Mineral Resources Branch

Geology of the Sydney Basin, Cape Breton and Victoria Counties, Cape Breton Island, Nova Scotia

Memoir ME 11

R.C. Boehner and P.S. Giles

Nova Scotia
Natural Resources

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NOVA SCOTIA
Natural Resources

Honourable David Morse
Minister

Peter Underwood
Deputy Minister

Halifax, Nova Scotia
2008

Cover Photo

This photograph shows a wind turbine at North Head near Lingan, Cape Breton County. The turbine represents the latest energy contributor to the regional mix, while the rocks of this headland are coal measures of the Sydney Basin, which have contributed energy for 300 years. Photo by R. C. Boehner, 2006.

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Geology of the Sydney Basin, Cape Breton and Victoria Counties, Cape Breton Island, Nova Scotia

R. C. Boehner and P. S. Giles

Abstract

The Sydney Basin, a northeasterly elongated synclinorium in eastern Cape Breton Island, contains up to 3500 m (stratigraphic thickness) of continental and marine sedimentary rocks. The strata range in age from Early Carboniferous (Tournaisian) to Late Carboniferous (Cantabrian-Stephanian) and overly, with angular unconformity, Neoproterozoic (Hadrynian) to Devonian age metasedimentary and igneous rocks. Contacts with the bounding basement blocks are complicated by syn- and post-Carboniferous fault movements. The earliest basin fill is dominated by coarse grained alluvial strata probably of Tournaisian to early Viséan age which comprise the Grantmire Formation of the Horton Group.

The Viséan Windsor Group onlaps parts of the borders of the basement blocks. The Windsor Group is an interstratified sequence of marine evaporite, carbonate and continental redbeds up to 1000 m thick. The Windsor Group contains numerous industrial mineral occurrences including celestite, gypsum, anhydrite, salt, potash, dolomite and limestone as well as occurrences of base metals including Cu, Pb and Zn.

The Mabou (Canso) Group conformably overlies the Windsor Group and comprises up to 150 m of late Viséan-early Namurian grey and red mudrocks, gypsum and anhydrite. These represent the return to continental lacustrine and fluvial deposition. The basin fill has a major internal unconformity indicated by the absence of strata of late Namurian to early Westphalian B age.

The South Bar Formation at the base of the Morien Group comprises up to 850 m of fluvial grey sandstone. These unconformably overlie an eroded landscape of Windsor Group and Mabou Group strata and the base of the Morien Group is locally a zone for sandstone hosted Pb and Zn mineralization, e.g. the apex of the Pottle Lake Syncline (similar to the Yava lead deposit). The South Bar Formation is overlain by and is, in part, facies equivalent to the Waddens Cove Formation (up to 300 m) dominated by redbed fluvial strata including sandstone, mudstone and locally coal. The South Bar and Waddens Cove formations are succeeded by the coal-bearing Sydney Mines Formation (up to 1000 m). These units of late Westphalian B to Stephanian age dominate the onshore Basin area. The Sydney Mines Formation contains the principal coal resources in the Province and is conformably overlain by up to 1000 m of Pictou Group redbeds (the 'Undivided Permo-Carboniferous' map unit). These strata occur entirely in the offshore extension of the Basin.

The present Basin configuration reflects a two-part structural system with block faulting and folding-tilting and erosion of the Mabou Group and older rocks, followed by deposition of the Morien Group and subsequent faulting and folding into open synclines and anticlines. These structures are often coincident with the older structures (inherited from Lower Carboniferous) and indicate tectonism occurred both during the late Westphalian deposition and post-Stephanian with last movement on the Bateston-Lennox Passage Fault being younger than the latest Carboniferous strata. The paleogeographic relationship of the Sydney Basin to the adjacent Loch Lomond Basin and Glengarry Half Graben is enigmatic. The significant differences in their stratigraphic records in the Namurian and early Westphalian suggest the present day juxtaposition may be allochthonous and perhaps is related to major strike slip faulting (Bateston-Lennox Passage Fault).

Nova Scotia Department of Natural Resources, Mineral Resources Branch, Memoir ME 11

Introduction

The Sydney Basin is a large Carboniferous structural basin situated in eastern Cape Breton Island, Nova Scotia (Figs. 1 and 2). The stratigraphy and structure are discussed (Fig. 3). The onshore area included in this report (approximately 2000 km^2) is composed of parts of the following National Topographic Survey (NTS) map sheets: 11F/16, 11K/01, 11K/02 East, 11K/08 and 11J/04. It is bounded approximately by latitudes 45°57' to 46°20'N and longitudes 59°45' to 60°41'W (Figs. 1, 2 and Map 86-1, in pocket). The map area is accessible from the Strait of Canso through St. Peters along Routes 104 and 4 toward Sydney, or from the Strait of Canso through Baddeck on the Trans-Canada Highway 105. There is a good system of paved and unpaved roads which provide easy access to most of the map area.

The rocks described in this report occur principally in a lowland area which is characterized by gently rolling terrain where elevations rarely exceed 100 m. This area is bordered to the south by the highlands including the Mira Hills or Fourchu Block, East Bay Block, Coxheath Hills and Boisdale Hills and to the west by Kellys Mountain Block (Figs. 4, 5, 6a and 6b). Elevations in the highlands rise abruptly to 150-300 m. The Basin area is traversed by numerous low gradient drainage systems characterized by small streams and small scattered lakes and stillwaters. The area has many coastal embayments, the drowned Mira River estuary to the south and the Great Bras d'Or to the northwest. Although the streams and rivers typically have low profiles there is modest bedrock exposure in the river beds. Tributary streams, with steeper profiles on basement rocks, also have moderate outcrop.

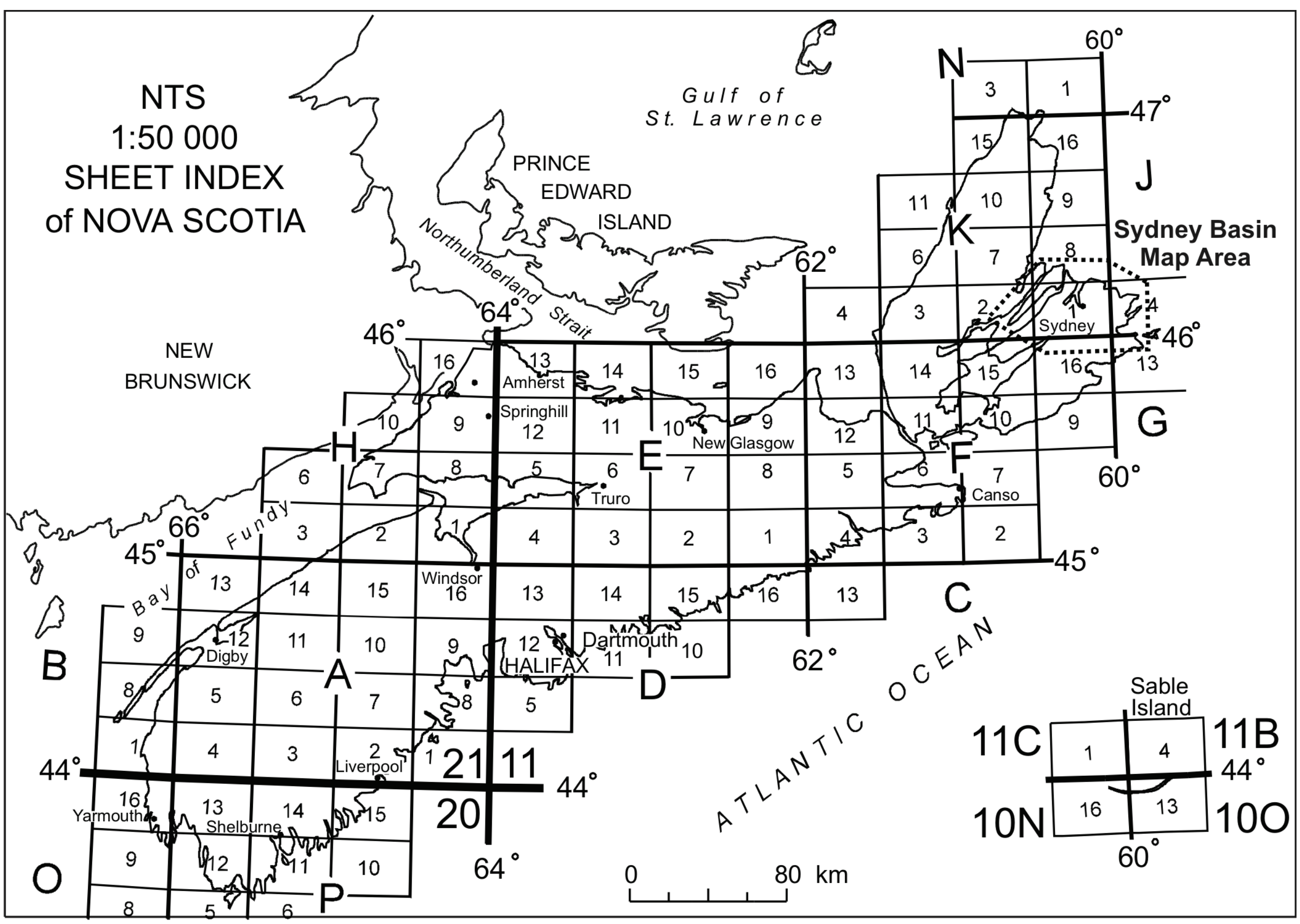

Figure 1. NTS reference map of Nova Scotia showing the Sydney Basin map area location.

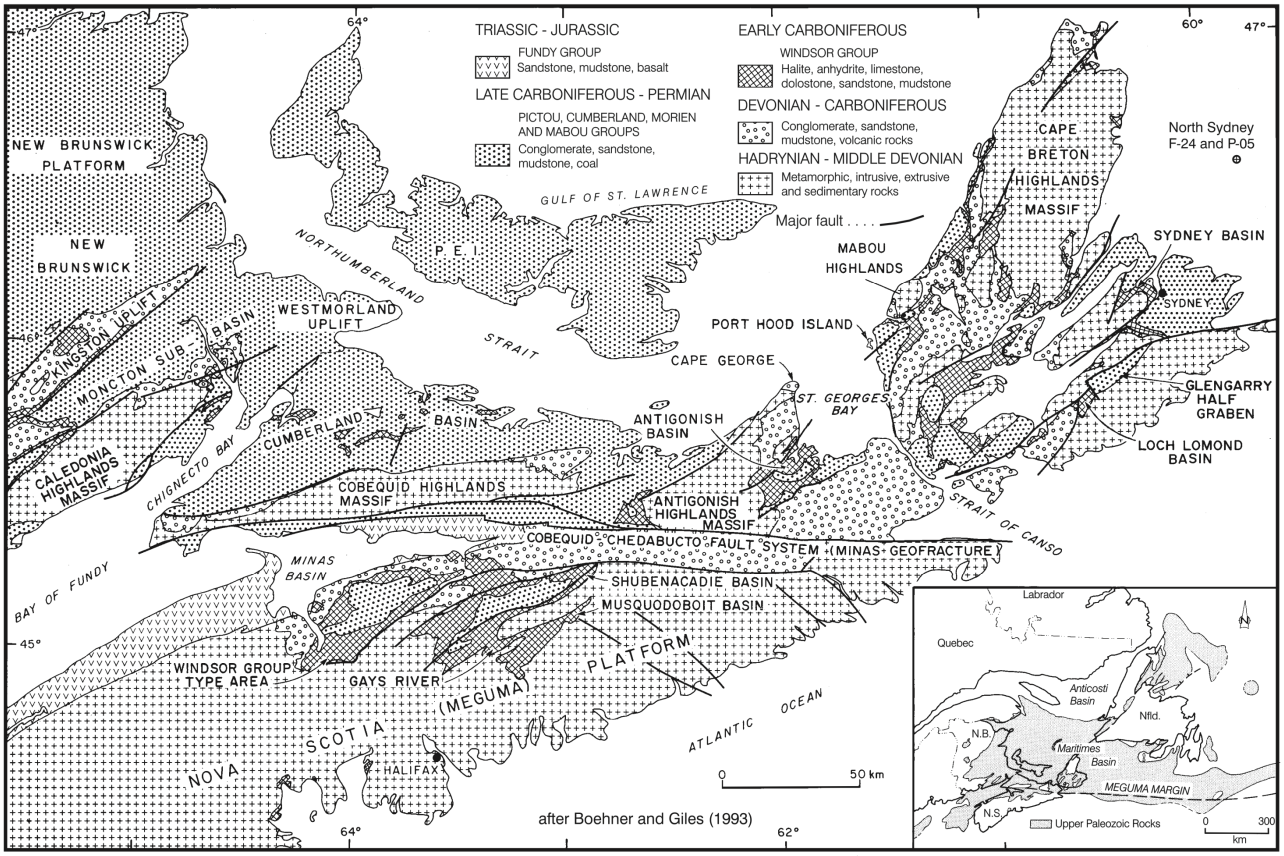

Figure 2. Simplified geological map showing the location of the Sydney Basin.

Mining activity in the area has concentrated on the extensive coal resources over the past 200 years with more limited quarrying of limestone-dolomite for use in the steel industry. Mineral exploration has focused on base metals in the basal Windsor Group and sandstone hosted base metals at the base of the South Bar Formation Morien Group. The two recently closed underground coal mines in the area were operated by the Cape Breton Development Corporation. These were the Prince Mine near Point Aconi and the Phalen Mine near Lingan (Fig. 5). Dolomite of the George River Group is quarried at Kellys Cove-New Campbellton by Mosher Limestone Company Limited. Small open-pit coal mines operate in the Point Aconi area.

Carboniferous basins in Nova Scotia are a primary or exclusive source for a variety of economically important coal resources and metallic and nonmetallic minerals including lead, zinc, gypsum, anhydrite, salt, limestone, dolomite, barite and celestite. Production from Carboniferous rocks is the dominant component of the mineral industry in Nova Scotia and these basins continue to be the focus of exploration for petroleum, coal, industrial and metallic minerals.

The Sydney Basin is one of the largest Carboniferous outcrop areas that has been investigated as part of a Carboniferous basins mapping program by the Nova Scotia Department of Mines and Energy (now Natural Resources). Other areas include the Lomond Basin and Glengarry Half Graben (Boehner and Prime, 1985, 1991, 1993), Shubenacadie and Musquodoboit Basins (Giles and Boehner, 1979, 1982a), Eureka area (Giles, 1982), Antigonish Basin (Boehner and Giles, 1982, 1993), Sydney Basin (Boehner and Giles, 1986) and the Cumberland Basin (Ryan and Boehner, 1990; Ryan *et al.*, 1990a, b, c). A large volume of subsurface data, principally from more than 1000 diamond-drill holes by the coal mining and mineral exploration industries, have provided the basis for a greater understanding of the geology and mineral resource potential of the basins. These mapping studies have benefited from abundant, previously unavailable, subsurface data. The

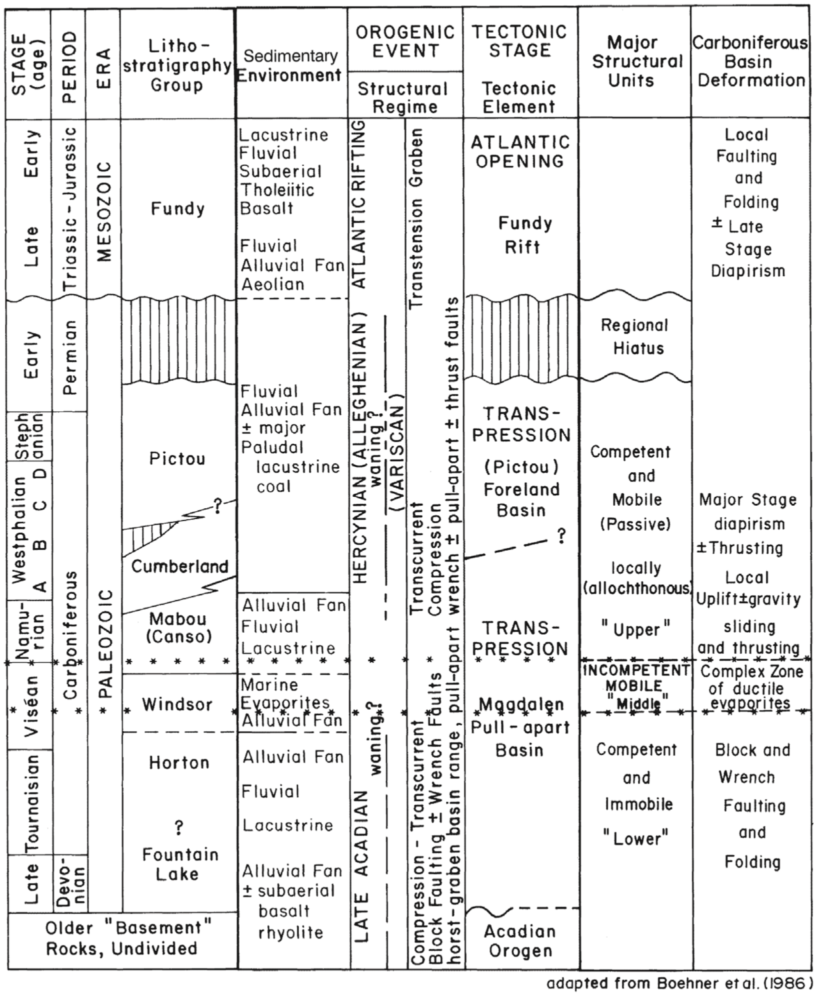

Figure 3. Stratigraphic, tectonic, depositional and structural deformation summary of late Paleozoic to early Mesozoic in Atlantic Canada.

Sydney Basin contains the bulk of the coal resources of the Province and has significant mineral potential.

Purpose

The primary goals of this study were to describe the geology of this economically important area, using all available outcrop and critically important subsurface information from exploration drillholes. Emphasis was placed on determining the stratigraphy and structure of the Carboniferous strata, especially the Horton, Windsor and Mabou (Canso) groups and identifying the related mineral deposits. Comparisons and correlations were to be made, where possible, with other Carboniferous basins and outcrop areas (e.g. the adjacent Loch Lomond Basin and Glengarry Half Graben). The pre-Carboniferous rocks were not examined in detail and are informally considered to be basement to the Basin succession. The geology of these basement rocks has been described by Hutchinson (1952), Weeks (1954), Milligan (1970), Barr *et al.* (1982) and Barr and Setter (1984).

Methods and Acknowledgments

Field mapping, drill core logging of selected holes and limited stratigraphic drilling were conducted during the summers of 1982, 1983 and 1984 with the assistance of D. Creaser, A. Boucher, D. Hogg, R. Secco and D. Webber. Related university research and thesis work supervised by Brian Rust at University of Ottawa and Martin Gibling at Dalhousie University, Halifax resulted in numerous publications such as Best (1984), Bird (1987), Dilles (1983), Gibling (1991), Masson (1985) and White (1992). These contributed extensively to the understanding of the stratigraphy and sedimentology of the South Bar, Waddens Cove and Sydney Mines formations. Traverses were made of all stream and river sections as well as examinations of road cuts and previously reported outcrops. Field data were compiled on field maps at a scale of 1:15 840 (Boehner and Giles, 1991) for final publication at 1:50 000 (NSDME Map 86-1, in pocket). A simplified version is presented for reference as Figure 5. All subsurface data, from exploration drillholes, were compiled, drillhole sections plotted and selected drillholes logged. These data were used to construct a series of drillhole cross-sections which supplement the outcrop information in determining stratigraphy and map unit boundary placement. S. Forgeron, Cape Breton Development Corporation, Coal Mining Division, contributed unpublished, compiled information on coal

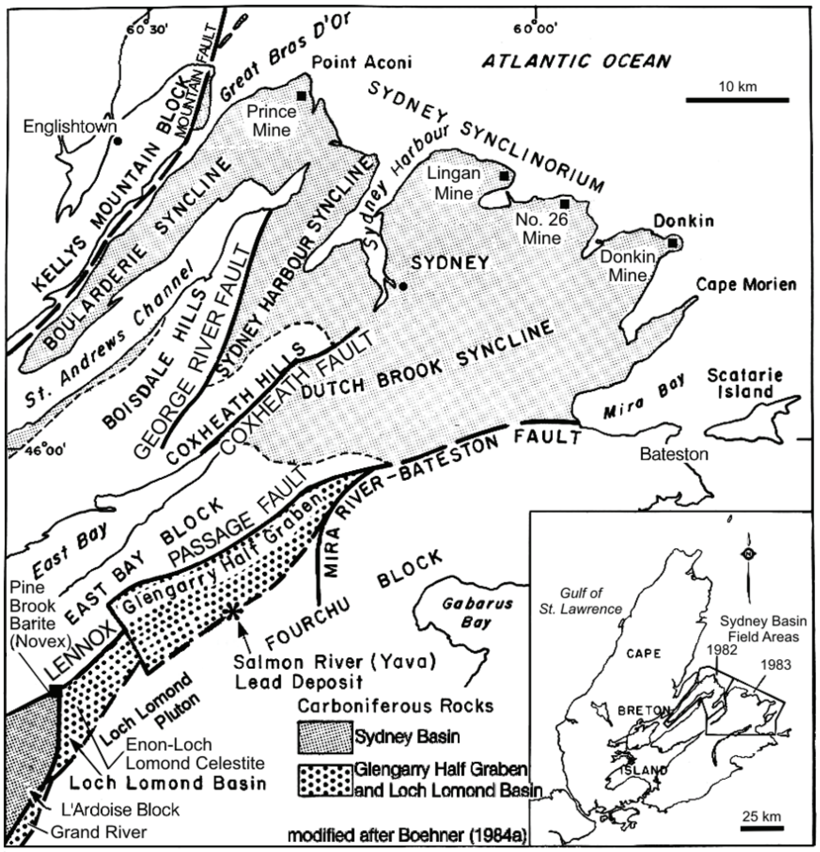

Figure 4. Local general geological and location map for the Sydney Basin, eastern Cape Breton Island.

exploration drillholes, the Sydney Mines Formation structure, coal seam locations and coal mine locations. Much of the information on the geology of the Morien Group strata is compiled with acknowledgment from concurrent and subsequent workers.

Thanks are extended to D. J. MacNeil and R. Naylor who critically read and offered constructive suggestions for the manuscript. The reviews, however, do not necessarily imply agreement with the conclusions reached in this paper.

Identification of spore assemblages used in supporting this project were kindly provided by M. S. Barss of the Geological Survey of Canada and G. Dolby of G. Dolby and Associates, Calgary. The interpretation of these assignments into the lithostratigraphic framework, however, is the responsibility of the authors alone.

Word processing for the paper was completed by B. MacDonald of the Geoscience Information Services Section, Nova Scotia Department of Natural Resources, cartography by J. Campbell and the Cartography Section of the Nova Scotia Department of Mines and Energy , subsequently updated by P. Belliveau, W. Burt and C. Phillips of the Graphics and Mapping Services of the Nova Scotia Department of Natural Resources, and photography by R. Morrison and C. Murphy. K. A. Mills and D. R. MacDonald edited several versions of this report and improved it substantially. The authors gratefully acknowledge the contribution of each of the above.

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Errata

Several errors have been identified since the publication of the Geological Map of the Sydney Basin, Map 86-1 (in pocket). In the stratigraphic sequence of coal seams, the McRury Seam is mislocated beneath the Mullins Seam and should have been located beneath the Emery Seam. Several coal mine sites are not located on the map and therefore the map cannot be considered an authoritative record of all coal mines in the area (Millward, 1985). A few coal exploration drillholes, of the hundreds located on the map, are inadvertently mislabelled and map users are advised to consult original location maps and descriptions included in original files of the former Coal Resources Section, with the Nova Scotia Department of Natural Resources.

Geological Investigations

Although exploitation of coal from seaside

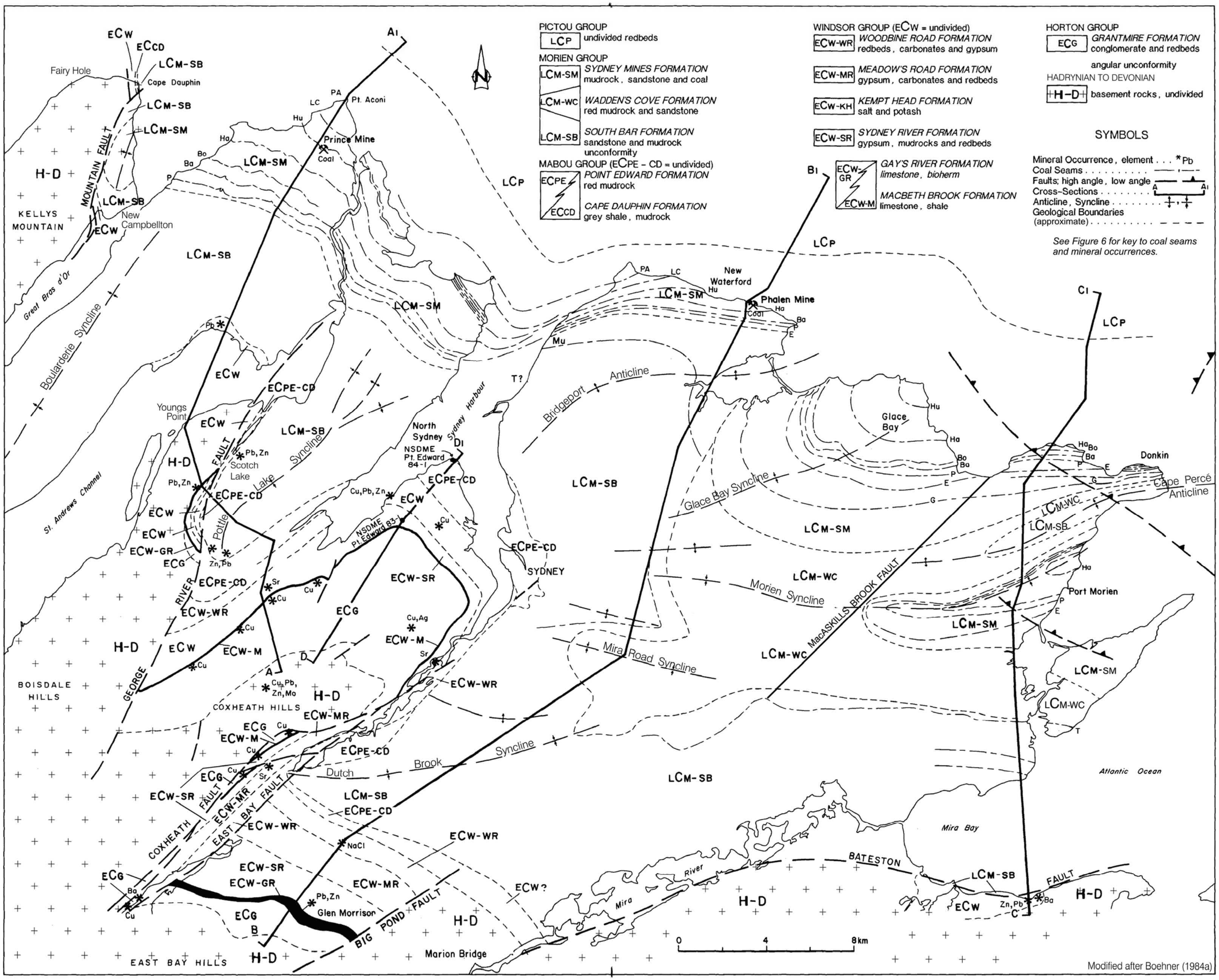


Figure 5. Simplified geological map of the Sydney Basin. See Figure 6a for cross-sections and Figure 6b for extended legend..

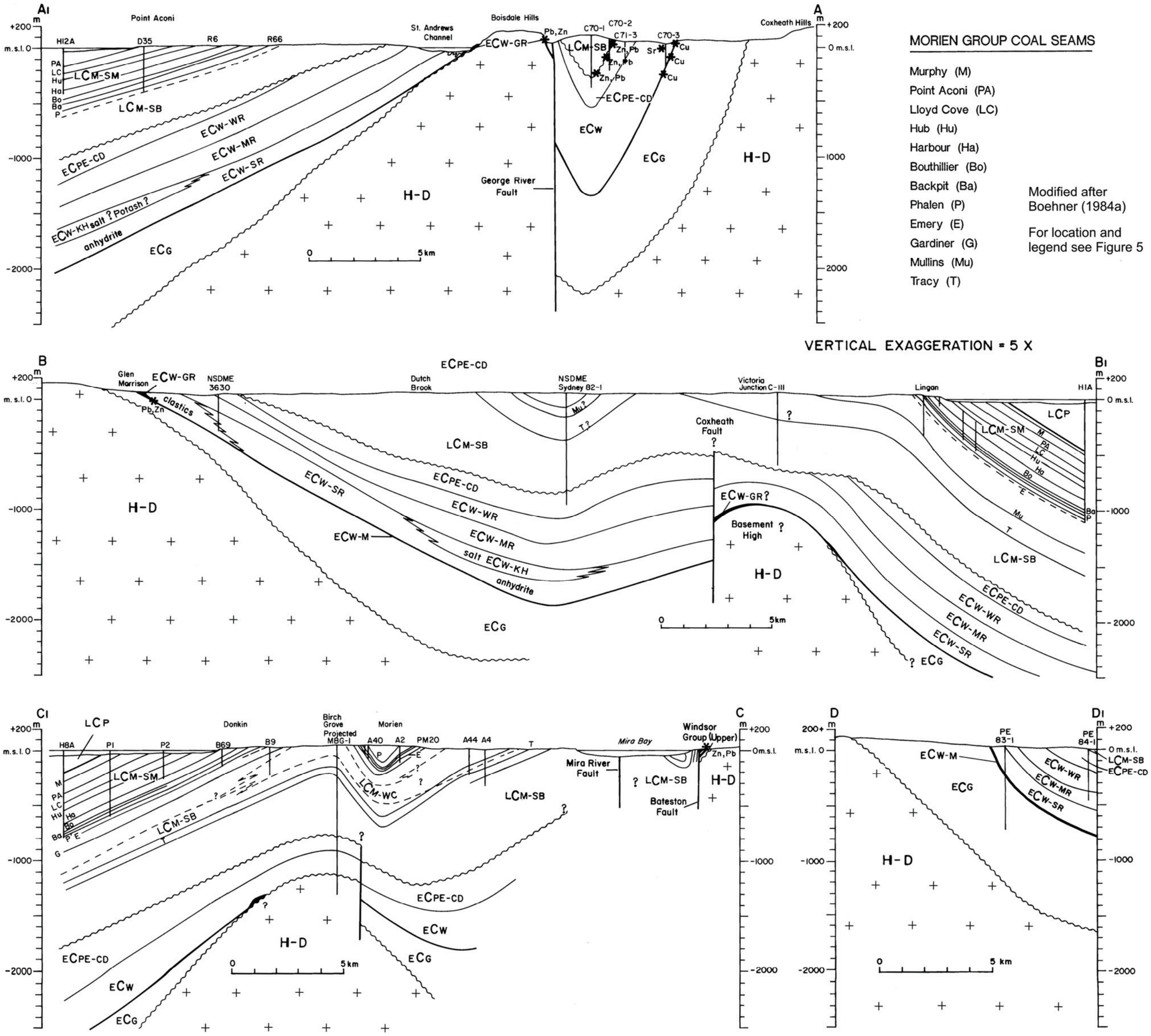


Figure 6a. Cross-sections A, B, C and D in the Sydney Basin. See Figure 5 for legend and locations and Figure 6b for extended legend.

outcrops occurred in the early 1700s, the earliest geological accounts of the area were not reported until the early 1800s (Brown, 1871; Hayes and Bell, 1923). These reports were generally of a reconnaissance nature or focused on the coal measures. The most significant of those who reported their observations and layed the foundations for the geological units in the area were: Brown (1871) and Dawson (1855, 1868, 1891). The first systematic mapping and detailed descriptions were included in the reports and maps of Robb (1873, 1874, 1876), Robb and Fletcher (1876) and Fletcher (1878, 1887, 1898, 1899a, b) including revisions. This mapping at a scale of one inch equals one mile (Sheets 133, 134, 135) is of particular value in attempting to relocate stratigraphically useful outcrops of coal, gypsum and limestone. Additional detailed work was undertaken by Hyde (1913), a coal resource inventory by Dowling (1915) and a methodical survey of part of the coalfield was recorded by Hayes and Bell (1923) and Bell (1938).

The Basin area was subsequently mapped by the Geological Survey of Canada by the following: Hayes *et al.* (1938a, b), 11K/01 East and 11J/04; Bell and Goranson (1938a, b), 11K/01 West and

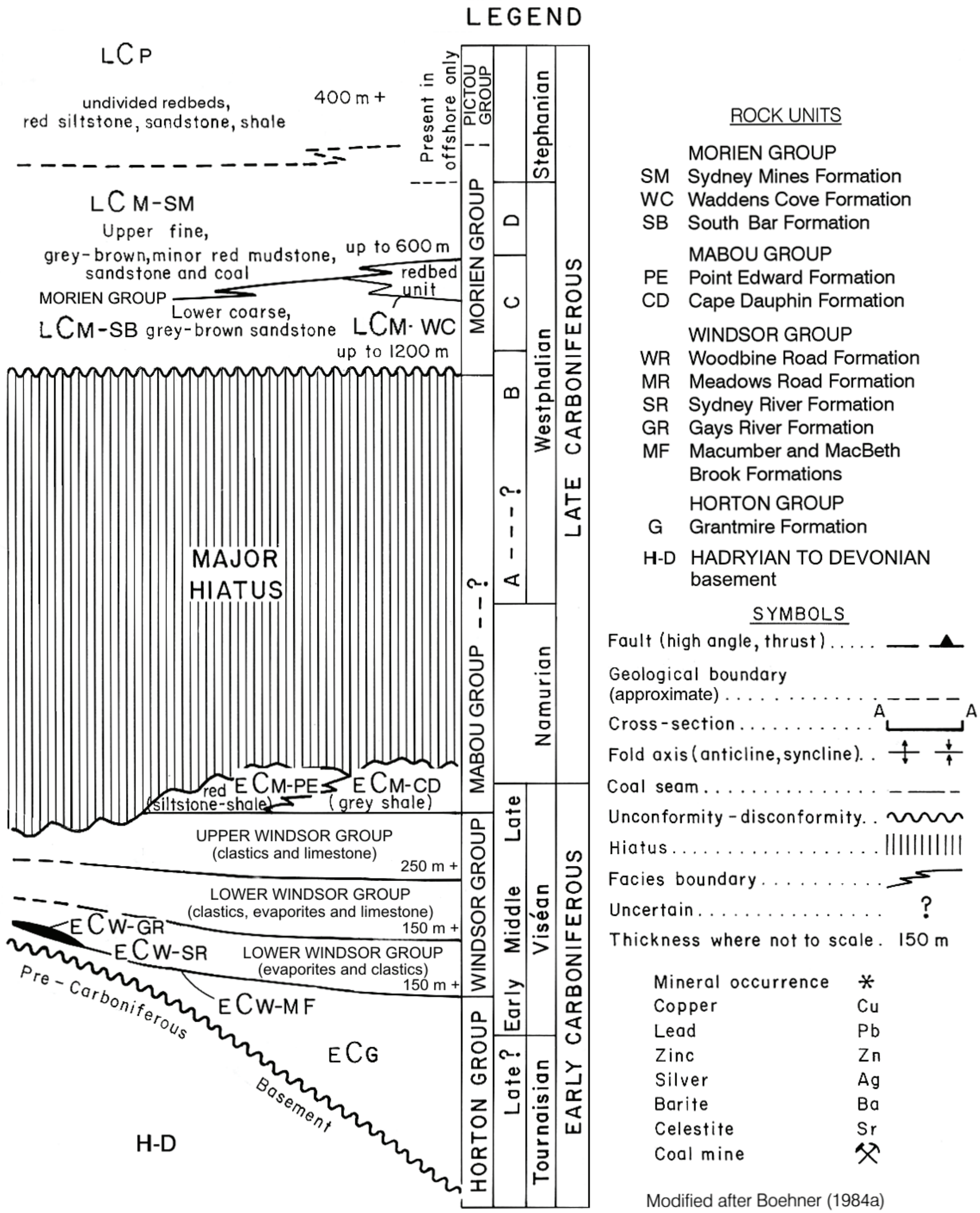


Figure 6b. Extended legend for Figures 5 and 6a.

11K/08; Kelley (1968), 11K/02; Weeks (1954, 1955), as part of 11F/15; and Weeks and Hutchinson (1958) as part of 11F/16. As a result of extensive coal mining and exploration activities in the area, numerous published and unpublished geological reports and maps have been produced on the geology, sedimentology and paleontology of the coal bearing strata. These include the work of Hacquebard, Haites, Cameron, Barss, Forgeron, Duff, Gibling, Rust and Zodrow.

Coal mining has been active in the Sydney Basin for more than 200 years with extensive bulk mining for nearly 150 years. Total recorded production from the mid-1800s to 1993 is approximately 450 Mt. Steel manufacturing, historically, was a major consumer of coking coal as well as local limestone resources for flux (Shea and Murray, 1969; Irish Cove, Frenchvale and Point Edward area).

In the 1960s there was active exploration for base metals by New Jersey Zinc Corporation in the Leitches Creek area and by Mariner Mines near Frenchvale Brook. In the early 1970s Cerro Mines, Mindamar Mines and Imperial Oil explored the Windsor Group for base metals near Frenchvale and Glen Morrison. Chevron Resources re-examined the Glen Morrison area in the early 1980s. Kaiser Celestite Mining Ltd. explored for celestite near Frenchvale and Sydney River and operated a strontium chemical production plant in the Point Edward area near Sydney in the early 1970s. Morton Chemical of Canada Ltd. drilled for salt in the early 1960s in the Meadows Road area. Following a seismic survey, Murphy Oil drilled Birch Grove No. 1 in 1968 on the crest of the Birch Grove Anticline near Sand Lake. This hole terminated in basement rocks and was dry and abandoned.

With the exception of the major offshore and smaller onshore coal resource drilling projects by the Nova Scotia Department of Mines and Energy in the late 1970s to early 1980s, there has been limited mineral exploration activity in the area. The Nova Scotia Department of Mines and Energy drilled six holes (total of 3940 m; Boehner, 1985c) for stratigraphic information in the Sydney Basin as part of the Sydney Basin Project, 1981-1984. In addition to documenting key stratigraphic problems, the following two new mineral prospects were discovered: salt and potash in the Boularderie Syncline and celestite mineralization in the Woodbine Road area (Map 86-1, in pocket).

Specific studies of the Windsor Group mineralization in the Sydney area were included in Binney and Kirkham (1974) and Smith and Collins (1984) on the base metals; and Felderhof (1978) on the celestite. Shea and Murray (1969) described the limestone and dolomite deposits in the area. Their location maps and descriptions of the deposits are very useful in relocating the stratigraphically important carbonate outcrops. The general geology of the carbonate buildups in the area was described by Boehner *et al.* (1988) and Boehner (1987). The Glen Morrison Bank is currently in production as a limestone resource for the fluidized bed coal-fired generator at Point Aconi.

The most recent systematic mapping in the area was completed by Boehner and Giles (1986, Map 86-1, in pocket). The lithostratigraphy used on this map is formally defined in this report. Preliminary reports on the results of this study have been previously published by Giles (1983) and Boehner (1984a, 1985a, b).

The stratigraphy of the Carboniferous section above the Windsor Group in Nova Scotia was studied and described by Belt (1964, 1965). Belt (1964) proposed a revised stratigraphic nomenclature that involved dropping the names Canso and Riversdale groups and reranking the Mabou Formation (Norman, 1935) to group status. Strata, formerly assigned to the Canso Group and locally the Riversdale Group, were included in the Mabou Group which comprises variably subdivided locally named formations. Although revisions to the Mabou Group, proposed by Belt (1964, 1965), had not previously gained wide usage, they were adopted by Ryan *et al.* (1991) in a related revision of Upper Carboniferous stratigraphy and are adopted in this report.

General Geological Setting

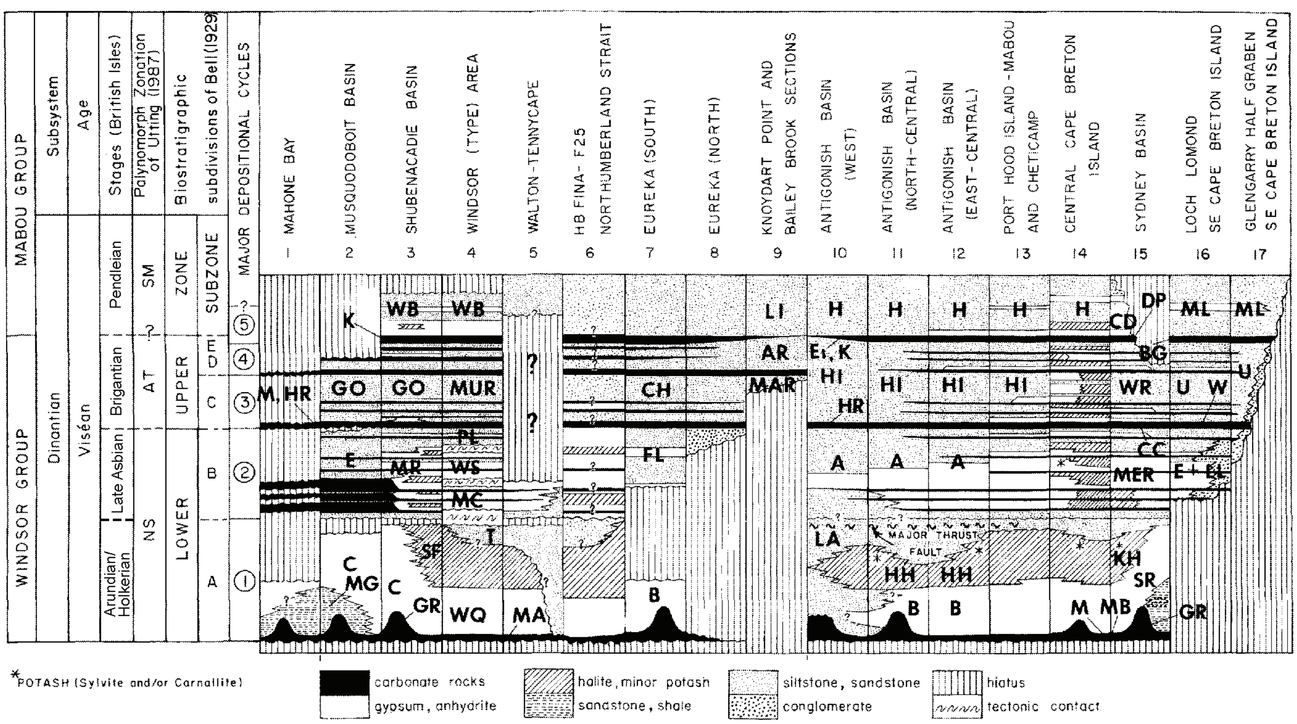
The Sydney Basin is a structural basin defined by a succession of Carboniferous rocks that range in age from Tournaisian to Stephanian-Cantabrian (Figs. 4, 5, 6a, 6b and Map 86-1, in pocket). Middle Devonian McAdam Lake Formation strata occur only in the Boisdale-Coxheath Hills area to the southwest of the Sydney Basin. The

Carboniferous basin-fill is dominated by a heterogeneous sequence of stratified continental siliciclastics. These range from coarse boulder-pebble conglomerate, sandstone and minor siltstone in the lower part with a major section of coal-bearing strata and finer grained facies including siltstone, sandstone and redbeds in the upper part.

Although recent studies indicate a possible marine biota in parts of the Sydney Mines Formation (Thibaudeau and Medioli, 1986; Wightman *et al.*, 1992, 1993), the only major marine deposition in the Carboniferous is recorded by the interstratified marine carbonate and evaporite, and redbeds (including fanglomerates) of the Windsor Group (Figs. 7 and 8).

The Sydney Basin, like most Carboniferous basins, has a prominent northeast-southwest structural trend defined in the Namurian and older strata by the regional structural fabric. There also is a well developed east-west trend in the Late Westphalian strata in the eastern part of the Basin. This is emphasized by the Cape Percé Anticline, the Morien Syncline and the Bateston (Lennox Passage) Fault, the major basin bounding Fault. The Basin extension to the northeast displays gentle folds coincident with many of the structures in the older strata beneath the unconformity (late Namurian to Westphalian B).

The Sydney Basin onshore map area, described in this report, is a small (2000 km^2), but economically important part of an extensive offshore basin (>150 000 km^2) extending northwards and eastwards nearly to Newfoundland (Hacquebard, 1983; Bell and Howie, 1990). This predominantly subsea level basin is one of the larger structural elements of the Late Paleozoic basin system in Atlantic Canada referred to by Boehner *et al.* (1988) as the Maritimes Basin (Fig. 2). The collection of basins containing Carboniferous rocks has been variously called the Fundy Epieugeosyncline (Kelley, 1970), Fundy Basin (Bell, 1958; Belt, 1968a) and Fundy



A	ADDINGTON FORMATION	E+LL	ENON & LOCH LOMOND FORMATIONS	LI	LISMORE FORMATION	PL	PESAQUID LAKE FORMATION
AR	ARDNESS FORMATION	FL	FORBES LAKE FORMATION	M	MUSQUODOBOIT MEMBER	SF	STEWIACKE FORMATION
B	BRIDGEVILLE FORMATION	GO	GREEN OAKS FORMATION	MA	MACUMBER FORMATION	SR	SYDNEY RIVER FORMATION
BG	BIG GLEN MEMBER	GR	GAYS RIVER FORMATION	MB	MACBETH BROOK FORMATION	T	TENNYCAPE FORMATION
C	CARROLLS CORNER MEMBER	H	HASTINGS FORMATION	MC	MILLER CREEK FORMATION	U	UIST FORMATION
CC	CRAWLEY CREEK MEMBER	HH	HARTSHORN FORMATION	MG	MEAGHERS GRANT FORMATION	W	WAVY MEMBER
CD	CAPE DAUPHIN MEMBER	HI	HOOD ISLAND FORMATION	ML	MACKEIGAN LAKE FORMATION	WB	WATERING BROOK FORMATION
CH	CHURCHVILLE FORMATION	HR	HERBERT RIVER MEMBER	MR	MACDONALD ROAD FORMATION	WQ	WHITE QUARRY FORMATION
DP	DIXON POINT MEMBER	K	KENNETCOOK MEMBER	MAR	MARTIN ROAD FORMATION	WR	WOODBINE ROAD FORMATION
E	ELDERBANK MEMBER	KH	KEMPT HEAD FORMATION	MER	MEADOWS ROAD FORMATION	WS	WENTWORTH STATION FORMATION
E1	E1 LIMESTONE MEMBER	LA	LAKEVALE FORMATION	MUR	MURPHY ROAD FORMATION		

After Boehner and Prime (1993); modified after Giles (1981); stages from von Bitter *et al.*, 2006

Figure 7. Windsor Group stratigraphy and correlation in Nova Scotia.

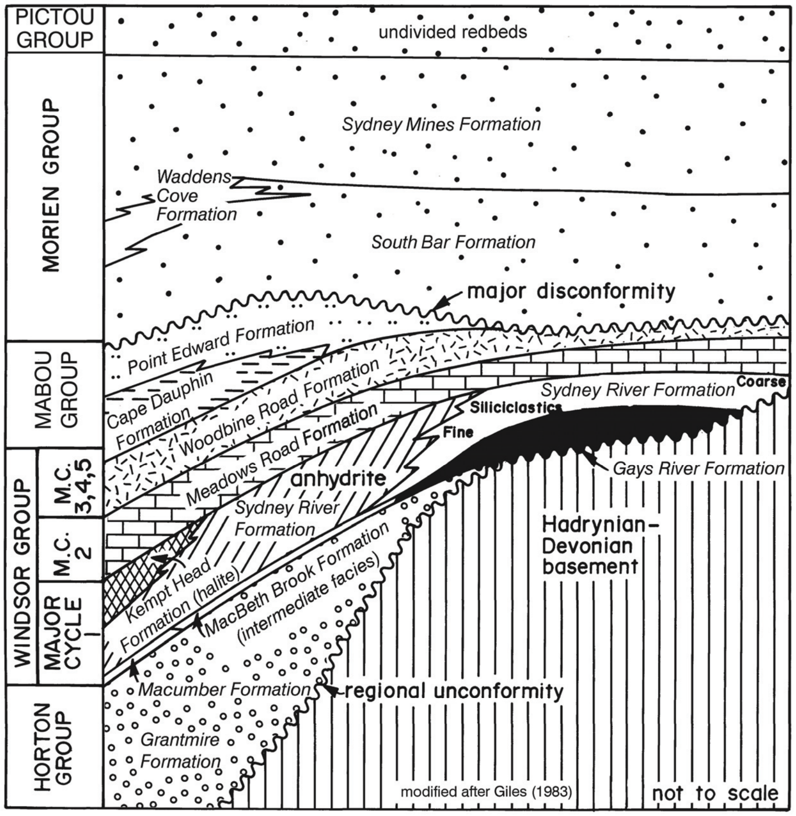


Figure 8. Diagrammatic representation of major stratigraphic relationships in the Sydney Basin.

Aulacogene (Keppie, 1977). Structural and stratigraphic models applied to the Carboniferous rocks in the Maritimes Basin have been diverse at both the regional and local scales. The Basin nomenclature is complicated because it is based on a mixture of structural and sedimentary models (Fig. 3). The name Maritimes Basin, after Roliff (1962) and Boehner *et al.* (1988), is used here as a nongenetic, general term for reference to areas in Atlantic Canada underlain by Late Paleozoic strata.

The Carboniferous succession generally records deposition in a complex series of fault block and down warped intermontane troughs developed upon the folded Acadian Orogen (Ryan, *et al.*, 1987; Belt, 1968b). A great thickness of dominantly molassic sedimentary deposits accumulated in the deeper central mobile area beneath the Gulf of St. Lawrence where up to 10 000 m is indicated by Howie and Barss (1975). Although the sedimentary rocks are dominantly Carboniferous, the succession includes strata as old as Middle-Late Devonian (e.g. McAdam Lake Formation) which locally contain interstratified volcanic rocks and in the central area (Prince Edward Island and the Magdalen Islands) Permian age strata (Howie and Barss, 1975). One of the more interesting aspects of the Sydney Basin and the Glengarry Half Graben is the contrasting Namurian to early Westphalian stratigraphic records in two basin outcrop areas that are so close together (Boehner and Prime, 1993).

Stratigraphy

The following sections contain descriptions and interpretations of the major rock units in the map area (Figs. 8 and 9). They are described in ascending order from oldest to youngest and closely follow the sequence of map units on Map 86-1 (in pocket). Pre-Carboniferous crystalline rocks were not examined in detail and are considered informally as the basement to the Carboniferous basin fill. The Sydney Basin has a maximum projected thickness of 3500 m (Figs. 5, 6, 7 and 8) of Carboniferous sedimentary rocks in the onshore part of the Basin. The strata range from Viséan to Stephanian in age. The sedimentary sequence consists primarily of fine- to coarse-grained continental siliciclastics and, to a lesser extent, paralic or limnic mudrocks, limestones, evaporites and very minor marine carbonates. The stratigraphy and sedimentology in the Windsor and Mabou groups is generally similar to the Loch Lomond Basin and Glengarry Half Graben (Boehner and Prime, 1993). The early Carboniferous onlap in the Sydney Basin occurs only at the level of Windsor Group Major Cycle 1 onto basement highs (Gays River Formation). Further onlapping of younger strata is not preserved. The late Carboniferous sedimentary cover may have been thick to have been able to entirely cover the basement highland paleotopography.

A brief summary of the Carboniferous stratigraphy in the area is shown in Figures 3 and 7 and outlined below. Please note that most of the Mississippian (Lower Carboniferous) units have coarse grained alluvial facies near the underlying

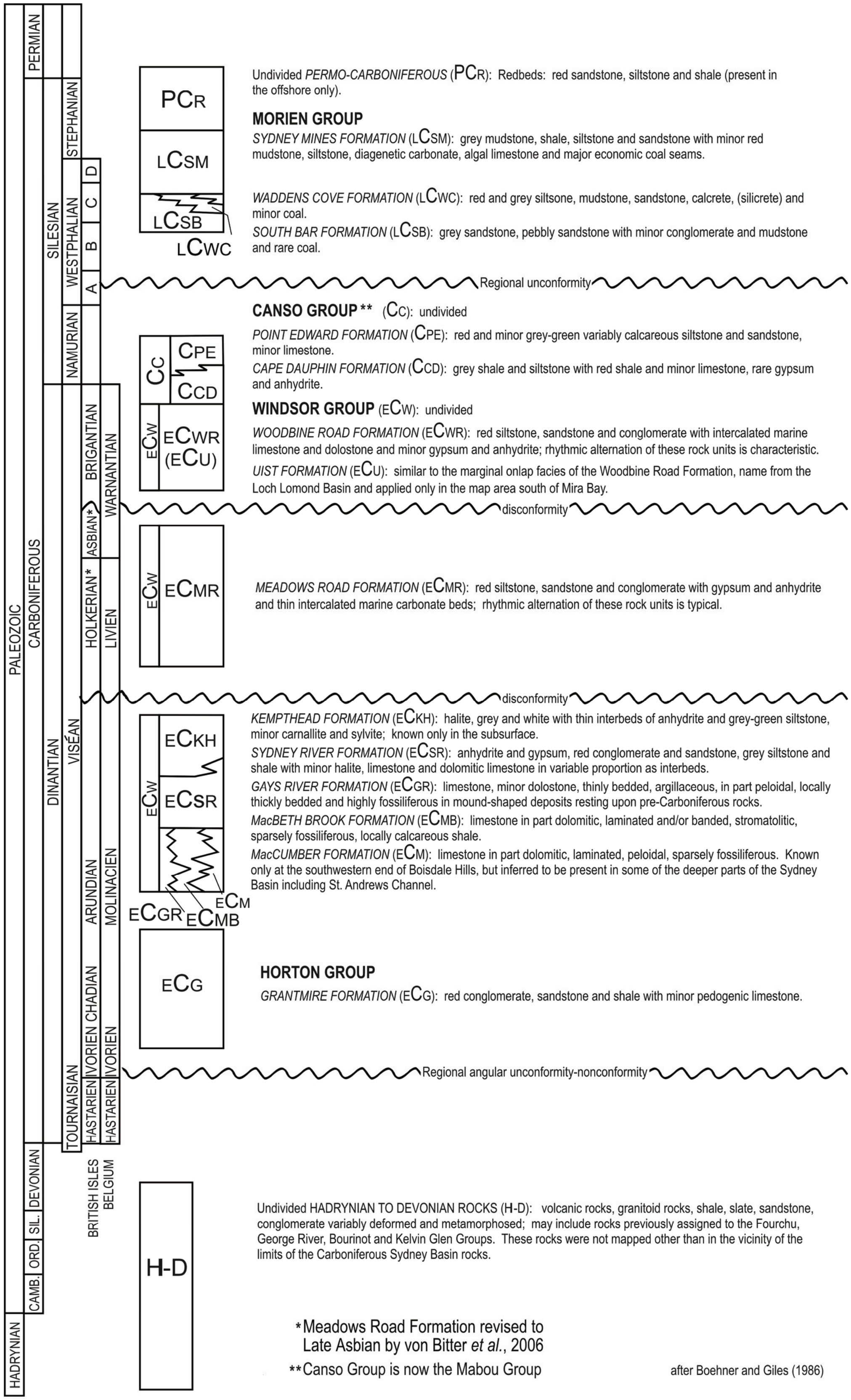


Figure 9. Legend for the Geological Map of the Sydney Basin, Cape Breton Island, Nova Scotia Department of Mines and Energy, Map 86-1. (Note: Canso Group is now called Mabou Group and Meadows Road Formation is revised to Late Asbian by von Bitter *et al.,* 2006).

basement rocks. This makes it difficult to pick formation boundaries in the Point Edward-Coxheath area because of the disappearance of the definitive marine carbonate members.

The oldest stratigraphic unit included in the Carboniferous basin is the Grantmire Formation of the Horton Group (Figs. 5, 8 and 9). This is an undivided conglomeratic unit that rests unconformably on the Neoproterozoic (Hadrynian)-Devonian basement. Similar lithologies occur as marginal facies of the stratigraphically overlying Sydney River and Meadows Road formations Windsor Group, which comprise an interstratified sequence of evaporites, redbeds and marine carbonates. The Meadows Road Formation is disconformably overlain by the Woodbine Road Formation, an interbedded sequence of redbeds, marine carbonates and evaporites. Conformably to disconformably overlying the Woodbine Road Formation is the Mabou (Canso) Group Cape Dauphin Formation and Point Edward Formation, a section of interbedded grey shales, with minor limestone, evaporites and redbeds.

The Lower Carboniferous strata are unconformably overlain by the South Bar Formation of the Morien Group. The South Bar Formation comprises a package of grey sandstones with minor mudrocks and coal deposited unconformably on the Windsor and Mabou strata. The unconformity surface is, in part, an incised erosional and karst paleolandscape. Conformably overlying this, and in part intercalated with it, is the Waddens Cove Formation which comprises a mixed redbed and coal-bearing section of sandstone and mudrocks. This succession is in turn overlain by the Sydney Mines Formation which contains extensive coal resources. The Sydney Mines Formation comprises interstratified cycles of green-grey sandstone and mudrocks, major coal seams and minor redbeds. This unit is conformably overlain by redbeds of the Pictou Group identified only in the offshore areas as undivided Permo-Carboniferous. The entire basin fill is covered by a variably thick blanket of Pleistocene surficial deposits.

The paleontological age assignments in this report are based upon palynology of shales sampled through the key available stratigraphic sections. These zone assignments were provided by M. S. Barss of the Geological Survey of Canada, Atlantic Geoscience Centre, Dartmouth, Nova Scotia and Graham Dolby and Associates, Calgary, Alberta. This does not necessarily imply agreement with the interpretation of the results presented. The micro-paleontological age assignments are generally in agreement with those derived from recent work on the macroflora by Zodrow and Cleal (1985) who revised the original macroflora biostratigraphy of Bell (1938).

Pre-Carboniferous Basement

The crystalline rocks outcropping in the Kellys Mountain, Boisdale Hills, Coxheath Hills, East Bay Hills and Fourchu Block have been considered informally as basement to the younger sedimentary succession in the Sydney Basin (Figs. 5 and 6). These basement rocks have been described, mapped and subdivided in reports by Hutchinson (1952), Weeks (1954), Kelley (1967a), Milligan (1970), Barr and Setter (1984), Raeside and Barr (1990), Barr *et al.* (1996) and White and Barr (1998). No attempt is made here to contribute new information on these rocks, but a short summary of the major lithology and nomenclature is useful in understanding the background geology of the area. All basement rocks were included in an undivided map unit, but may be considered in the following two parts: (1) the stratified sedimentary, metasedimentary and volcanic rocks, and (2) the plutonic rocks.

Stratified Rocks

The stratified rocks include the Fourchu, George River, Kelvin Glen and Bourinot groups as well as the weakly deformed formations of the Cambrian sedimentary sequence and the Middle Devonian Macadam Lake Formation. These rocks collectively form a thick suite of interstratified metasedimentary, volcanic and volcaniclastic rocks and form a prominent component of detritus in the coarse grained Carboniferous basin fill. These are variably deformed with locally weak deformation. The older rocks typically have well developed cleavage and have undergone greenschist or higher grade metamorphism. Younger units may have undergone less complicated deformation.

Plutonic Rocks

The metasedimentary and volcanic rocks have been intruded by small granitoid plutons and porphyry. In the Boisdale-Coxheath Hills area, Barr and Setter (1984) described the Shunacadie, Boisdale Hills, Spruce Brook and Coxheath plutons. Barr *et al.* (1982) also described the Kellys Mountain Pluton and the Huntington Mountain Pluton. The plutonic basement rocks were also a prominent source of immature detritus in alluvial fanglomerates of the Carboniferous basin fill.

General Carboniferous Lithostratigraphy

Several new lithostratigraphic units at the member and formation rank have been defined, redefined and existing names introduced into the area. These include (Figs. 8, 9 and 10): Grantmire (redefined), Macumber, MacBeth Brook (new), Gays River, Sydney River (new), Kempt Head (new), Meadows Road (new), Woodbine Road (new), South Bar, Waddens Cove and Sydney Mines formations. The name Canso Group, used at the time of the original mapping (NSDME Map 86-1), is now abandoned and replaced by Mabou Group following the precedent of Belt (1964, 1965) and most recently the revisions of Ryan *et al.* (1991). For contact relationships involving Windsor Group onlap, or erosion and unconformity, the base of the Windsor Group has been placed in accordance with the suggested practice of Keppie *et al.* (1978). In these situations, continental siliciclastic rocks containing marine strata and where bounded by unconformities, but without basal or upper limestone markers, are included with the Windsor Group (e.g. the Sydney River and Meadows Road formations in the Point Edward area). These contain coarse siliciclastic facies similar to the underlying, revised Grantmire Formation.

Cross-sections A-A^1, B-B^1, C-C^1 and D-D^1 (Fig. 6a) were constructed to illustrate the general geology and structure in the Sydney Basin. Generally the sections may be considered in the following six lithologic packages: (1) pre-Carboniferous basement, (2) Horton Group, (3) Windsor Group, (4) Mabou (Canso) Group, (5) Morien Group, and (6) undivided Permo-Carboniferous redbeds of the Pictou Group. The basal contact of the Horton Group (Grantmire Formation) with basement is a regional angular unconformity-nonconformity. There is local stratigraphic onlap and carbonate buildup development in Major Cycle 1 of the Windsor Group. The Windsor-Mabou contact is concordant and conformable. The basal contact of the Morien Group is a distinct unconformity, locally characterized by extensive erosion and a disrupted brecciated zone extending down to near the top of the evaporitic Meadows Road Formation of the Windsor Group (Figs. 6b and 8). Angular discordance appears to be slight, however there is substantial stratigraphic record missing which represents the late Namurian to early Westphalian B.

Strata in the Horton, Windsor and Mabou groups typically have gentle dips in the range of 10-20°, but tend to steepen in areas adjacent to faulted basement blocks (e.g. Coxheath and Boisdale hills) (Fig. 6a, A-A^1). The dips in the unconformably overlying Morien Group are generally very gentle 5-15° in a series of gently plunging folds. However, similar to the underlying rocks, the dips steepen up to 15-40° near the projections of the faulted basement blocks. Dips tend to be less steep in the younger units of the Morien Group indicating a declining influence of the basement blocks with time. This coincidence with the basement blocks is interpreted to be due to loading, compaction and deformation around competent basement forms which was enhanced by sedimentation patterns controlled by paleotopography and probable synsedimentary growth fault history (Figs. 5 and 6). Solution collapse and foundering disrupted the soluble Windsor Group strata at the unconformity beneath the Morien Group (e.g. Boularderie Island area). Giles and Lynch (1993) have interpreted these breccias as related to a major decollement.

Horton Group

The lowermost units of the Carboniferous basin-fill were described by Bell (1929, 1944) as part of the Tournaisian Horton Group (see also Murray, 1960; Kelley, 1967a, b). The type area designated near Windsor, Hants County is also the type area for the overlying Windsor Group. The Horton Bluff and

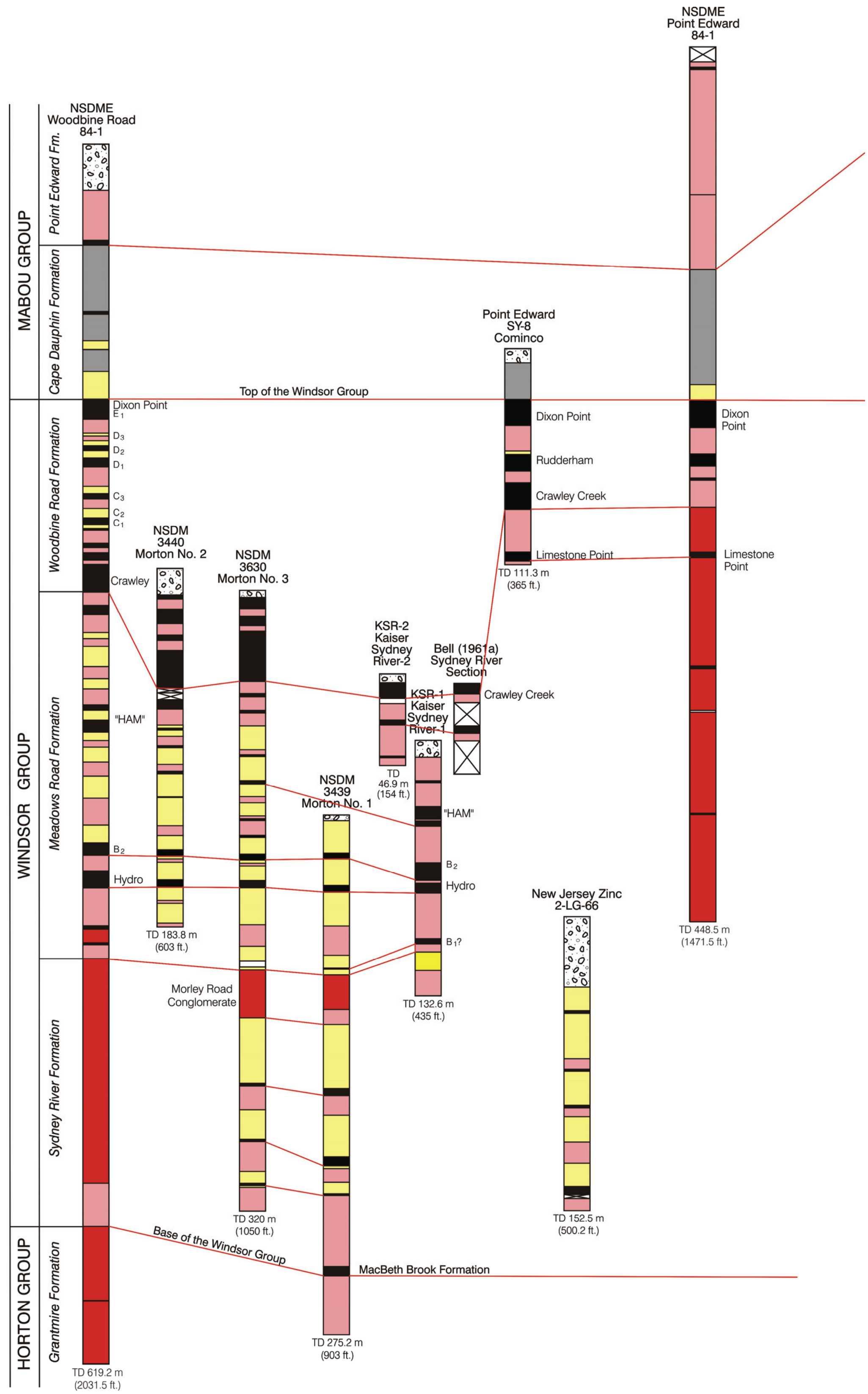


Figure 10. Correlation of drillhole sections representing the Mississippian (Lower Carboniferous) Horton, Windsor and Mabou groups in the Sydney Basin. Includes type and reference sections of the Grantmire, Sydney River, Meadows Road, Woodbine Road, Cape Dauphin and Point Edward formations. See Map 86-1 (in pocket) for locations of drillholes.

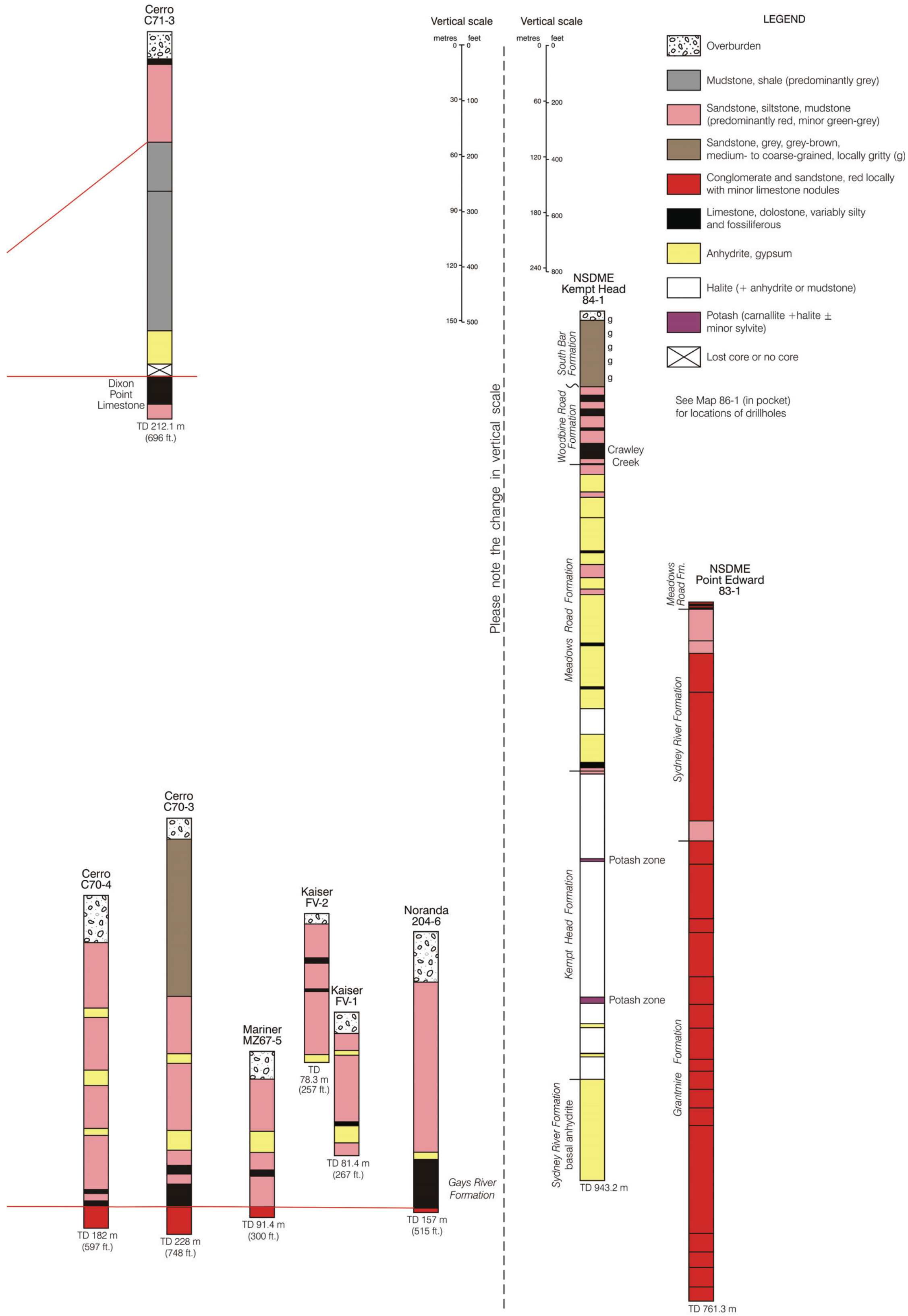


Figure 10. Continued.

Cheverie formations were recognized by Bell (1929) in the type area where the Horton Group comprises up to 1000 m of interstratified, grey and red sandstone, mudrock and conglomerate (fluvial and lacustrine). The base of the Horton Group in the Windsor area is a major angular unconformity or nonconformity with metasedimentary and granitoid rocks of the Meguma Zone. The Horton Group siliciclastics are concordantly to disconformably overlain by marine strata of the Windsor Group.

Regionally, most strata which overlie crystalline and metamorphic rocks deformed during the Acadian Orogeny (regional basement unconformity), and which underlie the evaporitic marine Windsor Group have been included in the Horton Group. An exception in Nova Scotia is the volcanic and siliciclastic Fountain Lake Group (replaces River John Group of Bell, 1944). Although primarily of Tournaisian age in the type area, strata of Late Devonian age were being identified at an increasing number of localities prompting boundary extensions by Kelley (1967b) to include these strata giving the Horton Group a range of Late Devonian to Viséan age. This redefinition without representation in the type area was problematic to Keppie *et al.* (1978) who excluded the pre-Tournaisian strata.

Palynological studies in the type area by Utting *et al.* (1989) indicated an age not older than late Tournaisian (TN3) with the entire section within the early to middle TN3. The late TN3 and most of the Viséan (V1 and V2) are not apparently represented due, in part, to a disconformity at the base of the Windsor Group. Unproductive redbeds at the top of the Cheverie Formation contribute to the uncertainty of the biostratigraphy at this level. Utting *et al.* (1989) recognized strata in the adjoining Shubenacadie Basin whose age apparently fills the gap at the Horton-Windsor contact. They consequently proposed expansion of the Horton Group to formally include these strata.

The inherent problems of age controlled group definition (Ryan *et al.*, 1991) are highlighted by the subsequent discovery of Late Devonian spore assemblages in strata at the base of the Horton Group (Horton Bluff Formation) exposed in Harding Brook, near the type area (Martel *et al.*, 1993). This, together with the marginal basin onlap disconformity relationship of the Cheverie Formation over the Horton Bluff Formation described by Martel (1990), indicates the type area constituents are incompletely exposed and are subject to redefinition as new data are acquired (e.g. in the deep subsurface).

Grantimire Formation

The evolution of the Horton Group litho- and biostratigraphy in the type area and Sydney Basin is similar to that of the Horton Group strata in other Carboniferous Basins. The contact between the basement rocks and the stratified rocks of the Sydney Basin is not always a simple, unconformable boundary with Carboniferous age rocks. Some of the rocks included with the basement include sedimentary rocks of the McAdam Lake Formation, are of Early to Middle Devonian age and may represent, in part, a syn- to post-tectonic (Devonian-Acadian) transition. They are not included in this study in the Horton Group. The geology of these rocks was described by Bell and Goranson (1938b) and was not further investigated in this study. They comprise steeply dipping grey conglomerate, arkosic sandstone and mudrock which locally includes organic-rich shale and minor volcanic tuff. These rocks occur in the Gillis Lake area as a wedge between the Boisdale and Coxheath hills and appear to be unconformably overlain by the conglomerates of the Grantmire Formation.

The Grantmire Formation is assigned to the Horton Group in the Sydney Basin. It is a coarse grained alluvial fan dominated sequence of redbeds which outcrops around the onshore perimeter of the Sydney Basin. Although it is the only unit recognized in the Horton Group, other units (Hamblin and Rust, 1989) may exist in the subsurface extensions of the Basin.

The name Grantmire was first introduced as a member, comprising a succession of red conglomerate and sandstone, in the area north and east of the Coxheath Hills (Figs. 4 and 5). Bell and Goranson (1938a, b) described it as thick deposits of conglomerate which form the lowest rock unit of the Windsor Group below marine limestone or sandstone of Lower Windsor age. Weeks (1954) formally raised the unit to formation status and applied it to all conglomeratic sequences forming the base of the Windsor Group.

Unfortunately, rocks now considered to be Horton Group were incorrectly identified and mapped as Grantmire Formation as the basal unit of the Windsor Group (e.g. Iona-Grand Narrows area). Kelley (1967a) concluded that in the Baddeck and Whycocomagh map areas, which adjoin the Sydney Basin map area, strata assigned to the Grantmire by Bell and Goranson (1938a, b) and Weeks (1954) were typical of the Horton Group.

Boehner (1981, 1983, 1985a) and Prime and Boehner (1984) showed that conglomerate units of the Grantmire lithology occurred as tongues and wedges at many stratigraphic positions in the Windsor Group making it an impractical unit to map in these situations. The distribution of conglomeratic strata in the Loch Lomond and Sydney areas is much better defined by subsequent exploration drilling. It is apparent that coarse grained conglomeratic units do occur throughout the Horton Group and Windsor Group sections. They are uncommon, but are locally significant as interbeds and are occasionally dominant components within the lowermost Windsor units. Examples include the Enon and Loch Lomond formations (Loch Lomond Basin) in the Amac and MacRae celestite deposits as well as in the Sydney River Formation in the area adjacent to the Coxheath Hills and Glen Morrison in the Sydney Basin. These conglomerate units were locally interpreted to be overthrust Horton Group by Smith and Collins (1984).

Giles (1983), based upon mapping in the type area in the Sydney Basin, recommended that the term be restricted to the succession of brick red to maroon conglomerate, sandstone and shale extending from the pre-Carboniferous unconformity to the base of the Macumber Formation or Gays River Formation of the Windsor Group. This was followed by Boehner and Prime (1993), Boehner and Giles (1986) and in this report.

Type Locality The Grantmire Formation type section is designated in Grantmire Brook and tributaries as well as a reference outcrop section in the adjacent Big Brook (Watson Creek) near Beechmont North. NSDME drillhole Point Edward 83-1 (Fig. 10) drilled near Point Edward, intersected the upper part of the Grantmire Formation between 258.5 m and the end of the hole at 761.3 m (Fig. 6, D-D[1]).

Lithology The Grantmire Formation comprises interstratified, red, polymictic conglomerate, conglomeratic sandstone, variably calcareous red siltstone and sandstone, minor grey shale and scattered pedogenic limestone concretions. Similar conglomeratic and siliciclastic facies, known to occur at higher stratigraphic levels within the Windsor Group, are treated as follows: where intercalated with definitive Windsor Group facies e.g. marine carbonates and evaporites, especially if a bounding basal carbonate member is present, they are included with the relevant Windsor Group formation e.g. Enon, Loch Lomond, Sydney River or Meadows Road formations.

Distribution and Thickness In its type section, the Grantmire Formation has a total thickness of 750-800 m. In onlap areas it thins to a few 10s of metres and locally may be absent (e.g Scotch Lake). The Formation is widely distributed throughout the Sydney Basin, but nowhere as well exposed as it is in the type area.

Relations to Other Units The Grantmire Formation rests with angular unconformity upon pre-Carboniferous crystalline basement and is concordantly and conformably overlain by the Windsor Group. It is overlain concordantly by the basal Windsor Group carbonate named the Macumber Formation or MacBeth Brook Formation and locally by the Gays River Formation (Fig. 8). The Grantmire Formation was originally correlated as a marginal facies (member) of the Windsor Group by Bell and Goranson (1938b), but is herein correlated with the Horton Group. Similar conglomeratic lithologies occur as tongues and wedges stratigraphically higher in the overlying Windsor Group (e.g. Point Edward-Coxheath Hills) and a boundary can generally be placed using key marine carbonate-clastic beds. The Grantmire Formation is concluded to be a marginal redbed fanglomerate facies of the Horton Group similar lithologically to the Wilkie Brook Formation in the Antigonish Basin area.

Depositional Environment The Grantmire Formation is interpreted to represent the coarse facies of an alluvial fan-braided stream depositional suite. Coarse, polymictic conglomerate are inferred to have been deposited proximal to the highlands (upper fan) grading to finer distal facies (mid to lower fan). Although exposed in the limited outcrop or drilling, lacustrine shales and associated limestone might occur in a basinward setting. The abundance of secondary pedogenic caliche limestone as irregular nodules and discontinuous layers within the finer grained strata indicates an arid to semiarid climate where seasonal precipitation prevailed.

Age Paleontological dating of the Grantmire Formation has been severely limited by the scarcity of productive lithology (e.g. fine grained, grey mudrocks for palynology). A spore assemblage similar to that of the Cheverie Formation was recovered from a grey shale section in the upper parts of the Formation section in drillhole PE 83-1. Assemblages from the Cheverie Formation were assigned by Higgs (1975) and Utting *et al.* (1989) to the Late Tournaisian.

Windsor Group

The Windsor Group is one of the most important stratigraphic and economic units in the Late Paleozoic basins of Atlantic Canada. It comprises a complex succession of interstratified evaporites including gypsum, anhydrite, salt and potash, fine- and coarse-grained redbeds, and fossiliferous marine carbonates (Fig. 7). The thickness ranges from a few metres up to more than 1500 m with 750-1000 m typical. It is widely distributed throughout Atlantic Canada. The evaporites of the Windsor Group are a dominant component of the nonmetallic mineral economy of Nova Scotia. The Windsor Group is also a principal host for base metal, celestite and barite deposits including the Walton, Gays River and Loch Lomond deposits (Boehner and Ryan, 1989).

The Windsor Group type area is located near Windsor, Hants County and was described in detail by Bell (1929). Windsor Group strata conformably or disconformably overly the continental siliciclastics of the Horton Group, and locally rest with angular unconformity upon older basin fill (Late Devonian-Early Carboniferous). In some areas it onlaps directly onto basement with angular unconformity or nonconformity. The Windsor Group is generally overlain conformably by mudrocks and evaporites of the basal Mabou (Canso) Group. In some areas it is unconformably overlain by younger Late Carboniferous units (e.g. Scotch Village Formation, Malagash Formation or South Bar Formation). The incompetent nature of the Windsor Group has resulted in a locally complex and highly variable structural configuration (Boehner, 1992). Multiple repetition in isoclinal recumbent folds, thrust and slide faults and extensive near surface solution collapse are locally common in highly deformed basins. Giles and Lynch (1993) have identified a significant decollement surface in the Windsor Group near Saunders Cove, on Boularderie Island.

The basic stratigraphic framework of the Windsor Group in the Sydney Basin was outlined by Bell (1958, 1961a, b) who used the major carbonate units as principal markers. The carbonate units were named using the outcrop section in the Point Edward area as the reference. The faunal subzones assigned were based upon the biostratigraphy of Bell (1929). The stratigraphy of the Windsor Group in Cape Breton Island had been previously studied and described by Stacey (1953) and Sage (1954) who included sections at Cape Dauphin in the Sydney Basin. It might appear that Sage (1954) and Bell (1958, 1961a, b) completely emphasized the megafauna zonation in identifying and correlating the carbonate units. In reality the distinctive lithologic characteristics of many of the units were important diagnostic criteria (Giles and Boehner, 1982b).

The paleontology and biostratigraphy of the Windsor Group in the Maritimes Basin has been studied and described by many workers including Bell (1929), Stacey (1953), Sage (1954), Globensky (1967), Moore (1967), Mamet (1970), Moore and Ryan (1976), von Bitter (1976), Dewey and Fahraeus (1982), Utting (1978, 1980, 1987), and Utting *et al.* (1989). Comparisons and correlations have been made with international stratigraphic schemes both in North America and Europe. Although the biostratigraphic boundaries are not always coincident, Giles (1981) concluded that a general agreement existed in assignment of the Windsor Group to the Middle to Late Viséan. Giles (1981) described the Windsor Group as a set of Major Cycles, 1 through 5, and assigned them to the following Dinantian stages: Arundian/ Holkerian, Asbian and Brigantian of the British Isles. Geldsetzer (1978a) correlated the Windsor Group with the Late Meramecian and Chesterian of the United States.

Paleotopography and tectonism have influenced deposition in the area, especially in the Horton Group and older units, but are also locally significant in the lower part of the Windsor Group. Coarser alluvial fanglomerates are marginal facies near the base of the Windsor Group only (e.g. the Morley Road conglomerate in the Sydney River Formation). Sections representing Major Cycles 2-5 (Subzones B, C, D and E) are typical of basinal sections elsewhere in the Province. This contrasts with the profound facies changes in the adjacent Loch Lomond Basin (Boehner and Prime, 1993) where, over distances of less than 3 km, these units change from evaporite dominated to marginal alluvial fanglomerate dominated. The Windsor Group in the Sydney Basin is especially interesting in that it has many similarities with the Loch Lomond Basin which has extensive associated mineralization defined almost exclusively in drillholes. Comparisons are useful in understanding and predicting the mineral potential within the area.

The level of stratigraphic onlap is of particular interest because of the relationship between mineralization and carbonate buildup facies in the Windsor Group (e.g. Gays River Formation, Boehner, 1988; Giles *et al.,* 1979). The basal carbonate of the Windsor Group has been a traditional exploration target. The term basal carbonate is a general term which typically has been restricted to the A Subzone (Major Cycle 1) Macumber Formation (and equivalents A1 etc.) and during the mid-1970s included the correlative buildup facies, Gays River Formation which onlaps basement. The Sydney Basin area was one of the areas identified where the A Subzone (Major Cycle 1) was locally deposited directly on basement. The basement onlap of Major Cycle 1 (Fig. 7) was previously well documented in many basins by Giles *et al.* (1979) and Boehner (1989). Basement onlap by Major Cycles 2-5 is well documented in the adjacent Loch Lomond Basin and Glengarry Half Graben by Boehner and Prime (1993).

The stratigraphy and correlation of the carbonate strata at the base of the Windsor Group are important to mineral exploration and limestone resource development. These units have been studied and described in many areas of the Maritimes Basin in Atlantic Canada and names applied to the various facies. Original stratigraphic interpretations and correlations were erroneous (specifically the assignment to the B Subzone) because of limited subsurface data and a bias based upon paleontology and biostratigraphy.

Gays River Formation

The name, Gays River Formation, was originally introduced in the Shubenacadie and Musquodoboit basins by Giles *et al.* (1979) for a highly fossiliferous carbonate bank or buildup unit present at the base of the Windsor Group. It is correlated with the Macumber Formation and MacBeth Brook Formation and is best developed in areas where the Windsor Group onlaps directly on pre-Carboniferous basement (Figs. 8 and 9). In these areas, the regionally distributed Macumber Formation (sparsely fossiliferous) laminite has undergone a facies change to highly fossiliferous carbonate buildups of the Gays River Formation.

Limited data are available to detail the character of the banks. At Glen Morrison, the typical basal siliciclastic unit is not well developed (Figs. 11 and 12), but this unit does occur at Scotch Lake, Youngs Point, Fairy Hole and Englishtown. Other facies, typical of the Gays River Formation, are present including the dominant mottled algal boundstone with minor skeletal wackestone and bafflestone (Fig. 13). Fauna recognized include *Cladachonus* tabulate corals, brachiopods, pelecypods, bryozoa, gastropods, ostracods and algae (Ryan, 1978). The lithofacies, fauna and stratigraphy are very similar to some of the Gays River Formation banks in the Musquodoboit Basin.

Diagenetic features are not well documented, however there are geopetal sparry calcite-filled shell cavities, stylolites, and locally extensive karstification near surface. Trace base metal mineralization is locally present, including sulphides and oxides of Cu, Pb and Zn. This type of mineralization, especially Cu, occurs very commonly near the base of the laterally equivalent Macumber Formation and MacBeth Brook Formation (e.g. Frenchvale and East Bay). The fauna at Youngs Point was described by Ryan (1978) and is typical of the Gays River Formation fauna of Giles *et al.* (1979).

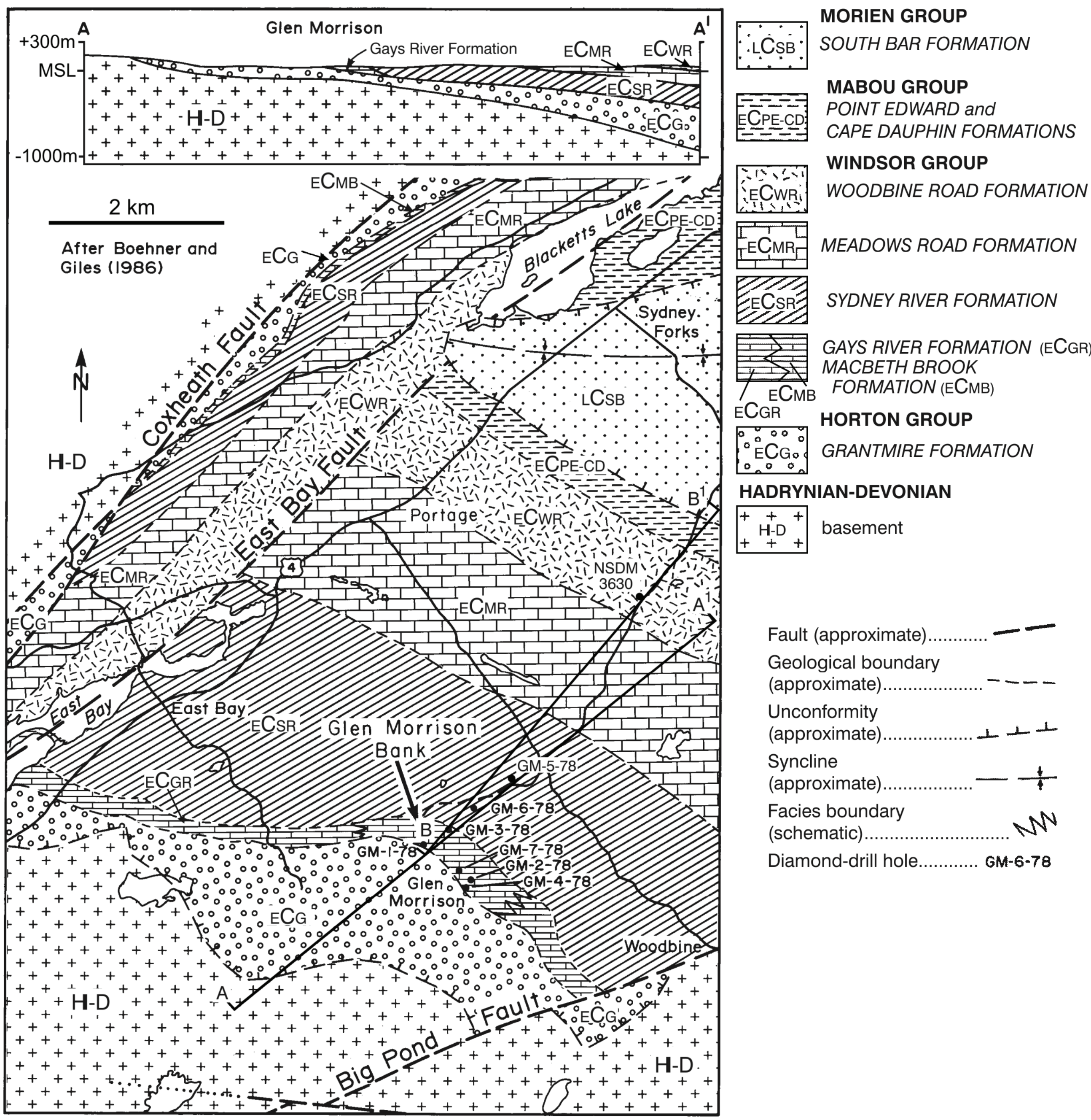


Figure 11. Geological map of the Meadows Road and Glen Morrison area, Sydney Basin.

The carbonate buildups of the Gays River Formation represent the deposits of the initial regional mid-Viséan transgression recorded at the base of the Windsor Group. The lateral facies equivalent Macumber Formation (and the local variation MacBeth Brook Formation) occur throughout the Sydney Basin with the bank buildups developed only locally as marginal basin perimeter reefs (Fig. 8). Depositional environments are inferred to be similar to those of the Gays River Formation Bank Complex and related isolated banks. The environments range from the carbonate-cemented basal siliciclastics/talus breccia (submarine) to subtidal coral bafflestone and skeletal wackestone. Algal boundstone predominates and may represent shallow subtidal to intertidal and perhaps supratidal deposition.

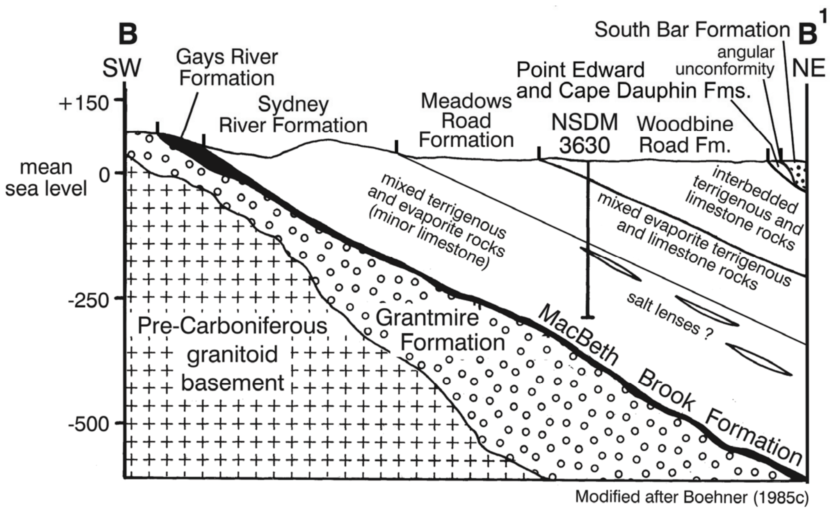


Figure 12. Geological cross-section B-B[1] in the vicinity of Meadows Road and Glen Morrison. See Figure 11 for location and legend. (Note: patterns have been left off or changed for the Windsor Group for clarity).

Carbonate banks have litho- and biofacies that generally reflect increasing salinity and eventual termination accompanying evaporite precipitation, clastic influx (e.g. Glen Morrison) or both. The predominance of limestone makes the carbonate buildups more similar to those in the Antigonish Basin, in contrast to the pervasive dolomitization of banks in the Shubenacadie and Musquodoboit basins. The Gays River Formation and correlatives are regionally major hosts to base metal and industrial mineral deposits. The Glen Morrison Bank has the most attractive potential for development as a limestone resource. Banks of the Gays River Formation regionally may also have potential as reservoir rocks.

The carbonate rocks herein assigned to the Gays River Formation were previously mapped in the Glen Morrison area by Bell (1961a) as B_2 or Glen Morrison limestone. The belief at that time was that the A Subzone was not fossiliferous, and all fossiliferous basal Windsor carbonates were given a B Subzone assignment. Reference sections are designated in drillholes GM-2-78, -3-78, -4-78, -6-78 and -7-78 (Figs. 11 and 13) drilled by Chevron Standard Limited (1979) at Glen Morrison. The small outcrop sections at Youngs Point, Fairy Hole and Glen Morrison are designated as outcrop reference sections (Map 86-1, in pocket).

Lithology Descriptions of carbonate buildups including the Glen Morrison Bank are included in unpublished mineral exploration reports by Bell (1961a, b), Imperial Oil Limited (1972) and Chevron Standard Limited (1979) (Figs. 11 and 13). Prior to this, the area was investigated for potential limestone resources and results of drilling are included in Goudge (1949) and Shea and Murray (1969). The stratigraphic position, distribution and facies relationships related to the carbonate buildups are included in Giles (l983), Boehner (1984b), Boehner *et al.* (1989) and Boehner and Giles (1986). Ryan (1978) described the lithofacies and fauna of the outcrop section at Youngs Point. The Gays River Formation is described in the following sections and comprises the following principal units: (1) basal siliciclastic rocks, and (2) bank or buildup facies. The interbank facies of Giles *et al.* (1979) is essentially the MacBeth Brook Formation which is a local transitional variation of the regional Macumber Formation.

Basal Siliciclastic Rocks The Gays River Formation has two basic contact relationships in the Sydney Basin. In the Glen Morrison area it overlies a thin interval of coarse siliciclastics of the Grantmire Formation. In the Scotch Lake and Youngs Point areas it onlaps the crystalline basement with distinct unconformity (Map 86-1, in pocket). These areas have a locally developed basal breccia. The breccia consists of poorly sorted, angular to subrounded, locally derived basement clasts in a variably siliciclastic rich carbonate matrix. It is irregularly distributed and appears to be thickest in local depressions on the basement erosion surface. The basement clast breccia conglomerate may occur locally as thin tongues near the base of the Gays River Formation bank facies or the contact may be very sharp with little or no siliciclastic material incorporated at the base of the limestone. The basal breccia is interpreted as representing variably reworked or

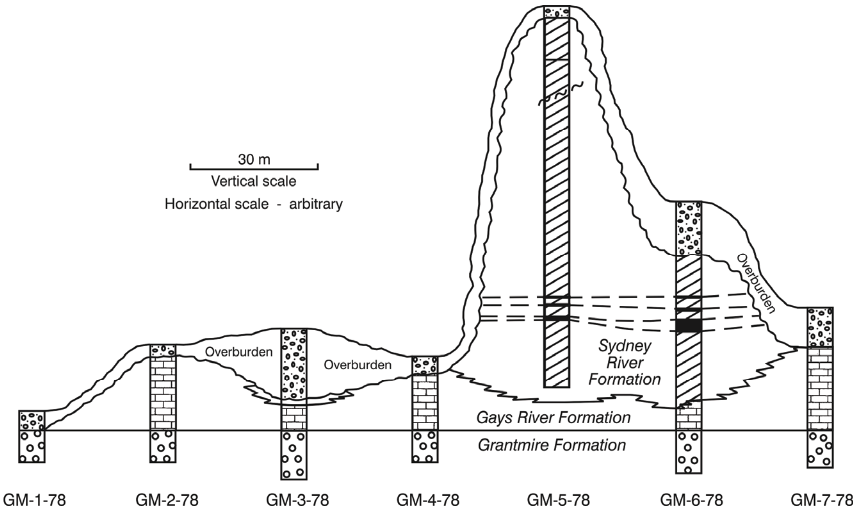


Figure 13. Drillhole stratigraphic sections of the Gays River Formation at Glen Morrison. See Figure 11 for locations.

recemented regolith and talus as irregularly distributed sheets or pockets on the basement erosional surface (pediment).

Buildup Facies The Gays River Formation carbonate buildups or banks are dominantly light to medium grey-brown, micritic limestone. The limestone is massive to poorly stratified, locally highly porous and consists mainly of mottled algal boundstone and medium to dark grey, finely bioclastic limestone and dolomitic limestone (wackestone with minor packstone). Thin, dark shaly partings and laminations are common and a small scale nodular to subnodular bedding is locally well developed. The carbonates are locally very silty to arenaceous, especially where they are overlain by the siliciclastics of the Sydney River Formation (Figs. 11 and 12).

Relations to Other Units The base of the Gays River Formation is placed at the base of the carbonate cemented siliciclastic rocks where present. In their absence the base is defined as the carbonate basement contact. The Gays River Formation is overlain concordantly and conformably by the massive anhydrite and gypsum of the Sydney River Formation (Fig. 8). The contact is generally sharp with limited gradation over a short interval. The top of the Gays River Formation is designated at the top of the main carbonate body.

The Glen Morrison Bank, typical of the Gays River Formation, forms a major east-west to northeast-southwest trending outcrop area along the southern border of the Sydney Basin (northeastern end of the East Bay Hills). It is situated in a paleotopographically high area at the updip limit of Horton Group continental siliciclastics (Figs. 2, 3, 5 and 11). The carbonate bank facies thins to a dark shaly laminated limestone facies (MacBeth Brook Formation). It is underlain by thin Horton Group siliciclastics or unconformably by Neoproterozoic (Hadrynian) to Devonian metasedimentary, volcanic or plutonic rocks. The bank facies is overlain by a section of fine, grey siliciclastic and carbonate rocks and thick evaporites (anhydrite).

Distribution and Thickness In a preliminary reconnaissance, Giles *et al.* (1979) indicated that carbonate units correlative with the newly defined Gays River Formation were probably present in other areas outside the Shubenacadie area. One of these areas was in the Glen Morrison area of the Sydney Basin. These areas were described by Ryan (1978), Boehner (1987) and Boehner *et al.* (1988). This study confirms the existence of mottled algal limestones typical of the Gays River Formation as buildups at several localities including Kellys Mountain, Boisdale Hills and Glen Morrison near the perimeter of the Sydney Basin and adjacent to basement blocks (Figs. 4, 5 and 11). These carbonate buildup localities are: (1) Scotch Lake, (2) Youngs Point on the margin of the Boisdale Hills, (3) Fairy Hole (Cape Dauphin), (4) near Englishtown on the margin of Kellys Mountain, and (5) near Glen Morrison on the northern end of the East Bay Hills. Outcrops are rare and with the exception of Glen Morrison; diamond-drill holes are few and scattered. Consequently the geometry and dimensions of individual banks are poorly defined, but are generally limited (thickness 15-30 m, length 100-200 m, width 50-100 m). Undefined buildups may exist over potential outcrop strike lengths of several kilometres. Average thickness is difficult to determine because of the scarcity of complete sections. The distribution of the Gays River Formation bank facies beyond these areas is undefined.

Biota The fauna and flora of the Gays River Formation have been described in reports by Boehner (1977), Giles *et al.* (1979) and Ryan (1978). The majority of fossils reported in the Gays River Formation are species of brachiopods, pelecypods, gastropods and bryozoans known from the type area (Giles *et al.*, 1979; Ryan, 1978). Tabulate corals and algae, including *Cladachonous* and *Koninckopora,* are locally present. The shelly fauna they described for the A Subzone, Gays River Formation is similar to that described in the B Subzone by Bell (1929) and Moore and Ryan (1976). Costate brachiopods are notably absent as are representatives of the Phylum Echinodermata which are prolific in the B Subzone. The similarities of the fauna has caused confusion regarding the true stratigraphic relationship of these carbonate buildups with the B Subzone assignment originally applied in Antigonish and Sydney.

Depositional Environment The lithology and biota of the Gays River Formation indicate carbonate deposition occurred in a dominantly subtidal marine environment in areas of Windsor Group onlap onto pre-Carboniferous basement terrain. The distribution of the bank facies indicates preferential development in the vicinity of paleotopographic highs. The areas in the Sydney Basin are local features near the depositional basin margin, e.g. Glen Morrison and Scotch Lake. In other basins the buildups were localized on intrabasinal knobs or in inselbergs (e.g. Williams Point-Southside Harbour in the Antigonish Basin (Boehner and Giles, 1993). The development of organic carbonate banks on paleotopographic highs was postulated by Geldsetzer (1978b) to be the result of salinity stratification in a major sea. In this model, only the highest sea bed topographic features may have been elevated into less saline layers which could support a prolific biota especially in areas with limited siliciclastic input and a hard substrate. This capability would change both with depth and time because of progressive salinity increase. The biota of the Gays River Formation in the Shubenacadie and Musquodoboit basins became restricted to increasingly saline tolerant species (euryhaline, Giles *et al.*, 1979). In addition, near shore marine siliciclastic deposition (e.g. Meaghers Grant Formation, Boehner, 1984b) in the MacBeth Brook Formation produced a further stressed environment for the biota and is similar to the situation near Glen Morrison where the Gays River Formation is overlain by siliciclastics of the Sydney River Formation.

Age Fauna of the Gays River Formation buildups in the Sydney Basin (Ryan, 1978) are typical of those described in the type area by Giles *et al.* (1979), who correlated the Formation with the A Subzone of the Lower Windsor of Bell (1929). Giles (1981) assigned these rocks to the early-middle Viséan. Correlative strata were assigned to palynological Zone NS, Late Arundian to Early Holkerian (V2-V3) by Utting (1987) and Utting *et al.* (1989) (Fig. 7).

MacBeth Brook Formation

The Macumber Formation lithology is not well represented in the Sydney Basin map area and the name MacBeth Brook Formation is introduced for correlative, but lithologically different basal carbonate rocks (Figs. 8 and 9). The Macumber Formation was defined and originally applied by Weeks (1948) to a well-bedded, laminated limestone overlying the Horton Group in the northern part of the Minas Sub-basin of Bell (1958). The Macumber Formation and correlatives are widely recognized at the base of the Windsor Group throughout Atlantic Canada (Schenk, 1967a; Kirkham, 1978, 1985).

In other areas the Macumber Formation has been informally referred to as the ‘ribbon limestone’ by Stacey (1953) or ‘basal laminite’ by Kirkham (1978) and Geldsetzer (1977, 1978a) or the A1, basal or sandy lime by workers including Sage (1954). The Macumber Formation is characterized as a finely laminated, grey to grey brown, locally dolomitized limestone (mudstone and wackestone). Its total thickness ranges from 6-10 m. The laminations range from 1-10 mm in thickness and are emphasized by differential weathering in outcrop sections.

Although the Macumber Formation name has not been applied in the parts of the Sydney Basin mapped in this project, carbonates typical of the Macumber Formation are present in the Grand Narrows area at the apex of the Boularderie Syncline (Binney and Kirkham, 1974, 1975). The name MacBeth Brook Formation is applied to the distinctive carbonate-siliciclastic unit in the Sydney Basin.

The southern part of the Sydney Basin is an area where the basal Windsor carbonate has a lithologic character different from the typical Gays River and Macumber formations end members. The MacBeth Brook Formation is introduced for this transition which is marked by thinning and facies change to mixed carbonate (including algal stromatolites) and siliciclastic rocks without significant skeletal biota. The characteristic peloidal laminite of the Macumber Formation is not well represented and consequently the new MacBeth Brook Formation unit is introduced for the distinct facies of the basal Windsor Group carbonate.

Type Locality The outcrop type area of the MacBeth Brook Formation is designated in outcrop sections in streams along the southern side of the Coxheath Hills including MacBeth, Battlements and Curry brooks (Map 86-1, in pocket). The MacBeth Brook Formation is best represented in exploration drilling and was intersected in several drillhole sections as well as in small outcrops in the area north of the Coxheath Hills including near Frenchvale-Rear Balls Creek. Reference sections are designated in drillhole Cerro C70-3 (Fig. 10), drilled by Cerro Mining Company of Canada Limited (1972) near Rear Balls Creek. At this reference section locality the top of the MacBeth Brook Formation occurs at a depth of 200.8-213.1 m (658.9-699.0 feet) with bedding dips of 20°-30°. An outcrop reference section is designated on the northwestern shoreline of East Bay at a point 2.2 km west of the East Bay Sand Bar (Map 86-1, in pocket). This well exposed section is approximately 9 m (30 feet) thick and was measured, described and illustrated by Binney (1975, p. 129-134).

Lithology The MacBeth Brook Formation typically comprises medium to dark grey-brown limestone and variable siliciclastics. Bedding in the limestone is highly variable, ranging from laminated stromatolites, stacked hemispheroids to thickly bedded or massive limestone. Lumpy, mottled-thrombolitic algal stromatolitic bodies are locally present. The MacBeth Brook Formation is a complex association of interstratified, finely laminated to thinly bedded limestone and grey, silty to arenaceous limestone and calcareous shale. The carbonates are silty, micritic limestone (mudstone and wackestone), locally finely bioclastic, thinly laminated and generally have thin, dark shaly interbeds. In conglomerate dominated areas (e.g. Point Edward-Coxheath) the Formation may only be represented by calcareous, grey shale and mudstone.

Pelletal and peloidal laminated limestone typical of the Macumber Formation are not well developed. It is interesting to note that carbonate breccias are not well developed in the MacBeth Brook Formation. This may be the result of the lack of substantial evaporite sections directly overlying which limit karst processes immediately above the basal carbonate. Boehner and Giles (1993) proposed that much of these carbonate breccias (e.g. Pembroke type) are karst related residual accumulation and solution collapse. Giles and Lynch (1993) interpreted some of these breccias to be the result of a major decollement structure. The MacBeth Brook Formation has a sparse shelly biota with occasional disarticulated brachiopod shells. Algal stromatolites, of the columnar and laterally linked stacked hemispheroid and massive mottled forms, are locally abundant (East Bay outcrop locality). Bell (1961a) reported the occurrence of *Conularia, Leptodesma* and *Lithophagus* in the drilling near Portage-East Bay (NSDM 3439) (Map 86-1, in pocket).

Distribution and Thickness The MacBeth Brook Formation is typically <4 m thick, but is locally up to 10 m and is more widespread in distribution than its laterally equivalent Gays River Formation bank facies. The 30 m (100 feet) thickness reported in the Frenchvale area (Bell, 1961a) appears to be substantially overstated. These measurements may be erroneously thick due to faulting and folding in the section east of Rear Balls Creek. It is widely distributed around the perimeter of the Sydney Basin from Glen Morrison

(East Bay Hills) through East Bay to the Balls Creek-Frenchvale area (Coxheath Hills).

Depositional Environment The MacBeth Brook Formation facies is inferred to be situated downslope and marginal to the biohermal Gays River Formation banks and has a less diverse and sparse biota. Siliciclastics form a locally significant component resulting in a complex carbonate-clastic lithology. Laminated domal algal stromatolites are a conspicuous feature, especially at the outcrop at East Bay where they form stacked hemispheroid structures similar to climbing ripples enveloped by calcareous mudrocks. Some of the carbonate sediment may, in large part, be allochthonous grains derived from adjacent banks. Laminated peloidal carbonate is also a major component and the MacBeth Brook Formation facies probably grades down dip into Macumber Formation laminite, especially in those areas where Major Cycle 1 evaporites predominate.

Similar to the Macumber Formation, the MacBeth Brook Formation is rarely fossiliferous. This is postulated to be attributed to the stressed marine environment with abnormal (decreased) salinity and turbid water related to the siliciclastic rich near shore environment near the perimeter of the basin. The Meaghers Grant Formation and Gays River Formation relationships in the Musquodoboit Basin in central mainland Nova Scotia are probably a close analogy. A similar situation has been described in equivalent strata including the Parleeville Formation in New Brunswick (McCutcheon 1981, 1988).

The environment of deposition and stratigraphic relationships of the various related basal Windsor Group carbonates have been the subject of contradictory opinions and models in recent times (Schenk, 1967a, b; von Bitter *et al.,*1988,1990; Geldstzer, 1977, 1978a; Kirkham, 1978; Giles *et al.,* 1979; Giles and Boehner, 1979). Schenk (1967b) interpreted the Macumber Formation as offlap strandline carbonate algal stromatolite deposition in a very shallow subtidal to supratidal environment. Analogy was made to the Recent strandline algal and related carbonates of the Persian Gulf. Schenk (1967b) concluded the Macumber Formation was a result of very sudden regional marine invasion followed by slow regression.

Subsequent workers, including Geldsetzer (1978b), have disputed the shallow strandline model of Schenk (1967b) proposing that the Macumber Formation is a cryptalgal laminite deposited in deep water (bacteriolaminites of von Bitter *et al.*, 1988, 1990). The predominantly subtidal deposition with a scarcity of fauna is attributed to hypersalinity that preceded a major evaporite cycle.

Giles and Boehner (1979) concluded that stratigraphic and lateral facies evidence placed the Macumber Formation laminite in a basinal setting relative to the organic banks of the Gays River Formation that occurred on local, marginal paleotopographic highs. A similar conclusion is reached in the Antigonish Basin (Boehner, 1987; Boehner *et al.*, 1988) where comparable stratigraphic and facies relationships are present (Fig. 2). The Macumber Formation is considered, in this study, to be a dominantly subtidal deposit recording rapid marine inundation (fauna at, or near, base) followed by increasing salinity and salinity stratification in the Windsor seas (Boehner, 1989). Slight regression may have occurred with the increasing salinity and possibly is recorded by the breccia dissolution zone at the top of the Macumber Formation in marginal outcrop areas. More recently, von Bitter *et al.* (1988, 1990) have proposed that the Macumber Formation may be a deep water bacteriolaminite and that the biohermal Gays River Formation correlative in Newfoundland may be the result of subsea exhalation (vent communities).

Relations to Other Units The Glen Morrison-East Bay area in the southern part of the Sydney Basin is an area of transition of the MacBeth Brook Formation to the Gays River Formation (Map 86-1, in pocket). This transition is marked by thinning and facies change to mixed carbonate (including algal stromatolites) and siliciclastic rocks without significant skeletal biota. The typical peloidal laminite of the Macumber Formation is not well represented and the MacBeth Brook Formation unit is believed to be transitional downdip into the Macumber Formation laminite. Bell (1961a) referred to the unit in the Frenchvale-Point Edward area as the Frenchvale Limestone (B3) and the Kelly Hill Limestone.

The MacBeth Brook Formation is overlain by, and locally gradational upward into, a mixed siliciclastic section of the Sydney River Formation (Fig. 8). The top of the MacBeth Brook Formation is placed at the carbonate-clastic contact. The base of the Formation is placed at the base of the main carbonate body which typically overlies conglomerate of the Grantmire Formation. This contact is very sharp with little gradation evident other than green re-reduction and calcareous cementation of the alluvial redbeds of the underlying Grantmire Formation.

The MacBeth Brook, Gays River and Macumber formations are correlated for several reasons. In the Sydney Basin as well as the Antigonish, Shubenacadie and Musquodoboit basins, it can be demonstrated that the formations are overlain by the same major evaporite-siliciclastic unit ranging from 150-300 m thick. The presently observed topographic distribution and lithological paleontological variations within the formations, together with common stratigraphic position strongly indicates correlation. The characteristic pelletal-peloidal laminite lithology of the Macumber Formation is present as a subordinate component within the MacBeth Brook Formation and sections of the interbank facies of the Gays River Formation. The facies variations in the basal Windsor Group carbonate (Major Cycle 1) may be explained by primary depositional factors related to bathymetry and deposition in a complex basin to basin margin setting influenced both by near shore marine siliciclastic and marine evaporite environments.

The Glen Morrison area is interesting in that thin fossiliferous limestone occurs in higher parts of Major Cycle 1, within the Sydney River Formation, in drillholes NSDM 3439, 3440 and 3630 (Bell, 1961b; also respectively identified as Morton Nos. 1, 2 and 3 in Figure 10). Shaly mudstone-wackestone beds contain sparse shelly fauna similar to that of the B Subzone (Bell, 1961a). This part of Major Cycle 1 is typically not fossiliferous and is usually dominated by evaporites.

Sydney River Formation

The Sydney River Formation (new name) is herein introduced in the Sydney Basin for a heterogeneous interstratified succession of coarse- to fine-grained, red and grey siliciclastics and evaporites (anhydrite, gypsum and rare salt) with minor thin carbonate interbeds (locally fossiliferous). The Sydney River Formation occurs near the base of the Windsor Group (Figs. 7, 8 and 10) and is the dominant part of Major Cycle 1 or the A Subzone. One end member facies, in the Boularderie Syncline, is dominated by anhydrite with minor carbonate and is essentially the basal anhydrite (correlative with the Bridgeville Formation and others). This basal anhydrite section is inferred to overlie the Macumber Formation (e.g. Boularderie Syncline and Iona), but is not sufficiently represented in drilling or outcrop to be given separate formation status at this time. The Sydney River Formation is lithologically more variable in the Glen Morrison (type area) and Coxheath Hills areas which are dominated by siliciclastic-carbonate facies (Meaghers Grant Formation type, Musquodoboit Basin) as well as coarse grained redbeds. The Formation is fairly well represented both in outcrop and in drilling in the Sydney Basin.

Type Locality The type section of the Sydney River Formation is designated in the interval 174-320 m (570-1050 feet) in drillhole Morton No. 3 (NSDM 3630) drilled near Meadows Road by Morton Chemical Company Ltd. (Bell, 1961b) (Fig. 10; Map 86-1, in pocket). This type section is incomplete at the base. Drillhole reference sections in the Sydney Basin are designated in the interval 83.8-240.8 m (275-790 feet) in a salt exploration drillhole Morton No. 1 (NSDM 3439) drilled by Morton Chemical Company Ltd. near Portage and in drillhole NSDME Woodbine Road 84-1 at depths of 402.4-550.75 m drilled by the Nova Scotia Department of Mines and Energy for stratigraphic information in the Woodbine Road area. The outcrop type section area is designated in Woodbine Brook, a tributary of the Sydney River south of Morrisons Lake (Map 86-1, in pocket) near the Morley Road. The reference section (incomplete at the base) of the basal anhydrite facies (Figs. 10, 14a and 14b) is designated in NSDME drillhole KH 84-1 near Kempt Head (832.9-943.2 m). Outcrop sections with stratigraphically significant sections are rare and typically incomplete including Rear Balls Creek and other scattered outcrops around Coxheath Hills.

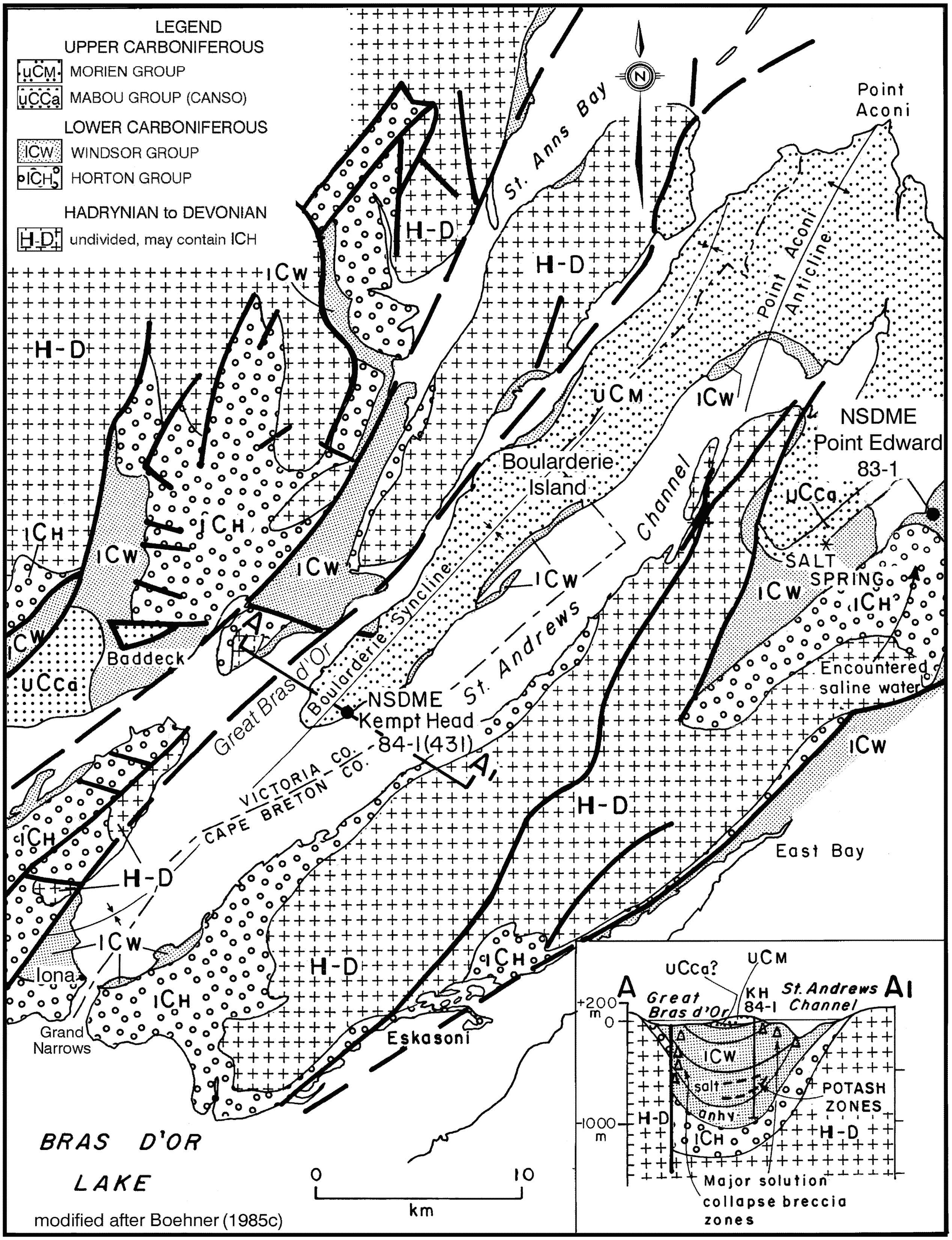


Figure 14a. Geological map of the Boulardrie Syncline area, including a northwest-southeast cross-section through the Syncline.

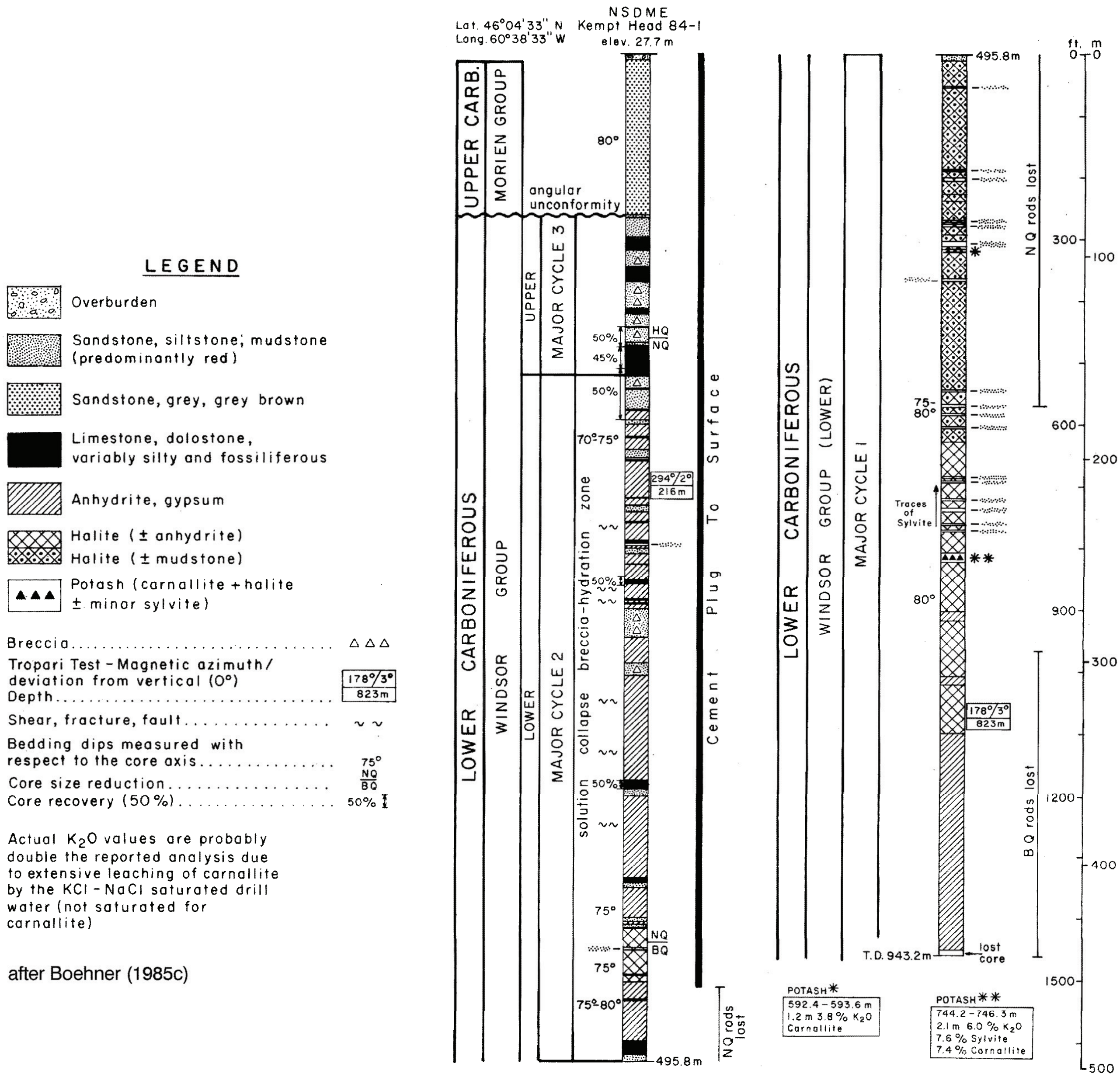


Figure 14b. Drillhole profile of NSDME Kempt Head 84-1, Boularderie deposit, Victoria County. See Figure 14a for location.

Lithology The Sydney River Formation is a heterogeneous, interbedded succession of red and grey siliciclastics ranging from siltstone to conglomerate; and evaporites comprising anhydrite, gypsum and rarely salt (halite) with minor, thin, carbonate interbeds (locally fossiliferous). Descriptions of the constituents follow below.

Evaporites The evaporites in the Sydney River Formation comprise poorly stratified, blue grey to grey brown anhydrite with scattered beds of light brown to yellow brown limestone. In near surface environments the anhydrite is hydrated to gypsum and may form significant deposits (Adams, 1988, 1991). The anhydrite has a variably developed, nodular texture ranging from a coarse irregular mosaic to fine incipient nodules (1-5 mm) in interstitial stringers or beds of limestone. The massive irregular mosaic is emphasized by wispy stringers of limestone. Lamination is not a common feature of the anhydrite except in the vicinity of some limestone interbeds where it is typically well developed. Minor salt occurs near the top of the Formation (near the top of the Morley Road conglomerate) in the East Bay-Woodbine Road area. The salt occurs as a poorly stratified mixture of halite and anhydrite or as minor inclusions in redbeds.

Carbonates Limestone is a minor constituent, but may form up to 15% of the basal anhydrite section. It typically is fine grained and poorly stratified, but in some areas it is locally well stratified. Minor, thin, shaly limestones occur as interbeds in the siliciclastic sections of the Sydney River Formation near Frenchvale and the type area near East Bay and Glen Morrison. Several carbonate intervals in the Morton Chemical drillholes near Meadows Road (Fig. 10) are locally fossiliferous with gastropods, brachiopods and bivalves (Bell, 1961b).

Siliciclastics Siliciclastics are a prominent component in basin margin areas, e.g. type area near Glen Morrison and in the Balls Creek-Frenchvale area. The fine grained clastic section comprises interstratified grey shale, mudstone, variably calcareous, red siltstone, sandstone and mudstone, and thin variably shaly limestone, locally fossiliferous. Evaporites comprise approximately 50% of the section in the type area, but less than 25% in the Frenchvale area.

The Morley Road conglomerate consists of coarse grained siliciclastics which are a significant component in the Glen Morrison and Balls Creek-Frenchvale areas. They comprise redbed alluvial fanglomerates, which are polymictic and poorly sorted, as well as sandstone and mudstone interbeds which typically have scattered white limestone nodules (calcrete) and green reduction spheres. Coarse grained strata dominate the sections on the northeastern end of the Coxheath Hills. Local tongues occur in the type area near Glen Morrison and where the Morley Road conglomerate is represented both in outcrop and in adjacent drillholes (e.g. Morton No. 1 and No. 3; Fig. 10 and Map 86-1, in pocket).

Distribution and Thickness The Sydney River Formation, similar to most Windsor Group map units, has a limited outcrop distribution. It is inferred to have a wide distribution throughout most of the subsurface of the Sydney Basin. Outcrop areas of the basal anhydrite facies of the Sydney River Formation are poorly defined. It is inferred, however, to have a wide distribution in the western and probably the central northern parts of the Basin where it may be associated with the salt facies of Major Cycle 1 (Kempt Head Formation).

The thickness of the Sydney River Formation, as known from present data, is highly variable. This variation may be attributed to differences in original depositional thickness, marginal facies change, but additionally because of post-depositional dissolution and erosion of evaporitic sections at unconformities. In drillhole KH 84-1, drilled near Kempt Head where the section is dominated by evaporites in the basal anhydrite facies, it is estimated to be 150 m thick. In the type area near East Bay it typically is less than 175 m thick and may be as thin as 100 m in the extreme marginal areas, e.g. around the Coxheath Hills.

Relations to Other Units The Sydney River Formation conformably to disconformably overlies strata assigned to the MacBeth Brook or Gays River formations or locally in their absence, the Grantmire Formation (Figs. 8 and 9). The contact is generally sharp with limited gradation. The contact with the evaporite dominated sections (e.g. Scotch Lake) is a zone of preferential water migration and karst solution trench development. The anhydrite units of the Sydney River Formation are typically hydrated to gypsum in the near surface environment especially in an envelope adjacent to permeable interbeds or fractures. Boehner (1985c) postulated that the extensive linear distribution of deep water areas in the vicinity of Boularderie Island (e.g. the 275 m plus deep St. Andrews Channel) was probably related to irregular karst solution trench features. They were interpreted as being the result of the dissolution of gypsum-anhydrite and salt of the Sydney River and Kempt Head formations around the perimeter of the Boularderie Syncline and may have been enhanced by fault related permeability.

The Sydney River Formation is conformably overlain by the salt section of the Kempt Head Formation, where present, or disconformably by the Meadows Road Formation (Fig. 8, Map 86-1, in pocket). The Sydney River Formation evaporite facies has similar lithology, thickness and stratigraphic position to the Carrolls Corner Formation in the Shubenacadie and Musquodoboit basins (Giles and Boehner, 1979) and the Bridgeville Formation in the Antigonish Basin (Boehner and Giles, 1982, 1993). The fine grained siliciclastics are lithologically similar to the Meaghers Grant Formation in the Musquodoboit Basin (Fig. 7) and the coarser redbed conglomeratic facies are typical of those in the underlying Grantmire Formation.

Depositional Environment The Sydney River Formation is interpreted to represent the first sustained phase of major marine basin evaporite deposition from hypersaline Windsor seas in the area. The deposition of the thick section of calcium sulphate (gypsum or anhydrite and followed by minor limestone) was, in part, contemporaneous with the deposition of the basal carbonate (Gays River Formation and others). The major evaporite deposition is inferred to reflect a trend of increasing salinity, first indicated by the facies distribution of the basal Windsor Group carbonates. Progressive salinity increase eventually terminated virtually all Gays River Formation bank growth. Saturation and precipitation of $CaS0_4$ was reached first in the denser and more saline brines in the basinal areas.

The contact zone with the basal Windsor Group carbonate of any facies is often gradational over a short interval recording a progressive rather than instantaneous change. Occasionally limestone deposition occurred concomitant with the calcium sulphate and is recorded by thin unfossiliferous units in the evaporite dominated sections. These variably, well laminated limestones occur as interbeds with nodular anhydrite. The limestones are locally fossiliferous where associated with the siliciclastics. They are inferred to represent freshening or dilution of the evaporite brines to near normal marine conditions by substantial influx of less saline water.

In the mixed siliciclastic marginal facies the depositional history is more complex. In these areas (e.g. East Bay-Glen Morrison), there is an interaction between shoreline marine mudflat clastics-carbonates, fanglomerates and evaporites. This gradation is inferred to represent the influx of terrigenous material into an evaporite basin in a tectonically unstable area. Although the extent of clastic influx is not well defined in the subsurface data, there appears to be an association with basement blocks (basin margins), including the East Bay Hills and the Coxheath Hills. The thickness of the evaporites and the presence of significant siliciclastic interbeds, together with the close facies association with major halite deposition, indicate a range of basin margin to marine evaporite basinal setting as the dominant environment of deposition for the complex Sydney River Formation.

Age Spore assemblages have not been recovered from the Sydney River Formation. Lithostratigraphic correlation with other basins indicate the strata are probably NS Zone of Utting (1987) Early Viséan (Arundian) (Fig. 7).

Kempt Head Formation

The Kempt Head Formation (new name) is introduced here for the major salt unit that is known only in the subsurface in the western part of the Sydney Basin (Map 86-1, in pocket, Figs. 8, 10 and 14). The unit consists principally of stratified halite with minor interbeds of anhydrite, grey green siltstone and thin, low grade potash salt zones (sylvite and carnallite).

Type Locality The type section of the Formation is named for Kempt Head (Map 86-1, in pocket), the area of the type section drillhole NSDME KH 84-1 which was drilled by the Nova Scotia Department of Mines and Energy in 1984. It includes the halite bearing section with top at 495.8 m and base at 832.9 m (Figs. 10 and 14b). The core for this section is stored by the Nova Scotia Department of Natural Resources in Stellarton. The section is apparently complete and not complicated by faulting. Remnant salt sections or brine bearing zones occur in drillhole sections, Morton No. 3 near Meadows Road and in the Rudderham Road area, NSDME PE 83-1.

Lithology The Kempt Head Formation is typical of Major Cycle 1 salt sections and comprises medium- to coarse-grained (1-2 cm) halite with colour ranging from clean and clear when pure to smoky grey and black when contaminated with disseminated anhydrite and clay. The alternation of pure and impure halite produces banding which is often concordant with interbeds of anhydrite and siltstone. The banding is inferred to represent primary bedding. The halite is gradational through interbedding with thin anhydrite interbeds. The anhydrite is typically pale grey brown and occurs as beds less than 10 cm thick. They are often broken by deformation. Thicker beds (up to 10 m) are known, but are not common. Red and green clay and siltstone are locally present as irregular fragments or inclusions and as thin interbeds. These interbeds are more abundant near the top of the sections.

Potash salts, including sylvite and minor carnallite, are known from the type section KH 84-1. The potash occurs in small subeconomic amounts in several thin zones (interbeds and disseminated) of sylvite and locally carnallite within the Formation. Grey green clay, siltstone, blue halite and reddish coloured halite are commonly associated with the potash salt occurrences. The best defined potash intersection in KH 84-1 (Figs. 10 and 14b) comprises 7.6% sylvite and 7.4% carnallite in the interval 744.2-746.3 m or 2.1 m of 6.0% K_2O. A thinner zone of carnallite (3.8% K_2O) occurs higher in the well at 592.4-593.6 m. The potash is associated with grey green clay and halite.

Distribution and Thickness The only significant section of the Formation is in drillhole KH 84-1 where 337.1 m were intersected. Since the Kempt Head Formation consists predominantly of highly soluble halite, it is known only from the subsurface and is not known to outcrop (Fig. 14b). Boehner (1985c) interpreted the extremely deep water in St. Andrews Channel (exceeding 275 m) to be the subcrop dissolution trench of evaporites of the Kempt Head Formation. Saline springs, seeps and water wells, indicative of the subsurface dissolution of salt, are rare, but scattered throughout the Basin including: Balls Creek, Point Edward, Sydney River and East Bay-Meadows Road. The thickness and distribution of the Kempt Head Formation is not well known because of the extremely limited number of drillhole sections available (Figs. 5 and 6). The maximum known intersection thickness is approximately 150 m and is as thin as a few metres in the East Bay salt occurrence. The unit may have a wide distribution in the deeper parts of the Basin including the Pottle Lake and Dutch Brook synclines.

Relations to Other Units The Kempt Head Formation overlies the Sydney River Formation concordantly and conformably (Fig. 8). The contact in KH 84-1 is a thin zone of gradation through interbedding (Fig. 10). The Kempt Head Formation halite is interpreted to be, in part, a facies equivalent of the basal anhydrite facies of the Sydney River Formation. The upper contact of the Kempt Head Formation is a disconformity at the base of the Meadows Road Formation. The Kempt Head Formation has similar lithology, thickness and stratigraphic position to the Stewiacke Formation (Fig. 7) described in the Shubenacadie Basin by Giles and Boehner (1979).

Depositional Environment The Kempt Head Formation is interpreted to represent increasingly saline marine evaporite deposition dominated by halite which followed and was, in part, a basinal facies of the basal anhydrite of the Sydney River Formation. The contact is inferred to be gradational both laterally and vertically through intertonguing. The anhydrite interbeds are interpreted to represent occasional changes in brine chemistry possibly as the result of periodic brine freshening from marine water influx (high stands of water). The red and grey green clay and siltstone interbeds near the top of the section are interpreted to represent periodic and localized influxes of largely aeolian material into the basin especially near the margins. These influxes occurred more frequently during low stands of water (saline mudflats) close to the end of the evaporite depositional phase. The potash salt horizon(s) in the central to upper parts of the Formation are interpreted to represent the most restricted saline evaporitic phases preserved in the Basin.

Age Paleontological dating of the Kempt Head Formation has not been undertaken, however relations to overlying and underlying strata indicate an Arundian to Holkerian age.

Meadows Road Formation

The Meadows Road Formation (new name) named after the Meadows Road type area (Map 86-1, in pocket), is herein introduced in the Sydney Basin for an interstratified succession of fine grained and locally coarse grained, red siliciclastics and evaporites (anhydrite, gypsum) with thin distinctive marine carbonate interbeds. The Formation occurs in the middle part of the Windsor Group and is the dominant part of Major Cycle 2 or the B Subzone (Figs. 7, 8 and 9). This section is typically dominated by evaporites except in marginal areas adjacent to basement blocks such as the Coxheath Hills where alluvial fanglomerates may dominate.

It is important to note that the stratigraphy of the correlative Loch Lomond and Enon formations in the Loch Lomond Basin and the MacDonald Road Formation in the Shubenacadie Basin would be virtually unknown if the extensive and, locally, deep core drilling were not available. The Formation is rarely well represented in outcrop (partial sections near Sydney River, Blacketts Lake, Point Edward, Saunders Cove, Island Point and Cape Dauphin). The Formation is best known from the drilling in the type area between Portage, Meadows Road and Woodbine Road.

Type Locality The name Meadows Road Formation is herein introduced and named for the community of Meadows Road (Map 86-1, in pocket) and is a prominent unit in exploration drillholes defining the nearby Meadows Road gypsum deposit (Adams, 1988, 1991) and East Bay salt occurrence (Boehner, 1985c). Strata, now assigned to the Formation, were previously described by Bell (1961a) and Boehner (1985c). The type section is designated in drillhole Morton No. 2 (NSDM 3440, Fig. 10, Map 86-1, in pocket), in the interval 74.7-183.8 m, and is incomplete at the base. This hole was drilled near the communities of Portage and Meadows Road, Cape Breton County, Cape Breton Island. Reference sections are designated in the nearby drillholes (Fig. 10), Nova Scotia Department of Mines and Energy Woodbine Road 84-1 (230.3-402.4 m) and Morton No. 3 (NSDM 3630) (44.5-160 m). A reference section of the thick, saline evaporite facies is designated in the Kempt Head drillhole KH 84-1 (Boehner, 1993c) in the interval 159.6-495.8 m (Figs. 10 and 14a, b).

Lithology The Meadows Road Formation is an interstratified sequence of evaporites (gypsum and anhydrite), red and minor green siltstone, sandstone and conglomerate with several distinctive fossiliferous marine carbonate members. The carbonate members are typically overlain by, and occasionally underlain by, gypsum and anhydrite. The gypsum is medium- to coarse-grained and selenitic. It is gradational downward through nodules in dolomitic limestone matrix into the carbonate units. The gypsum beds are typically <6 m thick and are the hydrated equivalent of anhydrite which dominates deeper in the subsurface.

Although not well defined from present data, halite may be expected in association with the anhydrite in the subsurface (e.g. Kempt Head KH84-1, 431.2-457 m, Fig. 14b). The Formation is dominated by evaporites in the basinward sections with substantial facies change to siliciclastic dominated in the marginal setting including both fine grained and conglomeratic sections. In these marginal sections the conglomeratic facies may predominate, evaporites are absent and the marine carbonates may be severely recrystallized and degraded to marginal calcirudites, reworked or entirely removed by erosion. Where dominated by redbed conglomerate (e.g. drillhole NSDME Point Edward 84-1, Fig. 10), and in the absence of the marine carbonates, the Meadows Road Formation may be inseparable from the redbed conglomerates of the Grantmire or Sydney River formations.

In the middle and upper parts of the Windsor Group, carbonate members can be used for regional correlation (Moore, 1967; Giles and Boehner, 1979, 1982b) and have thus received considerable historical emphasis. The Meadows Road Formation has several constituent carbonate members which are so similar to those in the adjacent Loch Lomond Basin and Glengarry Half Graben (Boehner and Prime, 1993) that the same nomenclature is used. The distinctive carbonate members recognized in the Meadows Road Formation include the Hydro, B_2, Hollow Algal Marker and the Point Edward or Limestone Point Limestone. A lower limestone, termed the B_1 Member in the Loch Lomond Basin, is not well represented in the Sydney Basin, but its correlative equivalent may be inferred using its stratigraphic position beneath the Hydro Member at or near the base of the Meadows Road Formation.

A section of 1-3 m of heterogeneous carbonate and grey shale occurs in the stratigraphic position of the **B_1 (limestone) Member** of the Loch Lomond Basin, in drillholes near Glen Morrison. It comprises variably silty, grey brown and medium to dark grey bioclastic limestone, and is locally stromatolitic (mottled algal boundstone). Marginal facies are characterized by nodular to conglomeratic, white recrystallized limestone. Drillhole sections are rare and the intersection in NSDME Kempt Head 84-1 contrasts with the sections in the eastern part of the Sydney Basin in that it is a skeletal buildup facies typical of Major Cycle 2. This facies is generally similar to, but not as thick as, the major biohermal buildup at Cape Dauphin (Boehner, 1988). It is not possible at this time to correlate these two localities.

The **Hydro Member,** in the Sydney Basin, is up to 8 m thick and is very similar to the Hydro described in the Loch Lomond Basin where it is up to 4.9 m thick (Boehner and Prime, 1993). The Hydro is well represented in the Woodbine Road, Glen Morrison and Sydney River areas. It comprises light to medium brown and grey brown bioclastic limestone and is similar to the overlying B_2 Member. It is distinctive in that it has oncolitic limestone and the basal contact is gradational with grey siltstone. The informal limestone, unit b, described in drillholes Morton Nos. 1 and 2 by Bell (1961b) is the Hydro Member.

The **B_2 Member,** in the Sydney Basin, is up to 7 m thick and is very similar to the B_2 described in the Loch Lomond Basin (Boehner and Prime, 1993) where it is up to 3 m thick. The B_2 comprises light to medium brown and grey brown bioclastic limestone and is generally similar to the underlying Hydro Member. It is distinctive in that it has a well developed oncolitic limestone interbed ('Bun Facies' of Loch Lomond) and the basal contact is sharp with grey siltstone or gypsum-anhydrite. The basal unit typically is a domal algal stromatolite. The top of the Member is marked by an upper domal to mottled algal stromatolite and a gradation upward with laminated algal stromatolitic limestone and gypsum-anhydrite ('Lacey Facies' of Loch Lomond). A celestite mineralization zone is frequently associated with the top of the B_2 Member in the Sydney Basin (e.g. Woodbine Road, Battlements Brook and Sydney River). The informal limestone, unit a, described in drillholes Morton Nos. 1 and 2 by Bell (1961b) is the B_2 Member.

The **Hollow Algal (Marker) Member** is a very distinctive unit described in the Loch Lomond Basin (Boehner and Prime, 1993) which is also represented in the Sydney Basin. In drillhole NSDME Woodbine Road 84-1 (Boehner, 1993a) it is exceptionally thick (6 m) and has carbonate facies more typical of the B_2 Member. Elsewhere in the area it is typically 3 m thick and consists of light grey to grey brown limestone with local red mottled hematitic stain. The contacts with overlying and underlying evaporites are sharp. The upper units comprise domal digitate and planar algal stromatolites and the lower part contains the distinctive oncolitic structures of uncertain algal affinity. The carbonate members described above occur in outcrop and drilling in the Portage, Meadows Road and Sydney River areas. The carbonate section at Sydney River is also described in detail by Bell (1961a).

In the Point Edward area, the name **Limestone Point Member** (from the term Limestone Point Limestone of Mather, 1944) is herein applied to the carbonate previously referred to by Bell (1961a) and Bell and Goranson (1938b) as the Point Edward limestone or Louisbourg Quarry limestone. Although the name, Point Edward, has precedence, it is currently applied to a formal unit of the overlying Mabou Group, and is no longer available.

The stratigraphy of the carbonate units in the Point Edward area has been a problem (too many units, too thick, identification, correlation) over the years (Bell, 1961a). Stratigraphic drilling by the Nova Scotia Department of Mines and Energy (Point Edward 83-1 and Point Edward 84-1; Boehner, 1993b) has revealed several mistaken correlations both within and between the respective northwestern and southeastern shoreline sections. Drilling in NSDME Port Edward 84-1 indicates there are only four significant carbonates in the section of which three are assigned to the overlying Woodbine Road Formation (see subsequent discussion of that Formation).

The most significant variation in the carbonate stratigraphy in the Point Edward area occurs in the strata beneath the Crawley Member (at the base of the Woodbine Road Formation) which are now assigned to the Meadows Road Formation (Figs. 7

and 10). The unit identified as the Point Edward limestone is most enigmatic in that it was not described or discussed by Bell (1961a), even though it is a major (10 m thick) unit indicated in the stratigraphic columns as stratigraphically above the Louisbourg Quarry limestone. Bell and Goranson (1938b), on the Sydney Sheet West, indicated the name ‘Point Edward Limestone’ in the Leitches Creek Station area on a projected line to Limestone Point at Point Edward. We therefore infer that the Point Edward Limestone must occur in the outcrops near Limestone Point.

It appears unlikely that the Point Edward, Louisbourg Quarry and Limestone Point limestones exist as separate units as originally identified by Bell (1961a). The unit, from separate outcrops along the northwestern section at Point Edward, is probably equivalent to that exposed in the quarry on Rudderham Road. Our preferred hypothesis about the Point Edward Limestone is that it was wrongly identified in a small fold (fault?) repeat section of the Limestone Point Limestone immediately north of Limestone Point. We have no explanation as to why Bell (1961a) did not describe the Point Edward Limestone unit in the same way he described all the other units. It is important to realize that the poorly exposed oblique sections are very difficult to measure with confidence and fold and fault disruption are probably underestimated in the sections. This has resulted in overstated thicknesses, too many units (repeats) and miscorrelation between the sections on each shore of the Point Edward area. The Limestone Point Limestone is probably the correlative of one of the Hydro, B_2 or Hollow Algal members recognized in the basinal sections.

Distribution and Thickness The Meadows Road Formation is widely distributed in the subsurface of the Sydney Basin (Figs. 6a, 7 and 8). It has a typical thickness of 150-175 m, but may be up to 225+ m in the evaporitic section in the Boularderie Syncline. It appears to thin drastically to 30 m in the Point Edward area around the end of the Coxheath Hills where conglomeratic facies predominate. The Formation is approximately 150 m thick in the type area near Portage.

Relations to Other Units The Meadows Road Formation concordantly overlies the Sydney River Formation or the Kempt Head Formation and the contact may be a disconformity (Figs. 8 and 9). The upper contact is a disconformity at the base of the Woodbine Road Formation. The Meadows Road Formation has similar lithology, thickness and stratigraphic position as the MacDonald Road Formation described in the Shubenacadie Basin by Giles and Boehner (1979) and the Enon and Loch Lomond formations described in the Loch Lomond Basin (Fig. 7) by Boehner and Prime (1993).

Depositional Environment The Meadows Road Formation (similar to the MacDonald Road Formation, Boehner, 1984b) is interpreted to represent repeated shallow water marine transgressions and regressions that produced cyclic alternations of fossiliferous micritic oolitic and algal carbonate, nodular gypsum and anhydrite and red continental siltstone and shale. More soluble evaporites, including halite and possible potassium salts, may have been deposited in the most saline facies deep in the Basin. Halite is known to be present in the Boularderie salt deposit (drillhole Kempt Head 84-1) and is a major component in stratigraphically equivalent rocks in the Malagawatch area and in the Strait of Canso area (Giles, 1981).

The carbonate members generally record the marine transgression with a variably well developed basal algal stromatolite overlain by lagoonal pelletal mudstone with minor oolitic packstone and grainstone. Deepest water is recorded by finely bioclastic mudstone and wackestone. Regressive facies are typically an inversion of the trangressive facies, but are usually better developed. The regressive carbonate suite is often capped by a diagenetic nodular sulphate gradational with the uppermost algal stromatolitic carbonate. The sulphate is overlain, in turn, by and gradational, in part, with fine grained, red siliciclastic rocks deposited in a saline mudflat environment. The regressive algal carbonate, nodular sulphate and redbed sequence records a sabkha type depositional model. In thicker sequences within the Meadows Road Formation, subaqueous nodular-mosaic sulphates with stratified halite may comprise additional components of the regressive facies mosaic. The depositional setting, suggested by these relationships, is similar to that recognized by

Boehner (1984b) in the Shubenacadie Basin where increasing salinity in stagnating and isolated lagoons and ponds resulted in precipitation during advanced stages of regression. The standing residual brines would be localized in a basinal setting, contemporaneous with the offlapping diagenetic sabkha evaporites. Halite, and possibly potassium salts, may occur in a complete vertical evaporite cycle. Wide spread progradation of the sabkha facies in this model is not a prerequisite for extensive evaporite facies including halite. Deposition due to physical or dynamic restriction of water flow could produce standing, saturated brines under conditions of static or fluctuating sea level, and a complete suite of algal and shallow water lagoonal carbonate facies may not be present in the regressive phase at the top of the carbonate members in a basinal setting.

Age Spore samples have not been analyzed from the Meadows Road Formation, although correlative strata from the adjacent Loch Lomond Basin were assigned to the Middle Viséan (Arundian-Holkerian) NS Zone by Utting (1978, 1987). Bell (1961a) considered the contained macrofauna to be part of the B Subzone of the Lower Windsor Group. The B Subzone has recently been assigned to the Late Asbian substage (von Bitter *et al.*, 2006; Utting and Giles, 2004).

Woodbine Road Formation

The Woodbine Road Formation, named for the type area near Woodbine Road (Map 86-1, in pocket), is herein introduced for the section of interstratified carbonates, redbeds and minor evaporites overlying the Meadows Road Formation (Fig. 8). The Woodbine Road Formation is correlative with the Uist Formation in the adjacent Loch Lomond Basin and Glengarry Half Graben (Fig. 7) (Boehner and Prime, 1993). It comprises Major Cycles 3, 4 and 5 of the Upper Windsor. The top of the Formation is placed at the top of the highest marine carbonate (Dixon Point Member, E_1 equivalent). Approximately eight marine carbonate members are recognized in the section and they are similar to those in the Hood Island Formation in the Antigonish Basin (Giles and Boehner, 1982b; Boehner and Giles, 1991).

It is important to note that the section becomes thinner and carbonates pinch out in the Point Edward area adjacent to the Coxheath Hills where marginal redbed fanglomerates predominate. The base of the Woodbine Road Formation is designated at the base of the Crawley Member and the upper contact at the top of the Dixon Point Member (correlates with the E_1 Member or Big Glen Member). Incomplete sections of the Woodbine Road Formation occur at Shawfield Point, George River Station and Cape Dauphin (Bell, 1958, 1961a; Stacey, 1953). The Formation is best known from the drilling in the type area between Portage, Meadows Road and Woodbine Road, and the Point Edward area.

Type Locality The Woodbine Road Formation type section is herein designated in drillhole Nova Scotia Department of Mines and Energy Woodbine Road 84-1 (Fig. 10) located in the Woodbine Road area, Cape Breton County, Cape Breton Island, in the interval between 131.7-230.3 m. Reference sections are designated in drillhole NSDME Point Edward 84-1 in the interval 180.8-235.8 m and the shoreline sections (Fig. 15) near Shawfield Point and at Cape Dauphin described by Stacey (1953) and Bell (1958; 1961a). Fairly complete reference sections of the Woodbine Road Formation are designated in the Point Edward and Edwardsville area, Shawfield Point and Saunders Cove area, and the Cape Dauphin area (Fig. 15, Map 86-1, in pocket). The locally structurally disrupted section along the northwestern shore of Point Edward was described and measured by several previous workers (Bell, 1958; 1961a). These sections are confusing and inconsistent with the subsequent drilling which has revealed several fewer carbonate units and a significantly thinner section than originally identified. As described below, this is in part due to the oblique nature of the section, poor exposure and probable faulting.

Lithology In the Sydney Basin the Woodbine Road Formation comprises two facies, the marginal conglomeratic facies in the Point Edward area, and the more typical basinal facies of the type area near Glen Morrison and Shawfield Point. The Woodbine Road Formation is an interstratified sequence of redbeds, siltstone and sandstone with local conglomerate and breccia in the marginal areas and especially in the area adjacent to the Coxheath Hills (Map 86-1, in pocket). Two key fossiliferous

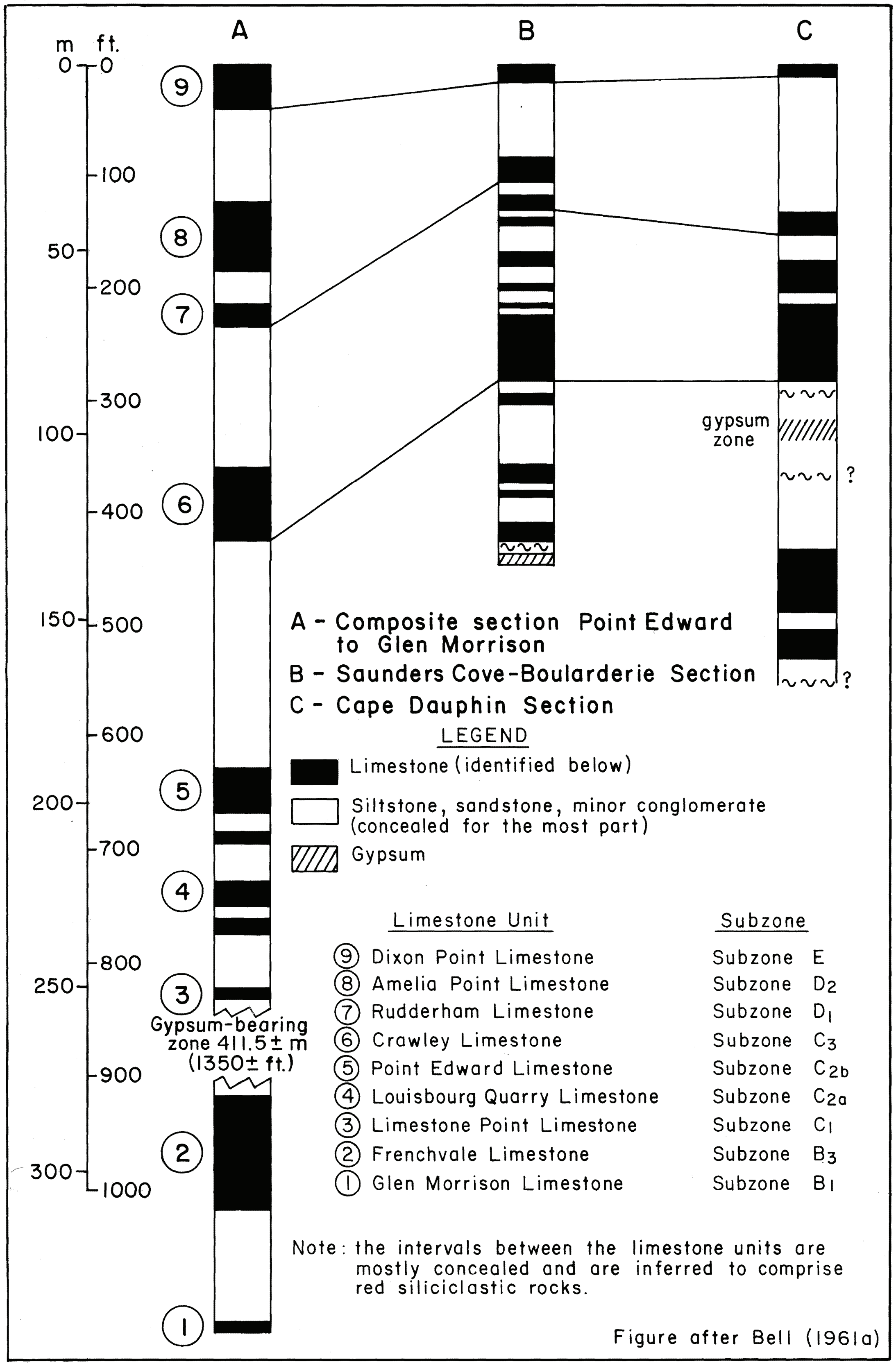


Figure 15. Detailed stratigraphic sections of the Windsor Group (Woodbine Road Formation) including sections at Point Edward to Glen Morrison (A); Saunders Cove-Boularderie (B); and Cape Dauphin (C).

marine carbonate members are present in the Formation and are referred to as the Crawley Creek Member at the base and the Dixon Point Member at the top (names after Bell, 1958; 1961a). In addition the C_1, C_2, C_3, D_1, D_2 and D_3 Limestones as well as unnamed carbonate beds occur between the Dixon Point and the Crawley Creek members (Figs. 10 and 15). The Woodbine Road Formation is dominated by fine grained redbeds with minor grey green continental clastics including siltstone, shale and fine grained sandstone in the basinward sections. There is a substantial facies change to coarser siliciclastic dominated sections in the marginal setting (conglomeratic) where thinning and pinch out are evident (e.g in the Point Edward area).

Similar to the underlying Meadows Road and locally the Sydney River formations, conglomeratic facies may predominate near the basement blocks where evaporites are absent and the only significant marine carbonate present is the Dixon Point (E_1) Member. Where dominated by redbed conglomerate and in the absence of the marine carbonates the conglomeratic parts of the Woodbine Road Formation may be inseparable from the underlying redbed fanglomerate bearing map units.

The Woodbine Road Formation is dominated by red with minor grey green continental clastics including siltstone, shale and fine grained sandstone. Carbonate and evaporite interbeds are the distinctive criteria used in recognizing the formation. The carbonates consist of oolitic algal and micritic argillaceous limestone and dolostone. The gypsum and anhydrite are nodular with variable siltstone and carbonate matrix. The gypsum and anhydrite beds in the Woodbine Road Formation are similar to those in the underlying Meadows Road Formation. They generally overlie the carbonate members and are gradational through nodular zones. Gypsum is predominant in the near surface and is a product of the hydration of the anhydrite that is common in the subsurface.

The conglomerates are immature, dominantly red in colour (minor green-grey mottle), matrix supported paraconglomerate with rare clast supported orthoconglomerate. They are polymictic representatives of the heterogeneous local basement with a diverse range of metasedimentary, metavolcanic and intrusive rocks. The clasts are typically subangular to subrounded. The units form irregularly developed fining and coarsening upward sequences and are generally poorly stratified except the finer grained intervals of sandstone and mudrocks. The coarser grained beds are typically massive with no internal sedimentary structures apparent.

Approximately eight carbonate members of the Woodbine Road Formation are recognized (Fig. 10) in the basinal drillhole section in NSDME Woodbine Road 84-1 and the incomplete outcrop sections at Saunders Cove and Cape Dauphin (Fig. 15, Map 86-1, in pocket). The carbonates correlate very well with those described in the Hood Island and Uist formations (Boehner and Giles, 1993; Boehner and Prime, 1993). Several of the members were previously recognized and described by Stacey (1953) in the Cape Dauphin section including the C_1, C_2, C_3, D_1, D_2, D_3, and E_1 limestones. Bell (1961a), after Robb (1876) and Hyde (1913), described the stratigraphy of the Windsor Group carbonates in the Sydney Basin area with emphasis on the sections exposed near Point Edward. Unfortunately these sections are incompletely exposed and several correlation problems and facies related problems are apparent in this Basin margin setting.

Near Point Edward, Bell (1958, 1961a) identified the following four major carbonates, in descending order: Dixon Point Limestone, Rudderham Point Limestone, Crawley Creek Limestone and Point Edward Limestone. On the broader Point Edward peninsula, Bell (1961a) described several others by name including: Limestone Point, Louisbourg Quarry and Amelia Point as well as unnamed units, and implied correlations between two stratigraphic sections which are on opposite sides of the Point Edward peninsula (Map 86-1, in pocket). Drilling in NSDME Point Edward 84-1 indicated, however, that there are only four significant carbonates in the section. The Dixon Point and Amelia Point (Bell, 1961a) are probably the same unit, but given separate names in each of the two sections. The Rudderham Limestone occurs in both sections as well as in the small quarry west of Sydport. Bell (1961a) indicated that the Rudderham Point Limestone does not outcrop in the northwestern section. However, the section in Bell (1958) by Mather, Tullis and Beck has the Rudderham Point

Limestone approximately 81.4 m (267 feet) above the Point Edward Limestone in this same section. The limestone which outcrops immediately north of Rudderham Point we believe to correlate with the Crawley Limestone. Bell (1961a) mentioned the occurrence of a Crawley fauna in carbonate beds in this vicinity. The Rudderham Point Limestone probably does occur in the section farther to the north and beneath the Dixon Limestone. The Crawley Limestone outcrops in Crawley Creek and locally in the community of Westmount.

The strata, here included in the Woodbine Road Formation, include units 9, 8, 7 and 6 (Fig. 15), identified by Bell (1961a) in the Point Edward area. Bell (1961a) named these limestones the Dixon Limestone (Subzone E), the Amelia Point Limestone (here equated with the Dixon Point Limestone), the Rudderham Limestone (Subzone D_1), and the Crawley Limestone (Subzone C_3 of Bell (1961a), here basal Subzone C). Bell (1961a) also identified underlying units (5, 4 and 3, Fig. 15) which we believe to be one and the same member and term the Limestone Point Member, is here included in the Meadows Road Formation (see previous discussion). The Limestone Point Member represents the fourth and lowest carbonate member intersected within the Point Edward peninsula section in NSDME Point Edward 84-1. Key members related to the recognition of the Woodbine Road Formation are the thick and regionally extensive Dixon Point Member (E_1 Limestone correlative) at the top and the Crawley Member (Wavy Member or Herbert River Member correlative) at the base.

The **Crawley Member** is best described from several exploration drillholes in the Sydney Basin and it correlates with the Wavy Member in the adjacent Loch Lomond Basin and Glengarry Half Graben. The member rarely outcrops in the map area with partially complete sections near Point Edward (the type section) and Portage near East Bay. The Crawley Member is generally similar to the correlative Wavy Member (Boehner and Prime, 1993) and the Herbert River Member described by Moore (1967). The Crawley Member is up to 14 m thick and characterized by medium brown to light grey brown limestone, typically massive and poorly stratified.

The name Crawley is introduced herein and comes from the type area at Crawley Creek near Point Edward and is derived from the name Crawley or Crawley Creek limestone described by Bell (1958, 1961a). Bell (1961a) reported a thickness of at least 19 m in the type area. The reference section for the Member is designated from 213.7-228.5 m in diamond-drill hole NSDME Woodbine Road 84-1 (approximately 14 m thick; Fig. 10) and in incomplete outcrop sections at Saunders Cove, Cape Breton County.

In the type area, the Crawley Member consists of massive, fossiliferous, light to medium grey limestone and dolomitic limestone. The carbonate is interbedded with arenaceous limestone and variably calcareous siliciclastics. The type area section is unfortunately affected by the marginal basin environment around the Coxheath Hills. It is interesting to note that only very minor, thin, carbonate interbeds were intersected in the NSDME Point Edward 84-1 drillhole at the tip of Point Edward. In other, more basinal drillhole sections near Meadows Road and Woodbine Road the Crawley Member comprises medium to light brown, grey brown, or grey, massive limestone. The base of the member is a gradational contact with underlying calcareous grey siltstone and sandstone. The lowermost carbonate unit is nodular and locally oncolitic. Irregular, dark organic stringers, which give the carbonate a crude, coarse, nodular texture, are well developed in some sections. Solitary cup corals are generally present in sections of the Member.

The Crawley Member is widely distributed throughout much of the Sydney Basin, but rarely outcrops. The Member is approximately 15 m thick making it one of the thickest carbonate units of the Windsor Group.

The Crawley Member in the Woodbine Road Formation in the Sydney Basin correlates with the Wavy Member in the Loch Lomond Basin (Boehner and Prime, 1993), the Herbert River Member of the Hood Island Formation in the Antigonish Basin (Boehner and Giles, 1993) and with the Murphy Road and Green Oaks formations in central mainland Nova Scotia.

The **C_1 Member** is approximately 3 m thick and comprises limestone at the top overlying silty dolostone to dolomitic limestone near the base. The basal contact with grey shale and siltstone is sharp. The upper contact is gradational with gypsum-anhydrite or siltstone. The top 1 m is a very distinctive unit of interbedded columnar, domal to mottled algal stromatolites.

The **C_2 Member** is 0.9-1 m thick and comprises light grey brown dolomitic limestone. The base is a sharp contact with grey shale and siltstone and the top is gradational up through nodular gypsum-anhydrite.

The **C_3 Member** is 4.5-5 m thick consisting of light grey to grey brown, locally dolomitized limestone. The base is sharp with green siltstone and the basal units include domal to planar algal stromatolites. The upper contact is similar with a thicker 1-2 m upper unit of mottled algal boundstone.

The **D_1 Member** comprises light to medium grey brown dolostone with wispy dark grey organic stringers and is approximately 4.5 m thick. The basal contact is sharp with green siltstone and the upper contact is gradational with gypsum-anhydrite. The **D_2 Member** comprises light to medium grey brown dolostone with dark grey shaly bands and is approximately 1.2 m thick. The basal contact is sharp with green siltstone and the upper contact is gradational with gypsum-anhydrite. The **D_3 Member** comprises light to medium grey brown dolostone and is approximately 0.5 m thick. The basal contact is sharp with green siltstone and the upper contact is gradational up over 0.6 m with nodular gypsum-anhydrite.

The **Dixon Point Member** is best described from several exploration drillholes in the Sydney Basin. The member correlates with the Big Glen Member in the adjacent Loch Lomond Basin and Glengarry Half Graben (Boehner and Prime, 1993) and with the E_1 limestone of Stacey (1953) in western Cape Breton Island. The member rarely outcrops in the map area. There are partial sections at Cape Dauphin and near Point Edward (the type section). The Dixon Point Member and the correlative Big Glen and E_1 members, are collectively facies variants of the Kennetcook Member described by Moore (1967) in the Windsor Group type area. The Dixon Point Member is up to 17 m thick and characterized by light to medium brown to grey limestone with distinctive dark grey wispy organic stringers and scattered calcite vug filling (<1 cm).

The name Dixon Point Member is herein introduced and comes from the type area at Dixon Point near Point Edward (approximately 9 m exposed) and is derived from the name Dixon or Dixon Point limestone described by Bell (1958, 1961a). The reference section for the Member is designated from 180.8-194.9 m in diamond-drill hole NSDME Point Edward 84-1 (approximately 14 m thick; Fig. 10) and in incomplete outcrop sections at Cape Dauphin and Saunders Cove, Cape Breton County. A reference section is also designated in the type section of the Woodbine Road Formation from 131.7-140.6 m in diamond-drill hole NSDME Woodbine Road 84-1 (approximately 9 m thick).

In the type area, the Dixon Point Member consists of massive, sparsely fossiliferous, light to medium grey limestone and dolomitic limestone. The massive carbonate has distinctive wispy, dark grey, organic-rich stringers and scattered anhydrite nodules or vugs. In outcrop the upper part is often vuggy, locally infilled by siliceous nodules which appear, in part, to occupy sites where nodular evaporites (anhydrite or gypsum) occur in the subsurface (dolomitic interval of up to 5 m thick in NSDME Point Edward 84-1). The colour may be dark brown, grey-brown, or grey. The base of the Member is a sharp contact with grey siltstone and sandstone and the lowermost carbonate unit is a mottled, planar or domal algal stromatolite. Small, 0.5-2 cm, spherical, calcite vug-fill after evaporite are ubiquitous as are irregular, dark, organic stringers which give the carbonate a crude, coarse, nodular texture in some sections.

The Dixon Point Member is widely distributed throughout much of the Sydney Basin, but rarely outcrops. The Member is approximately 9-14 m thick making it one of the thickest carbonate units of the Windsor Group.

The Dixon Point Member, in the Woodbine Road Formation in the Sydney Basin, correlates with the Big Glen Member in the Loch Lomond Basin (Boehner and Prime, 1993), the E_1 Member in the Hood Island Formation in the Antigonish Basin (Boehner and Giles, 1993) and the Kennetcook Member (Moore, 1967) in the Murphy Road and Green Oaks formations in central mainland Nova Scotia.

Distribution and Thickness The Woodbine Road Formation is widely distributed in the subsurface of the Sydney Basin (Figs. 6a, 7 and 8). The Formation is approximately 95 m thick in the type section in NSDME Woodbine Road 84-1 (Fig. 10) and is generally thinner in the conglomeratic sections near Point Edward where 40-50 m is typical. In the Saunders Cove-Shawfield Point area the section is not completely exposed and has an approximate maximum thickness of 129 m (Fig. 15, and Map 86-1, in pocket).

Relations to Other Units The Woodbine Road Formation disconformably overlies the Meadows Road Formation. Coarse grained siliciclastic strata are often associated with the Formation near the basement blocks, e.g. Coxheath Hills. The Woodbine Road Formation is conformably overlain by the Cape Dauphin Formation or Point Edward Formation of the Mabou Group (Figs. 8 and 9). The basal part of the South Bar Formation lies unconformably upon the middle to lower units of the Woodbine Road Formation in the Boularderie Island area near Kempt Head on the western side of the Basin. The Mabou Group and upper parts of the Woodbine Road Formation are eroded away at this locality. The contact between the Woodbine Road Formation and the underlying Meadows Road Formation is not exposed in outcrop, but was intersected in several drillholes. Although locally disrupted by faulting and solution collapse of the underlying evaporitic Meadows Road Formation, the contact appears to be concordant and disconformable. In these sections the Crawley Member rests concordantly upon a disrupted section of the Meadows Road Formation.

The base of the Woodbine Road Formation is designated at the base of the Crawley Member in complete sections and the upper contact is placed at the top of the Dixon Point Member which is well defined in drillhole sections (Fig. 10), but locally present in outcrop. The upper contact is concordant and conformable with overlying evaporites (anhydrite and gypsum) and grey to red, fine grained siliciclasics of the Cape Dauphin Formation (Mabou Group). This follows the practice of Giles (1982) and Boehner and Giles (1991) who excluded the evaporite bearing section above the uppermost Windsor Group marine carbonate member. The transitional siliciclastic and evaporite section consequently is included within the basal part of the Cape Dauphin Formation.

Depositional Environment The depositional model for the Woodbine Road Formation is very similar to that described for the underlying Meadows Road Formation. Evaporite facies are not as extensively developed, but the carbonate members tend to be better developed. The Formation is dominated by fine grained redbeds deposited in a continental to marginal marine mudflat environment. These are the distal equivalents of coarse grained alluvial fan conglomerates and breccias locally developed at the margins of uplifted basement blocks, e.g. Coxheath Hills in the Point Edward sections. The subangular to subrounded conglomerates represent alluvial fan deposition, including both poorly sorted debris flow deposits and well sorted water laid deposits. The disappearance of several of the carbonate members of the Woodbine Road Formation indicates the fan deposits were in close proximity to a marine environment during the Viséan.

The Formation is generally similar in lithology and stratigraphic position to the Green Oaks Formation in the Shubenacadie and Musquodoboit basins (Giles and Boehner, 1979, 1982a), the Hood Island Formation in the Antigonish Basin and the Uist Formation in the Loch Lomond Basin (Boehner, 1981).

Age Spore assemblages recovered from the Woodbine Road Formation were assigned to the AT Zone by Utting (1978, 1987). The AT Zone has most recently been assigned a Brigantian age (latest Viséan) by Utting and Giles (2004) and by von Bitter *et al.* (2006).

Mabou Group

The Mabou Group was described and introduced by Belt (1964, 1965) as a replacement for the original Canso Group. With the introduction of the name Mabou Group, Belt (1964, 1965) also made an extensive revision of the stratigraphy of late Viséan to early Westphalian age strata in Nova Scotia. These revisions included abandoning the name Canso Group (Fig. 9), which was replaced by the Mabou Group. The Riversdale Group was also abandoned, and constituent strata assigned partly to the new Mabou Group and partly to the overlying Cumberland Group. The Mabou Group comprises a succession of grey and red brown fluvial and lacustrine strata dominated by grey mudrocks and red sandstone and mudrock. It conformably overlies the Windsor Group (Figs. 5, 6, 8, 9 and 10) and is overlain by a sequence of grey and red fluvial sandstone and mudrock ('Coarse Fluvial Facies' of Belt, 1965).

The following two principal formations which represent the dominant lithofacies were described by Belt (1964, 1965) as the grey, mudrock dominated Hastings Formation, and the red sandstone and mudrock of the overlying Pomquet Formation. Boehner and Giles (1993) included the intercalated evaporite and grey mudrock section above the stratigraphically highest marine carbonate of the Windsor Group, within the basal part of the Mabou Group. Both the Hastings and Pomquet formations are represented in the Sydney Basin, where they were described as the Cape Dauphin Formation and the Point Edward Formation respectively by Bell and Goranson (1938a, b). These rocks are lithologically similar to, and correlate with, the Watering Brook Formation in the Shubenacadie Basin and the MacKeigan Lake Formation in the Loch Lomond Basin and Glengarry Half Graben (Fig. 7; Boehner and Prime, 1993).

Cape Dauphin Formation

Type Locality The name Cape Dauphin Formation was introduced by Bell and Goranson (1938a) and named for a section of grey mudrocks, evaporites and minor carbonates overlying the Windsor Group in the Cape Dauphin section on the western side of the Sydney Basin (Map 86-1, in pocket). The type area is near Cape Dauphin, Victoria County. Reference sections are designated in drillholes NSDME Point Edward 84-1, interval from 113.8-180.8 m at the tip of Point Edward and NSDME Woodbine Road 84-1, interval from 51.9-131.7 m in the eastern part of the Basin near Woodbine Road (Fig. 10).

Lithology The Cape Dauphin Formation comprises interbedded grey shale, gypsum and anhydrite, and minor thin, light grey to white limestone. The gypsum and anhydrite occur in the lower part of the section and are known only in the drillhole sections. The Formation is dominated by grey mudrocks with thin (10-30 cm) interbeds of limestone and silty limestone. The limestones, typically, are laminated to domal (locally convoluted) algal stromatolites. Red or green siltstone occurs in the upper part of the Formation. The section is, generally, well stratified and locally crosslaminated.

Distribution and Thickness The Formation is widely distributed throughout much of the Sydney Basin (Figs. 5, 6 and 10), but rarely outcrops due to its poorly indurated shaly nature. The Formation is approximately 80-85 m thick in the type section at Cape Dauphin, which is incomplete from a disconformity with the overlying South Bar Formation. It is approximately 65 m thick in drillhole NSDME Point Edward 84-1 and 75 m in NSDME Woodbine Road 84-1, the reference sections (Fig. 10). It may be totally removed by erosion where the South Bar Formation directly overlies the Woodbine Road Formation (Fig. 8) (e.g. in the Kempt Head area of the Boularderie Syncline).

Relations to Other Units The Cape Dauphin Formation conformably overlies the Woodbine Road Formation, is conformable with the Point Edward Formation and is disconformably overlain by the South Bar Formation (Figs. 8 and 10). It is conformably overlain by, and is laterally equivalent, through intertonguing, with part of the Point Edward Formation (e.g. Boularderie Syncline area, Fig. 16).

Depositional Environment The interbedded shale-evaporite section at the base of the Cape Dauphin Formation reflects a change from mixed marine continental deposition in the Windsor Group to a saline lacustrine environment with sustained standing water deposition perhaps in a marginal limnic or a paralic environment. Evidence for this includes the presence of thin stromatolitic limestones, similar to those in the Hastings Formation of Belt (1964, 1965), and occasional sedimentary breccia. The evaporite deposition low in the sequence suggest that restricted saline and arid climatic conditions existed initially, which perhaps reflect inherited evaporitic conditions

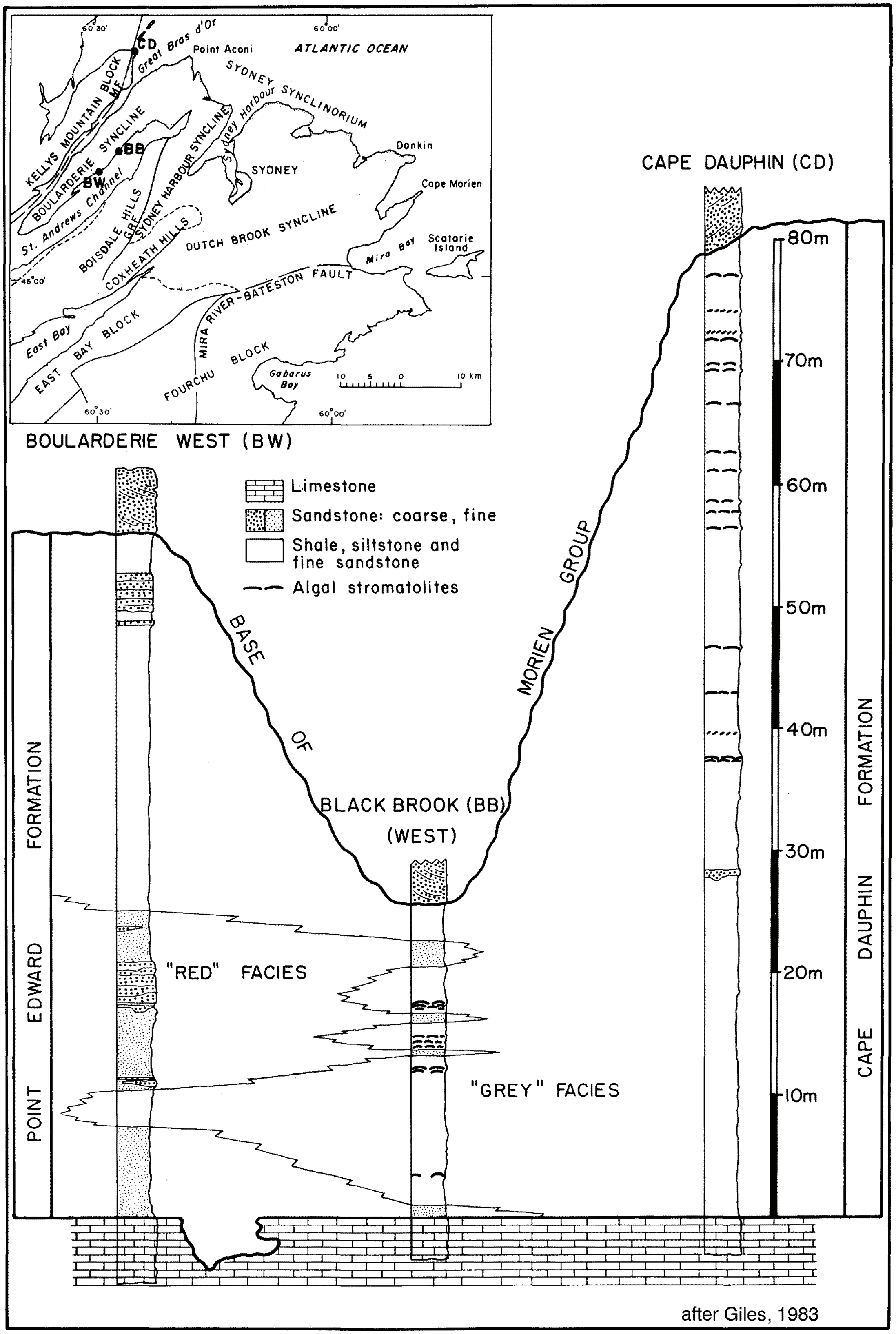


Figure 16. Outcrop sections of the Mabou Group and the relationship between the Cape Dauphin and Point Edward formations in the Boularderie Syncline area.

similar to the underlying Windsor Group. The disappearance of the evaporitic phase upsection could be the result of a moderation in climate and a typical evolution from a saline evaporite basin into a continental lacustrine environment.

The Cape Dauphin Formation (Boehner and Prime, 1993) is interpreted to represent sustained lacustrine deposition characterized by grey, sparsely fossiliferous (bivalves) shales with laminated planar and domal algal stromatolitic limestone and dolostone. Evaporites, including gypsum, anhydrite and possibly some dolomite occur as interbeds up to 8 m thick within the grey shale and siltstone. These evaporites are interpreted to represent waning and terminal phase marine grading to continental (playa lake) evaporite deposition. The evaporitic conditions followed the retreat of Windsor seas, which left behind an elevated residual salinity in an early stage lacustrine basin. The sedimentary sequence at the base of the Cape Dauphin Formation records the transitional period of mixed continental, evaporite and siliciclastic deposition. A large successor lacustrine basin is interpreted to have been the primary depositional setting of the Formation. Variations in the lake shoreline and fluvial sediment influx into the (permanent, but fluctuating) lake produced a lateral intertonguing of grey shales and subaerial redbeds with the Point Edward Formation including red sandstone, siltstone, shale and pedogenic carbonates (alluvial and fluvial mudflat deposits).

Age Miospore assemblages of the Cape Dauphin Formation are assigned by Utting (1987) to the SM Zone, currently thought to be of latest Viséan and Early Namurian age (Utting and Giles, 2004; von Bitter *et al.,* 2006).

Point Edward Formation

Type Locality The name Point Edward Formation was introduced by Bell and Goranson (1938b) for a section of red and grey mudrocks, sandstones and minor lacustrine carbonates overlying the Windsor Group in the Point Edward area near Sydney (Map 86-1, in pocket). The type area is located along the shoreline of Sydney Harbour near Point Edward, Cape Breton County. Reference sections are designated in drillholes NSDME Point Edward 84-1, in the interval from 7.5-113.8 m at the tip of Point Edward, and NSDME Woodbine Road 84-1 in the interval from 24-51.9 m in the southeastern part of the Basin near Woodbine Road (Fig. 10). Both of these drillhole sections are incomplete at the top. However, in the NSDME Point Edward 84-1 drillhole, the unconformity with the overlying South Bar Formation is only a few metres above the top of the drillhole section.

Distribution and Thickness The Point Edward Formation is widely distributed throughout much of the Sydney Basin, and similar to the underlying Cape Dauphin Formation, it rarely outcrops because of its poorly indurated nature (Figs. 5, 6 and Map 86-1, in pocket). The Formation is approximately 100 m thick in the type area at Point Edward, where it is incomplete beneath a disconformity with the overlying South Bar Formation. It is 106 m thick in drillhole NSDME Point Edward 84-1 and 28 m in NSDME Woodbine Road 84-1, the reference sections (Fig. 10). In hole NSDME Kempt Head 84-1, where the South Bar Formation directly overlies the Woodbine Road Formation (Fig. 10), not only the Point Edward Formation, but the entire Mabou Group appears to be missing through erosion.

Relations to Other Units The Point Edward Formation conformably overlies the Cape Dauphin Formation and is disconformably overlain by the South Bar Formation (Fig. 8). It is, in part, laterally equivalent through intertonguing with grey mudrocks of the Cape Dauphin Formation (Fig. 16) (e.g. Boularderie Syncline area).

Lithology The Point Edward Formation comprises a complex sequence of interbedded red and mottled grey-green and yellow-brown and minor grey siltstone, sandstone and shale with minor intraformational breccia and conglomerate. Limestone occurs as thin (<20 cm) interbeds and as nodules within the mudrocks. The basal part of the section consists of red to green siltstone.

The upper parts of the unit consist of a mixture of red mudstone, sandstone and conglomerate. Mudstone predominates and often contains green mottling and calcrete nodules with green grey envelopes. The siltstone and sandstone units often exhibit crosslamination, ripple marks and fining upward sequences. The conglomerate has granule- to pebble-sized intraformational clasts of limestone and mudstone. The top of the Formation has abundant pedogenic carbonate, colour mottling and locally (e.g. Point Edward section) stigmaria from the overlying South Bar Formation. This unconformity contact in drillhole NSDME Sydney 82-1, near Mira Road, is poorly consolidated and collapsed in the drillhole resulting in the abandonment of the drillhole.

Depositional Environment The fine grained redbeds and pedogenic carbonates and related mottled siliciclastics comprising the Formation reflect a change from continental lacustrine deposition in the underlying Cape Dauphin Formation to a predominantly subaerial fluvial mudflat environment with minor sustained standing water deposition. The lateral relationship of the red and grey facies and the pedogenic features within the redbeds of the Point Edward Formation reflect the lacustrine/fluvial mudflat interaction. The grey mudrocks interbedded low in the sequence indicate the transition from predominantly subaqueous to subaerial deposition, perhaps in a shoreline environment. Variations in the lake shoreline and/ or fluvial sediment influx into the (permanent, but fluctuating) lake produced a lateral intertonguing of grey shales and marginal basin clastics including red sandstone, breccia and shale (alluvial and fluvial mudflat deposits).

Arid to highly seasonal climatic conditions probably existed which may reflect inherited evaporitic conditions similar to the underlying Cape Dauphin Formation. The disappearance of the grey lacustrine mudrock-evaporitic phase upsection probably is the result of the evolution in the Basin from a sustained (centralized) continental lacustrine environment to extensive subaerial mudflat (fluvial dominated with local playa lakes). Calcrete nodules and variegated colour mottling, in the predominantly red mudstone, suggest semiarid conditions with fluctuations in ground water levels on the floodplain. This may have occurred at a time of slower sedimentation, decreased subsidence and perhaps erosion.

The upper part of the Point Edward Formation has been subsequently altered by pedogenic, weathering and erosional processes (including subunconformity root penetration) during the hiatus before the deposition of the fluvial sandstones of the South Bar Formation (Late Westphalian B). Strata representing the Middle Namurian to Westphalian B are absent at the unconformity. The possible extent of section removal by erosion is not clearly defined nor are the age assignments within the redbeds of the upper part of the Point Edward Formation.

Age The Point Edward Formation has been assigned a Late Viséan to Early Namurian age based upon palynomorph assemblages (SM Zone, of Utting, 1987).

Late Carboniferous Nomenclature

A thorough discussion of the evolution of stratigraphic nomenclature of the Late Carboniferous is not included here and readers are referred to Ryan *et al.* (1991) and Belt (1964, 1965) for discussions and nomenclature revisions. Important aspects of the stratigraphic evolution in the Late Carboniferous of the Maritimes Basin are described in Ryan *et al.* (1991) and Kelley (1967b) and are outlined below. Bell (1944), as a culmination of extensive regional stratigraphic and paleontological study, established a four group stratigraphic subdivision for Upper Carboniferous strata above the Windsor Group. This nomenclature was based upon units previously named as series. The revision of the Late Viséan to Namurian age strata of the Canso Group (abandoned) and replacement with the Mabou Group by Belt (1964, 1965), was described in the previous section of this report. The four groups of Bell (1944) included in ascending order: Canso, Riversdale, Cumberland and Pictou groups. Coal-bearing equivalents of the Pictou Group were locally differentiated (due, in part, to their economic significance) as the Morien Group and Stellarton Group. Bell (1944) correctly recognized the difficulty presented by the complex depositional conditions (inherent to intermontane environments with complex uplift and subsidence history) which produced laterally variable sedimentary sequences within and between sub-basins. This complexity in lithologic units was further compounded by the recognition that distinctive, laterally persistent marine marker beds were not present in the Upper Carboniferous section. Bell (1944) concluded that, given the available outcrop and limited subsurface data available, subdivision on a purely lithological basis was difficult and impractical.

Bell (1944) believed that a useful subdivision into a limited number of more natural groups could be done on the basis of tectonic history (unconformities) and on the sequence of fauna and flora (biostratigraphy). Specifically, Bell (1944) stated that his group divisions were: "...based primarily upon on the vertical distribution of plant species." and furthermore that, "tectonic events had locally brought about a subdivision into groups that coincided with those established by the plant evidence. Hence a group, in the sense used in this report (Bell, 1944), represents an assemblage of strata in which no major breaks of deposition have been detected, and which contains a fossil flora and fauna of the order of an epoch or subepoch of time as generally understood by geologists."

He recognized that the groups could be further subdivided into mappable formations, but only in small areas, resulting in a multitude of local formations. This was in contrast to his classification which recognized few major units, ie. groups.

"The economic value of lithological classification of strata has already been mentioned and is generally understood. The value of classification based on age is not so generally appreciated. Yet it is the only classification that permits reliable correlation." (Bell, 1944).

Bell (1944) believed that all of his groups were separated by unconformities or disconformities of regional time equivalence. Unfortunately, this assumption is not true because many of the contacts are conformable. The timing of the accelerated subsidence and sediment accumulation within the complex Maritimes Basin was not synchronous and varied from sub-basin to sub-basin. Consequently, the resultant unconformities differ in age from the idealistic coincident group boundaries, and unconformities are therefore untenable as a general rule.

Kelley (1967b) summarized the evolution of Carboniferous stratigraphic nomenclature and discussed the inherent problems and confusion where unconformities were not present at group boundaries and paleontological (age) criteria dictated the boundary placement. He pointed out that the designation of these units as 'groups' was contrary to the code of stratigraphic nomenclature, whereas Bell (1944) had assigned lithostratigraphic nomenclature to time stratigraphic units. Historically, age has been a primary criterion used to assign rock units to the basic group scheme in the Maritimes Basin (Belt, 1964, 1965). Kelley (1967b) retained the group nomenclature of Bell (1944), but revised it by extending the age ranges (overlapping) and by defining the varied contact relationships between the groups. This practice was followed and further defined by Barss and Hacquebard (1967), Hacquebard (1972, 1986) and Howie and Barss (1975). They used palynological studies to clarify the age relationships and correlation of the Late Carboniferous to Early Permian groups and formations (substantially diachronous) in the Maritimes Basin.

The nomenclature of the Late Carboniferous 'Coarse Fluvial Facies' was not fully addressed in the revised system of Belt (1964, 1965). This part of the stratigraphic section was more recently described and revised by Ryan *et al.* (1991) based upon the Cumberland Basin. Lithologic variation and relationships similar to those faced in the Mabou Group are also evident in the younger Carboniferous units, which include diverse strata assigned to the Riversdale (abandoned), Cumberland (redefined) and Pictou (redefined) groups. The Cumberland Group, in the type area in the Cumberland Basin, as an example, comprises seven formations, is up to 3900 m thick in the incomplete type section and locally may be in excess of 5000 m thick. It comprises strata which display a broad lithologic range from red and grey conglomerate dominated to red and grey mudrock dominated. Inclusion of all post Mabou Group strata, including these diverse formations, in the 'Coarse Fluvial Facies' would obviously oversimplify Late Carboniferous basin fill in the Maritimes Basin. A specific problem is the significant proportion of fine grained fluvial and lacustrine rocks, especially in the coal-bearing and mud-rich formations of the Cumberland and Pictou/Morien and Stellarton groups.

Application of the Pictou Group and Morien Group terminology was awkward, especially following the recognition of extensive coal-bearing strata (up to 1800 m thick) throughout the Gulf of St. Lawrence that are correlative with the Morien

Group in the Sydney Basin (Hacquebard, 1986). The presence of a thick section (up to 3000 m) of non-coal-bearing redbeds (Pictou Group) overlying the coal-bearing strata has further compounded group assignment in a regional context. In the Gulf of St. Lawrence, the name Pictou Group, applied by Hacquebard (1986), included both the coal-bearing (Morien Group correlative) section and the thick overlying redbeds. While in the virtually identical section in the Sydney Basin both the Pictou and Morien groups are identified. Because Bell's (1944) nomenclature has been so widely accepted and used, the revisions proposed by Ryan *et al.* (1991) adopt and improve the well established group nomenclature. This is based upon a system of mappable lithostratigraphic units, at the formation level, defined in accordance with the North American Commission on Stratigraphic Nomenclature (1983). The focus is placed on the formations as the fundamental components of the stratigraphic framework. They are placed in a modified group scheme (based as much as possible upon the traditional system) as a secondary priority. The assignments and revisions are subject to future modification if necessary. Age, although important in any rock unit, is not the critical factor in the definition and recognition of the units.

The nomenclature applied in the Sydney Basin retains the Morien Group designation of Bell and Goranson (1938a, b). Consideration was given to extending the redefined Cumberland Group (Ryan *et al.*, 1991) name into the area, but this is delayed until further work is completed in western Cape Breton Island and in the Gulf of St. Lawrence. The main problem relates to the benefit of restricting the Cumberland Group to the lower part of the section and retaining the Morien Group for the uppermost coal-bearing part of the section. The key limitation is the definition of a regionally recognizable boundary which occurs, for the most part, in the subsurface of the Gulf of St. Lawrence.

Morien Group

The Morien Group is one of the most significant economic units of the Carboniferous basin-fill of the Maritimes Basin of Atlantic Canada. It contains the bulk of the mineable coal resources in the region and has been an active producer for more than 200 years. Because of the importance of the coal, the geology and stratigraphy of these strata have been described methodically by numerous workers beginning in the mid-1800s and continuing today. The early history is extensively described by Hayes and Bell (1923) who identified key early workers including Brown (1871), Dawson (1873), Robb (1876) and Hyde (1913). The early terms 'Millstone Grit' and 'Productive Coal Measures' were applied to strata named the Morien Series by Hayes and Bell (1923). The term Morien Group was introduced by Bell (1944), although formal formations were not described. The Morien Group, instead, had a three part subdivision based upon megaflora, indicated first by Hayes and Bell (1923) and subsequently formally described by Bell (1938), Bell and Goranson (1938a,b) and Hayes *et al.* (1938a). These megafloral zones, of Late Westphalian C and D age, in ascending order, include the *Lonchopteris* zone, the *Linopteris obliqua* zone and the *Ptychocarpus unitus* zone. They are generally coincident with palynological zones identified later by Barss and Hacquebard (1967) and Barss *et al.* (1979) which are in the following ascending order: *Vestispora* zone, *Torispora* zone and *Thymospora* zone. Strata of the *Potoneisporites* zone (Stephanian) were not considered part of the Morien Group in spite of the fact that they were lithologically similar and in part coal-bearing (Hacquebard, 1986). The lowermost units of the Morien Group may be Late Westphalian B in age, and the uppermost units are now known to be Stephanian (Cantabrian), based upon recent megafloral assessment (Zodrow and Cleal, 1985) and palynolological studies by Dolby (1988, 1989).

Type Localities

The Morien Group type section was never formally or specifically designated. The name is derived from the Cape Morien area on the eastern side of the Basin where the units are exposed in shoreline sections along Mira Bay and Morien Bay near Port Morien (Map 86-1, in pocket). These sections were measured and described by Hayes and Bell (1923). Boehner and Giles (1986) subdivided the Group, recognizing the South Bar, Waddens Cove and Sydney Mines formations (Figs. 5, 6, 8, 17, 18, 19, 20, 21). The type sections for the South Bar Formation (Fig. 17 and Map 86-1, in pocket; measured and described by Rust and Gibling,

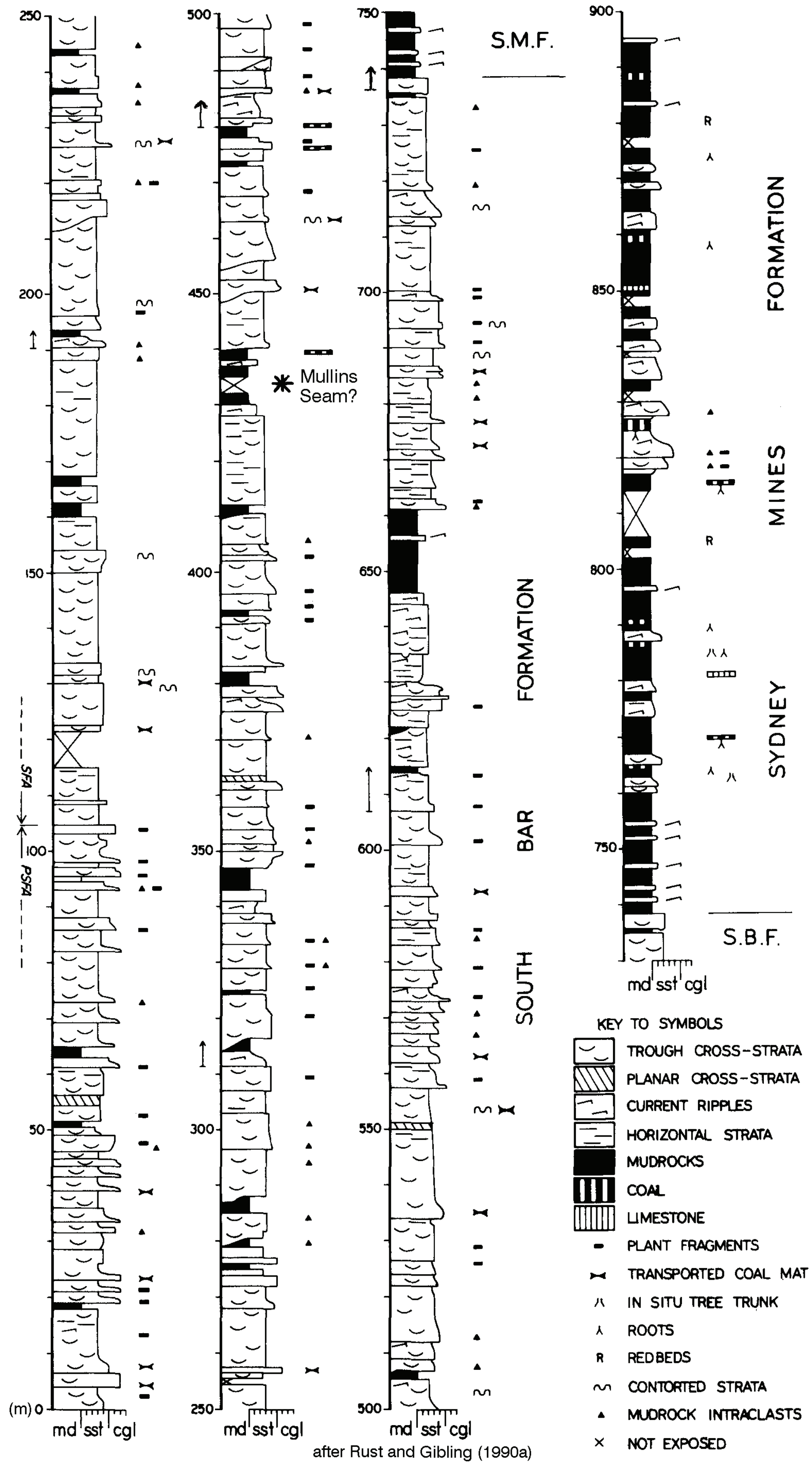


Figure 17. Type section of the South Bar Formation of the Morien Group, Sydney Harbour between South Bar and Victoria Mines.

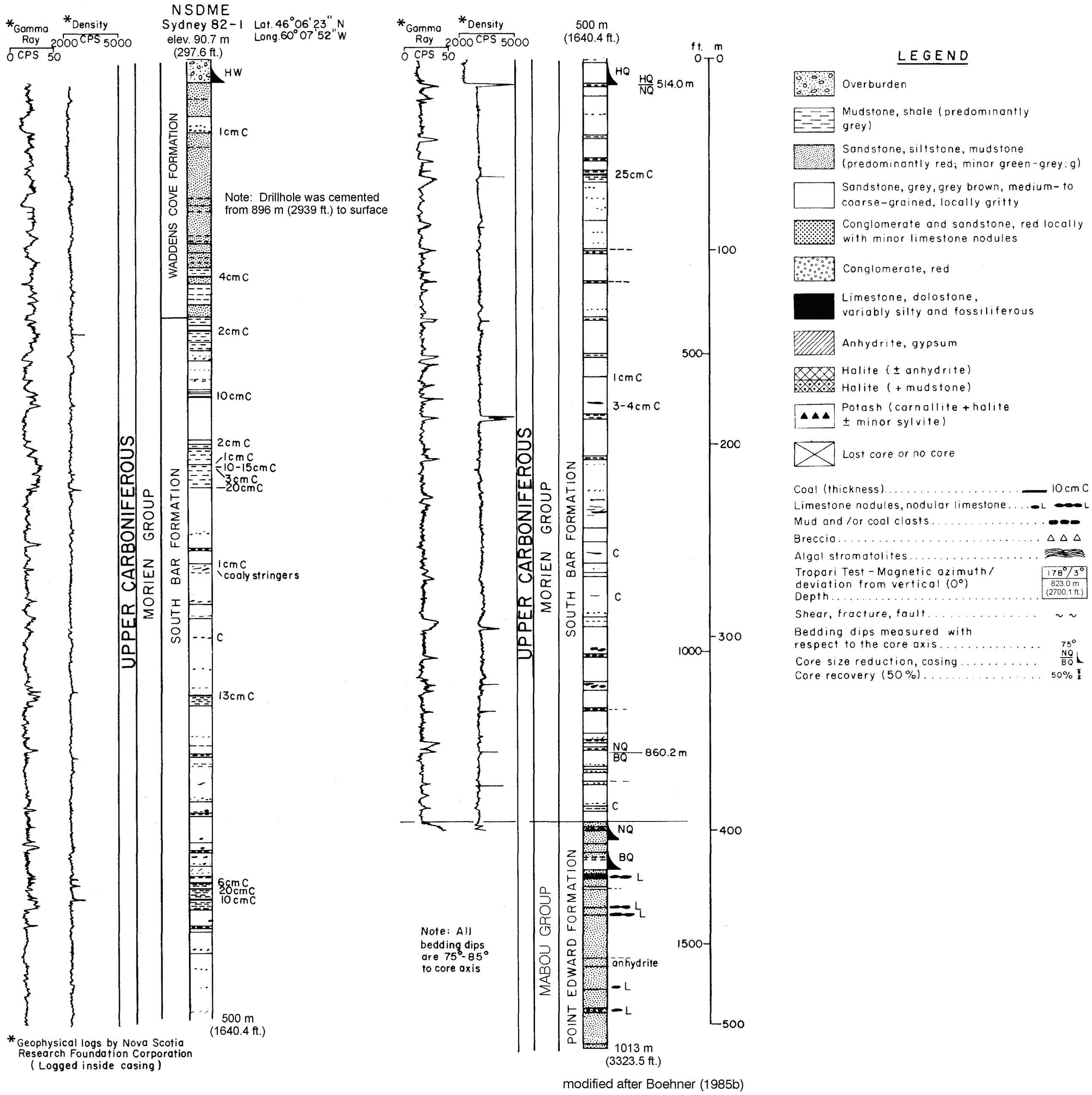


Figure 18. Reference section of the South Bar and Waddens Cove formations of the Morien Group in drillhole NSDME Sydney 82-1 near Mira Road. For location, see Map 86-1, in pocket.

1990a), and the Sydney Mines Formation (Fig. 20, after Gibling, unpublished synthesis, March 2, 1993), are designated in the area of Sydney Harbour (Map 86-1, in pocket). The type section for the Waddens Cove Formation (Fig. 19) is designated in the Port Morien area near Waddens Cove and has been described, in part, by Gibling and Rust (1990).

Lithology

The Morien Group comprises an interstratified sequence of grey sandstone, red sandstone, grey and red mudrocks, with subordinate conglomerate, coal seams and thin limestones. The Group is generally dominated by grey sandstone with minor mudrocks in the lower parts and is dominated by mudrocks with subordinate sandstone, economic

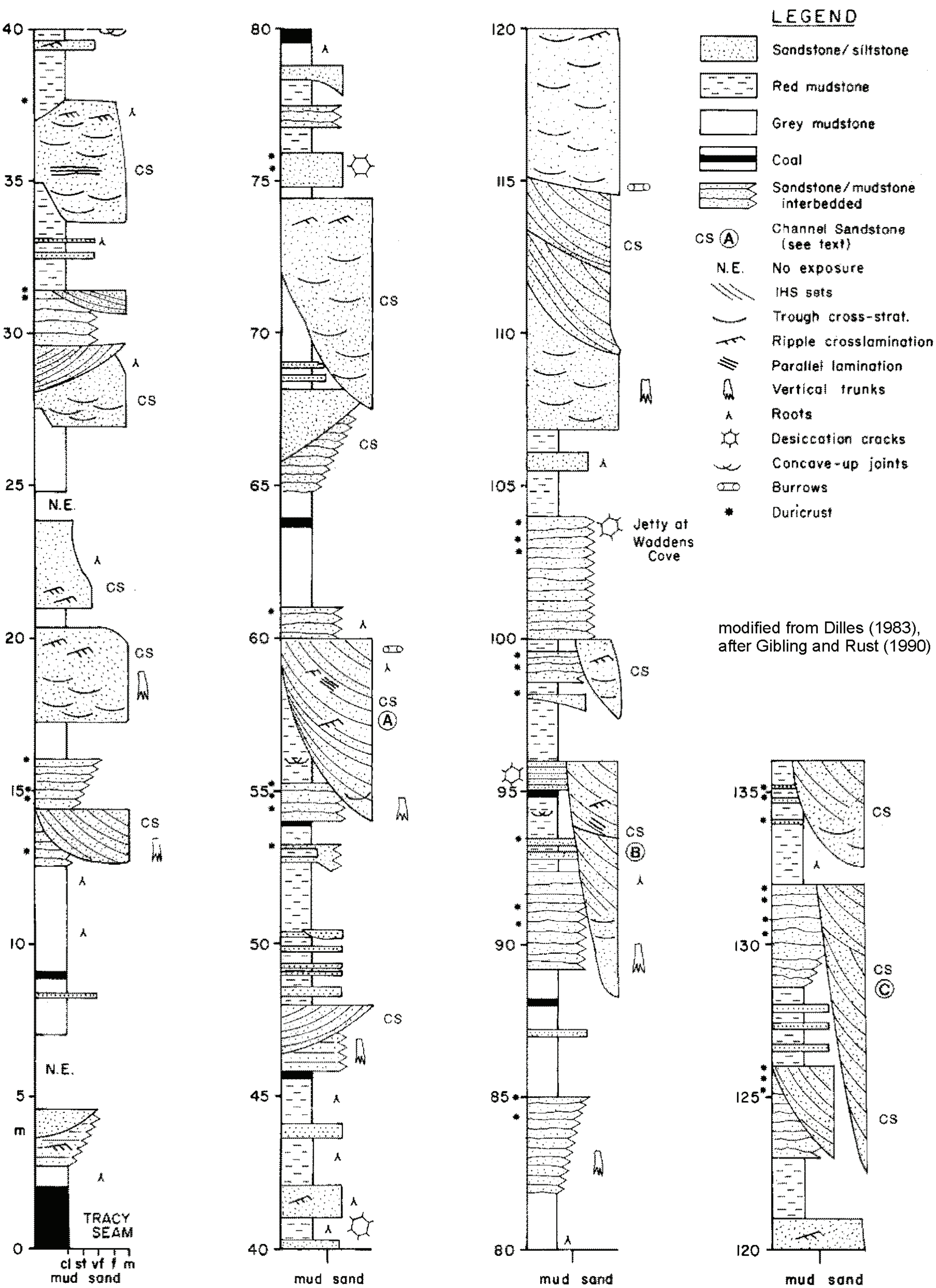


Figure 19. Type section of the Waddens Cove Formation of the Morien Group near Waddens Cove on Mira Bay.

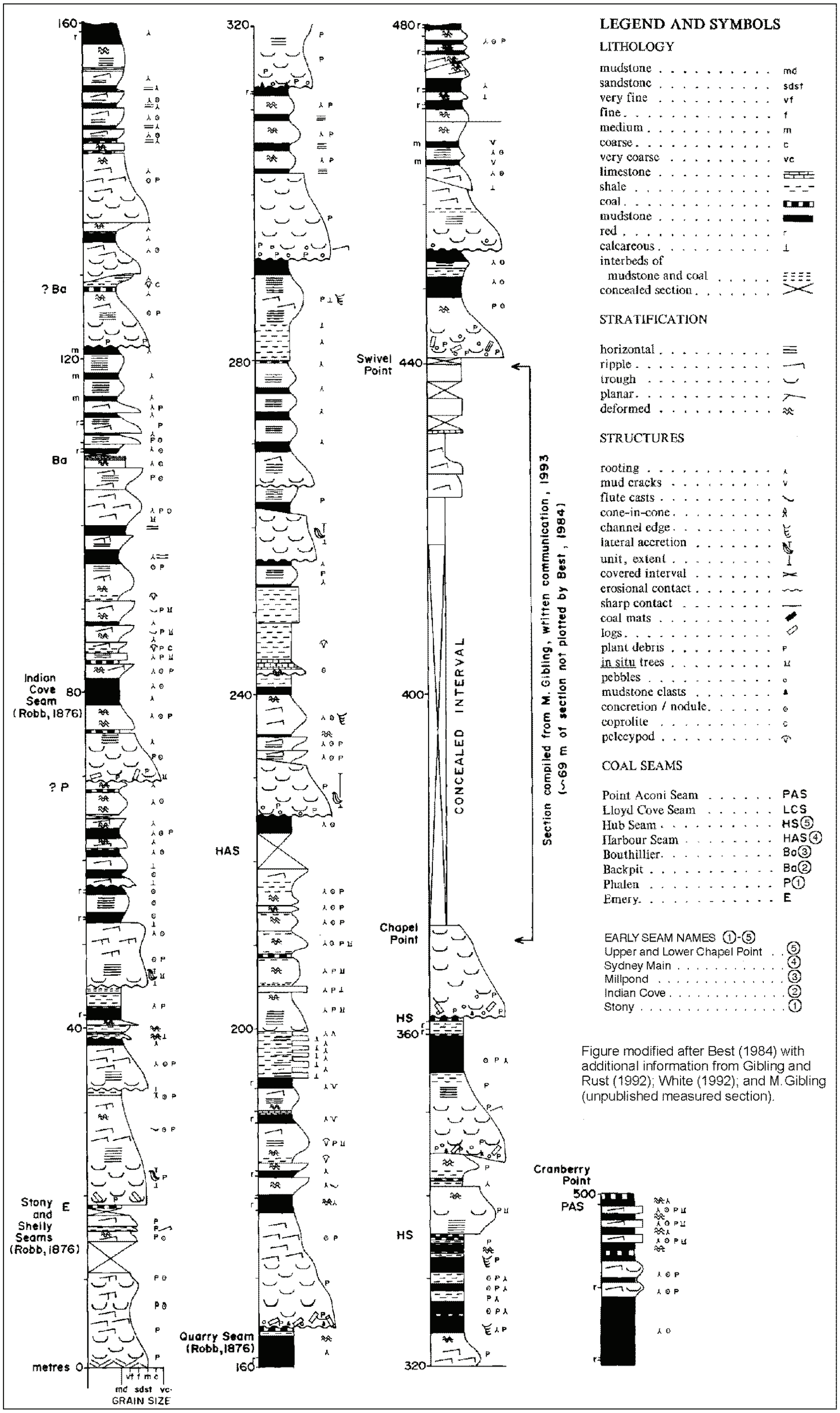


Figure 20. Type section of the Sydney Mines Formation of the Morien Group, Sydney Harbour between Stubbert Point and Cranberry Point.

coal seams and minor thin limestones in the upper parts. Approximately 13 economically significant coal seams are recognized and they range from <1 m to over 4 m in thickness. Please note that in the listing of coal seams on Map 86-1 (in pocket), the McRury Seam is misplaced and should be located between the Gardiner and Emery seams. The coal seams in the Sydney Basin are well described in numerous publications including Robb (1876), Bell (1938), Haites (1951), Cameron (1971), Hacquebard (1979, 1983, 1986), Hacquebard and Donaldson (1969) and Forgeron *et al.* (1986). The stratigraphy and sedimentology of the Morien Group has been described in numerous publications including Rust *et al.* (1983, 1987); Rust and Gibling (1990a, b); Gibling (1991); Gibling *et al.* (1987 1992a, b); Gibling and Rust (1984, 1987, 1990, 1992); Gibling and Kalkreuth (1991); Masson and Rust (1983, 1984), and in several related unpublished M.Sc. and Ph.D. theses by Best (1984), Bird (1987), Dilles (1983), Masson (1985) and White (1992). These are a major source of new information generated over the past 10 years on the detailed stratigraphy and sedimentology of the Morien Group in the Sydney Basin. Readers are directed to these sources for further reference to details not covered in this report.

The lowermost South Bar Formation is a grey sandstone dominated section with minor mudrocks and rare significant coal seams. The formation includes the strata of Bell's (1938) *Lonchopteris* zone, and lower *Linopteris obliqua* zone in the western part of the Basin. The Waddens Cove Formation has few significant coal seams and is a medial sequence characterized by the occurrence of redbeds, duricrusts and sedimentology intermediate to the overlying coal measures of the Sydney Mines Formation.

The mudrock dominated Sydney Mines Formation (strata included by Bell (1938), in the upper part of the *Linopteris obliqua* and *Ptychocarpus* zones), contains the bulk of the economic coal seams in the Basin. The contacts are typically interstratified and gradational, both vertically and laterally, giving a somewhat complicated stratigraphic relationship across the Basin. The Waddens Cove Formation appears to be confined to the eastern side of the Sydney Basin with limited extent to the west and north. It contains strata included by Bell (1938) in the lower part of the *Linopteris obliqua* zone. Similarly, in the western part of the Basin, where the Waddens Cove Formation is absent, the contact between the South Bar and Sydney Mines formations occurs at a higher stratigraphic level. In the east the base of the Sydney Mines Formation is near the Coalbrook or Gardiner seams, however in the west it is near the Emery Seam (beneath the Phalen Seam). The sandstone dominated sequences, characteristic of the South Bar Formation, thus occur progressively higher stratigraphically towards the western parts of the Basin.

Distribution and Thickness

The Morien Group ranges in thickness from 1500-1800 m in the onshore and near shore parts of the Sydney Basin. Thinner sections are apparently present in the area of the basement high block extension offshore (Boisdale Anticline) which was drilled by Murphy Oil (North Sydney F-24) and Shell Exploration (North Sydney P-05) in the early 1970s (Fig. 2). In this area, the Group is only 900 m thick with most of the thinning occurring in the lower parts of the section, especially in the South Bar Formation. The Morien Group has a wide distribution in the Sydney Basin portion of the regional Maritimes Basin in Atlantic Canada. According to Hacquebard (1983) the Group extends throughout an area of approximately 80 000 km^2 in the Basin between Cape Breton Island and Newfoundland, then eastward to near longitude 54° (Bell and Howie, 1990). Hacquebard (1986) established the correlation and extension of the coal-bearing strata into the larger Gulf of St. Lawrence area and identified a coalfield area larger than that of the Sydney Basin (~36 300 km^2). The onshore portion of the Morien Group distribution, described in this report, is very minor, but economically important for exploitable coal resources.

Relations to Other Units

The basal contact of the Morien Group is an unconformity with the underlying Mabou Group and Windsor Group strata (Figs. 6b and 8). Strata of Early Namurian through to the Middle Westphalian B are apparently absent due either to nondeposition or removal by erosion. The upper contact with the redbeds of the Pictou Group is

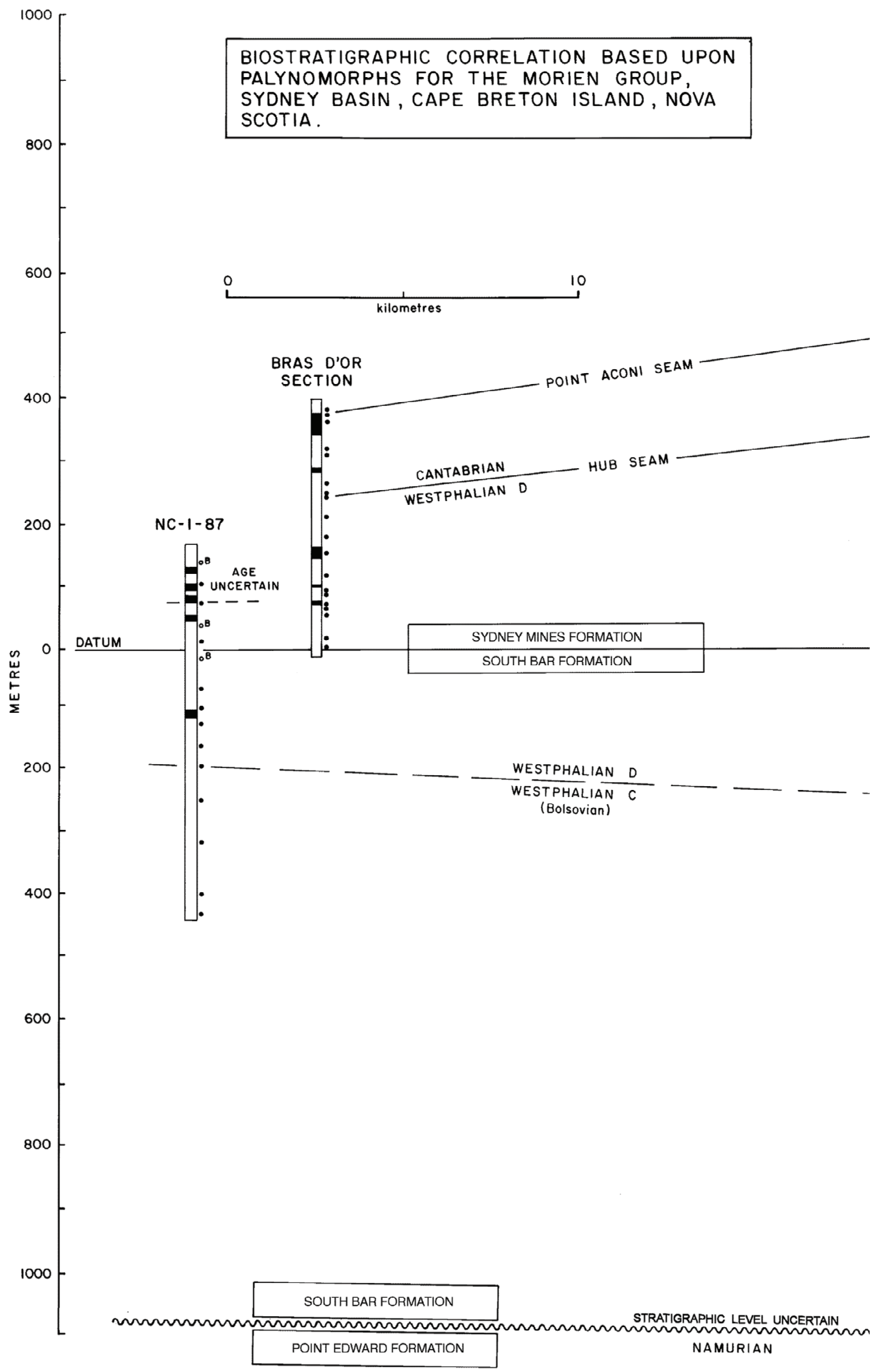


Figure 21. Morien Group biostratigraphy, palynology and correlation.

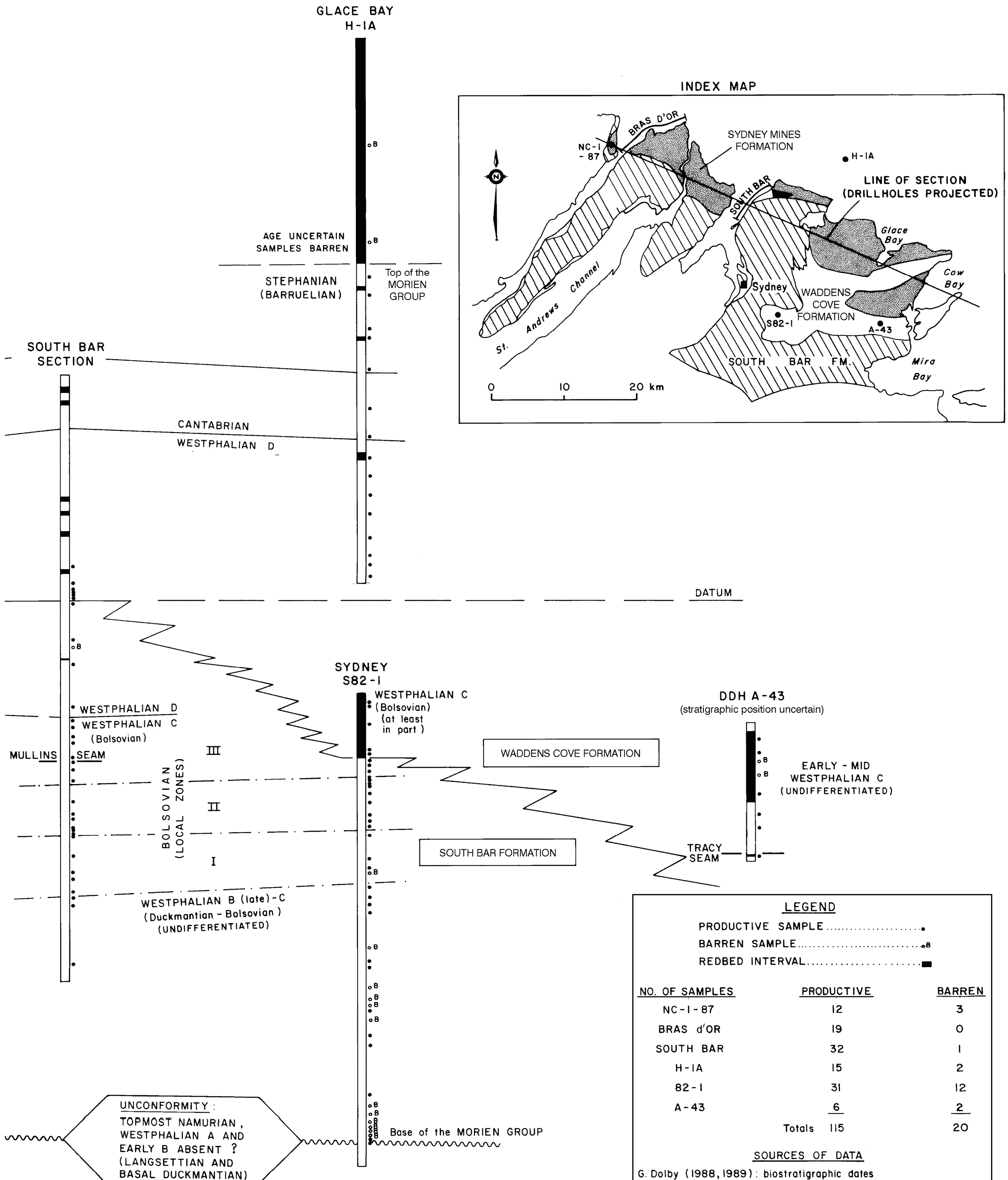


Figure 21. Continued.

conformable and interbedded similar to correlative sections in the Gulf of St. Lawrence described by Hacquebard (1986). The lowermost strata of the Group (South Bar Formation) are similar in age and lithology to parts of the Cumberland Group in the Cumberland Basin (e.g. Malagash or Ragged Reef formations). Prior to Boehner and Giles (1986), the term Morien Group was restricted to the predominantly grey, coal-bearing strata onshore in the Sydney Basin up to the highest seam at Point Aconi (Hacquebard, 1983). Coal and petroleum exploration drilling in the offshore extension of the Basin have established the presence of grey coal-bearing strata above the Lloyd Cove Seam (referred to as Post-Morien by Hacquebard, 1983). This section (200-300 m), up to the base of the Pictou Group redbeds, is now included in the Sydney Mines Formation of the Morien Group.

Depositional Environment

The strata of the Morien Group, according to Rust *et al.* (1987), Gibling *et al.* (1987) and Rust and Gibling (1990a, b), are dominantly alluvial sequences that represent deposition from long-lived regional drainage systems in a fairly stable tectonic regime. The fluvial sedimentology identifies deposition in braided rivers (sandy braid plain) in the lower part (South Bar Formation) and meandering river systems in the upper part (Sydney Mines Formation). Rust *et al.* (1987) indicated an evolution in the upper part (Sydney Mines Formation) to a finer grained (mud-rich) alluvial floodplain with unconfined large meandering rivers (sinuous sandstone channels), related overbank flood basin mudrocks, lakes, perhaps with brackish marine influence (Thibaudeau and Medioli,1986), and broad humid coal swamps in the flood basins. Rust *et al.* (1987) concluded that the uneconomic coals, typical of the South Bar Formation, were thin discontinuous deposits in well-drained swamps. Coals of the Waddens Cove Formation were interpreted by Rust *et al.* (1987) to have been deposited between incised meandering channels. The stable interchannel areas were controlled, in part, by the limitation of meandering by the development of duricrust surfaces, and channel incision related to base level variation.

The Waddens Cove Formation is similar, in part, to both the Sydney Mines Formation and the South Bar Formation. The Waddens Cove Formation has subequal mudrock and sandstone and the mudrocks are typically red. Related coals are thin and discontinuous and there is an abundance of siliceous and calcareous duricrusts interpreted as paleosols in a highly seasonal paleoclimate (Rust *et al.*, 1987). Coarse conglomeratic facies are not abundant and are represented by locally derived channel lags, and by far travelled or extensively reworked, well rounded and mature conglomerates. Input from basement highland blocks may be locally significant (e.g. Cape Dauphin, Robb, 1876).

The extensive paleocurrent data available (Gibling *et al.*, 1992b) are consistent with a predominantly northeasterly regional paleoflow as well as local influence by inherited paleotopography and syndepositional tectonics and basin-fill compaction, especially in the lower units. This local influence decreases in significance in stratigraphically younger units and although subtle, it bears significantly on the distribution of paleo-river channels which had an impact on former coal mining operations (Forgeron *et al.*, 1986; Duff *et al.*, 1982).

Age

The Late Westphalian (late B?, C and D) to Early Stephanian (Cantabrian) age of the Morien Group is well established by megaflora (Bell, 1938; Zodrow and Cleal, 1985) and by palynology (Barss and Hacquebard, 1967; Barss *et al.*, 1979; Dolby, 1988, 1989).

South Bar Formation

Rocks assigned, in this report, to the South Bar Formation (Figs. 5, 6 and 8) have previously been included in undivided Morien Group. The name South Bar Formation is herein introduced and comes from the type area along the southeastern shore of Sydney Harbour between Whitney Pier and Victoria Mines (Map 86-1, in pocket). Although hundreds of exploration drillholes have been drilled in the Basin, very few were located in the South Bar Formation because of the lack of economically significant coal seams.

Type Locality The type section of the South Bar Formation is nearly completely exposed along the southeastern shoreline of Sydney Harbour near South Bar (Map 86-1, in pocket). This section

(Fig. 17) has been measured and described by Rust and Gibling (1990a) and extends for more than 7 km from near McLennan Brook in the south, through South Bar to McGillivray Point in the north near Victoria Mines. The basal contact with the Mabou Group is not exposed in the type section, although there is an excellent outcrop exposure of this contact in the Cape Dauphin section on the northwestern side of the Basin. Cape Breton Development Corporation C-111 at Victoria Junction and NSDME Sydney 82-1, drilled near Mira Road, are stratigraphically significant coreholes, here designated as reference sections. Drillhole C-111 was lost at a depth of 876.4 m and did not reach the base of the South Bar Formation. Drillhole Sydney 82-1 (Fig. 18) intersected all of the South Bar Formation from 132-890.2 m giving an intersection thickness of 758.2 m. Sydney 82-1 is the only corehole to have a complete section from the base of the Waddens Cove Formation or Sydney Mines Formation to the top of the Mabou Group (Point Edward Formation). Other complete intersections were made in the Murphy *et al.* Birch Grove No. 1 well (Murphy Oil Ltd., 1968), and the offshore well North Sydney P-05 (Fig. 2), but are recorded only by well cuttings. The upper contact is exposed in the type section as well as other outcrop locations in the Basin. Reference outcrop sections are designated near Big Bras d'Or and Black Rock on the western side of the Basin, near North Sydney, and the shoreline between Round Island and Waddens Cove on the eastern side of the Basin.

Lithology The South Bar Formation comprises an interstratified sequence of medium- to coarse-grained, grey to grey-brown sandstone, pebbly sandstone, conglomerate with subordinate (10-15% maximum) grey to locally reddish mudrocks and rare thin coals. Plant debris is locally abundant, especially in conglomeratic channel lags at the base of major sandstone units. Pyrite nodules and stringers, scattered throughout the sandstone, are frequently associated with coalified plant detritus and coals. The Formation has not been subdivided into members.

Rust and Gibling (1990a) described the South Bar Formation in terms of three facies assemblages that comprise an overall fining upward succession of conglomerate, pebbly sandstone and sandstone. The sandstone facies assemblage is dominant in the southeastern parts of the Basin, but it is coarser to the west and northwest. The conglomerate is not thick or apparently widely distributed in the Basin and is best developed in a 66 m thick section at Cape Dauphin on the extreme western side of the Basin near the Kellys Mountain Block. The pebbly sandstones are best exposed in the lower 105 m of the type section at South Bar and are characterized by trough cross-stratified, medium- to coarse-grained sandstone with subordinate pebble lag and minor pebble conglomerate. According to Rust and Gibling (1990a), mudrocks make up approximately 3.5% of this facies assemblage. The upper 634 m of the South Bar Formation type section is the sandstone facies assemblage which is characterized by sandstones (finer grained) which fine upwards to crosslaminated mudrocks which form 9% of the section.

The sandstones are typically medium- to coarse-grained and grey to grey-brown in colour. They comprise multistoried cycles beginning with an erosional base, followed by massive intraformational or extraformational conglomerate and trough cross-bedded sandstone with finer rippled sandstones and mudrocks at the top. Numerous coal fragments (plant stems, debris and peat mats) are scattered throughout the coarser fraction. The lowermost few metres of the Formation in the apex area of the Pottle Lake Syncline (Sydney Harbour Syncline) near Leitches Creek are mineralized with galena and sphalerite similar to the Yava Deposit in the adjacent Glengarry Half Graben (Boehner and Prime, 1993; Sangster and Vaillancourt, 1990a).

Distribution and Thickness The South Bar Formation is the most widely distributed subdivision of the Morien Group in the Sydney Basin map area, and occurs extensively in the subsurface in the northerly and easterly extensions of the Basin (Figs. 5 and 6). The Formation has a measured thickness of 740 m in the type section, but is incomplete at the base. Where complete, the Formation has an intersection thickness of 758.2 m in drillhole NSDME Sydney 82-1 (dips are <10°). The intersection thicknesses in the petroleum exploration wells are more variable due to the position of the wells on anticlinal fold structures above basement horst blocks, or perhaps due to the diachronous nature of the upper contact of the Formation. Murphy *et al.* Birch Grove No. 1 (Murphy Oil Ltd., 1968) intersected approximately 792 m and Murphy North Sydney P-05 intersected approximately 300 m.

Relations to Other Units The South Bar Formation unconformably (disconformably) overlies Lower Carboniferous units of the Windsor and Mabou groups. The strata are typically concordant except in areas of solution collapse, e.g. Boularderie Island. The South Bar Formation overlies several formations, depending upon the depth of erosion at the unconformity, including: Point Edward, Cape Dauphin and Woodbine Road formations (Figs. 5, 6 and 8). The unconformity hiatus is reflected by solution collapse and caliche/ soil horizon development with large stigmaria penetration. The soft, multicoloured mud horizon that occurs beneath the basal contact is a serious diamond-drilling problem and is interpreted to be related to paleosol formation.

The South Bar Formation sandstones overstep the uppermost three formations of the Lower Carboniferous and this relationship could reasonably be extrapolated to older units as well, perhaps to the basement (e.g. adjacent Glengarry Half Graben, Boehner and Prime, 1993). In the Boularderie Island area (e.g. NSDME Kempt Head 84-1 drillhole, Fig. 10, the South Bar Formation sandstones rest on an eroded solution collapse landscape of Windsor Group carbonates, evaporites and clastics with the Mabou Group and the upper units of the Woodbine Road Formation apparently removed by erosion. The South Bar Formation is conformably overlain by the Waddens Cove (eastern part of the Basin) or Sydney Mines (western part of the Basin) formations (Fig. 8). The contact is an intercalated transition. Based upon well-defined, coal seam correlation and supportive biostratigraphy the contact is diachronous occurring at higher stratigraphic positions toward the western border of the Basin.

Depositional Environment The depositional environment of the South Bar Formation was described in detail by Rust and Gibling (1990a, b). The overall fining upward nature of the Formation was attributed to the proximal distal evolution in an extensive braid plain environment. The massive to horizontally stratified conglomerates, and related pebbly sandstones of the Conglomerate Facies Assemblage and Pebbly Sandstone Facies Assemblage were interpreted to have been deposited from moderately confined, proximal and intermediate braided rivers. The distal reaches of the braided river system are represented by the dominant Sandstone Facies Assemblage which comprises trough cross-stratified channel sandstone and subordinate overbank or channel plug mudrocks. According to Rust and Gibling (1990a, b), paleoflow in the coarser basal assemblages appear to be at least locally influenced by the paleotopography of the pre-Morien landscape. The Sandstone Facies Assemblage, in contrast, displays little influence. Extensive paleocurrent data from trough cross-strata indicates an eastward trend for the basal coarser units and a consistent northeastward trend for the dominant sandstone units.

There is a gradational change upward into the finer grained sandstone unit indicating a shift to a higher sinuosity fluvial system. The large proportion of fines is interpreted as flood basin deposits. Shallow lakes may also have developed on the floodplain and deposited grey shale beds. Laminated coaly shales and coal seams indicate local stability on the floodplain that was sufficient to support peat bog development.

The abundance of coaly material throughout the South Bar Formation indicates that a moderate climate with abundant rainfall existed, allowing the ephemeral development of interchannel vegetation and the local development of peat mires.

Age Based on palynomorphs, the South Bar Formation has been assigned a Late Westphalian B to Westphalian C age (Barss and Hacquebard, 1967; Dolby, 1988, 1989).

Waddens Cove Formation

Rocks assigned in this report to the Waddens Cove Formation (Figs. 5, 6 and 8) have previously been included in undivided Morien Group. The name Waddens Cove Formation is herein introduced and comes from the type area along the western shore of Mira Bay near Waddens Cove. Of the hundreds of exploration drillholes drilled in the Basin, only approximately 10 drillholes intersected the Formation. This is due to the lack of economically significant coal seams between the Tracy Seam and the Emery Seam and by the limited onshore areal extent of the Formation.

Type Locality The type section of the Waddens Cove Formation is nearly completely exposed along the western shoreline of Mira Bay at Waddens Cove on the eastern extremity of the Sydney Basin map area (Map 86-1, in pocket). This section (Fig. 19) has been measured and described by Gibling and Rust (1990), Dilles (1983) and Rust *et al.* (1987) and extends for more 2 km along the shoreline at Waddens Cove. The contact with the underlying South Bar Formation is exposed in the type section and is placed immediately above the Tracy Seam at the appearance of the distinctive duricrust and redbeds (Fig. 5). The contact on Map 86-1 (in pocket) has been revised after Gibling and Rust (1990) who extended the Formation down to include the strata immediately above the Tracy Seam. Gibling and Rust (1990) measured the type section comprising 136 m of strata up to the Coalbrook Seam. The Waddens Cove Formation strata continue in the inaccessible cliffs to the northeast, however details of these units are not available. Consequently the total thickness of the Formation in the type area has not been clearly established. The Formation rarely outcrops in the Basin, but is intersected in drillholes collared above the Tracy Seam to the west of the type section.

A reference section is designated in drillhole NSDME Sydney 82-1 (Boehner, 1993d) drilled near Mira Road (Fig. 18). Drillhole NSDME Sydney 82-1 was collared in the gently dipping Waddens Cove Formation and intersected redbeds from 12-132 m giving an incomplete intersection thickness of 120 m. Incomplete intersections were made in the CBDC-DEVCO A Series drillholes A-4, A-5, A-6, A-42, A-43, A-44 and A-45 (Map 86-1, in pocket). The upper contact is not accessible in the type section and is an interbedded gradation.

Lithology The Waddens Cove Formation is distinctive in that it displays lithology and sedimentology intermediate between the sandstone dominated South Bar Formation beneath, and the overlying mudrock dominated coal measures of the Sydney Mines Formation. It is a transitional unit comprising an interstratified sequence of medium- to fine-grained, grey to grey-brown and red sandstone occurring as narrow channels and as more laterally persistent sheets (levees or crevasse splays), and subequal red to grey mudrocks. Distinctive duricrusts are abundantly developed. Coals are a very minor component and tend to be thin (<30 cm.). Plant debris is locally abundant, especially in conglomeratic channel lags at the bases of major sandstone units. In the type section, the proportion of red to grey mudrocks increases upwards and sandstones are predominantly red in its upper parts. Grey rocks are rare in the reference section in drillhole NSDME Sydney 82-1. The Formation has not been further subdivided into members and is lithologically heterogeneous, typical of an alternating facies assemblage.

Gibling and Rust (1990) described the distinctive Waddens Cove Formation in terms of the following three associated components: reddening of the typically grey strata, abundance of siliceous duricrusts, and channel ribbon sandstone bodies in incised valleys. The incised channel sandstones have a characteristic ribbon geometry which contrasts with the braided sandstones in the South Bar Formation and the meandering sandstone channels in the Sydney Mines Formation. The Waddens Cove Formation is similar to the Sydney Mines Formation, but differs in the prevalence of incised channel sandstone geometry, prevalence of redbeds and siliceous duricrusts, and scarcity of coal seams of economic significance.

Distribution and Thickness The Waddens Cove Formation occupies the smallest outcrop area of the Morien Group in the Sydney Basin map area and occurs exclusively in the easterly extension of the Basin near Mira Bay and as far west as the eastern limb of the Glace Bay Syncline (Figs. 5 and 6). The Formation has a measured thickness of 136 m in the type section. This was not completely measured because of the inaccessible cliffs. Where complete, the Formation could be more than 300 m thick. The Formation has an intersection thickness of 120 m (incomplete at the top) in drillhole NSDME Sydney 82-1 (dips are <10°) (Fig. 18).

Relations to Other Units The Waddens Cove Formation conformably overlies and is transitional with the sandstone dominated South Bar Formation

(Figs. 8 and 9). It is inferred to be conformable and gradational with the overlying coal-bearing strata of the Sydney Mines Formation. The contacts with underlying and overlying strata are concordant and interbedded with basin wide lateral equivalence in part. The Waddens Cove Formation does not extend into the western part of the Sydney Basin and there is no apparent break in the stratigraphy. This, together with palynology and correlation of coal seams establishes the diachronous facies relationship with the South Bar Formation and part of the Sydney Mines Formation.

Depositional Environment The depositional environment of the Waddens Cove Formation was described in detail by Gibling and Rust (1990) and Rust *et al.* (1987) as being generally similar to the overlying Sydney Mines Formation. They recognized the distinctiveness associated with fluvial channel and adjacent alluvial components. These features included the extensive reddening of the typically grey strata, abundance of extensive siliceous duricrusts, and the consequent channel sandstone bodies localized in incised valleys. The incised channel sandstones have a characteristic ribbon geometry which contrasts with the braided sandstones in the South Bar Formation and the meandering sandstone channels in the Sydney Mines Formation. The Waddens Cove Formation is similar to the Sydney Mines Formation, but differs with its scarcity of coal seams of economic significance. Gibling and Rust (1990) concluded that the Waddens Cove Formation contained the channel sandstone deposits from rivers which were restrained from extensive migration by the development of duricrusts in the adjacent alluvium. The extensive development of the duricrusts in the vadose zone was interpreted to have been the result of a seasonal humid climate with lowering of the water table on the higher parts of the alluvial plain between the incised channels. Rust *et al.* (1987) related the channel incision to changes in base level at the basin or local scale or potentially to eustatic fall in sea level. The overall fining upward nature of the Morien Group continues through the intermediate Waddens Cove Formation and is attributed to the proximal to distal evolution in an extensive braid plain to floodbasin environment.

Age Based on palynomorphs, the Waddens Cove Formation has been assigned a Westphalian C age (Barss and Hacquebard, 1967; Dolby, 1988, 1989).

Sydney Mines Formation

Rocks assigned in this report to the Sydney Mines Formation (Figs. 5, 6, 8 and 9) have previously been included in undivided Morien Group. The name Sydney Mines Formation is herein introduced and comes from excellent outcrop exposures along the western shoreline of Sydney Harbour near Sydney Mines, the designated type area (Fig. 20). Hundreds of shallow and deep coal exploration drillholes have been drilled in the Basin and many were located in the Sydney Mines Formation due to the abundance of economically significant coal seams. The closure of the Lingan Mine on the Harbour Seam near New Waterford in 1993 left two underground mines being operated by the Cape Breton Development Corporation through the 1990s. Both of these were also subsequently closed (Gibling *et al.*, 1999). The Prince Mine operated on the Hub Seam near Point Aconi and the Lingan Phalen Mine operated on the Phalen Seam beneath the Lingan Mine near New Waterford. Because of the importance of this stratigraphic unit, the geology, stratigraphy and more recently the sedimentology of these strata have been methodically described by numerous workers beginning in the mid-1800s and various research activities continued through to the 1990s, e.g. Rust *et al.* (1987); Gibling and Rust (1987); Gibling and Bird (1994); and Gibling *et al.* (1999).

Strata of the Sydney Mines Formation were included in the *Ptychocarpus unitus* zone, the uppermost megafloral zone of Late Westphalian C and D age. These strata are included within the *Thymospora* zone (palynological zones) identified by Barss and Hacquebard (1967), and Barss *et al.* (1979). Younger strata of the *Potoneisporites* zone (Stephanian) were not considered part of the Morien Group despite their lithological similarity with the onshore coal-bearing sequences (Hacquebard, 1986). The Sydney Mines Formation is Westphalian D to Stephanian (Cantabrian) in age based upon recent megafloral assessment (Zodrow and Cleal, 1985) and palynolological studies by Dolby (1988, 1989).

Type Locality The type section of the Sydney Mines Formation is designated in the nearly completely exposed cliffs along the northwestern shore of Sydney Harbour between Stubbert Point and Cranberry Point (Map 86-1, in pocket, and Fig. 20). This section has been described in detail by Best (1984) with amendments by Rust and Gibling (unpublished), White (1992, Emery Seam to Phalen Seam interval), Johannes Paul (unpublished thesis work with Gibling, Phalen to lower Backpit split seams), Gibling (unpublished section of basal Bouthillier Seam to Harbour Seam) and a synthesis by White and Paul (written communication to Boehner, March 2, 1993). Several reference sections were identified (Gibling and Bird, 1994), across the Basin to represent the lateral variations within the Formation and its diachronous facies relationship with underlying strata. The correlative section to the west along the northwestern shore of Boularderie Island between Black Rock and Point Aconi is designated as a reference section (Gibling and Bird, 1994). A reference section is also designated in the steeply dipping section along the southeastern shoreline of Sydney Harbour between the top of the South Bar Formation at Victoria Mines to Low Point (Map 86-1, in pocket, and Fig. 17). Many of these sections were measured and described in whole or part by Robb (1876), Hayes and Bell (1923), and more recently by Rust *et al.* (1987), Rust and Gibling (1990a), White (1992) and Gibling and Bird (1994). Sections through the interval of the Emery Seam up to the Hub Seam are well exposed in the limbs of the Glace Bay Syncline between Dominion and Glace Bay.

The uppermost units of the Sydney Mines Formation above the Point Aconi Seam do not outcrop onshore and are known only from offshore petroleum and coal exploration wells (e.g. Murphy *et al.* North Sydney P-05, and coal exploration drillholes Glace Bay H-1A and H-2). Murphy *et al.* Northy Sydney P-05 intersected a stratigraphically reduced section of the Sydney Mines Formation from 564-1052 m. The partially cored coal exploration drillhole Glace Bay H-1A (Fig. 21) intersected Pictou Group redbeds from surface to 411.5 m and then the upper part of the Sydney Mines Formation between 411 m and the end of the hole at 1104 m. The base of the Formation was not reached. The Sydney Mines Formation has not been completely intersected in any coreholes. The upper contact with Pictou Group redbeds is not exposed in the Basin. The lower contact with the South Bar Formation is exposed in many of the shoreline sections (Map 86-1, in pocket).

Lithology The Sydney Mines Formation comprises an interstratified sequence of grey to locally reddish mudrocks with subequal medium- to fine-grained, grey to grey-brown sandstone. The section contains numerous economically significant coal seams, and thin stromatolitic limestones. Key coal seams of economic significance include in ascending order: Gardiner, McRury, Emery, Phalen, Backpit, Bouthillier, Harbour, Hub, Lloyd Cove, Point Aconi and Murphy seams. Please note that in the listing of coal seams on Map 86-1 the McRury Seam is misplaced and should be located between the Gardiner and the Emery seams. The coals and limestones are laterally extensive in the Basin and form important stratigraphic reference markers for correlation and establishing facies relationships both within and between formations. Plant debris is locally abundant especially in the conglomeratic channel lag at the base of the major sandstone units. Pyrite nodules and stringers are frequently associated with the plant detritus scattered throughout the sandstone. The Formation has not been further subdivided into members, however the dozen or more coal seams serve as key correlation units across the Basin. In the western part of the Basin sandstone facies appear at progressively higher stratigraphic levels established by the correlation of the major coal seams. This contrasts with the Glace Bay Syncline area where the alternating facies assemblage with subordinate sandstone extends to the lowest stratigraphic level in the Basin based upon the correlation of the coal seams.

Rust *et al.* (1987) described the Sydney Mines Formation as an alternating facies assemblage in contrast to the underlying sandstone facies assemblage characterizing the South Bar Formation. The Sydney Mines Formation comprises a subequal alternation of mudrocks and sandstone. Two types of sandstones were described by Rust *et al.* (1987): those less than 3 m thick (typically channel splays or levees) and those between 3 m and 15 m thick (major sandstone channels). The thinner sandstones are finer grained, cross-stratified, horizontally stratified, rippled, and frequently coarsen upwards. The thicker channel sandstones are laterally persistent and have erosional bases, basal lag deposits (intraclasts of coaly fragments, mudstone and siderite). They are dominated by cross-stratified sandstone and form an overall fining upward succession.

The interchannel rocks are dominated by grey and red overbank mudrocks with local limestones and siderite nodule concretions. The mudrocks are shaly, laminated, massive to bioturbated and have associated plant remains and bivalve debris. Coals form a minor proportion of the overall lithology of the Formation, but are economically important. These are the coalified peat deposits formed from very extensive mires which developed repeatedly and for prolonged periods in the Basin (Rust *et al.*, 1987) Limestones were recognized as laterally extensive markers by the early workers in the Basin including Robb (1876) and were subsequently examined and described by Masson and Rust (1983, 1984) and Vasey and Zodrow (1983). The laminated limestones are algal stromatolites, planar and oncolitic with variable siliciclastic content and frequently contain an abundant fresh water biota of bivalves, gastropods, ostracods and disarticulated fish remains. They are considered by Masson and Rust (1984) to have been deposited in shallow lakes developed on the flood plain. They are frequently associated with carbonaceous shale indicating a connection with coal formation. Thibaudeau and Medioli (1986) and Wightman *et al.* (1993) identified a biota indicative of a brackish marine influence in the limestone strata.

Distribution and Thickness The Sydney Mines Formation occupies a small outcrop area in the Sydney Basin map area because of the eroded synformal geometry. The onshore distribution is limited to the beveled edge of the seaward dipping sequences on the extreme north of the map area. The Formation occurs extensively in the subsurface of the offshore to the north and east (Hacquebard, 1983). This distribution severely limits the exploitability of the potentially vast coal resources of the area which extend beneath the Atlantic Ocean. The Formation has a thickness ranging from as little as 490 m in the Murphy *et al.* North Sydney P-05 well (above a basement horst block) to approximately 750 m in the Point Aconi area where sandstones extend up section to near the level of the Phalen Seam. The thickest section occurs in the mudrock dominated Glace Bay Syncline area where the complete section has a thickness of approximately 1000 m. The intersection thicknesses in the petroleum exploration wells (North Sydney P-05 and F-24, Fig. 2) are anomalously thinner due to the position of the wells on anticlinal fold structures above basement horst blocks.

Relations to Other Units The Sydney Mines Formation conformably overlies lower units of the Morien Group including the South Bar Formation in the central to western parts of the Basin and the Waddens Cove Formation in the eastern areas. The lower contact is a facies transition whose stratigraphic level is substantially diachronous across the Basin based upon the correlation of the coal seams and palynological dating. The Sydney Mines Formation is conformably overlain by the undivided redbeds of the Pictou Group (identified as ‘undivided Permo-Carboniferous redbeds’ on Map 86-1, in pocket). The conformable upper contact, like the basal contact, is an intercalated transition and is based upon the disappearance of grey coal-bearing sequences and the appearance of a dominantly redbed sequence. However, the upper contact appears, from limited drillhole sections, to be substantially less diachronous than the basal contact.

Depositional Environment The depositional environment of the Sydney Mines Formation was described in detail by Rust *et al.* (1987) and Gibling and Bird (1994). The overall environment for the Formation was attributed to predominantly alluvial deposition on a meandering fluvial floodplain. Mudrocks and finer sandstones were deposited as levee and crevasse splay deposits adjacent to the river channels as well as in lakes within the flood basins between the major meandering sandstone channels. According to Rust *et al.* (1987), the major rivers maintained a consistent northeastward flow throughout the Sydney Mines Formation with negligible influence by the pre-Morien landscape. The resulting alternating facies assemblage records the evolution to a distal alluvial floodplain from the sandy braid plain environment in the underlying South Bar Formation.

There is a gradational change upward into thinner and fewer sandstone channels indicating a waning trend in coarse fluvial input and a shift to a floodplain dominated system. The large proportion of fines is indicative of deposition on a distal floodplain. Shallow lakes may also have developed on the floodplain, suggested by the thick grey shale beds and fossiliferous carbonates. Research by Wightman *et al.* (1992, 1993) identified agglutinated foraminifera indicating the possible influence and proximity of marine waters. The extensive development of coal seams establishes that there was enough stability on the floodplain for prolific vegetation and extended peat bog development. The absence of outcrop exposure and extremely limited availability of diamond-drill core for examination has resulted in a very general interpretation of this fine grained unit.

The abundance of coaly material and plant remains throughout the Sydney Mines Formation suggests that a moderate climate with abundant rainfall existed. The abundance of red overbank mudrocks in the upper part of the Formation indicates the water table lowered at least on a local basis for periods of time sufficient to permit the diagenetic reddening of the typically drab sediments.

Age Based on palynomorphs, the Sydney Mines Formation has been assigned a Late Westphalian C to Stephanian age (Barss and Hacquebard, 1967; Dolby, 1988, 1989). The Late Westphalian (late C and D) to Early Stephanian (Cantabrian) age is well established by megaflora (Bell, 1938; Zodrow and Cleal, 1985). The biostratigraphic boundaries defined originally by Bell (1938) were placed lower in the section in the subsequent work of Zodrow and Cleal (1985) and Dolby (1988, 1989) who have identified the Westphalian D - Stephanian boundary at the level of the Hub Seam (Fig. 21). In the present work, we have followed the most recent interpretation of lithostratigraphic position for these important biostratigraphic boundaries based on palynomorph assemblages (Dolby, 1988, 1989).

Pictou Group

The redbeds above the Morien Group were informally referred to as undivided Permo-Carboniferous redbeds by Boehner and Giles (1986). Following the revisions to Upper Carboniferous strata by Ryan *et al.* (1991) they are now included as an undivided unit of the revised Pictou Group. The introduction of a formation name is not considered appropriate at this time. The Pictou Group was revised by Ryan *et al.* (1991) to include the predominantly redbed section above regionally extensive, grey coal-bearing strata in the Maritimes Basin of Atlantic Canada. Very little is known about the detailed stratigraphy and sedimentology of the redbeds in the Sydney Basin. This is, in part, due to their absence in onshore outcrop sections. Because of the lack of exposure and mineral or coal resources, the geology and stratigraphy of these strata have not been described methodically and they were not recognized until the petroleum exploration drilling in the early 1970s. The uppermost units of the Morien Group are now known to be Stephanian (Cantabrian) in age based upon megaflora by Zodrow and Cleal (1985) and palynology by Dolby (1988, 1989). The Pictou Group redbeds in the Sydney Basin therefore are not older than Early Stephanian.

Reference Area

Although a type section is not formally designated at this time, several drillhole sections are identified for reference. There are no outcrop sections of these strata in the onshore part of the Basin, but they are inferred to subcrop beneath the waters of the Cabot Strait. Pictou Group redbeds occur as incomplete sections in the upper parts of several offshore petroleum and coal exploration wells including Murphy *et al.* North Sydney P-05, North Sydney F-24, and coal exploration drillhole Glace Bay H-1A. Well P-05 intersected a section of the Pictou Group between 290 m and 564 m. The interval from surface to 290 m was not recovered, but is inferred to be redbeds. Well North Sydney F-24 intersected a similar section of the Pictou Group redbeds to a depth of approximately 640 m and the interval from surface to 290 m was also not recovered (Fig. 2). The partially cored coal exploration drillhole Glace Bay H-1A intersected Pictou Group redbeds from surface to approximately 411 m (Fig. 21). The top of the Sydney Mines Formation (base of the Pictou Group) is approximately 640 m above the Phalen Seam in drillhole H-1A. The Pictou Group has not been completely intersected in any of the drillholes.

Lithology

The Pictou Group comprises an interstratified sequence of red and grey mudrocks with subordinate red and grey sandstone. The section is dominantly red in colour with grey rocks forming a minor proportion. The stratigraphy and sedimentology of the Pictou Group, in parts of the Maritimes Basin outside of the Sydney Basin, has been described by van de Poll (1989) on Prince Edward Island.

Distribution and Thickness

The Pictou Group is inferred to have a wide distribution in the offshore of the Sydney Basin which is part of the regional Maritimes Basin in Atlantic Canada. Hacquebard (1983) indicated that the Upper Carboniferous coal bearing strata extend throughout the area between Cape Breton Island and Newfoundland then eastward to near longitude 54° (Bell and Howie, 1990). The Pictou Group redbeds, which overly the extensive coal measures of the Morien Group, are thus inferred to occupy much of this area. The Pictou Group has a maximum intersection thickness of approximately 640 m in the offshore drillholes. Thicker sections are inferred to be present in the offshore area where up to 1000 m of section are extrapolated above the Sydney Mines Formation. This is calculated using the structural contour map of the Harbour Seam by Hacquebard (1983) and the pick of the base of the Pictou Group projected from the Glace Bay H-1A drillhole.

Relations to Other Units

The basal contact of the Pictou Group is a conformable transition with underlying Sydney Mines Formation of the Morien Group (Fig. 8). The upper contact is a major unconformity with unconsolidated Quaternary sediments and to the east, Bell and Howie (1990) indicated the presence of Mesozoic rocks over the Sydney Basin (presumably including redbeds of the Pictou Group). The strata of the Pictou Group in the Sydney Basin are similar in age and general lithology to parts of the Pictou Group in the Cumberland Basin (e.g. Balfron Formation). The Balfron Formation is approximately the same age as the upper part of the Morien Group. It should be noted that prior to Boehner and Giles (1986), grey coal-bearing strata above the Lloyd Cove Seam were referred to as post-Morien by Hacquebard (1983). This section of coal-bearing strata (200-300 m) up to the base of the Pictou Group redbeds, is now included in the Sydney Mines Formation of the Morien Group.

Depositional Environment

The redbed strata of the Pictou Group are dominantly alluvial sequences representing deposition from long-lived regional drainage systems. These fluvial sediments, in the near shore Sydney Basin, were probably deposited as part of a distal (mud-rich) alluvial floodplain dominated by overbank flood basin mudrocks. The broad humid coal swamps in the flood basins of the underlying Sydney Mines Formation diminished and disappeared through the evolution to a drier climate characterized by more seasonal rainfall.

Age

The Late Westphalian to Early Stephanian (Cantabrian) age of the underlying Morien Group is well established by megaflora (Bell, 1938; Zodrow and Cleal, 1985) and by palynology (Barss and Hacquebard, 1967; Barss *et al.*, 1979; and Dolby, 1988, 1989). The predominantly redbed strata of the Pictou Group are not conducive to paleontological dating because of the absence of plant related remains. The stratigraphic position of these redbeds, conformably above Stephanian strata, indicates the Pictou Group is not older than Stephanian and that they probably are Stephanian to perhaps Early Permian at the youngest.

Summary of Sedimentary History

The sedimentary record (Figs. 3, 4, 5, 6 and 8) and facies relationships near the present day outcrop limits indicate the Sydney Basin and adjacent Glengarry Half Graben (Figs. 2 and 4) are closely related in the Early Carboniferous (Viséan to Namurian), but are only the erosional remnants of a formerly much larger depocentre. The similarity of Late Carboniferous stratigraphy and correlation of coal-bearing strata establishes a close relationship between the Late Carboniferous of the Sydney Basin and the central part of the Maritimes Basin in the Gulf of St. Lawrence (Hacquebard, 1986). Evidence supporting lateral facies changes characteristic of original, possibly faulted basin boundaries to the northwest or southeast (e.g. fault scarp alluvial fanglomerates or onlap unconformity), cannot be identified. These bounding faults have latest movement which postdates the Morien Group (Stephanian). However, movement in the Early Carboniferous may be inferred, based upon relationships in the vicinity of basement highs within the Basin. Coarse grained alluvial fanglomerates are evident in the areas of the internal basement horst blocks (e.g. Coxheath Hills and near Glen Morrison along the southern border), in both drill cores and in outcrop.

Based upon the stratigraphic record along the western border, the earliest sedimentation occurred during the Middle Tournaisian to Early Viséan with the development of a locally extensive pediment alluvial fan complex along the unconformable Basin edge (Grantmire Formation of the Horton Group). The alluvial fan environment waned and was localized adjacent to the internal basement blocks. Subsequently, and probably penecontemporaneously, the Basin underwent a rapid marine incursion (Windsor Group) with local onlap of marine carbonates onto exposed basement highs not covered by the alluvial deposits. The marine and alluvial fan environments occasionally overlapped, indicating close interaction throughout deposition of the marine carbonates, evaporites and siliciclastics comprising the major and minor cycles of the Windsor Group (Sydney River, Meadows Road and to a lesser extent the Woodbine Road formations). Alluvial fan development and siliciclastic sediment input probably occurred in conjunction with the uplift of the East Bay Hills and Boisdale Hills-Coxheath Hills source areas (Fig. 4). There is an apparent spatial association of the abundant conglomerates with the Point Edward area adjacent to the Coxheath Hills, suggesting an active link with synsedimentary uplift and faulting (Fig. 5). The presence of anomalous conglomerate sections has also been identified in several petroleum exploration wells drilled above basement high blocks in the Sydney Basin (North Sydney F-24 and Birch Grove No. 1).

During the Late Viséan and Early Namurian increased basin stability and evolution from arid to semiarid (seasonal) climatic conditions existed indicated by the deposition of a thick sequence of grey and red mudrocks, shales, limestones, and anhydrite-gypsum (Cape Dauphin and Point Edward formations of the Mabou Group). This sequence was deposited following exclusion of marine water from the Basin and the subsequent evolution to a lacustrine and mudflat environment.

The stratigraphic record of the onshore part of the Sydney Basin is broken at the top of the incomplete Mabou Group (Late Viséan-earliest Namurian). An extensive erosional landscape with deep karstification developed in the soluble rocks of the Windsor and Mabou groups. This period of nondeposition and erosion is recorded by the presence of rooted horizons immediately beneath lowest beds of the Morien Group, and by the removal of up to several hundred metres of Mabou Group strata in some parts of the Basin (Fig. 6b).

The rock record is not renewed until the latest Westphalian B with the appearance of an extensive sequence of medium- to coarse-grained sandstones and conglomerates at the base of the Morien Group. This sandy, braided river system deposited the South Bar Formation and heralded the establishment of a regionally (distally) derived fluvial depositional system that remained in the area throughout the remainder of the Late Carboniferous (Westphalian C to Stephanian). The erosion down through the Mabou Group into the Windsor Group does not preclude the presence of Namurian to Early Westphalian strata in the subsea extension of the Sydney Basin to the north and east. There is locally abundant recycled material including mudstone and carbonate clasts within the basal Morien Group. During the Westphalian C to D, the braided river system evolved into a high sinuosity river system with extensive development of peat mires in interchannel flood basins (Waddens Cove and Sydney Mines formations). The vertical sequence of the Morien Group is an expression of a large scale lateral relationship within a regional braidplain to floodplain environment. Extensive grey coal-bearing strata deposition diminished with time and ceased at the top of the Morien Group. The Pictou Group contains the redbeds which eventually dominated deposition in the Sydney Basin as well as the remainder of the Late Carboniferous to Early Permian in the Maritimes Basin in Atlantic Canada.

The fine grained nature of these fluvial deposits suggests a probable distant source outside of the Sydney Basin area with modest local input from transverse drainage in the lower parts of the Morien Group (e.g. off the adjacent basement terrains). The absence of significant alluvial fan deposits in the Morien Group indicates that the Sydney Basin was probably not an active fault controlled feature at this time. During the Late Westphalian B to Stephanian, the area was in a period of stability with regional subsidence and limited local tectonic activity. This stability is indicated by the proximal migration of high sinuosity fluvial sediments intermixed with lake and peat mire deposits (Sydney Mines Formation). Coal rank studies of coal seams in the Sydney Basin by Hacquebard (1984) indicated that substantial cover, in the order of more than 3000 m (inferred to have been subsequently removed by erosion), must have been present on top of the Sydney Mines Formation coals to produce their present day surface coal rank (postdeformational coalification). It is not difficult to speculate that the highland basement blocks, currently present, were completely buried beneath thick sections of the Morien Group and were uplifted post-Late Carboniferous to Early Permian. The buried basement blocks at Birch Grove and near the North Sydney wells on the offshore Boisdale Anticline, may be appropriate analogues of what the onshore highlands were like in the Late Westphalian.

Structure

The Sydney Basin and adjacent Glengarry Half Graben have a prominent structural trend oriented northeast-southwest (Figs. 2 and 4). The Sydney Basin is modified with the superposition of an east-west element in the Westphalian-Stephanian units of the Morien Group (Fig. 5). The northeasterly trend principally reflects the regional Appalachian structural fabric (Fig. 2) and is emphasized by the basement highland blocks, parallel faults, and the major basin bounding faults. The Basin extension to the southeast is truncated by the Bateston Fault (Mira River Fault) which converges with the Lennox Passage Fault to the southwest in the Glengarry Half Graben (Fig. 4). The Sydney Basin is a fault truncated synclinorium and is typical (larger version) of the numerous small structural elements which comprise Late Paleozoic structural basins in Atlantic Canada (Fig. 2). The map area is bounded to the northwest by the Mountain Fault, a northeasterly trending high angle fault (reverse?) with the basement rocks of the Kellys Mountain Block (Fig. 4). Several faulted basement elements form the indented irregular limits of the Basin to the southwest and include the Boisdale Hills, George River Fault, Coxheath Hills, Coxheath and East Bay faults, East Bay Hills and Big Pond Fault (Fig. 5 and Map 86-1, in pocket). These blocks which consist of Neoproterozoic (Hadrynian)-Devonian igneous and metasedimentary rocks form the basement for the Carboniferous basin-fill. Some of these basement blocks extend to the northeast as continuous highs or as separated highs beneath the covering sequence of the Morien Group (e.g. Boisdale Anticline offshore, Coxheath Hills to Victoria Junction (Forgeron, 1980) and the Birch Grove Anticline in the extreme northeastern part of the map area). Northwesterly trending faults are apparently not significant in the Sydney Basin. The southwestern boundary is a profound angular unconformity with the East Bay Block Neoproterozoic (Hadrynian)-Devonian basement.

The Upper Carboniferous strata within the Basin area are folded into open asymmetric synclines and anticlines with arcuate fold axes (Figs. 5 and 6). Bedding dips, typically, are less than 10° with steep dips in the flexures proximal to the underlying basement blocks. These folds appear to be genetically linked to the faulted and folded Lower Carboniferous rocks situated on the basement fault blocks. The basement and Lower Carboniferous rocks display an orthogonal outcrop pattern (similar to box folds) which is apparently expressed in a subdued manner in the unconformably overlying Morien Group folds. Dips of 5° are interpolated in the basal Windsor Group in the Glen Morrison area. Steeper dips on the basement unconformity reflect the greater erosional relief and perhaps are related to early block faulting.

Faults

The major and minor faults affecting the Carboniferous rocks in the Sydney Basin have one principal orientation, but variable movement histories. The faults are high angle, longitudinal faults which trend along the northeast-southwest. The exception is the Bateston Fault which forms the southern border of the Basin and has an east-west trend (Fig. 5). It is, however, an extension of the northeastly trending Lennox Passage Fault which extends through the adjoining Glengarry Half Graben (part of the Lennox Passage, Grand River and nearby Big Pond faults set). The northeasterly trending Mountain Fault forms the northwestern border of the Basin with the Kellys Mountain basement block. The Bateston and Mountain faults, therefore, are the major Basin bounding faults and have substantial apparent dip slip in the order of more than 1000 m with Westphalian strata faulted against basement. They are inferred to have substantial strike slip motion (e.g. Lennox Passage Fault, Boehner and Prime, 1993) and are accompanied by steep dips and locally overturning in the Basin strata.

The related parallel faults within the Basin are responsible for the pronounced northeast-southwest linearity and the linear offsets along the southwestern border of the Basin. The faults are as follows: Big Pond, East Bay, Coxheath, Grantmire Brook and George River (Map 86-1, in pocket). These faults are clearly related to the underlying basement rocks and most extend to the southwest, as part of the system which gives southern Cape Breton Island the block fragmented character of rectangular basement highlands and intervening basin lowlands. Exploration drilling for limestone resources in the Glen Morrison and Meadows Road areas has indicated the presence of a set of small northeastward trending faults which offset Windsor Group strata. The strong northeastward trend of the streams and related steps in the map unit boundaries are a reflection of these minor faults. The northeasterly extension of the minor faults, and of the larger, northeastward trending faults is often obscured by overlapping Westphalian strata of the Morien Group.

The expression of the faults at surface takes several forms (Map 86-1, in pocket). In some cases the lowermost Morien strata are offset by the faults (e.g. George River Fault). In most cases there is no clear offset, but a flexure in the Morien strata appears to be developed (Grantmire Brook and Coxheath faults). These flexures, over the projected flanks of the basement or Early Carboniferous blocks, die out to the northeast as stratigraphically higher units are encountered. Another manifestation of the northeastward trending fault set is a minor parallel set in the eastern part of the Basin. The Waddens Cove, Homeville and MacAskills Brook faults have minor apparent offsets in the middle part of the Morien Group. They are inferred to be genetically related to the northeastern fault set (Big Pond Fault and Coxheath Fault) and appear to converge with the east-west trending Bateston Fault on the southern border of the Sydney Basin.

The fault system in the Sydney Basin is dominated by elements of a complex structural system extending through southern Cape Breton Island from the Strait of Canso-Chedabucto Bay area which is situated immediately north of the Cobequid-Chedabucto Fault System. All the faults have components of dextral strike slip and dip slip offset as inferred qualitatively from map unit relationships. The faults are rarely seen in outcrop and details of the movement kinematics are rarely described. An exception is the Big Pond area, southwest of the Sydney Basin, where Bradley and Bradley (1986) presented evidence for dextral offset. Boehner and Prime (1993) found it difficult to estimate the apparent strike slip movement on the Lennox Passage and related faults. They concluded that the anomalous structural relationships with the allochthonous L'Ardoise Block indicated movements in the order of kilometres. Relative dip slip movement in the Glengarry Half Graben was inferred to be in the range of 1000 m. The amount of cumulative strike slip movement on the spatially linked Lennox Passage, Grand River and Bateston fault systems may be in the order of tens of kilometres. Although the faults are interpreted as nearly vertical normal faults they may locally or entirely have a high angle reverse geometry. Outcrop of overturned Morien Group strata at Bateston along the southern border of the Sydney Basin offers support for the reverse fault or local overthrust configuration.

Major transverse faults in the area do not obviously offset the Carboniferous basin-fill. The rectangular geometry of the outcrop of the basement blocks is suggestive of subsidiary northwesterly trending faulting, although no offset is clearly defined.

Minor thrust faults have been identified in the extreme northeastern part of the map area (Map 86-1, in pocket). Forgeron (1979) and Hacquebard (1983) have identified the arcuate trace of a small thrust fault with a northeastward trend in coal mine workings in the area of the Bridgeport Anticline and Glace Bay Syncline. Small faults with similar orientation are also identified in the area of the Cape Percé Anticline and Morien Syncline. A bedding parallel thrust is also identified in the northern limb of the Cape Percé Anticline. Hacquebard (1983) identified many of these small thrust faults and extensions into Morien Bay, as well as a northeastward trending thrust fault between the offshore coal exploration holes H-6 and H-8B (Map 86-1, in pocket).

Folds

The Sydney Basin is a fault truncated synclinorium comprising a series of open folds opening to the northeast into a wide synclinal offshore basin. With the exception of elongated domes over local buried basement blocks, the Sydney Basin has negligible structural features as expressed by the Westphalian and younger strata. The synformal basin is bounded by major faults to the northwest and south. Significant folds are associated with the faulted basement elements including Kellys Mountain, Boisdale Hills, Coxheath Hills, East Bay Hills and the Fourchu Block. The folds are clearly linked with extensions of these basement blocks as continuous highs or as separated highs beneath the covering sequence of the Morien Group. Examples of these basement features include the Boisdale high (offshore, beneath the Boisdale Anticline), the Coxheath Hills to Victoria Junction high (subsurface beneath Point Edward; Forgeron, 1980) and the Birch Grove high (subsurface only) in the extreme northeastern part of the map area. The principal folds mapped in Carboniferous cover rocks in the Basin are the New Campbellton Syncline, Boisdale Anticline, Point Aconi Anticline, Point Aconi Syncline, Florence Anticline, Florence Syncline, Pottle Lake Syncline, Sydney Harbour Syncline, New Waterford Anticline, Bridgeport Anticline, Glace Bay Syncline, Cape Percé Anticline, Morien Syncline, Mira Road Syncline and the Dutch Brook Syncline (Map 86-1, in pocket).

The Early Carboniferous rocks in the Sydney Basin have undergone folding around the squared ends of the elongated and faulted basement blocks. The box form is well developed in the Coxheath and Point Edward area as well as in the Boisdale and Saunders Cove areas. Elsewhere the folds (especially the synclines), involving the whole of the Carboniferous, are nearly coincident in spite of the unconformity between the Mabou and Morien groups. In the areas between the extensions of basement blocks most of the folds in the Morien Group are minor flexures. The Late Carboniferous strata, in the eastern part of the Basin, are folded into open asymmetric synclines and anticlines (e.g. Cape Percé Anticline and Morien Syncline). These converge to the west with a series of gentle flexures. The eastern part of the Basin is distinctive in that the arcuate fold axes reorient from the northeasterly trend to an easterly trend. Bedding dips, typically, are $<10°$ with steep dips of up to $45°$ in the steeper limbs of flexures proximal to the underlying basement blocks. These folds appear to be genetically linked to the faulted and folded Early Carboniferous rocks situated on the basement fault blocks.

The major fold features in the Morien Group are related to synsedimentary conformity to (inherited) major structural elements in the Early Carboniferous. Superimposed on these basic elements is post-Carboniferous folding (Permian? to Mesozoic?) related to movement on the major basin bounding faults and reactivation of Early Carboniferous structures. Small scale folding is rarely observed in outcrop, but locally complex and chaotic folding is probably present adjacent to the faults (e.g. Rear Balls Creek).

Economic Geology

Exploitation of coal deposits in the Sydney Basin has had a long history, closely related to the mining of limestone for steel production in Sydney. Celestite and lead mining projects in the Loch Lomond and Glengarry basins used processing and shipping facilities in Sydney in the mid-1970s to early 1980s. The area contains numerous mineral prospects and occurrences including base metals, salt, potash, celestite, limestone and gypsum in the Windsor Group (Map 86-1, in pocket). Base metal occurrences are also locally associated with the South Bar Formation of the Morien Group (Figs. 5 and 6). Substantial resources may potentially occur in the area.

Gypsum occurs locally in the subsurface, but has limited quarrying potential in the area (Adams, 1991). Limestone-dolostone, produced in the past for the steel making industry, is currently quarried at Kellys Cove and at Glen Morrison. Petroleum exploration drilling was undertaken in two prospect areas of the Basin. Murphy Oil Ltd. drilled Birch Grove No. 1 on the Cape Percé Anticline. This wildcat drillhole was dry and abandoned (Murphy Oil Ltd., 1968). Two offshore exploration wells were drilled by Murphy Oil Ltd. (Murphy *et al.* North Sydney P-05) and Shell Canada Ltd. (North Sydney F-24) on the Boisdale Anticline basement high block north of Sydney. Although minor natural gas was intersected, further drilling has not been undertaken at this prospect. Coal mining has operated for nearly 200 years on a series of major coal seams (Millward, 1985) and substantial resources have been identified in the submarine portions of the Sydney Basin (Hacquebard, 1983).

Detailed investigations of the mineral and energy occurrences and deposits in the area were not undertaken in this project and the reader is directed to available exploration reports, theses and publications. The mineral deposits and occurrences in the Sydney area are well documented by Forgeron (1977), Felderhof (1978) and Binney and Kirkham (1974).

Metallic Minerals

Exploration for base metals in the Sydney Basin has been focused in two settings: (1) the basal Windsor Group, mineral occurrences and prospects occur where the basal marine carbonates overlie Grantmire Formation redbeds or where they onlap basement, and (2) the basal sandstones of the South Bar Formation, where it rests disconformably on older Carboniferous (Mabou Group) strata (Figs. 5 and 6). The Windsor Group association is generally similar to that described by Kirkham (1978) and Binney and Kirkham (1974, 1975) in most other Carboniferous basins in Nova Scotia.

Principal base metal occurrences include Cu at Rear Balls Creek, Frenchvale and East Bay, as well as Pb and Zn sulphide mineralization in the Windsor Group near Bateston on the eastern side of the Sydney Basin. The copper minerals, principally malachite, chalcopyrite, azurite and chalcocite, as well as galena, sphalerite and equivalent oxides, are frequently associated with oxidation-reduction boundaries (e.g. redbed-marine carbonate contacts) in trace to minor amounts. This type of occurrence is also very abundant in the Enon-Loch Lomond area (Boehner and Prime, 1993).

The mineralization associations near the base of the Windsor Group in the Sydney and Loch Lomond basins were described by Binney (1975), Binney and Kirkham (1974), Kirkham (1978), Forgeron (1977) and Smith and Collins (1984). The minerals are concentrated in the green reduced zone in siliciclastic rocks immediately beneath the organic rich marine carbonates. In the Sydney Basin they are especially common near the base of the Windsor Group (MacBeth Brook Formation). These are identical to the basal Macumber Formation related occurrences. They occur as disseminations, minor aggregations and as clast coatings in conglomerate and sandstone and also within the lowermost part of the carbonates.

Binney (1975) concluded that the metals were leached from redbeds of the basal conglomerate unit and migrated in metal-bearing groundwater in aquifers controlled by the paleotopography at the unconformity. The metals were deposited in the vicinity of organic rich, reducing strata, especially the basal Windsor carbonate. This is essentially the model of Kirkham (1978) applied to the basal Macumber Formation-Horton Group contact mineralization and has been described elsewhere in Nova Scotia by Binney and Kirkham (1974), Binney (1975) and Kirkham (1985). The mineralization has been interpreted as representing early diagenetic sedimentary processes localized at an oxidation reduction interface between marine rocks deposited upon continental clastics. Trace amounts of galena occur with the celestite-barite zones in the Sydney Basin.

Minor galena and sphalerite mineralization and trace barite are associated with calcite fractures in limestone outcropping in a section of the Upper Windsor at Neal Cove near Bateston (Table 1; Map 86-1, in pocket). This area is part of the Catalone outlier of Uist Formation which is lithologically and geologically part of the Glengarry Half Graben and Loch Lomond Basin setting onlapping the Fourchu Block (Boehner and Prime, 1993). This type of mineralization is ubiquitous in the Windsor Group onlapping the Fourchu Block.

Table 1. Analysis of Carboniferous rocks from the Bateston-Neal Cove section, southern side of Mira Bay, Cape Breton County. The B series are samples in the lower part of the South Bar Formation with abundant pyrite. The BNC series are through the underlying Big Glen (E_1) Member section. BNC-1 is a sample of sulphide mineralized dolostone. The PB-83 sample is from the Novex barite openpit in the Loch Lomond Basin.

Locality	Sample	Ag ppm	Cu ppm	Zn ppm	Pb ppm	Mn ppm	Cd ppm
Bateston	RCB1983 B-1	0.2	8	337	35	3 000	
Bateston	RCB1983 B-2	0.7	16	4 040	13 200	2 800	
Bateston	RCB1983 B-3		4	110	70	2 340	
Bateston	RCB1983 B-4	0.4	4	700	70	2 750	
Bateston	RCB1983 B-5	0.1	5	61	3	5 000	
Bateston	RCB1983 B-6		12	300	30	6 500	
Bateston	RCB1983 B-7	0.1	6	80	28	1 450	
Bateston	RCB1983 B-8		5	61	2	1 330	
Pine Brook	RCB1983 PB-83	0.7	136	1 690	200	1 000	
Bateston	RCB1983 BNC-1	6.3	33	30 000	28 600	9 300	
Bateston	RCB1983 BNC-2	1.0	310	120	36	8 700	
Bateston	RCB1983 BNC-3	1.2	89	1 800	30	8 500	66
Bateston	RCB1983 BNC-4	1.0	5	173	46	6 500	
Bateston	RCB1983 BNC-5	1.2	6	3 500	210	7 000	31
Bateston	RCB1983 BNC-6	1.2	6	920	126	7 700	4
Bateston	RCB1983 BNC-7	1.2	3	370	50	4 200	10
Bateston	RCB1983 BNC-8	1.1	12	325	12	7 800	9

The carbonate buildups at the base of the Windsor Group have been major exploration targets as potential hosts for base metal deposits of the Gays River type. Although the buildups (Figs. 8, 11 and 12) are locally well developed near Glen Morrison and Scotch Lake they are not extensively dolomitized or mineralized with only trace to minor disseminations.

Significant Pb and Zn mineralization occur at the base of the grey, carbonaceous sandstones of the South Bar Formation at Leitches Creek. The Leitches Creek Prospect is in a setting generally similar to the Yava (Silver Mine) Deposit and the Terra Nova Prospect in the Glengarry Half Graben. The mineralization is present in exploration drilling (Cerro Mining Company Canada Limited, 1972; New Jersey Zinc Exploration Company (Canada) Ltd., 1967) at the apex of the Pottle Lake Syncline and is similar to that described at the Silver Mine (Yava) lead deposit by Sangster and Vaillancourt (1990a), Bonham *et al.* (1982), Scott (1978), Patterson (1988), Vaillancourt and Sangster (1984, 1986) and Vaillancourt (1985).

The work on the geology of these sandstone hosted Pb deposits identifies them as similar to the Laissval type, but hosted by continental rocks. Sangster and Vaillancourt (1990a) concluded the mineralization at the Yava Deposit in the Glengarry Half Graben was produced during a very early diagenetic event and is hosted in porous, grey, altered sandstone with highest grades localized in fluvial paleochannels rich in coaly debris above an eroded disconformity paleo-landscape. The sulphide mineralization infills porosity and the metals were derived from local basement rocks through the destruction of feldspars etc. Groundwater subsequently transported the metals downdip into the sandstone. The source of sulphur at Yava, according to Sangster and Vaillancourt (1990a), is compatible with derivation from the underlying Windsor Group or Mabou Group evaporites. This characterization and model is generally applicable to the mineralization at Leitches Creek and differs mainly in that the host sandstones do not onlap crystalline basement.

Nonmetallic Minerals

Celestite and Barite

Stratiform and stratabound celestite deposits are well documented in the Windsor Group in the Sydney Basin by Forgeron (1977), Felderhof (1978) and Boehner (1985a, b). Felderhof (1978, after Forgeron, 1977) described celestite occurrences at Sydney River and Frenchvale on the borders of the Coxheath Hills basement block (Map 86-1, in pocket). The celestite is generally similar to that in the Loch Lomond Basin. Barite occurs in the Sydney Basin only as a trace association in veins in the Windsor Group (e.g. Neal Cove near Bateston) and occasionally in small faults in the Morien Group.

Work in the Sydney Basin by Boehner (1985a, b) has resulted in the discovery of two additional occurrences of celestite (Map 86-1, in pocket) near Woodbine Road and Battlements Brook near Blacketts Lake. The Woodbine Road occurrence was intersected in drillhole NSDME Woodbine Road 84-1 (Boehner, 1993a) at a depth of 355.6-356.3 m and the 70 cm thick bed contained 27% celestite. The mineralization occurred at the top of the B_2 Member in the Meadows Road Formation and is very similar to the celestite in the Loch Lomond Basin to the south.

The occurrence in Battlements Brook lies on strike with celestite intersected by Kaiser Celestite at Sydney River (Forgeron, 1971). The Sydney River occurrence is also in the Meadows Road Formation, but is higher in the section and occurs approximately 35 m beneath the Crawley Member (the base of the overlying Woodbine Road Formation). The celestite bed is approximately 50 cm thick and contains up to 80% celestite. The celestite occurrence at Frenchvale differs in that it is enriched in barium and occurs as a replacement in gritty sandstone. It is hosted in the central part of the Sydney River Formation which comprises interstratified siliciclastic and evaporite strata.

The celestite in the Sydney Basin typically occurs as contact oriented stratabound mantoes, generally at the contact between marine carbonate members and overlying evaporites (gypsum after anhydrite), or between carbonates and redbeds. Celestite mineralization in vein systems is not abundant in the Sydney Basin, noted only with minor thin veins of calcite in the vicinity of faults.

Limestone and Dolostone

The limestone and dolomite deposits and occurrences in the Sydney Basin were described by Shea and Murray (1969). The most important deposits, currently in production, are located within the Windsor Group (e.g. Gays River Formation at Glen Morrison) and the crystalline basement of the George River Group at Kellys Cove near New Campbellton.

Gypsum

Gypsum outcrop areas are rare in the Sydney Basin and are hidden by surficial deposits of varying thickness. Karst topography related to the dissolution and weathering of the soluble gypsum occurs along the southern border of the Basin near East Bay and Glen Morrison (Adams, 1991). Gypsum also occurs in drilling near Point Edward, Frenchvale and Scotch Lake.

Salt and Potash

The first exploration for salt deposits was undertaken with exploration drilling by Morton Salt in the early 1960s (Bell, 1961b). This drilling near Meadows Road and East Bay intersected a thin impure salt section (Fig. 10) and further work on salt did not occur until 1984 when a major salt deposit with a significant potash occurrence was discovered in the Boularderie Syncline near Kempt Head (Figs. 10 and 14). The drillhole NSDME

Kempt Head 84-1 (Boehner, 1993c) intersected 337.1 m of salt section with a 5 m thick potash zone of carnallite and sylvite (6% K_2O). This discovery was the result of stratigraphic test drilling by the Nova Scotia Department Mines and Energy. Although the intersection thickness of the salt bearing section (Kempt Head Formation) is 337.1 m, the salt is low grade (<85% NaCl) except in the interval beneath the potash zone (approximately 750-833 m) where it is estimated to be 90-95% NaCl and contains scattered fragments and interbeds of anhydrite. Salt water (calcium and sodium chloride brine) is known to occur in the subsurface around the perimeter of the Coxheath Hills basement block near Rudderham Road and stratified salt probably occurs in the deeper subsurface of the Sydney Basin (e.g. Pottle Lake Syncline). The extent of salt and potential potash resources in the Sydney Basin is virtually unknown at this time and would require additional drilling to assess.

Coal

The Morien Group contains numerous economically significant coal seams. Key coal seams of economic significance include, in ascending order: Tracy, Gardiner, Emery, Phalen, Backpit, Bouthillier, Harbour, Hub, Lloyd Cove, Point Aconi and Murphy seams. The coals mined are all high volatile A bituminous and are used for metallurgical and thermal purposes (primarily electrical energy generation). Hundreds of shallow and deep coal exploration drillholes have been drilled in the Basin and many were located in the Sydney Mines Formation because of the abundance of economically significant coal seams (Hughes *et al.*, 1989). The Sydney Mines Formation is one of the most economically significant rock units in the Carboniferous basin-fill of the Maritimes Basin of Atlantic Canada. It contains the bulk of the mineable coal resources in the region (1.6 billion tonnes demonstrated resource (Hacquebard, 1979, 1983)) and has supported mining operations for more than 200 years (Millward, 1985). Details on the geology and technical characteristics of the coal resources in the Sydney Basin are not covered in this report and readers are directed to the extensive published and unpublished literature available. General references include Hacquebard (1979, 1983, and references contained therein) as well as Forgeron *et al.* (1986).

Summary and Conclusions

The Sydney Basin is a large structural basin at the eastern extremity of the onshore Maritimes Basin and contains strata that range in age from Early to Late Carboniferous (Tournaisian to Stephanian) (Fig. 22). The sedimentary succession in the onshore to nearshore part of the Basin has an estimated stratigraphic thickness of nearly 4000 m. The strata within the area rest with angular unconformity and progressively onlap crystalline basement comprising Neoproterozoic (Hadrynian) to Devonian rocks (igneous-metasedimentary).

The stratigraphic succession within the Basin is complex and is dominated by coarse- and fine-grained continental siliciclastics, with marine deposition recorded only by Windsor Group evaporite and carbonate rocks near the base of the onlapping succession.

The initial basin-fill in the Tournaisian to Early Viséan comprises an uncertain thickness of continental siliciclastics up to 1000 m or more. These rocks, comprising red and green conglomerate and subordinate mudstone and sandstone, are assigned to the Grantmire Formation which is here revised and included within the Horton Group (Fig. 9). These strata outcrop only in the south-central part of the Basin, but are inferred to occur extensively in the subsurface. The conglomeratic units of the Grantmire Formation record the early stages of development of a continental basin with piedmont alluvial and fluvial deposition. Similar conglomerates are also present as marginal facies of the lower and locally parts of the Upper Windsor Group (e.g. Point Edward area).

The continental alluvial fan-alluvial plain sedimentation at the base of the Basin was suddenly inundated and penetrated by marine invasion of the Windsor seas in the Early Viséan. The basal unit of the Windsor Group is a marine carbonate which occurs in several distinctive facies. The regionally extensive laminite facies is the Macumber Formation which is present only in the western part of the Basin. The correlative buildup facies is called the Gays River Formation and it is well developed at several localities on elevated topographic highs formed by basement rocks peripheral to the depositional basin. This type of carbonate facies distribution was previously described by Giles *et al.* (1979) and Boehner *et al.* (1989) and Boehner (1987, 1988). The

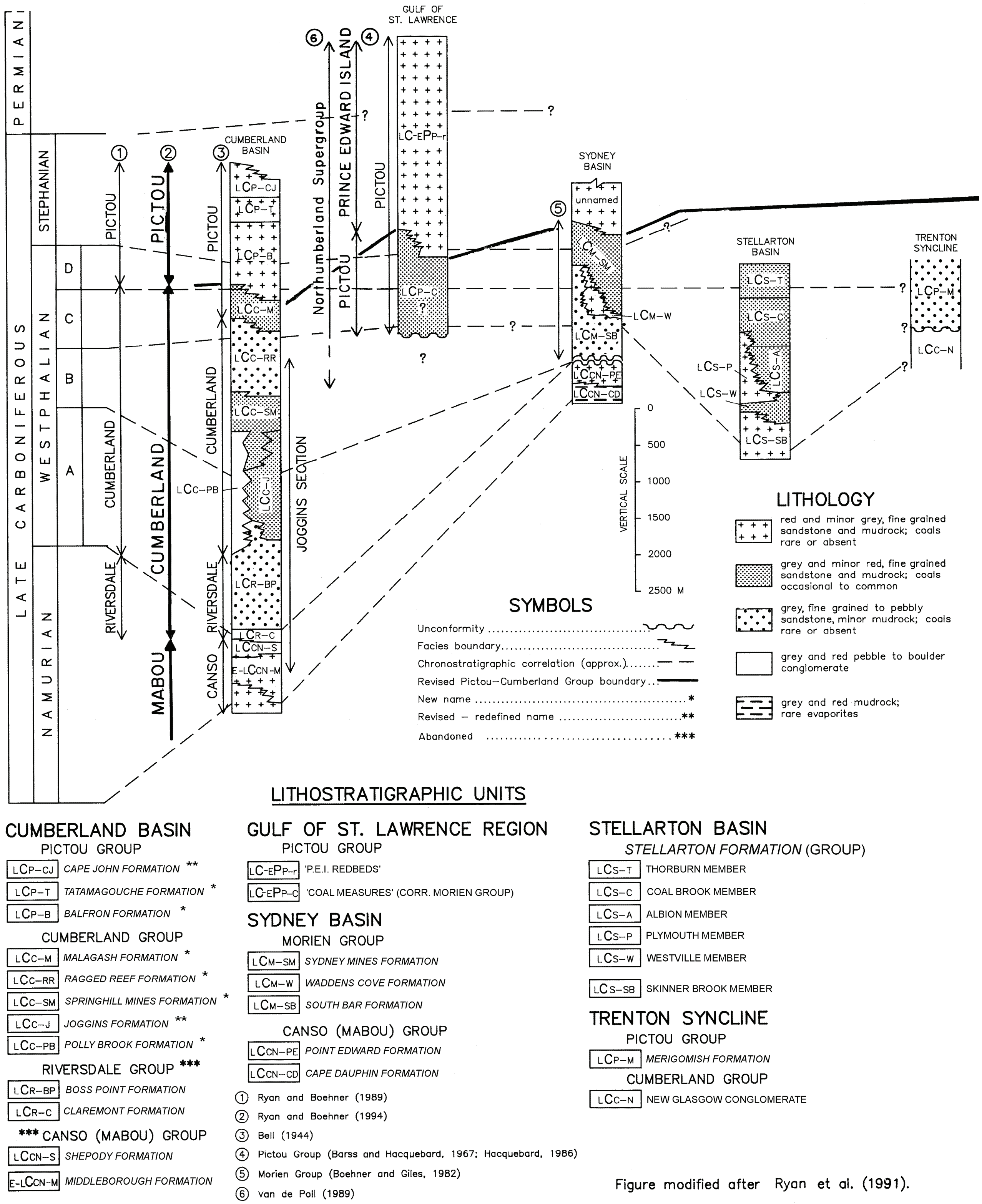


Figure 22. Summary of Pennsylvanian (Late Carboniferous) lithostratigraphy and correlation, northern Nova Scotia, Gulf of St. Lawrence and the Sydney Basin.

predominant basal carbonate facies outcropping in the Sydney Basin is a local, distinctive variant of the Macumber and Gays River formations and is referred to as the MacBeth Brook Formation. The Sydney Basin contains some atypical siliciclastics interbedded with the thick evaporites in Major Cycle 1. This unit is named the Sydney River Formation.

The typical basal evaporites and locally developed siliciclastics comprising the Sydney River Formation are overlain by strata typical of Major Cycle 2 which are named the Meadows Road Formation. Regionally, Major Cycle 2 comprises a package of interstratified gypsum, anhydrite (locally salt and potash), limestone, dolostone and red siltstone. This represents repeated marine transgressions and regressions individually recorded by fossiliferous marine carbonate overlain by nodular sulphate and continental clastics. The Meadows Road Formation is typical in that it comprises interstratified marine carbonates, evaporites (gypsum and anhydrite) and fine- to coarse-grained redbeds.

The Meadows Road Formation is very similar to the correlative Enon and Loch Lomond formations in the adjoining Loch Lomond Basin. The major difference occurs in that these strata onlap basement rocks in the Loch Lomond Basin. This indicates the marine invasions occurred over a terrain with substantial local paleotopographic relief and was accompanied by significant input of marginal basin siliciclastics. The carbonate rocks of the Meadows Road Formation are shallow water algal, oncolitic, oolitic and argillaceous micritic packstone, wackestone and mudstone. In the marginal siliciclastic dominated sections (typically conglomeratic, e.g. Point Edward area) the carbonates are extensively recrystallized and locally pinch out. The nodular sulphate and fine redbeds represent regressions with the development of sabkha type, hypersaline mudflats and hypersaline (subaqueous) lagoons.

It is particularly interesting to note the close relationship between fine- and coarse-grained alluvial redbed sediments (marginal conglomerates and breccias to basinal mudstone-sandstone), and the evaporites. In the Glen Morrison, Coxheath-Point Edward and Frenchvale areas peripheral to the basement blocks on the edge of the Basin, the Meadows Road Formation undergoes facies change from evaporite dominated in basinward sections to alluvial fanglomerate dominated near the basin margins. The evaporitic sections of the Meadows Road Formation and the underlying Sydney River Formation, and are affected by solution collapse in the near surface environment. This is especially well developed where the Morien Group rests with erosional unconformity above these units.

The conglomerate sections within the Meadows Road and Sydney River formations represent alluvial fan deposition along the active elevated margins of the Basin. Regressive periods between the marine transgressions are recorded by prograding alluvial fan conglomerate and sandstone-mudstone which locally overwhelmed marine carbonate deposition. Similarly, evaporites are absent, indicating that the area of deposition was elevated above the restricted hydrology required for subaqueous or sabkha-diagenetic evaporite deposition.

The Meadows Road Formation is overlain by a similar package of interstratified red siltstone, marine carbonate and minor evaporite comprising the Woodbine Road Formation. With the exception of an overall decreased evaporite and coarse grained redbed content, the depositional environment for the carbonates, sulphate evaporites and redbeds is similar to that described for the underlying Meadows Road Formation. The Woodbine Road Formation correlates with the Uist Formation and records the last marine carbonate deposition in the area.

The Windsor Group is succeeded conformably by grey (minor red) shale, minor sulphate evaporite and thin algal carbonate of the Cape Dauphin Formation of the Mabou Group. These strata represent the terminal phase of residual evaporitic conditions of the underlying Windsor Group and the return of the Basin to continental conditions. The Cape Dauphin Formation was deposited in a large lake or system of saline lakes inferred to have been developed following the retreat of Windsor seas. It is overlain by, and is in part a lateral facies of, redbed dominated fluvial mudflat (pedogenic) deposits of the Point Edward Formation at the top of the Mabou Group in the Sydney Basin.

Paleotopography and tectonism had an overall diminishing influence on sedimentation of the Early Carboniferous comprising the Horton, Windsor and Mabou groups (Gibling *et al.*, 1987). The importance and influence of topography decreased with time as erosion and successive deposition of onlapping strata buried the basement relief within and around the perimeter of the Sydney Basin. The sequence to the top of the Mabou Group displays a general pattern of fining upward and basinward with coarse alluvial facies developed in proximal areas at all stratigraphic levels up to near the top of the Windsor Group.

The mudrocks of the Mabou Group are overlain unconformably by the grey to grey-green sandstones of the South Bar Formation of the Morien Group. These braided fluvial strata record a fundamental change in the sedimentation pattern in the Sydney Basin and the regional Maritimes Basin with the return to sustained fluvial and alluvial deposition typical of the Late Carboniferous. The major unconformable contact with the underlying Early Carboniferous basin fill is evidenced by significant erosion and reworking/recycling. The unconformable contact of the South Bar Formation with the lower part of the Woodbine Road Formation at Kempt Head (drillhole NSDME Kempt Head 84-1) indicates the locally substantial erosion of Early Carboniferous strata at the unconformity beneath the Morien Group.

The unconformity is characterized by the presence of well developed karst dissolution and collapse features in the evaporite and carbonate sections of the Windsor Group. In addition, pedogenic processes operated on the upper units of the Mabou Group. The geological timing of the formation of the karst breccias and weathering features, beyond the limits of the Namurian to Early Westphalian age of the hiatus, is not clearly defined. Possible karst rejuvenation events (post-Carboniferous to Recent) would make the determination of age relationships very difficult. Local erosion and karstification of the outcrop areas of evaporites around the perimeter of the Carboniferous Basins is pervasive and is a major influence on present day landforms. The large and extremely deep water in St. Andrews Channel adjacent to Boularderie Island was interpreted by Boehner (1985c) as a solution trench feature related to the dissolution of salt and anhydrite in the Windsor Group.

The Late Westphalian to Early Stephanian Morien Group comprises in ascending order the South Bar, Waddens Cove, and Sydney Mines formations. The lowermost South Bar Formation is the grey sandstone dominated section with minor mudrocks and rare significant coal seams. The Formation includes the strata of Bell's (1938) *Lonchopteris* zone, and lower *Linopteris obliqua* zone in the western part of the Basin. The Waddens Cove Formation has few significant coal seams and is a medial sequence characterized by the occurrence of redbeds, incised channel sandstones, duricrusts and sedimentology intermediate to the overlying coal measures of the Sydney Mines Formation. The mudrock dominated Sydney Mines Formation contains the bulk of the economic coal seams in the Basin.

The Formation contacts are typically interstratified and gradational both vertically, and in a lateral facies sense giving a somewhat complicated stratigraphic relationship across the Basin. The Waddens Cove Formation appears to be confined to the eastern side of the Sydney Basin with limited extent to the west and north. Similarly, in the western part of the Basin, where the Waddens Cove Formation is absent, the contact between the South Bar and Sydney Mines formations occurs at a higher stratigraphic level. The sandstone dominated sequences characteristic of the South Bar Formation occur progressively higher stratigraphically towards the western parts of the Basin.

The redbeds above the Morien Group were informally referred to as undivided Permo-Carboniferous redbeds by Boehner and Giles (1986). Following the revisions to Upper Carboniferous strata by Ryan *et al.* (1991) they are now included as an undivided unit of the revised Pictou Group. The Pictou Group was revised by Ryan *et al.* (1991) to include the predominantly redbed section above regionally extensive grey coal bearing strata in the Maritimes Basin of Atlantic Canada. Because of the lack of exposure and mineral or coal resources, the geology and stratigraphy of these strata have not been methodically described and they were not recognized until the early 1970s petroleum exploration drilling.

The dominant structural features of the map area are the prominent northeastward trending faults including, Bateston (Lennox Passage), Big Pond, Coxheath, George River and Mountain faults. These are part of an extensive northeastward trending fault system extending from the Strait of Canso area through central and southeastern Cape Breton Island to the Sydney Basin offshore. The basin fill has the configuration of a synclinorium with northeastward to eastward trending synclines truncated on the northwest by the Mountain Fault and on the southeast by the Bateston (Lennox Passage) Fault. Substantial strike slip and apparent dip slip movement is indicated on these faults with a movement history which, at the latest, postdates the Westphalian. There are numerous minor and major folds in the Basin including the Morien Syncline, Cape Percé Anticline, Glace Bay Syncline, Bridgeport Anticline, Sydney Harbour Syncline and Boisdale Anticline. These folds are defined both by Early Carboniferous and Late Carboniferous strata. The folds are generally open and asymmetric with gentle and steep to locally overturned dips near the faults.

The mineral occurrences and deposits in the map area are located principally in the lower part of the Windsor Group and locally in the South Bar Formation of the Morien Group. Base metals, including copper with minor lead and zinc are found in contact oriented occurrences at or near the base of the Windsor Group carbonate members. These metals are present in the carbonates and related siliciclastics as chalcopyrite, malachite, galena, sphalerite and hydrous zinc oxides. Trace to minor celestite and rare barite mineralization occurs in the Lower Windsor especially in the vicinity of the Coxheath Hills and near Woodbine Road. This mineralization is very similar to the Loch Lomond Celestite deposits. Economically significant galena and sphalerite occurs at the base of the grey sandstones of the South Bar Formation in the apex of the Pottle Lake Syncline near Leitches Creek. This prospect is of the Yava Deposit type and is generally similar to the Terra Nova Prospect in the Glengarry Half Graben where sphalerite is a significant or dominant component.

Limestone, gypsum, anhydrite, salt and potash are major rock types of the Gays River, Sydney River, Meadows Road and Hartshorn formations of the Windsor Group and are present as potential resources in the Sydney Basin (e.g. Glen Morrison, Meadows Road and Kempt Head).

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