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THERMAL MATURATION OF PALEOZOIC STRATA IN EASTERN CANADA FROM CONODONT COLOUR ALTERATION INDEX (CAI) DATA WITH IMPLICATIONS FOR BURIAL HISTORY, TECTONIC EVOLUTION, HOTSPOT TRACKS AND MINERAL AND HYDROCARBON EXPLORATION

G.S. Nowlan
C.R. Barnes

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Preface

Conodonts are phosphatic microfossils that change colour as a result of heating and, therefore, are useful as indicators of thermal maturation. As the changes are progressive and irreversible, the colours can be calibrated as a series of conodont colour alteration indices (CAI), which may record temperatures as high as 600°C. This bulletin presents the compilation and interpretation of all available CAI data for the Canadian Appalachians, including the orogenic belt and the adjacent Quebec and Anticosti basins. Data are plotted on base maps, and summary isopleth maps have been constructed for regions where data are abundant.

The patterns of thermal maturity thus demonstrated are interpreted in several ways. Some high thermal anomalies are related to the passage of Mesozoic hotspot tracks, others are attributed to late orogenic intrusive events. Some low thermal anomalies have required structural interpretations, leading to advances in the understanding of tectonostratigraphy. Areas suitable for future exploration for oil and gas in the Canadian Appalachians are delimited. Conodont CAI data are also used to assess the temperature and timing of emplacement of ore-bearing fluids resulting in Mississippi Valley-type base metal deposits.

This work provides an important insight into the structural development of the Appalachian Orogen, and also serves as a guide to thermal maturity of strata, a property that is important in hydrocarbon and mineral exploration.

R.A. Price
Director General
Geological Survey of Canada

Préface

Les conodontes étant des microfossiles phosphatiques qui changent de couleur avec l'échauffement sont, de ce fait, des indicateurs utiles de la maturité thermique. Étant donné que les changements sont progressifs et irréversibles, les couleurs peuvent être calibrées en séries d'indices indicateurs de couleurs des conodontes <<colour alteration indices>> (CAI); ces couleurs indiquent les températures jusqu'à 600°C. Ce travail de recherche présente la compilation et l'interprétation de toutes les données disponibles relatives au (CAI) pour les Appalaches canadiennes, y compris, la zone orogénique et les bassins adjacents de Québec et d'Anticosti. Les données sont pointées sur les cartes de base et les cartes isoplèthes sommaires ont été dressées pour les régions où les données sont abondantes.

Les configurations de la maturité thermique sont interprétées de différentes façons. Certaines grandes anomalies thermiques sont reliées au passage de bandes à points chauds du Mésozoïque, d'autres seraient attribuées à des phénomènes intrusifs orogéniques tardifs. Certaines anomalies thermiques faibles ont commandé une interprétation structurale, c'est un guide pour pousser plus avant la connaissance de la tectonostratigraphie. Les régions susceptibles d'exploration éventuelle pour le pétrole et le gaz dans les Appalaches canadiennes ont été délimitées. Les données sur les conodontes relatives au (CAI) sont aussi utilisées dans le but d'évaluer la température et le temps de mise en place des fluides contenant des minerais dans les sédiments de métaux de base de type mississipien.

Ce travail permet une importante intromission dans le développement structural de l'orogène des Appalaches et sert aussi comme guide en ce qui a trait à la maturité thermique des strates, propriété importante pour l'exploration des hydrocarbures et des minéraux.

Le directeur général de la
Commision géologique du Canada.
R.A. Price

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Abstract

A complex pattern of sedimentary basins is preserved in the Appalachian orogen, foreland basins and St. Lawrence Platform. Thermal histories of these basins are interpreted, based on colour alteration indices (CAI) for conodonts from over 160 localities. These data are plotted on five base maps for divisions of the Ordovician and Silurian. In the Quebec basin, CAI values range from 4, south of Montreal, to 1½ near Quebec City, inferring temperatures of 190° to 50°C, respectively. The data define the thermal anomaly near Montreal that has previously been interpreted as resulting from the trace of a Cretaceous hotspot. In the western Anticosti Basin, CAI values are consistently 1, but in the east, in western Newfoundland, values from autochthonous carbonates range from 1 (south) to 3½ (north). Within the allochthons, CAI values range from 1 in the frontal thrusts to 5 close to the central obducted ophiolites, where temperatures probably exceeded 300°C. Regional variation of CAI data indicates that the two main Taconic allochthons in Newfoundland were discrete and that a Mesozoic hotspot trace may also have affected the northern platformal strata. CAI values in the Appalachian orogen show a wide variation. Those in the Dunnage and eastern Humber zones are typically 4 to 6 (about 190°-400°C), locally up to 8 close to Devonian granites. In Quebec, values diminish to 2 in frontal thrust sheets and to 1 in the eastern Gaspé. Thermal anomalies in the Chaleur Bay region are related to buried, probably granitic, intrusions. Areas appropriate for further hydrocarbon exploration are identified: particularly the eastern Gaspé, northern Quebec Basin, Anticosti Basin, and the overthrust zone on the western margin of the Appalachian orogen. It is proposed that conodont CAI data be used to determine the temperature of ore-bearing fluids in Mississippi Valley-type base metal deposits and to identify buried intrusions that may host other types of ore deposits.

Résumé

Un patron complexe de bassins sédimentaires est préservé dans l'orogène des Appalaches, dans des bassins frontaux, et dans la plateforme du Saint-Laurent. Les histoires thermiques de ces bassins s'interprètent, selon leurs indices coloratoires d'altération des conodontes provenant de quelques 160 localités. Ces données sont représentées sur 5 cartes de base, ce qui démontrent des divisions de l'Ordovicien et du Silurien. Dans le bassin de Québec, les valeurs ICA varient entre 4, au sud de Montréal, et 1½, près de la ville de Québec, représentant une variation de température variant entre 190°C et 50°C, respectivement. Les données délimitent l'anomalie thermique aux environs de Montréal que l'on considerait auparavant comme le résultat de la trace d'une zone de surchauffe crétacée. Dans le bassin d'Anticosti occidental, les valeurs ICA demeurent 1; cependant, vers l'est, en Terre-Neuve occidentale, les valeurs apparentant aux carbonates autochtones varient entre 1 (au sud) et 3½ (au nord). Parmi des dépôts allochtones, les valeurs ICA varient entre 1 aux failles frontales et 5 près des ophiolites centrales charriées, où des températures dépassent probablement 300°C. La variation régionale des valeurs ICA indique que les deux dépôts allochtones principaux et taconiques en Terre-Neuve étaient discrets et que la trace d'une zone mésozoïque de surchauffe possiblement influençait les strates à la plateforme nord. Les valeurs ICA relevées de l'orogène des Appalaches démontrent une grande variation; celles des zones de Dunnage et de Humber de l'est varient typiquement entre 4 et 6 (entre 190°C et 400°C), auprès des granites dévoniens. Dans la province de Québec, les valeurs diminuent jusqu'à 2 dans les nappes de charriage frontales et s'abaissent à 1 en Gaspésie de l'est. Des anomalies thermiques présentes dans la région de la baie de Chaleur ont rapport aux intrusions recouvertes d'origine probablement granitique. Des régions d'intérêt à l'exploitation des hydrocarbures y sont identifiées, surtout celles en Gaspésie de l'est, au bassin de Québec septentrional, au bassin d'Anticosti, et dans la zone de chevauchement sur la marge occidentale de l'orogène des Appalaches. Donc, on propose que les données ICA prises des conodontes prélevées servent à déterminer la température des fluides mineralisées caractéristiques des dépôts de métal pauvre du type de la vallée de Mississippi; d'ailleurs, ces données servent à identifier des intrusions recouvertes qui possiblement contiennent d'autres sortes de gisements métallifères.

Summary

New information from conodont Colour Alteration Index (CAI) studies is used to define areas of hydrocarbon potential in Appalachian foreland basins and to evaluate regional tectonic interpretations in the Canadian Appalachians. The authors have pooled their extensive conodont collections from Ordovician and Silurian strata of Eastern Canada and have examined other available collections. The colour alteration of many tens of thousands of conodonts was evaluated to provide CAI values for over 160 localities. A CAI value is recorded for each locality and the data plotted on five regional maps for divisions of the Ordovician and Silurian systems. A few data are reported for Cambrian and Devonian samples. Regional isopleths are drawn where data allow.

The St. Lawrence Platform, north and west of Logan's Line, was sampled in both the Quebec and Anticosti basins. In the Quebec Basin, Ordovician CAI values range from 4, south of Montreal, to 1½ near Quebec City. These data infer burial temperatures of 190°-300°C and 50°-90°C, respectively. They confirm earlier assessments, based on reflectance of organic matter, of a northward transition in thermal maturity across this basin from supramature to mature. The data corroborate, and more precisely define, the presence of a thermal anomaly in the Montreal area that Legall et al. (1982) interpreted as having been induced by a Cretaceous hotspot. The east-southeast tracking of this hotspot may also explain the Monteregian intrusions. In the Anticosti Basin, samples in the western part, from Anticosti Island and the Mingan Islands, yield CAI values of 1. Samples from outliers on the Canadian Shield have CAI values of 1-1½. In the eastern part of the basin, however, CAI values of autochthonous Ordovician and Silurian platform carbonates in western Newfoundland range from 1 in the south to 3½ in the north. Colour Alteration Index values also vary significantly within the Humber Arm and Hare Bay allochthons. These range from 1 in the ancient slope sediments preserved in the frontal thrust sheets, to 5 near the associated obducted ophiolites in the structurally higher and central parts of the allochthons. These regional variations in western Newfoundland suggest that the Humber Arm and Hare Bay allochthons were discrete emplacements of similar regional extent to their present areas. Evidence exists for another Mesozoic hotspot track across northern Newfoundland which, if confirmed, may be of significance for anticipating local thermal anomalies in the lower parts of the important Grand Banks Mesozoic sequence.

Collections from within the Appalachian Orogen show wide variation in CAI values, reflecting the complex thermal and burial history. In the Dunnage Zone, and the deformed eastern edge of the Humber Zone in Newfoundland, CAI values are typically 4 to 6 (indicative of temperatures of 190°-400°C), whereas in the Gaspé Peninsula, strata of the Dunnage Zone are only slightly thermally altered (CAI 1½). Upper Ordovician and Lower Silurian strata in eastern Gaspé Peninsula are thermally unaltered (CAI 1) but become progressively altered westward to CAI 3½ in central Gaspé and to CAI 5 in northwestern New Brunswick. In the Chaleur Bay area, CAI values increase from north to south, possibly as a result of closer proximity to Devonian plutons in northern New Brunswick. Elsewhere in New Brunswick and also in Nova Scotia, CAI values from Silurian strata are mainly in the 4-6 range, although local anomalies are recognized. A Silurian collection in northern Newfoundland has a CAI of 8, the highest possible, and this is interpreted as being the result of proximity to a Devonian granite.

The burial temperatures inferred from the CAI data have important implications for both hydrocarbon and base metal exploration. This paper considers a number of specific areas in Eastern Canada where CAI data are sufficient to enable the definition of areas most suitable for future hydrocarbon exploration, such as the eastern Quebec Basin, the eastern Anticosti Basin and the eastern Gaspé Peninsula. The data presented are substantial and allow for the delineation of some regional isopleths. Future studies will aim to provide a more complete coverage, including more subsurface assessment, and to address specific problems of economic potential, burial history and interpretation of the structure and terrane.

Sommaire

Des recherches récentes sur les Indices coloratoires d'altération de conodontes (ICA) facilitent l'identification des régions d'intérêt à l'exploration pétrolière dans les bassins frontaux des Appalaches; en outre, elles sont utilés dans l'évaluation des interprétations tectoniques régionales des Appalaches canadiennes. Les auteurs ont mis en commun leurs catalogues considérables de conodontes prélevés des strates ordoviciennes et siluriennes du Canada de l'est, en plus d'étudier d'autres catalogues disponibles. Les altérations coloratoires de plusieurs dix milliers de conodontes ont été évaluées afin de fournir des valeurs ICA de plus de 160 localités. Une valeur ICA a été calculée pour chaque localité et des données resultantes ont été mises en évidence sur 5 cartes régionales qui représentent des divisions des systèmes ordoviciens et siluriens. En plus, quelques données y sont rapportées pour des échantillons cambriens et devoniens. Des isoplètes régionales ont été tracées au cas où on se disposait des données nécessaires.

La plateforme du Saint-Laurent, au nord et à l'ouest de la ligne de Logan, a été prélevée dans les deux bassins de Québec et d'Anticosti. Dans le cas du bassin de Québec, les valeurs ICA de l'Ordovicien varient entre 4, au sud de Montréal, et 1½, près de la ville de Québec. Ces données indiquent des températures d'enfouissement qui varient entre 190°C à 300°C et de 50°C à 90°C, respectivement. De telles données confirment des évaluations précédentes qui étaient basées sur la réflectance des matières organiques et qui identifiaient une transition vers le nord de maturité thermique variant de supramûre à mûre, au travers du bassin. Les données confirment et définissent plus précisément la présence d'une anomalie thermique dans la région de Montréal, ce qui a été interprétée par Legall et al. (1982) comme le résultat d'une zone de surchauffe crétacée. Le traçage au sud-est de cette zone de surchauffe possiblement éclaircit l'existence des intrusions de Monterego. Dans le bassin d'Anticosti, des échantillons prélevés de la région occidentale de l'île d'Anticosti et des îles Mingan donnent une valeur ICA de 1. Des échantillons provenant des avant buttes du Boucle canadien donnent des valeurs ICA de 1 et de 1½. Cependant, dans la région est du bassin, les valeurs ICA des carbonates autochtones de la plateforme, datées de l'Ordovicien et du Silurien et situées en Terre-Neuve occidentale, varient entre 1 au sud et 3½ au nord. Les valeurs ICA varient d'une manière significative à l'intérieur des allochtones de Humber Arm et de Hare Bay. Celles-ci varient entre 1, aux sédiments anciens de talus préservés dans les nappes de charriage frontales, et 5, dans des ophiolites associées et charriées des régions structuralement supérieures et centrales des allochtones. Ces variations régionales en Terre-Neuve occidentale indiquent que les allochtones de Humber Arm et de Hare Bay étaient des emplacements discontinus d'etendue régionale semblable à leur etendue actuelle. On a démontré l'existence d'un autre trace de zone de surchauffe mésozoïque au travers de la Terre-Neuve septentrionale laquelle, une fois confirmée, sera significative dans l'identification des anomalies thermiques locales des parties inférieures de la séquence mésozoïque importante des Grands Bancs.

Des échantillons provenant de l'intérieur de l'orogène des Appalaches démontrent une grande variabilité en ce qui concerne les valeurs ICA, et indiquent une histoire thermique complexe d'enfouissement. Dans la zone de Dunnage et dans le bord oriental déformé de la zone de Humber en Terre-Neuve, les valeurs ICA varient typiquement entre 4 et 6 (ce qui indique des températures variant de 190°C à 400°C), tandis que dans la péninsule de Gaspé, les strates de la zone de Dunnage sont très peu altérées thermiquement (ICA = 1½). Les strates de l'Ordovicien supérieur et du Silurien inférieur de la péninsule de Gaspé orientale demeurent inaltéré (ICA = 1); cependant, elles deviennent progressivement altérées vers l'ouest pour arriver à des valeurs ICA de 3½ en Gaspésie centrale et 5 au Nouveau-Brunswick du nord-ouest. Dans la région de la baie de Chaleur, les valeurs ICA augmentent en allant du nord au sud, le résultat possible de leur proximité aux roches plutoniennes et devoniennes du Nouveau-Brunswick septentrional. Ailleurs au Nouveau-Brunswick, et également en Nouvelle-Écosse, les valeurs ICA des strates siluriennes varient principalement entre 4 et 6, bien que des anomalies locales y soient reconnaissables. Une collection silurienne de la Terre-Neuve septentrionale tient une valeur ICA de 8, ce qui représente la valeur la plus haute, et ce, le résultat de sa proximité à un granite dévonien.

Les températures d'enfouissement inférées des données ICA ont des implications significatives tant pour l'exploration pétrolière que pour l'exploration des métaux pauvres. Dans l'étude présente, on examine plusieurs régions particulières du Canada de l'est où les données ICA permettent la définition des régions qui conviennent à l'exploration pétrolière future, comme, à titre d'exemple, les régions du bassin oriental de Québec, le bassin oriental d'Anticosti et la péninsule de Gaspé orientale. Les données présentées sont considérables et permettent la délineation de quelques isoplètes régionales. Des études futures auront pour but une étendue plus compréhensive, y compris une évaluation améliorée de la subsurface. De plus, on s'adressera aux problèmes portant sur le potentiel économique, sur l'histoire d'enfouissement et sur l'interprétation des structures du terrain.

CONODONT COLOUR ALTERATION STUDIES

Introduction

Conodonts are the microscopic hard parts of a group of organisms of uncertain biological affinity (Lindström, 1964; Briggs et al., 1983). Each conodont animal possessed several individual conodont elements of varying morphology. Conodonts have a worldwide distribution in marine rocks of Cambrian through Triassic age. Their abundance in an individual sample varies widely from zero to several thousand elements per kilogram. They are most abundant in strata formed at slow depositional rates or in layers that have been considerably reworked by currents to produce lag deposits. Individual conodont elements typically range in size from 0.1-2.0 mm. They are composed of calcium phosphate approximating the mineral francolite in composition (Pietzner et al., 1968), and are thus easily extracted from carbonate rocks by using organic acids. Because of their mineralogy and structure they are resistant to metamorphism and can be recovered from strata of low-(greenschist facies) to medium-grade (amphibolite facies) metamorphism.

Variation in the colour of conodont elements has been recognized for some time (Ellison, 1944; Lindström, 1964), but it was not until the pioneer work of Epstein et al. (1977) that these colour differences were placed in a systematic context. Epstein et al. (1977) produced experimental data to show that colour alteration in conodonts is time and temperature dependent. They also compiled field data from the Appalachian Basin to support their experimental work, enabling them to draw isopleths delineating areas of similar thermal alteration. The sequential colour changes exhibited by conodonts in response to increasing temperature provide a valuable tool for assessing the thermal maturation and burial history of the enclosing strata. The change in colour is related to the progressive alteration of trace amounts of organic matter within the conodont elements. Epstein et al. (1977) were able to produce a numerical conodont alteration index scheme (CAI 1-8) corresponding to changes in colour from pale yellow (1) through light to dark brown to black (5) and from black to grey, through white to clear (8). The scheme from CAI units 1-5 was correlated with two other indices of organic metamorphism: palynomorph translucency and vitrinite reflectance determinations (see Figure 1). Epstein et al. (1977) were uncertain of the precise calibration of CAI units 6-8 because of the scarcity of conodonts with the higher indices and the total destruction of other associated organic matter in strata subjected to such high temperatures. Recently (A.G. Harris, pers. comm., 1985), studies have been conducted that calibrate these higher indices. The values obtained are: CAI 6 (350°-500°C), CAI 7 (480°-610°C), and CAI 8 (>600°C).

In addition to providing a numerical scale related to colour alteration indices, Epstein et al. (1977) were also able to make other observations based on their experimental data. They concluded that the observed colour changes are produced by heating alone and that the changes are "progressive, cumulative and irreversible" (*ibid.*, p. 4). It was found that alteration is dependent on time and temperature, and virtually independent of pressure. They also demonstrated that heating in an open system of air, argon or methane produces the same results, but that heating in a "wet" sealed system with argon or methane retards colour alteration considerably. Finally, by means of an Ahrrenius plot of data from conodonts in open-air heating runs, they showed that colour alteration begins at about 50°C and continues to about 550°C-600°C, at which temperature disintegration begins.

Several regional investigations of conodont colour alteration have now been completed. Data on the Appalachian Basin were supplied by Epstein et al. (1977), Harris et al. (1978), and Harris (1979). Harris and Milici (1977) provided an assessment of the Valley and Ridge Province in the southern Appalachians and Perry et al. (1979) made a structural re-evaluation of the Allegheny Frontal Zone based on conodonts from the Bane Dome. The structure, burial history, and petroleum potential of the frontal thrust belt and adjacent foreland in southwest Montana were examined by Perry et al. (1983), incorporating CAI data. In Canada, Mayr et al. (1978) briefly discussed conodont colour alteration indices from material in deep wells on Bjorne Peninsula, southwestern Ellesmere Island, Arctic Archipelago, and Legall et al. (1982) made a comprehensive study of conodont and acritarch colour alteration indices from Paleozoic strata of Southern Ontario and Quebec. The present study is intended to provide new information on the Appalachian Orogen and adjacent St. Lawrence Lowlands (Quebec and Anticosti basins). Data from the Quebec Basin, Anticosti Basin and the eastern Gaspé Peninsula are summarized in Figures 2-4.

Methods and objectives

Thousands of conodont samples have been processed from the Appalachian region of Canada but no comprehensive assessment of their colour alteration indices has been undertaken previously. Data from collections at the Geological Survey of Canada and at Memorial University of Newfoundland have been plotted on maps for each of the chronostratigraphic divisions: Lower, Middle and Upper

CONODONTS			PALYNOMORPHS			VITRINITE	
CAI	Temperature range °C	Approximate overburden (m)	AAI	Translucency index AMOCO	Weight per cent carbon in kerogen	Reflectance	Per cent fixed carbon
1	<50 - 80	<1200	1	1 - 5	<82	<0.8	<60
1½	50 - 90	1200 - 2400	2-3	5 - upper 5	81 - 84	0.70 - 0.85	60-65
2	60 - 140	2400 - 3600	4-5	5 - 6	81 - 87	0.85 - 1.30	65-73
3	110 - 200	3600 - 5500	Black to disintegrated	upper 5 - 6	83 - 89	1.40 - 1.95	73-84
4	190 - 300	5500 - 8000		6	84 - 90	1.95 - 3.60	84-95
5	300 - 400	8000+		upper 6 - 7	90+	3.60+	95+
6-8*	6: 350-435°C	6½: 425-500°C		7: 480-610°C		8: 600°C+	

Figure 1. *Correlation of some indices of organic metamorphism. Acritarch alteration index (AAI) correlation is after Legall et al. (1982), other palynomorph and vitrinite correlations are after Epstein et al. (1977). Approximate overburden ranges for conodont colour alteration index (CAI) values are based on Middle Ordovician rocks in the Appalachian Basin of the United States (Harris et al., 1978) and Lower Paleozoic rocks of southern Ontario and southern Quebec (Legall et al., 1982). It is emphasized that these are approximate and have little application in areas outside the Quebec and Anticosti basins in this study. Asterisk indicates temperature ranges for CAI values 6 to 8, which are based on an unpublished B.A. thesis by V.A. Rejebian at Princeton University (Dr. Anita Harris, written comm., 1985).*

Ordovician and Lower and Upper Silurian. Few data are available from the Cambrian or Devonian and they are discussed under interpretation of the Appalachian Orogen data. Each sample was assessed for CAI by comparing conodont elements with a set of standards kindly provided by Dr. Anita Harris of the United States Geological Survey. For each sample, several different element types were compared with the standards. After numerous assessments had been made, a selection of assessed samples was sent to the United States Geological Survey for cross-checking by Dr. Anita Harris to ensure that our colour assessments calibrated well with the original work. This qualitative technique is simple and economical, but some difficulties can be encountered in certain samples.

Most collections of conodont elements show variation in shape and size and thus colour. In our experience, it is best to determine the CAI from the lightest parts of elements, and to avoid those elements that are extremely compressed or thin walled. As noted by Epstein et al. (1977) large, robust elements will appear darker and it is necessary to assess such elements near a thin edge. Comparison of several different types of element with standards allows the greatest precision in CAI assessment.

Some problems are more difficult to surmount. If a sample comprises only neurodont elements (Lindstrom, 1964), then a precise determination of CAI is precluded. Neurodont elements commonly show a wide range of colour in a sample and are less sensitive for CAI assessment. Where neurodont elements are present with typical lamellar conodonts, they do not necessarily reflect the CAI indicated by those lamellar conodonts. We strongly advise against the use of neurodont elements in CAI analysis.

It has also been suggested that the lithology of the host rock may affect the CAI. Mayr et al. (1978) showed that the CAI value of conodonts from cuttings in a well drilled on Bjorne Peninsula, Ellesmere Island, Arctic Archipelago generally increased with depth, but that a reversal of the trend occurred across a transition from black shale to carbonate sediments. Values are anomalously high (CAI 3) in the lowest terrigenous sediments of the Cape Phillips Formation and revert to CAI 2 in subjacent carbonates of the Allen Bay Formation. Although mixing during recovery of chips from different stratigraphic levels cannot be ruled out, the evidence suggests that the colour and lithology of the host rock may influence the colour index by as much as one unit of CAI. Legall et al. (1982) indicated that conodonts from carbonate and shale samples of similar age in southern Ontario show a variation of up to 0.5 CAI units, particularly in areas of low CAI. They also noted differences in the colour range of specimens from carbonate and shale, such that elements with the pale colours associated with CAI 1-1½ did not occur in shale samples but were consistently darker. The reasons for this type of colour variation require further study, but it may be related to oxidizing and reducing conditions, with oxidation producing lighter colours and reduction producing darker colours, possibly with the introduction of hydrocarbons or pyrite into the conodont structure. Epstein et al. (1977) restricted their study to material derived from carbonate rocks in order to avoid such potential complications. All the samples discussed in this study are from carbonates; most are from limestone, but some are from dolostone, calcareous siltstone and calcareous sandstone. Independent studies by the authors indicate that conodonts recovered from cherts by use of hydrofluoric acid cannot be assessed for CAI without new calibration studies.

Samples from over 160 localities have been assessed for CAI values. The numbers examined are as follows: Lower Ordovician (38), Middle Ordovician (62), Upper Ordovician (31), Lower Silurian (44), Upper Silurian (6). Each of the localities sampled has been assigned a number that is shown beside the dots in Figures 5-9. The localities are listed in numerical order in the Appendix. In cases where a single locality represents a thick section encompassing two or more stratigraphic divisions, it retains the same number on different maps. For each locality, as many specimens as possible were assessed. In thick sections, at least three abundant samples were examined for each chronostratigraphic division, resulting in the examination of hundreds, or even thousands, of specimens in some cases. Some localities, particularly from the Appalachian Orogen, are represented by few specimens and these are indicated symbolically on the maps (Figs. 5-9).

Sample number(s), age(s), stratigraphic unit, latitude and longitude, CAI value, and a brief geographic description for each of the localities are included in the Appendix. This form of locality designation was chosen because it is the most readily applicable to the large area under consideration. Latitude and longitude co-ordinates can be utilized easily in any future computer analyses of the data. A brief geographical description of the locality is provided in the Appendix to enable additional material to be collected by other workers if desired.

One of the principal purposes of this paper is to interpret the thermal events and geothermal history of the foreland basins and deformed orogen of the Canadian Appalachians. The CAI data, as plotted in Figures 2-9, delineate thermal anomalies in the stratigraphic record of the region. From a knowledge of the geology of the area, interpretations are offered to explain these anomalies. From the pattern of isopleths on the maps (Figs. 2-4), areas of thermally immature, mature and supramature strata can be delineated and locally extrapolated to the subsurface. Such information is of value in the future hydrocarbon exploration of the region and is compared to existing data on illite crystallinity and vitrinite reflectance for the St. Lawrence Lowlands and the Gaspé Peninsula.

The CAI data assembled are also applied to tectonic interpretations and to particular aspects of the mineral deposit potential of the Canadian Appalachians. The data are also applied in terms of the concept of hotspot tracks that apparently affected parts of the Canadian Appalachians during the Mesozoic.

REGIONAL GEOLOGICAL FRAMEWORK

The area covered in this report comprises two main structural elements: the St. Lawrence Lowlands, which can be subdivided into the Quebec Basin in the west and the Anticosti Basin in the east, and the Appalachian Orogen (Figs. 2, 3). The northern and western boundary of the orogen is taken at the main basal thrust in the deformed belt, known as Logan's Line. The orogen is much more complex than the St. Lawrence Platform and its internal tectonostratigraphic divisions have been reviewed by St-Julien and Hubert (1975), Williams (1979) and Williams and Hatcher (1982; 1983). The principal divisions from west to east in the Canadian Appalachians are the Humber, Dunnage, Gander, Avalon and Meguma zones (see Williams, 1978), each of which may be further subdivided, but such details are beyond the scope and purpose of this paper.

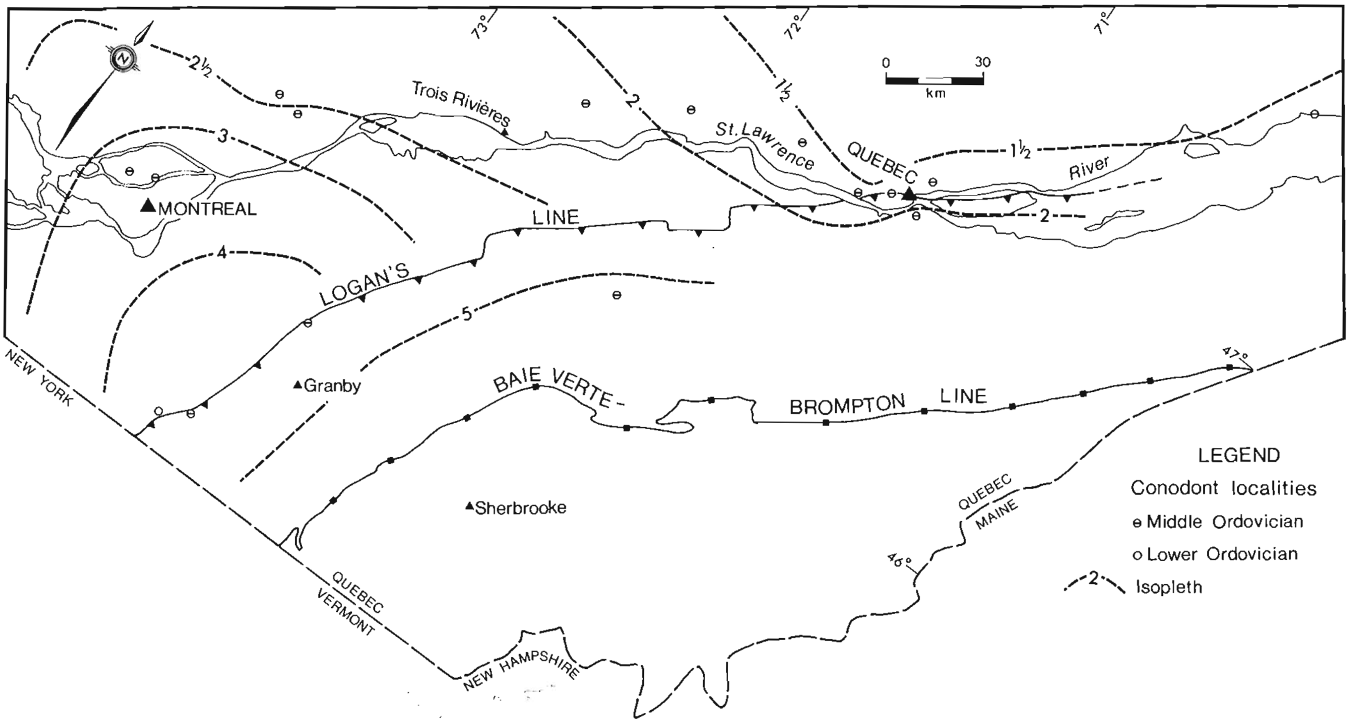


Figure 2. Summary map of conodont CAI values in the Quebec Basin. Note the high thermal anomaly in the Montreal area. Isopleths are drawn at the first occurrence of index values. Details of localities are provided in Figures 5 and 6 and in the Appendix.

St. Lawrence Platform: Quebec Basin

A review of the geology of the St. Lawrence Platform in Ontario and part of Southern Quebec was presented by Legall et al. (1982). The present study is concerned with data collected to the east and northeast of that area. The term Quebec Basin was originally introduced by Wilson (1946), although the term Montreal Basin is preferred by others (Clark, 1972). The stratigraphy is discussed in detail by Clark (1959, 1972), Sanford (1970), Hofmann (1972), Riva (1972), Clark and Globensky (1975, 1976 a-c, 1977), and Globensky (1978). The succession of sandstones, shales and carbonates is almost exclusively of Ordovician age.

The lowest strata belong to the Potsdam Group and are composed predominantly of feldspathic quartz sandstone that is conglomeratic at the base (Covey Hill Formation) and dolomitic at the top (Theresa Member, Chateauguay Formation). The total thickness is probably in excess of 800 m, although faulting and irregular topography of the basement preclude a precise measurement of the thickness. The basal sandstone may be Upper Cambrian, equivalent to trilobite-bearing strata in New York State. The dolostone, however, is of Early Ordovician age, based on conodont data (Sandi, 1978; Legall et al., 1982).

Disconformably overlying the Potsdam Group is a dolostone sequence of the Beekmantown Group (Lower Ordovician) that attains a thickness of approximately 300 m. A further disconformity separates the Beekmantown Group from the overlying Chazy Group (90 m). A minor stratigraphic break may lie between the latter and the overlying Black River (20 m) and Trenton (260 m) groups.

The Upper Ordovician strata are predominantly clastic, comprising a lower black shale unit (Lachine and Lotbinière formations, or "Utica"), a middle interval of grey siltstone and fine grained sandstone with rare limestone beds and biostromes (Nicolet River and Pontgravé River formations or "Lorraine"), and an upper unit of red shale and sandstone of predominantly nonmarine origin (Becancour River Formation, or "Queenston"). The three clastic units are variable in thickness but are approximately 100 m, 800 m and 600 m thick, respectively.

Within the Quebec Basin there is considerable variation in thickness in several of the main stratigraphic units noted above. There is typically a regional thinning to the northeast toward the so-called Quebec Re-entrant (from Montreal to Quebec) and a thickening south and east toward the Appalachian miogeocline. Much of the latter is covered by northwesterly directed thrust sheets of the Appalachian Orogen. Logan's Line approaches the northern edge of the preserved platform near Quebec City. The so-called Quebec Re-entrant (Williams, 1978) delineates the northeastern extent of the Quebec Basin and separates it from the Anticosti Basin to the east. The total thickness of strata now preserved in the Quebec Basin is approximately 2170 m. There is ample evidence, reviewed by Legall et al. (1982, p. 522), that the basin once accommodated at least 500 m of Silurian and Devonian strata. The minimum total thickness of strata in the basin was thus approximately 2670 m.

St. Lawrence Platform: Anticosti Basin

The Anticosti Basin lies mainly beneath the Gulf of St. Lawrence and good exposures of the succession are limited to the north shore of the Gulf, Anticosti Island, and western Newfoundland. These areas have been subjected to intensive stratigraphic and paleontological studies in recent years. General stratigraphic studies relevant to the present paper have been published by Roliff (1968), Bolton (1961, 1972) Petryk (1979, 1981 a, b), Barnes et al. (1981), Shaw (1980), Haworth (1978), Schuchert and Dunbar (1934), Sanford (1970), James et al. (1980), James and Stevens (1982), Klappa et al. (1980), Twenhofel (1921, 1926, 1928, 1938), Schuchert and Twenhofel (1910), Kindle and Whittington (1958), Knight (1977, 1983), Stouge (1981), and Whittington and Kindle (1969).

Some elements of the Anticosti Basin stratigraphy are similar to those of the Quebec Basin, but others are markedly different. Cambrian strata are known from outcrops on the Labrador south coast and in western Newfoundland, especially the Port au Port Peninsula. Thin sandstone at the base is overlain by a thick sequence of carbonate, predominantly dolostone, of the Labrador and Port au Port groups, respectively. The total thickness is in excess of 500 m.

Lower Ordovician ("Beekmantown") dolostones are referred to the Romaine Formation on the Mingan Islands and subsurface, and to the St. George Group in western Newfoundland. Their thickness in these two areas is approximately 65 m and 1400 m, respectively. They are disconformably overlain by lower Middle Ordovician limestones (Mingan Formation [Chazyan] on the Quebec north shore; Table Head Group [Whiterockian] in western Newfoundland). These also thicken to the southeast, being 50 m and 400 m, respectively, in the two areas. The subsurface and outcrop stratigraphy of Anticosti Island comprises a 300 m thick Middle Ordovician limestone unit overlain by Upper Ordovician black shale (Macasty Formation, "Utica"; up to 100 m) followed by the Vauréal Formation (limestone and shale, 1000 m), the Ellis Bay Formation (limestone and shale, 90 m) and a 400 m Lower Silurian limestone sequence (Becscie, Gun River, Jupiter and Chicotte formations). This sequence is in contrast to that of western Newfoundland. The Table Head Group is overlain successively by 800 m of flysch and the strata of the Humber Arm Allochthon (up to 2300 m) as a result of deformation and ophiolite obduction in the orogen. This allochthon is composed of several slices totalling over 10 km in composite thickness, but with a structural thickness of about 1-2 km (Williams, 1975). The Hare Bay Allochthon (Fig. 3) comprises several slices and is structurally thinner, being approximately half the thickness of the Bay of Islands Allochthon. A 900 m sandstone and limestone unit (Long Point Formation; Middle Ordovician) rests unconformably on the Humber Arm Allochthon and in turn is overlain by a thin, condensed, largely continental clastic sequence, the Winterhouse Formation of Middle to Late Ordovician, and possibly Silurian age. The overlying 500 m of fossiliferous limestone and clastic rocks of the Clam Bank Group are of Late Silurian (Pridoli) age. The Carboniferous Anguille, Codroy and Barachois groups in western Newfoundland are predominantly a clastic sequence with minor coal, gypsum, shale and limestone. They are found in fault bounded basins, in which up to 4000 m of strata are preserved.

It is unlikely that there were significant accumulations of post-Permian strata over the Anticosti Basin area. The Triassic was a period of rifting and uplift and the offshore Mesozoic-Tertiary strata thin markedly to the west. On this assumption, the total minimum thickness preserved in the Anticosti Basin may have been close to the total now preserved. Clearly, there were major regional variations in thickness. The strata penetrated by the well near Southwest Point, south coast of Anticosti Island, totalled 4180 m (uppermost Lower Silurian to Precambrian basement). The total thickness in western Newfoundland, including the allochthon, is approximately 10 800 m. In the latter area it is conceivable that the Permo-Carboniferous strata were once more extensive and thicker than those now preserved, but most of the accumulation probably occurred to the south of Anticosti Island, where up to 9000 m of upper Paleozoic sediments were deposited in the Magdalen Basin. Most of the Anticosti Basin may therefore have received about 6000-10 000 m of sediments, thinning to the west and north and thickening to the east and south, particularly near emplaced allochthons and at depocentres of late Paleozoic sedimentation.

Appalachian Orogen

The Appalachian Orogen lies to the south and east of the Canadian Shield and the (marginal) St. Lawrence Lowlands Platform. The northwestern margin is marked by the northwest limit of Appalachian thrusting and deformation. The Appalachian Orogen approaches the North American craton closely in the Quebec and Newfoundland re-entrants, but is considerably narrower at the intervening St. Lawrence Promontory (see Williams, 1978). Logan's Line (Figs. 2, 4) is well defined near Quebec City and runs northeastward just offshore from, and through part of, the Gaspé Peninsula, turning sharply eastward south of Anticosti Island; its position between Anticosti and Newfoundland is uncertain (Figs. 2-4; Haworth, 1978). In western Newfoundland, allochthonous Lower Paleozoic rocks overlie a Cambro-Ordovician carbonate platform indicating that Logan's Line extends offshore locally along the western coast of Newfoundland. The eastern margin of the Appalachian Orogen is covered by Mesozoic and Cenozoic sediments that form the Atlantic Continental Shelf.

In recent years, several attempts have been made to define tectonostratigraphic subdivisions in the Appalachians. Initially, Williams (1964) suggested a tripartite subdivision including the Western Platform, Central Volcanic Belt and Avalon Platform. Williams et al. (1972) provided nine, lettered zonal subdivisions of the Appalachians. These were later acknowledged by Williams (1979) to be too sophisticated and thus inadequate for the Appalachians as a whole because they were based too strongly on a Newfoundland cross-section. Williams (1978; 1979) therefore reduced the number of zones to five in order to allow regional correlation along the length of the Appalachian Orogen. These zones are labelled from northwest to southeast: Humber, Dunnage, Gander, Avalon and Meguma. These are the most convenient units on which to base this brief discussion of the Appalachian Orogen. Recently, there has been a trend to consider complex orogenic belts in terms of suspect terranes (e.g., Coney et al., 1980). Williams and Hatcher (1982) have provided such an assessment for the Appalachians. The largest terranes described by those authors almost coincide with the earlier tectonic lithofacies belts of Williams (1978; 1979). Most are composites or superterranes and each may contain smaller units of uncertain paleogeography. These terranes and superterranes are mainly subdivided on the basis of distinctive lower Paleozoic (as young as Middle

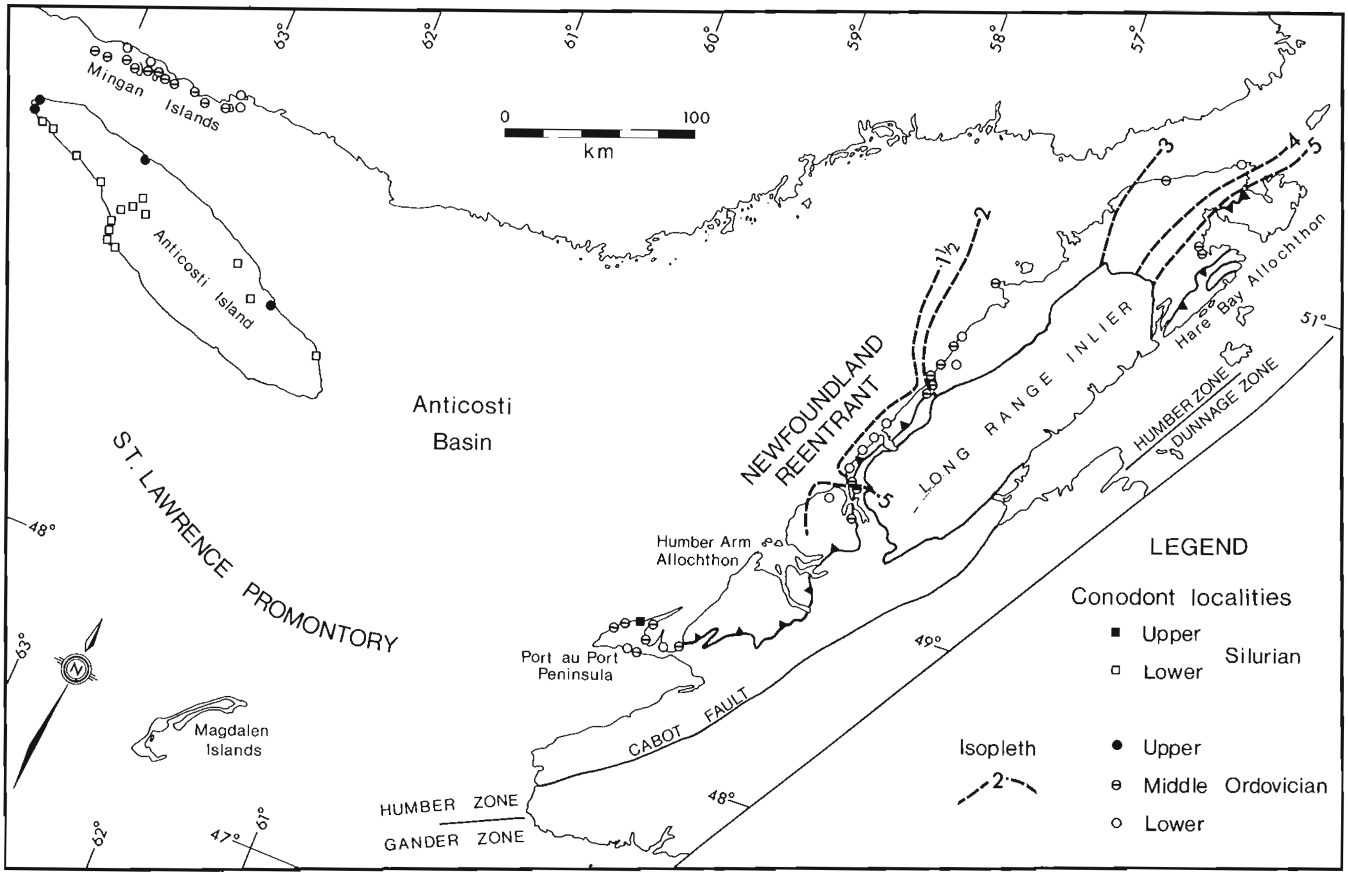


***Figure 3.** Summary map of conodont CAI values in the Anticosti Basin and frontal thrusts of western Newfoundland. Isopleths are drawn at the first occurrence of index values. Main structural features mentioned in the text are shown, for additional information see Williams (1978). Details of localities are provided on Figures 5 through 9 and in Appendix.*

Ordovician) or older rocks; younger rocks (mainly Silurian-Carboniferous) are overlap assemblages. Lower Paleozoic rocks have been affected by three orogenies: the Taconic in the early Middle Ordovician, affecting mainly the northwestern part of the orogen; the Acadian in the mid-Devonian, which affected the entire orogen; and the Alleghenian, which had a limited effect in the area considered. In terms of CAI it is therefore important to know the age of the sample and the zone from which it comes before an interpretation is made.

The westernmost Humber Zone represents the ancient continental margin of eastern North America that lay to the west of the Iapetus Ocean. The western margin of the zone is marked by the northwest limit of Appalachian deformation and the eastern margin is drawn at a steep zone of ophiolites known as the Baie Verte-Brompton Line (Williams and St-Julien, 1982). The zone is underlain by Grenvillian basement. This is overlain by an autochthonous Cambrian-Middle Ordovician carbonate sequence (St. George and Table Head groups of the Anticosti Basin, see above). The relatively undeformed carbonate sequence is overlain by clastic rocks derived from the east, which reflect the onset of thrusting, followed by mélange zones and a variety of transported slices (Stevens, 1970). The lower transported slices comprise sediment deposited at the continental margin, such as the coarse carbonate breccias of the Cow Head Group. The higher structural slices comprise ophiolite suites up to 10 km thick, representing oceanic crust derived from the east (Williams, 1971). Toward the east, the carbonate platform and its cover become progressively more deformed until, in the eastern margin of the Humber Zone there are sediments that show polyphase deformation probably related to ophiolite obduction and partial subduction of the lithosphere (Williams, 1977).

The Dunnage Zone represents vestiges of the Iapetus Ocean and comprises mostly island arc sequences and mélanges built on oceanic crust. This zone is wide in north-central Newfoundland, but narrows southward to be entirely cut out at the St. Lawrence Promontory in southwest Newfoundland (Fig. 3). Rocks similar to those of the Dunnage Zone in north-central Newfoundland occur in northern New Brunswick (e.g., the Fournier Complex, see Rast et al., 1976), where they are faulted against sialic rocks of the Miramichi Anticlinorium. Similar ophiolitic suites occur in the Gander River Ultramafic Belt at the eastern margin of the Dunnage Zone (Pajari and Currie, 1978).

The level of deformation and metamorphism of rocks in the Dunnage Zone is much lower than that of adjacent parts of the Humber and Gander zones. Typically the rocks of the Dunnage Zone are ophiolite complexes, such as the Betts Cove Complex (Upadhyay et al., 1971), overlain by thick sequences of volcanic and volcaniclastic rocks. The famous Dunnage Mélange (Hibbard and Williams, 1979) crops out over a wide area near the eastern margin of the Dunnage Zone. It has been generally considered to mark the site of an oceanic trench (Williams and Hibbard, 1976; McKerrow and Cocks, 1977, 1978), but more recent assessments also suggest olistostromal deposition in a back-arc basin (Pajari et al., 1979; Hibbard and Williams, 1979; Karlstrom et al., 1982).

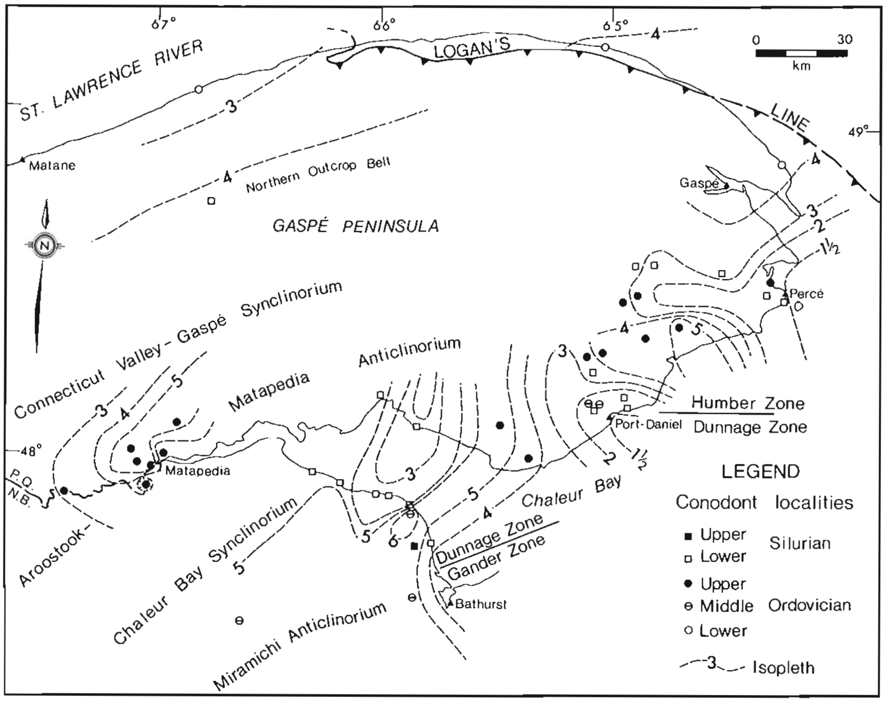


Figure 4. *Summary map of conodont CAI values in the Gaspé Peninsula and adjacent New Brunswick. Main structural features mentioned in text are shown, for additional information see Williams (1978). Isopleths are drawn at the first occurrence of index values; hachured to indicate closed area of lower index. Details of localities are provided in Figures 5 to 9 and in the Appendix.*

The age of volcanism and sedimentation in the Dunnage Zone shows that island arcs were active east of the Humber Zone up to the time of final emplacement of the allochthonous slices on the western margin. The volcanic rocks are overlain typically by black shale of Caradoc age, which marks the end of volcanism in the region. An important, but unanswered, question is whether or not some rocks of the Dunnage Zone are allochthonous (Colman-Sadd and Swinden, 1984).

The Gander Zone represents the history of a continental margin that lay to the east of the Iapetus Ocean. It comprises mostly pre-Middle Ordovician arenaceous rocks that are polydeformed and metamorphosed. More highly metamorphosed migmatitic rocks in the region are interpreted as being either the basement of the arenaceous rocks (Kennedy, 1976) or a deeper portion of the deformed clastic cover (Pajari and Currie, 1978). Equivalent to the Gander Group in Newfoundland is the lower Tetagouche Group of New Brunswick, which is also composed mainly of clastic sedimentary rocks. The eastern boundary of the Gander Zone is drawn at the Dover Fault in northeast Newfoundland (Blackwood and Kennedy, 1975).

The Avalon Zone represents a stable platform that existed during the early Paleozoic when the Iapetus Ocean was open to the west. It consists mainly of Upper Precambrian-Lower Cambrian volcanic and sedimentary rocks. The level of deformation and metamorphism is much lower than that in the adjacent Gander Zone. A thin sequence of Cambro-Ordovician shale and sandstone conformably overlies the Upper Precambrian-Lower Cambrian clastic sequence. Rocks of the Avalon Zone also occur in the southeastern part of Cape Breton Island, Nova Scotia, in eastern New Brunswick and probably in the Antigonish Highlands of northwestern Nova Scotia (Williams, 1979). The eastern parts of the Avalon Zone are covered by Mesozoic deposits of the Atlantic Continental Margin.

Rocks of the Meguma Zone are exposed only on mainland Nova Scotia where they are in contact with rocks of the Avalon Zone along a major transcurrent fault. Schenk (1981, 1982) has interpreted the greywacke, shale and possible glaciogenic rocks of the Ordovician Meguma Group (approximately 10 km thick) as having formed a continental embankment to a continent situated to the southeast.

The foregoing discussion takes account of strata of Middle Ordovician age, and older. The Taconic Orogeny affected the Humber Zone during the Middle Ordovician and events of similar age affected both the western part of the Dunnage Zone and possibly parts of the Gander Zone. The pattern of sedimentation for Upper Ordovician and for Silurian-Devonian rocks is entirely different from that for pre-Taconic time. A sub-Silurian unconformity is evidence of the partial closing and virtual destruction of the Iapetus Ocean. The post-Taconic Appalachian Orogen is characterized by several linear troughs and uplifted areas that controlled the depositional pattern of Upper Ordovician and Lower Silurian rocks. Williams (1978, 1979) regarded Silurian-Devonian and Carboniferous development in terms of these successor basins, which developed across the Appalachian System after the Taconic Orogeny.

Post-Taconic sedimentation in the Gaspé Synclinorium of southeast Quebec and northwestern New Brunswick began in Caradoc time with the deposition of the Grog Brook Group. The Grog Brook Group comprises argillite, sandstone and greywacke of deep water origin and is estimated to be about 7600 m thick; its base is not exposed (St. Peter, 1978). Strata of the overlying, and in part laterally equivalent, Matapedia Group are estimated to be 1250-4000 m thick (Nowlan, 1983a). These strata comprise thin bedded calcareous mudstone and siltstone, also of presumed deep water origin. Strata of the Matapedia Group extend along the southern Gaspé Peninsula and continue southwestward into Maine. They are developed in narrow, fault bounded troughs, and the sediments range in age from Late Ordovician to Early Silurian. In adjacent areas (e.g., the Chaleur Bay region), basal Silurian sediments lie unconformably on Middle Ordovician slate or polydeformed pre-Middle Ordovician units. The age of the lowest Silurian beds varies widely in the region from early to late Llandovery.

Locally in the Newfoundland Dunnage Zone there are also sequences of uninterrupted Ordovician-Silurian sedimentation. In these areas, marine Ordovician clastic rocks pass upward into Silurian conglomerates and coralline shales overlain by continental redbeds.

INTERPRETATION OF CONODONT CAI DATA

St. Lawrence Platform: Quebec Basin

The CAI values recorded from the Quebec Basin are nearly all from Middle Ordovician strata (Figs. 2, 6). Two CAI values of between 4 and 5, and two of CAI 3 were reported from the Chateauguay and Beauharnois formations south of Montreal by Legall et al. (1982). Middle and Upper Ordovician localities at the Lac St. Jean outlier on the Precambrian Shield (locs. 150-152) provided a CAI value of 1½. The discussion and interpretation of the Quebec Basin data can be treated as an eastward extension of the results of Legall et al. (1982) for southern Ontario and parts of southern Quebec.

In the Quebec Basin, CAI values from Middle Ordovician conodonts range from a low of 1½ near Quebec City (e.g., loc. 81), to 2, at localities such as Radnor Forge (loc. 99) and the Ouareau River (loc. 98), and 3-3½ in the Montreal area (locs. 104, 105). Legall et al. (1982) demonstrated a CAI isopleth gradient from 4½ south of Montreal, to 3 and 2½ near Ottawa, and 2 and 1½ in the upper Ottawa Valley and into southwestern Ontario. The thermal anomaly identified by Legall et al. (1982) is, therefore, confirmed and more precisely defined by adding the data reported here from the Quebec Basin (Fig. 2).

The general pattern of thermal maturity based on colour alteration of both conodonts and acritarchs established by Legall et al. (1982) has been confirmed by several recent geochemical studies of the oils and gases and the oil shales throughout southern Ontario (Barker et al., 1983a, 1983b; Barker and Pollock, 1984; Powell et al., 1984; Macauley and Snowdon, 1984; Snowdon, 1984). Macauley and Snowdon (1984, p. 7) concluded that the thermal maturation of the Upper Ordovician "Collingwood oil shale beds ranges from immature to only very marginally mature in the Collingwood area, to moderately mature in the Billings Formation equivalent near Ottawa. Oil shales in the Whitby and Ottawa areas have matured sufficiently to be oil source beds."

Other studies, in which the pattern of thermal maturation of strata in the Quebec Basin was examined, include those of Sikander and Pittion (1978), Ogunyami et al. (1980), Bertrand and Héroux (1981), and Bertrand et al. (1983). These studies involved reflectance of organic matter, and clay and carbonate diagenesis primarily from samples of selected wells. Sikander and Pittion (1978, Fig. 2) examined six wells north and south of Logan's Line between Montreal and Quebec City. They reported an increase in reflectance values toward Montreal. A similar increase in thermal maturation was reported by Bertrand et al. (1983) between Neuville, 25 km southwest of Quebec City, and Montreal, where the strata are mature and supramature, respectively.

Studies of conodont colour alteration, geochemistry, organic matter reflectance, and diagenesis all show a pattern of increased thermal maturation in the Montreal area. Values diminish away from this area into southern Ontario, up the Ottawa Valley into northern Ontario, and northeast toward Quebec City, north of Logan's Line. In the vicinity of Montreal, CAI values of 3 in the city and 4-5 to the south suggest burial temperatures of about 110-200°C and 190-300°C, respectively, resulting in the supramature state for organic matter. Near Quebec City, burial temperatures of about 50-90°C were reached, resulting in only an early level of maturation of organic matter.

The thermal anomaly recognized in the Montreal area was interpreted by Legall et al. (1982) as having been generated by a Cretaceous Hotspot. The trace of this hotspot may be defined by the line of the Cretaceous Monteregian intrusions in southern Quebec (Legall et al., 1982, Fig. 2). With the westward drift of North America, Crough (1981, 1983) believed the trace of this hotspot led to a location near the present Great Meteor Hotspot in the North Atlantic Ocean. Morgan (1981, 1983) also discussed this and other hotspot tracks. Additional supporting geochronological data were presented by Duncan (1982, 1984) in favour of a connection between the Monteregian Hills, the White Mountain Igneous Complex in New England, the New England Seamounts, the Corner Seamounts, and the area near, and south of, the Great Meteor Hotspot. There is, however, some debate on the significance of the geochronological data. Foland and Faul (1977) and McHone (1981) interpret the data from the Monteregian Hills and the White Mountains as being related to transform faulting associated with Mesozoic plate movements in the North Atlantic. An alternative explanation for the Monteregian intrusions is offered by Eby (1984), which involves the upward transport of a metasomatic fluid, perhaps with a coupled rise in mantle isotherms. Moberley and Campbell (1984) argue, however, that the long paleomagnetically normal intervals in the Jurassic and Cretaceous were times of high heat flux and increased hotspot activity that initiated continental rifting.

The data at hand cannot resolve this present debate on the significance of hotspots. The authors consider that the arguments advanced by Crough (1981, 1983), Morgan (1981, 1983) and Duncan (1982, 1984) have considerable merit. Such patterns can explain the thermal anomaly in the Montreal area and a similar anomaly in northern Newfoundland discussed in the next section on the Anticosti Basin.

St. Lawrence Platform: Anticosti Basin

As outlined above, CAI data were obtained from the outcrop belts of the Mingan Islands, Anticosti Island and western Newfoundland, but much of the wide extent of the basin remains unassessed, particularly the subsurface beneath the Gulf of St. Lawrence. Because of the nature of the CAI patterns obtained, the data from the basin will be considered in two parts: Mingan-Anticosti and western Newfoundland (see Fig. 3).

Figures 3 and 5-8 show that the western part of the Anticosti Basin, as exposed on the Mingan Islands and Anticosti Island, has been sampled in considerable detail. The CAI values from the Lower, Middle and Upper Ordovician and from the Lower Silurian are all CAI 1, indicating little alteration of organic matter. Preliminary results were given by Nowlan and Barnes (1981), McCracken and Barnes (1981) and Uyeno and Barnes (1983) from Anticosti Island. These data suggest that the outcropping strata have not reached burial temperatures greater than 80°C. This part of the basin probably received only a thin cover of Devonian and Carboniferous strata. The preserved sedimentary wedge on the northern part of the basin suggests a northward thinning such that the 4000 m thick succession penetrated by a well on the south coast of Anticosti Island may have thinned to half that value in the region of the Mingan Islands. It is probable that deeper levels in the Anticosti Island subsurface and in areas offshore to the south and east may provide higher CAI values, but no data are available at present.

In western Newfoundland (Humber Zone), the CAI data are from Lower and Middle Ordovician and Upper Silurian strata (Figs. 3, 5, 6, 9). The collections are principally from areas along the western coast and in the Hare Bay region of the Great Northern Peninsula. Unfortunately, few data are yet available for areas within the Bay of Islands, i.e. at different structural levels within the Humber Arm Allochthon. The regional CAI values range from 1 to 5 with the isopleths showing a similar pattern on both the Lower and Middle Ordovician maps.

The most westerly outcrops, on the Port au Port Peninsula (e.g., locs. 32-34, 126-127), produce CAI values of 1. In the Lower Ordovician strata of the Cow Head Group at Cow Head (loc. 30), Broom Point (loc. 31), Martin Point (loc. 114) and Green Point (loc. 115), toward the main part of the allochthon and probably representing slightly higher thrust slices, the values increase to CAI 1½. Farther south near the main obducted ophiolite complex of the Bay of Islands, CAI values increase sharply over a short distance. Two Middle Ordovician formations sampled 3-5 km east of Rocky Harbour (locs. 147, 148) provided CAI values of 4½ and 5. Equivalent strata farther within the Bay of Islands complex (loc. 143) also yielded conodonts with a CAI value of 5. Along the coast north of Cow Head (which has CAI 1), the CAI values increase to 2 and 2½ (e.g., Lower and Middle Ordovician at Daniel's Harbour, locs. 133, 134; Port au Choix Peninsula, loc. 113). About 100 km farther north, a CAI value of 3½ is attained at Eddie's Cove (loc. 111) and also near the northernmost tip of the Great Northern Peninsula near Cape Norman (loc. 76). Near the Hare Bay Allochthon (locs. 75, 116), high CAI values of 5 and 5½ are recorded from autochthonous strata (Fig. 3).

Unlike those of the Quebec Basin, there have been few other studies that provide alternative data concerning thermal maturity. The acritarchs from the Silurian of Anticosti Island studied by Duffield and Legault (1981) showed no colour alteration. It has so far been proved that acritarchs are absent or rare in western Newfoundland (Martin, 1978). Several wells have been drilled on Anticosti Island (Roliff, 1968), but later preliminary studies in organic maturation (Petryk, 1981a) indicated an immature to mature condition. Preliminary assessments of hydrocarbon potential, involving some geochemical data, have been published for western Newfoundland by Dobbin et al. (1982). They too show the hydrocarbons and organic matter to be in an immature or mature state.

As noted above, the total sedimentary thickness of all the units in western Newfoundland is 10 800 m, but this includes 4000 m of Carboniferous strata that were largely deposited in restricted, fault-bounded basins not involving the localities discussed here, and about 2300 m for the localized Humber Arm and Hare Bay allochthons. The 800 m flysch sequence derived from the allochthons was probably also of local extent. For the Port au Port area, the burial thickness for Lower and Middle Ordovician strata was probably only of the order of 2000-2500 m. A burial temperature of up to 80°C, inferred from a CAI value of 1, is therefore appropriate.

From these data, a general pattern of CAI isopleths can be discerned (Fig. 3). Further work should attempt to determine values from the poorer inland exposures for improved east-west isopleth patterns. From the largely north-south coastal outcrops, the CAI isopleths (Fig. 3) exhibit a sinuous pattern. The CAI values clearly increase close to the Hare Bay and Humber Arm allochthons, suggesting burial temperatures of about 300-400°C below these transported slices. The composite thickness of stacked slices in the Humber Arm Allochthon was approximately 8-10 km, but with a structural thickness of about 1-2 km. The temperature of the ophiolite slices when they were emplaced is uncertain, but this may have been a factor in the thermal alteration patterns. Both to the north and south, CAI values drop to 1 and 1½ within a relatively short distance. To the south on the Port au Port Peninsula, this suggests that the allochthon there was of limited thickness and that the present geographical limit may correspond approximately to its full original extent. To the north of the complex, the low CAI values of 1-1½ in the Cow Head Group, from Cow Head to Green Point, suggest that these transported, and tectonically lower, slices of continental slope facies were never buried deeply (i.e. burial temperatures of less than about 80°C) and were not covered by the higher ophiolitic thrust slices. At Daniel's Harbour, the CAI values of 2 are similar for both the thin allochthonous strata and the underlying autochthonous carbonates. Northward along the coast there is a progressive increase to a CAI value of 3½ at Eddie's Cove and Cape Norman, where burial temperatures of about 200°C were probably attained.

This thermal anomaly along the western coast of Newfoundland was unpredicted, and several possible explanations, or factors, can be put forward. As noted above, the conodont data suggest that the Humber Arm Allochthon was no more extensive than at present. Consequently it seems unlikely that the Hare Bay Allochthon was originally extensive enough to produce increased burial temperatures in this region. Post-orogenic Devonian and/or Carboniferous clastics may once have covered this northern region, but there is no evidence for major graben development to the west of the Long Range Inlier. The possibility exists of increased effects of the Acadian Orogeny in this region (Williams et al., 1985), but no other evidence beyond localized faulting is available. The interpretation favoured by the authors for this thermal anomaly is that this northern area was affected by the track of a Mesozoic hotspot.

Morgan (1981, 1983) has argued that the trace of the Madeira, Azores and Canary hotspots passed from Baffin Island through northern Quebec, Labrador, the Grand Banks, the Newfoundland Seamounts, and continued toward their present site in the North Atlantic. The hotspot track was reportedly responsible for the rifting between Labrador and Greenland, although the degree of rifting is currently in question. This argument is similar to that advanced by Crough (1981, 1983) and Duncan (1982, 1984), which was referred to above and applied to the Quebec Basin (Montreal area) by Legall et al. (1982). On both the Labrador and Greenland coasts of the Labrador Sea are Jurassic alkaline intrusions, particularly dikes (Watt 1969; Currie 1975). King and McMillan (1975) described a localized breccia of Jurassic age from near Makkovic Bay on the Labrador coast, from which vitrinite reflectance values of 2.21 indicated a burial temperature of at least 170°C. Hence the rifting, alkaline intrusions, relatively high reflectance value, and the predicted hotspot tracks of Morgan (1981, 1983) all give credence to the hotspot hypothesis. In northern Newfoundland, along the northeast coast, Clarke (1977) described alkaline intrusions with ages of between 115 and 145 Ma.

The conodont data reported here can therefore be explained by the concept of one or more Mesozoic hotspot tracks through Labrador and northern Newfoundland, probably leading to the present Madeira hotspot in the North Atlantic (Duncan, 1984, Fig. 3). The data from the eastern Anticosti Basin and southwestern Newfoundland, however, do not support the track shown by Duncan (*ibid.*) that runs past Anticosti Island and southwestern Newfoundland.

Such hotspot tracks have considerable significance for the generation of hydrocarbons, for example in the important thick Mesozoic sequences on the Grand Banks. The tracks shown by Duncan (1984, Fig. 3) suggest proximity to the Hibernia hydrocarbon field at about 100 Ma. Such tracks should be evident in the thermal maturation of lower Mesozoic strata in wells from the Canadian (and U.S.) east coast. The age of the tracks across the continental margin sequences will be critical. They may be prior to deposition of the main sedimentary sequences but this has yet to be firmly established. To date, few data on thermal maturation in Mesozoic strata intersected in East Coast wells have been published (e.g., Bujak et al., 1977; Issler, 1984). They show no indication of anomalies that may be attributed to hotspot tracks, but this possibility should be pursued further as new data become available.

Appalachian Orogen

Cambrian data

Only one sample from the Cambrian of the Appalachians has been assessed (loc. 85, CAI value 5) and no map representing the Cambrian has been compiled. The sample is from the McNeil Formation (Hutchinson, 1952) on McNeil Brook, Cape Breton Island, Nova Scotia. The relatively high degree of thermal alteration is not surprising considering the complex tectonic history of the area and it probably indicates that the unit was once deeply buried. It is anticipated that more Cambrian data will be added in the future, but it will be difficult to assign alteration indices because of the small, delicate nature of Cambrian euconodonts (confined to the Late Cambrian) and the different structure of Cambrian protoconodonts and paraconodonts.

Lower Ordovician data

Lower Ordovician strata from which conodonts have been obtained (Fig. 5) fall into three main tectonostratigraphic regions:

i) The parautochthonous and allochthonous strata adjacent to Logan's Line in Quebec (see St-Julien and Hubert, 1975)

ii) The Tetagouche Group of the Miramichi Anticlinorium in New Brunswick (Nowlan, 1981a)

iii) The Dunnage Zone of west central Newfoundland (Williams, 1979).

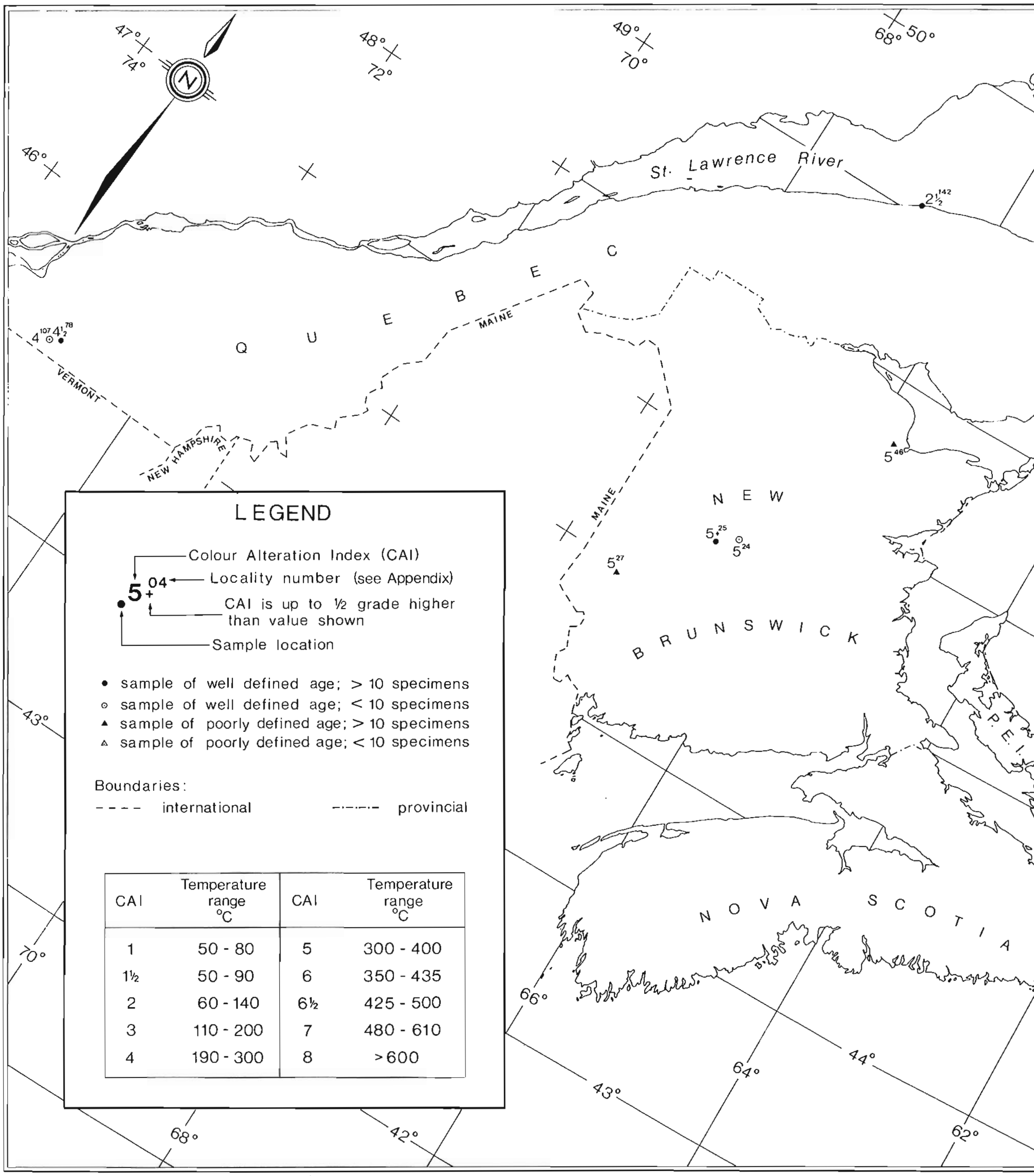
Data are sparse in all regions, but they permit some interpretation.

In southern Quebec, the parautochthonous Hastings Creek Formation has yielded conodonts with a CAI value of 4 (loc. 107). This is slightly lower than the value obtained from Lower Ordovician blocks within the Mystic Conglomerate (loc. 78), which is presumed to be allochthonous. Such a relationship of CAI values suggests that the allochthonous slices may have been thermally altered prior to emplacement and that the parautochthonous rocks may have been buried more deeply during movement of the slices. However, an alternative explanation based on the passage of a hotspot through the Montreal region may well account for the similar CAI values in both autochthonous and allochthonous rocks (see above under interpretation of the Quebec Basin).

On the northern shore of the Gaspé Peninsula, parautochthonous strata have lower CAI values than the overthrust allochthonous strata. Conodonts from carbonate clasts of Early Ordovician age from the parautochthonous Tourelle Formation have yielded a CAI value of 2½ (loc. 142), whereas those from the possibly allochthonous Cloridorme Formation (loc. 16) and Cap-des-Rosiers Formation (loc. 17) yield CAI values of 4. Clearly, the allochthonous rocks have been thermally altered prior to transport and emplacement. The lower values for parautochthonous strata in this region as opposed to those from Southern Quebec may lend credence to the theory that a hotspot track is responsible for the generally higher CAI values in the Montreal region (see above). Alternatively, it may suggest that the Gaspé parautochthonous strata were not as deeply buried as those in Southern Quebec.

Conodonts from the Lower Ordovician strata of the Tetagouche Group of the Miramichi Anticlinorium, part of the Gander Zone, are uniformly altered, with CAI values of 5 (locs. 24, 25, and 46). Reworked conodonts of probable Early Ordovician age, in the Silurian Scott Siding Slate (loc. 27) are also thermally altered to CAI values of 5. These uniform values for Lower Ordovician material within the Miramichi Anticlinorium may be a result of metamorphism from depth of sedimentary burial, but are more likely to be from the effect of tectonic burial and plutonism during the Acadian Orogeny. This conclusion is supported by the fact that most conodonts from Silurian strata in adjacent areas yield CAI values of about 5. Indeed, there is no difference in CAI values between derived, probable Lower Ordovician conodonts and Lower Silurian conodonts from the same sample of the Scott Siding Slate of southwest New Brunswick (loc. 27).

In the Dunnage Zone of the Newfoundland Appalachians, all the CAI values obtained from Lower Ordovician samples are greater than 5. Limestone blocks within the Lush's Bight Group (locs. 118, 131) of Notre Dame Bay and from strata of similar age in the Corner Pond area, near Glover Island to the south, yield CAI values from 5½ to 6. The thermal alteration of these strata was presumably initiated during the Taconic Orogeny and completed by the end of the Acadian Orogeny. Middle Ordovician samples from the area (e.g., locs. 68, 69, 92, 117) have CAI values ranging from 4 to 6, but the precise relationships between strata yielding the varying values are uncertain and shed no light on the timing of maximum thermal alteration. Local baking of limestone during incorporation as clasts in hot lava or pyroclastics may have been a factor, but such increased CAI values were likely to have been overprinted by later orogenic effects.



CAI	Temperature range °C	CAI	Temperature range °C
1	50 - 80	5	300 - 400
1½	50 - 90	6	350 - 435
2	60 - 140	6½	425 - 500
3	110 - 200	7	480 - 610
4	190 - 300	8	>600

Figure 5. *Lower Ordovician localities for which conodont CAI values have been assessed. Detailed information for each numbered locality is provided in the Appendix.*

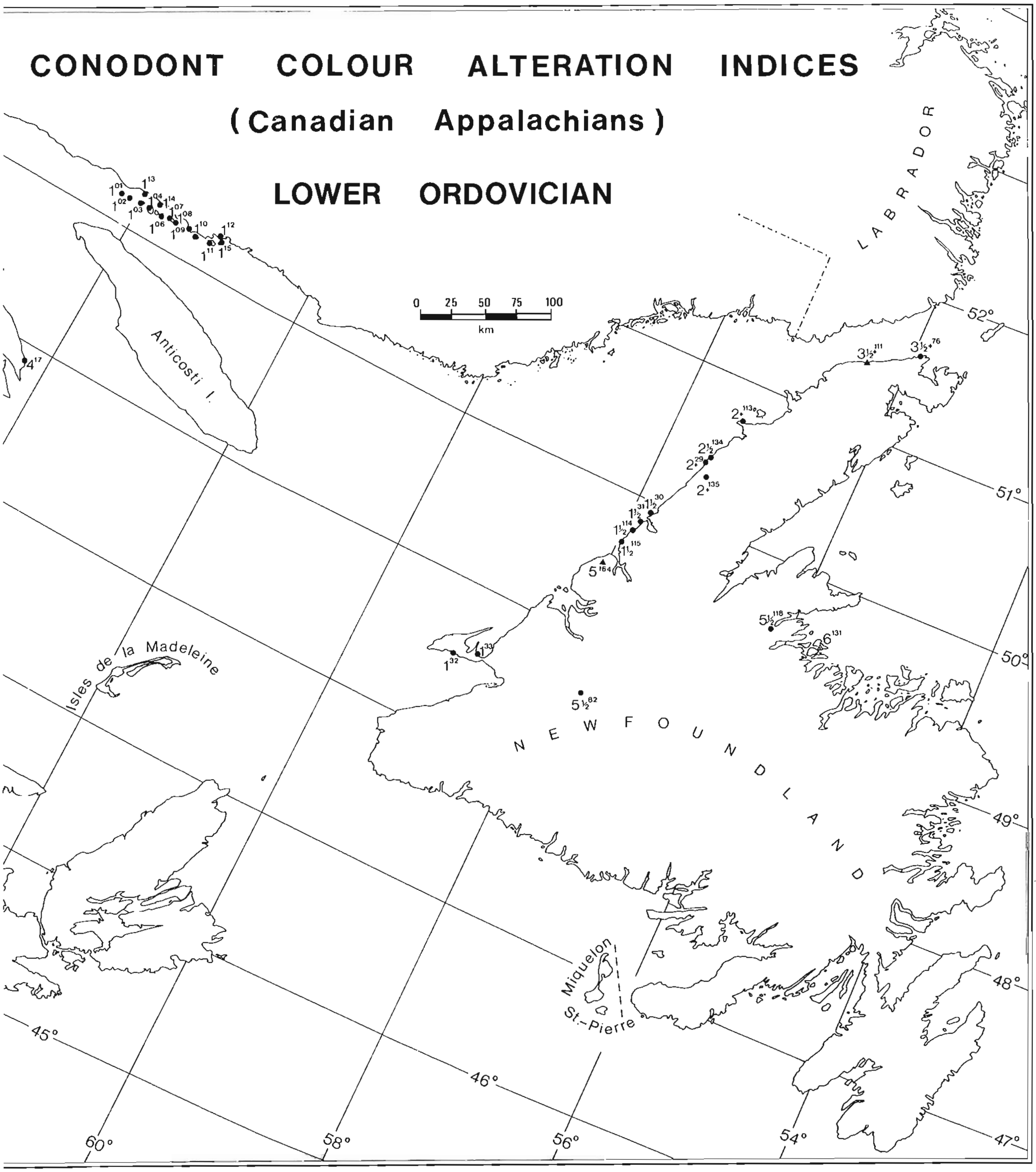


Figure 5. *(cont'd)*

Middle Ordovician data

Conodont-bearing, Middle Ordovician strata of the Appalachian Orogen (Fig. 6) are more widely distributed and are represented in a broader array of tectonostratigraphic regions than those of the Lower Ordovician. Middle Ordovician samples are from:

i) parautochthonous and allochthonous strata adjacent to Logan's Line (St-Julien and Hubert, 1975)

ii) strata adjacent to the Baie Verte-Brompton Line in the Gaspé Peninsula (Williams and St-Julien, 1982)

iii) the Tetagouche Group and related units of the Miramichi Anticlinorium (Nowlan, 1981a)

iv) the Craig Brook Limestone (St. Peter, 1982) of the Coldstream area, which may represent the margin of the Tetagouche and Matapedia basins

v) the Dunnage Zone of Newfoundland (Williams, 1979).

Middle Ordovician conodonts from the allochthonous Mystic Formation of Southern Quebec (loc. 78) yield the same value as those from Lower Ordovician clasts (CAI value 4½). This suggests that either the level of thermal maturity was developed in Middle Ordovician time just prior to, or during, tectonic transport or that the unit was overprinted by the passage of a hotspot (see above). The parautochthonous rocks of the Isle la Motte Formation (loc. 106) and Bulstrode Formation (loc. 28) yield conodonts with CAI values of 4 and 5, respectively. The value from the Isle la Motte Formation is the same as that from the parautochthonous Lower Ordovician Hastings Creek Formation. The higher value from the Bulstrode Formation may suggest a thicker loading of Taconic slices in the region, or closer proximity to the hotspot track. Additional collecting from this region should help to distinguish between orogenic effects and those of hotspot tracks on thermal maturation.

A sample from a block of calcareous siltstone in melange of the North-Port-Daniel River Complex (loc. 163) and a sample from a greywacke bed in the Mictaw Group (loc. 161) both yield conodonts with a CAI value of 1½. These units crop out near Port-Daniel in the southern Gaspé Peninsula, adjacent to the Baie Vert-Brompton Line, which is interpreted as the "surface trace of a structural junction between deformed rocks of an ancient continental margin and bordering ocean" (Williams and St-Julien, 1982, p. 177). The surprisingly low CAI values in both units suggest that the North-Port-Daniel River Complex (with mid to upper Arenig conodonts) and the Mictaw Group (with Llanvirn-Llandeilo conodonts) are of post-Taconic origin. Indeed, there has been little or no burial in the Port-Daniel region as indicated by the Silurian CAI values of 1½. Thus, although these units occur adjacent to the fault identified as the Baie Verte-Brompton Line they must post-date the orogenic event that resulted in obduction of ophiolitic slices from the region. Strata of the North-Port-Daniel River complex include blocks of ophiolitic, granitic, volcanic and metasedimentary rocks, suggesting deposition following deformation at or near the continental margin.

Samples from the Middle Ordovician Tetagouche Group yield conodonts with CAI values of 5 (e.g., locs. 23, 46). Conodonts from limestone pods in the Belle Lake Slate at Waterville, New Brunswick (loc. 26) (Nowlan, 1981a), indicate CAI values of 5 or slightly higher. As noted under the discussion of Lower Ordovician data, thermal alteration in this region probably occurred as a result of tectonic burial during the Acadian Orogeny, although the local thermal effects of Devonian plutons cannot be ruled out.

The Craig Brook Limestone is an assemblage of limestone units of Llanvirn to early Caradoc age that crops out in a restricted area of western New Brunswick (St. Peter, 1982). It occurs in a structurally complex area that may represent the margins of the Matapedia and Tetagouche basins. The unit is tectonically disturbed and is known to be thrust over Lower Devonian strata. Conodonts from this formation yield CAI values of 3, 4 and 5 in adjacent outcrops (see locs. 59, 62, 155, 156). The variation in CAI values is not related directly to the age of the samples: the youngest sample (loc. 156) yields a CAI value of 4, whereas those of slightly older age (locs. 59, 62, 155) yield values of 3 and 5. It may be suggested that this formation is of rather heterogeneous origin with different slices that have undergone varying degrees of thermal alteration. It cannot be stated whether this variation reflects alteration levels reached as a result of sediment loading or tectonic burial. Furthermore, there is no evidence of any major plutons in the immediate outcrop area that may have influenced the CAI values. Lower Silurian strata in the region yield conodonts with CAI values of 1½ to 3 (see below under Lower Silurian).

In the Newfoundland Appalachians, conodonts of Middle Ordovician age yield CAI values of between 4 and in excess of 6. The lowest values recorded are those from the Buchans Group (CAI value 4) (Nowlan and Thurlow, 1984). The highest CAI value reported is 6, from the Lush's Bight Group and Cobb's Arm Limestone in northern Newfoundland. The only discernible pattern based on these very sparse data is that the thermal maturation level increases northward. It is lowest in the Buchans Group (loc. 92, CAI value 4), intermediate (CAI value 5) in the Summerford and Badger Bay groups (locs. 69, 129) and highest (CAI value 6) in northernmost exposures (locs. 117, 130, 131). Isopleths drawn on these points run approximately east-west, cross-cutting the structural trend. It is unlikely that this pattern is significant; probably thermal maturation is variable across and along the Dunnage Zone.

The only samples from the Dunnage/Gander Zone boundary are those from the Davidsville Group near Carmanville (loc. 68). These have yielded conodonts with a CAI value of 5.

Upper Ordovician data

Upper Ordovician conodonts have been obtained from two main areas:

i) The Matapedia Basin extending from Percé to Matapedia, Quebec;

ii) Western New Brunswick in an area marginal to the Matapedia Basin (Figs. 4, 7).

Strata within the Matapedia Basin range in age from late Middle Ordovician (Caradoc) to late Early Silurian (Wenlock). Thick deposits of calcareous mudstone and siltstone are assigned to the Matapedia Group; clastic rocks are assigned to the Honorat and Grog Brook groups that underlie and are partially laterally equivalent to the Matapedia Group (Nowlan, 1981b; 1983a). At the eastern end of the basin near Percé, strata of the Matapedia Group are mainly placed within the White Head Formation, which includes a number of distinctive units that can be traced some distance to the west of Percé (Skidmore and

Lespérance, 1981). These units have been intensively sampled for conodonts and the thermal maturation levels reflected by the samples show a distinctive general pattern. In the Percé area (Fig. 4), CAI values from the White Head Formation are 1 or only slightly higher (locs. 42, 43). As the formation is traced westward, CAI values increase to 2½ (loc. 64) and 3½ (loc. 65) in Power Township. The reason for such a trend along the outcrop belt, presumably along the depositional strike, is not known. It is unlikely to be the result of sedimentary burial, as depositional thickness along this segment of the Matapedia Basin does not vary sufficiently. It is equally unlikely to be attributable to a hotspot because there is no evidence for one having passed beneath this region (Morgan, 1983). The preferred explanation is that overthrusting in Silurian and/or Devonian times caused deeper tectonic burial in the western part of this outcrop belt.

Elsewhere in the Matapedia Basin, CAI values are generally higher (3-5) than in the northeastern part (Fig. 4). Strata of undivided Matapedia Group to the south of the outcrop pattern of the White Head Formation yield CAI values of 4 (locs. 139, 158) increasing to 5 in close proximity to the Grand Pabos Fault (loc. 136). The variation reflected in this part of the basin is probably a result of tectonic activity for which there is a great deal of evidence, especially a series of east-west trending faults.

In the central and western parts of the Matapedia Basin, conodonts from the undivided Matapedia Group are mostly thermally altered to a CAI value of 5 (e.g., locs. 20, 21, 36, 39, 45) but locally, CAI levels of 3 and 4 are recorded (e.g., locs. 38, 40, 44). The levels of thermal maturity in these areas are also probably controlled by burial depth as a result of faulting during the Silurian and Devonian. The mass of faults recognized in the area demonstrates that the "Matapedia Basin" is far from being a simple, single basin and more likely represents a collage of fault slices possibly representing different basins or disjunct parts of the same basin.

Duba and Williams-Jones (1983a) applied illite crystallinity and organic matter reflectance techniques to the evaluation of burial metamorphic conditions of post-Taconic sediments in the Matapedia-Restigouche area of Quebec. Their work showed that the metamorphic grade of the Paleozoic succession decreases upward, although the Devonian Fortin Group has an anomalously high grade. They felt this high could be attributed to Acadian intrusions. Conodont CAI values from these strata are mostly 5 (locs. 20, 21, 36, 45) in the general vicinity of the anomaly, and decrease to values of 3 westward (loc. 162) and 4 to the east (loc. 44). There is a general correspondence in the two patterns. However, a strikingly anomalous low CAI value of 1½ was recently reported from the Grog Brook Group (loc. 58) in the Matapedia area (Nowlan, 1983a). This is from an area unsampled by Duba and Williams-Jones (1983a), but it shows that the thermal patterns for the area are complex and cannot be related simply to intrusive events. Two alternative models were proposed by Nowlan (1983a) to explain the juxtaposition of Grog Brook strata of low thermal maturity and Matapedia strata of high thermal maturity (CAI value 5): the first hypothesis involved Late Ordovician-Early Silurian thrusting with subsequent Acadian folding and faulting, and the second hypothesis proposed deposition of the Grog Brook strata on a structurally positive area with subsequent folding and thrusting. Such mechanisms may also account for less striking variations of CAI values in this region.

The only other area yielding CAI values for Upper Ordovician strata is in western New Brunswick (locs. 27, 60, 157). Locality 27 is in the Scott Siding Slate of Silurian age, but contains derived Ordovician conodonts. Locality 60 may be of Middle or Late Ordovician age and is in the Craig Brook area discussed in detail under Middle Ordovician data. The only sample from strata that is undisputedly Upper Ordovician is from locality 157 (CAI value 5). This value is based on data from conodonts derived from a limestone-pebble conglomerate and associated sandy limestone, which lie unconformably on the Middle Ordovician Craig Brook Limestone (St. Peter, 1982, p. 19).

Upper Ordovician data are lacking for Nova Scotia and Newfoundland.

Lower Silurian data

Data from Lower Silurian strata are the most geographically diverse and come from several different tectonostratigraphic regions (Fig. 8). These are:

i) The Northern Outcrop Belt of the Gaspé Peninsula, Quebec (Bourque, 1977)

ii) The Matapedia Basin of the Gaspé Peninsula and western New Brunswick

iii) The Chaleur Bay Synclinorium of the Gaspé Peninsula and northern New Brunswick (Bourque, 1975; Bourque and Lachambre, 1981; Lee and Noble, 1977; Noble, 1976)

iv) Western New Brunswick, in an area marginal to the Matapedia Basin (St. Peter, 1982; Venugopal, 1979)

v) The Meguma Zone of the Annapolis Valley, western Nova Scotia (Crosby, 1962)

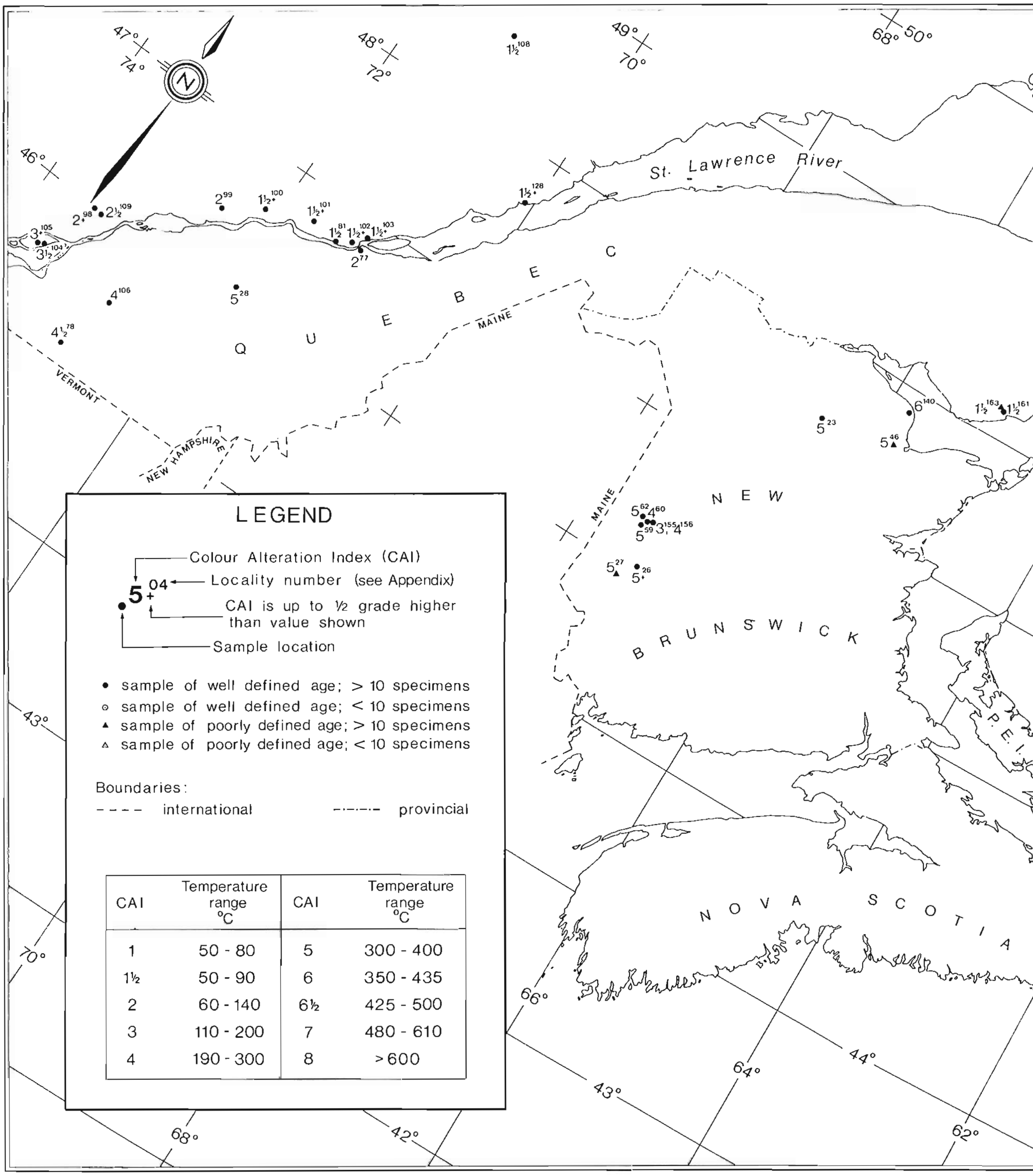
vi) The Antigonish Inlier, Arisaig area, northwestern Nova Scotia (Boucot et al., 1974)

vii) The Botwood Group of central Newfoundland (Williams, 1962).

Most of the conodonts used for Lower Silurian CAI determinations have been reported previously in recent summary papers (Nowlan, 1981b, 1983b).

Data from the Northern Outcrop Belt of the Gaspé Peninsula are sparse. A single sample from the Sources Formation (loc. 67) has produced conodonts with a CAI value of 4½. This relatively high level of thermal alteration is not surprising as the sample comes from strata that are in close proximity to the South Shickshock Fault Zone, which is a major fault that defines the southern margin of the Shickshock Group, a unit comprising metavolcanics and metasediments of presumed Cambrian age (Mattinson, 1964; Ollerenshaw, 1967). Extensive additional collecting was undertaken in the Northern Outcrop Belt in 1984 by one of the authors (G.S.N.) and it is hoped that these new samples will provide considerably more detailed information on the thermal maturation levels of Silurian rocks in this narrow outcrop belt.

As noted in the discussion of Upper Ordovician data, the Matapedia Basin is actually a structurally complex area that may be a collage of several sedimentary packages. The thermal alteration levels in the Lower Silurian part of the White Head Formation at the eastern end of the Matapedia Basin follow the same pattern as those in the Upper Ordovician (Fig. 4). The CAI levels are low, 1-1½ in



CAI	Temperature range °C	CAI	Temperature range °C
1	50 - 80	5	300 - 400
1½	50 - 90	6	350 - 435
2	60 - 140	6½	425 - 500
3	110 - 200	7	480 - 610
4	190 - 300	8	>600

Figure 6. *Middle Ordovician localities for which conodont CAI values have been assessed. Detailed information for each numbered locality is provided in the Appendix.*

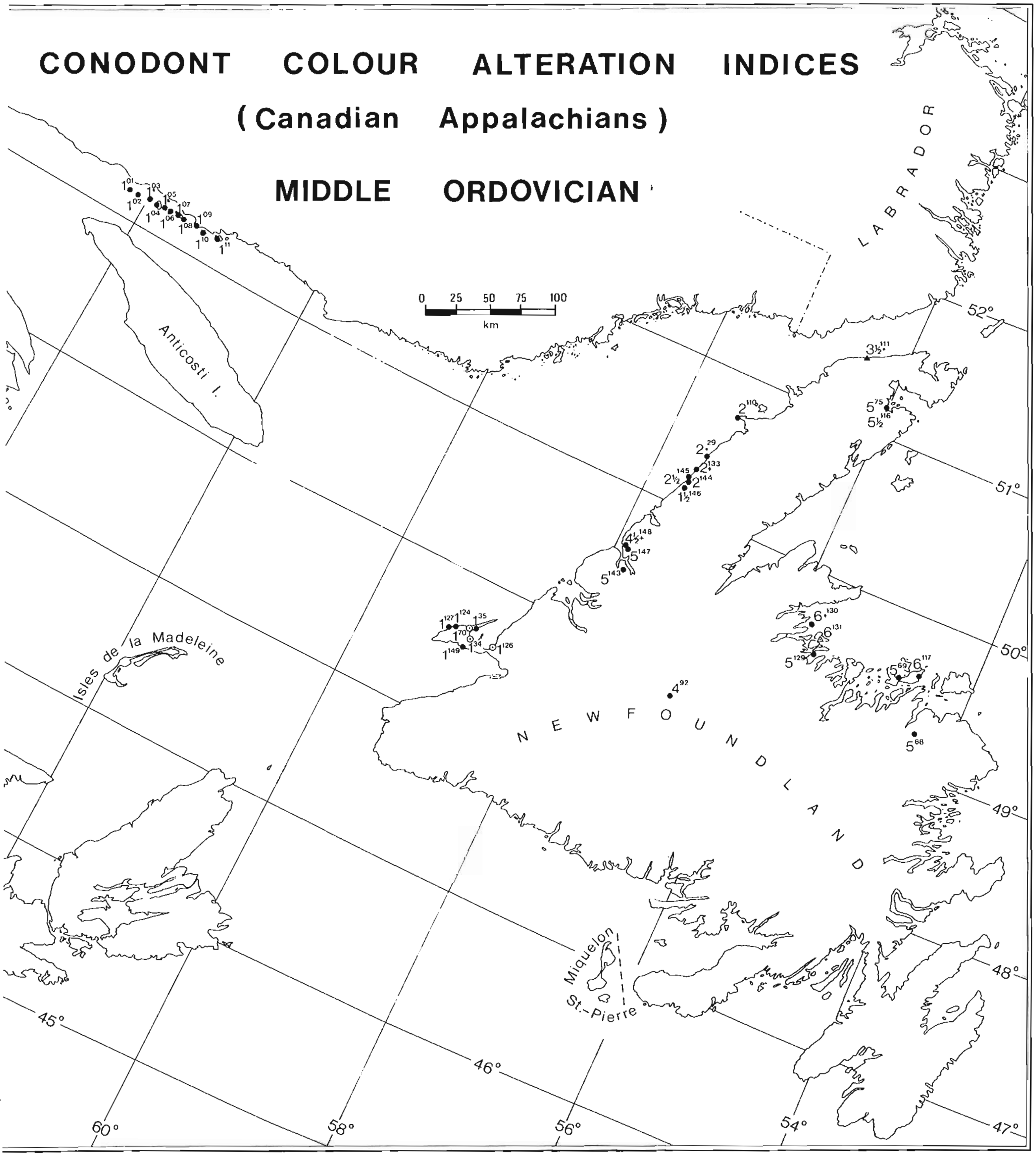
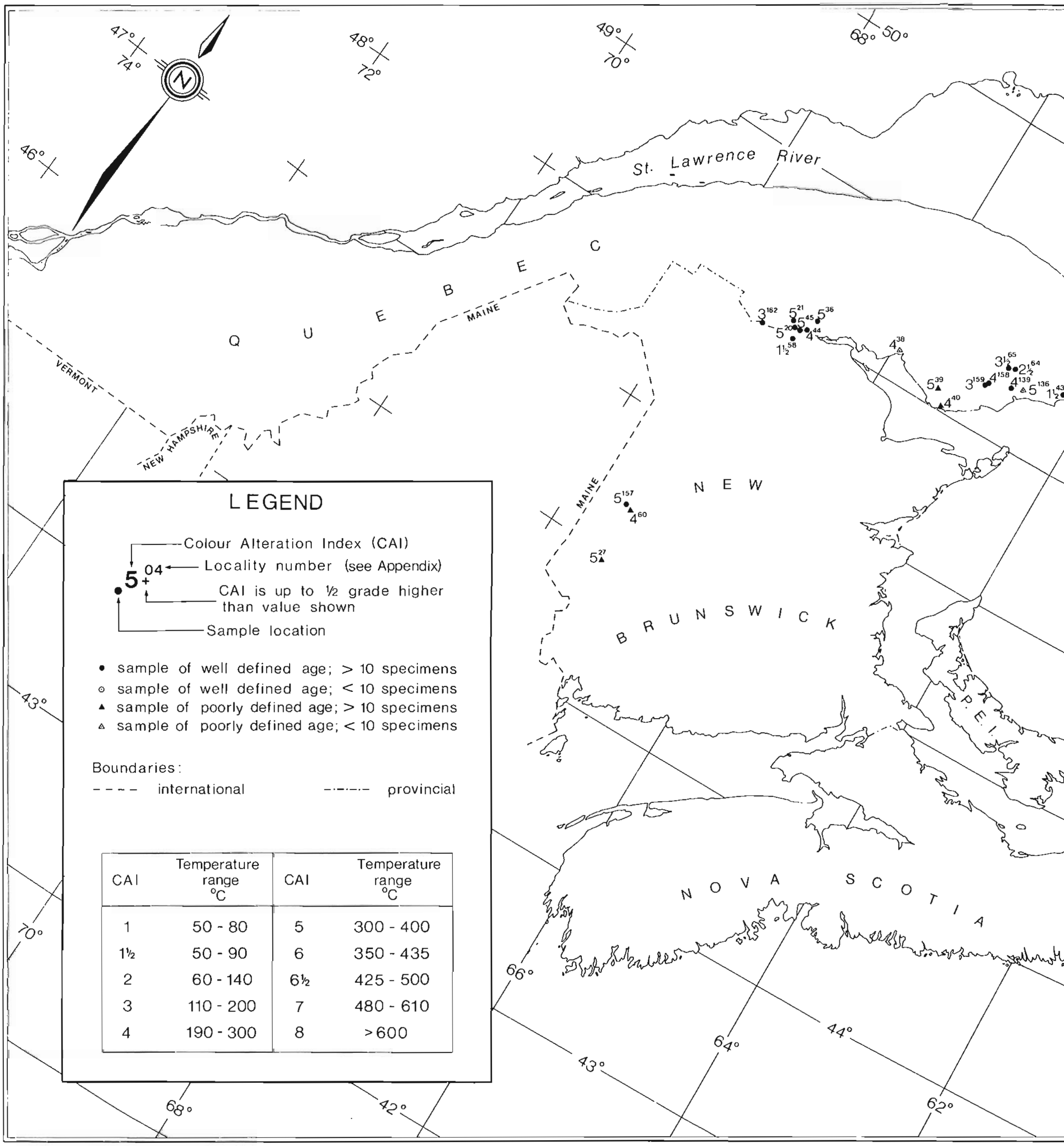
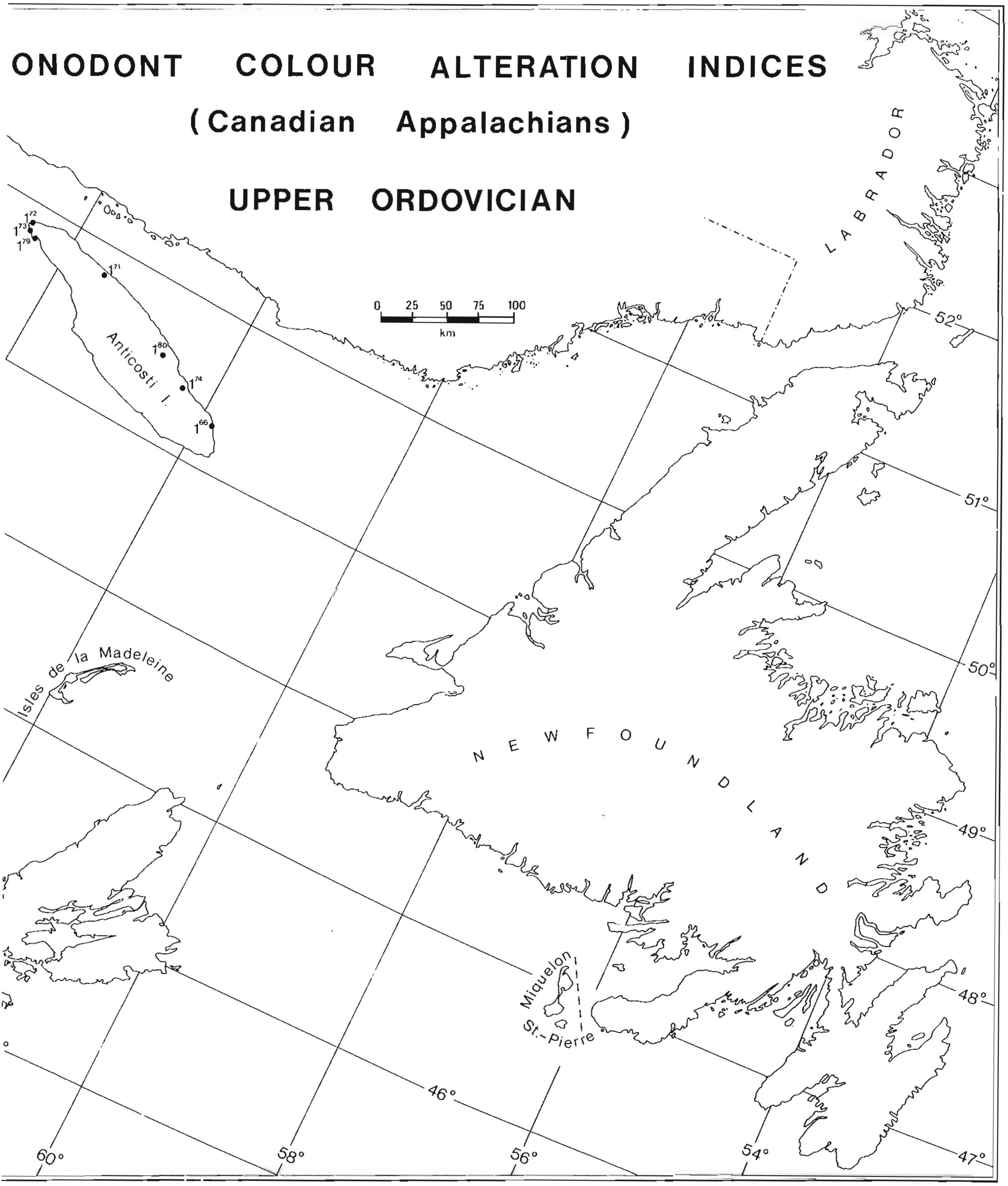


Figure 6. (cont'd)



CAI	Temperature range °C	CAI	Temperature range °C
1	50 - 80	5	300 - 400
1½	50 - 90	6	350 - 435
2	60 - 140	6½	425 - 500
3	110 - 200	7	480 - 610
4	190 - 300	8	>600

Figure 7. *Upper Ordovician localities for which conodont CAI values have been assessed. Detailed information for each numbered locality is provided in the Appendix.*



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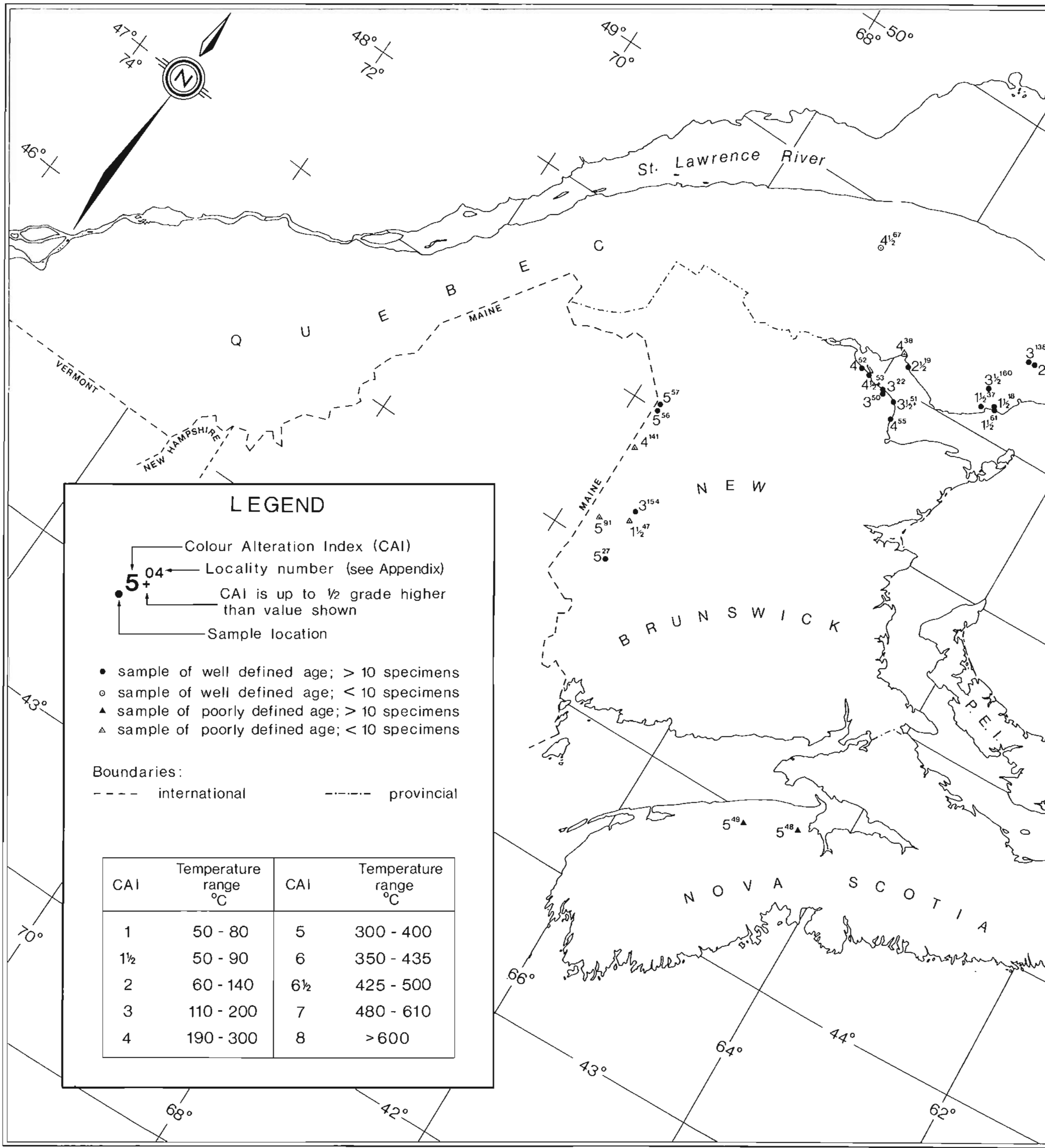


CAI	Temperature range °C	CAI	Temperature range °C
1	50 - 80	5	300 - 400
1½	50 - 90	6	350 - 435
2	60 - 140	6½	425 - 500
3	110 - 200	7	480 - 610
4	190 - 300	8	>600

Figure 8. *Lower Silurian localities for which conodont CAI values have been assessed. Detailed information for each numbered locality is provided in the Appendix.*

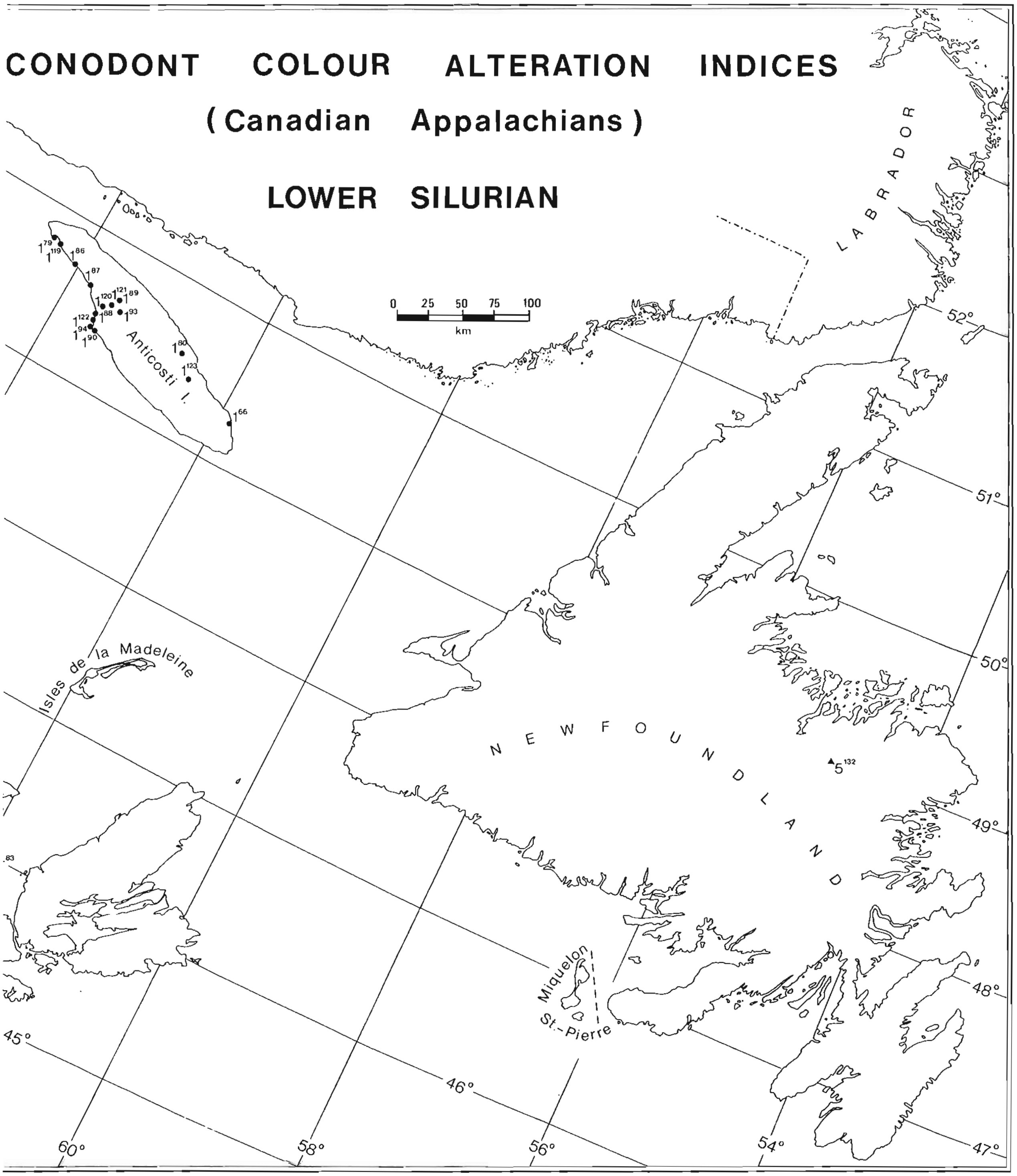


Figure 8. (cont'd)

easternmost exposures near Percé (locs. 42, 125), and increase steadily to the west to CAI values of 2 (loc. 63) and 3 in the westernmost locality along Grande Rivière Nord in Power Township (loc. 138). As suggested in the discussion of Upper Ordovician data, this trend of increasing CAI values along the depositional strike may be a result of deeper tectonic burial in the western part of the outcrop belt.

Elsewhere in the Matapedia Basin, CAI values are higher than in the eastern part characterized by strata of the White Head Formation (Fig. 4). In the Gaspé Peninsula, values of CAI 3½ (loc. 160) and 4 (loc. 38) have been obtained from samples of the Matapedia Group. Much farther to the southwest, in the Grand Falls area of New Brunswick, strata assignable to the Carys Mills Formation yield CAI values of 5. This unit, together with the Smyrna Mills Formation, is generally considered to be at least partially equivalent to the Matapedia Group (e.g., Pavlides and Berry, 1966; Roy and Mencher, 1976). The CAI values obtained are compatible with those known from Upper Ordovician strata in the basin in northwestern New Brunswick (see above). In adjacent areas of Maine, prehnite-pumpellyite facies metamorphism has been recognized in approximately equivalent strata (Richter and Roy, 1976). This metamorphism was thought to be Early Devonian and was attributed to the Acadian Orogeny (*ibid.*, p. 258). This level of metamorphism is compatible with a temperature of about 300°C, indicated by conodonts with a CAI value of 5. Thus, regional metamorphism may account for the thermal levels in the Grand Falls area. It is not known to what level Devonian plutonism may have affected the thermal regime in the area, but granitic intrusions are known from adjacent Maine (e.g., Roy and Mencher, 1976).

Within Lower Silurian strata of the Chaleur Bay Synclinorium there is a marked variation in CAI values (Figs. 4, 8). In eastern outcrops, on the north shore of Chaleur Bay near Gascons and Port-Daniel, Quebec (locs. 18, 37, 61), CAI values are 1½. The gradient rises westward to the New Richmond area (loc. 19) where the CAI value is 2½. Opposite New Richmond on the south shore of Chaleur Bay at Quinn Point, New Brunswick (loc. 22), the CAI level is between 2½ and 3, and the gradient increases to the southeast and west. Immediately to the south on the Culligan railroad cut (loc. 50) the CAI value is 3. To the east, the CAI value is 3½ at Hendry Brook (loc. 51) and increases to 4 at Limestone Point (loc. 55). Similarly, to the west of Quinn Point, CAI values increase to 4½ at Dickie Cove (loc. 53) and decline slightly to 4 farther west at Pointe LaRoche. It is difficult to explain these marked changes over such short distances as being a result of depth of burial, because an increase in CAI values from 2 to 4 suggests an increase in overburden thickness of 3000-4000 m. It seems unlikely that the Carboniferous cover was as thick as 7000-8000 m in the area, which would be necessary for a CAI value of 4½.

The most likely explanation for the variation in CAI values in the Chaleur Bay Synclinorium is the degree of proximity to Devonian plutons. No Devonian plutons are recognized in the southern part of the Gaspé Peninsula, but several occur in areas just to the south of the Silurian outcrops in northern New Brunswick. The pattern of CAI values in the Lower Silurian strata of northern New Brunswick may provide a means of tracing the subsurface extent of the thermal aureoles of granitic plutons.

In an area marginal to the Matapedia Basin in western New Brunswick, CAI values vary markedly in a restricted area (Fig. 8). An anomalously low value has been obtained from the Smyrna Mills Formation in a downfaulted block within the Miramichi Anticlinorium (CAI value 1½, loc. 47). The preservation of strata with this low thermal level suggests the presence of thrust faulting and/or deposition on a structural high, such as that proposed for Upper Ordovician strata in northwestern New Brunswick (Nowlan, 1983a). The CAI values obtained from the Smyrna Mills Formation in adjacent areas may vary from 3 (loc. 154) in the Becaguimec area to 5 in the Matapedia Basin proper near Payson Lake north of Woodstock, New Brunswick (loc. 91). The CAI level at the Becaguimec locality is lower than those for Middle and Upper Ordovician strata in that structurally complex area (see above). The CAI value for the Payson Lake area is compatible with other Lower Silurian data for the Matapedia Basin proper (cf. locs. 56, 57). Thus, it appears that CAI values in Lower Silurian rocks preserved in the Miramichi Anticlinorium (or near its margin with the Matapedia Basin) are lower than those in equivalent strata of the Matapedia Basin proper. This may be due to deposition on the structural high of the Miramichi Anticlinorium and the resulting thin overburden, or to the thrusting of less altered strata out of the basin prior to the main thermal event in the basin. Whatever the answer, it is clear that the conodont CAI values can play an important role in the structural evaluation of such complex areas.

Conodonts have been recovered from Silurian strata in the main areas of Nova Scotia: the Annapolis Valley in the Meguma Zone and the Arisaig area of northwestern Nova Scotia. In the Annapolis Valley, two separate areas are available for assessment: the New Canaan Formation near the village of New Canaan and the Kentville Formation at the Fales River section (Schenk et al., 1980). These Silurian strata probably range in age from Wenlock to Ludlow and are thus plotted on both Lower and Upper Silurian maps. They are preserved in the cores of synclines along the northern margin of the Meguma Zone that were presumably formed during the Acadian Orogeny, prior to intrusion of the South Mountain Batholith (Schenk et al., 1980). The level of thermal maturity in these strata may be the result either of tectonic burial during the Acadian Orogeny or of contact metamorphism associated with the South Mountain Batholith.

In northwestern Nova Scotia, conodonts have been recovered from Lower Silurian strata in School Brook Cove, Cape George (Keppie, 1980). These strata are cut by a differentiated intrusive sheet that may be responsible for the high level of thermal maturity (CAI values of 5½-6, loc. 83), but all the rocks at this locality occur in a major east-west fault zone and relationships of individual units are not clear (Boucot et al., 1974; Keppie, 1980). Upper Silurian strata from the same region yield CAI values of 3 (loc. 84).

A single sample from the Botwood Group near Glenwood in northern Newfoundland has produced conodonts with a CAI value of 5. The structural setting of this sample is uncertain but, in general, Silurian strata of the region are folded, faulted and intruded by plutonic rocks. The cause of the thermal alteration of this sample has not been established. More data will be required from Silurian strata of the region to permit recognition of thermal alteration patterns.

Upper Silurian data

Data from Upper Silurian strata are extremely sparse and only five localities are known from the entire Appalachian region (Fig. 9). New data points will soon be available as a result of recent collecting from strata of Ludlow and Pridoli age in Quebec and New Brunswick.

Information on the Upper Silurian of New Brunswick is restricted to a single sample from the Bathurst region (loc. 54) previously reported by Nowlan (1983b, p. 106). The sample comes from strata originally interpreted by Noble (1980) as being basinal equivalents of the Lower Silurian La Vieille Formation, but now shown to be of a level approximately equivalent to the Upper Silurian West Point Formation (Nowlan, 1983b). The sample yields a CAI value of 5; it is inland from coastal exposures of Lower Silurian strata that yield CAI values of 4 (loc. 55). This higher level of thermal alteration may be a result of closer proximity to Devonian intrusions (see discussion under Lower Silurian).

Upper Silurian data from Nova Scotia are from the same areas as Lower Silurian data. Samples from the Meguma Zone are from the same localities as the Lower Silurian (locs. 48, 49) and have CAI values of 5. Some samples from Fales River (loc. 49) are from Upper Silurian strata, but those from the New Canaan area (loc. 48) are of uncertain position in the Silurian. In northeastern Nova Scotia, samples from the Stonehouse Formation of the Antigonish Inlier originally reported by Legault (1968) yield conodonts with CAI values of 3 (loc. 84). The cause of this level of thermal alteration is uncertain, but proximity to faulting and intrusions can be invoked for Lower Silurian strata of higher thermal levels just to the east (loc. 83).

Samples from strata probably of Late Silurian age in Newfoundland have yielded the highest CAI value obtained from the Canadian Appalachians (loc. 112, CAI 8). The samples come from the Sops Arm Group in the White Bay region of northern Newfoundland. The conodonts are well preserved structurally, but highly altered thermally, being totally transparent due to complete removal of organic matter. The probable cause of such a high index is proximity to the Gull Lake Intrusive Suite (Smyth and Schillereff, 1982).

Devonian data

Samples from the Devonian are too few to merit a separate map. Only two samples from Devonian strata have yielded sufficient conodont elements for CAI assessment. One is from the Famine Limestone (MacKay, 1921) in St. George de Beauce, Quebec (loc. 96, CAI 5) and the other is from the Touladi Formation (Lespérance and Greiner, 1969) south of Cabano, Quebec (loc. 97, CAI 5). The high CAI values presumably reflect burial during the Acadian Orogeny. As more data are collected from Devonian strata, it is anticipated that a map for the system will be compiled.

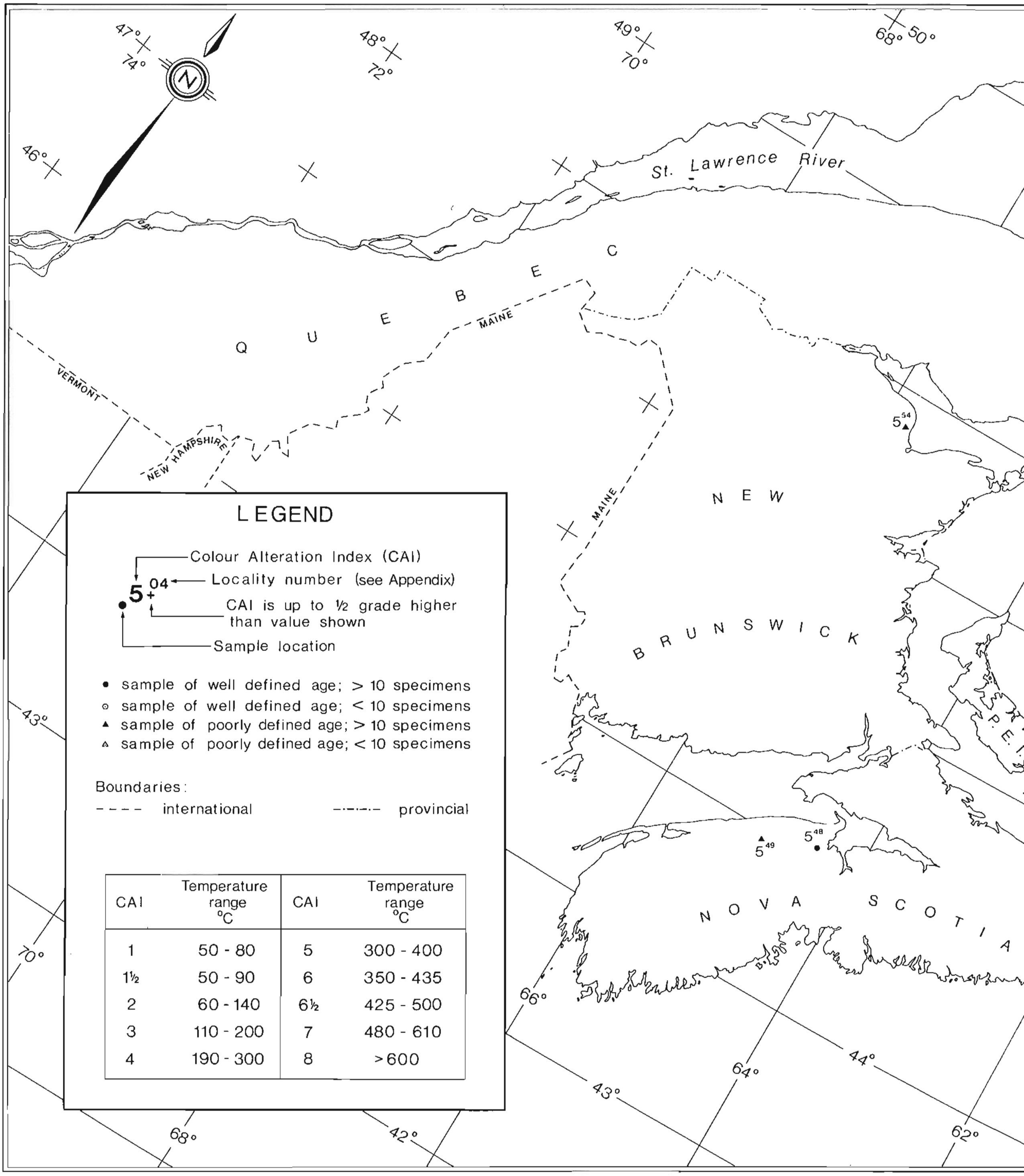
ECONOMIC POTENTIAL

The CAI values and patterns reported here reveal the general burial temperatures attained by some of the Paleozoic rocks of Eastern Canada. The regional patterns obtained for the St. Lawrence Platform are unlikely to change significantly with more data, whereas the complexities of the Appalachian Orogen will be increasingly revealed with new data and there are many tectonostratigraphic units and terranes to be sampled. Within these limitations it is useful to comment on the implications of the inferred burial temperatures for the economic potential of the region both for hydrocarbon and base metal deposits.

Hydrocarbon exploration

Thermal maturation is a critical factor in the generation of hydrocarbons from organic-rich source rocks and in their preservation in reservoir rocks. As shown in Figure 10, most oil is generated in strata that have attained burial temperatures in the range of about 60-120°C (the liquid window). Lower temperatures may help generate wet gas; higher temperatures may first result in dry gas and then eventually the total distillation of all organic matter. In terms of CAI values, oil generation from source rocks commences where values are approximately 1½. In the St. Lawrence Platform, such areas are (a) from just north of Montreal to Quebec City, and (b) from western Newfoundland north of Rocky Harbour (except for a short distance near Cow Head) to Eddie's Cove. Conodont CAI values, of course, can be expected to increase with depth in the subsurface. There are several potential source rocks including the Upper Ordovician "Utica" black shale (e.g., Lachine, Lotbinière, Macasty formations) of the Quebec and Anticosti basins and the Lower Ordovician black shale within the frontal allochthonous sheets (e.g., Lévis Formation, Quebec; Curling and Cow Head groups, western Newfoundland). Such units have yielded trace amounts, to small production amounts, of oil and gas across the St. Lawrence Platform, but no major fields have yet been discovered (e.g., Clark, 1956; Roliff, 1968; Petryk, 1981 a, b; and Dobbin et al., 1982). Generated hydrocarbons can be expected to migrate updip in these basins. However, few good reservoir horizons are yet known in the subsurface. The Quebec Basin can be adequately assessed using the many wildcat wells, but the Anticosti Basin has yet to be properly tested, particularly in the southern part under the Gulf of St. Lawrence (Roksandic and Granger, 1981), in the central part with the possible Banc Beaugé Basin (Haworth, 1978), and in part of offshore and inshore western Newfoundland as a prospective overthrust play. With the increasing appreciation of the role of thin-skinned tectonics in the Appalachian Orogen (e.g., Harris and Milici, 1977; Cook et al., 1979; Cook and Oliver, 1981), there could be renewed interest in such overthrust plays in both Newfoundland and Quebec and in the strata beneath the Gulf of St. Lawrence. Conodont CAI data has proven useful in identifying such tectonic relationships in the southern Appalachians (Harris and Milici, 1977) and in the structure, burial history, and petroleum potential in the overthrust zone of Montana (Perry et al., 1983).

In the Appalachian Orogen of Eastern Canada, only limited discoveries of hydrocarbons have so far been made (Sanford, 1970; Hacquebard and Donaldson, 1970; Hacquebard, 1974; Sikander, 1975; Macauley, 1984; Macauley et al., 1984). From the CAI data reported, the lower Paleozoic strata throughout nearly all this area are supramature with the exception of small areas in eastern Gaspé and the small anomalous areas near Matapedia, Quebec (loc. 58). Many of these strata with CAI values in the range 4-6 (e.g., the Caradoc black shales of the Dunnage Zone in Newfoundland) must have generated considerable hydrocarbons during or after the Acadian Orogeny, but few of the syn- or post-orogenic clastic basins are preserved (except for the Prince Edward Island – Magdalen Islands region). Most have so far proven barren of commercial hydrocarbon deposits, although studies of Carboniferous oil shales in Newfoundland are now under way. The present conodont CAI data for the Appalachian Orogen reveal only eastern Gaspé as a potential zone of maturity for organic matter. Reflectance studies by Sikander and Pittion (1978) of three wells in the Silurian and three in the Devonian strata of the Gaspé showed



CAI	Temperature range °C	CAI	Temperature range °C
1	50 - 80	5	300 - 400
1½	50 - 90	6	350 - 435
2	60 - 140	6½	425 - 500
3	110 - 200	7	480 - 610
4	190 - 300	8	>600

Figure 9. *Upper Silurian localities for which conodont CAI values have been assessed. Detailed information for each numbered locality is provided in the Appendix.*

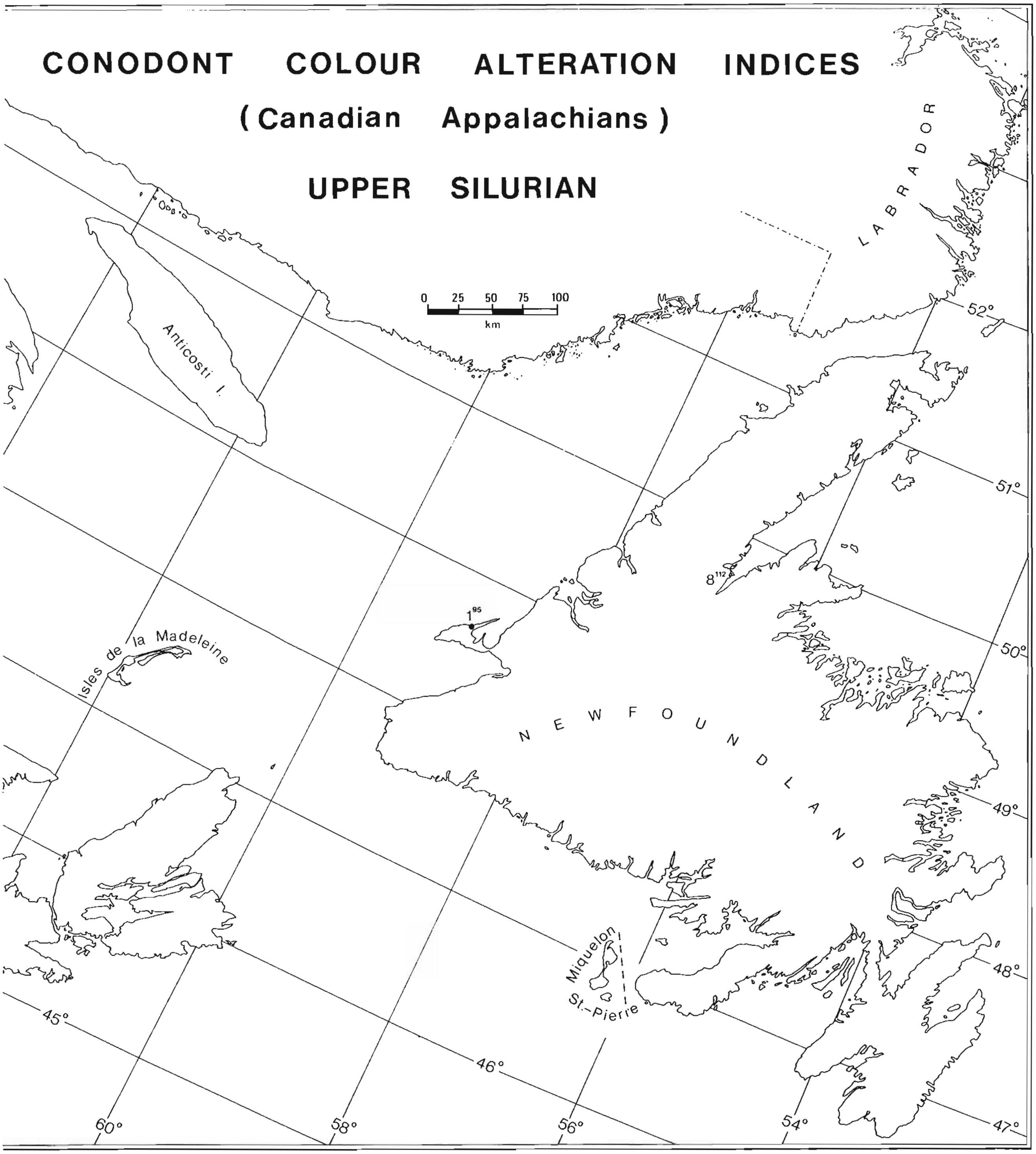


Figure 9. (cont'd)

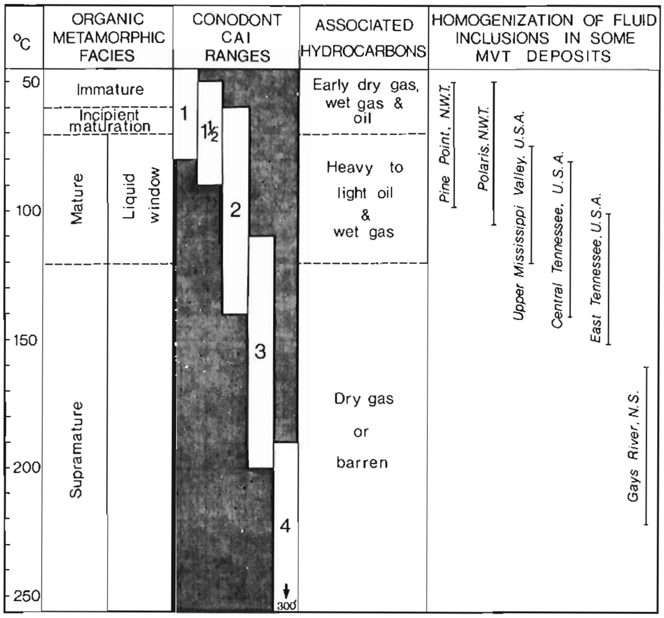


Figure 10. *Correlation of conodont CAI value temperature ranges with stages of hydrocarbon generation and homogenization temperatures of fluid inclusions in selected Mississippi Valley-type (MVT) lead-zinc deposits. CAI temperature ranges are from Epstein et al. (1977). Data in the columns for organic metamorphic facies and associated hydrocarbons are based on information presented by Legall et al. (1982). Homogenization temperatures of fluid inclusions are from Roedder (1976), except for those of the Gays River deposit, which are from Akande and Zentilli (1983).*

similar trends, with immature to mature states in eastern Gaspé increasing rapidly basinward (southwest) to become supramature.

In summary, the present CAI data give inferred levels of organic maturity for the surface outcrops sampled. The areas of maturity that could be considered appropriate for further hydrocarbon exploration include:

i) Eastern Gaspé

ii) Gulf of St. Lawrence east of the Gaspé

iii) South and east of Anticosti Island and west of western Newfoundland

iv) The northern Quebec Basin

v) Overthrust zones of the frontal thrusts in both Quebec and western Newfoundland.

Areas with immature values may have increased maturity with depth e.g., Anticosti Island, Port au Port Peninsula. Other areas of lower Paleozoic strata in Eastern Canada remain unassessed, such as the east coast offshore basins, e.g., east of the Avalon Peninsula.

The hotspot model advocated here to explain high thermal anomalies in the Montreal area and in northern Newfoundland has significance for offshore Mesozoic sequences. If such hotspots were to track under the continental margin after initial rifting and accumulation of potential source and reservoir rocks, the thermal effects could be important in the generation of localized hydrocarbons. Thermal maturity data from the Jurassic and Cretaceous rocks in offshore wells should be reexamined in the light of this possibility. Many of these data are proprietary to the oil companies.

Mineral exploration

Conodont CAI values have several applications in mineral exploration, particularly with respect to the identification of buried intrusions and the assessment of both timing and temperature of emplacement of ore-bearing fluids.

Patterns of CAI values may be used to indicate the proximity of any source of heat, such as buried intrusions, and thus can contribute to the location and discovery of some subsurface deposits (e.g., porphyry copper and skarn deposits). Duba and Williams-Jones (1983b) have used illite crystallinity, organic matter reflectance and isotopic techniques to identify buried intrusions in the Restigouche area at the head of Chaleur Bay. Conodont CAI data from Upper Ordovician strata of the same region (see above) show similar patterns of thermal alteration, but also demonstrate some marked anomalies, as noted originally by Nowlan (1983a). It is clear that a more closely controlled comparison of data obtained from conodont CAI values, illite crystallinity and organic matter reflectance would be very useful for intercalibration of the various schemes.

Conodont CAI data may also be used to detect the temperature of emplacement of ore-bearing fluids, particularly in carbonate-hosted Mississippi Valley-type (MVT) base metal deposits. Conodonts are readily obtainable from the enclosing carbonate rocks. In order to establish the temperature of emplacement of the fluid, it must be taken into account that the general burial temperature (both before and after emplacement) must have been lower than that of the ore-bearing fluid. The regional pattern of burial temperature can, of course, also be established on conodont CAI data. Assuming that a region is thermally unaltered (no appreciable burial), samples taken in close proximity to ore horizons should yield conodonts with CAI values reflecting the temperature of the ore-bearing fluid at the time of emplacement. Such samples should be taken within a few centimetres of the ore, because similar studies adjacent to a volcanic plug of known emplacement temperature (>600°C) suggest that heat is not transmitted very far (1 m) into the country rock (Nicoll, 1981). An important factor to consider in this connection, however, is that water has a high heat capacity and so hydrothermal fluids entering porous rocks might be expected to produce a broader thermal aureole than dry intrusions.

The reported temperatures of emplacement for a selection of Mississippi Valley-type deposits are presented by Roedder (1976) based on studies of fluid inclusions (Fig. 10). Some deposits are relatively "cool" (e.g., Pine Point district, Northwest Territories, Canada: 51°-97°C), whereas others are considerably "warmer" (e.g., East Tennessee district, U.S.A.: about 100°-150°C). The Gays River deposit of Nova Scotia is even hotter (Fig. 10). It may be difficult to detect any change in conodont CAI values close to the "cooler" deposits, because the range of temperature represented by CAI 1 is <50°-80°C, with alteration to CAI 1½ occurring in the 50°-90°C range. For the "hotter" fluids, however, it is to be expected that conodont CAI values will increase with increasing proximity to ore. A preliminary study of this type was undertaken by the senior author and Dr. D.F. Sangster (Geological Survey of Canada, Ottawa) on the Daniel's Harbour lead-zinc deposit in western Newfoundland. In this case however, the background burial temperature for the region was too high (CAI 2, suggesting burial temperatures in the 60°-140°C range). It is planned to make similar studies of the Pine Point district, Northwest Territories, where background burial temperatures are known to be about CAI 1 (however, it is also a low temperature deposit), and of the Polaris deposit on Little Cornwallis Island, Northwest Territories, where background temperatures are also expected to be low (see Figure 10). Polaris may offer the best result because fluid inclusion data indicate an ore-bearing fluid temperature range of 52°-105°C (Roedder, 1976), which may produce conodont CAI values of 1½-2, given a reasonable duration at that temperature range.

Even in cases where enclosing strata are known to be thermally altered, the conodont CAI values obtained, in combination with fluid inclusion data, may indicate something about the timing of emplacement of the ore-bearing fluids. For example, if conodont CAI data suggest deep burial, but fluid inclusion data indicate a low temperature of fluid emplacement, it can be postulated that the strata were buried and uplifted prior to emplacement of the deposit. Obviously burial and uplift take time, so assessment of conodont CAI values in the youngest strata available in the area will provide insight into the timing of ore-fluid emplacement. Such studies will have significance for both exhalative and Mississippi Valley-type deposits.

We expect that several other potential applications for conodont CAI values will be found in the context of mineral exploration. In the short term, it is important to achieve some level of intercalibration of the many different methods of thermal maturation assessment and to put them to the test using case histories of several mineral deposits and districts.

FUTURE STUDIES

This paper represents an initial review of conodont CAI data for Ordovician and Silurian strata of Eastern Canada. Sufficient data have been assembled to determine certain regional patterns and to provide an additional tool for the exploration of hydrocarbon or base metal deposits. Reports of conodonts from the Cambrian and Devonian strata of Eastern Canada are too few to provide significant regional data. Carboniferous conodonts have been widely described (e.g., Globensky, 1967; von Bitter, 1976; von Bitter and Plint-Geberl, 1982) and a later plot of this data will be valuable. It can be combined with organic maturity studies of Carboniferous strata in western Newfoundland currently in progress by R.S. Hyde, R.N. Hiscott and E.T. Burden at Memorial University of Newfoundland and the similar data from the Nova Scotia coalfields assembled by Hacquebard and Donaldson (1970), and Hacquebard (1974).

The authors plan to expand their own collections of lower Paleozoic conodonts from Eastern Canada and to update the conodont CAI maps periodically. Specific detailed projects are under way that involve conodont collections from the Gaspé, western New Brunswick and western Newfoundland with regard to geological structure, biostratigraphy, and the relationship of CAI values to hydrocarbon and base metal occurrences. Particular attention will be paid to acquiring more subsurface samples from both existing and future wells. The type of approach described in this paper has particular relevance to certain aspects of the proposed Lithoprobe East Project, e.g., the thermal history and sedimentary loading of the Anticosti Basin. With conodonts being analyzed from progressively more locations within the Appalachian Orogen, these data will aid substantially in the recognition and delineation of suspect terranes and in the interpretation of regional thrust tectonics as similar data have in the southern Appalachian and Cordilleran orogens.

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APPENDIX

LOCALITY INFORMATION

Each numbered entry in this appendix corresponds to a numbered location on the maps (Figs. 6-9). Data provided are:

A. Sample number(s), upon which CAI assessment for the location was made, with formation name and subsystemic level in parentheses; (abbreviations for samples are: GSC – Geological Survey of Canada locality number; CRB – collection made by C.R. Barnes; LEF – collection made by L.E. Fåhraeus)

B. A brief description of the locality with appropriate references in parentheses

C. Latitude and longitude of the sample(s)

D. Colour Alteration Index (CAI).

1. A. GSC loc. 95770 (Romaine Formation, Lower Ordovician); GSC loc. 95776 (Mingan Formation, Middle Ordovician).
   B. Perroquet Islets, Mingan Archipelago, Quebec (Twenhofel, 1938).
   C. 50°13'18"N, 64°12'24"W; 50°13'N, 64°12'W.
   D. 1

2. A. GSC loc. 95779 (Mingan Formation, Middle Ordovician).
   B. Northeast tip, Mingan Island, Mingan Archipelago, Quebec (Twenhofel, 1938).
   C. 50°13'30"N, 64°07'36"W.
   D. 1

3. A. GSC loc. 95791 (Romaine Formation, Lower Ordovician); GSC loc. 95793 (Mingan Formation, Middle Ordovician).
   B. Inner Birch Island and Outer Birch Island, Mingan Archipelago, Quebec (Twenhofel, 1938).
   C. 50°13'30"N, 64°00'12"W and 50°13'18"N, 64°00'12"W.
   D. 1

4. A. GSC locs. 95802, 95805, 95825 (Romaine Formation, Lower Ordovician); GSC locs. 95813, 95820, 95834, 95838 (Mingan Formation, Middle Ordovician).
   B. Large Island, Mingan Archipelago, Quebec (Twenhofel, 1938).
   C. 50°14'36"N, 63°54'48"W; 50°14'30"N, 63°54'54"W; 50°14'30"N, 63°53'30"W; 50°13'42"N, 63°55'36"W; 50°11'48"N, 63°51'54"W; 50°13'42"N, 63°52'06"W; 50°13'30"N, 63°52'00"W.
   D. 1

5. A. GSC loc. 95846 (Mingan Formation, Middle Ordovician).
   B. Quarry Island, Mingan Archipelago, Quebec (Twenhofel, 1938).
   C. 50°13'00"N, 63°50'30"W.
   D. 1

6. A. GSC loc. 95852 (Romaine Formation, Lower Ordovician); GSC loc. 95857 (Mingan Formation, Middle Ordovician).
   B. Niapisca Island, Mingan Archipelago, Quebec (Twenhofel, 1938).
   C. 50°13'42"N, 63°45'36"W; 50°13'12"N, 63°45'48"W.
   D. 1

7. A. GSC locs. 95867, 95885, 95897 (Romaine Formation, Lower Ordovician); GSC locs. 95874, 95881, 95895, 95900, 95905 (Mingan Formation, Middle Ordovician).
   B. Eskimo Island and Quin Island (GSC loc. 95874 and 95881 only), Mingan Archipelago, Quebec (Twenhofel, 1938).
   C. 50°14'18"N, 63°41'18"W; 50°14'06"N, 63°38'24"W; 50°13'42"N, 63°36'00"W; 50°13'36"N, 63°41'18"W; 50°13'12"N, 63°40'48"W; 50°13'06"N, 63°39'36"W; 50°13'36"N, 63°35'48"W; 50°13'30"N, 63°35'36"W.
   D. 1

8. A. GSC loc. 95915 (Romaine Formation, Lower Ordovician); GSC loc. 95918 (Mingan Formation, Middle Ordovician).
   B. Sea Cow Island, Mingan Archipelago, Quebec (Twenhofel, 1938).
   C. 50°13'24"N, 63°33'12"W; 50°13'30"N, 63°33'06"W.
   D. 1

9. A. GSC locs. 95936, 95954, 95964 (Romaine Formation, Lower Ordovician); GSC locs. 95946, 95962 (Mingan Formation, Middle Ordovician).
   B. Clearwater Point, Ammonite Point (GSC locs. 95954, 95962) and northwestern St. Charles Island (GSC loc. 95964), Mingan Archipelago, Quebec (Twenhofel, 1938).
   C. 50°13'42"N, 63°27'30"W; 50°12'54"N, 63°23'42"W; 50°13'00"N, 63°20'48"W; 50°12'42"N, 63°27'42"W; 50°12'06"N, 63°24'06"W.
   D. 1

10. A. GSC locs. 95971, 95983 (Mingan Formation, Middle Ordovician)
    B. St. Charles Island, Mingan Archipelago, Quebec (Twenhofel, 1938),
    C. 50°12'48"N, 63°21'12"W; 50°12'12"N, 63°18'48"W.
    D. 1

11. A. GSC loc. 95989 (Romaine Formation, Lower Ordovician); GSC loc. 95992 (Mingan Formation, Middle Ordovician).
    B. Hunting Island and Wood Island, Mingan Archipelago, Quebec (Twenhofel, 1938).
    C. 50°13'42"N, 63°11'36"W; 50°12'06"N, 63°12'00"W.
    D. 1

12. A. GSC loc. 95998 (Romaine Formation, Lower Ordovician).
    B. Indian Point, shore opposite east end of Mingan Archipelago, Quebec (Twenhofel, 1938).
    C. 50°16'30"N, 63°06'12"W.
    D. 1

13. A. GSC loc. 96012 (Romaine Formation, Lower Ordovician).
    B. Harbour Island, Mingan Archipelago, Quebec (Twenhofel, 1938).
    C. 50°17'06"N, 64°01'00"W.
    D. 1

14. A. GSC loc. 96019 (Romaine Formation, Lower Ordovician).
    B. Moutange Island, Mingan Archipelago, Quebec (Twenhofel, 1938).
    C. 50°16'42"N, 63°49'42"W.
    D. 1

15. A. GSC locs. 96003, 96005 (Romaine Formation, Lower Ordovician).
    B. Ste. Geneviève Island, Mingan Archipelago, Quebec (Twenhofel, 1938).
    C. 50°15'30"N, 63°04'12"W.
    D. 1

16. A. GSC loc. 96028 (Cloridorme Formation, Lower Ordovician).
    B. Roadside exposure near Petite Vallée, Quebec.
    C. 49°13'15"N, 65°02'12"W.
    D. 4

17. A. GSC loc. 96030 (Cap-des-Rosiers Formation, Lower Ordovician).
    B. Cap des Rosiers lighthouse, Quebec.
    C. 48°51'21"N, 64°12'07"W.
    D. 4

18. A. GSC locs. 96038-96040 (Anse à Pierre Loiselle Formation, Lower Silurian).
    B. Roadcut, 3.2 km northeast of Gascons, Quebec (Bourque and Lachambre, 1981).
    C. 48°12'20"N, 64°49'30"W.
    D. 1½

19. A. GSC locs. 96524, 96529, 96530, 96536 (La Vieille Formation, Lower Silurian).
    B. Black Cape Section, Howatson Point, near New Richmond, Gaspé Peninsula, Quebec (Bourque and Lachambre, 1981, Figs. 2, 24; Nowlan, 1983b).
    C. 48°08'30"N, 65°50'19"W to 48°08'23"N, 65°50'10"W.
    D. 2½

20. A. GSC locs. 96052, 96671, 96675, 96676 (Matapedia Group, Upper Ordovician).
    B. Section along Highway 132, west of Matapedia, Quebec, from Matapedia to Mann Settlement; type area of Matapedia Group (Nowlan, 1981b, Fig. 2).
    C. 47°58'53"N, 66°57'15"W to 48°00'02"N, 67°01'02"W.
    D. 5

21. A. GSC locs. 96053, 96677-96681, 96683-96686 (Matapedia Group, Upper Ordovician).
    B. Section along Highway 132, west of Matapedia, Quebec, from St. Alexis Station to Dawson; type area of Matapedia Group (Nowlan, 1981b, Fig. 2).
    C. 47°58'33"N, 66°56'43"W to 48°02'05"N, 67°02'40"W.
    D. 5

22. A. GSC locs. 97329-97331 (Armstrong Brook Formation), GSC locs. 97332-97343 (Limestone Point Formation), GSC locs. 97346-97357 (La Vieille Formation), GSC locs. 97380-97385 (Limestone Point Formation); all Lower Silurian.
    B. Quinn Point Section and Flanagan's Section (GSC locs. 97380-97385 only) near Jacquet River, New Brunswick (Noble, 1976, Figs. 1, 2; Nowlan, 1983b).
    C. 47°55'11"N, 65°56'42"W to 47°55'06"N, 65°57'18"W.
    D. 3

23. A. GSC locs. 96063, 96064 (Tetagouche Group, Middle Ordovician).
    B. Camel Back Mountain, northern New Brunswick (Nowlan, 1981a, Fig. 1).
    C. 47°33'03"N, 66°23'55"W and 47°33'05"N, 66°23'58"W.
    D. 5

24. A. GSC loc. 96066 (Tetagouche Group, Lower Ordovician).
    B. Arenig brachiopod locality, Lower Birch Island, Miramichi River, northwest of Boiestown, New Brunswick (Nowlan, 1981a, Fig. 4).
    C. 46°34'10"N, 66°34'20"W.
    D. 5

25. A. GSC loc. 96067 (Tetagouche Group, Lower Ordovician).
    B. Middle Hayden Brook, near Taxis River, New Brunswick (Nowlan, 1981a, Fig. 3).
    C. 46°27'25"N, 66°46'15"W.
    D. 5+

26. A. GSC locs. 96073, 96074, 97012-97014 (Belle Lake Slate, Middle Ordovician).
    B. Waterville Quarry, New Brunswick (Nowlan, 1981a, Fig. 5).
    C. 46°04'50"N, 67°19'10"W.
    D. 5+

27. A. GSC locs. 96076, 97492 (Scott Siding Slate, ?Lower Silurian with Middle-Upper Ordovician derived material).
    B. Trans-Canada Highway east of Canterbury Road, west of Fredericton, New Brunswick (Venugopal, 1979).
    C. 45°58'57"N, 67°26'15"W.
    D. 5

28. A. GSC locs. 96106, 96107 (Bulstrode Formation, Middle Ordovician).
    B. Bulstrode River, southwest of Princeville, Quebec (Globensky, 1978).
    C. 46°07'51"N, 71°53'40"W and 46°07'25"N, 71°55'11"W.
    D. 5

29. A. GSC locs. 96222-96227, (Table Head Group, Middle Ordovician) GSC loc. 99518 (St. George Group, Lower Ordovician).
    B. Table Point, western Newfoundland (Klappa et al., 1980; Fåhraeus, 1970).
    C. 50°21'39"N, 57°32'15"W to 50°22'28"N, 57°31'42"W.
    D. 2+

30. A. GSC locs. 96228-96230 (Cow Head Group, Lower Ordovician).
    B. Cow Head, western Newfoundland; type section of Cow Head Group (Kindle and Whittington, 1958; Fåhraeus and Nowlan, 1978).
    C. 49°54'57"N, 57°49'55"W.
    D. 1½

31. A. GSC locs. 96231, 96232; CRB-BP-45 (Cow Head Group, Lower Ordovician).
    B. Broom Point, western Newfoundland (Kindle and Whittington, 1958; Fortey et al., 1982).
    C. 49°50'06"N, 57°52'05"W.
    D. 1½

32. A. GSC locs. 96235, 96236 (Catoche Formation, St. George Group, Lower Ordovician).
B. Lower Cove, Port au Port Peninsula, western Newfoundland (Schuchert and Dunbar, 1934).
C. 48°31'11"N, 59°00'30"W.
D. 1

33. A. GSC locs. 96237, 96238 (St. George and Table Head groups, respectively, Lower Ordovician).
B. Aguathuna Quarry, Port au Port Peninsula, western Newfoundland (Schuchert and Dunbar, 1934).
C. 48°33'42"N, 58°46'15"W.
D. 1

34. A. GSC loc. 96239 (Table Head Group, Middle Ordovician).
B. West Bay Centre, Port au Port Peninsula, western Newfoundland (Schuchert and Dunbar, 1934).
C. 48°35'34"N, 58°55'17"W.
D. 1

35. A. GSC locs. 96241, 98707, 98708 (Long Point Formation, Middle Ordovician).
B. Black Duck Brook, Long Point, Port au Port Peninsula, western Newfoundland.
C. 48°41'04"N, 58°53'30"W.
D. 1

36. A. GSC loc. 96392 (Matapedia Group, Upper Ordovician).
B. Side road near Kempt Ouest River, north of Restigouche River, Quebec (Béland, 1958; Nowlan, 1981b).
C. 48°03'23"N, 66°49'19"W.
D. 5

37. A. GSC locs. 96397-96399, 96403, 96413, 96418, 96420, 96422, 96426-96428, 98054 (Clemville Formation), GSC locs. 96429, 96430 (Weir Formation), GSC loc. 96431 (Anse Cascon Formation), GSC loc. 96432 (La Vieille Formation); all Lower Silurian.
B. Clemville Anticline, Petit Port-Daniel River near Clemville, Quebec; includes type section of Clemville Formation and north and south flanks of Clemville Anticline (Bourque and Lachambre, 1981, Figs. 2, 16; Nowlan, 1981b, 1983b).
C. 48°10'42"N, 65°00'54"W to 48°10'53"N, 65°01'46"W.
D. 1½

38. A. GSC loc. 96471 (Matapedia Group, Upper Ordovician to Lower Silurian).
B. Beauglen, near St. Jules, Quebec (Alcock, 1935, p. 22).
C. 48°16'07"N, 65°58'22"W.
D. 4

39. A. GSC locs. 96473, 96474 (Honorat Group, Upper Ordovician?).
B. Duval River, 3.2 km northwest of St. Elzéar, Quebec (Bourque and Lachambre, 1981, Fig. 2; Nowlan, 1981b, p. 260).
C. 48°10'48"N, 65°25'26"W.
D. 5

40. A. GSC locs. 96513-96515 (Matapedia Group, Upper Ordovician?).
B. Ruisseau Chaput, north of Carleton Ouest, Quebec.
C. 48°07'28"N, 66°10'56"W to 48°07'20"N, 66°11'02"W.
D. 4

41. A. GSC locs. 27910, 96548, 98372 (White Head Formation, Upper Ordovician).
B. Grande Coupe (GSC loc. 27910) and Priest's Road localities, near Percé, Quebec (Schuchert and Cooper, 1930; Nowlan, 1981b, Fig. 3).
C. 48°32'09"N, 64°14'05"W and 48°32'26"N, 64°15'25"W.
D. 1½

42. A. GSC locs. 96554, 96557, 96559, 96566, 96568-96570, 96572, 96573, 96575, 96588, 96591, 96594, 96596, 96598, 96601, 96604, 96605 (White Head Formation, Upper Ordovician); GSC locs. 96617, 96618, 96631, 96632, 96634, 96640 (White Head Formation, Lower Silurian).
B. Amphitheatre (GSC locs. 96554, 96557 only), north side of Cap Blanc – type section of White Head Formation (GSC locs. 96559-96575), Flynn Road Section (GSC locs. 96588-96640), Percé area, Quebec (Schuchert and Cooper, 1930; Nowlan, 1981b, Fig. 3).
C. 48°31'18"N, 64°14'56"W to 48°31'13"N, 64°14'54"W (Amphitheatre);
48°30'48"N, 64°13'11"W to 48°30'18"N, 64°13'07"W (Cap Blanc);
48°30'43"N, 64°13'43"W to 48°30'27"N, 64°14'16"W (Flynn Road).
D. 1½

43. A. GSC locs. 96549, 96550 (White Head Formation, Upper Ordovician), GSC locs. 96645-96649, 96658, 96659 (White Head Formation, Lower Silurian).
B. Murphy Creek (GSC locs. 96549, 96550) and "Cannes-de-Roches" Brook, Percé area, Quebec (Skidmore and Lespérance, 1981; Nowlan, 1981b, Fig. 3).
C. 48°33'28"N, 64°21'12"W and 48°31'24"N, 64°16'12"W to 48°31'07"N, 64°16'06"W.
D. 1½

44. A. GSC locs. 96662, 96663 (Matapedia Group, Upper Ordovician).
B. Highway 132, northeast of Matapedia, Quebec, at McDavid and Delaney creeks (Nowlan, 1981b, Fig. 2).
C. 47°59'19"N, 66°52'35"W, 49°59'49"N, 66°53'35"W.
D. 4

45. A. GSC locs. 96664, 96668, 96669 (Matapedia Group, Upper Ordovician).
B. Matapedia, Quebec (Nowlan, 1981b, Fig. 2).
C. 47°58'33"N, 66°56'42"W to 47°58'39"N, 66°56'22"W.
D. 5

46. A. GSC locs. 97006, 97009 (Tetagouche Group, Lower to Middle Ordovician).
B. Tetagouche Falls, west of Bathurst, New Brunswick (Nowlan, 1981a, Fig. 1).
C. 47°38'30"N, 65°43'13"W.
D. 5

47. A. GSC loc. 97092 (Smyma Mills Formation, ?Lower Silurian).
    B. Pole Hill Road on south branch of Burlock Creek (Fyffe, 1982).
    C. 46°16'04"N, 67°23'10"W.
    D. 1½

48. A. GSC loc. 97320 (New Canaan Formation, Lower to Upper Silurian).
    B. New Canaan gravel pit, Nova Scotia (Crosby, 1962).
    C. 45°02'02"N, 64°28'40"W.
    D. 5

49. A. GSC loc. 97326 (Kentville Formation, Lower to Upper Silurian).
    B. Fales River Section, Nova Scotia (Schenk et al., 1980; Crosby, 1962).
    C. 44°57'16"N, 64°53'55"W.
    D. 5

50. A. GSC locs. 97358-97378 (La Vieille Formation, Lower Silurian).
    B. Culligan railroad cut, northern New Brunswick (Noble, 1976).
    C. 47°54'58"N, 65°55'50"W.
    D. 3

51. A. GSC locs. 97386-97407 (Limestone Point Formation, Lower Silurian); GSC locs. 97408-97412 (La Vieille Formation, Lower Silurian).
    B. Hendry Brook Sections, northwest of Pointe Verte, New Brunswick (Noble, 1976; Nowlan 1983b).
    C. 47°53'06"N, 65°48'23"W to 47°53'24"N, 65°48'56"W.
    D. 3½+

52. A. GSC locs. 97416-97425 (La Vieille Formation, Lower Silurian).
    B. Pointe La Roche, New Brunswick (Lee and Noble, 1977, Figs. 3, 6).
    C. 47°58'37"N, 66°14'04"W.
    D. 4

53. A. GSC locs. 97427-97433, 97436-97438, 97450-97453 (Limestone Point Formation, Lower Silurian), GSC loc. 97449 (Matapedia Group, Lower Silurian).
    B. Dickie Cove Brook (GSC locs. 97427-97433), Dickie Point (GSC locs. 97436-97438), Black Point (GSC locs. 97449-97453), New Brunswick (Lee and Noble, 1977, Figs. 2, 6; Nowlan, 1983b).
    C. 47°57'07"N, 66°07'45"W; 47°57'12"N, 66°07'21"W; and 47°56'34"N, 66°06'24"W.
    D. 4½+

54. A. GSC locs. 97455-97457, 97459, 97470, 97471 (?West Point Formation, Upper Silurian to Lower Devonian).
    B. Highway 11 at Laplante Road overpass, northern New Brunswick (Noble, 1980; Nowlan, 1983b, p. 106).
    C. 47°46'35"N, 65°46'25"W.
    D. 5

55. A. GSC locs. 97473-97481 (Limestone Point Formation, Lower Silurian), GSC locs. 97482-97488 (La Vieille Formation, Lower Silurian), GSC loc. 97707 (Armstrong Brook Formation, Lower Silurian).
    B. Limestone Point, New Brunswick; type section of Limestone Point Formation (Noble, 1976, Figs. 1, 2; Nowlan, 1983b).
    C. 47°48'54"N, 65°43'34"W.
    D. 4

56. A. GSC locs. 97503-97505 (Matapedia Group?, Lower Silurian).
    B. Trans-Canada Highway, south of Grand Falls, New Brunswick.
    C. 47°00'15"N, 67°45'14"W.
    D. 5

57. A. GSC loc. 97693 (Carys Mills Formation, Lower Silurian).
    B. Gorge in Grand Falls, New Brunswick.
    C. 47°03'05"N, 67°44'14"W.
    D. 5

58. A. GSC locs. 97709, 98330-98332, 98336-98340, 98343 (Grog Brook Group, Upper Ordovician).
    B. Restigouche River, New Brunswick, 7 km south of Matapedia, Quebec (Nowlan, 1983a, Figs. 1, 2).
    C. 47°54'22"N, 66°56'42"W.
    D. 1½

59. A. GSC loc. 97514 (Craig Brook Limestone, Middle Ordovician).
    B. Ashland Quarry, Coldstream area, New Brunswick (St. Peter, 1982, p. 18).
    C. 46°18'50"N, 67°25'45"W.
    D. 5

60. A. GSC loc. 98006 (Craig Brook Limestone, Middle to Upper Ordovician).
    B. Craig Brook, 700 m upstream from its confluence with Becaguimec River, New Brunswick (St. Peter, 1982, p. 17).
    C. 46°22'00"N, 67°23'29"W.
    D. 4

61. A. GSC locs. 98183, 98185, 98187, 98189, 98191, 98193 (Anse à Pierre Loiselle Formation, Lower Silurian), GSC locs. 98195, 98201, 98213, 98223, 98225 (La Vieille Formation, Lower Silurian).
    B. Railroad cut above Anse à Pierre Loiselle, near Gascons, Quebec (Bourque and Lachambre, 1981, Figs. 2, 12; Nowlan, 1983b).
    C. 48°12'13"N, 64°49'05"W.
    D. 1½

62. A. GSC loc. 98624 (Craig Brook Limestone, Middle Ordovician).
    B. Markey Brook, south bank, near Windsor, New Brunswick (St. Peter, 1982, p. 19).
    C. 46°23'15"N, 67°25'42"W.
    D. 5

63. A. GSC loc. 98734 (White Head Formation, Lower Silurian)
B. Unnamed brook running northeastward into Portage River, Canton de Fortin, Quebec.
C. 49°34'27"N, 64°30'46"W.
D. 2

64. A. GSC locs. 98735, 98736 (White Head Formation, Upper Ordovician).
B. Pabos Road, Canton de Joncas, 1-2 km south of bridge over Grand River, Quebec.
C. 48°34'50"N, 64°49'10"W; 48°34'55"N, 64°50'30"W.
D. 2½

65. A. GSC locs. 98737, 98738, 99438, 99440, 99442 (White Head Formation, Upper Ordovician).
B. All samples within a kilometre of Pabos Road bridge over Petit Pabos River: Pabos Road, about 1 km south of Petit Pabos River (GSC locs. 98737, 98738); Russeau Boisvert, 1 km upstream from confluence with Petit Pabos River (GSC loc. 99438); Petit Pabos River about 250 m downstream from bridge (GSC loc. 99440); Pabos Road, about 150 m west of bridge (GSC loc. 99442).
C. 48°33'40"N, 64°54'40"W; 48°33'57"N, 64°53'43"W; 48°33'57"N, 64°54'05"W; 48°34'08"N, 64°54'10"W.
D. 3½

66. A. GSC locs. 98739, 98745 (Ellis Bay Formation, Upper Ordovician), GSC locs. 98747-98749 (Bescie Formation, Lower Silurian).
B. Section about 1.6 km west of Fox Point, Anticosti Island, Quebec (Nowlan, 1982, Figs. 1, 2).
C. 49°19'14"N, 61°51'32"W.
D. 1

67. A. GSC loc. 49950 (Sources Formation, Lower Silurian).
B. Roadside outcrop on east side of Cap Chat River about 0.9 km southeast of confluence with Ruisseau Alphonse, Quebec (probably the same as F2 of Mattinson, 1964, p. 76).
C. 48°46'18"N, 66°42'26"W.
D. 4½

68. A. GSC locs. 96216, 96217 (Davidsville Group, Middle Ordovician).
B. North side of Cuff Pond, south of Island Pond, Newfoundland (close to localities noted by Stouge, 1980).
C. 49°15'00"N, 54°18'00"W.
D. 5

69. A. GSC locs. 87755, 87756 (Cobbs Arm Limestone, Middle Ordovician).
B. Squid Cove at Fairbank, New World Island, Newfoundland (probably equivalent to conodont locality 9 of Bergstrom et al., 1974, Fig. 6).
C. 49°33'30"N, 54°43'12"W.
D. 5

70. A. GSC loc. 87777 (Table Head Group, Middle Ordovician).
B. Southwest of Lourdes, Port au Port Peninsula, Newfoundland (Fåhraeus, 1973, Fig. 1).
C. 48°38'54"N, 58°59'52"W.
D. 1

71. A. Samples 1, 2, 6, 13, 27, 35 and 41 of Nowlan and Barnes (1981) (Vauréal Formation, Upper Ordovician).
B. Oil River Section, Anticosti Island, Quebec (Nowlan and Barnes, 1981).
C. 49°50'26", 63°33'00"W to 49°45'32"N, 63°34'20"W.
D. 1

72. A. Samples 44-96 of Nowlan and Barnes (1981), (Vauréal Formation, Upper Ordovician).
B. English Head to West Point, Anticosti Island, Quebec (Nowlan and Barnes, 1981).
C. 49°54'07"N, 64°29'25"W to 49°51'51"N, 64°31'25"W.
D. 1

73. A. Samples 99-101 of Nowlan and Barnes (1981), (Vauréal Formation, Upper Ordovician).
B. Anse aux Fraises, Anticosti Island, Quebec (Nowlan and Barnes, 1981).
C. 49°51'16"N, 64°27'16"W.
D. 1

74. A. Sample 102 of Nowlan and Barnes (1981), (Vauréal Formation, Upper Ordovician); samples S01-S10 of McCracken and Barnes (1981), (Ellis Bay Formation, Upper Ordovician).
B. Salmon River Section, lower part, Anticosti Island, Quebec (Section IIIA, McCracken and Barnes, 1981).
C. 49°24'28"N, 62°20'40"W to 49°23'53"N, 62°24'21"W.
D. 1

75. A. LEF-M$_1$TH (Table Head Group, Middle Ordovician).
B. Little Springs Inlet, Newfoundland (Fåhraeus, 1970, p. 2067).
C. 51°13'15"N, 55°51'10"W.
D. 5

76. A. Samples A and B of Barnes and Tuke (1970), (St. George Group, Lower Ordovician).
B. Cape Norman, Newfoundland (Barnes and Tuke, 1970, p. 80, Fig. 5).
C. 51°36'51"N, 55°56'10"W.
D. 3½+

77. A. GSC locs. 82740, 82742-82744, 82749, 82750, 83354, 83355 (Lévis Formation, Middle Ordovician).
B. Côte Fréchette and Montcalm St. (GSC locs. 83354, 83355 only), Lévis, Quebec (Uyeno and Barnes, 1970).
C. 46°48'25"N, 71°11'10"W and 46°48'59"N, 71°10'55"W.
D. 2

78. A. GSC locs. 11425, 38642 (Mystic Formation, Lower Ordovician) GSC locs. 84522, 84523, 84531, 84533, 84541, 84544; CRB-MCI to MC37 (Mystic Formation, Middle Ordovician).
B. Localities 3 km north and 0.8 km west of Mystic, Quebec (Barnes and Poplawski, 1973, localities 1-3).
C. 45°11'08"N, 72°59'11"W and 45°09'41"N, 72°59'31"W.
D. 4½

79. A. Samples E02-E42 of McCracken and Barnes (1981), (Ellis Bay Formation, Upper Ordovician), samples E43-E61 of McCracken and Barnes (1981), (Ellis Bay Formation, Lower Silurian).
B. Cape Henry, Ellis Bay, Anticosti Island, Quebec (McCracken and Barnes, 1981, Sections IA, IB, IB').
C. 49°49'11"N, 64°23'55"W.
D. 1

80. A. Samples V05-V21 of McCracken and Barnes (1981), (Ellis Bay Formation, Upper Ordovician).
B. Vauréal River section, Anticosti Island, Quebec (McCracken and Barnes, 1981, Section II).
C. 49°32'39"N, 62°41'59"W.
D. 1

81. A. Samples NS.1.3, NS.2.4, NS.2.16, NS.3.3, NS.3.7, NS.4.6 of Globensky and Jauffred (1971), (Trenton Group, Middle Ordovician).
B. Neuville Station, Quebec (Globensky and Jauffred, 1971, Fig. 2).
C. 46°43'15"N, 71°33'23"W to 46°43'02"N, 71°33'06"W.
D. 1½

82. A. GSC locs. 97971, 98687 (Glover Formation, Lower Ordovician).
B. Grand Lake area, 3 km northeast of Corner Pond, west central Newfoundland.
C. 48°38'00"N, 57°42'00"W.
D. 5½

83. A. GSC locs. 96154, 96166 (unnamed unit, Lower Silurian).
B. East side of School Brook Cove, Cape George, Nova Scotia (Keppie, 1980, Fig. 1).
C. 45°53'01"N, 61°55'50"W.
D. 5½+

84. A. GSC locs. 38996, 39013, 39022, 39070, 39093, 70360 (Stonehouse Formation, Upper Silurian).
B. Shore of Northumberland Strait, south of Arisaig, Nova Scotia; type section of the Stonehouse Formation (Legault, 1968).
C. 45°44'04"N, 62°12'32"W.
D. 3

85. A. GSC loc. 96085 (McNeil Formation, Cambrian).
B. McNeil Brook, Cape Breton Island, Nova Scotia (Hutchinson, 1952, p. 45).
C. 46°58'43"N, 60°13'05"W.
D. 5

86. A. Samples 001-008 of Fåhraeus and Barnes (1981), (Becscie Formation, Lower Silurian).
B. Coastal section at mouth of Becscie River, Anticosti Island, Quebec (Fåhraeus and Barnes, 1981, Figs. 1, 2).
C. 49°42'42"N, 64°03'49"W.
D. 1

87. A. Samples 144-164 of Fåhraeus and Barnes (1981), (Gun River Formation, Lower Silurian).
B. Coastal section near mouth of La Loutre River, Baie Lafayette, Anticosti Island, Quebec (Fåhraeus and Barnes, 1981, Figs. 1, 2).
C. 49°37'05"N, 63°48'01"W.
D. 1

88. A. GSC locs. C-92651 - C-92668, C-92680 - C-92697 (Jupiter Formation, Lower Silurian).
B. Sections north and south of the mouth of the Jupiter River, Anticosti Island, Quebec (Uyeno and Barnes, 1983, Fig. 1).
C. 49°28'47"N, 63°36'52"W.
D. 1

89. A. Samples 167-189 of Fåhraeus and Barnes (1981), (Becscie Formation, Lower Silurian).
B. Jupiter River, 24-mile lodge, Anticosti Island, Quebec (Fåhraeus and Barnes, 1981, Figs. 1, 2).
C. 49°37'34"N, 63°25'48"W.
D. 1

90. A. GSC locs. C-92670 - C-92674 (Jupiter Formation, Lower Silurian) GSC locs. C-92676, C-92677 (Chicotte Formation, Lower Silurian).
B. Brisants Jumpers, Anticosti Island, Quebec (Uyeno and Barnes, 1983, Figs. 1, 2).
C. 49°22'49"N, 63°31'57"W.
D. 1

91. A. GSC loc. 98599 (Smyrna Mills Formation, ? Lower Silurian).
B. East ditch of highway, 30 m north of private road leading east to Payson Lake, New Brunswick.
C. 46°14'37"N, 67°39'28"W.
D. 5

92. A. GSC locs. 98950, 98961, 98965-98970 (Buchans Group, Middle Ordovician).
B. Diamond drill holes H2764 and H2933, 5 km southwest of Buchans, Newfoundland (Nowlan and Thurlow, 1984, Fig. 1, appendix).
C. 48°47'39"N, 56°54'27"W (H2764), 48°47'32"N, 56°54'34"W (H2933).
D. 4

93. A. GSC loc. C-92669 (Jupiter Formation, Lower Silurian).
B. Fire Tower Road, Anticosti Island, Quebec (Uyeno and Barnes, 1983, Fig. 2).
C. 49°32'20"N, 63°21'20"W.
D. 1

94. A. GSC locs. C-92678, 92679 (Chicotte Formation, Lower Silurian).
B. Southwest Point, Anticosti Island, Quebec (Uyeno and Barnes, 1983, Figs. 1, 2).
C. 49°23'39"N, 63°35'06"W.
D. 1

95. A. GSC loc. 98704 (Clam Bank Formation, Upper Silurian).
B. Red Point, Port au Port Peninsula, Newfoundland (Rodgers, 1965).
C. 48°39'08"N, 59°01'45"W.
D. 1

96. A. GSC loc. 96103 (Famine Limestone, Devonian).
B. St. George de Beauce, Quebec, intersection of Avenue du Cap with Boulevard Lacroix on Highway 173 (MacKay, 1921).
C. 46°07'38"N, 70°40'42"W.
D. 5

97. A. GSC loc. 96102 (Touladi Formation, Devonian).
B. 6.5 km south of Cabano, Quebec (Lespérance and Greiner, 1969, fossil locality, Fig. 28).
C. 47°37'45"N, 68°51'10"W.
D. 5

98. A. CRB-07, 09 (Leray Formation), CRB-011 (Rockland Formation), CRB-013 (Deschambault Formation) – all Middle Ordovician.
B. Ouareau River Section, Quebec (Clark and Globensky, 1976b, p. 14).
C. 45°59'18"N, 73°30'35"W.
D. 2+

99. A. CRB-RFQ-1, 2, 3 (Leray Formation, Middle Ordovician), CRB-FQ-1, 2, 3 (Ouareau Formation, Middle Ordovician).
B. Radnor-des-Forges Quarry (RFQ samples) and Fontaine Quarry (FQ Samples), Quebec (Clark and Globensky, 1976c, Fig. 9).
C. 46°29'40"N, 72°32'48"W and 46°29'19"N, 72°31'11"W.
D. 2

100. A. CRB-STAQ-1, 2, 3, 4 (Deschambault Formation, Middle Ordovician).
B. Dam section on Sainte-Anne River just southeast of St. Alban, Quebec (Clark and Globensky, 1975, Fig. 23).
C. 46°42'29"N, 72°04'29"W.
D. 1½+

101. A. CRB-PRQ 1, 2, 3 (Black River Group, Middle Ordovician).
B. Section along Jacques-Cartier River at Pont-Rouge, Quebec (Clark and Globensky, 1973, p. 16).
C. 46°45'30"N, 71°42'54"W.
D. 1½+

102. A. CRB-LQ-1, 2 (Ouareau Formation, Middle Ordovician).
B. Loretteville, Quebec.
C. 46°51'30"N, 71°21'03"W.
D. 1½+

103. A. CRB-MQ 2, 4, 8 (Deschambault, Middle Ordovician).
B. Left bank of Montmorency River, above Montmorency Falls, Quebec (Riva, 1972, Stop 1b).
C. 46°53'32"N, 71°09'12"W.
D. 1½+

104. A. CRB-V8, 9 (Leray – Ouareau formations, Middle Ordovician).
B. Quarry, just south of Saint-Vincent-de-Paul, Montreal region, Quebec (Clark, 1972).
C. 45°36'19"N, 73°39'26"W.
D. 3½

105. A. CRB-STM-5, 7, 9 (Chazy Group, Middle Ordovician).
B. Cap-Saint-Martin Quarry, Montreal region, Quebec (Clark, 1972, p. 59).
C. 45°35'30"N, 73°42'30"W.
D. 3+

106. A. CRB-STD-3, 5 (Isle la Motte Formation, Middle Ordovician).
B. Quarry, 0.8 km northwest of St. Dominique, Quebec (Kay, 1958, p. 72, Fig. 6).
C. 45°35'05"N, 72°52'35"W.
D. 4

107. A. CRB-AC-1 (Hastings Creek Formation, Lower Ordovician).
B. Stanbridge station, Quebec (Eakins, 1963, Stop 2, p. 81, 89).
C. 45°04'48"N, 73°02'42"W.
D. 4

108. A. CRB-CHQ1, 2, 5, 6, 8-12, 14-16 (Black River Group, Middle Ordovician).
B. Chicoutimi, Quebec (Sinclair, 1953).
C. 48°28'57"N, 71°06'12"W.
D. 1½

109. A. GSC locs. 84869, 84871, 84873, (Deschambault Formation, Middle Ordovician).
B. Abandoned Lavallée quarry 5 km south of Sainte-Elizabeth, west of Berthierville, Quebec (Clark and Globensky, 1976a).
C. 46°00'03"N, 73°21'17"W.
D. 2½

110. A. GSC loc. 82096 (Table Head Group, Middle Ordovician).
B. Black Point, Pointe Riche Peninsula, western Newfoundland (Klappa et al., 1980, Section 11).
C. 50°42'50"N, 57°23'38"W.
D. 2

111. A. GSC locs. 88285-88287, 88301, 88302 (St. George-Table Head groups, Lower to Middle Ordovician).
B. Eddies Cove, Northern Peninsula, Newfoundland (Knight, 1977).
C. 51°15'04"N, 56°12'45"W to 51°25'55"N, 56°06'57"W.
D. 3½+

112. A. CRB-SA3, 6 (Natlins Cove Formation, ? Upper Silurian).
B. West side of Little Spear Cove and point between Spear Cove and Little Spear Cove (Smyth and Schillereff, 1982).
C. 49°43'02"N, 56°48'40"W to 49°44'06"N, 56°48'47"W.
D. 8

113. A. GSC loc. 83100 (St. George Group, Lower Ordovician).
B. South side of Barbace Cove, Port-au-Choix Peninsula, western Newfoundland (Schuchert and Dunbar, 1934).
C. 50°43'30"N, 57°21'37"W.
D. 2+

114. A. CRB-MP 35, 37, 38 (Cow Head Group, Lower Ordovician).
B. Martin Point, western Newfoundland (Kindle and Whittington, 1958).
C. 49°46'11"N, 57°54'42"W.
D. 1½

115. A. CRB-GP-1A (Cow Head Group, Lower Ordovician).
B. Green Point, western Newfoundland (Kindle and Whittington, 1958).
C. 49°40'02"N, 57°58'00"W.
D. 1½

116. A. LEF-1970-Bowater Station (Table Head Group, Middle Ordovician).
B. North of Main Brook, Hare Bay at Bowater Station (Fåhraeus, 1970).
C. 51°11'45"N, 56°00'30"W.
D. 5½

117. A. LEF-QCS-13 (Cobb's Arm Limestone, Middle Ordovician).
B. Quarry Cove Section, Cobb's Arm, Newfoundland (Bergstrom et al., 1974, conodont locality 3).
C. 49°37'49"N, 54°33'42"W.
D. 6

118. A. GSC loc. 42437 (Lush's Bight Group, Lower Ordovician).
B. South Catcher Pond, Notre Dame Bay, Newfoundland (Dean, 1970).
C. 49°31'00"N, 56°14'21"W.
D. 5½

119. A. CRB-E-073, 075, 076 (Becscie Formation, Lower Silurian).
B. Cap à l'Aigle, Anticosti Island, Quebec (Petryk, 1981b).
C. 49°46'52"N, 64°19'05"W.
D. 1

120. A. CRB-E-1004, 1005, 1006 (Gun River Formation, Lower Silurian).
B. 9 mile pool, Jupiter River, Anticosti Island (Fåhraeus and Barnes, 1981, Section 10).
C. 49°31'11"N, 63°32'23"W.
D. 1

121. A. CRB-E-0112, 0115, 0117 (Gun River Formation, Lower Silurian).
B. 16 mile pool, Jupiter River, Anticosti Island, Quebec (Fåhraeus and Barnes, 1981, Section 8).
C. 49°35'19"N, 63°32'21"W.
D. 1

122. A. CRB-E-1044, 1045, 1046 (Jupiter Formation, Lower Silurian).
B. Côte Verte, between mouth of Jupiter River and Southwest Point (Petryk, 1981a, b).
C. 49°25'20"N, 63°35'28"W.
D. 1.

123. A. CRB-E-1082, 1083, 1084 (Becscie Formation, Lower Silurian).
B. Salmon River, main falls, Anticosti Island, Quebec (McCracken and Barnes, 1981).
C. 49°23'26"N, 62°27'52"W.
D. 1

124. A. GSC loc. 98703 (Mainland Formation, Middle Ordovician).
B. Three Rock Point, Port au Port Peninsula, Newfoundland, near contact with Long Point Group (Fåhraeus, 1973).
C. 48°37'29"N, 59°06'19"W.
D. 1

125. A. GSC loc. 98373 (White Head Formation, Lower Silurian).
B. Lemieux Road Quarry, Percé area, Quebec (Skidmore and Lespérance, 1981, loc. P-4, p. 40).
C. 48°33'11"N, 64°21'16"W.
D. 1+

126. A. GSC loc. 98701 (Table Head Group, Middle Ordovician).
B. Coastal exposure, 3 km north of the village of Port au Port on Highway 59, western Newfoundland (Klappa et al., 1980, Fig. 3).
C. 48°35'00"N, 58°41'35"W.
D. 1

127. A. GSC loc. 98702 (Mainland Formation, Middle Ordovician).
B. Small rocky island off the coast from Low Point, north of Mainland, Port au Port Peninsula, Newfoundland (Klappa et al., 1980).
C. 48°34'57"N, 59°10'18"W.
D. 1

128. A. GSC locs. 99530, 99533 (Pont-Rouge Formation), GSC loc. 99535 (Deschambault Formation), GSC locs. 99537, 99545, 99547 (Saint-Casimir Formation) – all Middle Ordovician.
B. Cap à l'Aigle, north shore of St. Lawrence River, Quebec (Belt et al., 1979).
C. 47°39'35"N, 70°06'20"W.
D. 1½+

129\. A. GSC loc. 99505 (Badger Bay Group, Middle Ordovician).
B. Northwest shore of Duck Island, Notre Dame Bay, northern Newfoundland (Dean, 1977).
C. 49°28'34"N, 55°39'32"W.
D. 5

130\. A. GSC loc. 99506 (Lush's Bight Group, Middle Ordovician).
B. Little Bay Island, Murcell Cove, Notre Dame Bay, Newfoundland (Dean, 1977).
C. 49°38'52"N, 55°48'56"W.
D. 6+

131\. A. GSC loc. 99508 (Lush's Bight Group, Lower-Middle Ordovician).
B. Milkboy Cove, south shore of Long Island, Notre Dame Bay, Newfoundland (Dean, 1977).
C. 49°34'26"N, 55°40'44"W.
D. 6

132\. A. GSC locs. 99226, 99514 (Botwood Group, Lower Silurian).
B. Glenwood area, Newfoundland: 1 km east along lumber road that intersects the Trans-Canada Highway, 1.5 km north of bridge at Glenwood (GSC loc. 99226) and 150 m east of CN overpass on Trans-Canada Highway (GSC loc. 99514).
C. 49°00'08"N, 54°52'22"W; 48°59'54"N, 54°53'36"W.
D. 5

133\. A. GSC loc. 99517 (Cape Cormorant Formation, Middle Ordovician).
B. Coastal exposure at Daniel's Harbour, Newfoundland.
C. 50°14'22"N, 57°35'20"W.
D. 2+

134\. A. GSC loc. 99516 (Catoche Formation, St. George Group, Lower Ordovician).
B. Coastal exposure north of Table Point, western Newfoundland (Klappa et al., 1980).
C. 50°25'22"N, 57°30'08"W.
D. 2½

135\. A. GSC loc. 99515 (St. George Group, Lower Ordovician).
B. Exposure just north of Daniel's Harbour mine site, western Newfoundland.
C. 50°17'12"N, 57°27'56"W.
D. 2+

136\. A. GSC loc. 99441 (White Head Formation, ? Upper Ordovician).
B. Petit-Pabos River, right bank, about 5 km northwest of the mouth of the river, Gaspé Peninsula, Quebec.
C. 48°24'22"N, 64°39'10"W.
D. 5

137\. A. GSC loc. 99443 (White Head Formation, Lower Silurian).
B. Grand River Northwest, left bank, Joncas Township, Gaspé Peninsula, Quebec.
C. 48°35'56"N, 64°46'49"W.
D. 2½+

138\. A. GSC loc. 99439 (White Head Formation, Lower Silurian).
B. Grand River Northwest, Power Township, Gaspé Peninsula, Quebec.
C. 48°35'52"N, 64°41'23"W.
D. 3

139\. A. GSC loc. 99730 (Matapedia Group, Pabos Facies, Upper Ordovician).
B. Pellegrin Road, 1.5 km southwest of church in St-Edmond-de-Pabos, Quebec.
C. 48°25'57"N, 66°44'49"W.
D. 4

140\. A. GSC locs. 99366, 99367 (Pointe Verte Formation, Fournier Group, Middle Ordovician).
B. Roadcut on Highway 11 at exit to Pointe Verte, New Brunswick (Rast and Stringer, 1980).
C. 47°48'54"N, 65°48'52"W.
D. 6

141\. A. GSC loc. 98013 (Smyrna Mills Formation, ? Lower Silurian).
B. Roadcut on Highway 560, 3 km west of River de Chute and Trans-Canada Highway, New Brunswick.
C. 46°35'40"N, 67°45'40"W.
D. 4

142\. A. CRB-Tourelle/Hiscott (Tourelle Formation, Lower Ordovician).
B. East of Anse à Carlot, north shore, Gaspé Peninsula, Quebec (Hiscott, 1980).
C. 49°10'15"N, 66°21'40"W.
D. 2½

143\. A. CRB-E-3075 (?Table Head Formation, Middle Ordovician).
B. Barter's Brook, Woody Point area, Bonne Bay, Newfoundland.
C. 49°26'51"N, 57°46'00"W.
D. 5

144\. A. CRB-E-3147 (Cape Cormorant Formation, Middle Ordovician).
B. North of bridge at Portland Creek, western Newfoundland.
C. 50°11'08"N, 57°36'20"W.
D. 2

145\. A. CRB-E-3149 (Cape Commorant Formation, Middle Ordovician).
B. Portland Point, western Newfoundland.
C. 50°12'45"N, 57°36'22"W.
D. 2½

146\. A. CRB-E-3146 (Cape Cormorant Formation, Middle Ordovician – but conodonts are from clasts of Lower Ordovician limestone).
B. Portland Hill, western Newfoundland.
C. 50°08'45"N, 57°38'00"W.
D. 1½

147. A. CRB-E-3143 (Table Head Group, Middle Ordovician).
B. Roadcut, southeast of Rocky Harbour, western Newfoundland.
C. 49°35'15"N, 57°53'12"W.
D. 5

148. A. CRB-E-3153 (Cape Cormorant Formation, Middle Ordovician).
B. Rocky Harbour, western Newfoundland.
C. 49°35'23"N, 57°53'40"W.
D. 4½+

149. A. CRB-E-3131 (Watt's Bight Formation, Middle Ordovician).
B. Ship Cove, Port au Port Peninsula, western Newfoundland.
C. 48°31'00"N, 58°57'45"W.
D. 1+

150. A. CRB-PBQ1, 2 (Black River Group, Middle Ordovician).
B. Pointe Bleue, Ouiatchouan Indian Reserve, Lake St. John, 6 km north of Roberval, Quebec (Sinclair, 1953).
C. 48°33'24"N, 72°13'32"W. (N.B. Not on map used in this study.)
D. 1½+

151. A. CRB-PPQ-1 (Richmond Group, Upper Ordovician).
B. Pointe Plate, 1 km south of Roberval on shore of Lake St. John, Quebec (Sinclair, 1953).
C. 48°30'05"N, 72°12'53"W. (N.B. Not on map used in this study.)
D. 1½

152. A. CRB-RNQ-1, 3, 4, 5 (?Rockland Formation, Middle Ordovician).
B. Roberval Quarry North, 2 km north of Roberval on shore of Lake St. John, Quebec (Sinclair, 1953).
C. 48°32'16"N, 72°13'30"W. (N.B. Not on map used in this study.)
D. 1½

153. A. GSC locs. 76005-76013 (Trenton Group, Middle to Upper Ordovician).
B. Mouchalagan Lake, Manicouagan, Quebec.
C. 51°27'00"N, 68°15'00"W. (N.B. Not on map used in this study.)
D. 1+

154. A. GSC loc. 97517 (Smyrna Mills Formation, Lower Silurian).
B. Tributary of Craig Brook, north of Carlisle, New Brunswick (St. Peter, 1982, p. 30).
C. 46°22'43"N, 67°23'56"W.
D. 3

155. A. GSC loc. 98596 (Craig Brook Formation, Middle Ordovician).
B. West bank of North Becaguimec River, 800 m north-northeast of mouth of Craig Brook, New Brunswick (St. Peter, 1982, p. 16).
C. 46°22'10"N, 67°22'51"W.
D. 3

156. A. GSC loc. 97516 (Craig Brook Formation, Middle Ordovician).
B. South bank of a small brook on the west side of North Becaguimec River, New Brunswick (St. Peter, 1982, p. 16).
C. 46°22'25"N, 67°22'35"W.
D. 4

157. A. GSC locs. 98625, 98626 (unnamed unit, Upper Ordovician).
B. Markey Brook, southwest of Windsor, New Brunswick (St. Peter, 1982, p. 19).
C. 46°23'17"N, 67°25'47"W.
D. 5

158. A. GSC locs. 99732, 99733, 99734 (Matapedia Group, Pabos Facies, Upper Ordovician).
B. Grand Pabos River South, Raudin Township, Gaspé Peninsula, Quebec.
C. 48°25'48"N, 65°03'30"W, 48°26'20"N, 65°02'10"W and 48°26'20"N, 65°02'10"W.
D. 4

159. A. GSC loc. 99735 (Matapedia Group, Pabos Facies, Upper Ordovician).
B. Grand Pabos River South, near confluence with Duguay Creek, Gaspé Peninsula, Quebec.
C. 48°25'30"N, 65°05'30"W.
D. 3

160. A. GSC loc. 99731 (Matapedia Group, Lower Silurian).
B. Headwaters of Grand Pabos River South, Raudin Township, Gaspé Peninsula, Quebec.
C. 48°24'40"N, 65°04'30"W.
D. 3½

161. A. GSC loc. 100233 (Mictaw Group, unit 3b, Middle Ordovician).
B. Petite Port-Daniel River, 150 m northeast of road bridge at Clemville, Quebec (De Broucker, 1984).
C. 48°10'56", 65°00'34".
D. 1½

162. A. GSC loc. 100235 (Grog Brook Group, Upper Ordovician).
B. Restigouche River, south bank, 2 km east-southeast of Cross Point, near Marshall Island, in Marshall's Gulch Stretch, New Brunswick.
C. 47°53'20"N, 67°19'06"W.
D. 3

163. A. GSC loc. 100226 (Rivière Port-Daniel Nord Complex, ?Middle Ordovician).
B. Rivière Port-Daniel du Milieu, 325 m upstream from confluence with Ruisseau Mictaw (R. Neckwick), Quebec; calcareous block in mélange (DeBroucker, 1984).
C. 48°12'36"N, 65°01'49"W.
D. 1½

164. A. CRB-Green Gardens (Little Port Complex, ?Lower Ordovician).
B. Close to parking lot for trail to Green Gardens, Highway 44, Newfoundland, limestone lens in pillow lava.
C. 49°29'40"N, 58°04'57"W.
D. 5

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