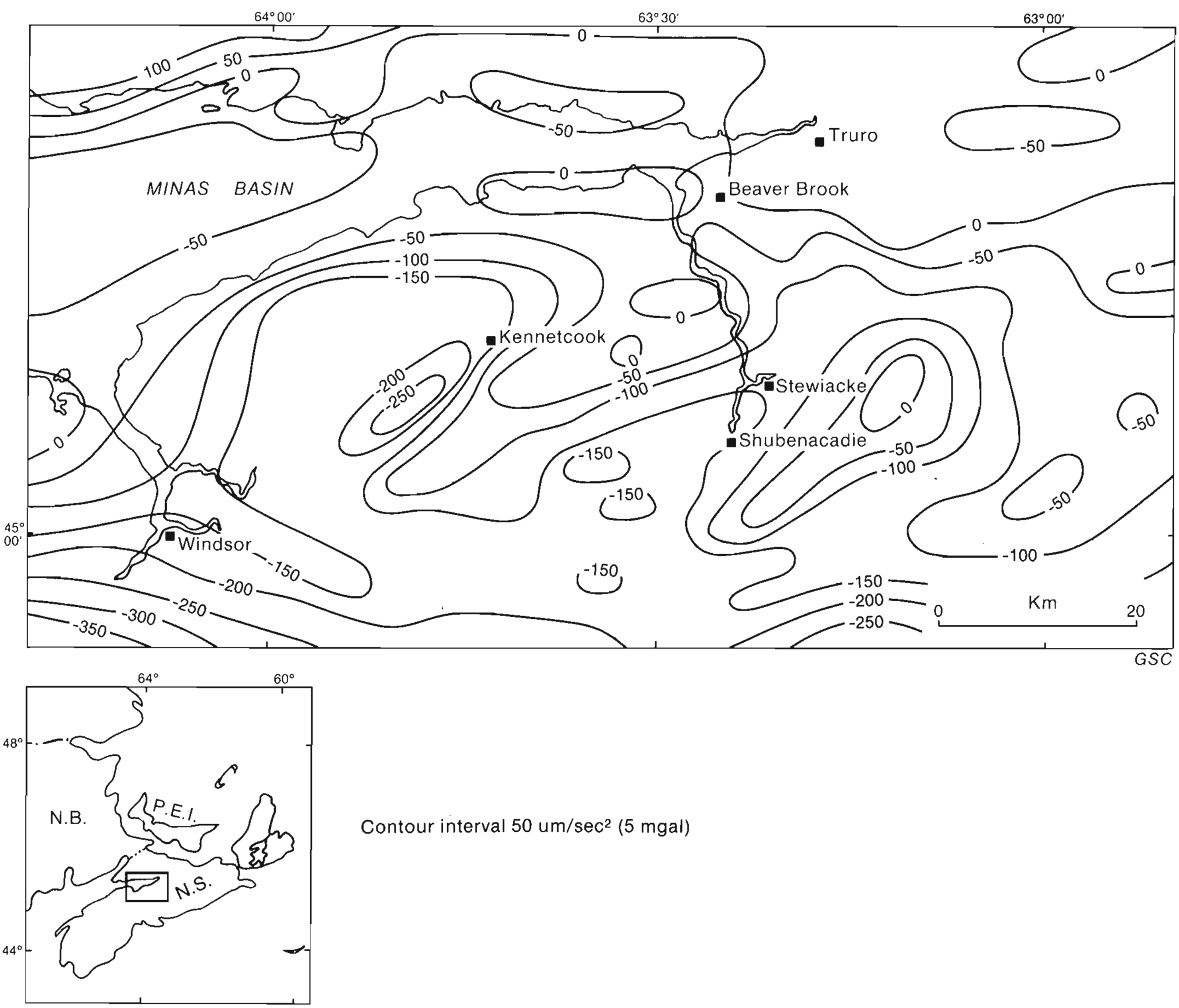


Figure 51. Bouguer gravity map of the Windsor-Truro area, Nova Scotia.

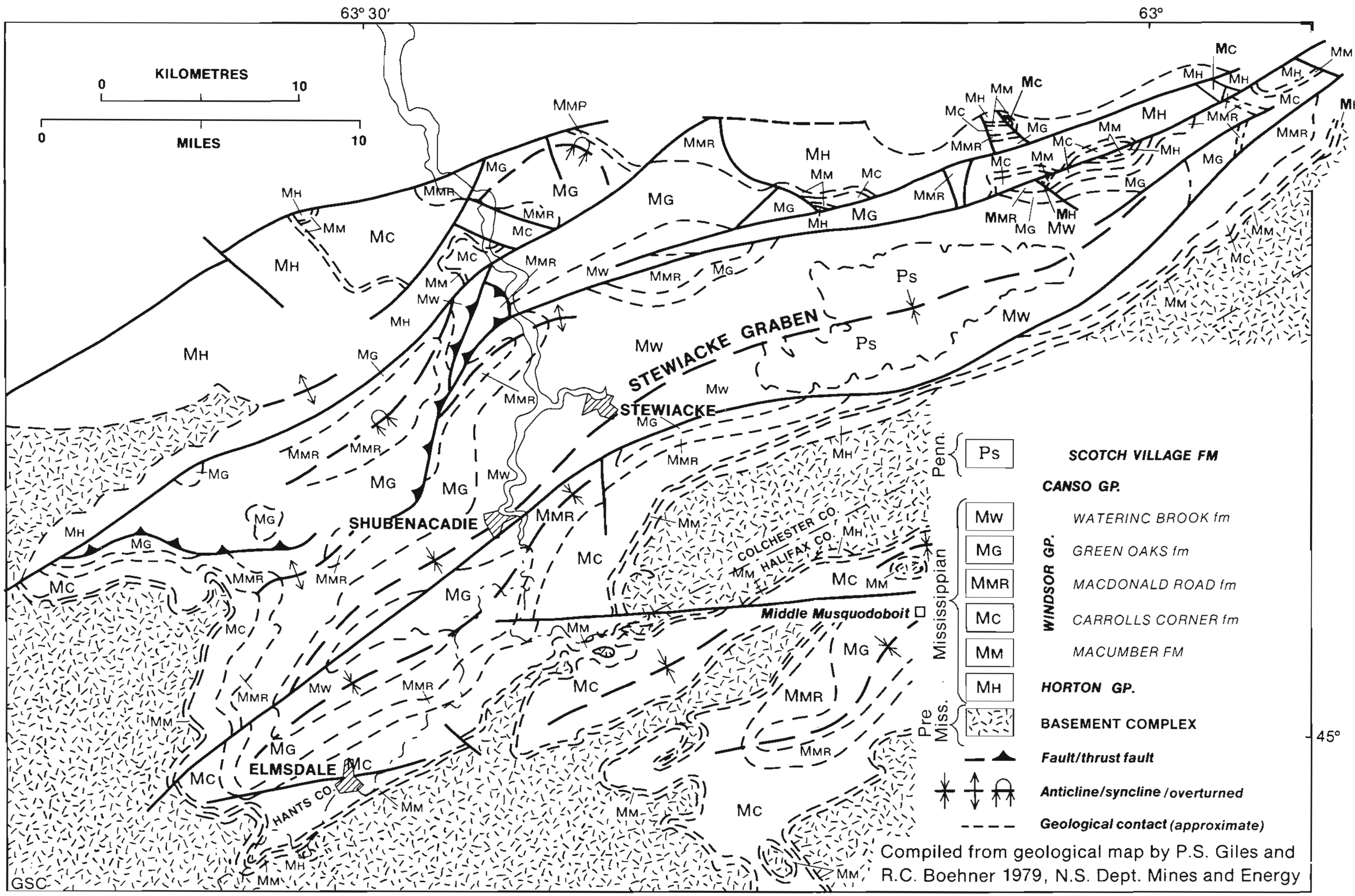


Figure 52. Geological map, eastern Minas subbasin, Nova Scotia.

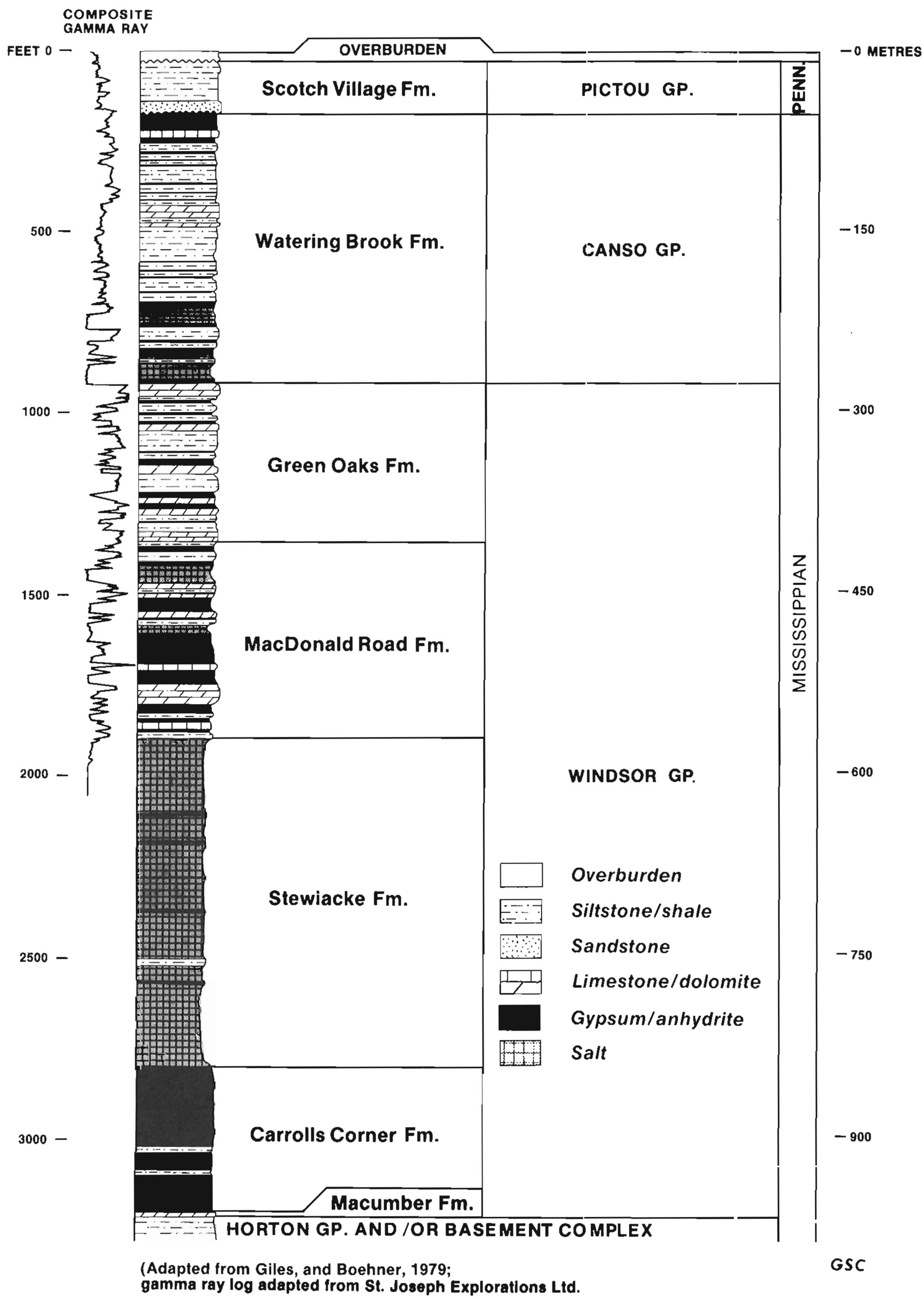


Figure 53. Composite Mississippian and Pennsylvanian successions, Minas subbasin, Nova Scotia.

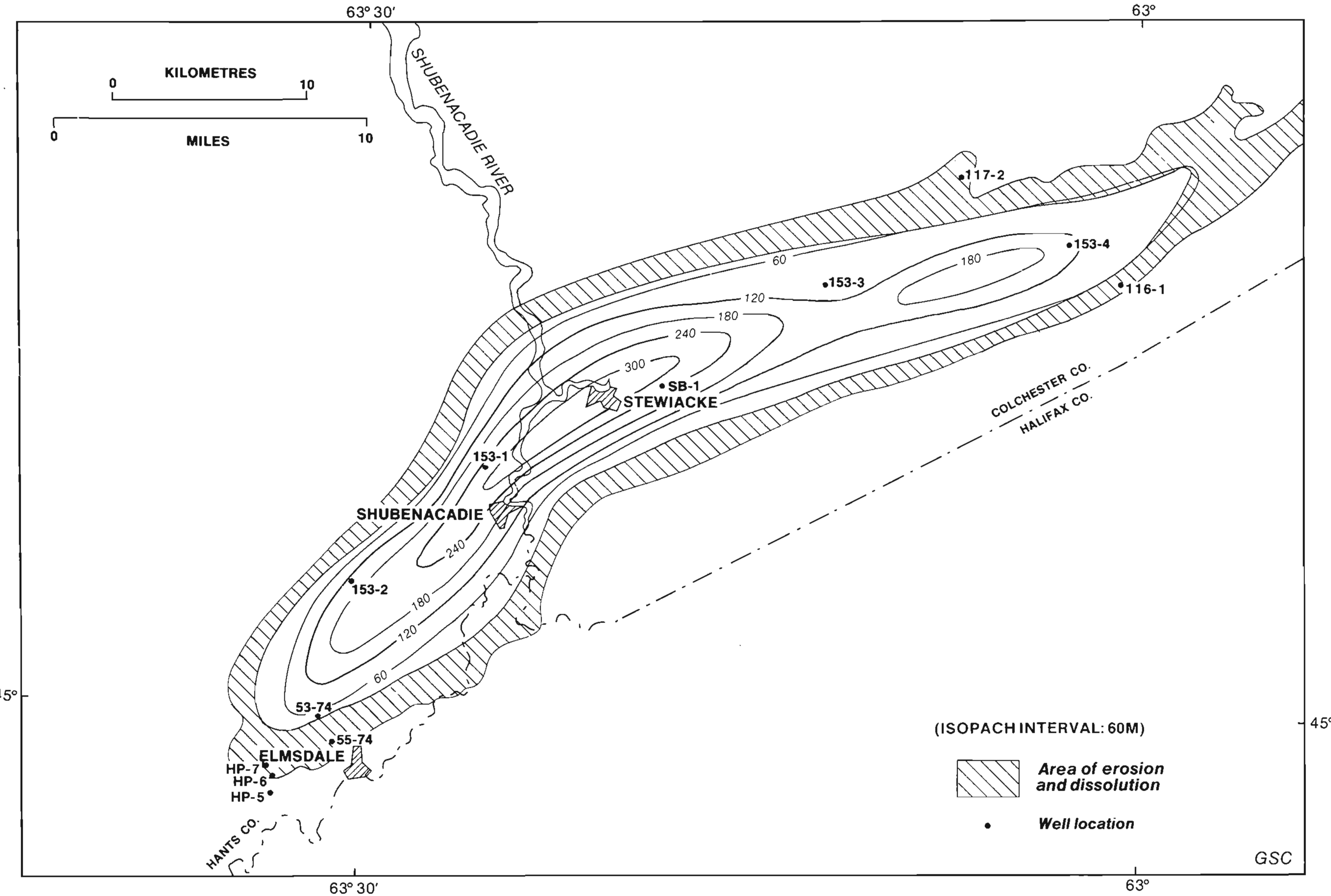


Figure 54. Isopachs of Stewiacke formation, Minas subbasin, Nova Scotia.

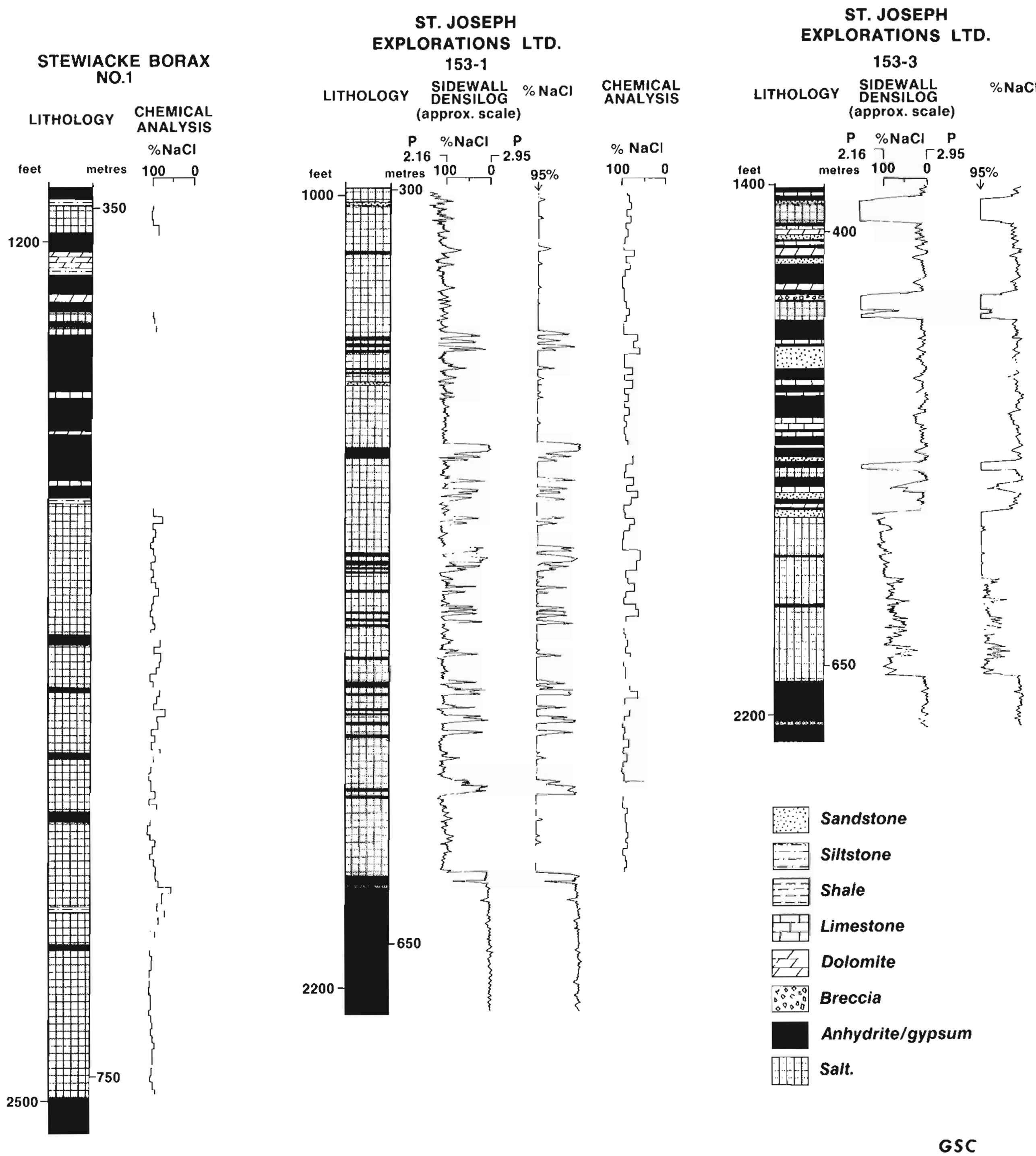


Figure 55. Stewiacke formation salt analysis from three holes, Stewiacke graben, Minas subbasin, Nova Scotia.

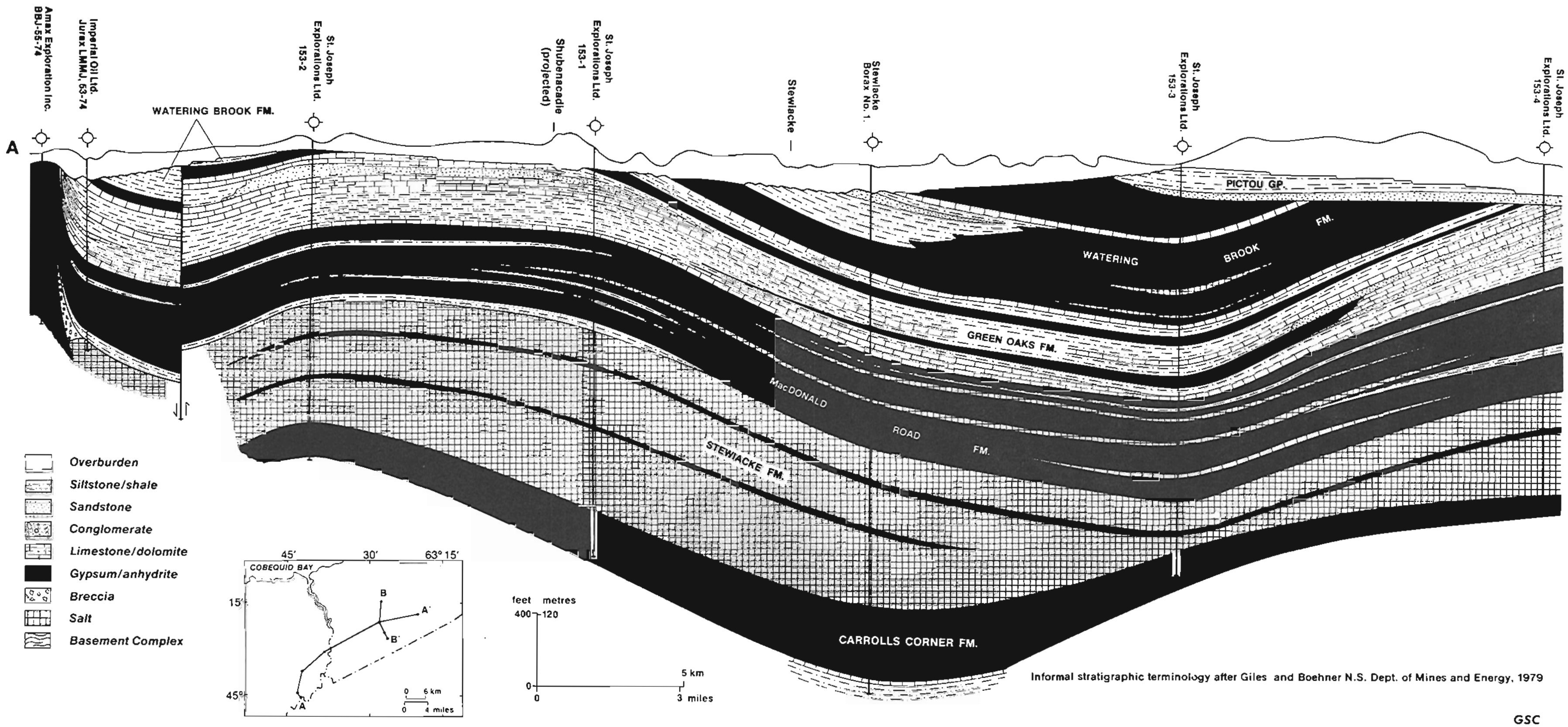


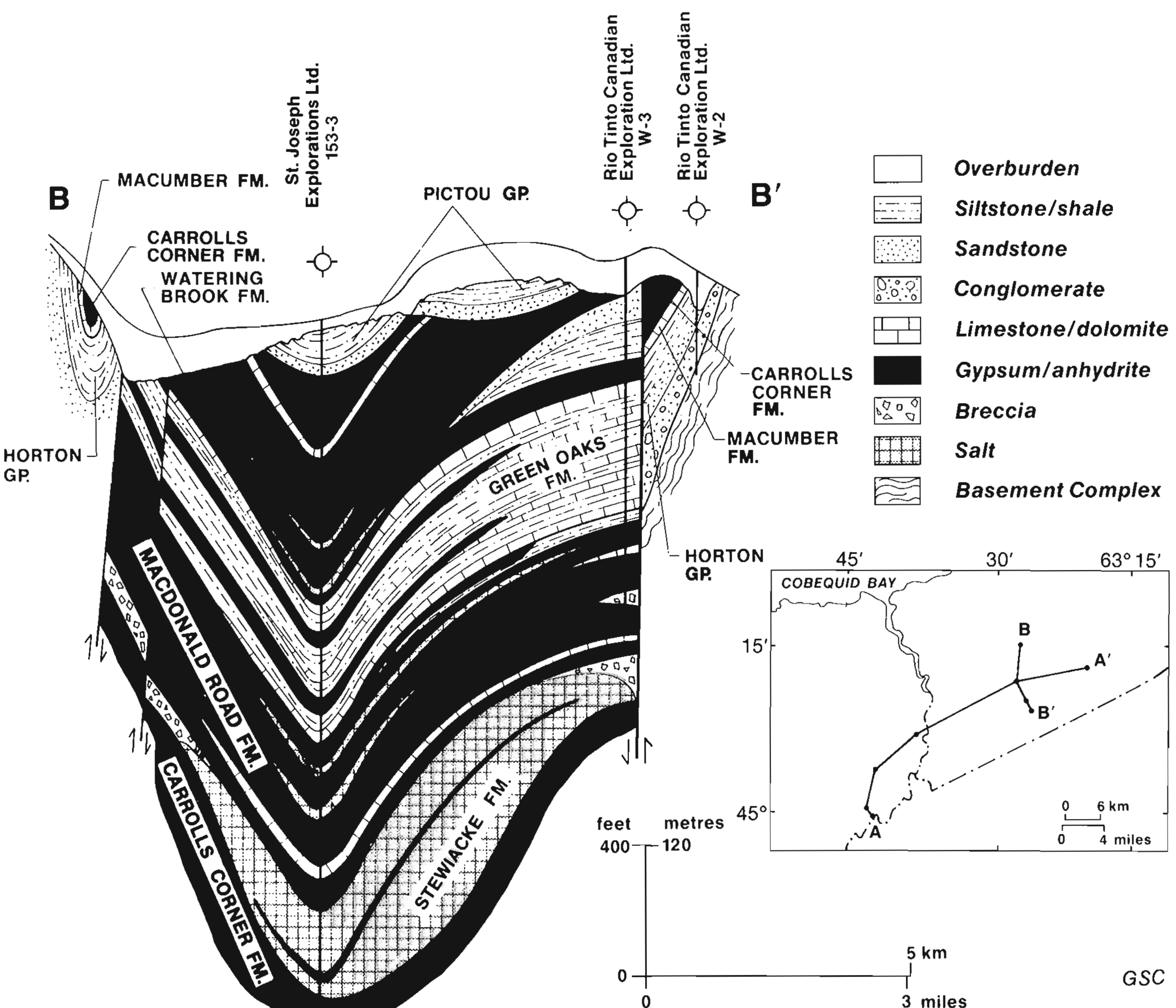
Figure 56. Cross section A-A', Minas subbasin, Nova Scotia.

appear to represent only a locally preserved facies. Two of the three thin salt zones intersected within the MacDonald Road formation have also been recognized in the Stewiacke Borax No. 1 borehole, suggesting that the sequence can be correlated locally.

In borehole 153-3 the Stewiacke Formation appears to be fairly thin, compared with the thickness intersected in some of the other boreholes in the area, if the anhydrite at the bottom of the hole is assigned to the underlying Carrolls Corner Formation. However, if the anhydrite zone near the base of the hole is interpreted as a lens within the Stewiacke Formation, additional Stewiacke salt may be present beneath it.

B-B' is a north-south cross-section (Fig. 57) with borehole 153-3 in common with the previous section. Although the beds in this section also dip at a few degrees from horizontal, the vertical exaggeration required to plot section A-A' and B-B' at the same scale has greatly oversteepened the beds.

The Stewiacke Formation at one time presumably occupied a much larger area than at present. Prior to the deposition of the MacDonald Road Formation, the period of subaerial erosion that removed part of the Carrolls Corner Formation (Giles and Boehner, 1979) probably also removed salt of the Stewiacke Formation. Cross-section B-B' is bounded south and north by faults. During the Maritime Disturbance (Carboniferous to Permian; Poole, 1967),



Informal stratigraphic terminology after Giles, and Boehner 1979, N.S. Dept. Mines and Energy

Figure 57. Cross section B-B', Minas subbasin, Nova Scotia.

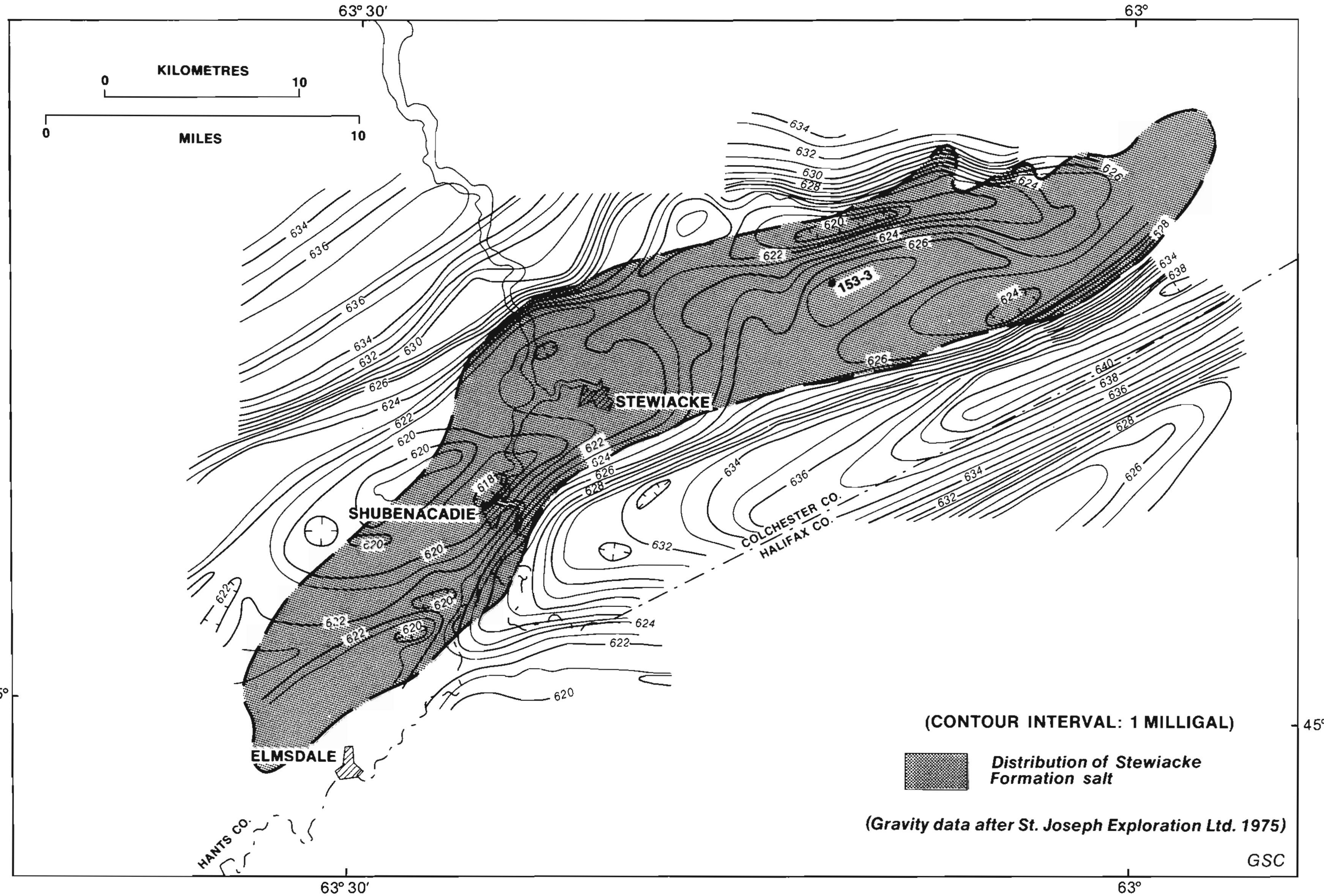


Figure 58. Bouguer gravity map, Stewiacke area, Minas subbasin, Nova Scotia.

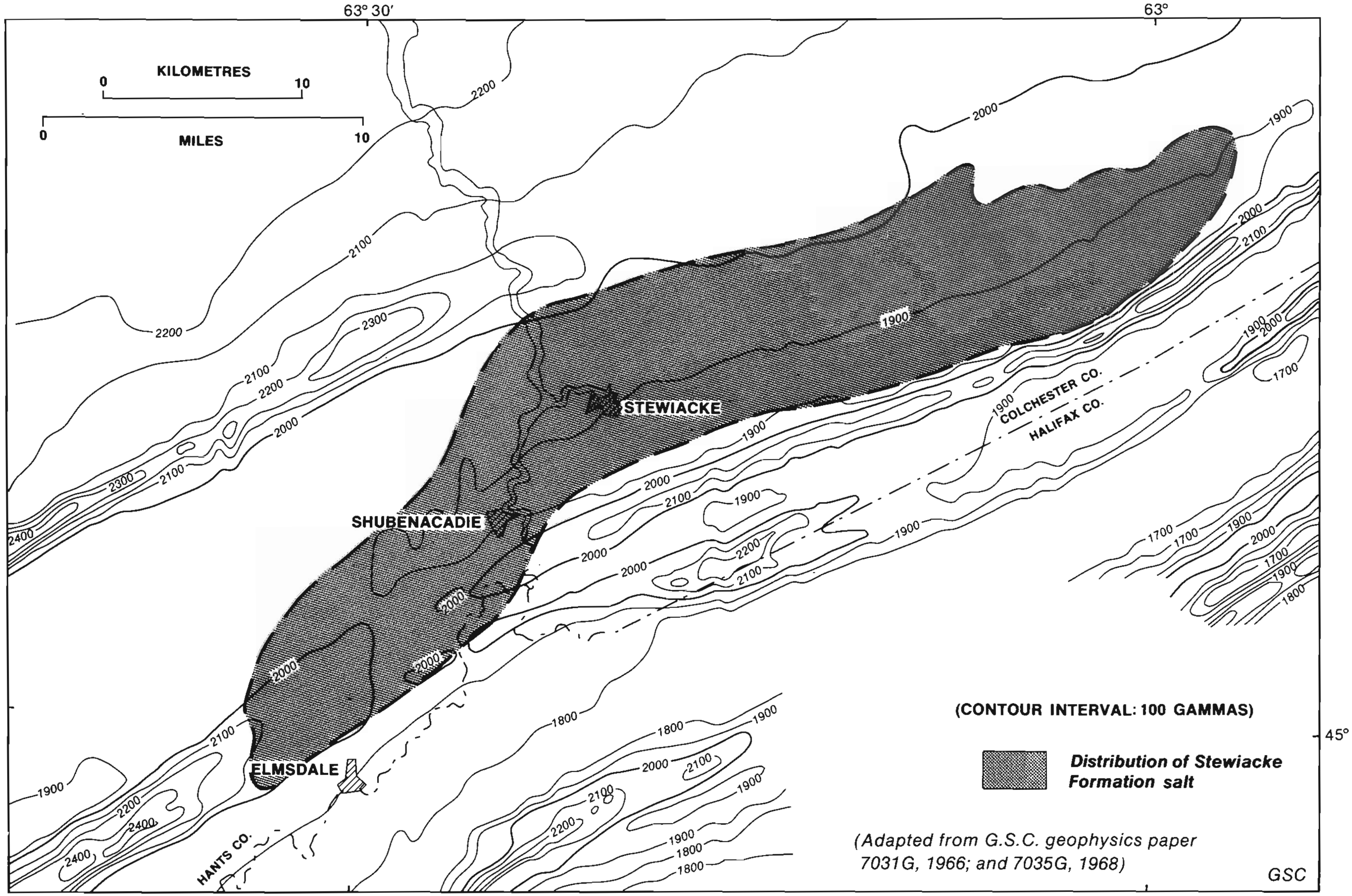


Figure 59. Aeromagnetic map, Stewiacke area, Minas subbasin, Nova Scotia.

the central core of the Stewiacke graben was down-faulted relative to the rest of Nova Scotia Platform, preserving a large area of bedded salt beneath a substantial thickness of anhydrite, siltstone and carbonate. Along the perimeter of the graben, most of the salt has probably been removed by erosion and dissolution, as indicated in Figure 54.

To some extent the distribution, thickness and tectonic setting of the Windsor Group evaporites in the Stewiacke graben appear to have influenced the gravity and aeromagnetic signature of the area. The outline of the Stewiacke Formation salt has been superimposed on a detailed gravity map of the area (Fig. 58). Although this is a relatively shallow sedimentary feature, there is a 20 mgal gravity contrast between the minima in the centre of the Stewiacke graben and the maxima along the basement outcropping to the south. The variation in the gravity data appears to have been determined by the depth and thickness of the salt, and the nature of underlying and overlying strata. The gravity contour adjacent to borehole 153-3 indicates a slight increase in density rather than a decrease, which would be expected along the axis of the salt basin. The increase may be attributed to an anomaly within the basement or a local basement high. If the anhydrite in the lower part of this borehole is considered to be part of the Carrolls Corner Formation rather than a local facies of the Stewiacke Formation, the gravity anomaly may represent a basement high.

The elongate gravity low along the edge of the salt deposit, north of borehole 153-3, and the small gravity low, north of Stewiacke on the east side of the Shubenacadie River, suggest an increase in thickness of the sedimentary section adjacent to a fault zone. The gravity low at Shubenacadie is also attributed to a thick evaporite sequence.

The outline of the Stewiacke Formation salt was also superimposed on the aeromagnetic map of the area (Fig. 59). The masking effect of sediments in a shallow graben on the magnetic contours is clearly shown.

It would appear that the Stewiacke Formation of the Windsor Group, in a depression on the Nova Scotia Platform known as the Stewiacke graben, is the main salt-bearing sequence in the Minas subbasin of Nova Scotia. It is a near- horizontal, bedded deposit, 56 km long, 11 km wide, and up to 300 m thick, occurring at about 450 m below surface near the structural centre of the basin (Fig. 56). Mechanical logs and chemical analyses of a number of holes indicate at least 60 m of the salt section has a purity equal to, or better than, 93 %. This occurrence may have potential as a future mineral deposit or for underground storage of hydrocarbons.

9. Antigonish subbasin, Nova Scotia

Salt springs and salt ponds, often associated with gypsum, have been known in the Antigonish subbasin for over 100 years (Cole, 1930; Pohl, 1931). As early as 1866, the Nova Scotia Salt Works and Exploration Company conducted drilling operations in the region to locate the brine source. A 15- cm borehole completed at 47 m produced a concentrated brine from below a 5.5 m section of gypsum (Dawson, 1878). Although the exact location of this brine well is not known, Fletcher (1887) indicated it was at Town Point, approximately 9 km northeast of Antigonish. A second borehole with a 23- cm casing was completed at approximately 48 m near the location of the present Antigonish railway station. This well produced a considerable quantity of salt before its brine became too dilute. When a third well drilled to 198 m near the railway station location failed to flow brine the project was abandoned.

The Antigonish area is underlain by Horton to Riversdale group rocks that have been mapped by Williams (1914), Sage (1954), Bell(1958), MacNeil (1959), Belt (1965), Benson (1970a), Boehner (1980a), and others. The geological map of the Antigonish area (Fig. 60), adapted from Boehner and Giles (1982), outlines a northeast-trending basin or complex graben structure that gradually deepens to the northeast to accommodate the youngest Carboniferous rocks in this region. Most of the faults appear to display normal movement except for the thrust front present along the west and southwest part of the map. The presence of salt springs, exploratory drilling, geological mapping and geophysical surveys indicate the subsurface presence of a salt near Ohio, James River, Antigonish, Southside Antigonish Harbour, and near Pomquet Forks (Fig. 61).

In the Ohio area, about 12 km south of the town of Antigonish, Maritime Exploration Limited intersected thin beds of salt in the AN-AH No. 1 hole (Fig. 61). The salt was found within a 40.2- m massive anhydrite, dipping at approximately 30°. Veins of salt about 2.4 cm thick were intersected at 289 m and 291.3 m, as well as a 0.6- m bed of reddish salt at about 301 m (log on file with the Nova Scotia Department of Mines and Energy). The hole was completed in Windsor Group anhydrite at 301.8 m. As this was the only hole drilled at this location, it is not clear if the thin salt bed represents the upper member of an interbedded salt-anhydrite sequence, the upper beds of a thick salt sequence, or a minor salt occurrence in a thick anhydrite zone.

A Bouguer gravity map (Fig. 62) indicates that the An-AH No. 1 drillhole is located on the south end of gravity high. The available data do not indicate any gravity lows in the immediate area of the Ohio occurrence. The aeromagnetic map of the same area (Fig. 61) indicates that the hole is located on the northern flank of a magnetic high, which appears to correspond with a change in the elevation of the basement. If the area is underlain by a thick section of Windsor Group salt, it is not obvious on either the gravity or magnetic maps.

The James River-Addington Forks area represents the most westerly extension of the Carboniferous rocks in the Antigonish subbasin (Fig. 60). This highly faulted area is characterized by a distinctive gravity low, first described by Pohly (1952). The KEH-5 hole, drilled on the southern flank of this gravity low by Kenneco Explorations (Canada) Limited in 1966 (Fig. 60, 61), was spudded in argillaceous Windsor Group rocks dipping at approximately 30°. A few few salt veins and a few thin salt beds were intersected between 164.3 m and 279.3 m before the hole was completed in the Horton Group at 471.6 m. The JR-3 hole, drilled in 1974 by Millmore-Rogers and Quebec Uranium

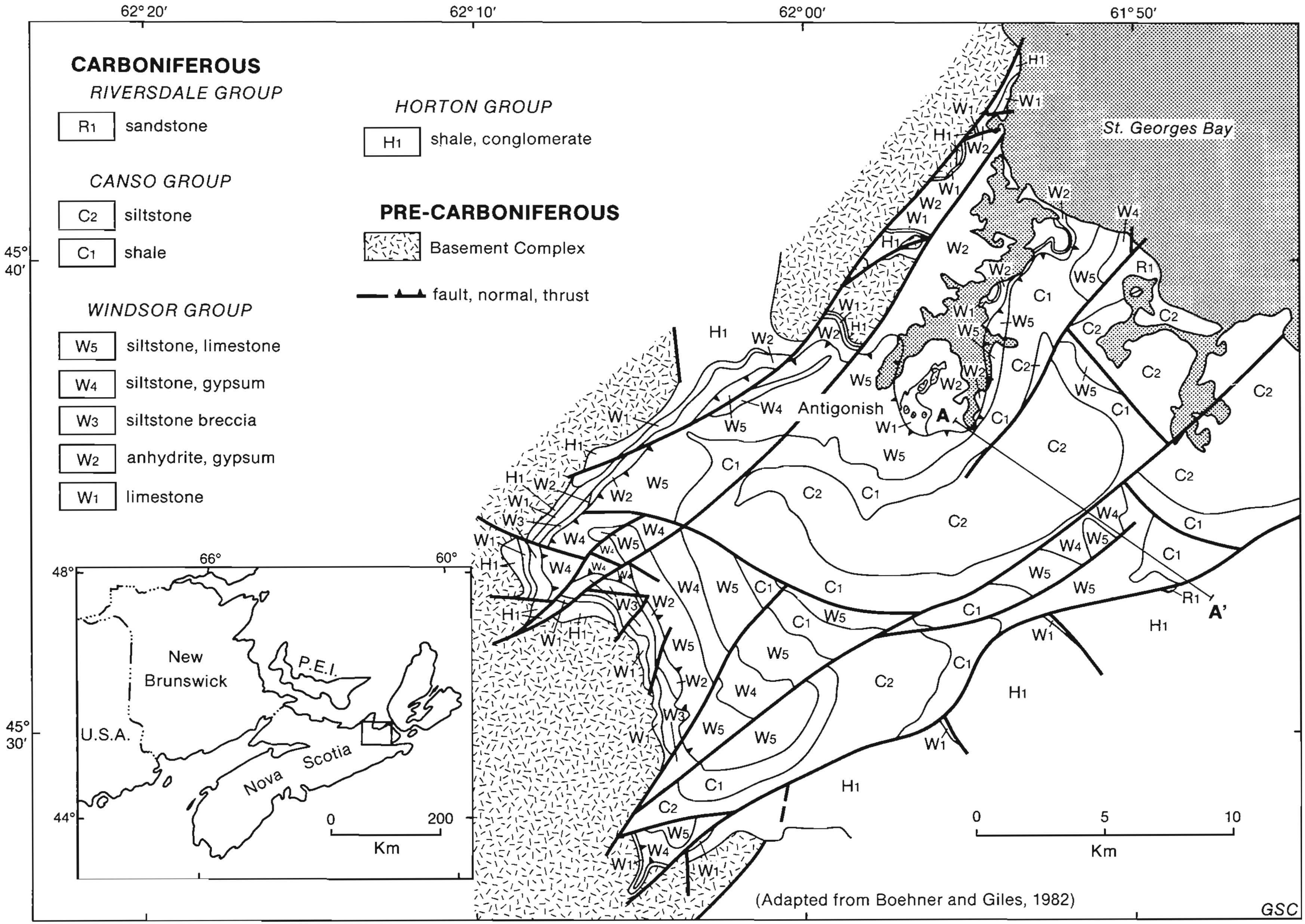


Figure 60. Geological map, Antigonish subbasin, Nova Scotia.

et al., penetrated approximately 40 m of salt before it was completed in salt at 250 m. A third hole, the AP-1-74, also drilled in 1974 by Amax Exploration Incorporated about 1 km east of JR-3, intersected about 210 m of interbedded argillaceous salt, salt with anhydrite, and salt from about 408 m to about 621 m. This well was completed at 675.6 m. Both the JR-3 and AP-1-74 wells contained minor low grade potash mineralization (1-6.5 % K_2O) (Boehner, 1981, 1986).

The three wells that intersected Windsor salt in the James River-Addington Forks area are located on the westward extension of a well defined gravity low (Fig. 62). This anomaly appears to be the result of a significant subsurface occurrence of low-density Windsor Group evaporites. According to the gravity data, the thickest section of salt should be just north of Addington Forks. The aeromagnetic map (Fig. 61) for this area does not contain any data in the vicinity of the salt wells. Although the size of the deposit has not been established by drilling, based on the Bouguer gravity anomaly, it has been estimated to be approximately 3000 m long, 1500 m wide, and up to 100 m thick (Boehner, 1986).

In the Antigonish-Salt Springs area the presence of subsurface salt has also been known from very early in the settlement of the area (Dawson, 1878; Pohl, 1931). In 1966 Kenneco Exploration (Canada) Limited intersected 52 m of Windsor Group evaporites in the KEH-1 drillhole (Fig. 61). This well penetrated Windsor salt from 319 to 366 m before it was completed in gypsum at a depth of 371 m. A second hole that penetrated salt in the area was AP-2-74, drilled by Amax Exploration Incorporated in 1974. This hole, located approximately 1.6 km south of KEH-1, intersected a mixture of salt and shale from 388 to 486 m. Over this 98 m interval, the salt content varied from 10 to 90 %. The hole was completed in red shale with minor salt in cavities and fractures at 556.7 m.

Both the KEH-1 and AP-2-74 holes are located on the southwest flank of a Bouguer gravity low, northwest of Salt Springs (Fig. 61, 62). As both holes contain salt it is interpreted that at least part of the gravity anomaly can be attributed to a significant subsurface salt deposit. The aeromagnetic map (Fig. 61) for this area does not contain any data in the vicinity of the salt wells.

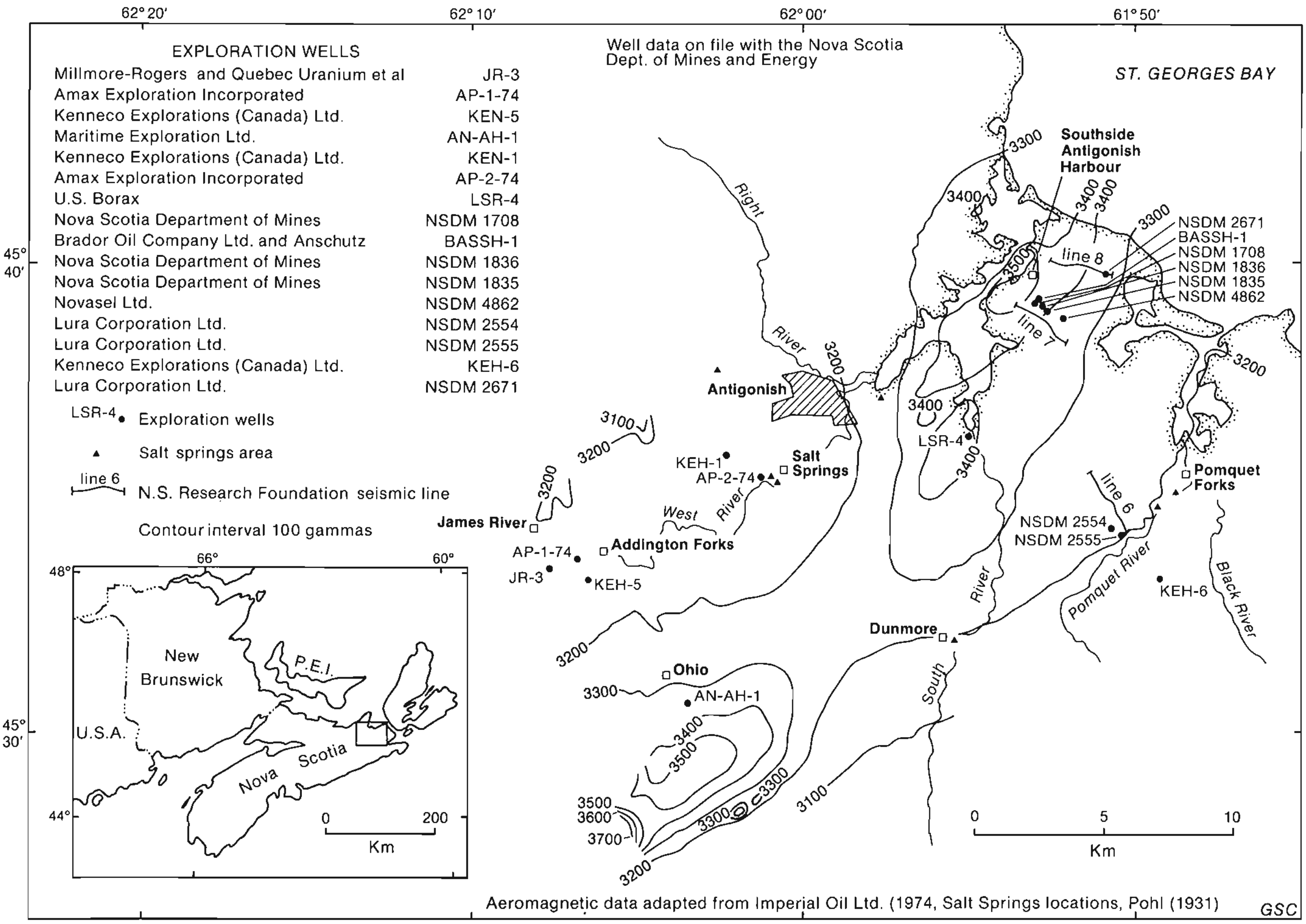


Figure 61. Aeromagnetic map, Antigonish subbasin, Nova Scotia.

Southside Antigonish Harbour is located about 10 km northeast of Antigonish. The presence of salt in this part of the Antigonish subbasin was established in 1951 when the Nova Scotia Department of Mines encountered it at 236 m in NSDM 1708 hole (Fig. 61). This hole, completed in salt at 297 m, was followed by the NSDM 1835 and NSDM 1836 holes which intersected salt at 227 m and 233 m respectively. The thickest intersection was in the NDSM 1836 hole, where 192.6 m was confirmed.

In 1969, Novasel Limited drilled Novasel No. 1 (NSDM 4862) in an attempt to establish the eastern limits of the salt. From 242 m to the bottom of the hole at 365.8 m the drill penetrated 114 m of salt associated with gypsum, anhydrite, and numerous mud stringers. In 1976 the Brador Oil Company Limited drilled the Brador Anschutz No. 1 hole (BASSH-1) just north of NSDM 1708 and NSDM 1836. This hole intersected mainly red shale, with several beds of salt from 250 to 274.4 m, 341.5 to 344.5 m, 350.6 to 420.7 m, and from 448 to 460 m. The drill did not encounter the thick zone of salt anticipated. The lowermost salt horizon penetrated was underlain by anhydrite and limestone.

About 2.5 km northeast of the Brador hole the Lura Corporation Limited drilled Lura No. 1 (NSDM 2671). Spudded in 1958, this hole penetrated 365 m of red and grey shale with thin interbeds and veinlets of salt from 233 to 595 m. The well was abandoned at 607.6 m, due to technical difficulties, without penetrating the main evaporite section.

In 1958, two northwest-trending reflection seismic lines were run for the Lura Corporation Limited by the Nova Scotia Research Foundation Corporation (Fig. 61). The profile of line No. 7 suggests that the strata overlying the proposed salt structure are nearly horizontal (Blanchard, 1959). Although line No. 8 was difficult to interpret, the eastern end of the profile outlined the western limit of a slightly disturbed anticline.

The Bouguer gravity contours in the vicinity of the Southside Antigonish Harbour holes (Fig. 62), trend in a north-northeast direction, and are characterized by a steep gradient which gradually decreases to the east. The trend of these contours appears to reflect the regional structure of the area and does not appear to be influenced to any great extent by the low density evaporites observed in a number of wells.

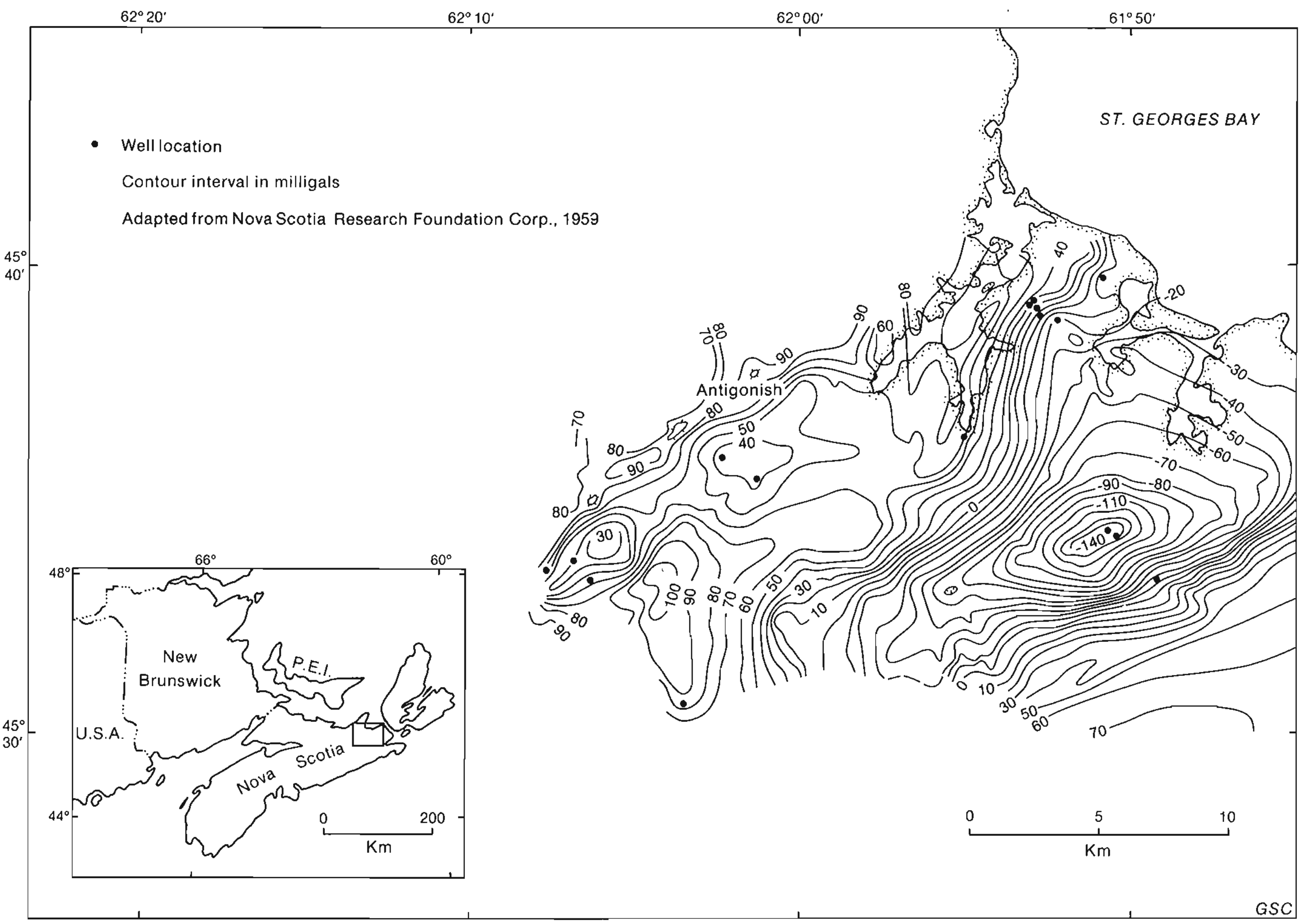


Figure 62. Bouguer gravity map, Antigonish subbasin, Nova Scotia.

This may indicate that the salt section was not of sufficient thickness to significantly alter the regional trend of the contours. The close spacing of the contours that gradually spread out to the east may indicate a very rapid change in the density of the basement complex. This interpretation is consistent with a complex graben-type basement which was overlain by a thick section of sediments, as interpreted from the geological map and borehole data.

The aeromagnetic contours (Fig. 61) trend in a general northeast direction with a 3500 gamma contour in the Southside Antigonish Harbour area that diminishes to 3200 gammas near the eastern edge of the map. These changes in values may be entirely due to a change in the magnetic properties within the basement complex, or they may also reflect the regional structural trends and masking of the magnetic values by a thick section of sedimentary rocks. The general trend of the contours is in accordance with the regional structure for the area, and the change from 3500 to 3200 gammas corresponds to a general thickening of the sedimentary section from west to east, as already suggested from the geological map, borehole data, and gravity map.

The Pomquet River area, about 6.5 km south of Pomquet Forks, is on the eastern portion of the Antigonish subbasin (Fig. 60). According to Pohl (1931) salt springs have been known in this area for many years. Gravimetric surveys conducted in the Antigonish subbasin by the Nova Scotia Research Foundation Corporation between 1952 and 1958 for Lura Corporation Limited indicated that this area is underlain by a pronounced gravity low (MacNeil, 1959). It was believed that a large body of salt about 300 m below the surface was responsible. Following the results of these preliminary investigations, the Lura Corporation Limited drilled the NSDM 2554 exploratory well (Fig. 61). A very strong flow of brine containing 88 parts per million of potassium was encountered at 25.9 m. Salt breccia was intersected from 363 to 378.7 m. The hole was completed at 401.2 m in a limestone-anhydrite-shale breccia. A second hole, NSDM 2555, was drilled near a fault or breccia zone about 488 m south of NSDM 2554. Unfortunately, this hole was completed in Windsor Group strata at 255.5 m, due to caving, without intersecting salt.

Subsequent to the 1958 drilling program, a seismic line (No. 6) was run by the Nova Scotia Research Foundation Corporation near the Lura Corporation Limited wells. This profile confirmed a subsurface anticlinal salt structure (Blanchard, 1959).

In 1966 Kenneco Explorations (Canada) Limited drilled the KEH-6 hole. This hole penetrated about 4 m of shale containing salt at 203 m, and was completed at 372.2 m without intersecting any additional salt. From 70 m to the bottom of the hole, much of the drill core was fractured or brecciated.

The Bouguer gravity map (Fig. 62) indicates a distinctive gravity low centred over the NSDM 2554 and 2555 holes. This low is considered to be the result of a thick section of Carboniferous rocks that probably contain a considerable volume of low density Windsor Group evaporites. The combination of a thick sedimentary section also containing a considerable volume of salt appears to have accentuated the gravity anomaly.

The aeromagnetic map indicates that a 3200 gamma contour passes through the Pomquet River area. This is considerably less than the 3500 gamma contour in the Southside Antigonish Harbour area. The change may be entirely due to a change in the magnetic properties within the basement complex, or it may also reflect regional structural trends and masking of the magnetic values by a thicker section of strata at Pomquet River. The geological map supported by drillhole data indicates that there is a thicker section of Carboniferous rocks in the Pomquet River area than at Southside Antigonish Harbour.

As shown on the geological map (Fig. 60), A-A' is a southeast-trending cross-section through the Pomquet River area (Fig. 63). Although the LSR-4 hole, drilled by U.S. Borax, near the western end of this section, did not intersect salt, it has been included to show the stratigraphic control for the area. Southeast of the basement ridge, defined by this hole, a large graben is shown to contain in excess of 2 km of Horton to Canso group rocks. As indicated on the geological map, this graben occupies a considerable area of the Antigonish subbasin. This structure is shown to contain some Windsor evaporites, although most of the salt has probably flowed up-dip towards the adjacent faults. The local unconformity on the north side of the graben between units W4 and W5 is attributed to the effects of salt flowage. The unconformity and the thick bed of salt suggest there was very little groundwater migrating along the fault otherwise the salt would have been removed adjacent to the fault.

The graben block immediately to the southeast is shown to contain a thick accumulation of salt. Some of this salt probably flowed into the area forming a domal to diapiric structure. The highly fractured to brecciated rocks in the NSDM 2554 hole and the presence of an anticlinal structure as indicated by seismic section No. 6 (Blanchard, 1959) support this theory. The hole is considered to have been completed in the upper few metres of a partly diapiric salt structure. The NSDM 2555 hole was probably drilled in a fault zone and consequently did not penetrate any salt.

Near the southeast end of the Antigonish subbasin the KEH-6 hole was completed at 372.6 m, after penetrating 4.2 m of shale with salt stringers from 203.7 to 207.9 m. This hole is shown as a broken line because it is located a little south of the line of section. A considerable volume of salt is also shown at depth in this part of the section. Some of this may have flowed into the main salt structure to the northwest and/or along the fault southeast of the KEH-6 exploratory hole.

10. Mabou subbasin, Cape Breton Island, Nova Scotia

The Mabou subbasin, located in southwestern Cape Breton on St. Georges Bay, contains a thick succession of Horton to Pictou group rocks (Fig. 64). Although the structure and stratigraphy of this area has been described by Norman (1935), MacNeil (1945), Stacey (1953), Bell (1958), Belt (1962), Kelley (1967a), and others, a lack of adequate exposures, drillholes and considerable local tectonism have resulted in a variety of geological interpretations. Brine springs on Glendyer Brook, about 20 km northeast of Port Hood, was reported by Hayes (1920) and Norman (1935). This location is not shown on Figure 64.

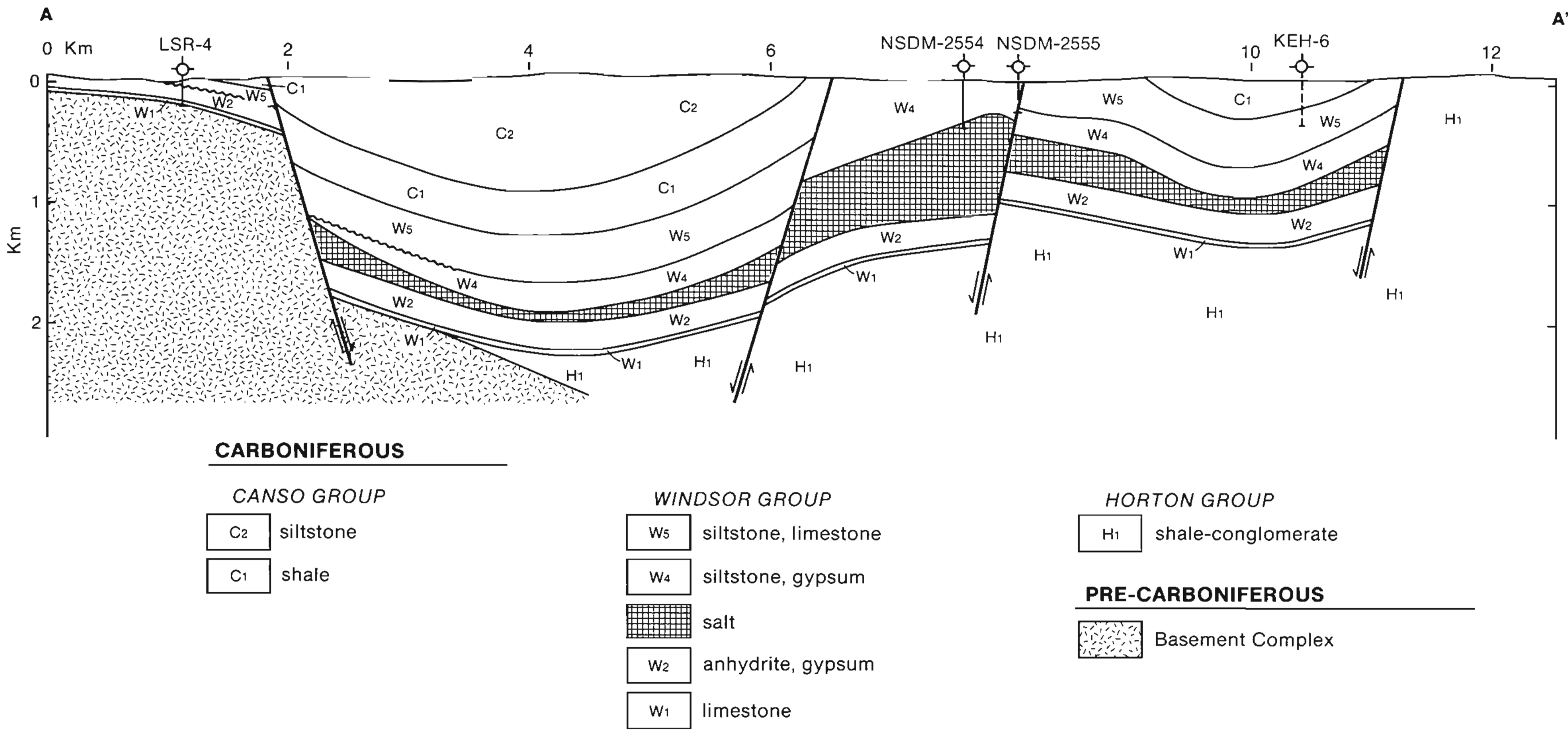


Figure 63. Cross section of Pomquet River salt structure, Antigonish subbasin, Nova Scotia.

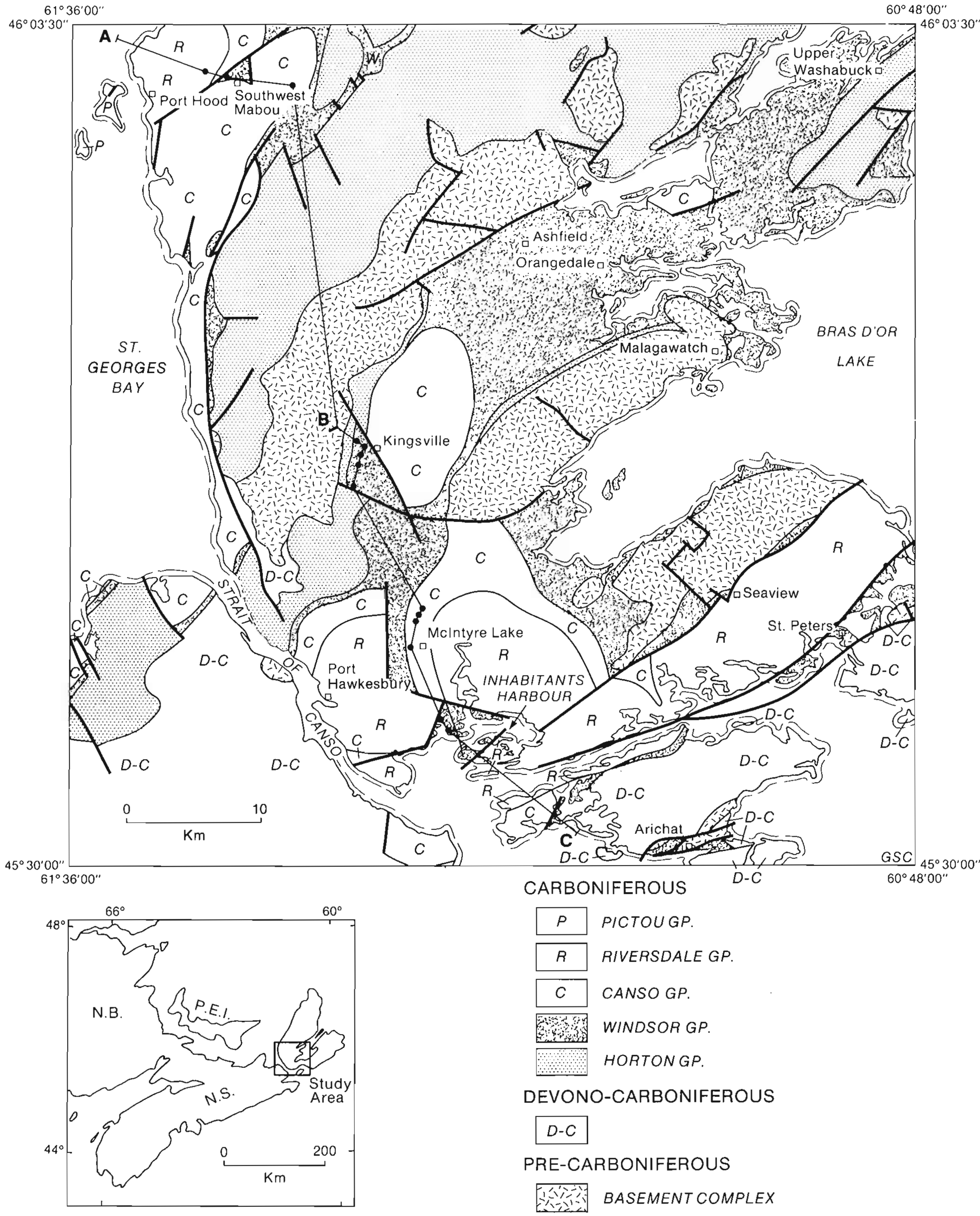
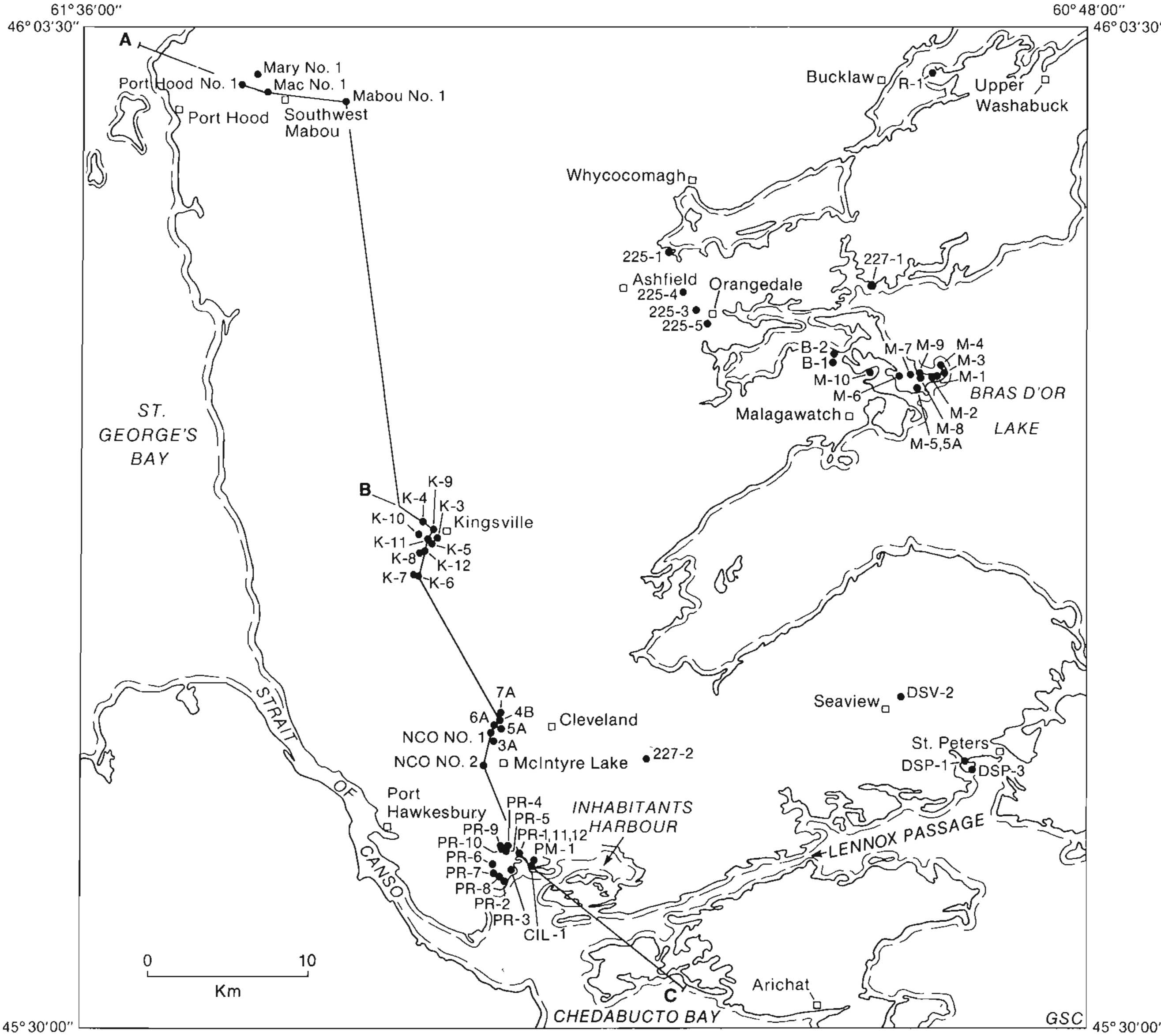
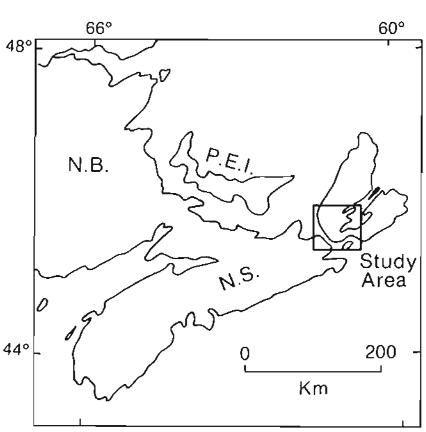


Figure 64. Geological map, southwestern Cape Breton Island, Nova Scotia.



(Well data on file with the Nova Scotia Department of Mines and Energy)



Dow Chemical Port Malcolm	PM-1
Dow Chemical Port Richmond	PR-1 to PR-11
Canadian Industries Ltd.	CIL-1
Murphy Oil Co. Ltd. and North Canadian Oils Ltd.	NCO-1, NCO-2
Home et al.	3A, 4B, 5A, 6A, 7A
Domtar Kingsville	K3 to K12
Llon Oil Refining Co.	Mary No. 1, Mac No. 1
Imperial Oil Ltd.	Mabou No. 1, Port Hood No. 1
Domtar St. Peters	DSP-1, DSP-3
Domtar Seaview	DSV-2
Chevron Irving Malagawatch	M1- M10
Chevron Irving Bras D'or	B-1, B-2
Chevron McIvor Point	R-1
Noranda Estmere	227-1
Noranda Ashfield	225-1, 3, 4, 5
Noranda Cleveland	227-2
Noranda Orangedale	225-3

Figure 65. Salt boreholes and related wells, southwestern Cape Breton Island, Nova Scotia.

In 1944 the Lion Oil Refining Company drilled Mac No. 1 in a geologically deformed area near Southwest Mabou (Fig. 65). This hole was completed at 1700.5 m after penetrating 1275.2 m of salt interbedded with varying amounts of shale, gypsum and limestone below 425.3 m. A second hole, Mary No. 1, also drilled by Lion Oil Refining Company, located about one kilometre northwest of Mac No. 1 was completed at 2094.2 m after intersecting about 700 m of salt, gypsum and minor shale from 1365.9 to 2067 m. Below this salt there is a 27.2- m section of fairly massive gypsum, that according to the company log may also contain some interbeds of salt. It is not known if this gypsum is an impurity within the main salt or part of the basal anhydrite member of the Windsor Group.

In 1960 Imperial Oil Limited drilled Port Hood No. 1 about 2 km west-o northwest of Mac No. 1. This hole, which bottomed in the Horton Group at 300 m, first encountered salt as fracture filling in a dolomitic limestone from 2019.8 to 2028.9 m. Below this interval to about 2966.4 m there was 880 m of salt interbedded with shale varying in thickness from about 6 to 56 m. From the lowermost salt to the top of the Horton Group at 2982 m, there is 16 m of Windsor Group anhydrite and limestone. In 1959 the Imperial Oil Limited Mabou No. 1 hole, drilled about 5 km east of Mac No. 1, was completed in the Horton Group at 1568.6 m. The Canso-Windsor Group contact intersected at 622 m was characterized by 26 m of fractured to brecciated shale, containing salt from 689 to 715 m. The base of the Windsor Group was at 745.4 m. In this well the entire Windsor Group was only 123.4 m thick.

A Bouguer gravity map of southeastern Cape Breton (Fig. 66) indicates a gravity low-trending north-northeast in the Port Hood area. The orientation of this anomaly is in accordance with the regional structure of the area and its presence corresponds fairly well with the known location of a considerable volume of salt intersected in a number of drillholes. The location of a basement ridge between Port Hood and Ashfield as shown on Figure 64 is void of contours on the gravity map because it was outside of the area surveyed by the Nova Scotia Research Foundation Corporation.

The aeromagnetic map of the same area (Fig. 67) indicates widely spaced, fairly smooth contours with a small magnetic low about 20 km southeast of Port Hood. This is in marked contrast to the closely spaced contours over the basement ridge to the southeast. Unless there is a dramatic change in the rock type between the two areas, most of the difference can probably be attributed to a thick mantle of sedimentary rocks in the Mabou subbasin that has attenuated the basement anomalies.

The geological cross section ABC, Port Hood to Chedabucto Bay (Fig. 68) has been prepared to illustrate some of the deformed salt deposits in southwestern Cape Breton Island. Although this section is almost 80 km in length, only the northwestern part of the section will be discussed at present.

The area is characterized by a highly faulted basement overlain by a thick section of Horton and Windsor group rocks. The Windsor Group contains a considerable volume of salt, some of which appears to have flowed updip forming domal to diapiric structures. At Southeast Mabou the attitude of the beds indicates that the area is underlain by a northeast-trending structure attributed to the upward flow of Windsor Group salt. The combination of a thick section of salt, mixed with shale, gypsum and occasional limestone in the Port Hood No. 1, Mary No. 1 and Mac No. 1 holes is probably due to diapiric movement of salt into the overlying beds. Salt-filled fractures in the dolomitic limestone overlying the main salt mass in the Port Hood No. 1 hole, suggests that the carbonate bed is a section of broken caprock.

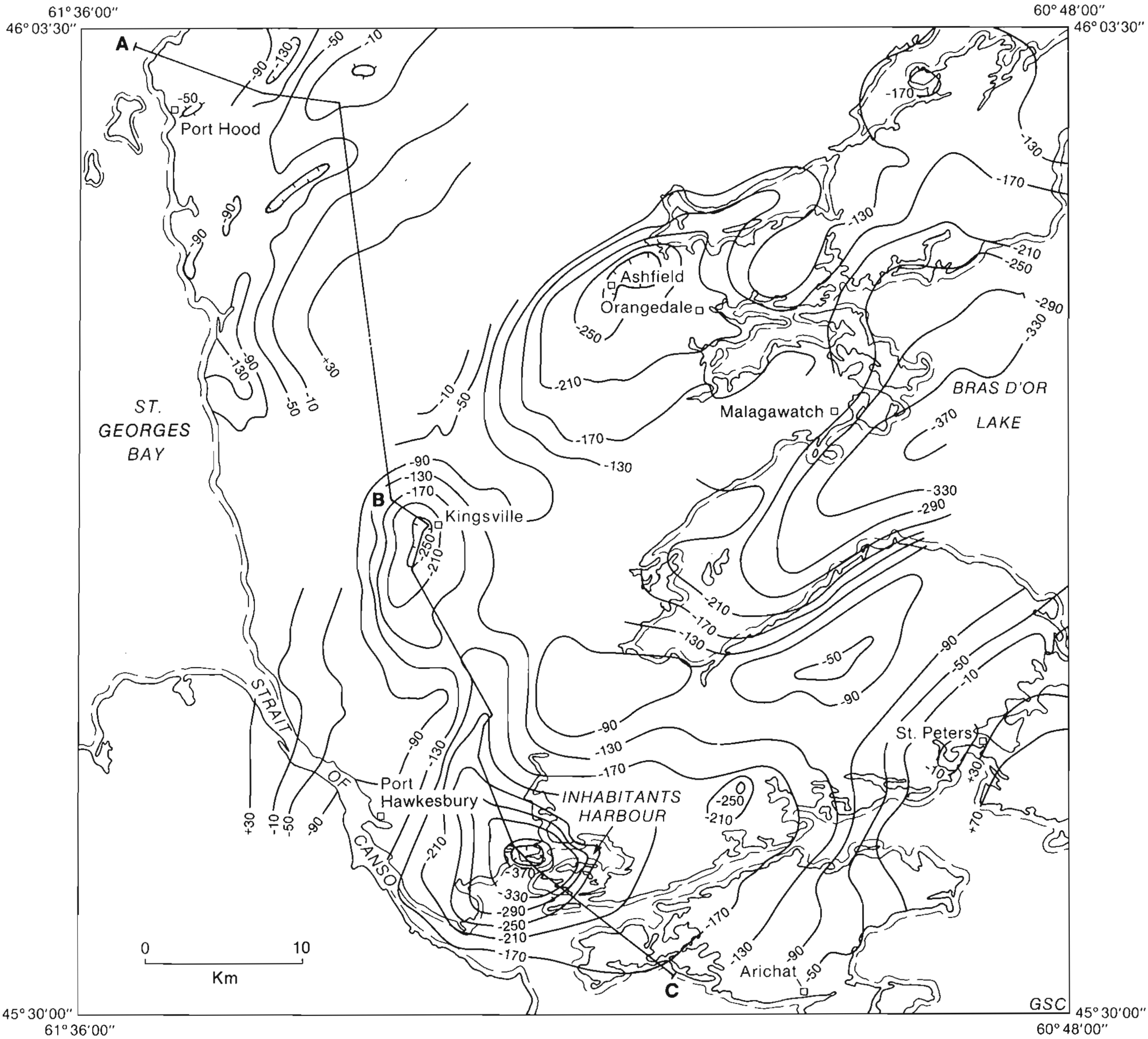
The northeast-trending fault along the west side of the salt structure may be directly related to an offset in the underlying basement, a near-surface feature due to salt migration, or a combination of both. West of the fault the salt zone is shown to thin gradually and then thicken slightly in the Gulf of St. Lawrence west of Cape Breton Island. As the central part of the Magdalen Basin east of Îles de la Madeleine between the Cumberland subbasin of Nova Scotia and western Newfoundland appears to be the main depocentre for Windsor Group evaporites, it is logical to assume that the offshore area west of the Mabou subbasin contains some thick salt deposits.

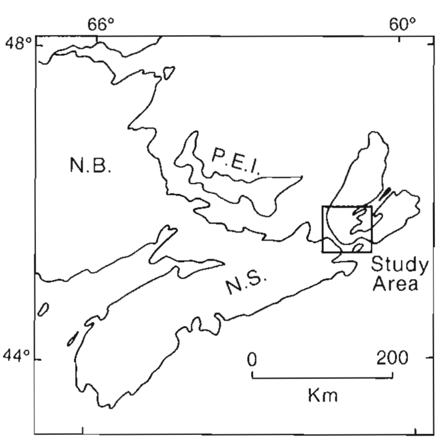
The Canso Group west of the main Mabou salt structure is shown to contain a number of salt lenses. As Canso Group salt is present in the Stewiacke graben, Minas subbasin and in central Cape Breton Island it is considered to also be present in this area (Boehner, 1983, 1986; Howie, 1985).

The Imperial Mabou No. 1 well drilled about 5 km east of Mac No. 1, penetrated 123.4 m of Windsor Group rocks before it was completed at 1568.6 m in the Horton Group. This well is shown to be east of the main salt mass because the only salt present in the well is in shale fractures from 689 to 715 m. From the Horton-Windsor Group contact to the base of the shale, the Windsor Group contains 15 m of limestone overlain by about 15 m of anhydrite. As the Windsor Group in this hole is relatively thin, some of the section may have been removed by faulting. The company log for this well indicated "much leaching", associated with the brecciated shale-salt horizon. It is not known if the leaching was due to unsaturated drill mud or to percolating groundwater associated with faulting and/or fractures.

11. Kingsville area, Cape Breton Island, Nova Scotia

The Kingsville area, about 75 km north of Port Hawkesbury (Fig. 64) is covered by the Whycocomagh map sheet. A geological map of this region (Kelley, 1967), indicates much of the area east of Kingsville is devoid of outcrop and covered by overburden. The aeromagnetic map (Fig. 67) indicates a 2000 gamma contour passing through the Kingsville area. This gamma level is also associated with the basement complex both east and west of Kingsville. If the Carboniferous section has to any extent masked the anomalies within the basement, it is not obvious from the contours.



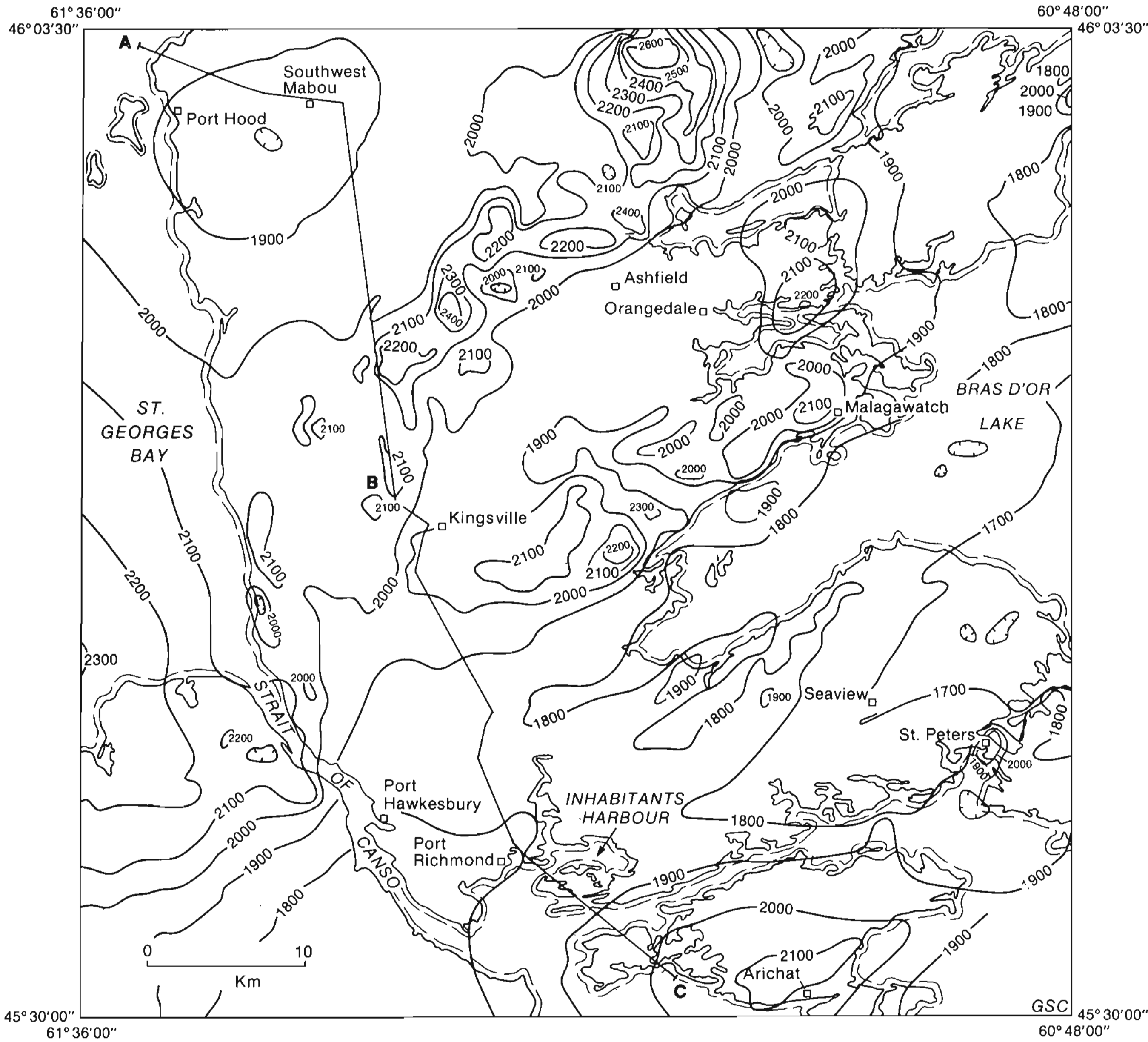


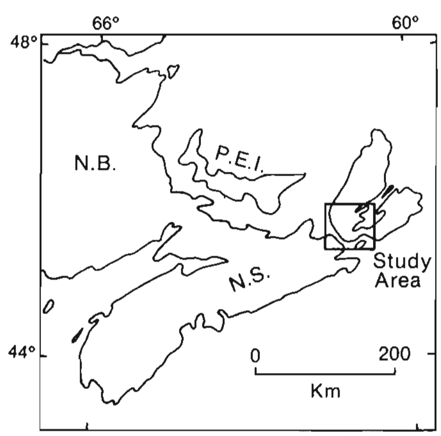
A—B—C Line of Section

Contour interval 40 um/sec² (4 mgals)

Adapted from Nova Scotia Research Foundation Corporation maps 1967, 68 and 72; Imperial Oil Ltd. map, 1958 and Noranda maps, 1981; on file with Nova Scotia Department of Mines and Energy.

Figure 66. Bouguer gravity map, southwestern Cape Breton Island, Nova Scotia.





A—B—C Line of Section

Contour interval 100 gammas

(Adapted from GSC geophysical papers 7034G, 1966 and 7038G, 1968)

Figure 67. Aeromagnetic map of southwestern Cape Breton Island, Nova Scotia.

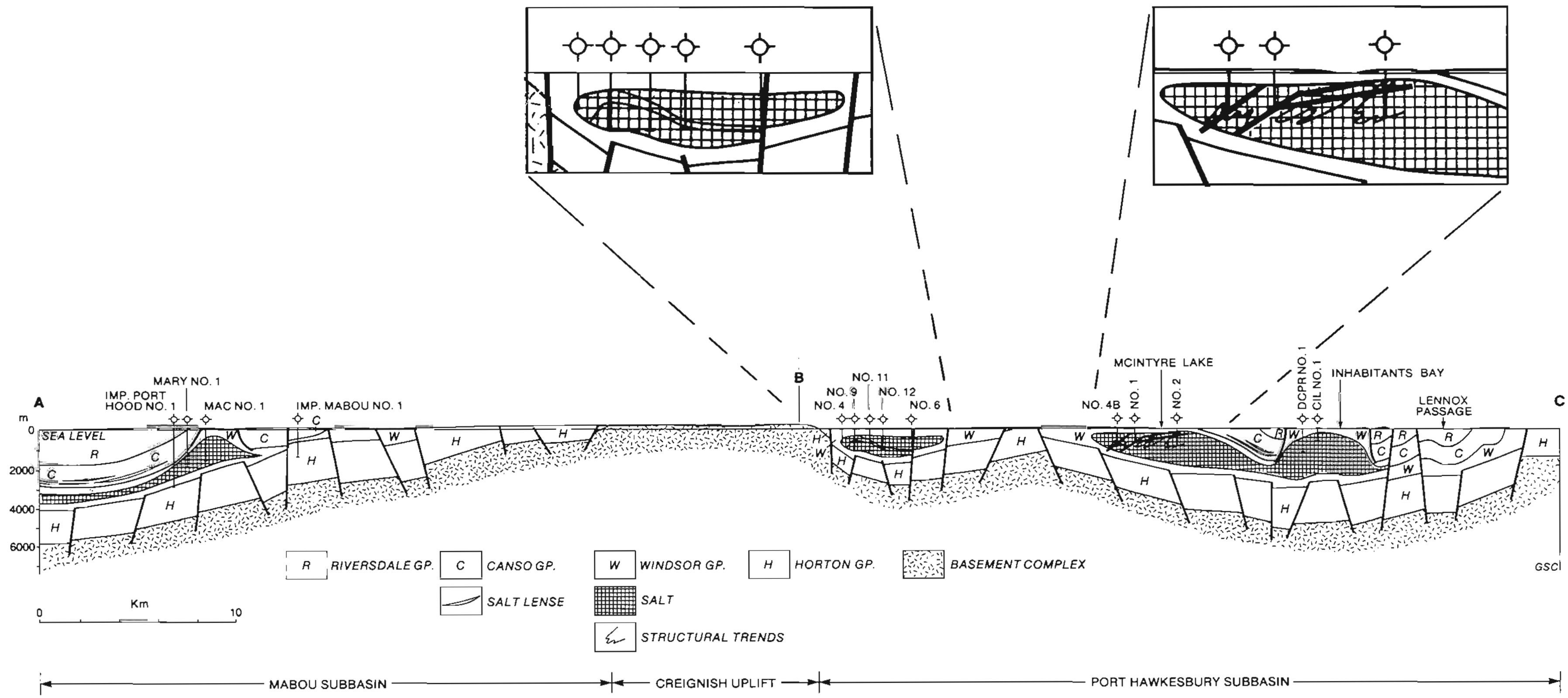


Figure 68. Cross section ABC, Port Hood to Chedabucto Bay, Cape Breton Island, Nova Scotia.

Gravity surveys conducted by the Nova Scotia Research Foundation Corporation for Domtar Incorporated, from 1968 to 1970 indicated a gravity low underlying the area mapped as overburden. This anomaly (Fig. 66) trending south-southwest is about 3.2 km long and at least 1200 m wide. Each of the ten salt exploration holes that were drilled by Domtar Incorporated in this area during 1970-71 penetrated salt (Fig. 65, holes K-3 to K-12). The salt is interbedded with varying amounts of anhydrite, limestone and siltstone. Siltstone appears to be the major rock type near the perimeter of the basin as well as the major component forming the caprock. Gypsum is only present above the main salt, which is tentatively considered to belong to the lower part of the Windsor Group (Subzones A and/or B).

The salt mass is interpreted as a diapiric anticline or ridge that plunges gently to the south. Along the northern crest of this ridge salt was intersected from 381 to 396 m while to the south the top of salt ranges between 503 and 518 m. Drillholes near the crest of the structure contained the purest salt (over 95 % NaCl) and recorded dips of from 50 to 70°. Some of the steeply dipping beds appear to be overturned in places and drag folds are common throughout. Fold structures appear comparable to those observed in the salt mine at Pugwash. On the flanks of the salt structure away from the diapiric core, the beds appear to be relatively undisturbed with gentle dips as low as 10° and salt grades of around 60 %. A broad breccia zone occurs in this area, initially caused by the fracturing of the rocks due to the upward intrusion of salt. This zone has been subjected to intense leaching resulting in the formation of a significant collapse breccia. As very little water was observed in the wells close to the top of the salt, the present top of the salt is probably the limit of percolating paleo-groundwater.

Section line B to C of Figure 68, passes through the Kingsville salt deposit. Three of the five faults shown to have influenced the thickness of the Carboniferous section, are basement faults that can be observed on the surface. The basement faults located directly below hole No. 9 and hole No. 12 are shown to be related to a horst structure. The section between hole No. 4 and hole No. 9 indicates the steep dips that are present on the flanks of this structure. From hole No. 9 to the southern end of the salt mass the section line is along the crest of the structure. The change in the dip of the beds from north to south indicates that the salt overlying the basement horst has been uplifted and subsequently eroded by percolating groundwater.

South of the salt mass, the Windsor Group is shown to be cut off from the McIntyre Lake area. This is only apparent due to the location of the line of section. If the line of section had been plotted farther to the east, the Windsor Group would have been shown to be continuous across the area.

Potash has not been reported in any of the holes at this location. If potash was originally present, it may have flowed upward into areas of low stress within the diapir where it would have been removed by groundwater leaching.

Based on drilling results Domtar Incorporated estimated the proven salt reserves at approximately 28.6 million tonnes (Boehner, 1986). At the completion of the drilling project a decision was made to suspend work on the development of a salt brine mine, or underground storage for petroleum.

12. McIntyre Lake area, Cape Breton Island, Nova Scotia

The presence of salt in the McIntyre Lake area was first indicated by Ferguson (1946), who noted an anomalous salinity in brook water passing over Windsor Group rocks. Gravity surveys of Carboniferous areas in Cape Breton Island in 1967 and 1971 (Nova Scotia Research Foundation Corporation, 1972), indicated a well-defined gravity low in the McIntyre Lake area (Fig. 66), attributed to a thick section of low density sediments. Wide spacing of aeromagnetic contours over the same area (Fig. 67), also suggested the presence of a thick Carboniferous section and/or basement rocks with a low mafic content. A follow-up residual gravity map prepared for Murphy Oil Company Limited (1971) outlined a large area that could be interpreted as a salt collapse breccia.

From 1972 to 1974 Murphy Oil Company Limited and Northern Canadian Oils Limited drilled two holes to confirm the occurrence of salt in the area and to determine its suitability for possible underground storage of high pressure liquid petroleum gas (LPG) and other petroleum products. The NCO No. 1 hole (Fig. 65), intersected salt at 256.7 m, penetrated 31.4 m of anhydrite from 531.7 to 563.1 m and was completed in salt at 670.7 m. The 381-m salt section in this hole was considered to be of a suitable quality for construction of a solution cavity. The NCO No. 2 hole, located about 2 km south of NCO No. 1, intersected salt at 254.9 m and was completed at 916.8 m in a claystone-salt mixture. Apart from two pure salt horizons (more than 95 % salt), about 32 and 25 m thick, the mixture of salt and claystone, anhydrite and limestone made the hole an unsuitable target for further evaluation as a possible storage cavity.

Variable bedding with dips ranging from 20 to 70° (Murphy Oil Company Limited, 1974) indicate a significant amount of structural deformation within the salt mass. Bedrock above the salt in both wells is interpreted as caprock composed of gypsiferous clay, anhydrite and limestone. This rock sequence is thought to represent a collapse breccia caused by groundwater leaching and by the upward movement of evaporites into the overlying beds.

After the completion of the two Murphy wells, Home Oil Company Limited bought into the consortium and arranged for two geophysical surveys in this area. The gravity project (Home Oil Company Limited, 1977a) further detailed the known gravity low. The seismic survey (Home Oil Company Limited, 1977b) attempted to define the top of the salt structure. The resultant data failed to produce an event that could be correlated with the top of the salt as recorded in the drillholes because brecciation and intermixing of evaporites in the zone above the salt and solution and migration of salt combined to dissipate the seismic signal.

By 1979 Home Oil Company Limited et al. had completed five additional holes (3A, 4B, 5A, 6A, and 7A) totalling approximately 4500 m which helped to delineate the salt mass and give some indication of the age of deposition. Unlike the NCO No. 1 and 2, that were cored from surface to total depths (T.D.), these holes were only cored from the top of salt to T.D. Some of the internal salt structure as shown on the cross-section (Fig. 68), is the trace of the lowermost limestone in the Upper Windsor (subzone C of Bell, 1929). The lowest Windsor section at McIntyre Lake belongs to faunal subzone B of Bell (1929). According to Giles (1981a) this section can also be correlated with the MacDonald Road Formation of Giles and Boehner (1979) (Fig. 53), with the following modifications: (1) the section at McIntyre Lake is about 610 m thick, which is about four times thicker than observed in the Minas subbasin; and (2) the McIntyre Lake section has a higher percentage of salt in relation to anhydrite, carbonate and siltstone.

Tectonic squeezing, folding and faulting of Paleozoic strata has caused the accumulation of masses of salt at McIntyre Lake with varying purity and steeply dipping beds up to 100 m thick. Folds appear to be generally overturned to the south (Giles, 1981a), perhaps in association with low angle faults. Although the salt mass is diapiric in nature, its upward limit, which coincides as a topographic high, has presumably been controlled by groundwater percolation. Above the salt in the NCO No. 1 hole there were two artesian freshwater zones that flowed 230 to 460 litres per minute. The low chloride and potassium content of the water indicated that at present this water flow is not in contact with the underlying salt. This was the only well that was reported to contain a large volume of water in the bedrock above the salt.

At this location all occurrences of potash in the form of sylvite are present in Subzone B of the lower Windsor. Sylvite is present in wells No. NCO No. 1, 2, 4B, 6A, and 7A as a number of thin beds associated with salt and silty salt (Giles, 1981a). The presence of potash was not recorded in well No. 3A and 5A. No decision has been made to further explore this salt deposit for potash, salt or for underground storage.

The Windsor Group at McIntyre Lake is dominated by salt which occurs in both the lower and upper parts of the Windsor sequence. The presence of substantial thicknesses of salt in the Upper Windsor may indicate that not all major salt bodies in Nova Scotia should necessarily be assigned to subzone A. In some areas the entire Windsor Group may be dominated by salt, that also may extend up into the Canso Group. Boehner (1983, Fig. 5) indicates anhydrite and salt are locally present at the base of the Canso Group in the Shubenacadie area of the Minas subbasin and in central Cape Breton Island. Although the Canso Group section immediately south of McIntyre Lake (Fig. 68) has not been drilled it is shown to contain some lenses of salt.

13. Inhabitants Harbour area, Cape Breton Island, Nova Scotia

The Inhabitants Harbour-Port Richmond area is about 8 km east-southeast of Port Hawkesbury (Fig. 64). This area was geologically mapped by Ferguson (1946), Ferguson and Weeks (1950), Collins (1962), Shea and Wallace (1962). The possible occurrence of salt was not recognized until gravity surveys of some Carboniferous areas in Cape Breton during 1967 (Nova Scotia Research Foundation Corporation, 1972), indicated a well-defined gravity low in the Inhabitants Harbour area (Fig. 66). This anomaly was interpreted to suggest the presence of a thick section of low density sedimentary rocks and/or an anomaly within the basement rocks similar to that observed in the Codys area of New Brunswick (Fig. 21, this paper). In the Inhabitants Harbour area, wide spacing of the aeromagnetic contours (Fig. 67) suggest a masking of the basement complex by a thick section of Carboniferous rocks and/or a low mafic content in the basement complex over a wide area.

Early in 1967, Dow Chemical Company of Canada Limited drilled the Dow Chemical Port Richmond No. 1 (DCPR No. 1) to explore the salt potential of this area. At this location, 492 m of caprock composed of claystone, siltstone, anhydrite and gypsum with dips from 70 to 90° was intersected. At 508 m, 245 m of salt and salt intercalated with anhydrite and siltstone was penetrated, which in turn was underlain by about 10 m of siltstone and siltstone breccia with salt in the fractures. The borehole was completed in evaporite at 763 m.

The second well DCPR No. 2, located about 1.6 km south-southwest of DCPR No. 1 penetrated 543 m of caprock, composed of siltstone, shale, gypsum and anhydrite. A shale zone immediately above the salt was found to be highly fractured, impregnated with salt and to dip at about 75°. The salt intersected at 549.3 m continued to 643.2 m. This 93.9- m section was analyzed and shown to contain about 70 % NaCl (Boehner, 1986). The salt mass is highly contorted with dips ranging from 40 to 75°. Siltstone and shale are present as granules or fragments 2 to 20 cm in diameter or as beds from 20 to 40 cm thick. Anhydrite is present as specks to narrow beds 2 cm thick. Minor amounts of carnallite were observed in a 24- m section from 608 to 632 m. Below the evaporite section a zone of very hard black shale dipping at 48 to 58° was penetrated from 643.3 to 703 m. This was underlain by conglomerate and quartzite with thin seams of coal, from 703 m to the bottom of the well at 729 m. Unfortunately a palynology check was not done on the coal before the core was lost.

The DCPR No. 3 well is located about halfway between DCPR No. 1 and DCPR No. 2. The caprock is composed of anhydrite, shale and shale with minor anhydrite. As this section was not cored there is no information on the dip of the beds. From 528 to 1509.4 m the drill cut bedded salts, siltstone and shale with salt- filled fractures and breccia. Salt-bearing rocks that contain more that 50 % rock fragments are designated as breccias. Anhydrite is also present as specks or as sand-size grains. Analyses of 29 composite salt samples indicated a range of values from 27.53 % to 91.82 % NaCl, with an overall average salt purity between 55 % and 60 %. The salt mass is highly contorted with fold structures similar to those observed in the Pugwash salt mine. Dips vary from 30° to about 86°. Very minor carnallite is present in a siltstone-salt breccia from 657.3 to 370.4

m, and associated with thin anhydrite bands in salt from 755.8 to 766.1 m. The well was completed at 1576.8 m in fractured siltstone containing salt.

In 1970 Dow Chemical completed 503 m of drilling in seven shallow core holes (DCPR No. 4 to No. 10) to determine the near-surface geology around the earlier holes. Except for about 5.8 m of gypsum in the DCPR No. 8 well, evaporites were not intersected in the wells.

In 1972 Dow Chemical Company of Canada Limited completed the second phase of their exploration program with the Port Malcolm well (DCPM No. 1), located about 1.6 km east of DCPR No. 1. The 282.4 m of caprock in this well consisted of claystone (dip 28°), gypsum (dips 40-80°), limestone and anhydrite. The underlying 330.4 m salt section is composed of interbedded salt, anhydrite, claystone and some limestone and dolomite. This also appears to be a highly deformed section, with the salt purity varying from less than 10% NaCl to about 95%, NaCl. Dips vary from 10 to 80°. From the bottom of the salt at 612.8 m to total depth at 624 m the drill penetrated 11.2 m of anhydrite. Because the overall thickness of the salt in this area has not been established, it is not known if this anhydrite zone is part of the salt sequence or is part of the basal anhydrite usually present below the lower salt zone.

In 1973 Dow Chemical Company of Canada Limited started the second phase of their exploration program by completing the DCPR No. 11 well at 1227 m. This first brine test well was actually a redrilling and deepening of DCPR No. 1. The three intervals selected for leaching were: Zone 1, from 578.4 to 673.5 m, which is 95 m thick; Zone 2, from 787.4 to 852.4 m which is 68 m thick; and Zone 3 from 857.3 to 907.9 m which is 50.6 m thick. Because the resultant cavities as indicated by sonic surveys were found to be unsuitable, a second brine well was drilled. This well, DCPR No. 12, was located approximately 305 m west of DCPR No. 11. Two favourable salt zones were identified in the well from 484.8 to 535.3 m which is 50.5 m thick, and from 675.6 to 752.4 m which is 76.8 m thick (Boehner, 1986). Brining commenced in 1975. The problems encountered in brining in both locations are related to the complex geology caused by salt flowage. Although the brine wells were only a few hundred metres apart, there appears to have been very little correlation due to the internal deformation and flowage of the salt mass. Similar conditions are also known to exist at the Pugwash salt mine where horizontal holes are drilled prior to mining to avoid removing large masses of anhydrite.

Exploratory drilling in the Inhabitants Harbour area indicates that the large negative gravity anomaly shown on the gravity map and the wide spacing of the contours on the aeromagnetic map can be attributed to a large domal to diapiric salt mass (Fig. 68). The overlying caprock is generally highly complex due to diapiric movement of the evaporites and the formation of collapse breccias. Many of the shale, anhydrite and carbonate beds within the salt section are also contorted and brecciated, a result of internal deformation of the salt mass.

As a large part of this salt structure is beneath Inhabitants Harbour, it is probably less attractive economically than a similar structure located entirely on land. There has been no additional drilling for salt in this area since 1975.

14. Cleveland area, Cape Breton Island, Nova Scotia

In 1981 the Noranda Exploration Company Limited drilled the 227-2 Cleveland hole about 9 km east of McIntyre Lake (Fig. 65). This location represented an intermediate position between the strong gravity low associated with the Inhabitants Harbour — McIntyre Lake areas and the outcropping basement complex to the east (Fig. 64, 66). The wide spacing of the contours on the aeromagnetic map may indicate a fairly thick Carboniferous section (Fig. 67). However the 1800 gamma contour that passes through the well site also passes over the basement complex to the east. This may indicate that the contour value may be more closely related to the basement rock type than to the masking of a basement anomaly by a fairly thick section of sedimentary rocks.

Approximately 732.6 m of Riversdale to Windsor Group sediments with an average dip of 10 to 15° were penetrated above the salt. This sequence contains 272.8 m of red mudstone with minor interbeds of grey siltstone and fine-grained sandstone, less than 2 m thick; and 456.7 m of interbedded grey shale and red mudstone with minor gypsum and dolomite bands less than 1 m thick. The salt zone extended from 732.6 to 878.5 m, dips from 10 to 40°, and contains approximately 15% interbedded mudstone and shale breccia. Below the salt is 120.5 m of interbedded carbonate, evaporites and fine-grained clastics. The lowermost unit in this sequence is a 10.8- m limestone bed containing algal material typical of the basal unit of subzone C Windsor Group (Noranda Exploration Company, 1981b). A 53.7- m sequence of interbedded salt and mudstone breccia below the subzone C limestone and a brecciated limestone from 1052.8 m to the bottom of the hole at 1053.9 m is probably a local facies equivalent to the upper part of subzone B evaporites. Potash mineralization was not encountered in this well, but it is possible that it could be present at a greater depth.

15. Seaview area, Cape Breton Island, Nova Scotia

The Seaview area of Richmond County is about 8 km northwest of St. Peters and about 30 km east-northeast of Port Hawkesbury (Fig. 64). The area was first investigated for salt and potash by Kindle in 1931, who prepared a geological sketch map, showing the location of four salt springs. It was also included in geological maps and reports published by Weeks (1954, 1964).

The Seaview area is part of a northeast-trending graben in which Riversdale and Canso group rocks are exposed. Gravity surveys of Carboniferous areas in southern Cape Breton Island conducted by the Nova Scotia Research Foundation Corporation during 1967 and 1968 (Fig. 66), indicate a northeast-trending zone of low gravity in the Seaview area, considered to have been partly caused by low- density evaporites. The trend and spacing of the gamma contours on the aeromagnetic map (Fig. 67) could be interpreted as supporting evidence for the Carboniferous section in this graben that appears to thicken to the southwest.

In 1968 Domtar Incorporated, spudded Domtar Seaview No. 2 (DSV-2), on the low gravity trend about 1.5 km northeast of Seaview (Fig. 65). At this location the hole penetrated about 380 m of shale and siltstone of the Canso and Riversdale groups and about 120 m of siltstone, anhydrite and gypsum presumed to belong to the Windsor Group, before intersecting salt as veins in a shale- siltstone breccia from 500 m to the bottom of the hole at 660 m (Boehner, 1986).

The salt section penetrated was not sufficient to account for the observed gravity low. It is not known if additional salt is present at depth or if the anomaly is mainly due to tectonism along the edge of the graben and/or a variance within the basement complex. Potash was not observed in this hole.

16. St. Peters area, Cape Breton Island, Nova Scotia

St. Peters is located in southern Cape Breton Island about 38 km east of Port Hawkesbury. The geology of the area has been described by Weeks (1954, 1964) and Keppie (1979). Gravity surveys of some Carboniferous areas in southern Cape Breton Island conducted by the Nova Scotia Research Foundation Corporation during 1967 and 1968 indicated a 10 mgal gravity low just west of St. Peters (Fig. 66). This anomaly straddles a northeast-trending fault which defines the eastern limit of a northeast-trending graben in which Riversdale Group and some Canso group rocks are exposed (Fig. 64). On the aeromagnetic map (Fig. 67), the trend and spacing of the gamma contours could be interpreted to suggest that the Carboniferous section in the graben gradually thickens to the southwest. Just east of St. Peters the 2000 gamma local anomaly can be attributed to basement- type rocks exposed at the surface (Keppie and Smith, 1978).

Based on the results of the gravity data, Domtar Incorporated spudded Domtar St. Peters No. 1 (DSP-1) in Riversdale Group rocks about 1 km southwest of the town (Fig. 65) in 1968. About 244 m of coarse red sandstone, siltstone and some minor green shale of the Riversdale Group was underlain by about 204 m of shale, gypsum and anhydrite considered to be part of the Windsor Group. From 448 to 548.8 m the section comprises siltstone with interbeds of salt. After penetrating 26.2 m of salt with varying amounts of shale the hole was terminated in salt at 575 m. The dip of the beds over the entire hole varied from 40 to 60°. This may be due to the proximity of the well to the fault, and/or differential flowage of the salt.

A second hole, DSP-3, was drilled about 400 m southeast of DSP-1. This hole also penetrated a thick section of siltstone, gypsum, anhydrite and some beccia zones with dips ranging from 30 to 70° before intersecting the main salt zone at 376 m. The salt with various amounts of shale and anhydrite was penetrated to 925 m. The total thickness of the section in this area is not known.

The presence of salt in both wells and the highly deformed nature of the caprock suggest the presence of a domal to diapiric salt structure. The gravity low may be due to the presence of salt, an offset in the basement as suggested by the fault, a variance within the basement complex or a combination of the above. Potash was not reported from this location.

17. Malagawatch-Ashfield-Orangedale area, Cape Breton Island, Nova Scotia

Malagawatch is approximately 39 km northeast of Port Hawkesbury. A geological report by Kelley (1967) includes Orangedale and the western part of the Malagawatch area. A geological report and maps by Weeks (1954, 1955) covers the western and eastern parts of the Malagawatch area. Prior to 1976, when Chevron Standard Limited started to examine the area for base metals associated with the basal Windsor Group limestone, there had been very little geological exploration in the area. Although three of the six holes drilled during 1978 penetrated to the targeted carbonate horizon, no base metal showings were located. In these holes the carbonate was not developed as a reefoidal facies, but hole No. 3-78 did produce an intermittent oil scum associated with the carbonate. A second hole (No. 3A-78), drilled about 1.8 m away from the first well indicated a major oil show and several minor shows. Water injection of this well yielded about 2 gallons of 40.4° API crude oil per minute for five minutes through a 2'' valve (Chevron Standard Limited, 1982).

In 1979 encouraged by this discovery, Chevron Standard Limited and Irving Oil Limited conducted a regional gravity survey and a three-hole rotary drilling program in the area. The Chevron-Irving Bras D'Or No. 1 (B-1, Fig. 64) redrilled the No. 3-78 hole and extended the hole to basement. At this location the drill penetrated gypsum from 10 m to 35 m. This was underlain by 165 m of anhydrite containing two 5-m-thick limestone beds at 75 m and 85 m. Below 200 m a 5-m-thick basal carbonate graded into a granite wash over an interval of 2.5 m. This hole terminated in granite at 216 m. Subsequent drillstem testing of the oil-bearing basal carbonate deemed it noncommercial. A second exploratory hole, Chevron-Irving Bras D'Or No. 2 (B-2, Fig. 64) was drilled about 350 m down dip from Bras D'Or No. 1. The drill encountered gypsum with some dolomite and siltstone in the upper part and anhydrite with some limestone horizons similar to the No. 1 hole in the lower part. It was terminated in granite at 375 m. As in the No. 1 hole, anhydrite overlies a thin basal Windsor limestone resting directly on basement. As this hole also did not contain commercial quantities of hydrocarbons the drill rig was moved to Malagawatch for the third hole.

The Chevron-Irving Malagawatch No. 1 well location (M-1, Fig. 65) was based on a small Bouguer gravity anomaly, interpreted as a basal Windsor Group biohermal build-up that could contain crude oil (Chevron Standard Limited, 1982). The regional Bouguer gravity survey of this area (Fig. 66) indicated a large gravity low centred in the Bras D'Or Lakes area just east of Malagawatch, of about the same magnitude as the low recorded in the Inhabitants Harbour area to the south. This low may indicate a thick section of low density sediments and (or) an anomaly within the basement complex. An aeromagnetic map of the same area (Fig. 67), also indicates a low over the Bras D'Or Lake east of Malagawatch. This low combined with a fairly wide spacing of the gamma contours suggests a masking of the basement complex by a thick section of cover rocks and/or an anomaly within the basement.

Rotary drillhole results at the Chevron Irving Malagawatch No. 1 location indicated gypsum from 10 m to 25 m and limestone from 25 m to 40 m. Below the limestone there was 240 m of gypsum with some interbeds of siltstone and limestone up to 5 m thick. The salt zone, intersected at 280 m, consisted of a mixture of salt, mudstone and anhydrite. When the basal Windsor Group limestone target area was not encountered by 560 m, abandonment procedures began until the presence of potash mineralization was noted on the gamma ray log from 487 m to 560 m. The hole was subsequently cored to 948 m with potash being recorded down to 572 m. As core was only available for the lower 12 m of the potash zone, another hole, the Chevron-Irving Malagawatch No. 2 hole (M-2, Fig. 65) was spudded 18 m west of the discovery hole. From the start of this hole in December 1979 until July 1981, nine additional holes (M-3 to M-10 and R-1), were drilled for potash.

Windsor Group evaporites in the Malagawatch area appear to have been uplifted into a northeast-trending ridge or anticline. Section A-A' (Fig. 69) trending northeast through holes M-5/5A, M-8 and M-9, indicates that the evaporites are multifolded and overturned to the north (Chevron Standard Limited, 1982). The stratigraphic control is based on the occurrence of the main potash zone, a borate marker and a breccia zone. The borate marker (identified by chemical analysis) consists of anhydrite containing disseminated granules of borate. The normal fault between M-5/5A and M-8 indicates that the beds north east of the fault were uplifted. Geophysical surveys and drillhole data also indicate that the structure from the M-6 hole to the M-3 hole (Section B-B') is intersected by three steeply dipping to vertical northwest-trending normal faults. The potash zones as observed in the wells have been used as stratigraphic markers. The repetition of the main potash zone in wells M-9, M-2 and M-1 combined with the fold axis gives some indication of the internal structure of the salt mass. The elevation of the top of the salt zone and the thickness of the solution collapse zone varies across the area. It is not known if this variance is due to tectonism, availability of groundwater, or the lithology of individual beds in contact with the groundwater.

The fault between M-6 and M-7 is considered to have a vertical displacement of 190 m (Chevron Standard Limited, 1982). As indicated on cross-section B-B' (Fig. 69) the beds west of the fault are downdropped relative to the beds east of the fault. As shown on the index map, there appears to be a horizontal as well as vertical displacement along this fault. The beds on the eastern side of the fault moved northwest relative to the beds on the western side. The central fault between M-7 and M-9 (Section B-B'), is considered to have a vertical displacement of 590 m. The western block is down-dropped relative to the eastern block. The horizontal component indicates that the eastern block moved northwest relative to the western block. Although the amount of vertical movement between M-1 and M-3 at the eastern end of the section is difficult to document due to a lack of stratigraphic control, it would appear that the M-3 side of the fault is down-dropped relative to the M-1 side. Although not documented, if the western side of the fault moved northwest relative to the eastern side, the block containing the M-7, M-9 and M-2 hole may have been subjected to the maximum horizontal as well as maximum vertical movement documented to date in this area.

Post-Windsor adjustments in the basement due to tectonism and salt migration folded the Windsor Group evaporites into a northeast-trending anticline that is overturned to the north. Due to continued or renewed compression the ridge appears to have been sheared by three northwest-trending faults. Subsequent vertical movement along these has influenced the formation of at least two horst structures.

It is very difficult to establish the structural correlation here due to intense folding associated with salt flowage and diapirism, block faulting, and the cyclical nature of the section. In some wells many of the evaporite cycles appear to be incomplete due to repeated marine incursions causing a dilutation of the precipitating brine and subsequent beginning of a new evaporite cycle. Because potassium is one of the last products to be removed from an evaporite brine, it is unlikely it would be deposited in this type of environment. Windsor Group sediments above the salt in the various holes can be described as a zone of solution collapse (attributed to circulating groundwater), and brecciation (caused by upward migration of the salt). This caprock composed of mudstone, carbonate, gypsum and (or) anhydrite extends from the surface to 181 m in M-9 and 415 m at the M-5A hole. A little farther west in the Orangedale area (to be discussed later), this dissolution zone extends to 571 m in the Noranda Ashfield No. 225-1 hole. Structurally holes M-5, M-5A and M-6 are the only holes with a normal upward-facing Windsor Group section drilled to date. All the other holes exhibit complex folding, overturning and structural repetition. Even in closely spaced holes correlation is often very difficult. Boehner (personal communication, 1986) suggested that complex folds rather than high angle faults are largely responsible for the variance in lithology observed in the holes.

Because the Lower Windsor section (subzones A and B of Bell, 1929) was not completely drilled in any of the Malagawatch holes a composite stratigraphic section (Fig. 70), was prepared from holes No. M-5A, M-8, M-1, M-10 and the Noranda Orangedale No. 225-3 hole. Although the basal carbonate and basal anhydrite were not penetrated in any of the holes, they were included to complete the section. From their exploration, Chevron Standard Limited (1982) concluded the Lower Windsor on land may be up to 2000 m thick and up to 4000 m in the central part of the Bras d'Or Lakes east of Malagawatch.

Subzone A of the composite stratigraphic section is shown to contain a thick section of salt interrupted only by anhydrite, carbonate and in some areas by minor siltstone. These beds often contain one or two potash zones. The lower or main potash zone contains from 20 to 65 % sylvite (KCl), with a K_2O content that varies from 12.6 % to about 40.5 %. In the M-8 and M-9 wells, this potash zone is repeated a total of seven times due to complex folding of the evaporite section. The thickest potash usually occur in and near the nose of anticlinal folds, with thicknesses ranging from 2.6 to 9.2 m and K_2O values ranging from 6.1 to 27.1 %. In the M-8 hole from 972.7 to 977.5 m the grade averaged 31.3 % K_2O. The highest grade intersected during the drilling program, 40.5 % K_2O, occurred between 917.8 and 919.6 m in the M-9 hole. In both the M-8 and M-9 holes bedding dips were generally quite steep, varying from 30 to 70°. The M-1 discovery hole penetrated a 25.2- m potash zone with more than 25 % K_2O. The lower potash zone is the only zone in this prospect area that seems to have economic potential. Unfortunately lateral variation in thickness, dip and depth to ore seriously downgrade the prospect. Most of the future target areas are in the offshore, creating significant drilling problems.

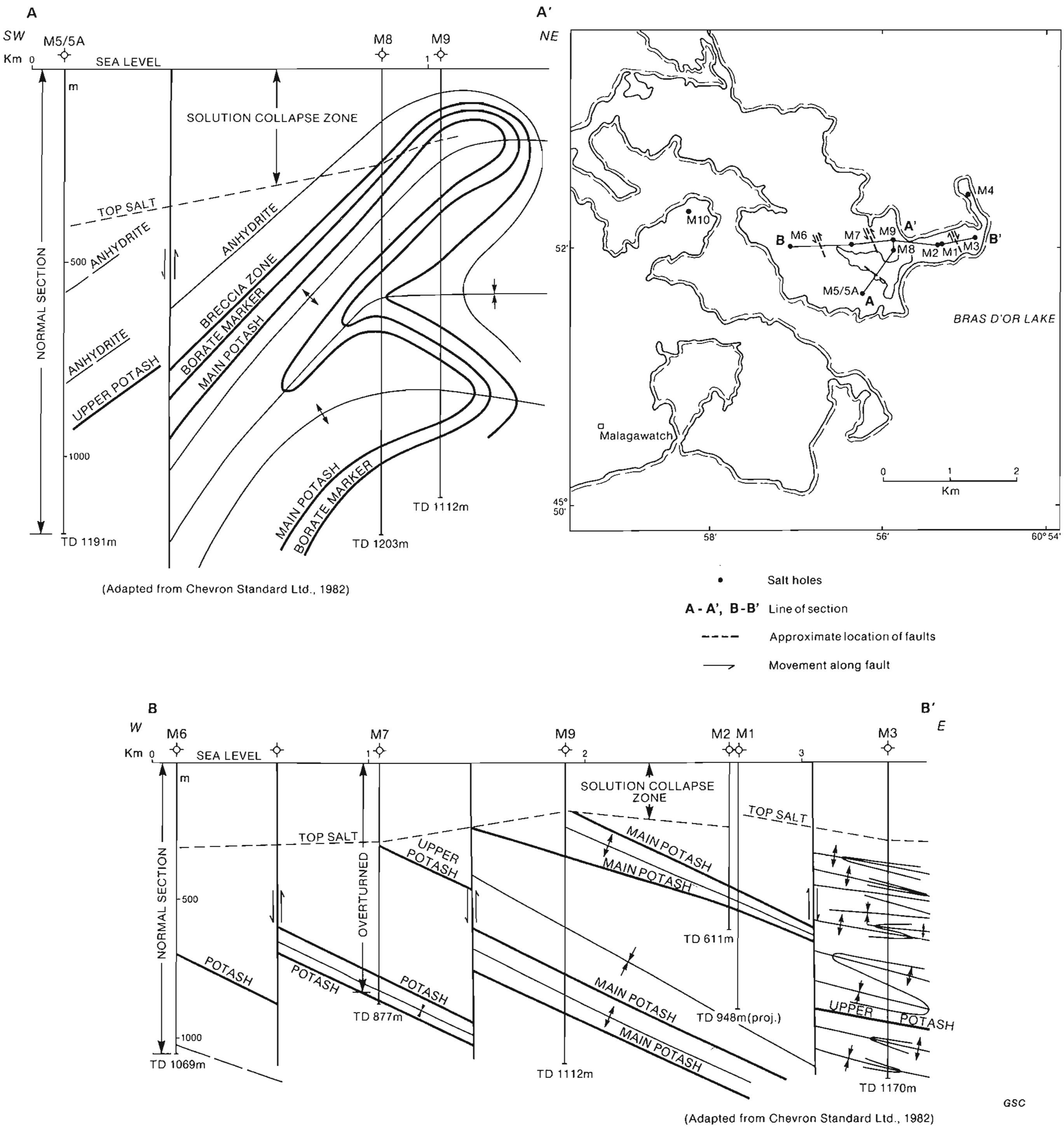


Figure 69. Geological cross sections, Malagawatch area, Cape Breton Island, Nova Scotia.

Data obtained from the M-2 hole indicate that the middle potash zone contains about 80 % salt. The K_2O content from sylvite is usually less than 9 %. In the Noranda Orangedale 225-3 hole, the grade was 20.7 % K_2O over 2.3 m. This is approaching mineable width and grade. Unfortunately the middle potash zone appears to be the least persistent potash zone.

Subzone B contains many thin evaporite depositional cycles that include numerous carbonate units, which indicate frequent open marine conditions. This sequence may also contain an upper potash zone. In the Noranda Orangedale 225-5/5A hole, the upper potash zone was encountered three times in large fold structures. Salt usually represents more than 60 % of the section with sylvite grades of less than 20 % and carnallite less than 8 %. The average K_2O content is usually less than 15 %.

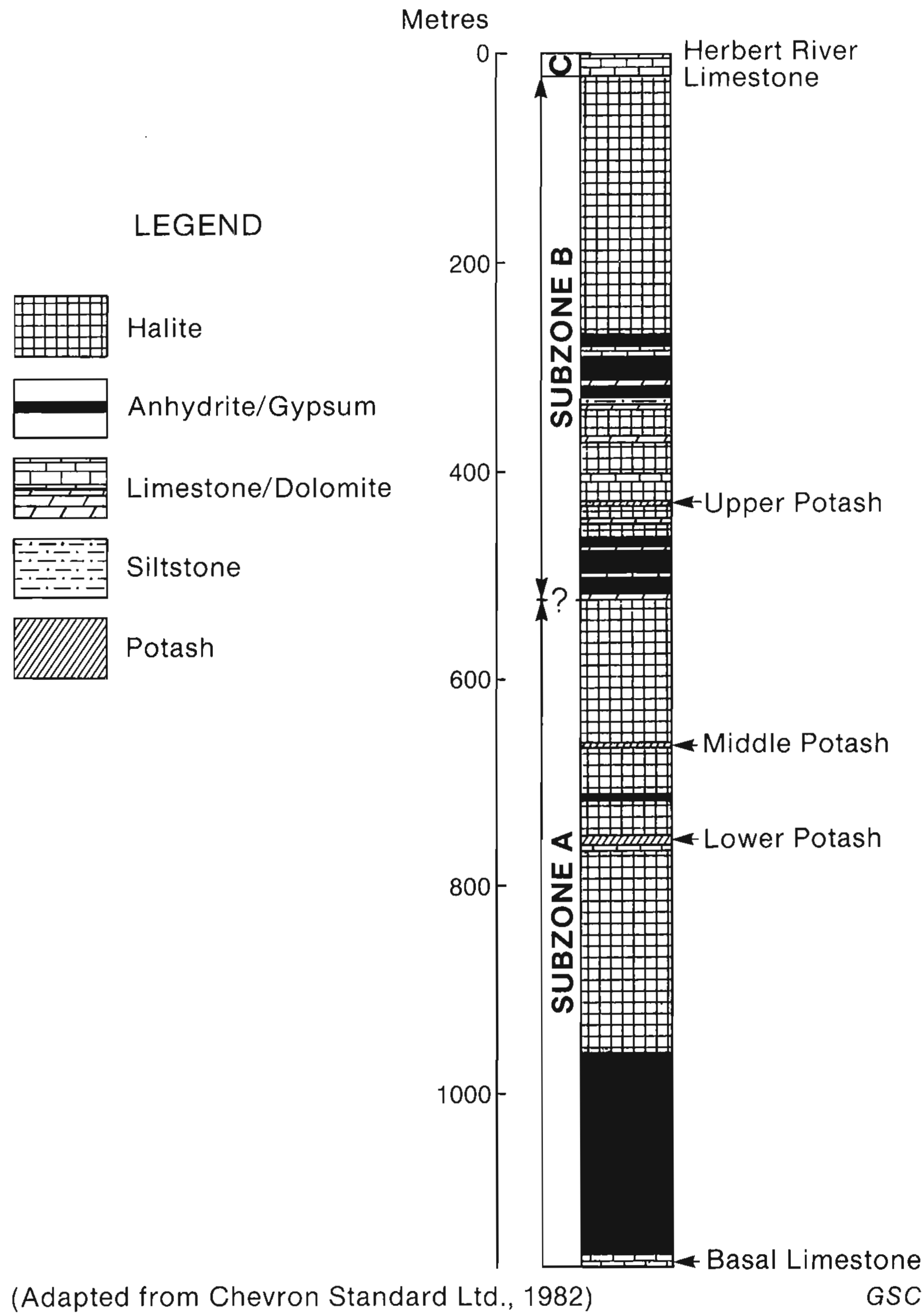


Figure 70. Composite stratigraphic column, Lower Windsor Group evaporites, Malagawatch and Orangedale areas, Cape Breton Island, Nova Scotia.

At the top of the stratigraphic column (Fig. 70) the lowermost unit of sub zone C is shown as a carbonate. Based on lithology and a fossil assemblage, this zone, known as the Herbert River limestone (Moore, 1967) has been used as a marker bed in a number of areas to indicate the contact between the Lower and Upper Windsor Group. Although not included on this section, hole M-5/5A indicated that there is about 17 m of salt interbedded with mudstone, anhydrite and carbonate above the Herbert River Limestone. This evaporite sequence does not contain potassium salts.

At Bucklaw about 20 km north of Malagawatch (Fig. 65) the presence of a salt spring was known as early as 1873 (Cole, 1930). Located about 91 m south of the Whycocomagh — Baddeck highway and just east of the Inverness — Victoria County line, the spring was observed to discharge about 4 tons of salt per day (Hayes, 1931). During 1922 in order to try to locate the source of the salt, three shallow holes (52 m or less) were drilled. Three years later another hole was drilled to 143 m, penetrating a near-vertical section of gypsum with interbeds of limestone. No salt was encountered (Nova Scotia Department of Mines, 1926).

In 1981 about 3 km east of Bucklaw on McIvor Point, Chevron Standard Limited spudded Chevron McIvor Point No. R-1/R-1w (Fig. 65) on a small gravity low (Fig. 66). Some salt was present from 395 m to 1169 m. Although the Upper potash zone was not encountered the middle potash zone was present in a normal and overturned position at 475 m and 502 m respectively. This zone consisted of mainly low grade (10-20 %) carnallite. The lower or main potash zone was not encountered. It is not known if this zone was stratigraphically absent, removed by faulting, or still present in the section below the completed depth of the hole. The hole was abandoned at 1185 m after penetrating 13 m of anhydrite.

In summary, the salt at this location appears to be only about 774 m thick, unless additional salt is present below the anhydrite at the bottom of the hole. If the observed salt represents the entire section, it is not of sufficient thickness to account for the entire gravity low over McIvor Point. This low may be attributed in part to variance of rock type within the basement.

The Estmere 227-1 hole (Fig. 65) was drilled by Noranda Exploration Company Limited in 1981 to check the continuity of the potash beds between the Chevron Standard Limited holes at Malagawatch and the Noranda holes at Orangedale. This hole penetrated moderately to steeply dipping (15°-80°) Windsor Group carbonates, evaporites and fine-grained clastics. Spudded in the lower part of subzone C a more or less complete section of subzone B and the upper part of the subzone A salt was intersected before the hole was abandoned at 860 m. The true thickness of this sequence has been estimated at 609 m (Noranda Exploration Company Limited, 1981).

Massive salt of subzone B was first encountered at 399 m. Although this salt contains potash mineralization at both Malagawatch and Orangedale it does not seem to be present at the Estmere drill site. Bromine analyses of the evaporites suggest the salinity may not have been high enough to precipitate potash at this location. The substitution of bromine for chlorine in salt increases as the concentration of the brine increases. Normal salt contains 65 to 70 ppm bromine. Potash can be expected when bromine in salt exceeds 150 ppm. The hole was abandoned above the projected depth of the potash in subzone A. The bromine content of the salt was similar to that found above the middle potash zone at Orangedale therefore it is not unreasonable to suggest that potash may be present below the T.D. of this hole.

Estmere 227-1 was not drilled on a gravity low, but on the flanks of a fairly large gravity low, an extension of the Malagawatch anomaly (Fig. 66). Unless the gravity contours in the vicinity of the well have been influenced by a variance within the basement complex, the Windsor Group section below the well should contain a considerable thickness of salt. The aeromagnetic map of the same area (Fig. 67) indicates that the hole is about 15 km northeast of a 2200 gamma high. This may indicate an anomaly within the basement and/or a topographic high. If this is a shallow topographic high, it may have partially separated the Malagawatch and Orangedale area into two basinal areas rather than one large basinal area.

The Ashfield — Orangedale area is at the western end of the Bras d'Or Lakes, about 40 km north-northeast of Port Hawkesbury. The area is underlain by subzone A to C Windsor Group rocks that are in fault contact with a pre-Carboniferous basement complex to the north and underlain by Horton Group rocks to the south (Kelley, 1967; Keppie, 1979; Noranda Exploration Company Limited, 1983). Structurally the area appears to be a poorly defined syncline or half graben that is downdropped to the north. A regional gravity map (Stephens et al., 1971) supplemented by field data from the Nova Scotia Research Foundation Corporation, was instrumental in outlining a large gravity low in the Ashfield area (Fig. 66) suggesting the presence of a thick section of Windsor Group evaporites. Based on this compilation Noranda Exploration Company Limited drilled five holes between 1978 and 1981. Four of the five holes intersected salt. Two of these also intersected potash. One hole was abandoned at 142 m in subzone C of the Windsor Group due to mechanical difficulty. None of the remaining four holes was thought to have completely penetrated the Windsor Group evaporite section.

Hole 225-1 was spudded in subzone C of the Windsor Group and completed in the upper part of subzone B. It is located on the northern flank of the Ashfield gravity low and penetrated a thick section of gypsum, siltstone, anhydrite and carbonate before encountering salt at 571 m. The hole penetrated 322 m of structurally complex salt, siltstone, anhydrite and carbonate horizons before being completed in salt at 892 m. If the potash present in the exploratory holes at Malagawatch is projected into this area it could be present below 915 m (Noranda Exploration Company Limited, 1982).

The No. 225-3 hole located just west of Orangedale was spudded in steeply dipping (45 to 60°) rocks belonging to subzone C (Noranda Exploration Company Limited, 1983). The 183 m of caprock in this well contains interbeds of siltstone, gypsum and minor limestone, underlain by 21 m of anhydritic limestone and 260 m of interbedded anhydrite, siltstone, and minor gypsum belonging to subzone B. The upper potash zone near the base of subzone B at Malagawatch (Fig. 70) does not seem to be present in this hole. From 485 m to the bottom of the hole 269 m of subzone A Windsor Group was encountered. This section appears to be mainly salt with some interbeds of anhydrite, siltstone, carbonate and two potash zones. The main potash zone from 609 to 613 m with a true thickness of slightly more than 3 m is approximately 50 % sylvite. The second horizon from approximately 655 to 656 m with a true thickness of slightly over 1 m is about 25 % sylvite and carnallite. The hole was completed in salt at 754 m.

The 225-4 hole, located a little southeast of the Ashfield gravity low, was drilled into an overturned asymmetrical fold containing Windsor Group subzone A and B beds. The hole was spudded in subzone A rocks. Because the beds were overturned the drill penetrated 171 m of leached caprock consisting of gypsiferous siltstone and carbonate before intersecting salt in the upper part of subzone A. The drill penetrated 237 m of salt and siltstone before encountering 44 m of subzone B dolomite and anhydritic dolomite. This was underlain by 236 m of anhydrite, some dolomitic anhydrite to anhydritic dolomite and minor claystone before passing into salt at 627 m. The lower 268 m in this hole is composed of overturned subzone B salt with some interbeds of anhydrite, claystone and dolomite with dips that range from 10 to 55°. The hole was abandoned in anhydritic claystone at 895 m. The subzone B potash zone appears to be absent. Although the hole was drilled through an overturned fold, the bromine analysis indicates that the salinity in both subzones A and B were very close to the point of precipitating potash (Noranda Exploration Company Limited, 1983).

The 225-5 hole located about 2 km west of Orangedale, intersected a highly folded subzone B sequence. This hole spudded in the overturned lower B subzone, penetrated five fold axes before being completed in the upright lower B subzone. The upper beds represent a leached caprock composed of gypsum, limestone, mudstone, dolomite and dolomitic limestone and is 292 m thick. Below this caprock is a 4- m zone of anhydrite and interbedded anhydrite and salt. Massive salt first appeared at 296 m. The hole was completed in salt at 1078 m after penetrating 783 m of salt containing potash and 295 of anhydrite, mudstone breccia, limestone and dolomite. Due to the highly folded nature of this sequence, the potash horizon was intersected three times (Noranda Exploration Company Limited, 1982). A gamma log of the hole indicated that the first potash intersection had the highest grade and thickness. This first potash horizon can be divided into an upper sylvinite zone and a lower carnallite zone. This 3- m zone from 543 m to 546 m contains approximately 30 % KCl. The next best zone from 787 m to 789 m only contained about 10 % KCl (Noranda Exploration Company Limited, 1983).

Post-depositional tectonism in the Ashfield-Orangedale area folded and overturned the Windsor Group rocks to the southwest. In the Malagawatch area about 10 km to the southeast, Windsor Group rocks are faulted, folded and overturned to the northwest. Although these recumbent folds appear to suggest compression from opposite directions, the apparent difference is attributed to local tectonism. A thick section of Windsor Group rocks adjacent to a basement horst was probably locally folded and possibly overturned away from the area of uplift. Regional instability as reflected by the movement of local basement blocks northwest of Ashfield and at Malagawatch, is considered to be the motivating force that produced the two opposing sets of recumbent folds.

18. Kempt Head area, Cape Breton County, Nova Scotia

Kempt Head, near the southwest end of Boularderie Island is underlain by Windsor and Pictou group rocks (Kelley, 1967). A geological map of the area (Fig. 71), also indicates that Windsor Group rocks outcrop at a number of locations around the shore of Great Bras d'Or Lake. Although the land distribution of the Windsor Group suggests that it is also present beneath Great Bras d'Or Lake, there is very little information available as to the presence of a possibly considerable thickness of salt.

A Bouguer gravity map (Fig. 72), indicates a gravity low trending southwest along the Boularderie Island syncline (Boehner, 1984) and then west across Great Bras d'Or Lake. This gravity low may indicate the presence of a thick Carboniferous section that could contain salt. Widely spaced contours on the aeromagnetic map (Fig. 73), that trend southwest along Boularderie Island and across Great Bras d'Or Lake suggest that any basement anomalies have been masked by a thick blanket of Carboniferous strata. This contour pattern is in sharp contrast to the basement complex east of Upper Washabuck, which displays a fairly strong magnetic anomaly.

Exploratory drilling to the southwest at Ashfield-Orangedale, Malagawatch and at Bucklaw (this report) indicate the presence of a thick deposit of salt. At Baddeck Bay about 6 km northwest of Boularderie Island, a strong brine has been reported flowing from two salt springs in the area (Cole, 1930; Hayes, 1931).

In order to obtain more stratigraphic control a 943- m hole was drilled by the Nova Scotia Department of Mines and Energy near the south end of Boularderie Island. Kempt Head 84-1 (Fig. 71) penetrated a section of weakly deformed Windsor Group rocks that contained about 400 m of salt, interbedded with varying amounts of gypsum/anhydrite, sandstone, dolomite/limestone and two zones of potash. The potash was in the lower part of the Windsor Group (subzone A). Section A-A' (Fig. 74) is a generalized cross-section of the Kempt Head area adapted from Boehner (1984). Although not shown on Figure 71, Boehner indicates a wedge of Canso Group rocks between the Windsor and Pictou group rocks west of the bore hole.

An expanded view of the salt section in the borehole as obtained from Boehner (1984) indicates the location of the potash. The upper potash zone from 492.4 to 593.6 m contained 3.8 % carnallite. Minor sylvite was also present from 493.6 to 594.7 m. The lower potash zone extending from 744.2 to 749.2 m contained 7.6 % sylvite and 7.4 % carnallite.

Farther to the northeast in the Sydney area, a salt spring and saline groundwater have been reported from Leitches Creek and Point Edward. It is now evident that the distribution of Windsor evaporites is far more widespread than previously realized.

19. Gulf of St. Lawrence

The Gulf of St. Lawrence south of latitude 48°20', as well as other areas of southeastern Canada, is underlain by Upper Paleozoic rocks that range in age from Middle Devonian (Eifelian) to Lower Permian (Wolfcampian). In this region the Magdalen salt basin is a northeast-trending lens-shaped area that extends from Prince Edward Island to the west coast of Newfoundland (Fig. 19). Although Prince Edward Island is approximately a 5600 km^2 land area in the Gulf of St. Lawrence it is an intergral part of the Magdalen structural basin, and as such has been included as part of this study area. On Prince Edward Island salt has been intersected at 1896, 3353 and at 3738 m in the H.B. Fina et al. Irishtown 1, H.B. Fina et al. Green Gables 1 and in the Island Development Co. Hillsborough 1 holes respectively. This Windsor Group salt, due to depth, is probably not of economic interest. Most of the data from the Gulf of St. Lawrence have been compiled by government and industry in and around the Îles de la Madeleine — northern Cape Breton Island area.

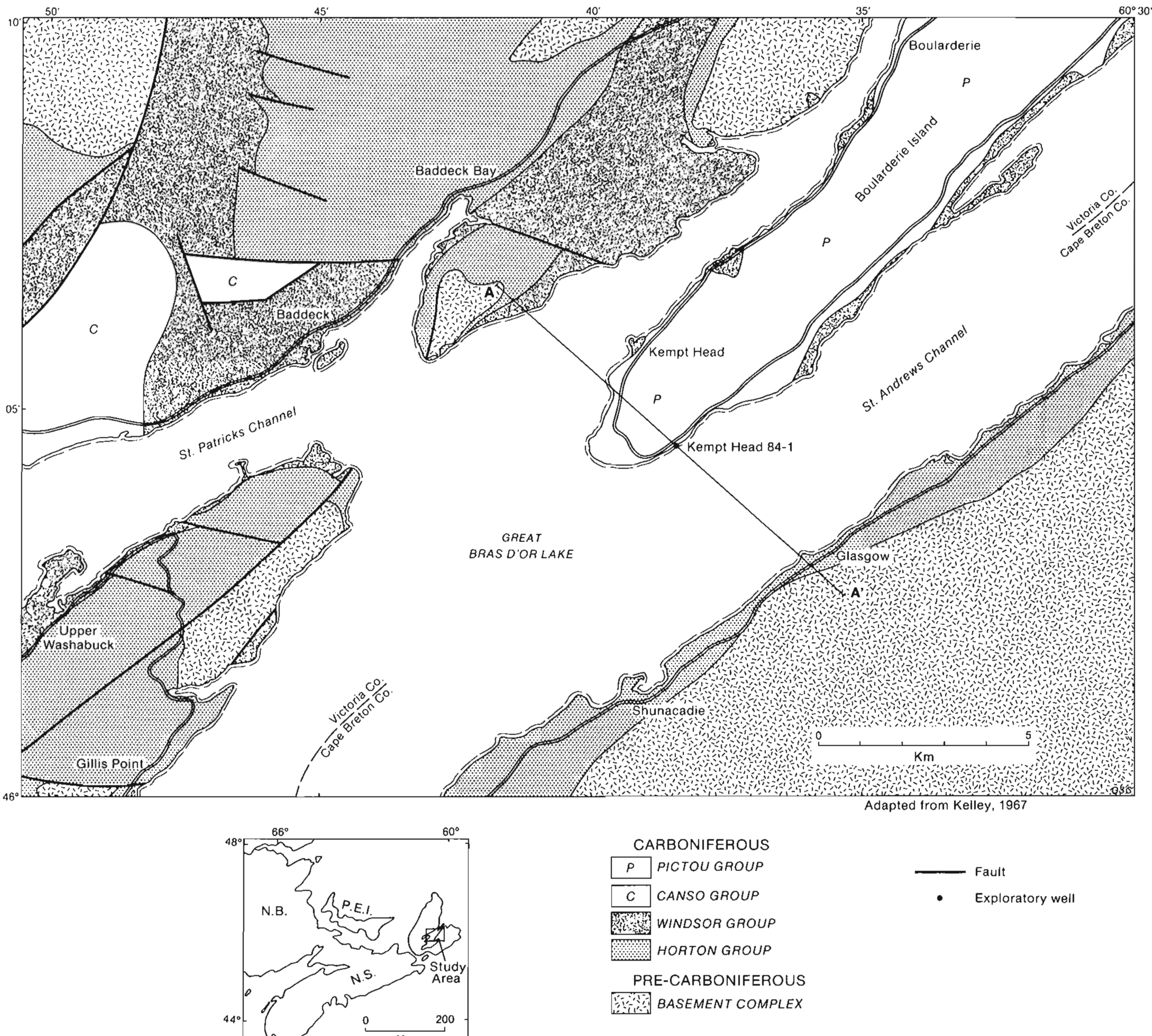


Figure 71. Geological map, Baddeck area, Cape Breton Island, Nova Scotia.

Near the centre of the Gulf of St. Lawrence, 225 km southeast of Gaspé and 72 km north of Prince Edward Island is the Magdalen archipelago or shelf. This area is underlain by a thick succession of Carboniferous rocks composed of some 15 islands with a total land mass of about 388 km^2. Seven of the larger islands, joined together by tombolos, were the main source of geological information prior to exploratory drilling. Since their discovery by Jacques Cartier in 1534, the geology of the islands has been described by more than 15 geologists, a few of whom are: Richardson (1881); Alcock (1940, 1941); Weeks (1940); Sanschagrin (1964); Tiphane (1970) and Brisebois (1981).

The rocks on the eight major islands vary in age from Viséan (Windsor Group) to possible Permian (Pictou Group) (Fig. 75). The Havre aux Maisons Formation exposed mainly on Île du Havre Aubert, Île d'Entree, Île du Cap aux Meules and Île du Havre aux Maisons, is seen

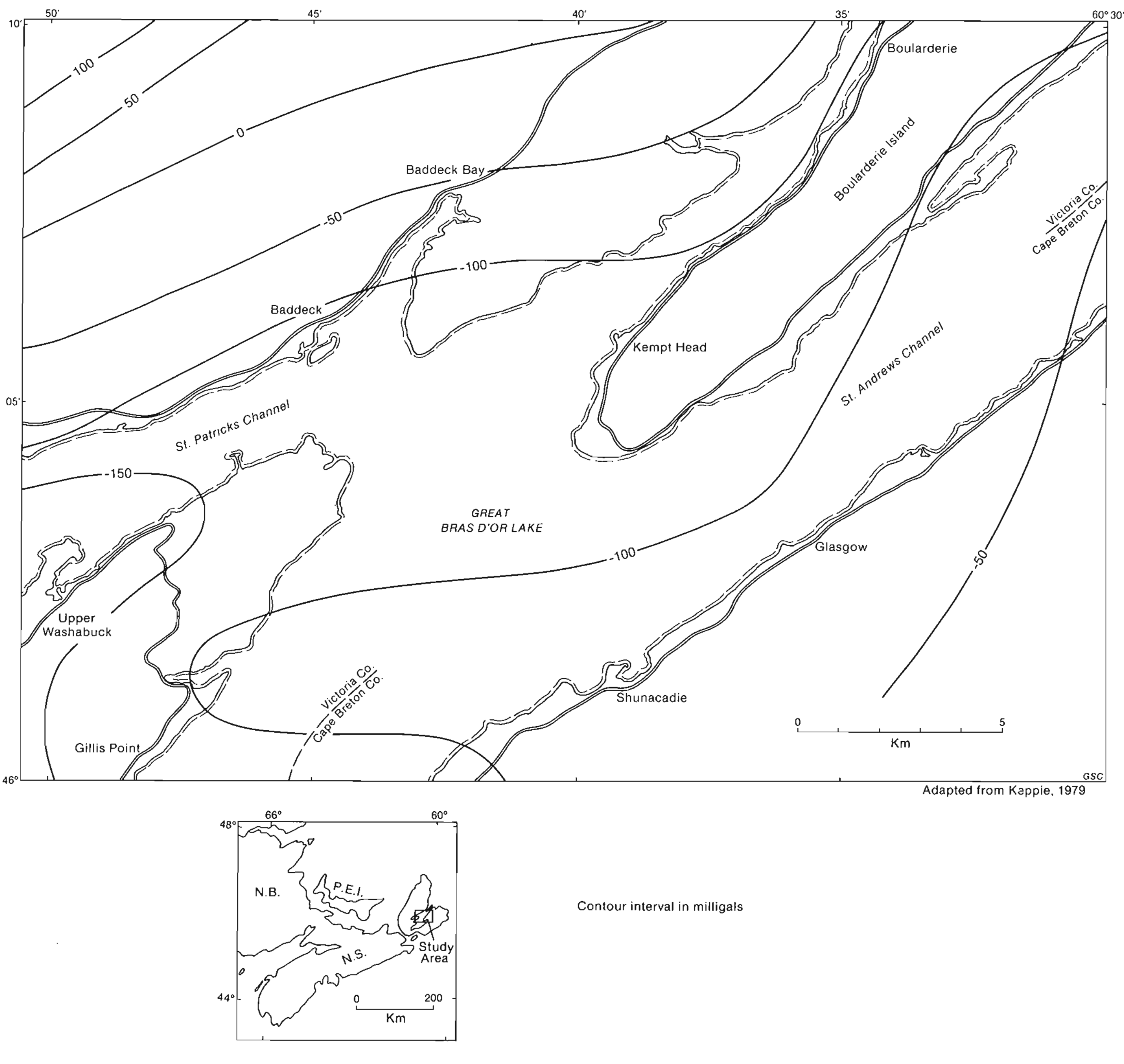
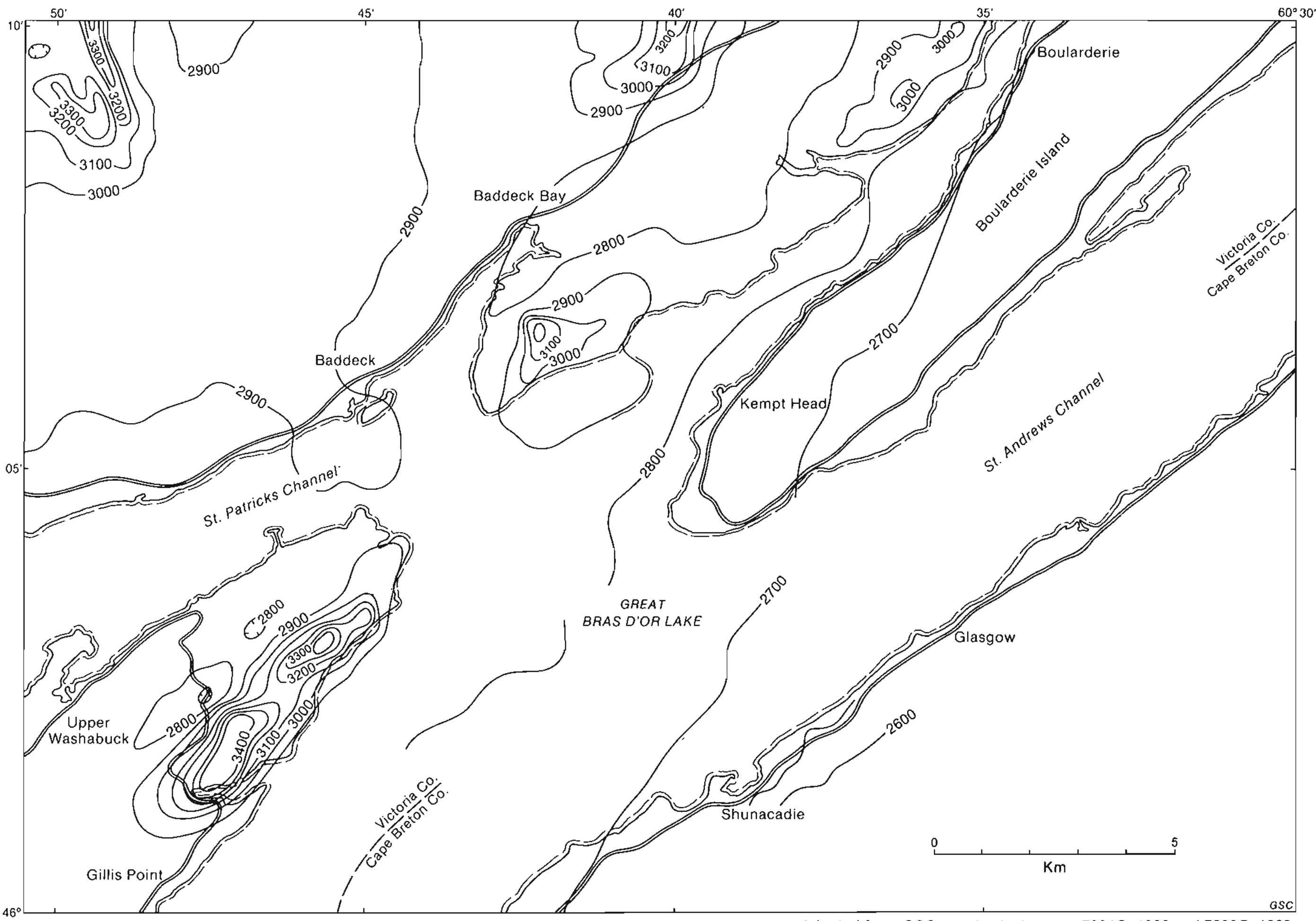


Figure 72. Bouguer gravity map, Baddeck area, Cape Breton Island, Nova Scotia.

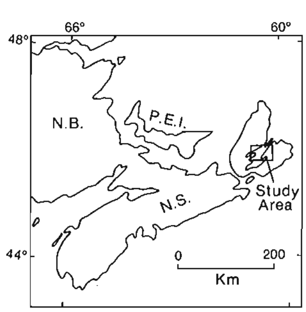
in outcrop as a collapse breccia composed of mudstone or siltstone, carbonate, gypsum and usually some volcanics. Exposures of this formation on Île de la Grand Entree do not contain volcanics.

The Havre aux Maisons Formation varies in thickness from 60 to more than 305 m and is considered to be a residual remnant of salt formations which have been removed by erosion (Gagnon, 1981). This mudstone is sometimes massive or foliated and may be interbedded with gypsum, but it is generally sheared and brecciated. It is overlain by basalts and pyroclastics of the Cap au Diable Formation, which in turn is overlain in a few areas by gabbroic dykes and stocks, also ascribed to the Windsor Group. This unevenly distributed blanket of volcanic rocks was erupted on a thick sequence of evaporites, and subsequent salt tectonics has produced an intermixing of evaporites and volcanic rocks (Barr et al., 1985; Gagnon et al., 1984). On Île du Havre Aubert, Île d'Entree and Île du Cap aux Meules, Île du Havre aux Maisons Windsor Group rocks are associated with east-west parallel anticlines that have developed into horst structures.

The Cap aux Meules Formation, composed of grey-green sandstone, mudstone and calcareous conglomerate of the lower l'Etang-du Nord Member and red eolian sandstone of the upper l'Etang-des Cap Member, is present on each of the nine islands shown on the map. As this formation



Adapted from GSC geophysical papers 7034G, 1966 and 7038G, 1968



Contour interval in gammas

Figure 73. Aeromagnetic map, Baddeck area, Cape Breton Island, Nova Scotia.

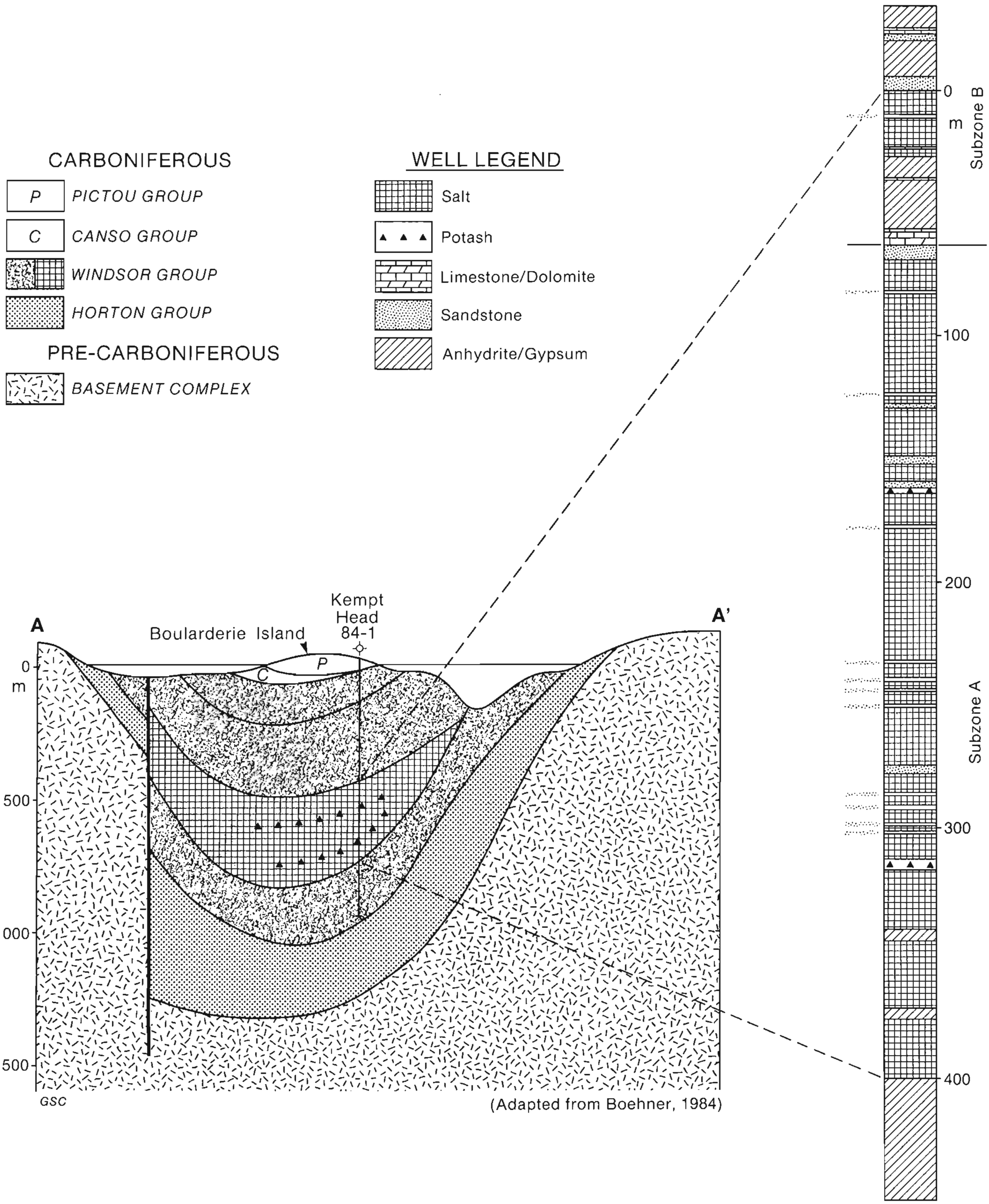


Figure 74. Geological cross section, Boularderie Island, Cape Breton Island, Nova Scotia.

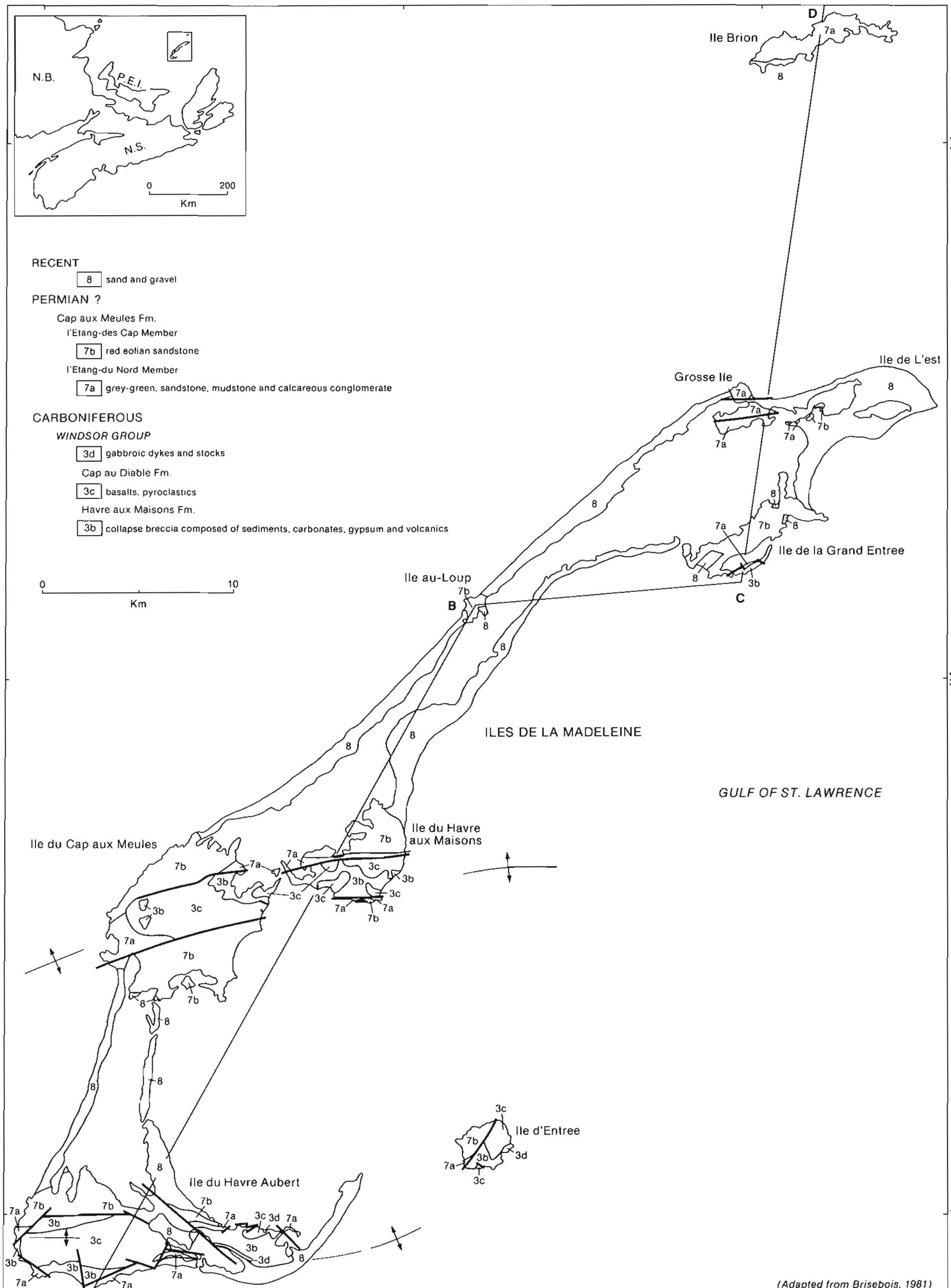


Figure 75. Geological map, Îles de la Madeleine, Gulf of St. Lawrence.

appears to be void of fossils, it has been assigned on the basis of lithology to the Canso Group by Sanschagrin (1964), Canso-Riversdale groups by Gagnon (1981); Pictou Group (Permian), by Brisebois (1981); and the Permian to Triassic by Richardson (1881). On Grosse Île the formation outcrops along an east-west-trending anticline that has developed into a slight horst as outlined by two parallel faults. The deformation of the Cape aux Meules Formation is less intense on Grosse Île and Île de l'est than on the islands to the south that have been disrupted by volcanic activity.

A generalized south to north cross-section through the Îles de la Madeleine (Fig. 76, A-D) illustrates the diapiric nature of the underlying Windsor Group evaporites. In the deeper parts of the Magdalen Basin, the thick sequence of salt is considered to have become diapiric shortly after deposition (Gagnon et al., 1984). The Île Brion area, near the northern edge of the original evaporite basin, appears to be underlain by a thinner section of salt, which is domal rather than diapiric. Post-Windsor Group Carboniferous rocks appear to have infilled the area between the growing diapirs. Between the top of the Carboniferous and the overlying Permian or younger sediments there appears to be an unconformity reflecting a period of nondeposition or erosion. In the Île Brion area the unconformity appears to be a little less definite (Brisebois, 1981; Gagnon et al., 1984).

During 1965 the Pan American Petroleum Corporation drilled the Pan Am Cape Breton No. 1 hole (Fig. 77) in the Gulf of St. Lawrence to determine the lithologic nature of a stratigraphic feature delineated by seismic and magnetic surveys (Pan American Petroleum Corporation, 1966). This hole, located between the Îles de la Madeleine and the northern tip of Cape Breton Island, intersected Windsor Group salt about 195 m below the seafloor before being completed in diapiric salt at 202 m. A second hole Sarep HQ- Brion Island No. 1 drilled on Brion Island in 1970, penetrated 1915 m of the Pictou Group and 740 m of the Riversdale-Canso groups before intersecting Windsor Group salt at 2705 m. This hole was completed in a salt pillow at 3196 m.

In 1972, following a gravity survey of the Magdalen Bank and Islands, Soquem drilled a 610- m hole on Île du Havre Aubert in search of salt. This hole intersected salt at 148 m and penetrated 451 m of continuous salt grading about 98 % NaCl (Carbonneau, 1977). This was the first of 51 diamond-drill holes that intersected salt at seven locations over depths ranging from 30 m to 976 m. The location of these drill sites and the distribution of Windsor Group salt in the Îles de la Madeleine area is shown in Figure 78. At the Havre Aubert diapiric deposit the top of salt in the A-1 hole was intersected between 148 m and 172 m (Gagnon, 1981). A number of well illustrated cross sections of the Havre Aubert area are recorded in the Soquem Annual Report for 1972-1973, p. 15, 18 and 19.

On Grosse Île at the Rocher-aux-Dauphins diapir, in the vicinity of the M-1 hole, the top of salt is between 25 m and 64 m and gave continuous intersections of 105 m t 97.9 % salt and 63 m at 98 % respectively. Within 915 m of the surface, this deposit contains 4 billion tons of salt of which 23 % is over 97 % pure. The salt at this prospect dips about 55° to the northwest. A few potash intersections average better than 7 % over 1.5 m, which may increase to 18 % on

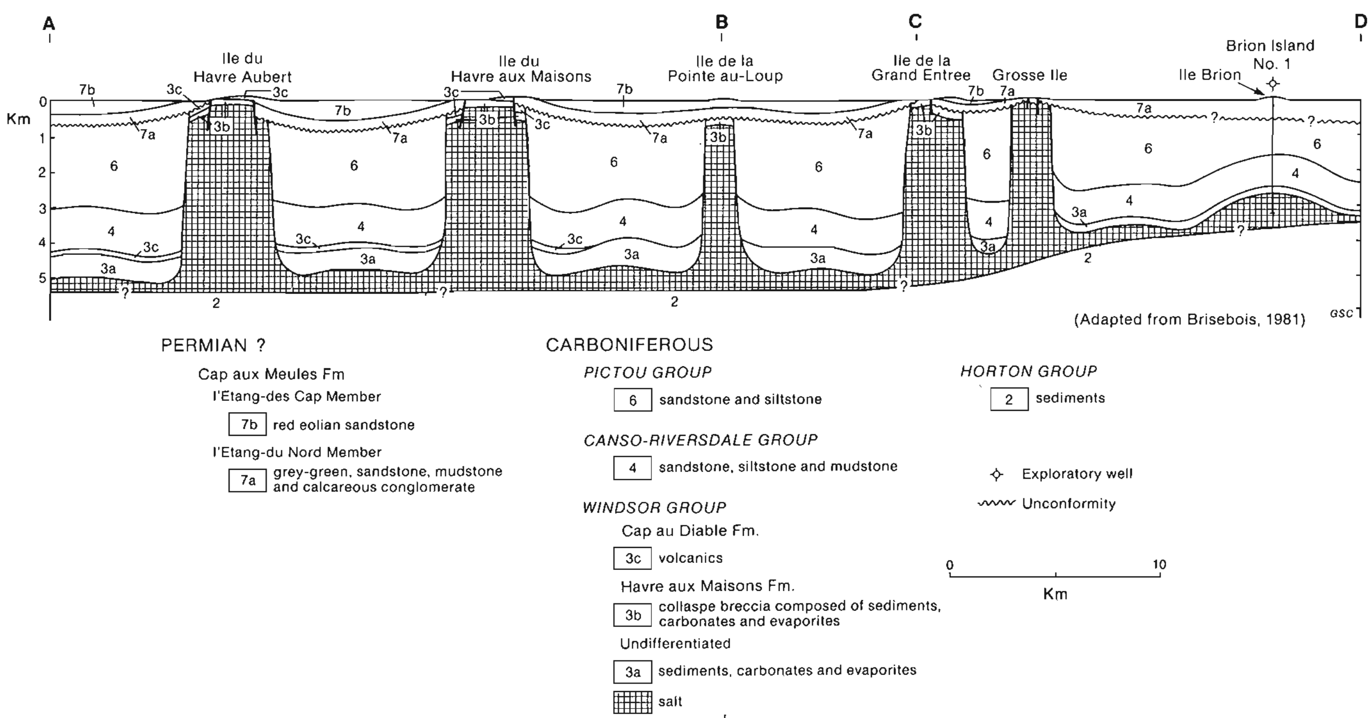


Figure 76. Generalized cross section through the Îles de la Madeleine.

the flanks of the structure. The relative uplift of this deposit at Grosse Île is about 518 m (Gagnon, 1981).

Salt was intersected at 305 m in the Cap aux Meules diapiric deposit at the site of the M-13 hole, but contained a number of volcanic blocks, some gypsum, clay and a little potash. On Île d'Entree at the site of the A-16 hole, diapiric salt was encountered at 256 m, which analyzed 91.5 % salt over 160 m in one hole and 91 % over 129 m in another hole. At this location all holes bottomed in good salt at about 610 m.

At the Grosse Île semidiapiric deposit at the site of the M-4 hole, salt is overlain by up to 2.7 m of fossiliferous limestone and 153 m of anhydrite. Here there are no known volcanics. Mudstone is generally absent except at one location, west of Grosse Île, where under a thin layer of mudstone the salt is overlain by beach sand. The Grosse Île deposit as outlined by a gravity survey and 15 core holes was drilled to a maximum depth of 984 m with an average depth of 732 m. In this subhorizontal deposit, the top of the salt was intersected between 259 m and 457 m. The salt deposit to a depth of 915 m has been estimated at nearly 45 billion tons. Salt beds about 94.5 % pure up to 61 m thick are separated by rhythmic salt and anhydrite cycles with anhydrite banks 1 to 3 cm thick. Only one bed of anhydrite, about 1 m thick, has been cored to date in this sequence. Clay horizons in the salt appear to be minor. There are a number of potash zones that vary from slightly more than 10 % up to 18 %, K_2O. A number of well-illustrated cross-sections for this area are recorded in the Soquem Annual Report for 1973-74, p. 10, 11 and 13.

At Bois Brule, a semi-diapiric deposit and the site of the A-10 hole, salt was intersected at 61 m. A north-south section across this horst indicates that salt can be correlated from flank to flank across the structure. At Anse a la Cabane and the site of the M-11 hole, semi-diapiric salt was intersected at 96 m. A mixture of mainly salt and argillite was cored to 749 m.

Four of the seven salt deposits explored by Soquem were considered potentially useful as a source of salt, a reservoir for the storage of oil and gas, or as a wind-compressed air reservoir for elecric power generation (Carbonneau, 1977). The Rocher aux Dauphins deposit and the Grosse Île deposit together form one of the largest and shallowest salt structures in North America (Gagnon, 1981). In 1976 an exploration shaft was sunk at Rocher aux Dauphins for the purpose

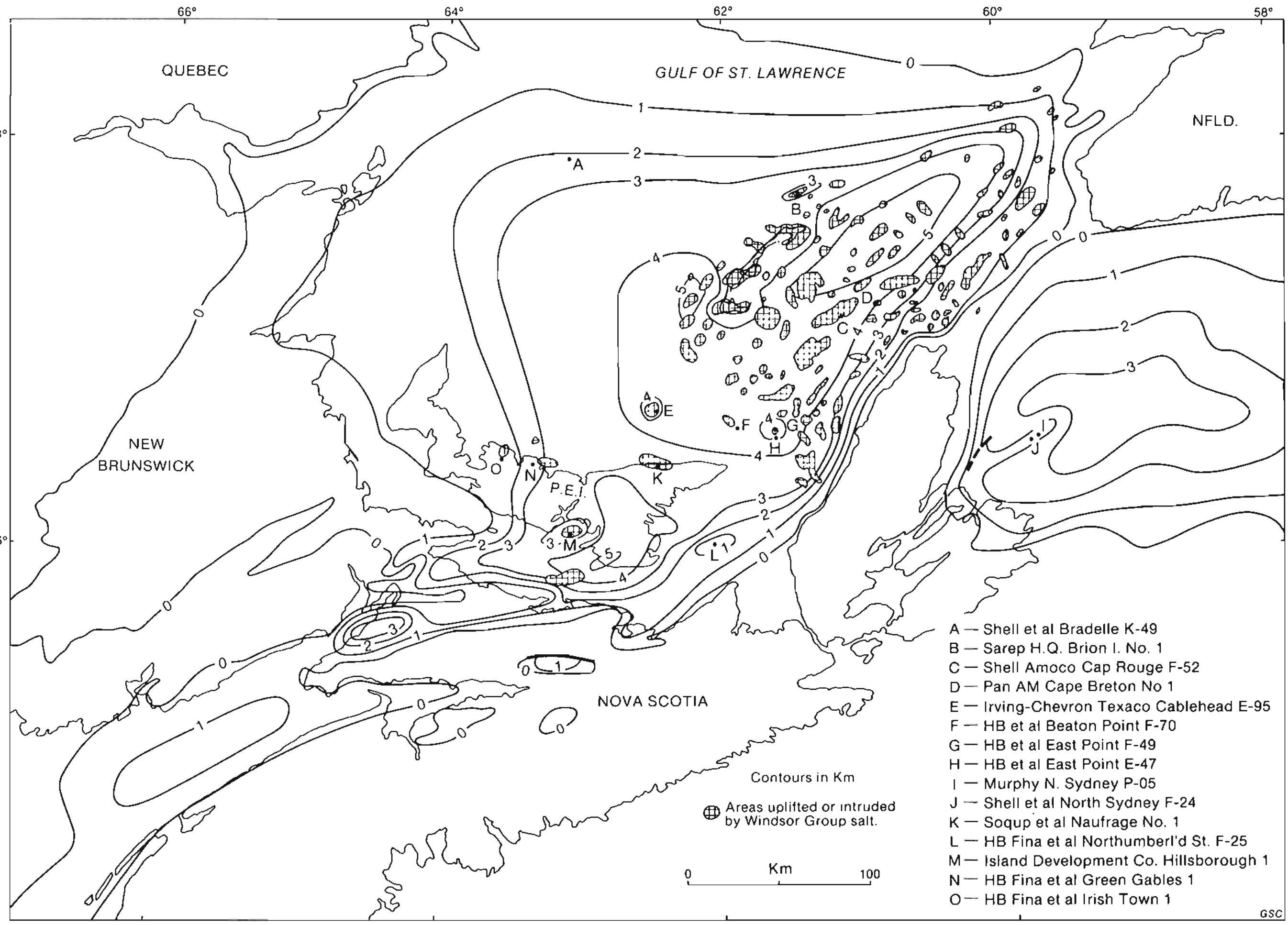


Figure 77. Isopach of Cumberland and Pictou groups.

of developing a rock salt mine and investigating the economic potential of the associated potash mineralization. In the spring of 1983 Mines Seleine Inc. (a subsidiary of Soquem) commenced to mine salt. This underground operation has a production capacity of 1.23 million tonnes per year with sufficient reserves for 20 years (Prud'homme, 1985). In 1983 production was 640443 tonnes. After only two years of operation the mine has experienced numerous equipment failures and transportation problems. Reports indicte that unless there is an injection of new capital to make production improvements the mine may cease operation (Mail-Star, Halifax, Nova Scotia, November 4, 1985, p. 41).

The Shell Soquip-Amoco Bradelle K-49 hole was drilled in 1973 about 190 km northwest of the Îles de la Madeleine (Fig. 77). This hole, spudded on the sea ward extension of the New Brunswick platform (Wade et al., 1977), penetrated 1681 m of the Pictou Group, 789 m of the Riversdale-Canso groups, 285 m of the Windsor Group, and 1029 m of the Horton Group before being completed in the Horton Group at 3793 m. Salt was not present as part of the Windsor Group in this hole. In 1973 the Shell-Amoco Cap Rouge F-52 hole was also drilled in the Gulf of St. Lawrence about 50 km east of Île du Havre Aubert. Although sample collection was started in salt at 305 m the sonic log of this hole indicated that salt was present up to at least 152 m below sea level (66 m below the seafloor). Salt, anhydrite and shale are the main lithologies intersected in this diapiric structure down to 4896 m. Below this interval 137 m of shale is underlain by 9 m of quartzose sandstone and 18 m of volcanics. The hole was completed in volcanics at 5027 m. The age of the volcanics is not known.

The distribution of volcanics on the Îles de la Madeleine probably follows the gamma contours on the aeromagnetic

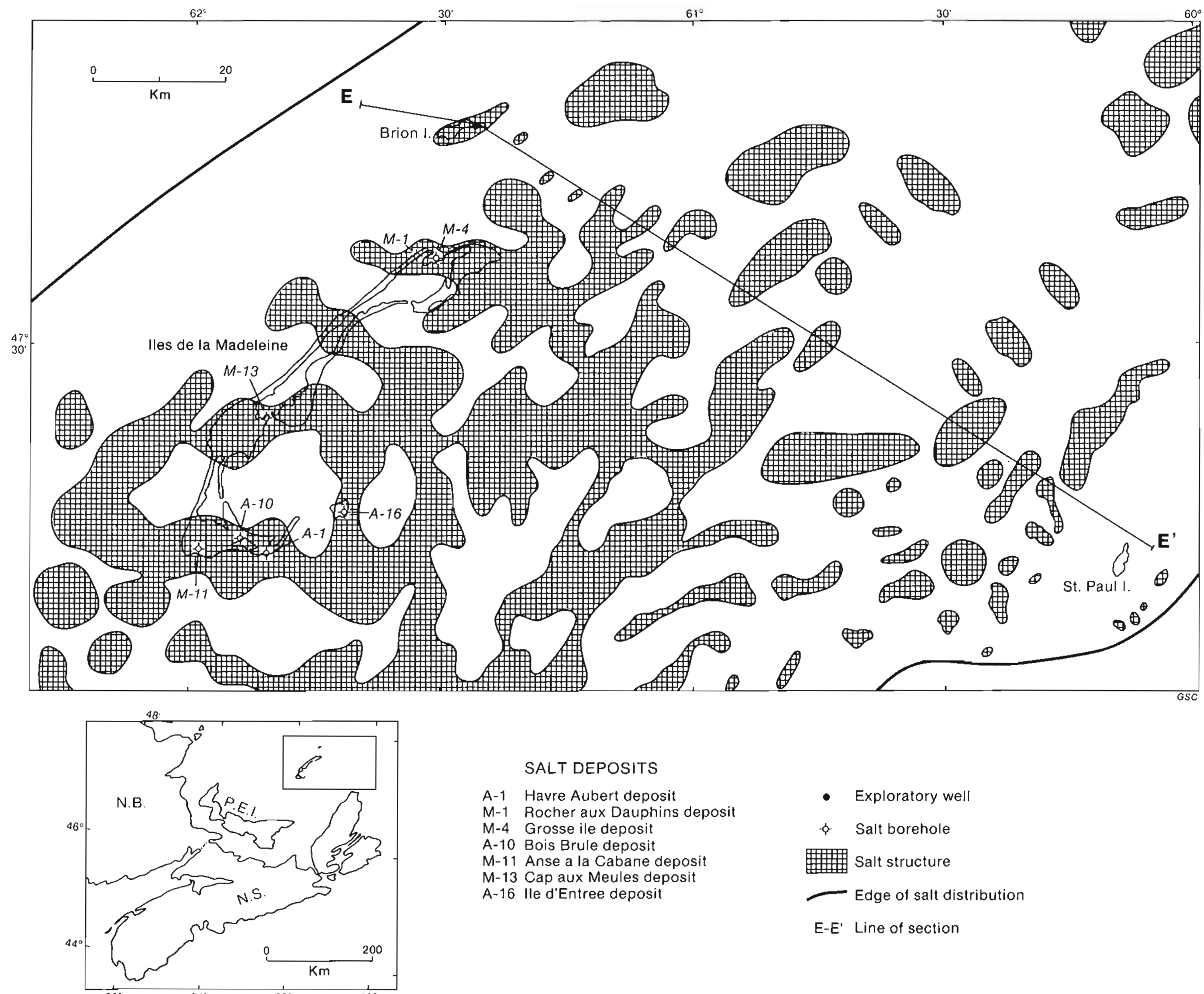


Figure 78. Distribution of Windsor Group salt structures in the Îles de la Madeleine area, Gulf of St. Lawrence.

map (Fig. 79), which indicates the volcanics have a general west-east trend and were probably extruded along basement faults. The volcanics near the bottom of the Shell Cap Rouge F-52 hole are on trend with the volcanics in the Îles de la Madeleine, suggesting that they may have been extruded along the same fault system. Farther east and just north of Cape Breton Island a general west to east fault (Wade et al., 1977) is also on trend with the two volcanic occurrences, suggesting the presence of a west to east fault zone between the Îles de la Madeleine and the offshore areas immediately north of Cape Breton Island.

On the aeromagnetic map the contours are generally fairly widely spaced and smooth, except for the area influenced by the volcanics. Unless there is an anomaly within the basement complex, this indicates the presence of a thick blanket of sediments. North of Île Brion and in the St. Paul Island area an increase in the contour values suggest a thinning of the sediment cover.

The Bouguer gravity map (Fig. 80) suggests a large gravity low east of the Îles de la Madeleine, trending in a northeast direction, that can probably be attributed to a thick section of low density evaporites. Exploratory drilling and a number of cross sections through the Îles de la Madeleine indicate that the area is underlain by a thick section of diapiric salt, but this is not evident from the gravity map. In the southern islands the gravity low usually associated with salt is masked by the presence of associated volcanics. In the northern islands the thick section of dense anhydrite above the salt has partly nullified the effects of the anticipated gravity low density salt (Carbonneau, 1977).

Adjustments in the elevation of various basement blocks during and since the post-Windsor Group Maritime Disturbance, combined with the migration of low density salt has greatly complicated the Carboniferous section in the Gulf of St. Lawrence as well as many adjacent onshore areas (Howie, 1986a, 1986b). Section line E-E' (Fig. 78 and 81)

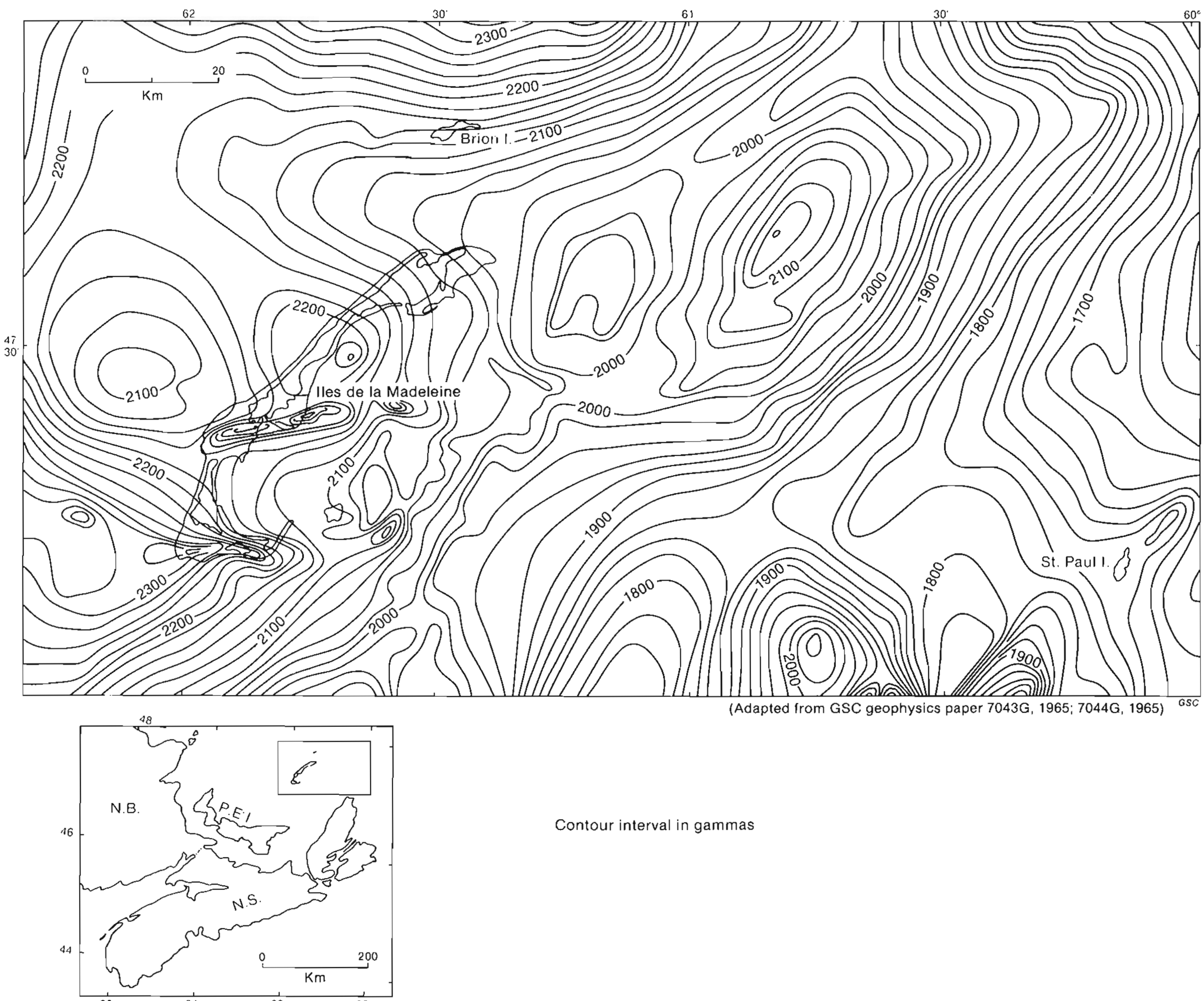


Figure 79. Aeromagnetic map, Îles de la Madeleine, Gulf of St. Lawrence.

from Île Brion southeast to the St. Paul Island area is considered to be representative of Windsor Group evaporites in this deep basinal area. Near the western end of this section the Sarep H.Q. Île Brion No. 1 hole is shown to have been completed in the upper beds of a Windsor salt pillow. This shallow dome is considered to occur near the perimeter of the main salt basin. The three dashed diapiric structures east of the hole are salt accumulations that are slightly off the line of section. In the deeper part of the basin to the southeast, diapiric salt structures are shown to have penetrated Windsor, Canso, Riversdale and most of the Pictou group sediments. On the eastern slope of the basin the salt structures grade from diapiric to slightly diapiric and are offset by numerous faults. This appears to be the eastern edge of the Magdalen salt basin. The horst structures east of the salt zone are part of an uplifted basement complex that separates the Magdalen and Sydney basins (Petro Canada, 1982; Texaco Exloration Ltd., 1970, 1971). St. Paul Island represents part of this complex.

The Pictou Group is the main rock type exposed in the southern part of the Gulf of St. Lawrence. Since this section has been intruded by numerous salt diapirs, the salt has been shown as cross-hatched areas in the isopach map of the Pictou Group (Fig. 77). Borehole data from H.B. et al. East Point E-49 and H.B. et al. East Point E-47 holes indicate that a composite section of about 4 km is not unrealistic for Pictou Group in the area. Seismic data from southern Prince Edward Island and the Îles de la Madeleine area indicate that over 5 km of Pictou Group rocks may be present (Prince Edward Island Department of Industry, 1974; Sarep, 1970; Shell Canada Limited, 1973; Texaco Exploration Company, 1970). The Cumberland and Pictou groups are combined on Figure 77 because they are in part contemporaneous and because the Cumberland Group of Howie and Barss (1975a) has a restricted distribution.

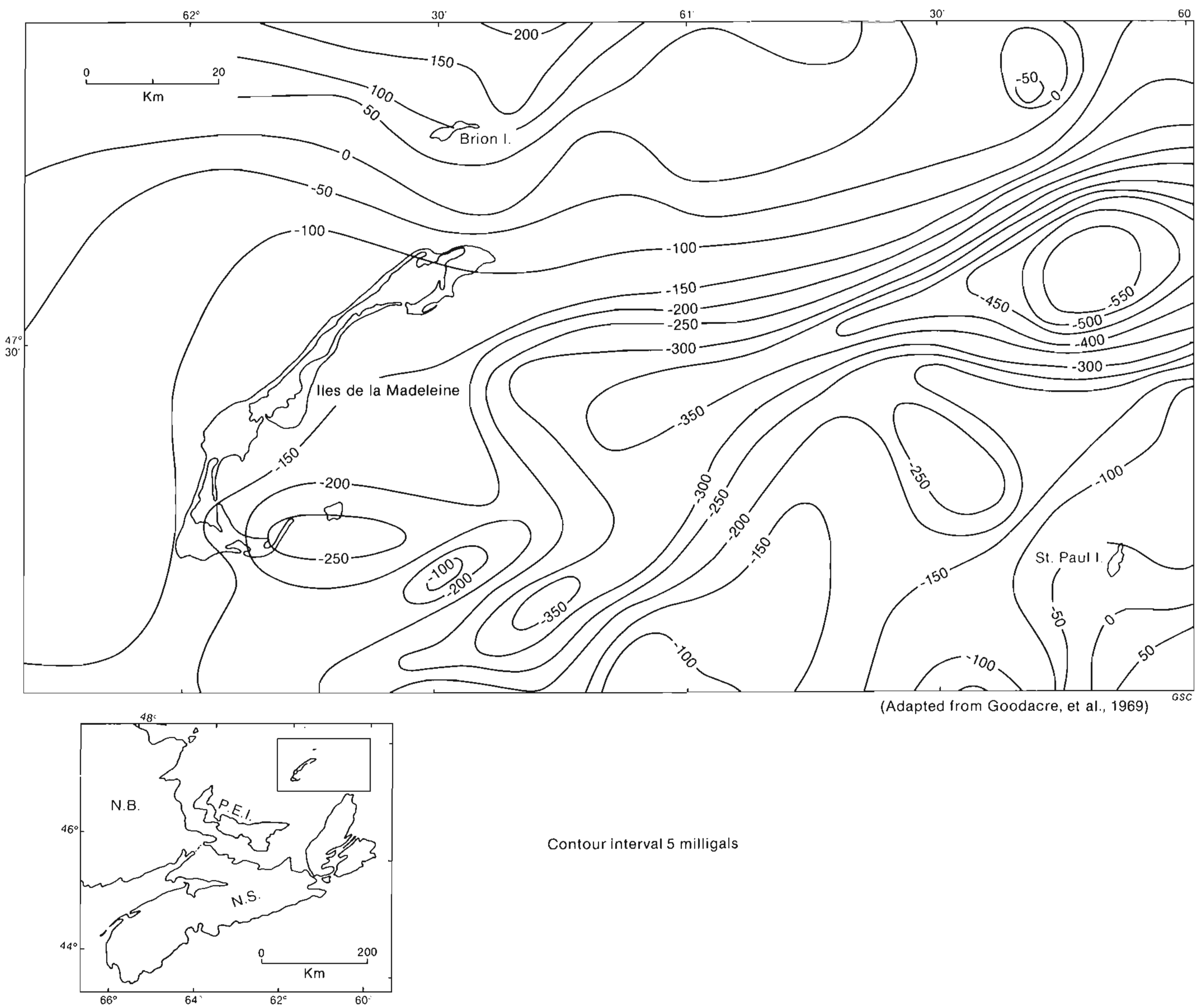


Figure 80. Bouguer gravity map, Îles de la Madeleine, Gulf of St. Lawrence.

20. *St. George's Bay area, Newfoundland and Labrador*

The Carboniferous rocks in the St. George's Bay area or St. George's subbasin (Wade et al., 1977) of southwest Newfoundland occupy an area about 22 km wide and 125 km long, with an approximate area of 2700 km (Knight, 1983). Underlain by approximately 10 km of sediments, this land area represents the northeastern extension of the larger Magdalen Basin (Poole, 1967; Williams, 1974). Over the years this Carboniferous sequence has been examined by Howley (1897), Hayes and Johnson (1938), Rose (1947), Bell (1948a), Blanchard (1953), Hooker Chemical Corporation (1971), Fong (1974), and others. As indicated on the correlation chart (Fig. 4), the sediments range in age from Eifelian (Horton Group) to Westphalian (Canso-Riversdale groups). Using local terminology (Fig. 82) the strata are divided into three groups: the Anguille Group, Codroy Group and the Barachois Group. Although this sequence is composed of mostly non-marine terrigenous clastic sediments the Codroy Group is partly marine and locally contains evaporites.

The area is characterized by a pre-Carboniferous basement complex which is overlain by red and green sandstone, black shale, grey sandstone and conglomerate of the Anguille Group. This sequence, which may vary in thickness from 2000 m to over 4900 m is conformably overlain by the Ship Cove Formation of the Codroy Group. The Ship Cove Formation consists of 18 to 20 m of laminated limestone overlain by the Codroy Road Formation. This formation is a mixed sequence of sandstone, mudstone, shale, gypsum and carbonate which varies in thickness from 120 to 300 m. Both the Ship Cove and Codroy Road formations are considered equivalent to Subzone A of the Windsor Group in Nova Scotia (Bell, 1929).

The Codroy Road Formation is overlain by the Robinsons River Formation. This is a new name proposed by Knight (1983) for a complex succession of 3200 to 5000+ m of terrigenous rocks with lesser amounts of carbonate and evaporite strata which may include some salt. In some areas the Robinsons River Formation can be subdivided into the Jeffreys Village Member and the Highlands Member. The Jeffreys Village Member conformably overlies the Codroy Road Formation and consists of shale, mudstone, conglomerate, anhydrite, gypsum with salt and potassic salts in the subsurface. This sequence varies in thickness from 1400 to 2000 m and is equivalent to subzone B of the Windsor Group (Knight, 1983). The Highlands Member is composed of thick sandstone with intercalated thick siltstones and some limestones (possibly marine). This sequence, which is over 1200 m thick, is considered to be a lateral equivalent of Subzone C of the Windsor Group (Knight, 1983).

Also in the southwest of the basin the name Woody Cape Formation was proposed by Knight (1983) for a fluviomarine succession approximately 690 m thick of well bedded grey to green mudstones and shales intercalated with sandstones and carbonates. This forms the uppermost unit of the Codroy Group and may be equivalent to Subzones D and E of the Windsor Group.

The Barachois Group is the youngest rock unit in the St. George's subbasin. This Canso-Riversdale groups equivalent consists of a thick succession of sandstones intercalated with siltstones, mudstones, shales and some coal beds. The Searston beds, elevated to the Searston Formation by Knight (1983), appears to be the lateral equivalent of part of the Barachois Group. The Barachois Group-Searston Formation sequence has an estimated thickness range of 1500 to about 2500 m.

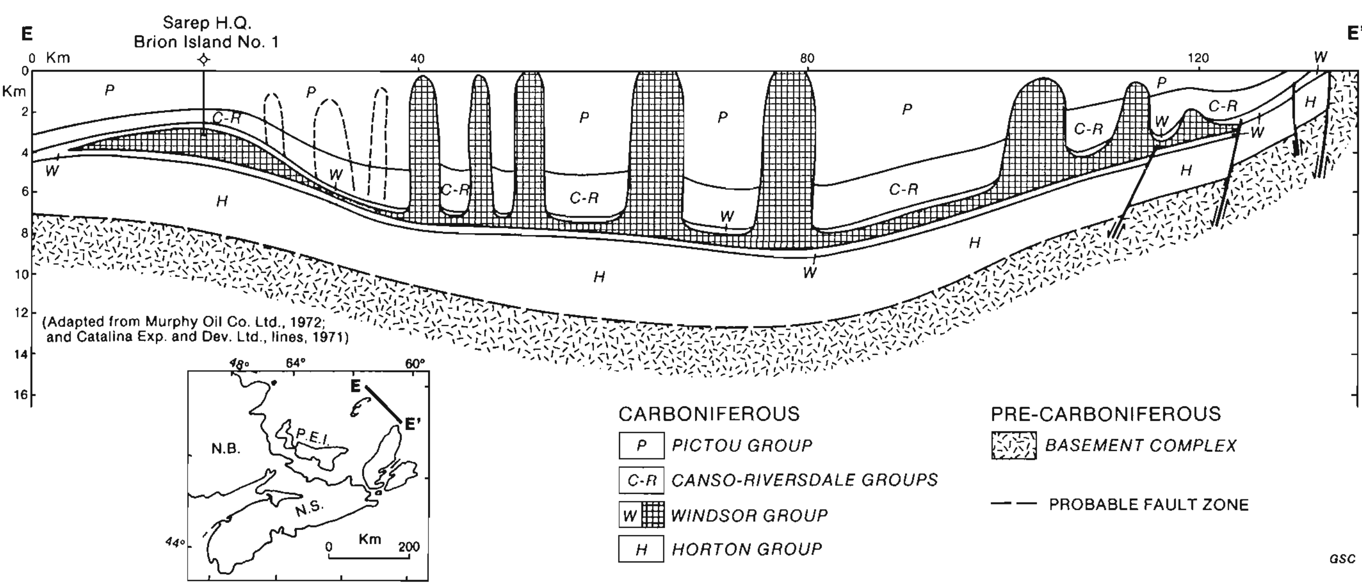


Figure 81. West to east cross section, Îles de la Madeleine area, Gulf of St. Lawrence.

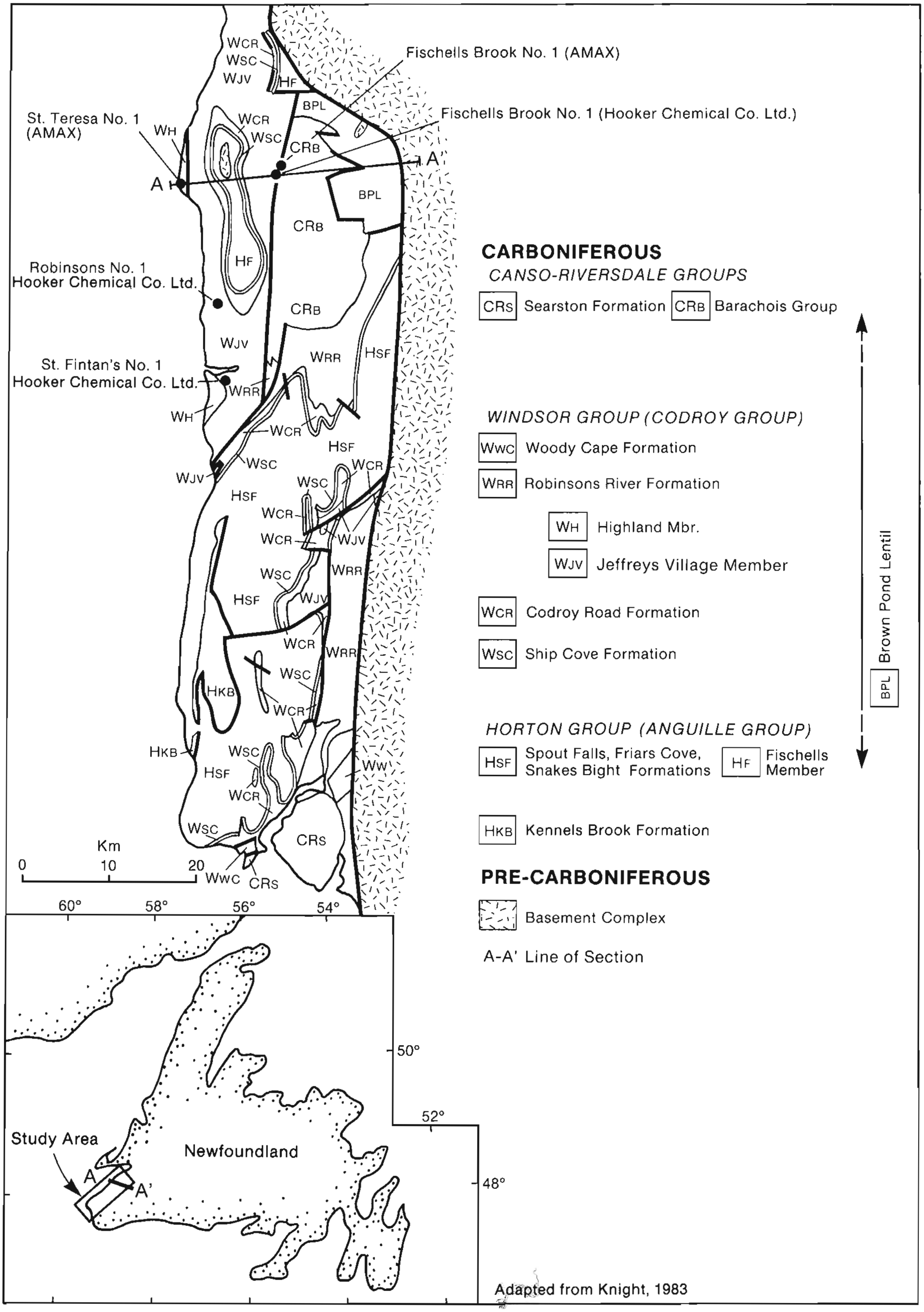


Figure 82. Geology of the Carboniferous, St. George's Bay area, Newfoundland.

The Brown Pond Lentil section is basically a piedmont deposit composed of arkosic grit and sandstone containing some plutonic and metamorphic fragments. Although it is considered to be mainly equivalent to the Robinsons River Formation, its exact stratigraphic position is unknown, and it may be considered contemporaneous with most Carboniferous units in the area (Knight, 1983).

The presence of salt associated with the Codroy Group was known from salt springs on Fischells Brook, Robinsons River, Middle Barachois Brook, Crabbes Brook and near St. Fintans (Hayes and Johnson, 1938; Snelgrove, 1953). Brine springs have also been reported along the shore of St. George's Bay just north of Robinsons and on the Highlands River (Newfoundland and Labrador Department of Mines and Energy, Mineral File 12B/07SLT002 and 12B/02SLT001). Each of the occurrences is located in the northern half of the Carboniferous map of the St. George's Bay area.

Gravity surveys of the St. Fintan's area (Blanchard, 1953; Verrall (1954a, 1954b) in the St. George's Bay area have been successful in locating several gravity lows. The most significant anomalies (Fig. 83) occur as lows over the

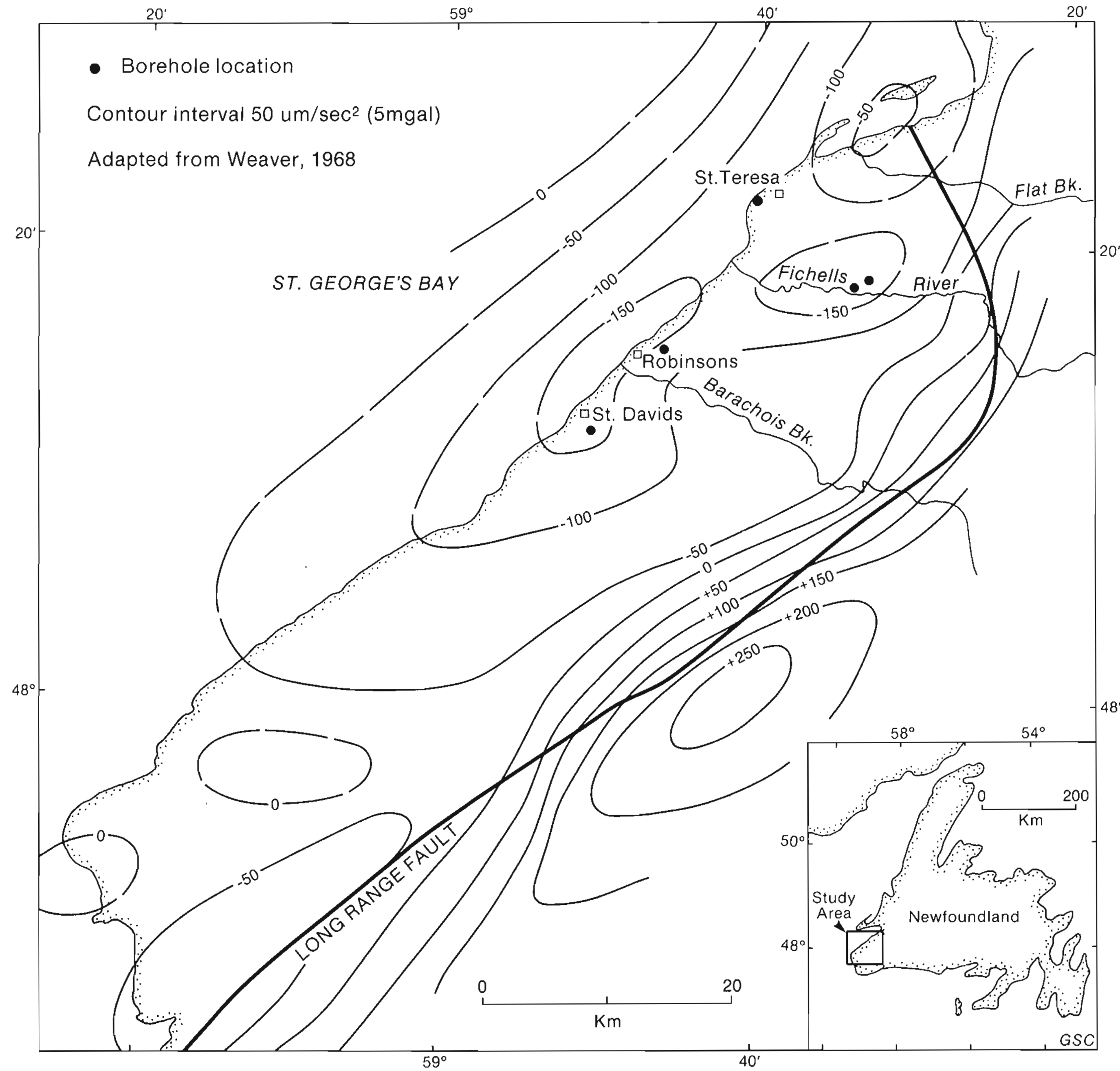


Figure 83. Bouguer gravity map of Carboniferous rocks, St.George's Bay area, Newfoundland.

St. David's-Robinsons area and to the east along Fischells River. An aeromagnetic map (Fig. 84) of the same area, contains contours that parallel the general trend of the Carboniferous basement and highlights a basement high within the subbasement.

In 1967, encouraged by favourable gravity data, Hooker Chemical (Nanaimo) Limited obtained a concession agreement from the provincial government to explore for sodium and potash salts over most of the St. George's Bay subbasin. Detailed gravity surveys near Fischells Brook (Fig. 85) indicated a well defined gravity low adjacent to the Trans Canada Highway (Hooker Chemicals, 1968b). Based on this information the Fischells Brook No. 1 hole was drilled in an attempt to discover salt in sufficient quantity and quality on which to base the establishment of a possible chemical plant. In this hole the salt zone is at least 743 m thick and is overlain by 63 m of overburden and 294 m of interbedded red pebbly sandstone, siltstone, shale and gypsum of the Codroy (Windsor) Group. The hole was completed in salt at 1099 m (Hooker Chemical Limited, 1968a). Knight (1983) interprets it as part of the Jeffreys Village Member of the Robinsons River Formation. Impurities associated with the salt included a few salt-bearing siltstones, various amounts of polyhalite and salt with 3 to 30 % anhydrite. In

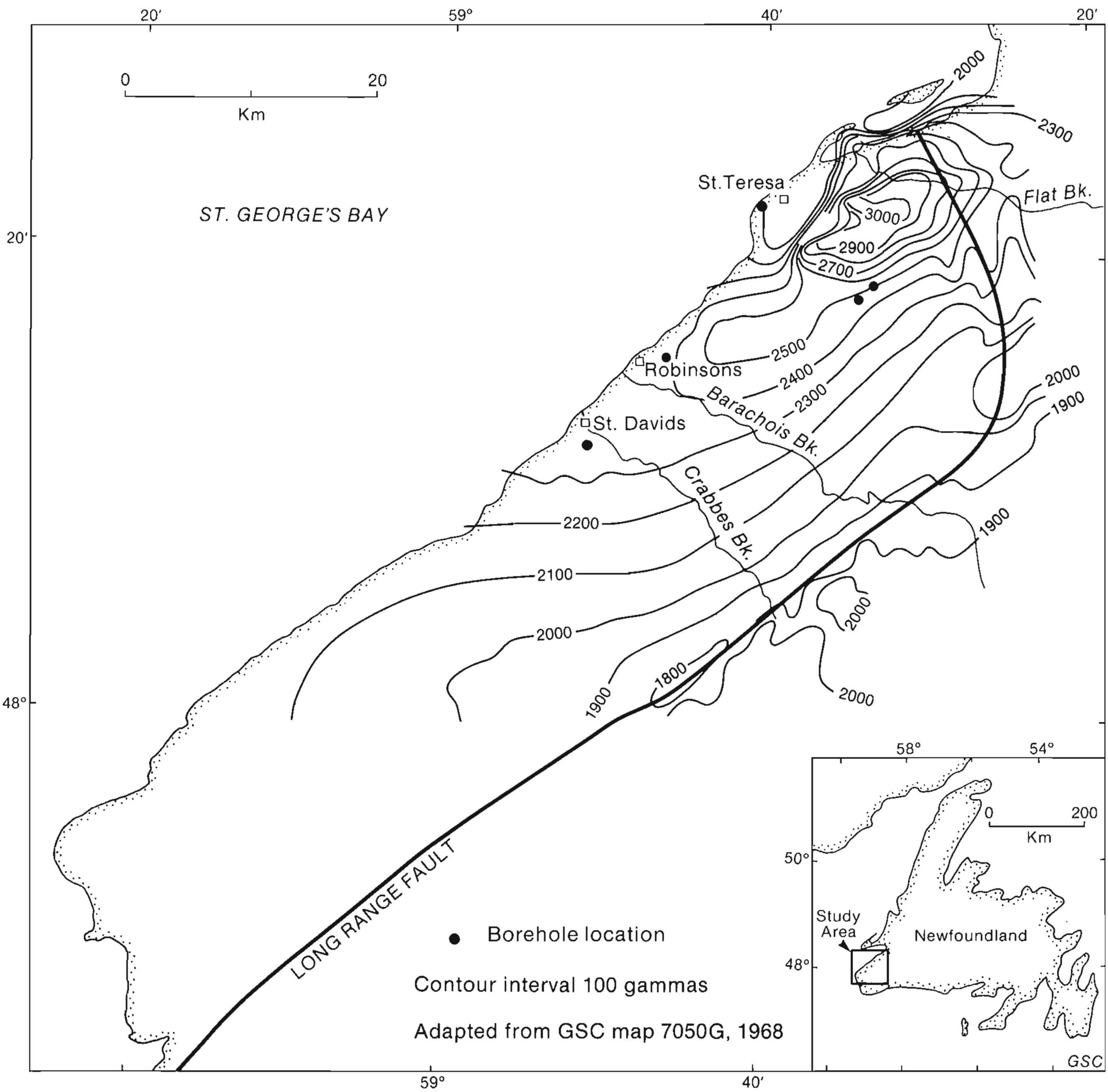


Figure 84. Aeromagnetic map of Carboniferous rocks, St. George's Bay area, Newfoundland.

the lower 183 m the anhydrite-gypsum content may increase to 60 % in some horizons. Sylvite was observed near the top of salt section from 358 to 399 m, with 20 to 25 % sylvite from 376 to 378 m and 10 % from 378 to 384 m. This deposit is considered to contain salt of sufficient quantity and quality for commercial use (Newfoundland and Labrador Department of Mines and Energy, Mineral Inventory Number 12B/071SLT001).

In 1976 Amax Exploration Limited optioned the Fischells Brook prospect from Hooker Chemical Limited and drilled a hole on the northeast flank of the gravity anomaly. This hole penetrated about 900 m of sandstone, shale and conglomerate (Barachois Group) and some Codroy Group sandstone and shale before being completed at 990 m in the Codroy Group without intersecting salt (Amax Exploration Limited, 1976). The presence of slickensides and breccia throughout the hole suggest it was drilled close to a major fault zone (Fig. 82). Recent drilling at this salt prospect by Pronto Exploration Limited and Camflo Mines (R.P.F. Syndicate, 1980) penetrated salt with encouraging intersections of potash (Knight, 1983).

In 1972 Hooker Chemical Limited drilled a hole near Robinsons on a gravity anomaly (Fig. 86). The Robinsons No. 1 drillhole penetrated about 45 m of overburden, 167 m of Codroy Group clay with scattered gypsum before intersecting 7 m of salt at 213 m. This salt was underlain by 4.6 m of shattered dolomite which in turn was underlain by approximately 233 m of salt which contained scattered mudstone inclusions and numerous beds from 331 to 341 m. From 470 m to the bottom of the hole at 616 m the section

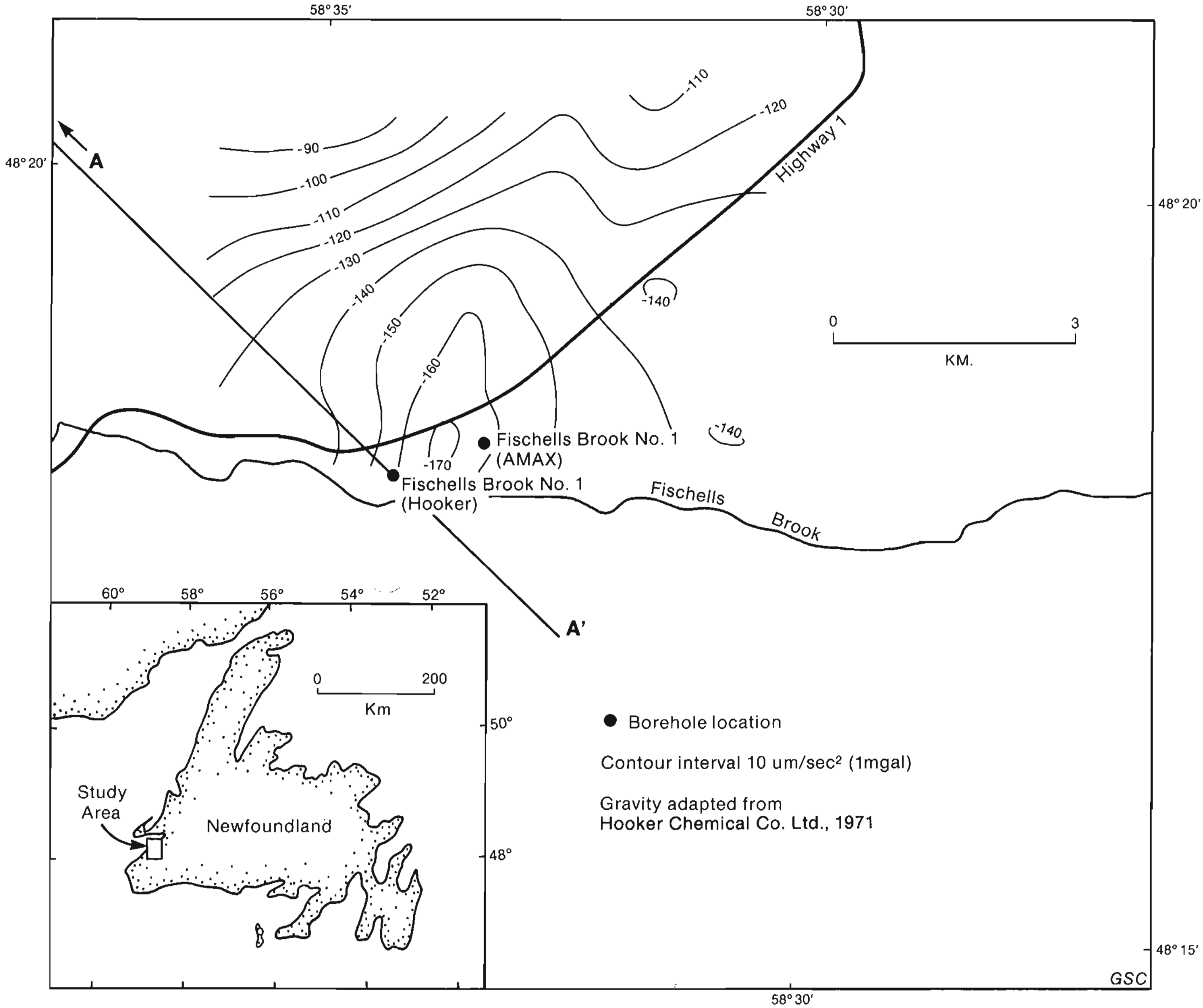


Figure 85. Detailed Bouger gravity map, Fischells Brook, St. George's Bay area, Newfoundland.

is composed of brecciated to slickensided mudstone and salt. Bedding within the sequence maintains dips that vary from 26 to 70° which appear to be part of a domal structure. There are fourteen potash-bearing zones, 1 to 8.7 m thick scattered throughout the deposit. K_2O values vary between 2.7 to 6.3 % (Knight, 1983, Table 15). These potassic zones account for approximately 20 % of the salt section. This percentage increases to 30 % if additional secondary zones are included. Sylvite and carnallite occur in the higher zones but only carnallite in the lower zones.

The salt penetrated in the Robinsons No. 1 hole is considerably less than that expected based on gravity data. The difference may in part be due to the thick overburden, additional low density evaporites at depth or a local variance within the basement.

In 1973 Hooker Chemical Limited drilled St. Fintans No. 1 hole on a gravity low between St. David's and St. Fintan's (Fig. 87). This hole penetrated 213 m of overburden and 17 m of the Jeffreys Village Member (Codroy Group), shale and gypsum before intersecting salt at 230.4 m. This evaporite section composed of salt, anhydrite and

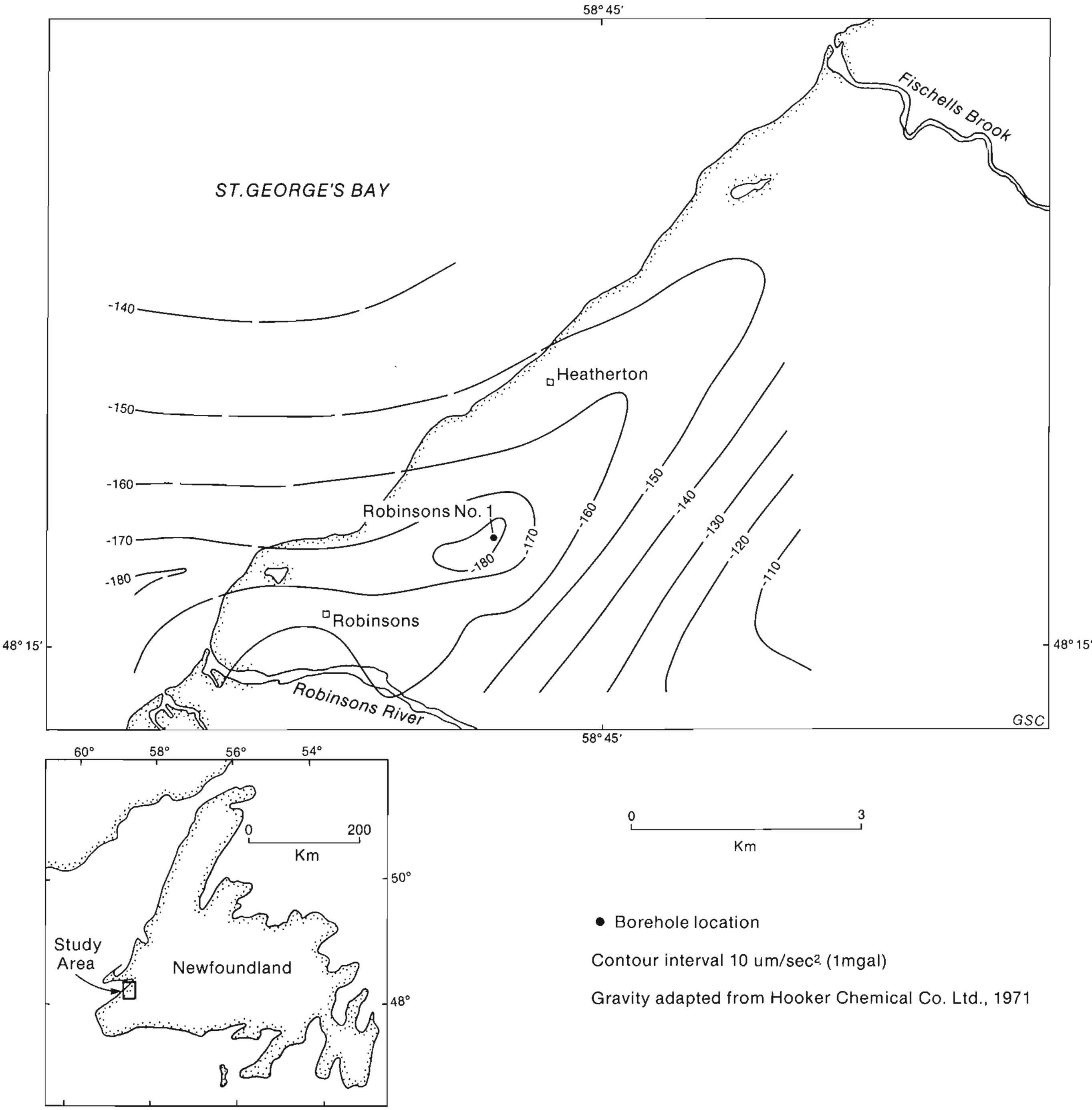


Figure 86. Robinsons Bouguer gravity map, St. George's Bay, Newfoundland.

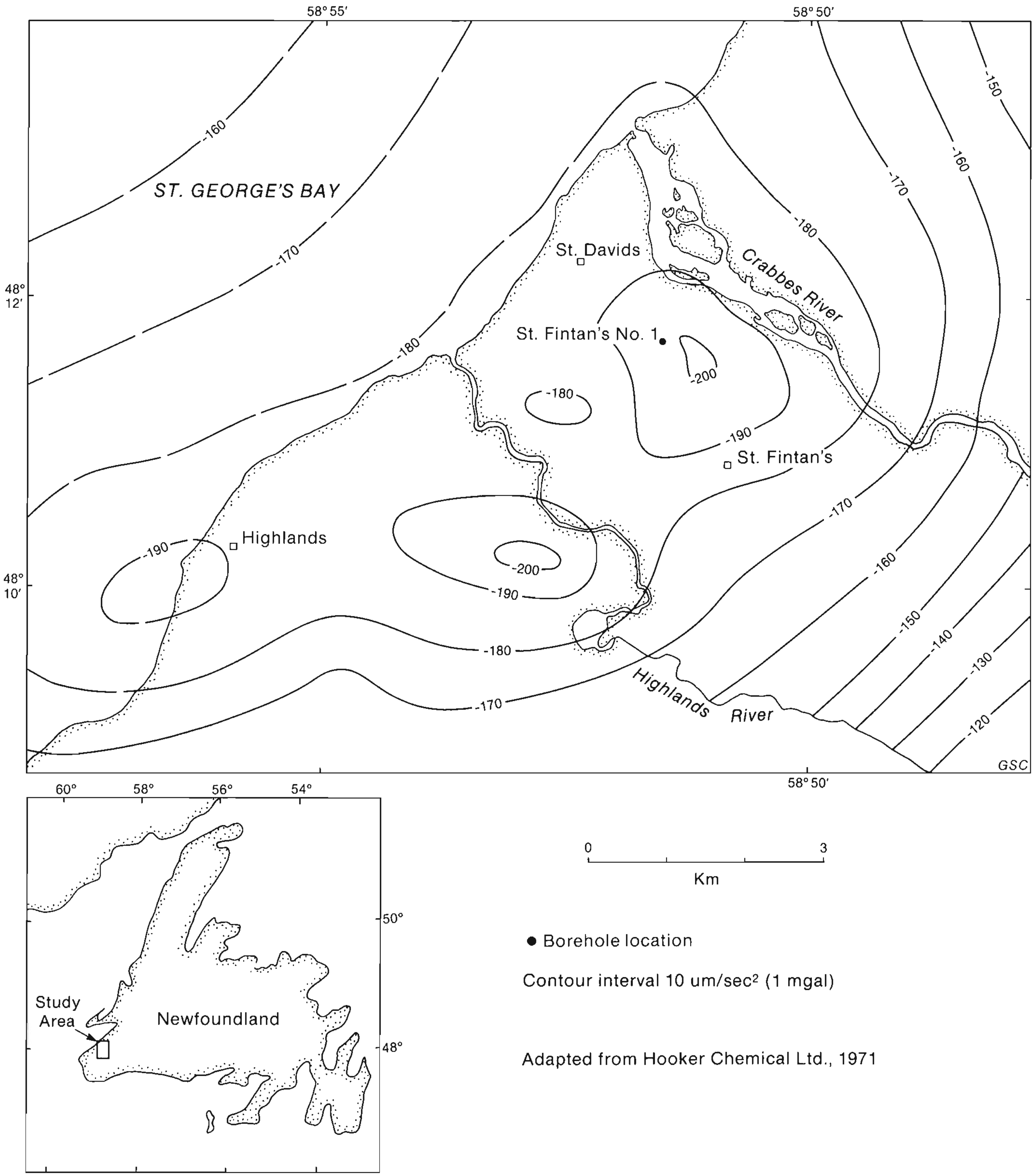


Figure 87. Bouguer gravity map, St. Fintan's, St. George's Bay area, Newfoundland.

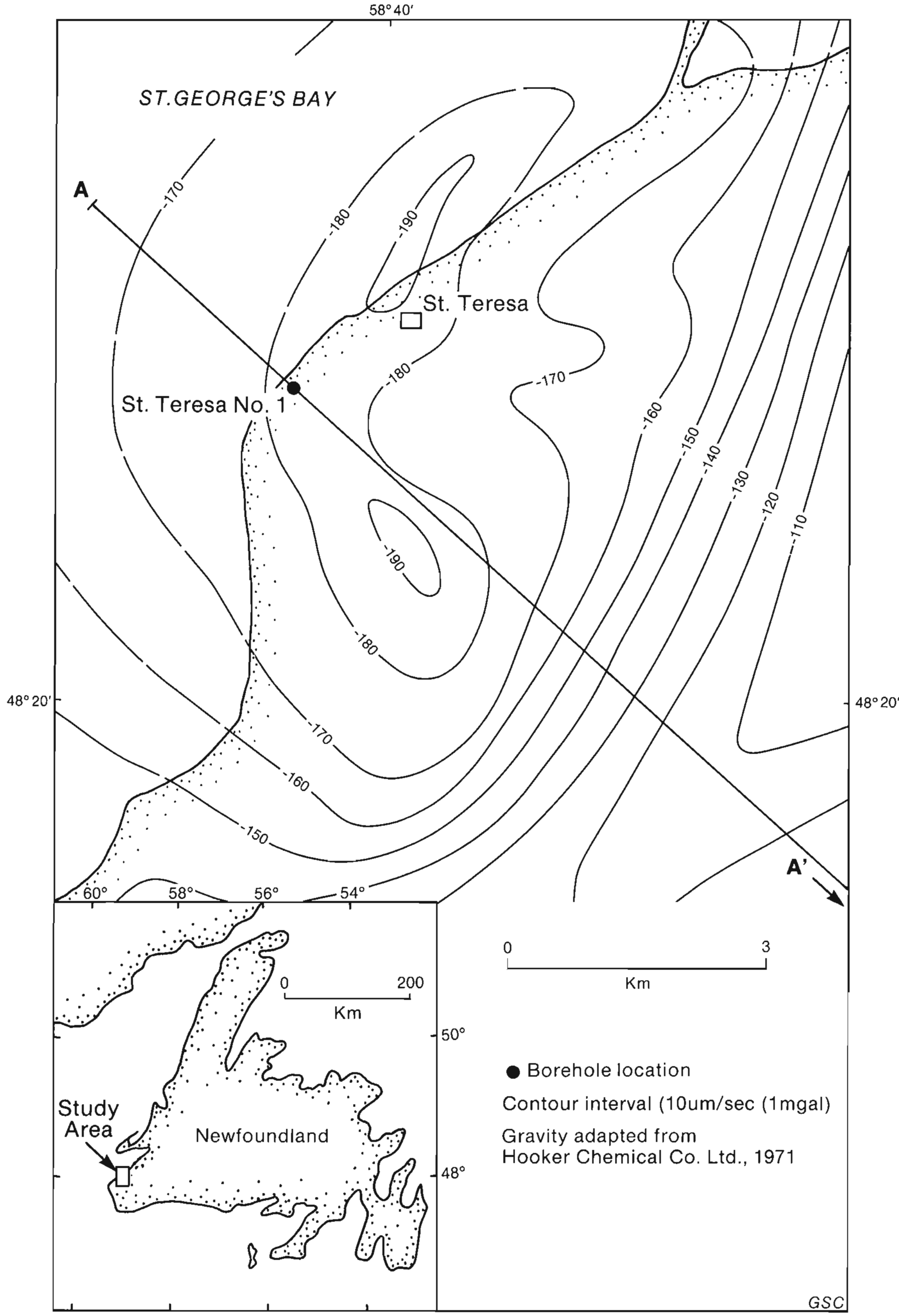


Figure 88. St. Teresa Bouguer gravity map, St. George's Bay area, Newfoundland.

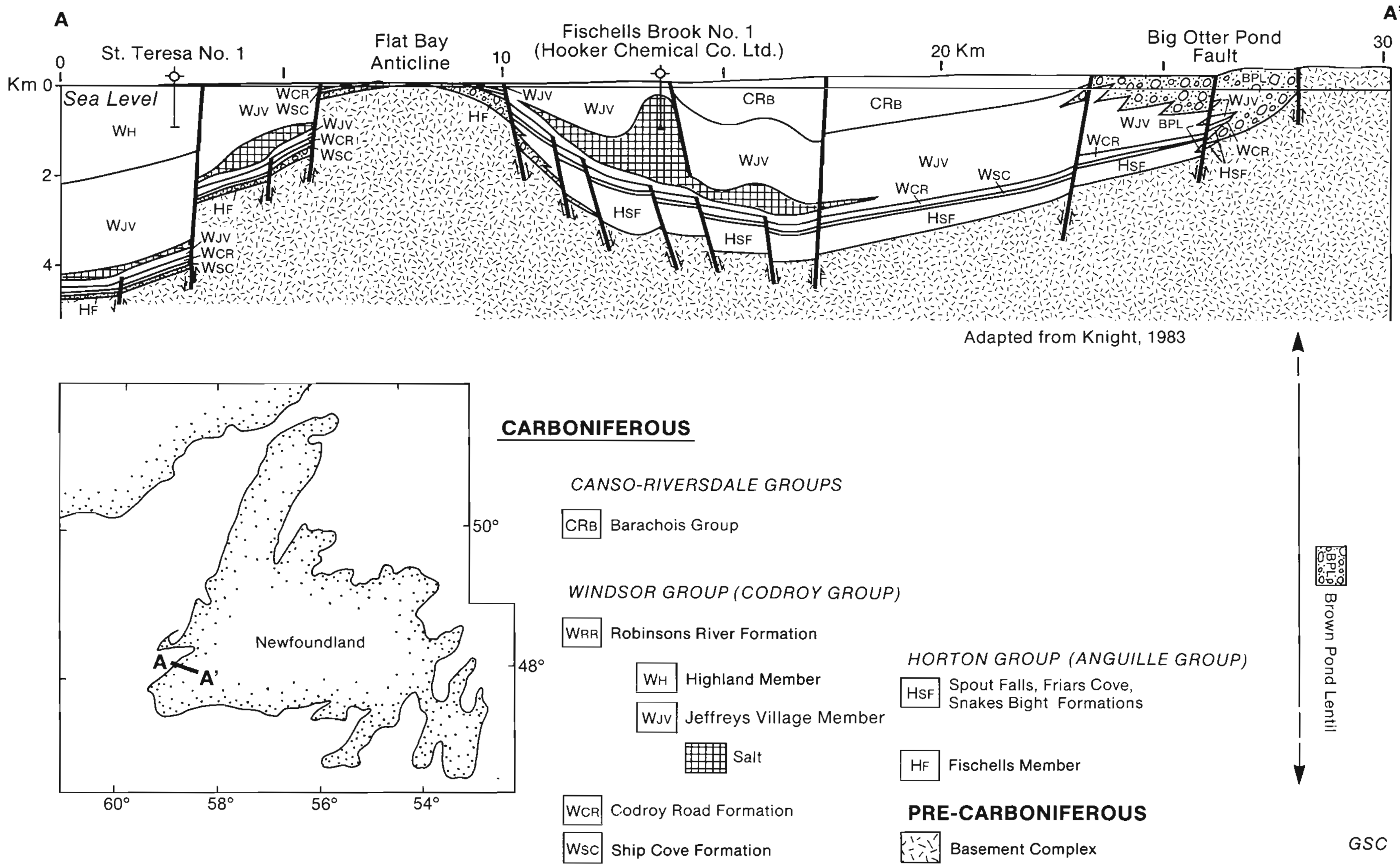


Figure 89. Fischells Brook Carboniferous salt structure, western Newfoundland.

minor shale extends to 319 m. Below this depth salt is a minor constituent in a predominately shale sequence with some anhydrite except for about a 3 m zone of 65 % salt at 367 m. The hole was completed in shale at 459 m. The average dip of the beds was 33°. Chemical analyses of the salt zone (Hooker Chemical, 1973) indicated eleven potassium-bearing zones ranging from 0.5 to 6 m thick with 3.5 to 9 % K_2O (Knight, 1983, Table 15). Carnallite mineralization occurs in interbedded and intermixed red and white crystalline salt. Sylvite does not seem to be present. In the overall deposit the salt purity is generally less than 90 % for beds equal to or greater than 3 m.

As in the Robinsons area, the volume of salt penetrated by the drill is considerably less than suggested by the gravity low. The difference may be due to the thick mantle of overburden, additional low density evaporites at depth or a local variance within the basement. No exploration on the flanks of this gravity low was undertaken.

In 1976, Amax Exploration Incorporated in search of salt, located the St. Teresa No. 1 hole on a gravity low southwest of St. Teresa (Fig. 88). This hole, which coincided with a down-faulted basement block (Fig. 82), penetrated 38 m of overburden and 952 m of coarse red beds assigned by Knight (1983) to the Highlands Member (Robinsons River Formation) without intersecting salt (Amax Exploration Incorporated, 1976). This upper Codroy Group section is composed of pebbly sandstone,

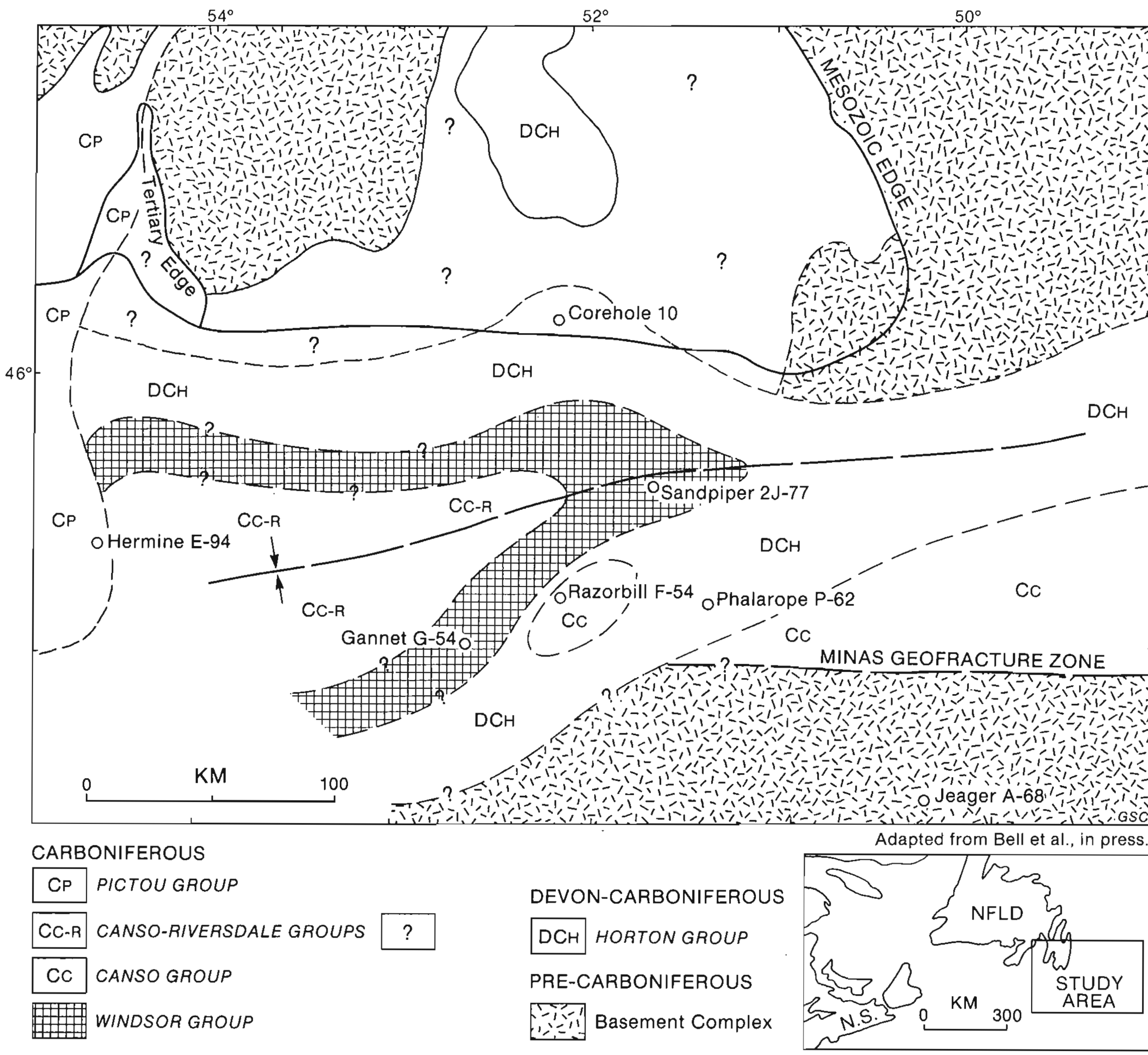


Figure 90. Geological map, Grand Banks, Newfoundland, with Tertiary and Mesozoic rocks removed.

shale, and siltstone, with nonmarine caliche, some limestone and intraformational conglomerate, which constitutes a sequence that is estimated to exceed 1200 m thick (Knight, 1983). The absence of low density evaporites associated with the well may be attributed to the difference in elevation of basement across the fault, a combination of a thick Carboniferous sequence and salt below the drillhole, and also a variance in rock type within the basement complex across the fault.

A generalized west to east cross-section A-A (Fig. 89) has been drawn through the St. George's subbasin of southwestern Newfoundland to show the probable distribution and probable thickness of Codroy (Windsor) Group salt. At the western end of the section the St. Teresa No. 1 hole is shown to have been spudded and completed in the Highlands Member of the Robinsons River Formation without penetrating salt. As this location appears to be part of a graben structure that is coincident with a gravity low, part of the low is attributed to the thick Carboniferous section. The Jeffreys Village Member shown to underlie the Highlands Member may contain some salt, although its presence or thickness cannot be substantiated without additional work.

East of the St. Teresa hole in an adjacent fault block, the Jeffreys Village Member is exposed at the surface (Fig. 82). The depth to basement in this area is shown to be considerably less than in the western part of the section. A large part of this gravity low east of St. Teresa is considered to be due to a salt pillow (Fig. 87). The Flat Bay anticline (Fig. 89) is a pre-Carboniferous basement high that locally dissects the St. George's Bay Carboniferous sequence into two areas. To the east of the Flat Bay anticline the basement drops down and is overlain by approximately 4 km of sediments. In this area the Fischells Brook No. 1 (Hooker Chemical) hole is shown to have been completed in a salt plug or diapir. Based on gravity data the structure should contain about 7000 million tonnes of salt (Knight, 1983). Although the basement faults are highly speculative, this is the type of structure that is considered necessary to accomodate a thick section of Anguille to Canso-Riversdale group sediments.

East of the Fischells Brook structure the Jeffreys Village Member is shown to contain some salt since this area and the Fischells Brook area are both part of the same basinal area, which should logically contain some salt. Near the eastern end of the cross-section on both sides of the Big Otter Pond fault, the Brown Pond Lentil interfingers or overlies rocks that range from the Anguille to the Canso-Riversdale groups. This arkosic grit-sandstone sequence with a provenance area to the east appears to have been deposited during most of the Carboniferous.

21. Grand Banks south of Newfoundland

On the Grand Banks south of the Avalon Peninsula, Newfoundland, exploratory holes have encountered Windsor Group evaporites beneath Mesozoic and Cenozoic sediments. Figure 90 is a geological map of this area with the post Paleozoic rocks removed. Although the Mesozoic and Tertiary rocks have been removed the trace of maximum onlap has been retained.

Upper Paleozoic rocks have been encountered in six holes. The distribution of the subcrop units suggests that a 150 m wide east-west trending structural basin is present south of the Avalon Peninsula, which contains rocks equivalent in age to the Horton, Windsor and Canso-Riversdale groups (Avery and Bell, 1985). The overlapping Pictou Group as observed in the Hermine E-94 hole, is considered to rest unconformably on the Riversdale Group. This sequence may represent the eastern edge of a blanket of Late Carboniferous rocks extending from Cape Breton across the Sydney Basin (Avery and Bell, 1985).

In the Hermine E-94 hole, 2455 m below the surface, 813 m Windsor Group section was encountered containing 616 m of salt and 67 m of gypsum and anhydrite. Farther to the east, in the Gannet O-54 and Sandpiper 2J-77 holes, although salt was absent, 230 m and 248 m of anhydrite was present. Windsor Group rocks were not present in the Razorbille F-54, Phalarope P-62, Jaeger A-49 holes or in core hole 10. The salt in the Hermine E-94 hole is considered to represent an erosional remnant of a much larger Windsor Group salt deposit.

22. St. Anthony Basin, Newfoundland

In the St. Anthony Basin and on the continental shelf off southeastern Labrador, seismic reflection, magnetic, gravity, bathymetric data, a number of shallow core holes and three exploratory wells have been used to prepare a preliminary geological interpretation of the area. A geological map with the post-Paleozoic rocks removed (Fig. 91) has been prepared by Bell et al. (in prep.) with the trace of the Mesozoic edge retained. The area designated as the St. Anthony Basin on the basement structure map of Eastern Canada (Wade et al., 1977) appears to be tectonically separated by a basement ridge into the Notre Dame Subbasin on the west, and the Belle Isle Subbasin in the east.

The Mississippian and Pennsylvanian fill rest unconformably on a pre- Carboniferous basement complex. A single channel seismic reflection profile indicates that the Carboniferous rocks in the Notre Dame Subbasin are folded, faulted and may be locally intruded by salt (Haworth, Grant et al., 1976; Haworth, Poole et al., 1976). Some of these rocks are Codroy (Windsor Group) equivalents as confirmed by palynology and petrography (Barss and Jansa, personal communication in Haworth, Grant et al., 1976). Northeast-trending faults which extend out from the land and offset the Mississippian rocks, form horst and graben structures that appear to die out before being overlapped by Pennsylvanian rocks to the east. Near the central or deepest part of this subbasin, five Mississippian breached diapirs or withdrawal structures are shown to have penetrated the Pennsylvanian rocks in a general north-south trend. These structures have not been drilled but are considered to contain salt.

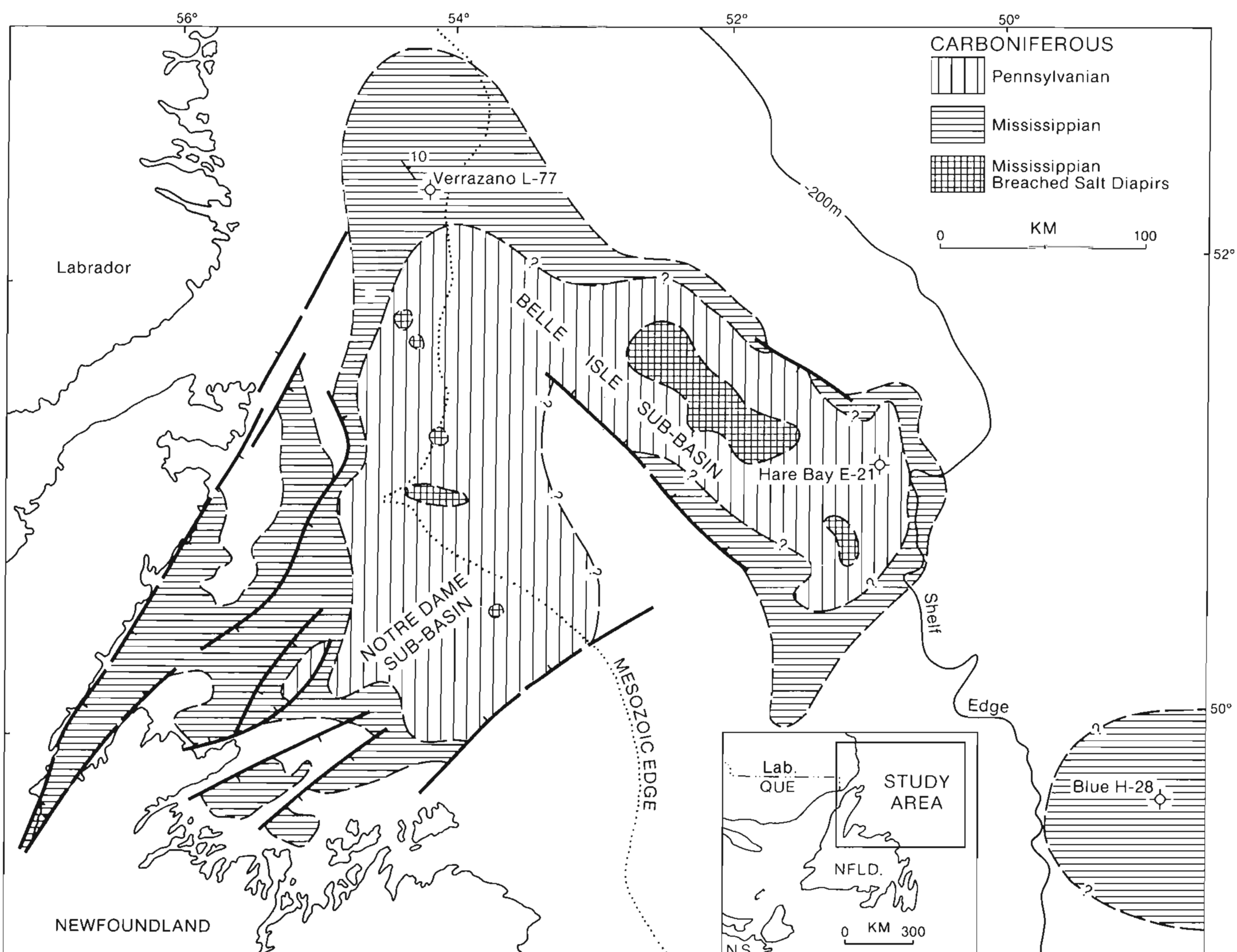
Northeast of the Notre Dame subbasin Carboniferous rocks occur on the South Labrador Shelf in the Belle Isle Subbasin (Cutt and Laving, 1977). This sequence fills a northwest-trending structural basin which may merge with the northern extension of the Notre Dame Subbasin. As there are indications of discordancies between reflectors on the seismic profiles reproduced by Cutt and Laving (1977), it is not clear how the two subbasins are joined (Bell et al., in prep.). They may in fact be separate structural basins divided by a northwest-trending basement high that parallels the present edge of the continental shelf.

From north to south two holes have been drilled in this subbasin. The Verrazano L-77 hole penetrated 264 m of Mississippian sandstone and shale before it was completed at 460 m still in the Mississippian. The Hare Bay E-21 hole intersected 1474 m of Pennsylvanian red beds before it was completed at 4874 m still in the Pennsylvanian. The central or deeper part of this subbasin contains two areas of Mississippian breached diapirs. Although these features are considered to have been caused by salt, the structures have not been drilled.

23. East Newfoundland Basin

Southeast of the Belle Isle subbasin and east of the Continental Shelf (Fig. 91), the Blue H-28 hole is considered to have been completed in Carboniferous rocks at 6103 m. From 5281 m to the bottom of the hole 822 m of Mississippian, limestone, sandstone and shale was penetrated. Spore assemblages indicate a Carboniferous age of probable Viséan to Namurian (Barss, 1983).

Geological data extrapolated on the basis of seismic character, indicate structures that appear to relate to salt that could be older than Jurassic (Grant and McAlpine, in press).



Adapted from Bell et al., in prep.

Figure 91. Geological map, St. Anthony Basin, Newfoundland, with Mesozoic rocks removed.

As Carboniferous salt is considered to be present in the St. Anthony Basin on the shelf northeast of Newfoundland, it could also be present in this area. However, if this area is considered analogous with the Zechstein of northwest Europe (Ziegler, 1981) Permian evaporites could be present.

WINDSOR GROUP, PALEOGEOGRAPHY AND DEPOSITIONAL ENVIRONMENT

Near the close of Horton Group sedimentation many of the positive features that existed south and east of the Gulf of St. Lawrence, persisted into the Viséan (Fig. 16). Crustal downwarping, a semiarid to arid climate, abrupt marine flooding and basement highs combined to produce a restricted marine environment with deposition of evaporites over a wide area (Geldsetzer, 1978; Kirkham, 1978). Thick accumulations of salt that were once thought to be restricted to Subzones A and B of the Windsor Group, have been observed in Subzones A to E and to a limited extent in the overlying Canso Group of Namurian age (Fig. 18). The salt may vary in thickness from a few centimetres to over 6000 m in diapiric struc tures in the Gulf of St. Lawrence (Fig. 81).

The Carboniferous section east of the Îles de la Madeleine is estimated to be about 12000 m thick (Fig. 92). This depocentre also appears to coincide with massive accumulations of salt in the form of walls, ridges, anticlines, pillows and diapiric structures. The Cumberland subbasin of northern Nova Scotia, a southwestern extension of the Magdalen Basin, is estimated to contain 6000 to 7000 m of Carboniferous strata. In this area the Windsor Group, with a relatively low arenaceous content in comparison to the type section also contains very thick deposits of structured salt (Fig. 45, 46). As both these areas of deep subsidence appear to have been somewhat removed from large provenance areas during the Viséan and early Namurian, conditions were favourable for the accumulation of a very thick and probably uninterrupted sequence of evaporites.

Evaporation of seawater in a restricted basin may cause the precipitation of successive beds of limestone, anhydrite, salt and potash salts (Howie, 1985). Under normal conditions this cycle would be repeated with each influx of seawater. However in an area where there is a basal 300-m zone of virtually pure anhydrite and gypsum overlain by an equally thick deposit of fairly pure salt (Fig. 53), this method of precipitation does not seem to apply.

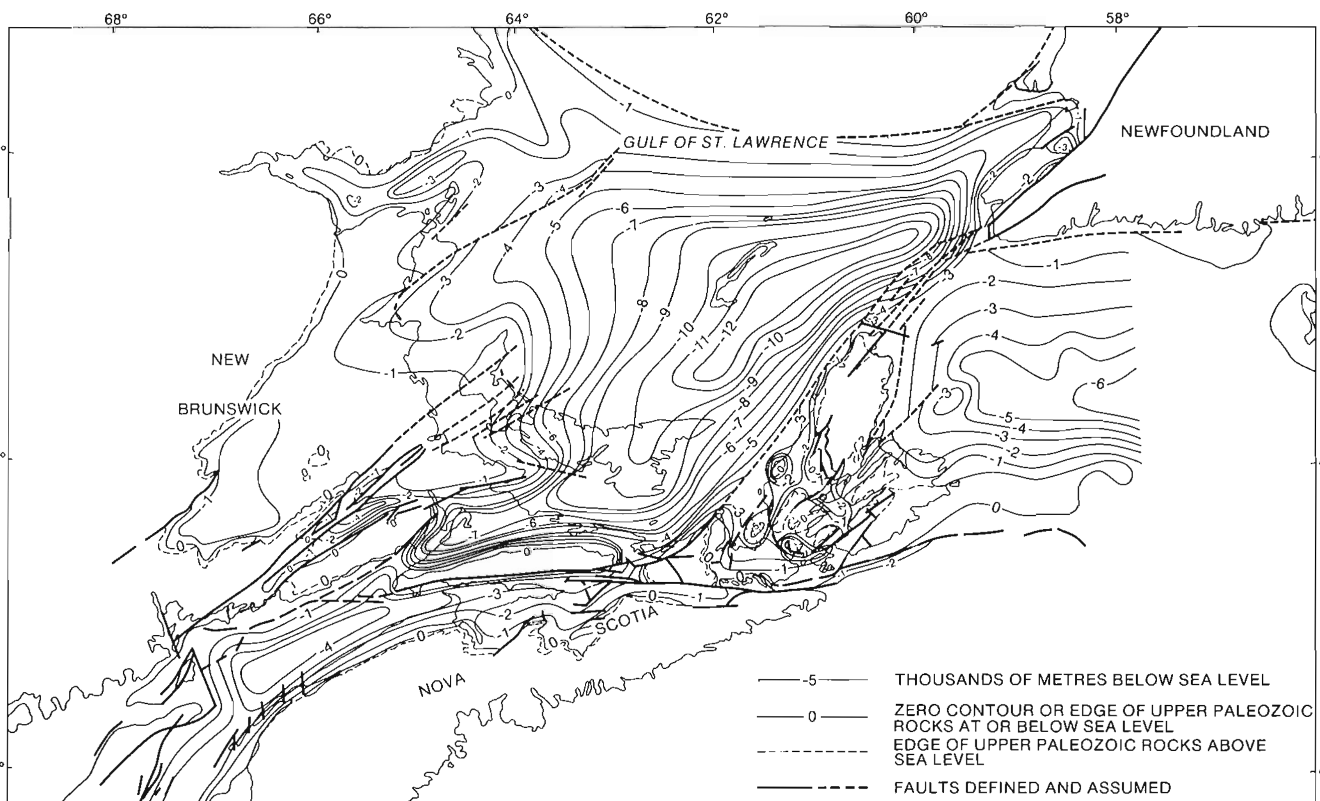


Figure 92. Contours of basement rocks, Atlantic Provinces and Gulf of St. Lawrence.

In an attempt to explain this apparent contradiction, a paleogeographic and facies map (Fig. 93), was constructed to show the possible distribution of depositional environments that prevailed during Windsor Group time. The distribution of the various rock types indicates that precipitation by evaporitic fractionation of brines may be applicable (Grayston et al., 1964; Phleger, 1969). The arrows on the map indicate the possible directions of marine transgression. As there was some tectonic instability during the deposition of the Windsor Group, not all access channels shown on the paleogeographic map may have existed at any one time. Very slight changes in sea level would also greatly alter the facies boundaries over a wide area. In this type of model (Fig. 94, Section A-A'), seawater of normal salinity passes over a shallow sill where calcium carbonate is deposited either through biogenic activity or concentrated by evaporation. Continued evaporation behind the first barrier results in the chemical precipitation of calcium sulphate. Further evaporation in the main basin results in the precipitation of fairly pure salt, and if the evaporation proceeds to completion, potash salts are deposited. Along the north side of the main basin red, wind-blown clastics are shown to interfinger with the salt (Shell Canada Limited, 1974). It is postulated that thick deposits of anhydrite, carbonate, and salt at 23 locations across the Atlantic provinces, the Gulf of St. Lawrence and offshore southeastern Canada (Fig. 17, 19), owe at least part of their existance to this mode of deposition.

MIGRATION OF WINDSOR GROUP SALT

In southeastern Canada most of the Windsor Group evaporites have been disrupted to some extent by salt flowage. (The only exception documented to date is in the Shubenacadie-Stewiacke area of Nova Scotia — area 8 of this report) Although each of the areas studied may have had a slightly different tectonic and depositional environment, salt migration was probably due to one or more of the following: thickness and type of sediment cover, thickness of salt body and tectonism.

Trusheim (1960) indicated that depth of burial and thickness of salt were the main factors in determining the migration and shape of salt bodies preserved as dome, diapirs or anticlines in the Zechstein Basin of northern Germany. He considered 305 m of salt with 915 m of cover rock was sufficient to induce flowage. Nettleton (1934) suggested about 610 m of salt, exclusive of tectonism was necessary for salt

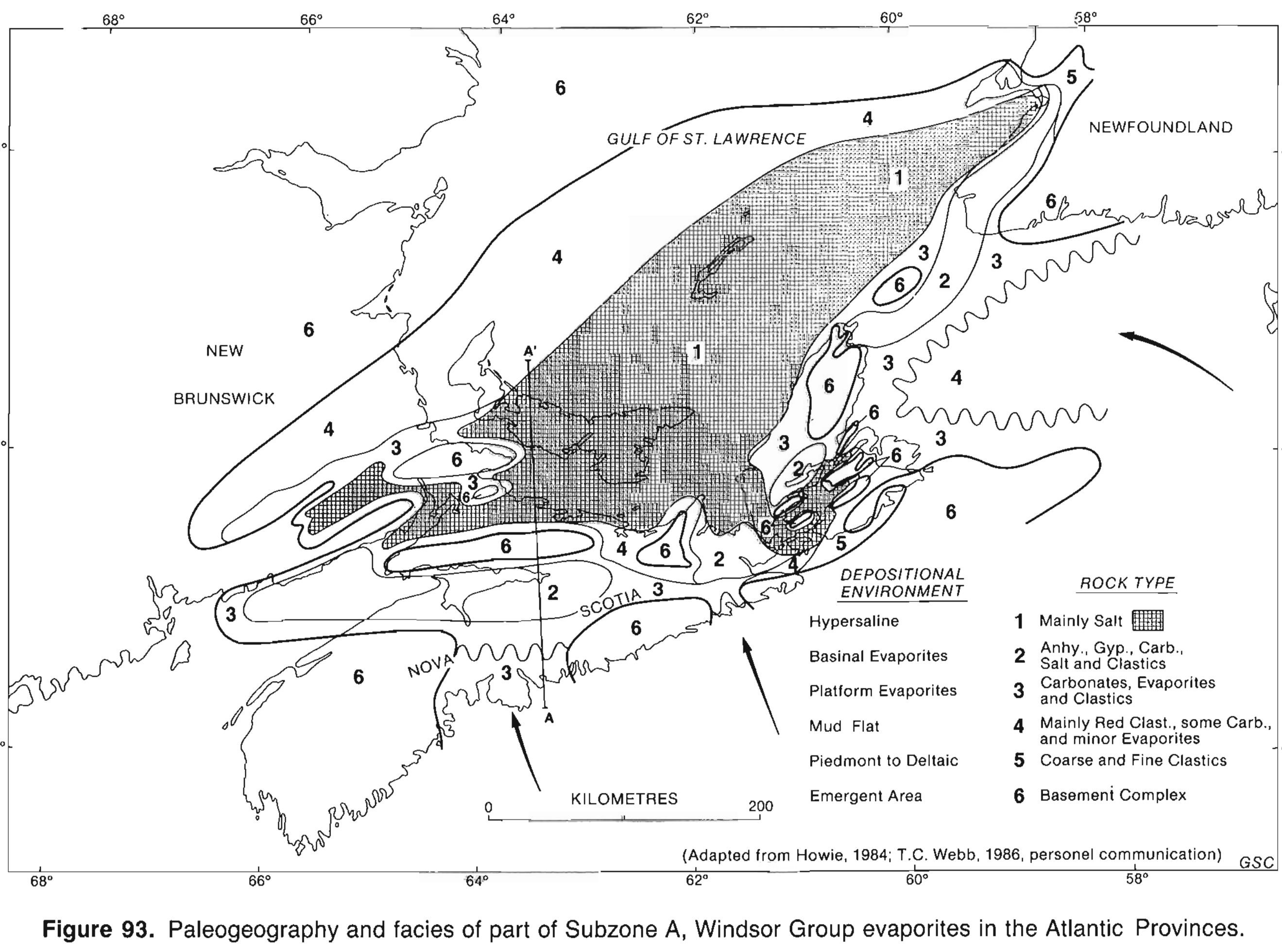


Figure 93. Paleogeography and facies of part of Subzone A, Windsor Group evaporites in the Atlantic Provinces.

migration. Based on experimental data, Parker and McDowell (1955) concluded a salt thickness of 1524 m was a more realistic figure. In each of the above calculations no provision seems to have been made for the competency of the cover rock.

In an area where the cover rock is dominated by thick, dense carbonates, the local pressure from an underlying salt mass is spread over a wide area. The salt would only be able to rise if and when it could overcome the competency of the carbonate. The Prairie Evaporite salt (Middle Devonian) of Alberta and Saskatchewan is overlain by less than 900 to over 2400 m of cover rock. In this area about 300 m of limestone and dolomite cover rock directly overlies the salt (Meijer-Drees, 1986). In southwestern Ontario the Salina salt (Silurian) is overlain by 300 to 400 m of dolomite which accounts for at least 30 % of the section above the salt (Poole et al., 1970). In both areas the bedded salt appears to be virtually undisturbed regardless of the thickness of the cover rock.

In eastern Texas, northern Louisiana, northern Mississippi, Alabama and other on land areas of the Gulf of Mexico basin, more than 300 salt diapirs are known with the probability of as many more offshore (Murray, 1966). These diapiric structures are not concentrated on the carbonate platforms, but in areas of thick clastics. It has been estimated that the southern Gulf Coast has subsided to receive around 15000 to 18000 m of sediments (Martinez et al., 1975). A block model of the Anse Le Butte salt dome in Louisiana is flanked and overlain by mainly shale and sandstone (Murray, 1966). A cross-section through a Zechstein salt stack at Gorleben, northern Germany, is also flanked and overlain by mainly sandstone and shale (Trusheim, 1960). In both areas the cover rock is predominantly shale and sandstone which is not as competent as dense carbonates.

Salt with a density of about 2.2 is generally less than the surrounding sediments below 900 to 1200 m (Murray, 1966). In order to reach a state of equilibrium with the surrounding rocks, the salt tries to work its way up through the section. If the salt mass is fairly large and not affected by tectonism the deciding factor for migration should be the competency of the cover rock.

In Atlantic Canada, although there are a number of carbonates overlying the Windsor Group evaporites, they are only a minor component in comparison to shale, sandstone and conglomerate. Although the composition of the cover rock would probably tend to encourage rather than discourage salt migration, it is not considered to be the primary reason for salt migration in the Carboniferous of southeastern Canada. The post-Windsor Group Maritime Disturbance (Poole, 1967) appears to have regionally disrupted the earlier deposited Carboniferous rocks thus initiating the salt flow. Once the plasticity of the salt has overcome the resistance to flow, the density contrast between the salt and the surrounding rock appears to be sufficient to maintain growth of the salt structure. In areas where salt has a thick sediment cover, the vertical element of crustal deformation overshadows all other directions of strain because of the density contrast between the salt and the overlying sediments (Murray, 1966). As a result salt will rise until gravitational equilibrium of the salt and surrounding rock is reached. This has been observed in the Gulf of St. Lawrence (Fig. 81) where some of the salt diapirs are over 7000 m thick.

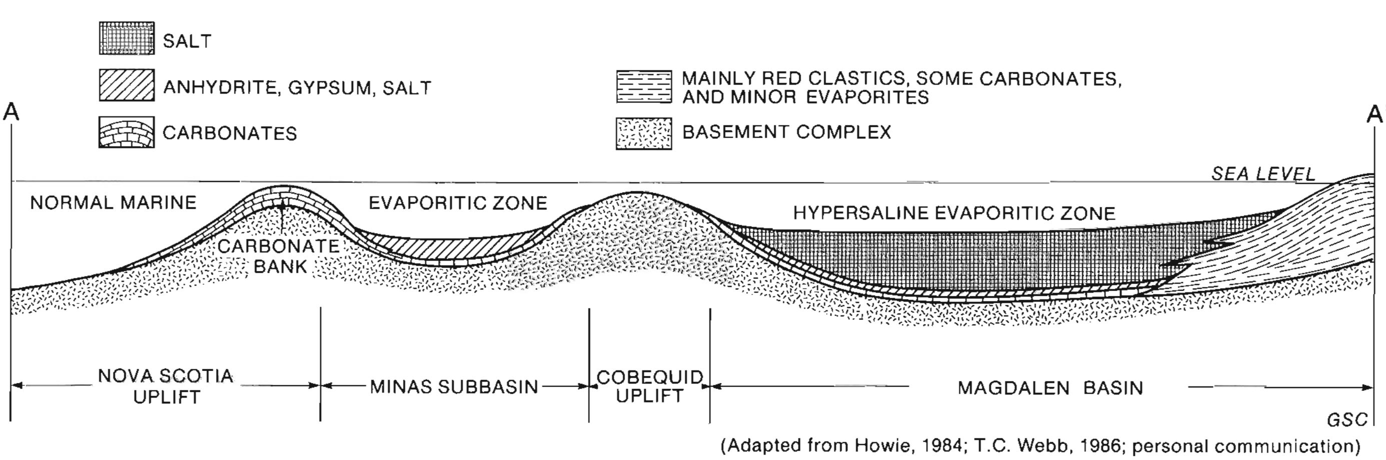


Figure 94. Depositional model for some Windsor Group subzone A evaporite sequences in the Atlantic Provinces.

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