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TECTONOSTRATIGRAPHY OF THE MIDDLE ORDOVICIAN
CARILLON FORMATION, EASTERN ONTARIO

BY

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A Thesis

submitted to the Faculty of Graduate Studies and Research

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ABSTRACT

In the Ottawa Embayment, the Middle Ordovician Carillon Formation forms the uppermost unit of the Beekmantown Group, a platform-interior succession coeval with a regional platform developed along eastern North America, generally interpreted to represent deposition along an ancient passive-margin continental shelf. In eastern Ontario, this platform is overlain by the siliciclastic Rockcliffe Formation, locally defining onset of the Taconic foreland basin. The Carillon Formation is composed of peritidal carbonates and siliciclastics. It thickens eastward, from approximately 32 m at Ottawa to about 64 m along the Ontario-Quebec border. Using a subsurface transect of 5 cores extending about 115 km along the axis of the embayment, the Carillon Formation is divided into lower and upper divisions; the former, representing about 30 m, is restricted to the east, whereas the latter is of regional extent. The boundary between the lower and upper divisions is marked by a 1-2 m thick interval of green sandstone similar to Rockcliffe strata. The Carillon Formation defines regional onlap, but the presence of the green sandstone, as well as local to regional differences in thickness of intraformational units within the upper division, identify a history of differential subsidence along the embayment prior to and during Carillon deposition. Synsedimentary tectonism is further supported by compacted fractures in dolomitic mud, filled with sand, as well as brittle deformation of some dolomudstone units. The Carillon Formation records Taconic foreland tectonism earlier than previously interpreted. Differential subsidence likely arises from reactivated basement faults of the Ottawa-Bonnechere Graben. Rockcliffe-like sandstone within the Carillon Formation may indicate that the two units are, in part, coeval. This supports a previous interpretation of a minimal hiatus at the formation boundary, and further de-emphasizes this boundary's tectonostratigraphic significance.

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STATEMENT OF CONTRIBUTION

The style, language, and written presentation of this thesis reflect considerable help and input from my supervisor. Collection of facies and stratigraphic data define my own work, while data interpretation represents discussions with my supervisor.

"Initiation of the Taconic Foreland Basin, Eastern Ontario: A not so passive Beekmantown platform" by G.R. Dix, Z. Al Rodhan, and Chris Boyd was accepted for presentation at a symposium on Taconic Foreland Basin Development at the NE GSA Conference in New York, March 2005. About half of the data presented is derived from this thesis

TABLE OF CONTENTS

Title Page	i
Acceptance Form	ii
ABSTRACT	iii
ACKNOWLEDGEMENTS	iv
STATEMENT OF CONTRIBUTION	iv
TABLE OF CONTENTS	v
List of Table	vi
List of Figures	vi
List of Appendices	vi
INTRODUCTION	1
GEOLOGIC SETTING	6
METHODOLOGY	7
LITHOFACIES OF THE CARILLON FORMATION	8
Facies 1: Interbedded Laminated Dolostone and Shale	8
Facies 1a: Thinly Laminated Shale	8
Facies 1b: Thinly laminated dolostone	13
Facies 1c: Thickly laminated-thinly bedded dolomudstone	13
Facies 1 Interpretation	14
Facies 2: Bioturbated Dolomudstone	14
Facies 2 Interpretation	15
Facies 3: Massive Dolomudstone	15
Facies 3 Interpretation	16
Facies 4: Fossiliferous Dolopackstone and Dolograinstone	16
Facies 4 Interpretation	19
Facies 5: Sandstone	19
Facies 5 Interpretation	19
Facies 6: Microbial-laminated dolostone	20
Facies 6 Interpretation	20
Facies 7: Evaporite	20
Facies 7 Interpretation	21
INTRAFORMATIONAL STRATIGRAPHY AND FACIES CORRELATION	21
Formation boundaries	21
Datum and intraformational stratigraphy	26

Spatial and Temporal Change in Facies	30
EARLY DIAGENESIS	33
DISCUSSION	37
Stratigraphic Architecture	37
Impact of Tectonism	40
CONCLUSIONS	42
REFERENCES	43
APPENDICES	46

LIST OF TABLES

Table 1	Lithofacies and paleoenvironmental interpretation	9
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LIST OF FIGURES

Fig. 1	Location of cores in the Ottawa Embayment	2
Fig. 2	Lower Paleozoic stratigraphic succession, eastern Ontario	4
Fig. 3	Lithofacies 1 and 2	11
Fig. 4	Lithofacies 3 to 6	17
Fig. 5	Lithofacies 7	22
Fig. 6	Upper and lower boundaries, Carillon Formation	24
Fig. 7	Intraformational lithostratigraphy, Carillon Formation	28
Fig. 8	Intraformational distribution of facies, Carillon Formation	31
Fig. 9	Compaction and fractures	34
Fig. 10	Development of the lower and upper divisions of the Carillon Formation	38

LIST OF APPENDICES

Appendix 1	Stratigraphic section of DH OT-5 (GSC Lebreton)	47
Appendix 2	Stratigraphic section of DH RU-24 (GSC Russell)	49
Appendix 3	Stratigraphic section of GSC Observatory Crescent (or GSC Experimental Farm)	51
Appendix 4	Stratigraphic section of DH AL-3 (Imperial Laggan #1)	53
Appendix 5	Stratigraphic section of DH AL-1C GSC (McCrimmon's Corner)	56
Appendix 6	Legend; explanation of symbols used in the appendices	59

INTRODUCTION

The Carillon Formation is the upper unit of the Middle Ordovician Beekmantown Group within the Ottawa Embayment (Fig. 1; Bernstein, 1992), geomorphologically part of the St. Lawrence Lowlands (Sanford, 1993). The Carillon Formation consists mostly of interbedded dolostone and shale, with minor limestone, and represents restricted inner platform facies (Bernstein 1992). There are few outcrops of the formation in the embayment (Fig. 1), and the only published summary of the formation lithology and stratigraphy is from a reference drill core (Loc. 4, Fig. 1) along the Quebec-Ontario border (Bernstein, 1992).

The Carillon Formation is an important stratigraphic unit. Historically, the boundary between the passive-margin succession and the Taconic foreland basin succession within this ancient craton interior region has been placed at the boundary between the largely carbonate Beekmantown Group and the overlying siliciclastic Rockcliffe Formation (Fig. 2) (Sloss, 1963; Sanford, 1993). This boundary is referred to as the Sauk-Tippecanoe sequence boundary (Sloss, 1963). Within the foreland succession, two additional carbonate platforms (Hog's Back Formation, Ottawa Group; Fig. 2) succeed the Rockcliffe Formation (Dix et al., 1997). The Carillon Formation (or the upper part of the now abandoned Oxford Formation; Wilson, 1946; Bernstein, 1992) has been usually viewed to be a craton-interior component of the passive continental shelf succession facing the Iapetus Ocean basin (Bernstein, 1992).

However, in the Ottawa region, more recent work (Dix and Molgat, 1998; Dix et al., 1998) identified development of synsedimentary fractures and local paleokarst along the upper and lower contacts of the Carillon Formation. These were considered manifestations of local reactivation of underlying Precambrian basement linked to onset of distal Taconic orogenesis. The question remained: are these anomalous, or does the Carillon Formation define a new tectonostratigraphic relationship between the passive and foreland basin successions?

Research for this thesis illustrates that the Carillon Formation records episodic tectonism similar to what has been found associated with lithostratigraphically equivalent units elsewhere along the Appalachian orogen (Cable and Beardsley, 1984; Knight and James 1987; Lesser and

Fig. 1 Location of studied cores and identified outcrops of the Carillon Formation in the Ottawa Embayment. The Carillon likely underlies the entire embayment, the boundaries defined by the surface margin of the Precambrian (after Dix et al., 1998). Core locality names are as follows (details are provided in the text): 1-Lebreton, 2-Observatory Crescent, 3-Russell, 4-Laggan, 5-McCrimmon's Corners.

Fig. 2 Lower Paleozoic stratigraphic succession, eastern Ontario. After Dix and Molgat (1998)

- Dolostone: thinly bedded with quartz arenite
- Dolostone: medium to thick bedded
- Arenaceous dolostone / dolomitic sandstone
- Limestone
- Interbedded dolostone, limestone, mudrock
- Quartzoze feldspathic sandstone
- Arkosic sandstone / conglomerate

Coogan, 1993; Holland and Patzkowsky, 1997). This new information has been made possible through examination of subsurface data across eastern Ontario using available drill cores (Fig. 1), and, from this, extracting a detailed succession of regional stratigraphy and lithological patterns. This study, therefore, provides a new view about the regional impact of Appalachian orogen tectonism on carbonate platform stratigraphy during the Middle Ordovician well within the craton interior, in the Ottawa Embayment.

GEOLOGIC SETTING

Distribution of Cambro-Ordovician strata in eastern Ontario defines an “embayment” of sedimentary rock surrounded to the south, west, and north by Precambrian rocks of the Grenville Structural Province (Sanford, 1993). Although this geometry defines the present erosional remnants of a once present Lower Paleozoic succession, a similar paleogeographic geometry of shallow-water siliciclastic and carbonate sediments existed during the Late Cambrian to Middle Ordovician forming a closed seaway, open to the east (Kay, 1942). Moving seaward (to the east), platform sediments were continuous with more offshore, deeper water platform strata in southwestern Quebec. Today, the structural margin of the Appalachian Orogen (Fig. 1) defines the eastern extent of relatively undeformed Lower Paleozoic strata. The Taconic Orogen became active by late Early-Middle Ordovician time, well to the east of the embayment (Sanford 1993).

The relatively narrow geometry of the embayment also reflects, in part, a structural origin (Dix and Robinson, 2003). Along its axis, high-angle normal faults and gentle folding, define the structural corridor of the Ottawa-Bonnechere Graben (Kumarapeli, 1985). This structure, with related mineralization, has a complex history of formation and reactivation in the Paleozoic and Mesozoic (Dix and Robinson, 2003), but had its origins as a failed rift or fault zone related to opening of the late Precambrian Iapetus Ocean basin (Kumarapeli, 1985).

METHODOLOGY

There are a few outcrops of the Carillon Formation (Dix and Molgat, 1998; Dix et al., 1998) along the Ottawa River at the Carillon Dam (Loc. 8), in the Cumberland area (Loc.7), and south of Ottawa along Hwy 416 in the Kemptville (Loc.6) region (Fig. 1). However, these exposures reveal only a few metres along the base and top of the formation. Instead, the thesis focuses on five cores (Fig. 1) that intersect the entire formation, and are stored at the Geological Survey of Canada's Tunney's Pasture facility. These cores include the following (using drillhole (DH) nomenclature of the Ontario Geological Survey (Williams, 1991) where available, as well as the Geological Survey of Canada terminology):

- DH OT-5 (GSC Lebreton) (Loc. 1)
- DH RU-24 (GSC Russell) (Loc. 2)
- GSC Observatory Crescent or Experimental Farm (Loc. 3)
- DH AL-3 (Imperial Oil Laggan # 1) (Loc. 4)
- DH AL-1C GSC (McCrimmon's Corners) (Loc. 5)

Details of geographic locations of core shown in Fig. 1, and a detailed geological core log for each locality is presented in the Appendix.

For each site, the lithology was described, and samples were taken of representative facies types. Depositional conditions were interpreted from clastic and non-clastic (evaporite, carbonate) sedimentary facies (Wilson, 1975; Tucker and Wright, 1990). Stratigraphic analyses defining the formation's regional distribution, thickness, and internal stratigraphic and lithofacies makeup followed. Early diagenetic attributes were noted.

For microfabric analysis and mineral identification, unpolished thin sections were made from characteristic lithofacies that constitute the formation. Thin sections were stained with Alizarin Red S and potassium ferricyanide to distinguish calcite from dolomite and their relative iron contents (Dickson, 1965). To better understand the diagenetic history of dolomite, thin sections were examined using cathodoluminescence using a ELM-2 cathodoluminescope with settings at 50 mA, 12 KV and 40 milltorr. Powder X-ray diffraction (Cu K α , Phillips PW 1710 diffractometer) of clay- and bulk (shale) samples was used to confirm carbonate mineralogy, and

identify minerals associated with shales. For the latter, oriented XRD sections of the clay fraction were used. Their preparation included centrifugation of clay-size particles from the shale-water solution for 10 seconds at 10,000 revolutions per minute. The suspension was then transferred onto glass slides to air-dry. Spot analysis for the Fe content of dolomite was carried out by wavelength dispersive x-ray analysis using an electron probe (Camebax MBX) and polished, carbon-coated thin sections using an acceleration voltage of 15 kv, beam diameter of 15 nA, and a counting interval for each analysis of 20 seconds.

LITHOFACIES OF THE CARILLON FORMATION

Seven facies, with associated subfacies, have been identified (Table 1), and are described below with an interpretation of paleoenvironment (Wilson, 1975; Tucker and Wright, 1990; Bernstein, 1992).

Facies Assemblage 1: Interbedded Laminated Dolomudstone and Shale

Facies 1a: Thinly laminated shale-This facies has a wide geographic distribution across the study area. It is abundant, making up 20% of the Carillon Formation (Appendix). It usually occurs in beds or laminae, typically about 5 cm in thickness, but ranges in thickness from isolated laminae (1mm) to relatively thick beds (< 30 cm) (Appendix).

Facies 1a is usually soft, fissile, and easily parted in core (Fig. 3A). Its lithology varies from dark grey clay-shale to medium grey silty and sandy shale. X-ray diffraction of oriented samples show the clay size fraction to be dominated by illite and kaolinite whereas bulk samples include quartz, dolomite, calcite, and mica. Laminations are continuous and discontinuous (across a core diameter), parallel, wavy, and lenticular. There are rare very thin laminae of evaporite (Facies 7) associated with this subfacies. A subdivision of this subfacies is represented by shale interlaminated with network and single burrows, bioturbation, and dolomitic siltstones (Fig. 3B). Mud cracks and laminae of mud-chip conglomerates and breccias also occur, but are rare.

Table 1. Lithofacies and paleoenvironmental interpretation of Carillon Formation

Lithofacies	Sedimentary Features	Fossils	Interpretation
Facies 1: Interbedded laminated dolomudstone and shale			
<i>1a: Thinly laminated shale</i>	Black, soft fissile to dark gray silty, biomottled with horizontal burrows and mud cracks Rare evaporite (laminae)	Rare brachiopod (Lingulid?), ^c onodonts, ostracods	Low energy, peritidal setting
<i>1b: Thinly laminated dolomudstone</i>	Interlaminae of dark gray silty to non-silty cryptocrystalline dolomudstone with local dolomitic siltstone interlaminae. Lenticular, to continuous, smooth, wavy to parallel (microbial) lamination. Rare burrows and evaporite.	None	Restricted shallow marine setting (lagoon)
<i>1c: Thickly laminated to thinly bedded dolomudstone</i>	Alternating medium gray, fine- and coarser-grained peloidal dolomudstone. Fining upward from silty intraclastic peloidal bases to fine-grained dolomudstone tops. Rare stylolites, mudcracks, burrows, and evaporite	Rare shell fragments	Moderate energy, peritidal
Facies 2: Bioturbated dolomudstone	Brown gray mottled, massive to bedded, cryptocrystalline to fine crystalline dolomudstone to dolowackestone, with intraclasts,, peloids, and detrital silt to sand grains. Horizontal burrows >> vertical burrows. Rare mudcracks, stylolites and syndimentary brittle fractures. Common calcite filled fractures.	Rare shell fragments (bivalve?)	Subtidal

Facies 3: Dolomudstone	Light gray finely crystalline dolomudstone with minor detrital silt and sand. Massive, rare stylolites and framboidal pyrite, and vertical compacted synsedimentary fracture filled with sand	None	Restricted sub-tidal
Facies 4: Fossiliferous dolopackstone to dolograinstone	Medium gray massive to thinly bedded, slightly bioturbated with rare sorted sand and silt-size grains. Intraclasts, ooids, lumps, and peloids are common. Rare mudcracks, stylolites, calcite filled fractures and evaporite.	Ostracods, gastropods, and bivalve fragments.	Restricted lagoon (ostracods) to open subtidal marine shoals (ooids).
Facies 5: Sandstone	Fine to coarse-grained arenite, thinly, wavy to lenticular, continuous laminated interbedded with dolomudstone.	None	Peritidal
<i>5a: Gray sandstone</i>			
<i>5b: Green sandstone</i>	Alternating arenite and siltstone laminae. Dominated by illite and koalinite, pyrite and rare glauconite	Phosphatic brachiopod shell fragments	Shallow subtidal to lower intertidal
Facies 6: Microbial-laminated dolostone	Small columnar stromatolites. Laminated structures consist of alternating of very thin, dark cryptocrystalline dolomudstone and thicker light gray silty peloidal finely crystalline dolomudstone.	None	Intertidal
Facies 7: Evaporite	Laminae, thin beds, and nodules. Gypsum associated with shale, anhydrite associated with dolomudstone. Fibrous gypsum fills subhorizontal fractures	None	Shallow hypersaline peritidal

Fig. 3 Lithology of Facies 1 and 2. Scale bars = 1 cm. A) Facies 1a; thinly laminated black shale (dark) interbedded between lighter dolomudstone. Loc.1, 240.8 m. B) Facies 1a; biomottled silty and sandy shale. Loc.5, 64m. C) Facies 1b; thinly laminated dolomudstone. Loc.5, 55.7m. D) Facies 1b; thinly laminated dolomudstone with interlaminae of sandstone and siltstone. Loc. 1, 232 m. E) Facies 1c; thickly laminated to thinly bedded dolomudstone. Loc.1, 251.5 m. F) Facies 2; bioturbated dolomudstone. Light coloured marks are acid artifacts. Loc.4, 180 m.

Skeletal fossils are rare. One locality contains ostracods (Loc.4: 122.3m) and the other broken phosphatic (lingulid?) brachiopod shells (Loc.5: 184.7 m). Three conodont elements were recognized in hand specimen at Loc. 3 (574.8 m and 601.9 m).

Facies 1b: Thinly laminated dolomudstone.-This facies is widely distributed widely making up about 23% of the formation (Appendix). Typical thickness of facies intervals is 30 cm, but ranging from 5 cm to up to 1m (Appendix).

Facies 1b consists of variably interlaminated dark gray, silty and non-silty cryptocrystalline dolostone (Fig. 3C), but locally there are interlaminae to thin beds of dolomitic siltstones (Fig. 3D). Laminations are very thin, lenticular to continuous (within the available core “window”), smooth but wavy to parallel, or crinkly (possibly similar to microbial lamination). There are rare mudcracks, as well as framboidal pyrite. Early synsedimentary soft-sediment and brittly deformed laminae are common (see below). Small vertical fractures filled with calcite were noted at Loc. 1 and 5.

Rare detrital sand-size grains of quartz occur scattered in this subfacies. In places, the presence of siliciclastics define fining-upward couplets. A few small nodules and very thin beds to laminae of anhydrite (Facies 7) were observed at Loc. 4 and 5. No skeletal fossils were noted, and horizontal and vertical burrows are very rare.

Facies 1c: Thickly laminated–thinly bedded dolomudstone.-This subfacies is distributed unevenly both laterally and vertically through the succession in the study area, representing about 25% of the core at Loc. 4, 10% at Loc. 1 and 2, and only about 5% at Loc. 3 and 5 (Appendix). Facies intervals are usually about 60 cm, and ranging from about 20 cm at Loc. 2 to as much as 2 m as at Loc. 4 (Appendix).

This facies is characterized by alternating laminae to thin beds of medium gray, fine-grained and light gray, coarser-grained peletal dolomudstone (Fig. 3E). This facies is usually disrupted by a number of thin shale laminae or claystone seams (e.g., Loc. 2). Silt- and fine-grained sand grains, as well as pellets are preferentially distributed within this facies, typically showing upward gradation from silt-, intraclast- and pellet-rich bases to dolomudstone-rich tops

(Fig. 3E). The subrounded intraclasts are aligned parallel to bedding. Bioclasts are very rare, represented by broken shell fragments with micritic envelopes and phosphatized brachiopods.

Lamination and thin beds are typically planar (Fig. 3E). Syndimentary fractures, stylolites, mudcracks, burrows, framboidal pyrite and anhydrite nodules and thin laminae are rare.

Facies 1 Interpretation.-By itself, shale of Facies 1a offers little by which to precisely define the depositional environment. Abundant burrowing illustrates bioproductivity, often associated with influx of siliciclastic detritus (Fig. 3B), yet presence of few skeletal remains, including lingulid-type brachiopods, may indicate a very restricted environment. The associated mudcracks and evaporites may suggest periods of exposure and occasional hypersalinity, and mud-chip conglomerates identify rip-up clasts of consolidated mud. It is likely that the shale and related siltstone accumulated within relatively low-energy peritidal environments that fluctuated in salinity thereby controlling productivity.

The thin laminae of Facies 1b also do not lend themselves to any unique environment. However, the stratigraphic association of subfacies 1b with rare bioturbation, possible microbial lamination, and the presence of rare evaporitic nodules, thin beds, and mudcracks suggest a restricted, shallow marine peritidal setting; possibly lagoonal.

The silty peloidal- to intraclastic dolomudstone of Facies 1c represents an environment of moderate, but alternating or rhythmic change in energy, possibly tidal. Alignment of the intraclasts suggests current deposition, but they may also represent influence from waves. The silt-size and fine-grained quartz sand grains may reflect aeolian deposition or simply reworking of detritus introduced from the shoreline. With the rare occurrence of mudcracks, and occurrence of possible ostracodes, it is likely that the dolomudstone represents a subtidal to peritidal lagoonal environment, but one more open to circulation than other Facies 1 lithologies.

Facies 2: Bioturbated Dolomudstone

Facies 2 is fairly common in the formation, evenly distributed laterally and vertically in a given core, but with higher percentages (up to 50%) at Loc. 3, 4, and 5 in comparison to much

lower abundances (< 10%) in other cores (Appendix). The typical thickness of this facies interbedded with others is about 1 metre, but ranging from 10 cm to 2 metres (Appendix).

Facies 2 consists of brown gray, mottled to massive, thin to thick bedded cryptocrystalline to finely crystalline dolomudstone and dolowackstone (Fig.3F). Thin shale (Facies 1a) and rare anhydrite (Facies.7) laminae are associated with this facies.

The dolowackstone contains relatively abundant dolomicrite intraclasts, ranging in size from a few μm to < 2 mm, less common dololmicritic peloids, and rare skeletal (possible bivalve fossil) fragments that are broken and altered. The dolowackstone has rare irregular-shaped porosity.

Detrital quartz of silt or fine-grained sand size is present, but rare (<10 %). Within the dolowackstone, there is porosity filled with calcite. Facies 2 dolostone is typically massive to biomottled, with rare wavy bedding. Bioturbation of this facies is moderate, but locally well developed. As a result, many dolostone beds appear massive, but mottled. Horizontal burrows are more common than vertical burrows, but discrete burrows, in general, are rare. In addition, both types of burrows are dolomitized selectively. Mud cracks and stylolites are rare in this facies. There are numerous calcite-filled fractures in Facies 2 strata, and rare synsedimentary brittle fractures (see below).

Facies 2 Interpretation.- The biomottled fabric, and more abundant horizontal than vertical burrows, suggests that Facies 2 represents an environmentally stable subtidal environment; one in which burrowing organisms were not strongly influenced by vertical environmental gradients as typical of intertidal zones. Intraclasts represent rip-up clasts that may have been derived from the impact of storm or tidal currents.

Facies 3: Massive Dolomudstone

This facies has a wide geographic and subsurface distribution representing as much as 40% of the core at Loc.5 to as little as 10 % at Loc. 3 (Appendix). This facies occurs with thicknesses of approximately 70 cm, ranging from 20 cm to about 2 metres (Appendix). The lithology is

light gray, finely crystalline dolomudstone (Fig. 4A), with minor silt- and sand-size subrounded to well rounded quartz grains either disseminated within the sediment or preferentially distributed along compacted synsedimentary fractures (see below). There are no skeletal fossils.

Calcite-filled irregular porosity, framboidal pyrite, and stylolites are present. A large subvertical paleocavity (with a minimum 30-cm length; see text and photo below) filled with lighter massive, silty dolomudstone (Facies 3) is preserved at Loc.1. Vertical and sub-vertical, compacted synsedimentary fractures, of centimeter-scale (see below), are common in L3 dolostone. These are filled with coarse, rounded quartz grains, and dark (blackened) microcrystalline dolostone fragments with ragged boundaries.

Facies 3 Interpretation.-The paleoenvironment of this facies is uncertain. The absence of evaporite nodules and mudcracks indicate no tendency for hypersalinity nor exposure. Facies 3 likely represents a subtidal, yet restricted (no fossils) setting. Presence of synsedimentary fractures, filled with sand grains, indicates fracturing of cohesive fine-grained sediment, with some source of coarse-grained sediment. The blackened, ragged dolomite fragments identify likely oxidized, but relatively soft, fragments.

Facies 4: Fossiliferous Dolopackstone and Dolograinstone

Skeletal dolograinstone and -packstone are two associated lithologies of this facies, and occur interbedded in the upper (<10 m) part of the formation (Appendix). Overall, however, the facies is relatively minor, representing only 4% of the whole formation. The typical facies thickness is 20 cm, ranging from 10 cm to 1 m.

Dolopackstone, but with minor dolograinstone, occurs thinly bedded to massive, to slightly bioturbated (Fig. 4B). This facies is predominantly in the upper 1 m of all cores, represented by ostracode-rich lithologies. However, the facies occurs near the base and center of some cores as well (Appendix). There are few silt-sized siliciclastics and very rare well sorted sands. Allochems include bioclasts (ostracods, with locally accessory gastropod and bivalve

Fig. 4 Lithology of Facies 3 to 6. Scale bars = 1 cm. A) Facies 3; sandy massive dolomudstone. Loc. 2, 587 m. B) Facies 4; dolopackstone to dolograinstone. Loc.1, 253.5 m. C) Facies 5a; gray argillaceous sandstone overlying dolomudstone (Facies 3). Loc.1, 252.2 m. D) Facies 5b; green sandstone interlaminated with siltstone (dark layers). Loc.5, 81.9 m. E) Facies 6; columnar microbial lamination forming a stromatolite, overlain by mudstone that is truncated by an erosional surface. Note the rip-up clasts of mudstone in the overlying lighter dolomudstone of Facies 2. Loc.1, 251.6.

fragments), subrounded dololmicritic intraclasts, lumps, peloids, and locally rounded pyritic clasts. At the base of the formation at Loc. 1, fragments of ooids are present as well.

Calcite-filled non-skeletal porosity, framboidal pyrite and anhydrite nodules (Facies 7) occur rarely. Stylolite, mudcracks (associated with packstone) and some calcite-filled fractures are also present.

Facies 4 Interpretation.-Ostracod rich-beds suggest a subtidal, semi-restricted, setting, such as one might find in a lagoon. Ostracods are of indeterminate species. However, the presence of ooids and peloids identify likely subtidal marine shoals environments (Wilson, 1975; Tucker and Wright, 1990). Thus, it is likely that the environment was a shallow-water system with shoals and more protected areas, possibly of more restricted circulation.

Facies 5: Sandstone

There are two different types of sandstones. First, grey fine- to coarse-grained arenite, mostly quartz, sometimes argillaceous, and usually thinly laminated (Fig. 4C) occurs interbedded with various carbonate facies. This sandstone (Facies 5a) usually forms beds < 5 cm thick within metre-scale successions of dolostone. Lamination is thin, wavy to lenticular, continuous to discontinuous, and often associated with admixed or interlaminated dark grey siltstone to claystone.

The second (Facies 5b) sandstone looks and is compositionally similar to sandstone of the Rockcliffe Formation that overlies the Carillon Formation. Facies 5b contains alternating quartz arenite and siltstone (Fig. 4D), the latter with sericite and muscovite. There is framboidal pyrite, rare glauconite, and locally abundant phosphatic brachiopod shell fragments associated with the sandstone. Ferroan calcite cement fills local intergranular porosity (2%). X-ray diffraction shows that the clay-size fraction is dominated by illite and kaolinite, whereas bulk samples include quartz, illite, calcite, and mica.

Facies 5 Interpretation.-There are no distinguishing sedimentary features of subfacies 5a, apart from that it is interbedded with dolomudstone of peritidal origins. In contrast, subfacies

5b was likely deposited in a marginal marine, shallow subtidal to lower intertidal setting given the presence of phosphatic brachiopod debris (Tasch, 1973). The alternating coarse/fine-grained laminations identify some rhythmic change in energy of deposition.

Facies 6: Microbial-laminated Dolostone

This facies occurs mostly in the top part of the Carillon Formation (Appendix). In core, it is distributed across the area, but makes up only 6% of the stratigraphic succession. This facies has been recognized in outcrop at Loc. 8 in the lower part of the formation. Typical thickness of facies beds is 8 cm, but ranges from 6 to 20 cm (see Appendix).

This facies consists of small columnar stromatolites that demonstrate synoptic relief of up to 20 cm (Fig. 4E). Oncolites occur in some laminations and intermound sediment. From core it is impossible to identify if the columns are isolated or laterally-linked. In outcrop, the structures are isolated.

The laminated structures consist of alternating very thin, dark cryptocrystalline dolomudstone (1mm) and thicker (< 1cm) light gray silty peloidal finely crystalline dolomudstone. Typically, columns are overlain by mudstone to lithoclastic floatstone, clasts derived from the mounds. Some laminated structures have what appears to be fenestral and paleoporosity, now filled with calcite.

Facies 6 Interpretation.-The laminated structures are stromatolites. The presence of peloidal dolostone laminae identifies a somewhat energetic environment, and the fenestrae now filled with calcite may indicate an intertidal environment. However, stromatolites can also be subtidal.

Facies 7: Evaporite

This facies has a very limited vertical and lateral distribution within the formation. In general, it occurs very rarely, making up only about 1% of the formation's thickness (Appendix), forming thin beds (2 cm), thick laminae (2 mm), nodules (< 1cm), and fracture-fill deposits.

Gypsum laminae are typically associated with thin shale (Facies 1a) interbeds and laminae.

Anhydrite nodules are associated with dolostone (Fig. 5A). In places, irregular shaped anhydrite masses are associated with irregular shaped domains of deformed dolomudstone (Fig. 5B). Finally, fibrous gypsum fills sub-horizontal fractures (Fig. 5C), forming 20- to 50-cm thick intervals are restricted in distribution to the lower part of the core at Loc. 4. Angular fragments of dolomite are caught up in the gypsum fill.

Facies 7 Interpretation.-Interbeds and interlaminae of evaporite with shale and thinly laminated to thickly laminated dolomustone suggest a possible shallow, hypersaline peritidal setting. Evaporite nodules are secondary, their growth in the subsurface indicating hypersaline porewaters. The irregular shaped masses of dolomudstone and evaporite (Fig. 5B), and other core sections that show low-angle disruption of dolostone laminae may indicate complete to partial removal of evaporite by dissolution. The precipitation of fibrous gypsum in veins or horizontal fractures is secondary, but identifies low-temperature migration of hypersaline pore waters (Machel 1985).

INTRAFORMATIONAL STRATIGRAPHY AND FACIES CORRELATION

Formation Boundaries

The upper boundary of the Carillon Formation, in contact with the overlying Rockcliffe Formation, is preserved in all cores except Loc. 5 where the boundary was either not recovered or not preserved once collected. On the basis of correlation, the formation top is likely within a few metres of the top of the preserved core (Fig. 7). The Carillon- (or Beekmantown)-Rockcliffe contact has been usually viewed to define a prominent break in time (Wilson, 1946; Sanford, 1993). As shown in outcrop (Dix and Molgat, 1998) and core (see below), however, the contact is quite variable in appearance. For example, the contact is smooth but irregular, and sharply defined at Loc. 1 (Fig. 6A). At Loc. 4, Rockcliffe sandstone is interbedded with grey shales similar to the Carillon Formation, suggesting a gradational, if alternating lithological change. In

Fig. 5 Lithology of Facies 7. Scale bars = 1 cm. A) Anhydrite nodule in dolomudstone. Loc.1, 245 m. B) Anhydrite sandwiched between disrupted dolomudstone, likely representing solution collapse structures. Loc.1. C) Horizontal fractures in dolomudstone filled with fibrous gypsum. Loc.5, 64.3 m.

Fig. 6 Lower and upper boundaries, Carillon Formation. **Left)** Irregular disconformity separating dolomudstone (dark) of the Carillon Formation from the overlying sandstone (light) of the Rockcliffe Formation. Loc. 1, 221.5 m. **Right)** Basal conglomerate of the Carillon Formation overlying Beauharnois Formation dolostones. Loc.2, 158 m

outcrop northwest of Ottawa, Dix and Molgat (1998) documented a gradational contact defined by alternating dolostone and green sandstone.

The lower boundary of the Carillon Formation is usually not easy to locate because of the continuation of dolomudstone down into the underlying Beauharnois Formation. However, in one core (Loc. 2), the base of the formation is clearly disconformable, with pebble conglomerate (Fig. 6B). In outcrop at Loc. 6 (south of Ottawa), Dix et al. (1998) demonstrated what they thought was a locally fractured, karsted upper surface of the Beauharnois Formation. Elsewhere, in core, however, the Carillon-Beauharnois formation contact is best defined as conformable, marked by the upsection appearance of thinly laminated dolomudstone (Facies 1b), along with a greatly increased presence of intraformational erosional surfaces, the appearance of vertical fractures, and greater abundance of shale interbeds and interlaminae. This upsection change generally coincides with the last (upsection, and in outcrop) appearance of coarse-grained highly fossiliferous dolostones (typically crinoidal) that is typical of the Beauharnois Formation (Bernstein, 1992).

Datum and Intraformational Stratigraphy

Using the above formation boundary definitions, the thickness of the Carillon Formation doubles moving east between Loc. 3 and 4; from about 32 m at Loc. 3 to 66 metres at Loc. 4 and 60+ metres at Loc. 5. Although Bernstein (1992) noted a similar regional thickening of this unit, detailed stratigraphic analysis reveals new information about why this occurs.

Before one can discuss intraformational change in paleoenvironments, a clear internal stratigraphic correlation needs to be established. This is difficult due to the lack of significant variety in carbonate facies; that is, they all represent peritidal environments. There are no obvious index fossils nor outstanding individual carbonate marker beds that can be traced regionally. The ostracod-rich facies near the top of the formation cannot be used with confidence because it shows some regional variability in lateral distribution and vertical position, and it lies at or very near the formation boundary. Using this facies as a horizontal surface could

introduce bias into how one interprets the extent of erosion across the region after Carillon deposition (see below).

Instead, an intraformational framework is established using the prominent shales. Bernstein (1992) noted an anomalous abundance of shale in the Carillon Formation compared to the Beekmantown Group in general. Hence, it is useful to investigate if such an anomaly could prove stratigraphically useful. In Fig. 7, the distribution of shale beds (or units dominated by shale laminae) and prominent sandstones are highlighted against the general lithological background of what is peritidal dolomudstone.

Examination of this figure reveals the regional extent of an obvious shale-bed couplet, although at Loc. 5 only one bed of the couplet is present. Given the predominance of peritidal facies throughout the formation, this couplet is interpreted to have likely been horizontal, and defines a regional datum (Fig. 7). Using this datum, the formation is divided into informal units defined by shale beds or intervals (T1-T12; Fig. 7). From this, the following observations are made:

- 1) The eastern localities 4 and 5 are well correlated stratigraphically, which is not surprising given their close (~8 km) proximity (Fig. 1). These localities reveal a formation thickness of about double that of the more western localities (1-3; Fig. 7). The lower half of the formation at Loc. 4 and 5— that is, from formation base to about T5 — has no stratigraphic equivalent succession at the western localities (Fig. 7). The two equivalent lower intervals at Loc. 4 and 5 are, therefore, older than the Carillon Formation succession preserved at localities 1-3 (Fig. 7).
- 2) From the above observation, the Carillon Formation can be subdivided into a “lower” and “upper” division, the boundary being (vaguely) the interval of green sandstone (Facies 5b) labeled T6 (Fig. 7). The lower division has no stratigraphic equivalent in the western part of the study area. The green sandstone (=T6) is restricted to Loc. 5, but stratigraphic correlation to Loc. 4 and further west suggests that this sandstone may be time equivalent to the lower few metres of the formation to the west (Fig. 7).

Fig.7 Intraformational stratigraphic correlation, Carillon Formation, and possible locations of basement faults that influenced sedimentation. The datum is a prominent shale couplet, with only part of the couplet occurring at Loc. 5. A legend follows this diagram.

- 3) The presence of Facies 5b at Loc. 5, but not at Loc. 4, suggests that there was either a) a southwest lateral restriction to the transport and deposition of the sandstone; or b) rapid fining of sandstone to shale. As will be discussed (see below), this sandstone is geologically significant because it is lithologically similar to the overlying Rockcliffe Formation, and demonstrates a required drop in sea level, yet one that was differential over the 8 km distance between Loc. 4 and 5.
- 4) Tracing the distribution of informal (T1-12) units reveals a higher-order variation in lateral thickness and vertical displacement moving from west to east (Fig. 7) within the “upper” division of the Carillon Formation; for example, the interval T10 to T11 (Fig. 7).
- 5) The thickest shale beds are found in the “lower” division of the formation at Loc. 4 and Loc. 5 (Fig. 7) and in the “upper” division of the formation at Loc. 1, Loc. 2, and Loc. 3. This defines an apparent non-random distribution of thick shales, one that might be explained by the regional development of the formation relative to sea level (see below).
- 6) From the above distribution of informal intraformational stratigraphy (Fig. 7), it becomes clear that differential erosion occurred at the top of the Carillon Formation as defined by the different thickness of the informal unit T12.

Spatial and Temporal Change in Facies

With a regional stratigraphic correlation defined (Fig. 7), it is now possible to examine general changes in paleoenvironments both across the Ottawa Embayment at any given time, but also through deposition of the Carillon Formation. In Fig. 8, facies distribution reveals an intimate interbedding and lateral distribution of peritidal facies. However, within this mosaic there are some general patterns:

- 1) Loc. 3 reveals a prominent vertical change from bioturbated and massive facies (2, 3) below the datum to microbial laminated and bioturbated facies (1c, 2) above the datum.

Fig. 8 Intraformational facies distribution and regional correlation, Carillon Formation.

The obvious correlations are retained from Fig. 8, as are thick shales. Patterns refer to specific facies types. The arrows refer to obvious lateral change in facies assemblages moving in a seaward direction.

- 2) Moving seaward from Loc. 3, above the datum, there is a prominent seaward change to interbedded bioturbated (2) and coarse-grained facies (4) suggesting a change to more open circulation, higher energy environments. Moving west from Loc. 3, the same stratigraphic interval shows interbedding of bioturbated and more restricted facies.
- 3) Above the datum between Loc. 4 and 5, there is a similar change to more bioturbated facies association (2, 3).

These broad regional patterns are indicating the following. First, during the latter stages of Carillon Formation deposition there may have been some barrier to circulation (e.g., a shallower depositional setting) at Loc. 3, with higher energy facies lying seaward (Loc. 4 and 5) and quieter, more restricted facies lying landward (Loc. 1 and 2). Second, the facies assemblage of the lower division of the Carillon Formation is similar to the facies composition of the landward (Loc. 1, 2) sites of the upper division. In other words, there may be a net "backstepping" of overall facies development with time during Carillon time. This suggests a net onlap, and transgressive succession.

EARLY DIAGENESIS

From staining and study of cathodoluminescence, thin sections reveal a complex history of diagenesis. Here, attention is restricted to evidence that defines timing of the most prominent dolomite type visible in the host strata of the Carillon Formation (Fig. 3-6), and its relationship to compaction (both mechanical and chemical) and fracture development (Fig. 9).

In general, shales of Facies 1 contain abundant evidence for compaction of burrows (Fig. 9A) that contain dolomite, but this dolomite appears to replace detrital siliciclastics, and are somewhat larger (40-60 microns) than the dolomite making up the host sediment. This latter dolomite is microcrystalline (1-4 microns) and contains intergrown ferroan and non-ferroan dolomite crystals and crystal domains. Microprobe analysis failed to produce a reliable Fe content

Fig. 9 Compaction and fracture types, Carillon Formation. A) Compacted burrows of silt and microcrystalline dolomite in shale (Facies 1a). Loc. 5, 76.8 m. Scale bar = 1 cm. B) Thin section (cross-polarized light) showing compaction of synsedimentary fracture filled with coarse to fine-grained sand and possibly Mn-oxidized dolomite clasts. Loc.1, 525.7 m. Scale bar = 4 mm. C) Vertical fracture or paleokarst within Facies 3 dolomudstone, filled with lighter coloured dolomudstone of similar facies. Loc.1, 246.6 m. Scale bar = 1 cm. D) Vertical stylolite (dark seam) cross-cutting calcite-filled vertical fracture (light coloured) in Facies 3. Loc. 5, 85.5 m. Scale bar = 1 cm. E) Synsedimentary brittle fracture offsetting dolomudstone bed of Facies 1c. Loc.4, 174.2 m. Scale bar = 1 cm

estimate for either dolomite type. However, examination of the cathodoluminescence (CL) reveals that the unstained microcrystalline dolomite crystals have no or very dark CL.

These two dolomite types demonstrate an early stage of formation relative to burial; that is, the peritidal dolostone facies of the Carillon Formation was produced essentially as a syndimentary deposit. Evidence for this is as follows.

- 1) formation of cm-scale syndimentary compacted fractures within the host microcrystalline dolomite in Facies 3 of Loc. 1 (Fig. 9B);
- 2) a fracture (Fig. 9C) that appears to have occurred in semi-lithified sediment, in which light coloured Facies 3 fills a cavity developed in Facies 3 dolomudstone. This fracture is very different from relatively common calcite-filled fractures found in several of the cores (Fig. 9D);
- 3) lithoclasts of peritidal dolomicrite are found encased in dolomicrite (e.g., Fig. 4E; Facies 1C); typically, these clasts are similar in texture to the immediately underlying bed, the latter capped by an erosional surface;
- 4) rare formation of syndimentary brittle fractures (Fig. 9E; Loc. 1 – Facies 2; Loc. 2 – Facies 1B; Loc. 4 – Facies 1C); in other words, where there is laminated strata which can easily define stratigraphic displacement; and,
- 5) fragments of dolomititic ooid grainstone are deposited within microcrystalline dolomite (Facies 4).

Dolomite crystals coarser (40-60 micron) than the prominent microcrystalline host dolomite are found in burrows (see above) and scattered in the host microcrystalline dolostone. They are often zoned relative to Fe content: cores are unstained, and microprobe analysis reveals low Fe (0.07 %) content, whereas the rims are stained blue, and possess elevated Fe (5.37-5.72 %) percentages. Framboidal pyrite is usually found associated with the unstained cores of the coarser rhombohedra. Framboidal pyrite is also found scattered throughout the microcrystalline unstained dolomite. This may indicate that microcrystalline dolomite formed in association with sulphate reduction, a process that can occur within the very near surface burial environment (Irwin et al.,

1977). Unfortunately, the unstained and stained microcrystalline dolomites are typically found intergrown precluding a clear sampling separation for isotopic analysis.

DISCUSSION

Stratigraphic Architecture

In his revision of Beekmantown Group stratigraphy for eastern Ontario and southwestern Quebec, Bernstein (1992) noted a general regional eastward increase in thickness of the Carillon Formation. Lack of index fossils and carbonate marker beds make correlation of peritidal carbonate facies across eastern Ontario very difficult. However, use of shale bed markers, especially the shale-couplet datum, helps reveal a coherent regional stratigraphy and net transgressive succession making up the Carillon Formation.

Re-examination of subsurface data now demonstrates that the thickness increase noted by Bernstein (1992) arises from a lower stratigraphic interval (formation base to T6; Fig. 8) found at Loc. 4 and 5 that is not represented (or possibly only the uppermost part) at the more western localities (Fig. 7). In contrast, an upper division (T6 to formation top) is of regional extent (Fig. 7). This division brings attention to two important stratigraphic elements: 1) the Carillon Formation defines a history of net regional onlap across the underlying Beauharnois Formation (Fig. 10); and 2) subsidence restricted to the area of Loc. 4 and 5 predates deposition of the Carillon Formation, and is required to accommodate the added thickness of the lower division (Fig. 7). With regard to regional onlap, some cores (and one outcrop locality; Loc. 6, Dix et al., 1998) show a disconformity, while others reveal an apparent conformable succession. Note that prominent thick shale beds in the lower part of the Carillon Formation at Loc. 4 and 5 are also found at Loc. 1 and 2 in the upper division. It may be that these define some paleogeographic-restricted occurrence associated with the leading edge of transgression.

The impact of required local subsidence is also reinforced by an apparent locally restricted base level change that suggests uplift. The green Rockcliffe-like sandstone that forms a boundary separating the lower and upper divisions at Loc. 5 is absent moving to the SW (Loc. 4), but may

Fig. 10 General summary of stratigraphic development of the two divisions and deposition of the green sandstone making up the Carillon Formation: 1) shallow slope to horizontal “basement” of the Beauharnois Formation; 2) local subsidence and deposition of the lower division (a), then drop in relative base level that allowed the green sandstone to be transported from the north; and 3) deposition of the upper division, with likely local faults controlling lateral thickening and thinning of stratal units.

be correlative with the shaley basal upper division strata at more western localities (Fig. 7). This sandstone requires a drop in base level in order for its transport out across what had been carbonate peritidal environments (Fig. 10; Wilson, 1975); yet this base level change is not well defined at any other locality (see below).

Within the lower division of the Carillon Formation, lateral correlation of shale beds is reasonably well defined. However, this is likely partly due to the proximity of the two core locations, separated only by about 8 km. Within the upper division, however, there is much more lateral and vertical variation in lithofacies, yet all remaining within peritidal environments. Nonetheless, there are some informal stratigraphic units that clearly define lateral and vertical changes in thickness or stratigraphic position indicating differential subsidence (or uplift). This is discussed in detail below.

The top of the formation also reveals a regional disconformity, and highlights the difficulty of using carbonate lithofacies as marker beds for correlation. Ostracod-rich dolostones appear to be laterally restricted in their distribution; that is, forming regional lens geometries. Definition of the top of the Carillon as a horizontal or sub-horizontal erosional surface parallel to any one bed would lead to an erroneous intraformational correlation.

Impact of Tectonism

The regional lateral differences in thickness of intraformational units, the overall stratigraphic architecture of the Carillon Formation, and the restriction of green sandstone to Loc. 5 are, combined, interpreted to reflect the impact of tectonism. Added support for this process is the occurrence of soft-sediment, locally compacted, synsedimentary fractures, some filled with fine- to coarse-grained sand (Fig. 9B). Like those reported by Dix and Molgat (1998) from the formation's upper contact, as exposed in outcrop northwest of Ottawa, these fractures identify seismic disruption of cohesive carbonate mud. The host material throughout the Carillon Formation was variably lithified as attested to by rip-up clasts of dolomite, and other related features (see above), that demonstrate that the bulk of microcrystalline dolomite was typically

syndimentary. The more argillaceous dolomitic muds were less lithified, able to take up seismic or compaction stress (=not show deformation) compared to brittle deformation of interbedded dolostones (Fig. 9E).

Intersite lateral differences in unit thicknesses and/or the vertical position of a given bed/unit along the transect can be explained by differential movement of underlying basement fault blocks. As shown in Fig. 8, faults are tentatively identified between core localities. Dix and Molgat (1998) suggested that local fracturing along the base and top of the Carillon Formation (as exposed in outcrop in the Ottawa region) coincided with weakly developed block faulting of underlying basement, vertical displacement translated up through the overlying sedimentary strata. Their hypothesis requires that regional stress migrated west from the developing Taconic orogen, and caused reactivation of basement faults that underlie the Ottawa Embayment, part of the intracratonic Ottawa-Bonnechere Graben (Kumarapeli, 1985).

In western Newfoundland, along what would have been the more outer part of the Early to Middle Ordovician continental shelf, the Aguathuna Formation defines a lithostratigraphically equivalent formation to the Carillon Formation (Bernstein, 1992). It is divided into two tectonostratigraphic units (Knight and James, 1987); a lower section (=lower and middle Aguathuna Formation) is part of the passive-margin succession, whereas the upper Aguathuna Formation defines sedimentation during the initial development of the foreland basin succession. For eastern Ontario, a more protracted history may have occurred: initial subsidence along the eastern margin (Loc. 4 and 5) accommodated lower Carillon sediments (Fig. 10); the “lower” and “upper” Carillon division boundary, with sandstone, defines relative uplift and migration of siliciclastics from the north (Fig. 10); then, renewed subsidence and regional onlap, yet with still minor local changes in base level (= shifting basement fault blocks) as recorded by lateral thickness variation of units within the upper division (Fig. 10). Such tectonic activity and stratigraphic response has been also documented along the western margin of the Taconic orogen in the United States (Cable and Beardsley, 1984; Lesser and Coogan, 1993; Holland and Patzkowsky, 1997).

The green Rockcliffe-like sandstones within the Carillon Formation are an important discovery. They reflect a hinterland source equivalent to the Carillon peritidal carbonates, a source that prograded briefly southward onto the carbonate platform at Loc. 5. Their absence at Loc. 4, only 8 km to the southwest of Loc. 5 (Fig. 1), may indicate that the sandstones formed a regionally constrained depositional system. The younger Rockcliffe Formation is likely of shallow-water estuarine origin (Dix et al., 1997); the greenish Carillon sandstone, likewise, may define a brackish water environment given the presence of phosphatic brachiopods (Tasch, 1973). The stratigraphic relationship suggests that upper Carillon carbonate sedimentation occurred with shoreward siliciclastics; that, eventually, a drop in base level allowed progradation of these siliciclastics out across the basin, represented now by the Rockcliffe Formation. If correct, this further diminishes (along with evidence for local gradational Carillon-Rockcliffe contacts; Dix and Molgat, 1998; this study) the tectonostratigraphic significance of the Carillon-Rockcliffe boundary.

CONCLUSIONS

Important results of this study are as follows:

- 1) the Carillon Formation is composed of carbonate and siliciclastic peritidal facies;
- 2) the eastward thickening of the Carillon Formation, as previously noted by Bernstein (1992), is due to a stepped regional onlap, resulting from initial local subsidence restricted to the eastern part of eastern Ontario;
- 3) intraformational stratigraphic correlation reveals lateral variation in thickness of informal units that can be interpreted to be the result of differential local subsidence or uplift during Carillon deposition;
- 4) the intraformational stratigraphy is interpreted to reflect the impact of regional tectonism, related to onset of distal Taconic orogenesis, leading to reactivation of basement (Precambrian) faults that are part of the Ottawa-Bonnechere Graben;

- 5) discovery of Rockcliffe-like sandstone within the Carillon Formation suggests that the Rockcliffe Formation source formed some hinterland equivalent to the peritidal depositional environments, and extended locally across the platform as a result of local variation in base level;
- 6) the Carillon Formation, not the Rockcliffe Formation, defines the onset of Taconic orogenesis, and represents sedimentation during the onset of foreland basin development.

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APPENDICES

Stratigraphic sections for the Carillon Formation from core localities 1 through 5.

A legend accompanies these figures, and is found at the end.

- Appendix 1 Stratigraphic section of DH OT-5 (GSC Lebreton)
- Appendix 2 Stratigraphic section of DH RU-24 (GSC Russell)
- Appendix 3 Stratigraphic section of GSC Observatory Crescent
 (or GSC Experimental Farm)
- Appendix 4 Stratigraphic section of DH AL-3 (Imperial Laggan #1)
- Appendix 5 Stratigraphic section of DH AL-1C GSC (McCrimmon's
 Corners)
- Appendix 6 Legend; explanation of symbols used in the appendices

Appendix 1

Location 1: GSC Lebreton

NTS map sheet: 31G ; Grid Zone 18T

UTM Coordinates: Easting: 44900, Northing: 25700

Reference: Williams (1991)

Depth(m)	Facies	Lithology	Sedimentary Structures																
			Rockcliffe Fm.																
222	4																	Ca	Py
	1b																		=
	2																	Ca	Py
224	1b																		
	4																		
	4																	Ca	
	2																		=
226	2																		
	2																		
	2																		
	6																	Ca	
	3																	Ca	
228	3																	Ca	
	4																	Ca	
	3																	Ca	
	2																	Ca	
230	1b																		=
	1b																		=
	1b																		=
232	1b																		
	1c																		
234	2																	Ca	Py
	2																	Ca	
236	3																	Ca	
	2																		S
	2																		S
238	3																		
	2																		
240	2																		S
	2																		
	3																		

Appendix 1 cont.
Location 1: GSC Lebreton

Appendix 2
 Location 2: GSC Observatory Crescent
 NTS map sheet: 31G ; Grid Zone 18T
 UTM Coordinates :Easting: 440470, Northing: 5026700
 Reference: Williams (1991)

Depth(m)	Facies	Lithology	Sedimentary Structures														
			Rockcliffe Fm.														
130	4																
	3																
	1c																
	1c																
	1c																
132	2																
	6																
	3																
134	3																
	2																
	2																
136	3																
	3																
	3																
	3																
138	1b																
	1b																
	3																
140																	
	2																
	2																
142	4																
	1b																
	1b																
	4																
144	1c																
	3																
146	2																
	2																
	2																
148	3																
	2																
150	2																

Appendix 2 cont.
Location.2. GSC Observetory Crescent

Appendix 3
 Location 3: GSC Russell
 NTS map sheet: 31G ; Grid Zone 18T
 UTM Coordinates :Easting: 469400, Northing: 5017600
 Reference:Bernstein(1991)

Depth(m)	Lithology	Sedimentary Structures														
		Rockcliffe Fm.														
554	2	S	V	T	/	M	Q		→						Ca	S
	1b		V	T	/	M	Q									
556	2	S	V	T	/	M									Ca	S
	4		V	T	/	M									Ca	S
	4		V	T	/	M									Ca	S
	2		V	T	/	M									Ca	S
558	4		V	T	/	M									Ca	S
	3		V	T	/	M									Ca	S
	3		V	T	/	M									Ca	S
	1c		V	T	/	M									Ca	S
560	1c		V	T	/	M									Ca	S
	1b		V	T	/	M	Q		→						Py	=
	3		V	T	/	M										
	3		V	T	/	M										
562	2	S	V	T	/	M									Ca	S
	3		V	T	/	M									Ca	S
564	2	S	V	T	/	M									Ca	S
566	1c		V	T	/	M									Ca	S
	1b		V	T	/	M									Ca	S
	1c		V	T	/	M									Ca	S
568	2	S	V	T	/	M									Ca	S
	1b		V	T	/	M									Ca	S
570	2	S	V	T	/	M									Ca	S
	3		V	T	/	M									Ca	S
572	2	S	V	T	/	M									Ca	S

Appendix 3 cont.
Location 3: GSC Russell

[illegible]

Appendix 4
Location 4: Imperial Oil Laggan
NTS map sheet: 31G ; Grid Zone 18T
UTM Coordinates : Easting: 521200, Northing: 5026300
Reference: Bernstein (1991)

[illegible]

Appendix 4 cont.
Location4: Imperial Oil Laggan

[illegible]

Appendix 4 cont.
Location 4: Imperial Oil Laggan

Appendix 5
 Location 5: McCrimmon's Corners
 NTS map sheet: 31G ; Grid Zone 18T
 UTM Coordinates :Easting: 520100, Northing: 5029900
 Reference:Bernstein (1991)
 Note: The upper part of Carillon Formation is not cored

Depth (m)	Facies	Lithology	Sedimentary Structures																
54	2		Σ	Υ	Υ														S
	4																		
	1b																		
56	2		Σ	Υ	Υ														S
	2																		
	2																		
	1b																		
58	2		Σ	Υ															
	2																		
60	2		Σ	Υ															
	4																		
62	2		Σ	Υ	Υ														
	2		Σ																
64	4																		
	1b		Σ	Υ															
66																			
	2		Σ																
68	3																		
	1b																		
70	2		Σ		Υ														S
	3																		
	2		Σ	Υ	Υ														S
72	3																		
	2																		
74			Σ																

Appendix 5 cont.
Location 5: McCrimmon's Corners

Depth(m)	Facies	Lithology	Sedimentary Structures															
76	2		S	V	T												U	=
	3			V														
	3	---																
78	2		S		T	/											U	= S
	3			V														
80	1b						M											=
	5b		S		T		M										U	Py
82	2		S		T													S
	2																	
	5b		S		T													
84	3																	
	2		S	V		/												
	3																	
	3																	
	2		S			/												
86	1c																	
	6					Q												Py
	3	---																
88																		
	2		S			/												=
90																		
	2		S	V	T	/											U	
92	2		S	V	T		M											
	2																	
	5b					/	M										U	Ca Py =
	3																	
94	1c					/	M											Ca
	2		S			/												
	3			V		/												

Appendix 5 cont.

Location 5: McCrimmon's Corners

Depth(m)	Facies	Lithology	Sedimentary Structures														
	2		S			/		8									
98																	
	2		S			/	M										
100	1c					/											
	3					/											
	2		S					8									
102	3																
		5b					M	8		→							
	3																
104																	
	3	2	S						Δ	→							Py
	3																
	2		S			/											Py
106																	
	3		S			/			Δ								Py
107	2		S														
	2		S				M			→							
			Beauharnois Fm.														

Legend

Lithology

Shale		Shale <1cm
Evaporite		Shale 1-3 cm
Sandstone		Shale 3-5 cm
Dolomudstone		Shale 5-10 cm
Dolograinstone		Rockcliffe Formation
Stromatolitic unit		Beauharnois Formation

Sedimentary Structures

Stylolite
Parallel lamination
Wavy lamination
Lenticular laminae
Normal grading
Reverse grading
Desiccation cracks
Synsedimentary deformation
Vertical fracture
Compacted synsedimentary Fracture filled with sand & brittle Fractures
Burrow mottled
Moderately bioturbated
Erosional Surface

Diagenetic Effects

Ca	Calcite nodule
Py	Pyrite
Evaporite nodule

Bioclast types

Bioclast
Ostracod
Stromatolite

Non-skeletal Grains

Intraclast
Peloid
Ooid

Ichnofossils

Vertical burrow
Horizontal burrow