BEDROCK GEOLOGY OF THE CAPE ST. MARY'S PENINSULA, SOUTHWEST AVALON PENINSULA, NEWFOUNDLAND

(INCLUDES PARTS OF NTS MAP SHEETS 1M/1, 1N/4, 1L/16 and 1K/13)

Terence Patrick Fletcher

Report 06-02

St. John's, Newfoundland
2006

Department of Natural Resources
Geological Survey

COVER

The Placentia Bay cliff section on the northern side of Hurricane Brook, south of St. Bride's, shows the prominent pale limestones of the Smith Point Formation intervening between the mudstones of the Cuslett Member of the lower Bonavista Formation and those of the overlying Redland Cove Member of the Brigus Formation. The top layers of this marker limestone on the southwestern limb of the St. Bride's Syncline contain the earliest trilobites found in this map area.

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MAP

Map 2006-02. Bedrock geology of the Cape St. Mary's Peninsula, southwest Avalon Peninsula, Newfoundland (includes parts of NTS map sheets 1M/1, 1N/4, 1L/16 and 1K/13), Open File NFLD/2929. This map accompanies Report 06-02, but is sold separately, is available and can be purchased from the Geoscience Publications and Information Section, St. John's, NL.

PREFACE

This publication embodies meticulous research by Dr. Terence Fletcher on the Ediacaran to Cambrian stratigraphy and paleontology of the Cape Shore region of the Avalon Peninsula, southeastern Newfoundland. It includes a detailed report on many aspects of his work dating back to 1959, supplemented with numerous photographs and diagrams, and - importantly - a full-coloured, 1:50 000-scale geological map of the succession. The comprehensive analysis and description of one of the world's most complete sections of the Early-Mid Cambrian were done as a part of the author's 1972 Ph.D. dissertation at Cambridge University, England. Dr. Fletcher went on to a long and productive career with the British Geological Survey, but maintained his research interests in Newfoundland over the years on his own time. With a unique in-depth knowledge of this world-class section, the author has since made many significant contributions to Cambrian biostratigraphy and trilobite paleontology worldwide, and has published his results extensively.

Although the Geological Survey of Newfoundland and Labrador has not been involved in the funding or supervision of this research on the Avalon Peninsula, we are pleased to have facilitated its publication. Now the body of work, including the map, is available to all investigators, including our clients, who seek to understand the evolution of the margin of the Gondwana supercontinent in the Late Proterozoic and early Paleozoic.

R. Frank Blackwood
Director

DEDICATION

This report is dedicated to all the families of Branch, Point Lance and St. Bride's whose kindnesses have engendered in me such a strong affection for the Cape Shore.

ABSTRACT

This report describes the bedrock geology of the Cape St. Mary's Peninsula south of Gooseberry Cove on the eastern coast of Placentia Bay and Cape Dog on the western coast of St. Mary's Bay. The survey of this region was undertaken as part of a study of the Early Cambrian biostratigraphy and this account largely reflects a focus on the fossiliferous sequence.

The openly folded rocks form the southerly extensions of Ediacaran-Late Cambrian outcrops described elsewhere on the Avalon Peninsula. The oldest Musgravetown Group sequence differs little from its type development in the northern map areas and is well exposed in largely inaccessible cliff sections. It comprises the Bull Arm, Maturin Ponds, Heart's Content and Crown Hill formations and these have been partly subdivided into locally recognized members. In contrast, the Cambrian Adeyton-Harcourt group succession is described in much more bed-by-bed detail, because it not only represents the most fossiliferous Newfoundland sequence, but the sections are of international importance, being especially notable for the succession of trilobites pertinent to the global correlation of different faunal realms involving olenellid, redlichiid and paradoxidid sequences. In addition to the sedimentary rocks, significant Cambrian volcaniclastic and pillow lavas occur as two members (flows) of different age. Prominent layered, radiometrically dated Silurian gabbroic sills, indicative of a rifting phase, form major topographical features characterizing the main synclinorium in the southeastern part of the map area and their remnant palaeomagnetism has provided important data on the closing of the Iapetus Ocean and the contemporary palaeolatitude. Following the main phase of Siluro-Devonian folding and cleavage, conspicuous diabasic dyke swarms have cut through the peninsula, some of which may be of Triassic age and reflect the opening of the Atlantic Basin.

As indicated in a previous survey of the superficial deposits, the rocks away from the coast are generally masked by a complex Pleistocene and Recent cover and are intermittently exposed in the lower reaches of rivers and streams and in the upland areas.

INTRODUCTION

LOCATION AND ACCESS

Cape St. Mary's Peninsula is the south-projecting peninsula between Placentia Bay and St. Mary's Bay forming the southwestern part of the Avalon Peninsula of southeastern Newfoundland. Geologically, it lies within the northeastern part of the tectonostratigraphical Avalon Zone of the Appalachian Orogen (Figure 1). The area described in this report lies south of Gooseberry Cove in the west and Cape Dog in the east and is covered by four 1:50 000 National Topographic Series maps, Ship Cove (1M/1-southeastern part), Placentia (1/N4-southern part), St. Brides's (1/L16) and St. Mary's (1K/13) (Figure 2). It is about 665 km^2 in area and located south of latitude 47°06'N between longitudes 53°42' and 54°15' W.

Access into this region is via two paved roads. Highway 100, on the western side of the peninsula, extends south from the Argentia Junction on Trans-Canada Highway to St. Bride's, Cape St. Mary's, Point Lance and Branch; on the eastern side, it can be approached along Highway 90 from the Salmonier Line Junction on the Trans-Canada Highway on to Highway 91 from St. Catherine's to Colinet and down Highway 92 southwestward through North Harbour to Branch (Figure 2).

The rivers in the area are short and fast and not suitable for boat or canoe. Access to the interior is mainly on foot, but four-wheel, all-terrain vehicles are able to take advantage of sled-paths formerly used for hauling wood that are not yet overgrown.

PREVIOUS WORK

It is remarkable that the Cape St. Mary's Peninsula has remained relatively remote from the interests of Newfoundland geologists. Its geology has an important bearing on Avalon Zone history, but relevant biostratigraphical, geochronological and palaeomagnetic information available in this area has until recently lain untapped. This is especially true when one considers the Cambrian System, because Branch, on St. Mary's Bay, yielded the first diagnostic Cambrian fossil in the Province, namely *Paradoxides (Eccaparadoxides) bennetti* (Salter, 1859). However, until the 1980s, the peninsula was served by one gravel road that was largely untravelled by all but local inhabitants and mariners.

The historic 1839-43 Newfoundland surveys of J.B. Jukes (1839, 1840, 1842, 1843) "skirted" this peninsula and no mention of it was made on his sea journey to St. Pierre from St. John's. When he later referred to the region, following a traverse just north of this map area from North Harbour to Point Verde and Placentia Harbour (Figure 2), he considered it to be "composed of the lower slate formation" (Jukes, 1843, p. 72), then regarded as Precambrian.

The scant literature prior to the establishment of the Geological Survey of Newfoundland refers to some field activity that most likely was mineral prospecting. The Cambrian trilobite described by Salter was named after its collector; another trilobite from Branch was later described by Billings (1865) as *Bathyurus gregarius* from beds of "primordial slates". Other related fieldwork is indicated in separate publications of the Boston Society of Natural History, where Jackson (1859) and Rogers (1859) exhibited trilobites from St. Mary's Bay.

Alexander Murray, the first Director of the Newfoundland Geological Survey, visited the southwest Avalon in 1868 (*in* Murray and Howley, 1881a). His initial concern was topographical mapping and he acknowledged Mr. John English of Branch for a sketch of the topography of the peninsula. Murray's report for 1868 describes a journey down the Cape Shore road into the ground not examined by Jukes, where he noted the basal Cambrian unconformity at Gooseberry Cove and the numerous dykes along the coast to Distress Cove at St. Bride's. The "resemblance of colour" made it difficult for him to differentiate Precambrian and Cambrian rocks and his subdivision was based on the "absence of lime" in the "lower formation". His recording of a fault in Deadman's Cove downthrowing Cambrian beds to the south is perhaps a misprint, because only downthrows to the north in that region have been recognized more recently. He recorded a barite vein at Cross Point (i.e., in Deadman's Cove) before crossing "Branch Country", where he observed a conglomerate [Bellevue Beach Member] and an intrusion [Silurian sill in the Gull Cove Formation] before descending to the Branch River to collect specimens at the type locality of *P. (E.) bennetti* in the Wester Cove of Branch Cove. As a result of this traverse, he postulated the presence of an anticline exposing members of the "lower formation" striking north to Trinity Bay, more or less coinciding with the "principle range of hills" striking "from Cape Dog in St. Mary's Bay to the neighbourhood of Chapel Arm in Trinity Bay" noted by Jukes (1843, p. 37). His miscorrelation of the sill in the Cambrian Gull Cove Formation with volcanics in the Precambrian Bull Arm Formation he had seen at Sawyers Hill southeast of Placentia, led to his suggestion that a "great intrusive mass" stretched "from near Cape St. Mary's in a moderately straight line for Chapel Arm in Trinity Bay" forming "the hills and highest summits of the

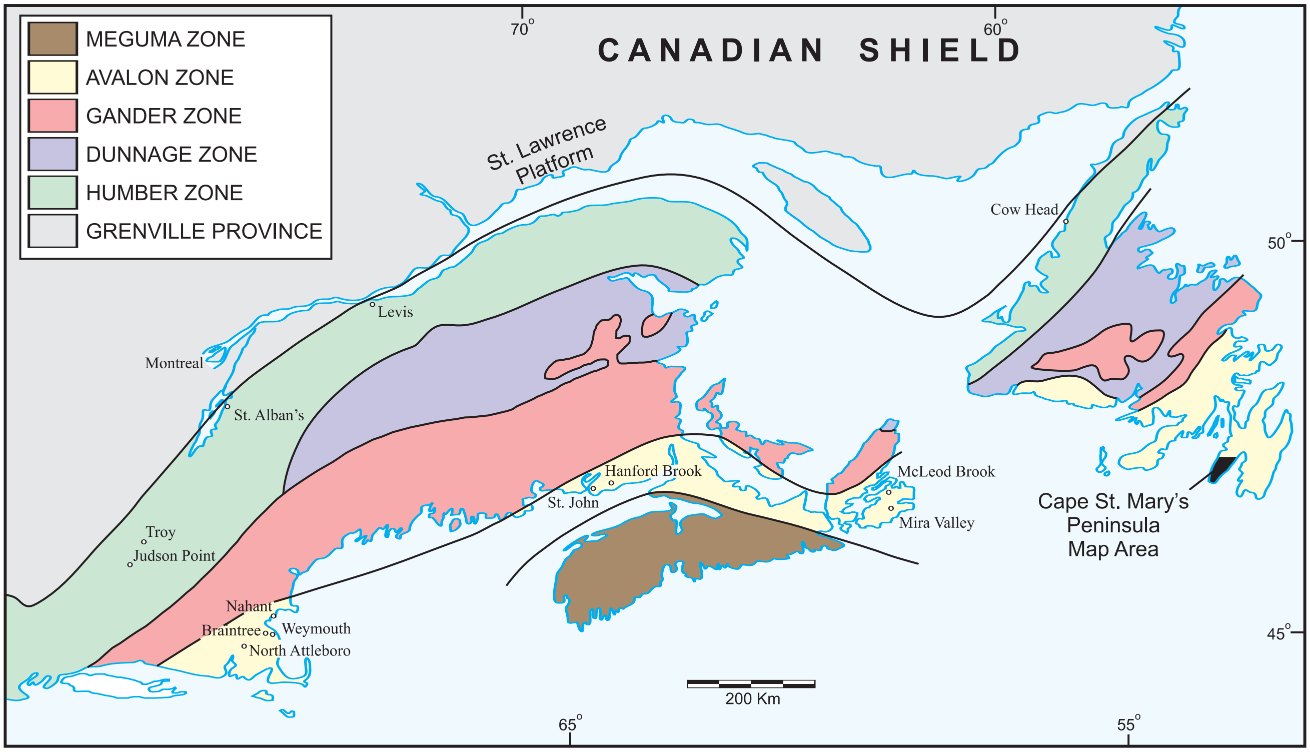

Figure 1. *Tectonic setting of the Cape St. Mary's Peninsula.*

watershed, including the Platform Hills, Castle Ridge and Sawyers Hills".

Unfortunately, because of "the state of the weather", Murray was apparently restricted to the immediate environs of Branch and his descriptions are largely limited to features of the Chamberlain's Brook Formation in Wester Cove and isolated limestone [tuff] blocks on the shore of Beckford Head. Cleavages are mentioned that "divide the rock into splintery fragments so remarkably fragile that there is difficulty in procuring a specimen of any required size or shape". "The fossils are usually more or less distorted lying irregularly quite parallel with the bedding and chiefly in the green and purple parts, but sometimes in the red, in which case, it was observed that the spot surrounding the fossil had invariably the green tinge". He also saw dykes offset by faults with throws of 6 to 9 m to the southwest. On a boat trip around Branch Head, he noted spherical concretions as large as "an 18-lb. cannon ball" in dark grey shales now recognized as the Manuels River Formation. On his return to Placentia, he was able to demonstrate the synclinal structure in which the Cambrian sedimentary rocks were preserved inland from the fishing settlements of Angel's Cove and Patrick's Cove (Figure 3).

In the same season, Murray visited Cape Dog, where he found "*Paradoxides*" and an intrusion of amygdaloidal "trap"; he also recorded copper occurrences in quartz veins near Cape Dog and also at Little Barachois 6 miles to the southwest. His field assistant, James P. Howley (*in* Murray and Howley, 1881a, Report for 1869, p. 189), collected specimens and marked the coastal boundaries of the different formations. He concluded that a large area of the peninsula "was spread over by rocks of Primordial Silurian age, but the inland boundaries of the formations are still undiscovered; and the nature of the country, which is for the greater part concealed under enormous marshes, renders the task of following the outcrops always exceedingly difficult and sometimes impossible; nevertheless there is sufficient evidence to assume that the formation is divided into at least two troughs, one towards the shores of Placentia Bay, the other towards St. Mary's Bay".

In the reports for 1870, Murray and Howley (1881a) describe and illustrate a generalized stratigraphical column typifying their "Primordial Silurian Formation" and reasonable estimates of those parts on Cape St. Mary's Peninsula are given. However, a less reliable section from near the mouth of Little Salmonier River on the east coast is given that displays a more complete sequence than is now recognizable there. In their discussion of intrusive rocks, they note that the "Primordial rocks of the peninsula are divided by great masses of trap from Bull Island Point and Point Lance" and that dykes "also intersect the strata running oblique or at right angles to the great north and south masses, many of which may be seen upon the coast, both on the St. Mary's and Placentia sides particularly near Branch in the former and Distress in the latter". Their joint efforts cul-

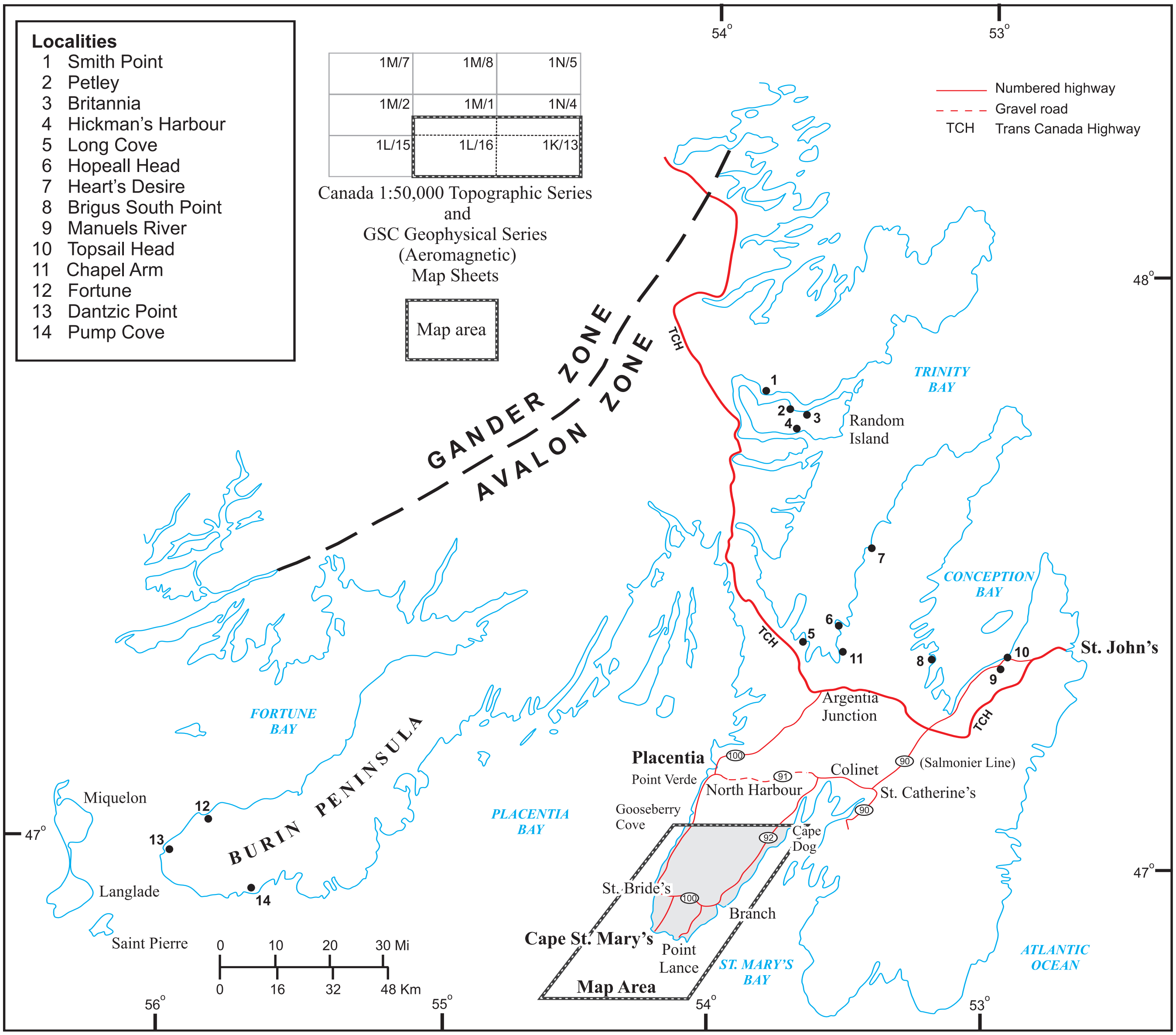

Figure 2. *Southeastern Newfoundland, text localities and access roads to the map area.*

minated in a 1:63 360-scale geological map of the "Peninsula of Cape St. Mary's" and a 4-inch to 1-mile map of the Avalon Peninsula (Murray and Howley, 1881b) and a description of a new Cambrian trilobite *Agraulos affinis* Billings, 1874 associated with *P. (E.) bennetti* at its type locality in Branch Cove.

Matthew (1889), Walcott (1900a) and the Princeton geologists, van Ingen (1914), Dale (1915) and Howell (1925) concentrated on the more accessible Cambrian sections on Conception and Trinity bays, which for long were regarded the classic Cambrian sections of eastern North America. Hence, the more complete sequences exposed on the Cape St. Mary's Peninsula remained unrecognized. In the years preceding Hutchinson's (1953) studies, no fieldwork in the map area is documented, although periodic references were made to the fossils of St. Mary's Bay and boat-trip observations and undocumented fieldwork gave rise to the modified geological boundaries on the maps of Howley (1907) and Baird (1954).

In a discussion of the basal Cambrian contacts in the Harbour Grace map area, Hutchinson (1953, p. 23), briefly described a disconformable junction between the Random Formation and the Cambrian on Cape St. Mary's Peninsula at Cape Dog and at Cuslett Point. Later he published the most comprehensive work on the Cambrian of southeastern Newfoundland in which a general outline of the Cape St. Mary's sequence and main exposures are documented (Hutchinson, 1962, p. 5). The formations established in the

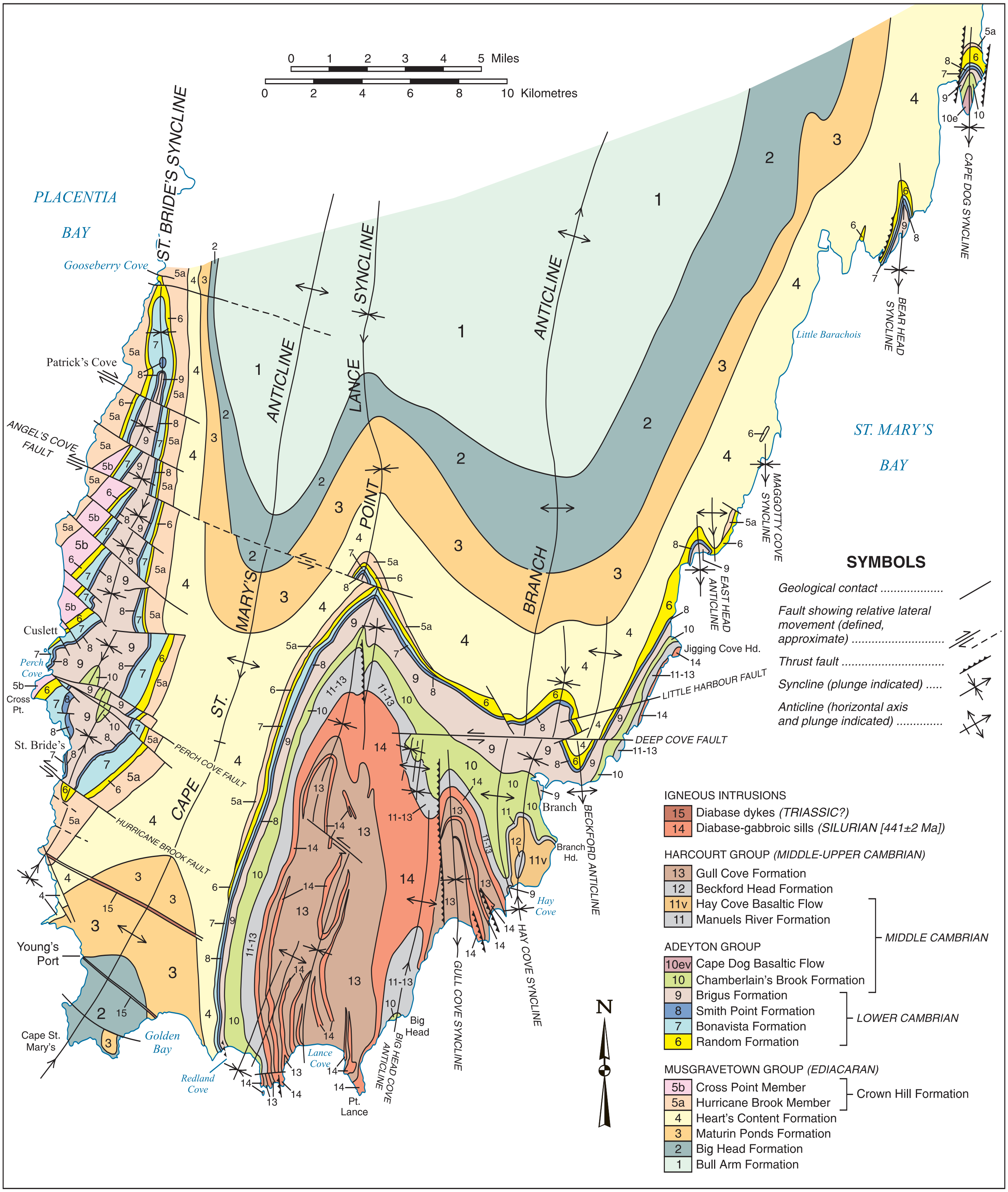

Figure 3. *Bedrock geology of the Cape St. Mary's Peninsula map area; sketch map.*

north were traced southward and five measured sections (Hutchinson,1962, pp. 137-142) provided data for the construction of isopach maps of each formation over this region. Some fossils were collected at this time, not all of which were identified.

Between 1954 and 1957, McCartney mapped the area to the north of the St. Bride's and St. Mary's map areas for his Ph.D. thesis at Harvard University and this was later published by the Geological Survey of Canada (McCartney, 1967).

The writer spent the summer of 1959 on the peninsula as a student member of the Durham University Exploration Society expedition, responsible for establishing the geological aspects of work on the local soils by four other members. At that time, trilobites were collected from Branch Cove and a geological map of the map area accompanied the expedition report submitted to the University Senate (University of Durham Gazette, 1960). Concomitantly, Henderson (1972) covered the area in his Geological Survey of Canada survey of the Pleistocene and Recent deposits of the Avalon Peninsula.

Greene (1962a) mapped the Cambrian rocks of the Point Lance-Branch outlier for his M.Sc. thesis and subsequently published a brief account on the "Middle Cambrian" mudstone sequence and tuffs in that structure (Greene, 1962b).

For very short periods in the summers of 1963, 1964, 1965 and 1966, the writer collected trilobites from Branch Cove and Redland Cove to support contentious faunal conclusions made in the 1959 expedition report. Probably the main result of this collecting was the recognition of an unbroken fossiliferous sedimentary sequence between the Brigus and Chamberlain's Brook formations. Here, a unique fauna of undescribed eodiscid trilobites, an oryctocephalid trilobite and large species of *Paradoxides* occur below the prominent manganese bed that elsewhere in Newfoundland was recognized as the marker for a major break in sequence between the two formations. Fortuitously, the identification and significance of the eodiscids was highlighted by the publications of Rasetti (1966, 1967) and Rushton (1966) that indicated the Branch fauna probably provided the first possibility of correlating different faunal realms of the Cambrian. Recognition of this led to the commencement of the writer's Ph.D. research studies in 1967 under Professor H.B. Whittington at Cambridge. Fieldwork was undertaken the following summer on the Avalon Peninsula and in New Brunswick, as well as examination of relevant fossils in the Sedgwick Museum, Cambridge; Geological Survey Museum, London; British Museum of Natural History, London; Natural History Museum of New Brunswick, Saint John; Redpath Museum, Montreal; Geological Survey of Canada, Ottawa; Royal Ontario Museum, Toronto; Cornell University; Harvard University; State University of New York at Stony Brook; Columbia University; Princeton University and Smithsonian Institution, Washington, D.C.

Pollett (1968) made brief mention of isolated surficial deposits on the peninsula in a provincial report on peat resources. After completing his thesis, Fletcher (1972) published a one-day field guide of the region (Fletcher and Brückner *in* King *et al.*, 1974, pp. 38-44). The quartz arenite deposits were considered in more detail by Butler and Greene (1976) in an extensive assessment of the economic potential of the local Random Formation.

Following Fletcher's (1972) observations, Hodych and Patzold (1980) and Hodych and Buchan (1994, 1998) established the Silurian age and palaeomagnetism of the mafic sills. Greenough (1984) carried out a petrological and geochemical study of the Cambrian volcanic rocks as part of a Ph.D. thesis, and Greenough and Papezik (1985a, b, 1986) documented features of the chemical and tectonic origins of the Cambrian volcanic rocks and Silurian sills: further accounts followed dealing with the age (Greenough *et al.*, 1993) and petrological aspects (Greenough and Hodych, 2001) of these igneous rocks. Landing (1996) included a review of Cambrian depositional sequences present on the Cape St. Mary's Peninsula.

The author has undertaken intermittent fieldwork since 1973 and up to August 2004 on the fossiliferous rocks, the results of which have formed the basis of information transmitted to the Subcommission on Cambrian Stratigraphy on matters concerning trilobite taxonomy, faunal correlation and subdivisions of the Cambrian System. Such information has highlighted the global significance of the exposures in Branch Cove and Redland Cove on St. Mary's Bay that was documented in subsequent publications (Fletcher, 1999, 2001, 2003, 2005, 2006; Fletcher *et al.*, 2005; Robison *et al.*, 1977).

Volume I of Fletcher (1972) was originally formatted as a Geological Survey of Canada memoir and this present manuscript represents modifications to that script, edited by Dr. W.H. Poole and additions in the light of subsequent published works. Important among these are the revisions of Ediacaran stratigraphical sequences to the north made by King (1988).

PHYSIOGRAPHY

Cape St. Mary's Peninsula is part of a glaciated plateau having an average elevation of 215 m above sea level within the Avalon Peninsula (Plates 1 and 2). The northeastern

Plate 1. *Musgravetown Group rock plateau of the southwest Avalon. View along the Branch Anticline from the Random quartz arenites on Hare Hill Longstone toward the Bull Arm volcanic outcrop of the Rocky Ridge – photographed in early June before summer growth when the dark areas mark the wooded river courses and drier gravel patches.*

Plate 2. *Northeasterly view from the outcrop of the Random Formation on Hare Hill Longstone across the southerly plunging Beckford Anticline to Jigging Cove Head. The lowland core comprises rocks of the Maturin Ponds–Golden Bay sequence, the middle wooded ridge Bellevue Beach Member–Random Formation rocks, the far lowland post-Random Formation, Adeyton Group rocks, and the far coastal ridge Silurian sills within the Harcourt Group sequence.*

trend of folds and faults has controlled the finger-like outline of the shore and longitudinal ridges and valleys throughout the Avalon Peninsula. In the Cape St. Mary's Peninsula area, the oldest rocks are exposed as the cores of major pitching anticlines and domes in the highest upland areas. A maximum elevation of just over 290 m above sea level is reached at the northern end of Castle Ridge, where resistant Ediacaran volcanic rocks crop out. The upland surface, generally at an elevation of 245 m above sea level in the north-central part of the peninsula, gradually slopes southwest to about 90 m above sea level and ends at the coast in many places with a rock cliff about 60 m above the ocean. The detailed character of the cliff surfaces is controlled by the lithology and structure of the rocks. The highest, and most nearly vertical cliffs have been cut in rocks in which the beds dip inland from the sea. Most of the well-developed cliffs are Ediacaran, like those at Cape St. Mary's, which are over 120 m high. Other prominent cliffs, such as those south of Branch on the eastern side of the Point Lance promontory, are intrusive igneous rocks. The smoother and less precipitous coastline northeast of Branch Cove is due to beds dipping seawards.

Plate 3. *Profile view of the southerly pitching Cape Dog Syncline from the southwest; the highest ridge, dipping down to Cape Dog headland, is the outcrop of the Cape Dog Basaltic Flow.*

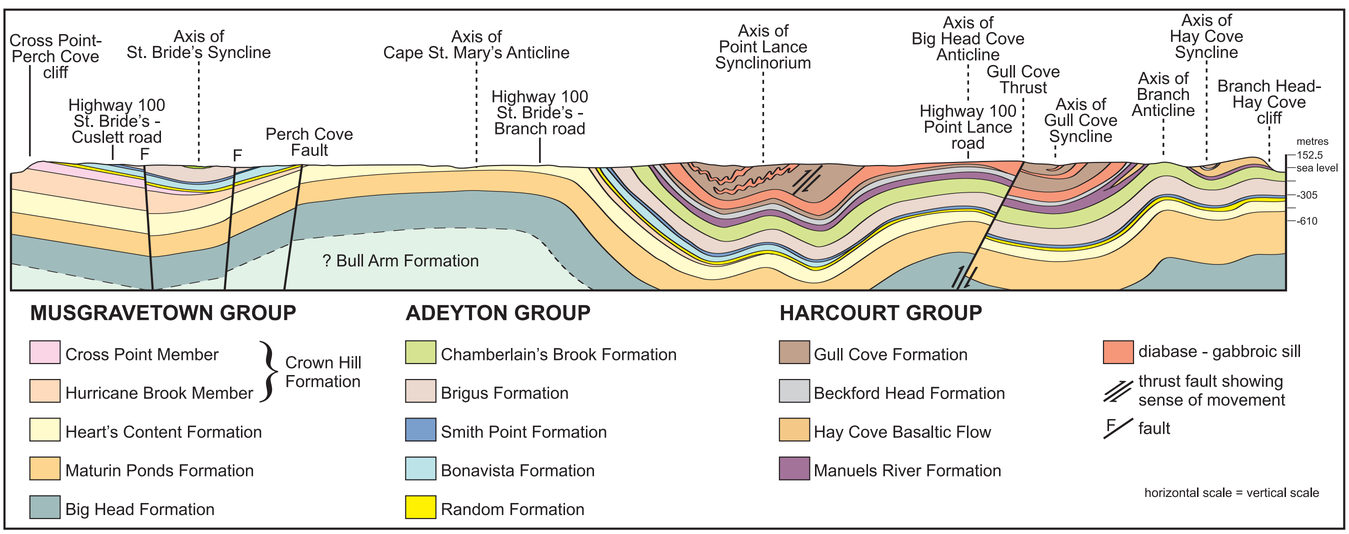

Figure 4. *Geological cross section of the Cape St. Mary's Peninsula.*

The coastlines of Placentia and St. Mary's bays contrast strongly, because of differences in the relationships between the coastline and the rock trend. Along Placentia Bay, the trends are nearly parallel and many of the small inlets are largely the result of erosion along cross faults and joints. In places, additional river-mouth erosion has given rise to larger bays and coves. The resulting general shortage of deep-water harbour facilities necessitated the costly construction of some artificial harbours to serve the local fishing communities, e.g., on the southern side of Distress Cove at St. Bride's. The coastline of St. Mary's Bay, on the other hand, is dominated by erosion across the strike of the major south-plunging structures (Plate 3). Thus, bays eroded from soft rock open southward between ridges of more resistant rock.

The interior part of the peninsula comprises ridges and low broad valleys covered with sphagnum/muskeg bogs and low scrub vegetation (Plate 2). The higher ridges are generally underlain by the more resistant rocks, such as the volcanic rocks of the Bull Arm Formation in the northern part of the area. Some ridges are flanked or capped by resistant Ediacaran conglomerates or the quartz-arenites of the Random Formation as on the Hare Hill Longstone. The high

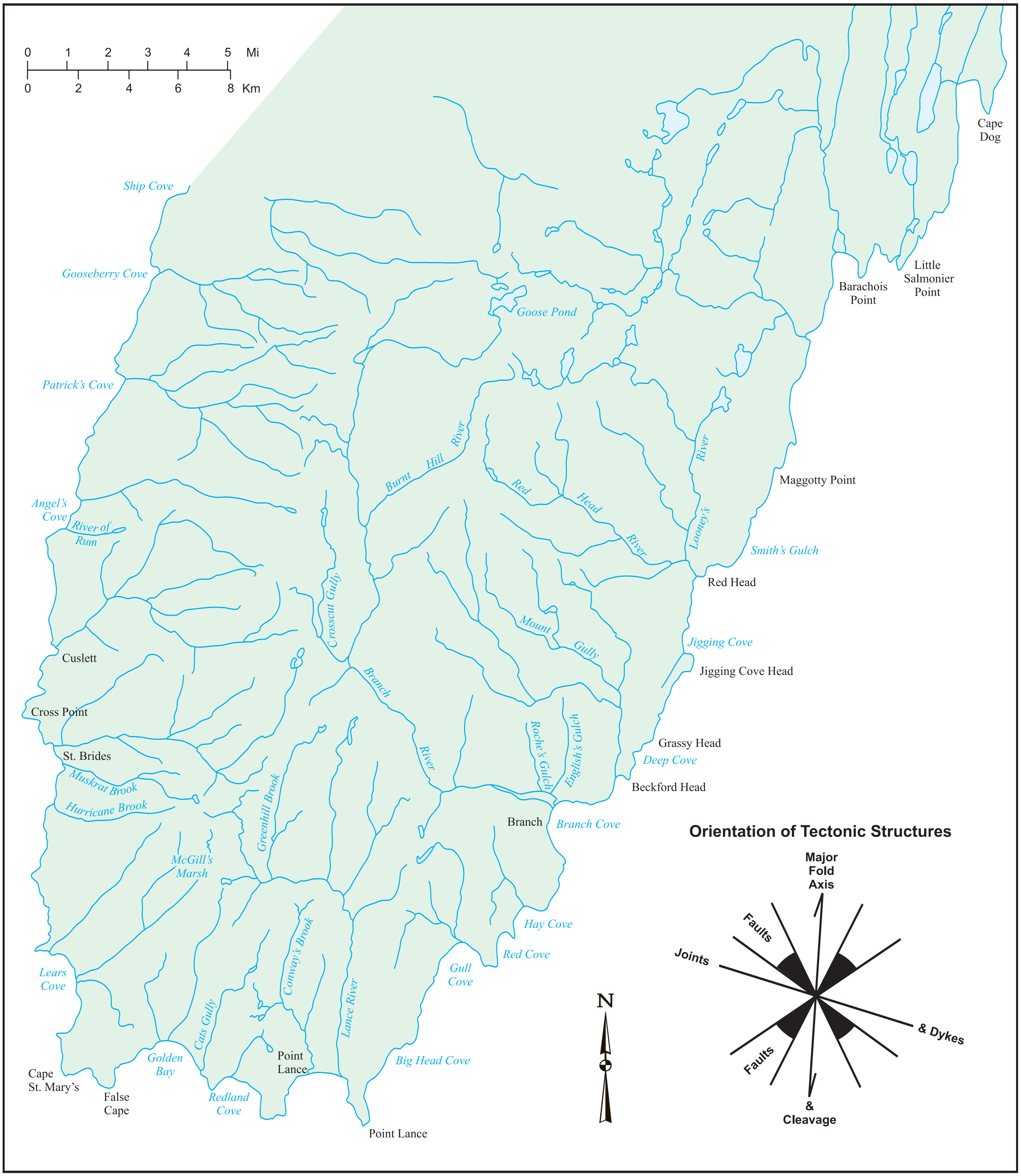

Figure 5. *Drainage pattern; influence of bedrock structures.*

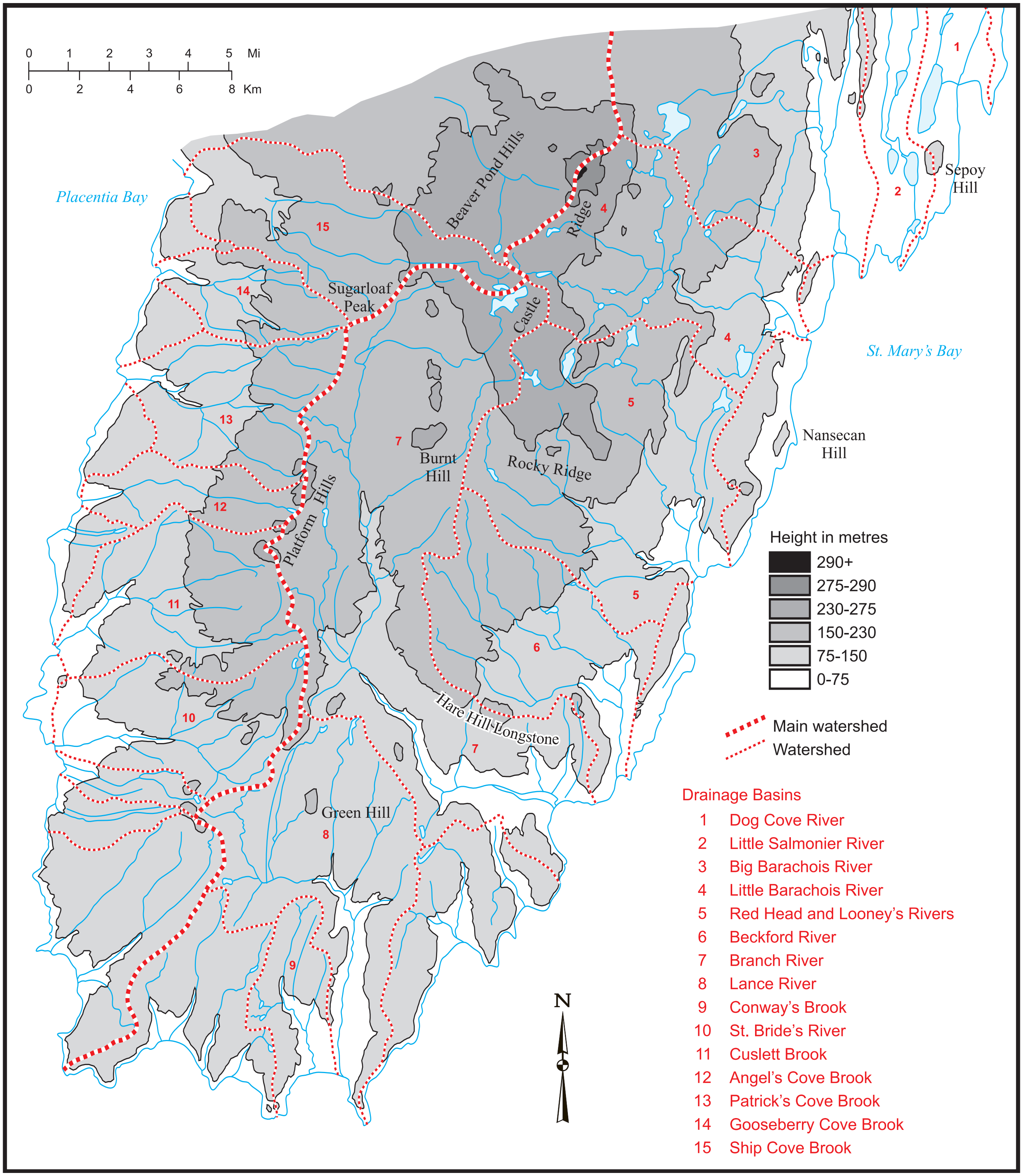

Figure 6. *Physiography; relief and principal drainage basins.*

region along Highway 100, 4 km east-southeast of St. Bride's, is underlain by the resistant sedimentary rocks of the Cats Cove Member of the Heart's Content Formation (Figure 4). Gabbroic sills underlie several less conspicuous ridges within the Cambrian terrane of the southern half of the area, where they are generally covered by thick bogland.

The drainage pattern has been strongly influenced by glaciation and bedrock structure (Figures 5 and 6). Glacial damming of many streams, as well as scouring by glacial ice has led to many lakes, ponds and swamps dotting a bog-ridden countryside. The drainage pattern is also influenced by faults striking northeast and northwest and the more easterly trending joints and dykes (Figure 5).

Three main types of vegetation cover are developed: lichen-covered dry barrens, wet boglands and forests. The barrens form the exposed higher ground and generally consist of smoothly glaciated bedrock that is commonly the gabbroic sills and Ediacaran strata, with little, if any, surficial deposits. The barrens support a sparse scrubby, windswept bush dispersed among wide bare tracts of frost-shattered rock. In the second type, thick deposits of peat have accumulated in broad, wet sphagnum boglands surrounded by almost impenetrable scrub bush (*see* Jukes, 1839, p. 19), e.g., the great bogs of McGill's Marsh, on the southern side of the Green Hills, and north of Beckford River. Of the third type, almost one fifth of the area supports poor quality tuckamore forests. Coniferous trees, predominantly black spruce, occur in all relatively sheltered areas and the better trees grow in the deeper river valleys (Plate 4). Many of the larger trees were used in the construction of the local houses and boats and few now remain.

Plate 4. *A typical immature, densely wooded valley deeply incised into the barren glaciated plateau; an eastern tributary of Branch River that enters the main stream between The Buckets and Crosscut Gully.*

REGIONAL GEOLOGY

REVIEW

Ediacaran and Cambrian sedimentary and volcanic rocks form the main mass of Cape St. Mary's Peninsula and are associated with intrusive Silurian sills (Figures 3 and 4). In Siluro-Devonian times, these were folded, cleaved and faulted and later intruded by basic dykes of possible Triassic age. They form part of the much broader tectonostratigraphical Avalon Zone (e.g., O'Brien *et al.*, 1983) that extends from southeastern Newfoundland through Cape Breton to southern New Brunswick and beyond (Rodgers, 1972; Figure 1). This tectonic belt is a major feature of the Appalachian–Caledonide mountain system and the Newfoundland Neoproterozoic and Palaeozoic representatives formed an important component in a mountain-building process that involved the Avalonian Orogeny and later Acadian Orogeny (Williams, 1995).

The oldest strata are bimodal volcanic rocks associated with subaerial to shallow-marine volcaniclastic sedimentary rocks that were deposited prior to a major depression of the basin. The overlying sedimentary rocks developed in response to a progressive shallowing and other changes, involving deep-marine and non-marine conditions, as the sedimentary basins were filled. By latest Ediacaran time, this region of the Avalon Zone had been converted to a shelf that later was differentially eroded prior to the deposition of Cambrian and Ordovician marine sediments.

The Precambrian rocks in the Cape St. Mary's Peninsula area are of late Ediacaran age and form part of the Musgravetown Group (Hayes, 1948) as defined by McCartney (1967, p. 46-60) and King (1988, legend) on the western side of the Avalon Peninsula. However, the Musgravetown Group succession is less similar to the type area, when traced southward toward the Cape St. Mary's Peninsula area. This is due to significant facies changes (McCartney, 1967, p. 46), e.g., in the basal Bull Arm Formation, where the oldest volcanic rocks are less rhyolitic and are interbedded with sedimentary strata near the top of succession (McCartney, 1967, p. 47). Assemblages of green and red arkosic sandstone and siltstone with intervals of shaly mudstone, coarse-grained sandstone and conglomerate overlie the volcanic sequence and generally display abundant shallow-water, marine and fluvial features. This Musgravetown Group sequence (Figure 7) is disconformably overlain by

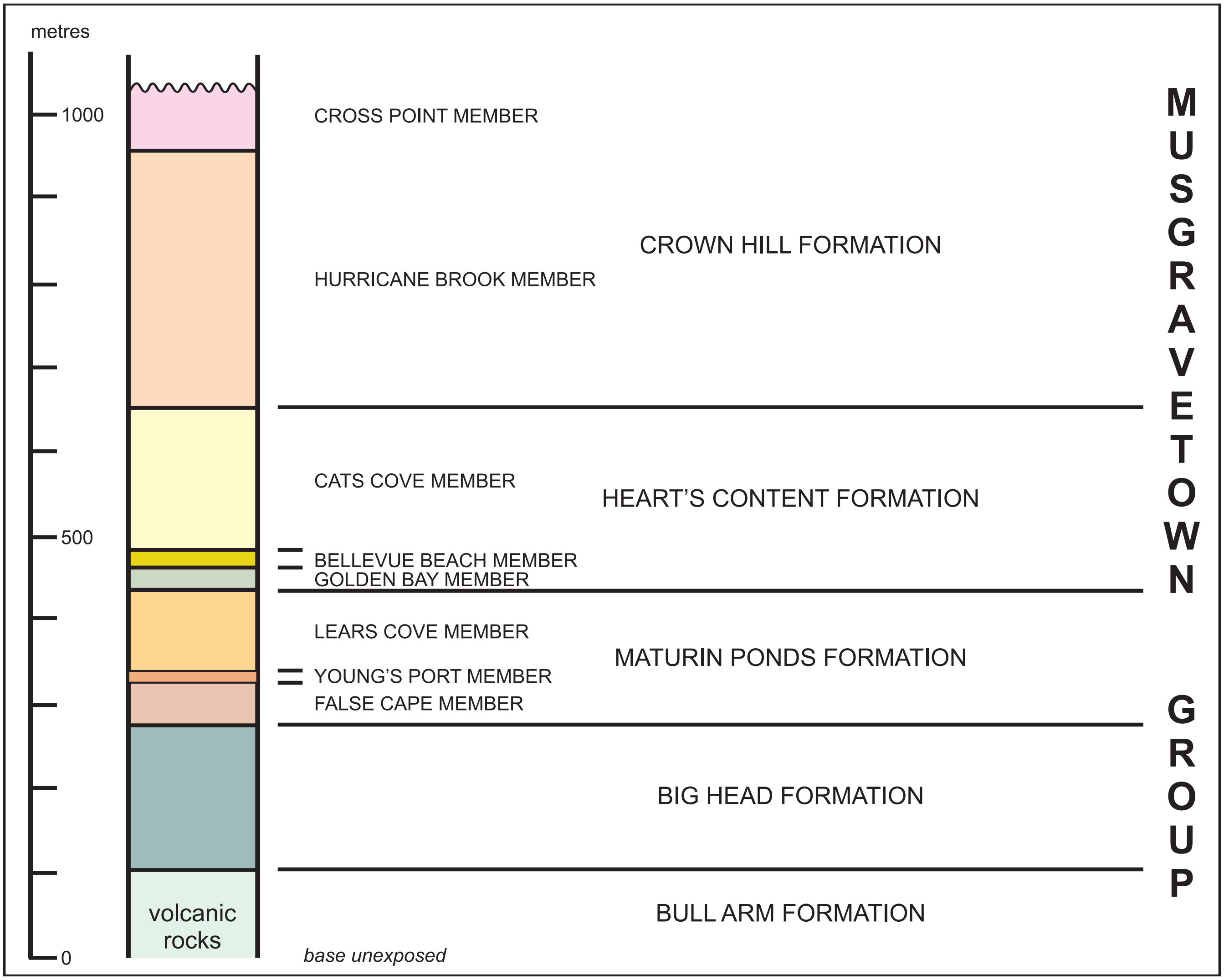

Figure 7. *Lithostratigraphy of the Musgravetown Group in the map area.*

Cambrian sedimentary and sporadic volcanic rocks of the Adeyton Group (Jenness, 1963, p. 59), which is locally marked at its base by the distinctive sequence of mature to super-mature quartz arenite and interbedded pebbly conglomerate, red and green siltstone and shale of the Random Formation (Walcott, 1900a; Hayes, 1948; Christie, 1950). The upper contact of the Random Formation is an unconformity on which younger formations have an onlapping relationship. Thus the Random Formation is everywhere overlain by pebbly limestone of variable age and thickness. The succeeding Adeyton Group sequence resembles that developed elsewhere in southeastern Newfoundland, and modifications of the broad formational divisions of distinctive calcareous, greyish-red and olive-green mudstones containing pink nodular limestones beneath the blackish-grey, shaly mudstone, siltstone and sandstone of the Harcourt Group (Jenness, 1963, p. 70) are easily recognizable in the Cape St. Mary's Peninsula map area.

Localized lensoid bodies of mafic volcanic rocks ranging from spilitic pillow lavas to waterlain, highly calcareous tuffs occur at two stratigraphical levels; one near the top of the Adeyton Group sequence (Hutchinson, 1962, p. 137), the other, near the top of the Manuels River Formation in the lowest part of the Harcourt Group (Fletcher, 1972, Vol. 1, p. 192, pls. 17-19; Figure 8).

Numerous Silurian gabbroic sills (Greenough *et al.*, 1993), many of which are layered (Fletcher, 1972, Vol. 1, p. 215), were emplaced within the youngest beds of the Harcourt Group, prior to a period of Devonian deformation that affected the whole succession. The main folds of this Acadian deformation have axes striking north-northeast and plunge a few degrees to the south-southeast or, to a lesser extent, to the north-northeast, to produce elongate domes and doubly plunging structures (Figure 3). The folds are slightly asymmetrical to the east with eastern limbs slightly

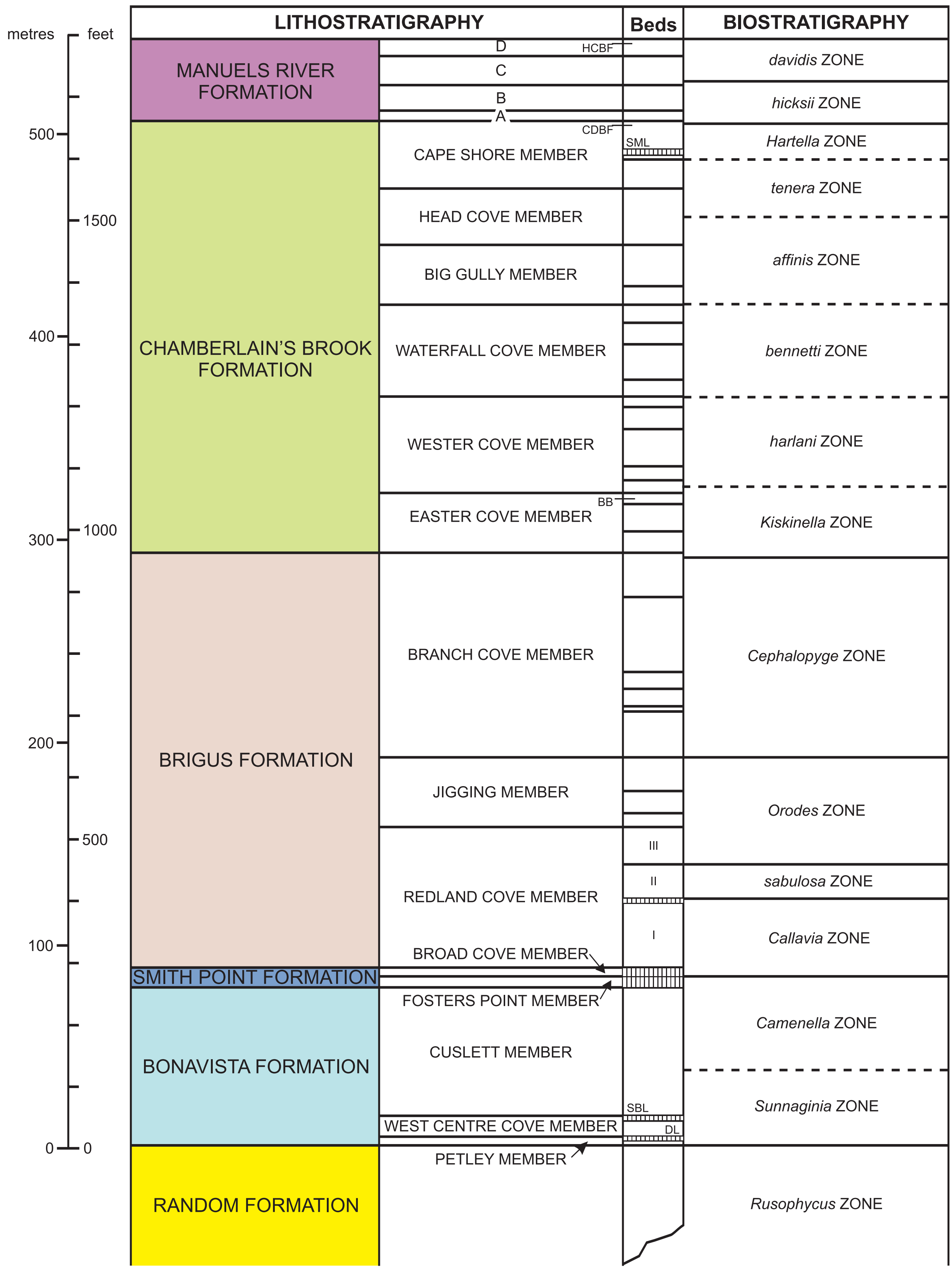

Figure 8. *Lithostratigraphy and biostratigraphy of the Cambrian rocks in the map area.*

steeper than the western limbs. Two main synclines and two anticlines, 5 to 8 km apart, characterize the regional structure, with the oldest rocks exposed in the northern part of the peninsula (Figure 3). Along the western anticlinal axis, only Ediacaran rocks are exposed and the westernmost syncline preserves Adeyton Group strata possibly as young as basal Chamberlain's Brook Formation in a drift-covered area (Figure 4). The tight syncline between the main anticlinal axes contains a Cambrian sequence as young as Late Cambrian, i.e., the Furongian Series (Peng *et al.*, 2006) that, in places, is affected by thrusts. Cambrian strata extend around the nose of the main eastern anticline and trend northeast to the coastline, along which, three, small, isolated, tight, southerly plunging synclines of Adeyton Group rocks probably represent marginal folds of a major synclinorium of Cambrian rocks underlying the western part of St. Mary's Bay. Locally, easterly directed thrusts are developed and, throughout the region, a prominent closely spaced axial-plane cleavage dips very steeply west to vertical. Concomitantly, a strong joint system was imposed and both lateral and vertical movements along fractures somewhat normal to the strike of the fold axes, i.e., northwest-southeast, facilitated the intrusion of diabase dyke swarms. Since some dykes have been faulted and have cross-cutting relationships, a later period of tectonic adjustment may also be indicated, possibly related to Triassic dyke activity recognized elsewhere on the Avalon Peninsula (Hodych and Hayatsu, 1980).

The entire area was glaciated during the Pleistocene and all the observed evidence on the peninsula relates to an easterly ice outflow from the central part of the Avalon in the early Wisconsin Glacial Period (Henderson, 1972). Scattered glacial and postglacial surficial deposits are well represented, but, for the most part, there are larger tracts of ground, where rock surfaces are barely masked by a thin cover of vegetation. No major raised beaches are preserved, since the postglacial rise in sea level exceeds the local isostatic land rise and the peninsula is rimmed by a virtually continuous cliffline.

Today, peat continues to accumulate in the numerous poorly drained depressions, and gravel, sand and silt are transported downstream out into the ocean, where storm beaches [barachois] and sandbars form at the mouths of the main rivers. At several localities, severe weathering of the softer rocks in cliffs has given rise to major screes and small landslips.

NOMENCLATURE

Ediacaran

The general stratigraphical sequence of the late Neoproterozoic Ediacaran rocks of southeastern Newfoundland is well known from Rose (1952), Hutchinson (1953), Jenness (1963), McCartney (1967), Williams and King (1979), O'Brien *et al.* (1977), Strong *et al.* (1978), Bengtson and Fletcher (1983) and King (1980, 1982, 1988). As a consequence of the variety of contemporaneous environments in Neoproterozoic times, the succession is marked by severe lateral facies changes that are now reflected by different lithostratigraphical nomenclature across the Avalon Zone. Each scheme roughly coincides with separate geographical belts parallelling the north-northeast to south-southwest structural trend of the Avalon Peninsula. The most complete Neoproterozoic sequence is exposed in an eastern Trepassey–St. John's belt, where four superimposed groups have been defined (Williams and King, 1979; King, 1988, 1990). Farther west, in a central belt stretching from western Bay de Verde to the Cape St. Mary's Peninsula, the only part of the latest Ediacaran sequence exposed is the Musgravetown Group, which is the lateral equivalent of the eastern Signal Hill Group, the youngest group in the Trepassey-St. John's sequence.

At the time of the writer's 1959-1968 survey of the Cape St. Mary's Peninsula, the relationships of the facies belts were not fully understood and the Hodgewater Group (Hutchinson, 1953) was then regarded as a distinct group throughout the Harbour Grace map area (Bay de Verde Peninsula), intervening between the Signal Hill Group to the east and the Musgravetown Group on the southern and western sides of Trinity Bay. Geographically, the sedimentary rocks of the Bay de Verde Peninsula strike southwestward into Cape St. Mary's Peninsula on separate sides of the northern bifurcated domal structure exposing volcanic rocks at the top of the Bull Arm Formation. Since some of the described formation boundaries in the type areas appeared to be based on coloured lithofacies changes, it was difficult to recognize them in the Cape St. Mary's Peninsula map area. Therefore, without reliable inter-belt correlation of the formations, Fletcher (1972, 1984) employed a local nomenclature of formations based upon units bound by easily mapped, distinctive, feature-forming, conglomeratic beds.

Today, the required correlations of the established schemes have been largely settled (King, 1988) and the Hodgewater Group has been abandoned in favour of the more extensive Signal Hill and Musgravetown groups that incorporate contemporaneous, regional formations. The lithostratigraphical nomenclature here employed for this map area largely follows King's (1988) modifications of formations recognized in Trinity Bay by Jenness (1963) and McCartney (1956, 1957, 1967) and on the Bay de Verde Peninsula by Hutchinson (1953). On Cape St. Mary's Peninsula, such Musgravetown Group formations are further divided into formal members (Table 1).

Table 1. Musgravetown Group

Musgravetown Group
Crown Hill Formation
Cross Point Member (newly defined)
Hurricane Brook Member (newly defined)
Heart's Content Formation
Cats Cove Member (newly defined)
Bellevue Beach Member (King, 1988)
Golden Bay Member (newly defined)
Maturin Ponds Formation
Lears Cove Member (newly defined)
Young's Port Member (newly defined)
False Cape Member (newly defined)
Big Head Formation
Bull Arm Formation

Cambrian

The Cambrian rocks in the Avalon Zone of southeastern Newfoundland form one of the important sequences of global significance and are especially notable for their fossil assemblages. Sedimentary rocks predominate, but some isolated volcanic units are conspicuous.

On Cape St. Mary's Peninsula, the Ediacaran Musgravetown Group is unconformably overlain by the Random Formation that, at various times, has been assigned to both the Precambrian and the Cambrian. The Neoproterozoic (Ediacaran)-Cambrian boundary has received considerable research and the global stratotype base of the Cambrian is now defined in the sequence preserved on the Burin Peninsula at the northwestern margin of the Avalon Zone (Fletcher, 1978; Bengtson and Fletcher, 1983; Narbonne *et al.*, 1987). However, it is defined on fossil evidence and is thus a biostratigraphical boundary. Its position within a formation in southeastern Newfoundland indicates that the Ediacaran-Cambrian contact in an unbroken sedimentary sequence does not coincide with a lithostratigraphical boundary.

Common to all regions of Cambrian strata in this part of the Avalon Zone is the Random Formation characterized by clean-washed quartz arenites. On the Burin Peninsula, the Random Formation lies well above the Cambrian base in the continuous sedimentary sequence. Therefore, although former doubts about its age have been resolved, the problem of its place in a lithostratigraphical group scheme has not been settled. In the Burin sections, a coarse-grained, pebbly, quartzose sandstone marks its base, but these exposures do not provide evidence of a major unconformity and the Random Formation might be considered a component of the group that includes the underlying Rencontre and Chapel Island formations described by White (1939) (*see also* O'Brien *et al.*, 1977; Bengtson and Fletcher, 1983). Outside the Burin Peninsula, no representative sequences of the pre-Random Formation Cambrian are preserved, but a major disconformable contact of the Random Formation with younger formations has been taken as the boundary of a sequence-stratigraphical group by Landing and Benus (1988a, b). The nature of the sub-Random Formation contact has been debated over the years. In the type-area on Random Island, there appears to be no sedimentary break between the conglomerates of the Crown Hill Formation and the quartz arenites of the Random Formation: "the base of the formation is difficult to recognize, and has been drawn somewhat arbitrarily" (Jenness, 1963, p. 56). However, the basal Random Formation conglomerate regionally transgresses a substantially eroded Musgravetown Group sequence and the evidence of one section, where reworking of unconsolidated weathered sediments masks the contact, should be treated with caution. Field observations, and those by Butler and Greene (1976) and Hiscott (1982) have demonstrated an overall uniformity within the Random Formation and that several individual members can be recognized over great distances (Figure 9). In the Cape St. Mary's Peninsula area, these members rest upon the Cross Point and Hurricane Brook members of the Crown Hill Formation in the Placentia Bay sections, where contacts similar to that on Random Island might have developed had not the base of the Random Formation been more cobbly and marked by a distinctive rock suite. Within a distance of only 6 km from the cliffs of Placentia Bay, the Random Formation beds transgress the bevelled edge of several hundred metres of Musgravetown Group strata (Figure 10). As lithostratigraphical groupings are governed mostly by lithological similarities rather than sequence breaks, the presence of nodular mudstones in some Random sequences, more typical of the immediately overlying Bonavista Formation, e.g., "on the north shore of Bull Arm" (McCartney, 1967, p. 61), at Hopeall Head, Trinity Bay and on the southern side of Cross Point, Placentia Bay, is here regarded sufficient to include it as the basal formation of the lithostratigraphical Adeyton Group.

Since the Early to Middle Cambrian succession of southeastern Newfoundland has become the focus of much international attention regarding stratigraphical subdivision (Narbonne *et al.*, 1987; Fletcher, 2003; Fletcher *et al.*, 2005), it is necessary to clarify the relationship between the two main Newfoundland successions, i.e., the pre-Random Formation succession and the Adeyton Group succession.

It is evident that the red and green sedimentary lithofacies of the latest Ediacaran and Cambrian Rencontre and Chapel Island formations below the Random Formation on the Burin Peninsula, and Cambrian formations of the overlying Adeyton Group are closely related and substantially different in facies from the underlying, essentially volcanic,

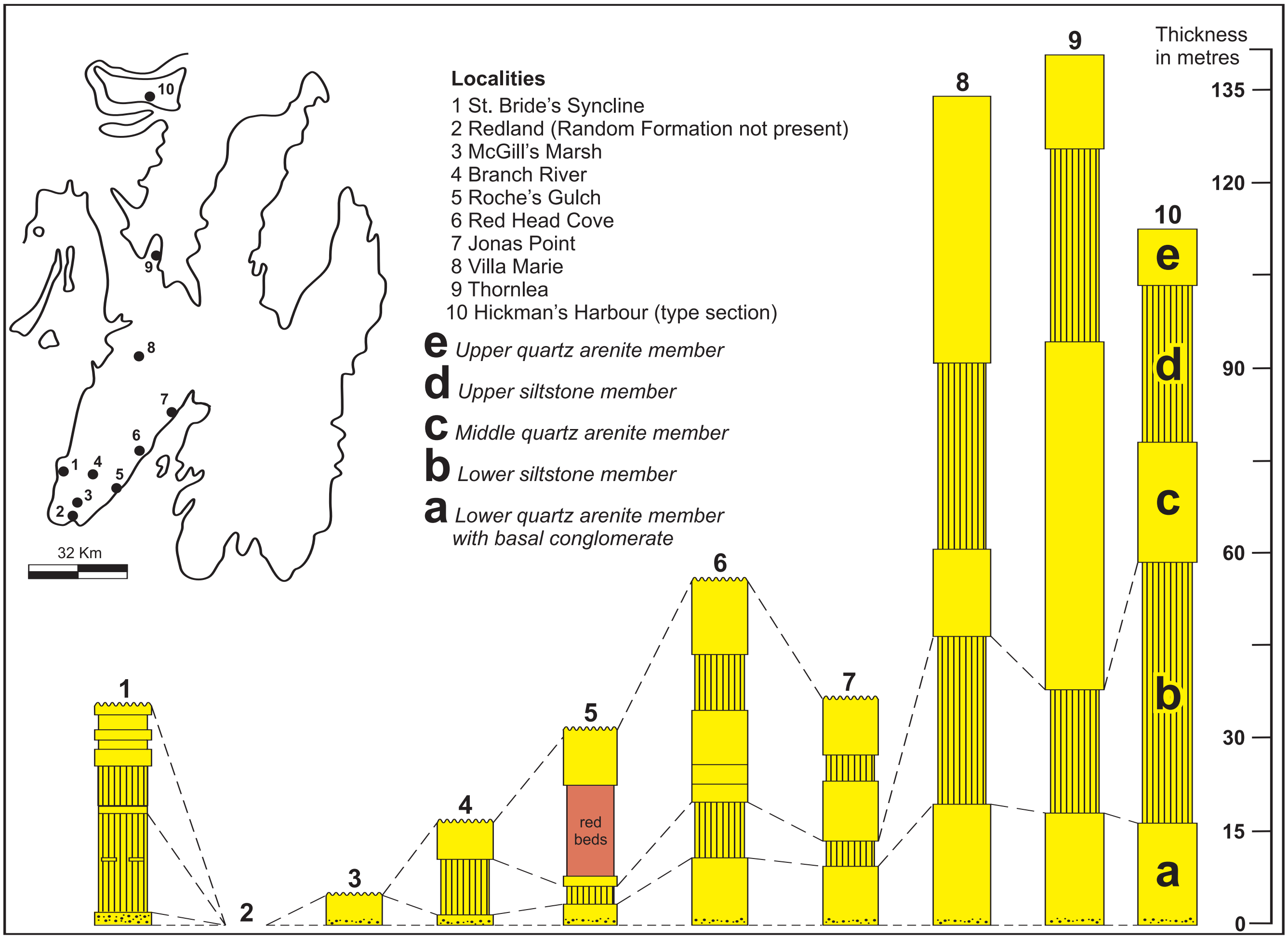

Figure 9. *Random Formation; comparative sections.*

Marystown Group (Strong *et al.*, 1976; O'Brien *et al.*, 1977, p. 2) and the overlying, blackish, shaly mudstones of the Harcourt Group (Jenness, 1963, p. 70). By the same lithostratigraphical criteria generally employed in the Avalon Zone for establishing mappable formations, the presently recognized informal members (Bengtson and Fletcher, 1983) of the Chapel Island Formation ought to be raised to formational rank with formal geographical names. Together with the underlying Rencontre Formation, they clearly represent a distinct group, linked lithologically to the Adeyton Group. For this reason, a new lithostratigraphic proposal is made here.

DANTZIC SUPERGROUP

Definition

The name Dantzic Supergroup is here proposed for the two successions of multi-coloured sedimentary rocks of late Ediacaran and Cambrian age in southeastern Newfoundland, namely the Fortune Group and the Adeyton Group. The main reference section of the supergroup is that along the Dantzic coast of southwestern Fortune Bay in the Lamaline 1L/13 map area (O'Brien *et al.*, 1977).

FORTUNE GROUP

Definition

The name Fortune Group is here proposed for the Rencontre and Chapel Island formations with the type area in the southwestern part of Fortune Bay, i.e., the red and green sedimentary succession above the volcanic Marystown Group and below the base of the Random Formation.

ADEYTON GROUP

Definition

The Adeyton Group was established by Jenness (1963, p. 59) to accommodate the fossiliferous, calcareous, red and green slaty mudstones with sporadic nodular limestones underlying the blackish-grey shaly mudstones, siltstone and sandstones of the Harcourt Group. This strikingly coloured

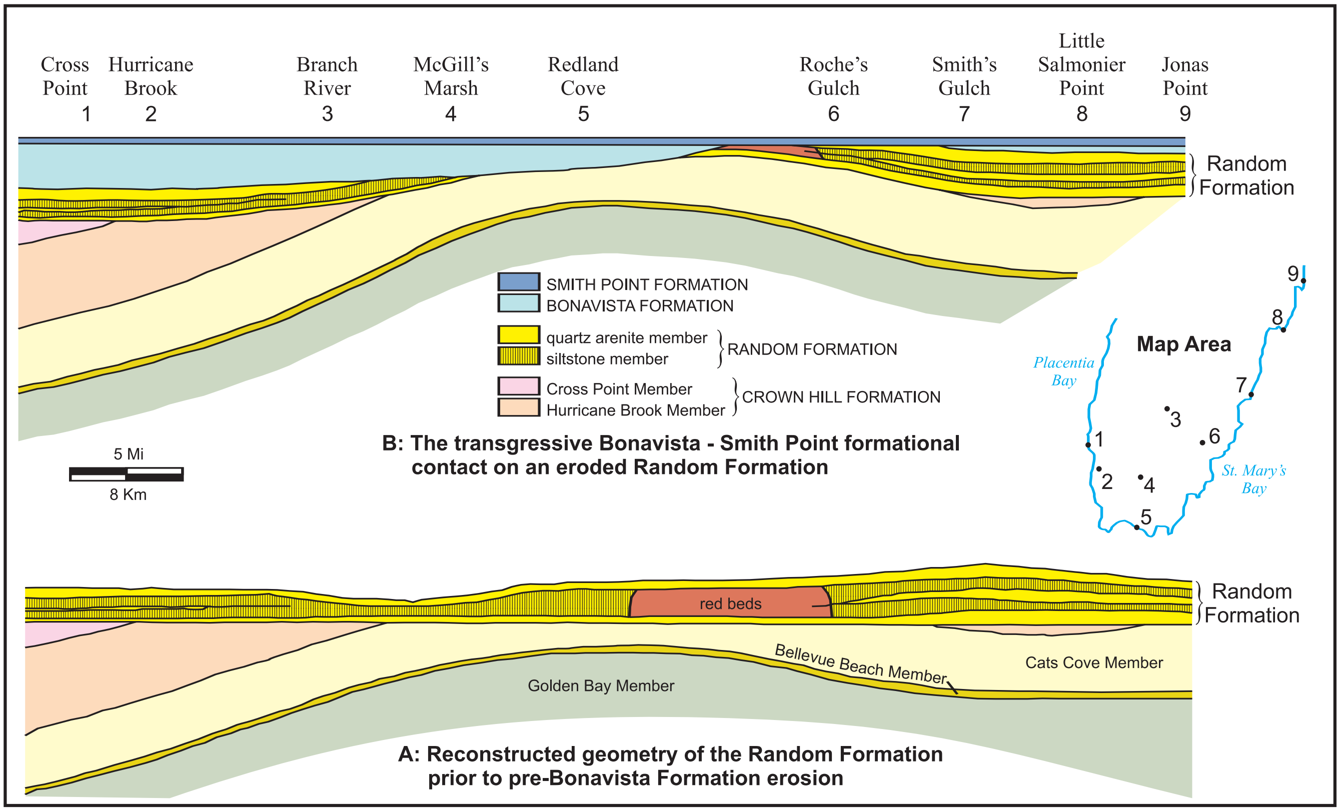

Figure 10. *Random Formation; contact relationships.*

group incorporated formations redefined by Hutchinson (1962), namely the Bonavista Formation (van Ingen, 1914), Smith Point Formation (Walcott, 1900a), Brigus Formation (van Ingen, 1914) and Chamberlain's Brook Formation (Howell, 1925, p. 60). As noted above, the Random Formation is now added as the basal formation.

The Harcourt Group conformably overlies the Adeyton Group. The boundary is drawn at the base of a distinctive white clay bed, first noted by Howell (1925, Bed 36, p. 50) and later referred to as the "Manuels Metabentonite" (Fletcher and Brückner, 1974, fig. 9, p. 42), marking the base of a prominent sequence of blackish, sulphurous, shaly mudstones containing sporadic limestone concretions named the Manuels River Formation (Hutchinson, 1962, p. 22). Elsewhere in southeastern Newfoundland, the top of the Harcourt Group comprises a variety of grey beds assigned to the Elliott Cove and Clarenville formations (Jenness, 1963, p. 72), but as presently described, they are not readily distinguished in the Cape St. Mary's Peninsula map area, and two local formations have been mapped, a lower Beckford Head Formation and an upper Gull Cove Formation.

GEOLOGY OF THE CAPE ST. MARY'S PENINSULA

In this account, some formations have been subdivided into members that facilitate correlations with sections outside the map area. Certain members and faunal zones, originally proposed by Fletcher (1972a) have been referred to in subsequent publications (Bengtson and Fletcher, 1983; Fletcher, 1984, 2003, 2005) and are formally defined in this publication (Table 2).

EDIACARAN ROCKS

MUSGRAVETOWN GROUP (Units 1 to 5)

Definition

Hayes (1948, p. 14) first defined the Musgravetown Group in the Bonavista Bay and Trinity Bay areas as "The Musgravetown, which overlapped the Connecting Point, is made up of sediments and lava flows which are in turn overlain by the Random…". Christie (1950) described it as a sequence of conglomerate, red, green and grey, shale and greywacke with lava flows and minor intrusive rocks that Jenness (1963) later subdivided into four formations. Modifications of Jenness's scheme were made in the Whitbourne map area to the southeast by McCartney (1967) and, in eastern Trinity Bay, beds in Hutchinson's (1953, p. 12) Hodgewater Group were reassigned by King (1988) to the Musgravetown, St. John's and Signal Hill groups and the name Hodgewater Group abandoned. King traced both established and revised formations in the Musgravetown Group southward into Cape St. Mary's Peninsula, utilizing the same stratigraphical boundaries defined by McCartney (1956, 1957, 1967). Correlations were made with lithostratigraphical units mapped on the 1:50 000-scale by Fletcher (1972), but due to the smaller 1:250 000 scale of his Geology of the Avalon Peninsula map (King, 1988), mainly formations, groups and major structures are shown.

New members in the formations of the Musgravetown Group (southern lithofacies) on Cape St. Mary's Peninsula are herein newly defined. Their names derive from headlands and coves along its coastline. The succession is generally well exposed and two cliffline sections occur on each side of the northerly plunging Cape St. Mary's Anticline

Table 2. Harcourt Group and Adeyton Group

Harcourt Group
Gull Cove Formation
Beckford Formation
Manuels River Formation with Hay Cove Volcanic Flow (newly defined)
Adeyton Group
Chamberlain's Brook Formation
Cape Shore Member (newly defined) with St. Mary's Limestone Bed (newly defined) and Cape Dog Volcanic Flow (newly defined)
Head Cove Member (newly defined)
Big Gully Member (newly defined)
Waterfall Cove Member (newly defined)
Wester Cove Member (newly defined)
Easter Cove Member (newly defined) with Blister Bed (newly defined)
Brigus Formation
Branch Cove Member (newly defined)
Jigging Member (newly defined)
Redland Cove Member (newly defined
Smith Point Formation
Broad Cove Member (newly substituted for the pre-occupied name Clifton)
Fosters Point Member
Bonavista Formation
Cuslett Member
West Centre Cove Member with St. Bride's Limestone Bed (newly defined)
Petley Member with Deadman's Limestone Bed (newly defined)
Random Formation

passing through the Cape. The sections are not complicated by any major faults and there is no difficulty in determining the sequence. Contact relationships with the overlying Adeyton Group can be examined in several areas and mapping has demonstrated that outcrops of certain marker beds are continuous into the described map areas to the north.

The total thickness of the group is incalculable, because the base lies at a considerable depth beneath the oldest strata exposed. All thickness mentioned in the descriptions have been estimated in a reconnaissance way and are only significant in conveying some measure of relativity; the inaccuracies are not likely to be major.

In the map area, no fossils have been found in the formations of this group, and no reliable radiometric dates have been obtained that will provide an age more refined than the late Neoproterozoic or late Ediacaran Period indicated by the regional field relationships.

Bull Arm Formation (Unit 1)

Definition

The Bull Arm Volcanic Formation has been fully discussed by Jenness (1963) and McCartney (1967) and their definition will suffice for the oldest volcanic sequence in the map area. The name "is used in a lithostratigraphic sense to designate the dominantly volcanic assemblage of rocks in the lower part of the Musgravetown Group" (Hayes, 1948; McCartney, 1967, p. 47), where "the base is arbitrarily selected at the lowest volcanic member. The top of the formation is likewise placed at the top of the uppermost volcanic member" (Jenness, 1963, p. 46). Jenness pointed out that these limits may be diachronous and this is generally accepted in correlations that interpret interfingering contacts with sedimentary rocks (*see* King, 1988, legend stratigraphical column).

Distribution and Thickness

The Bull Arm Formation is exposed in the north-central region of the Cape St. Mary's Peninsula area as the core of the main structural element forming the peninsula and continues to the north with its outcrop mapped by McCartney (1967) and King (1988). Its base is not exposed and lies at depth beneath the axes of the bifurcate domal outcrop marked by the Platform Hills in the west and Castle Ridge in the east. McCartney (*op. cit.*) recorded a thickness of 8000 feet (2440 m) in the type area of Trinity Bay, but only the topmost 60 m or so are exposed on Cape St. Mary's Peninsula. Individual flows are mappable in the relatively bare high grounds and warrant a separate study.

Lithology

Apart from the recording of structural dips within the outcrop, no detailed study of the volcanic sequence was undertaken. The local sequence, therefore, remains relatively unknown, with the limited information available to be taken mainly from McCartney's (1967) account and map of the northern exposures and King's (1988) map.

On the Avalon Peninsula to the north, the formation comprises mafic and felsic flows, breccias and pyroclastic rocks interbedded with tuffaceous arkose, red, green and grey-green arkose, siltstone and conglomerate. In Cape St. Mary's Peninsula area, only the upper part of the formation is structurally exposed and comprises volcaniclastic rocks interbedded with andesites, basalts, green and grey-green arkoses, tuffaceous arkoses and siltstone.

Contact Relations

Although the contact with the overlying sedimentary sequence is sharp and exposed at several localities in the highland barrens and river/stream sections in the northern part of the map area, the map boundary between the Bull Arm Formation and the overlying Big Head Formation is based largely upon exposures where volcanic rocks and sedimentary rocks are exposed in close proximity. As defined, the top surface of the youngest volcanic rock marks the boundary and, because that rock is generally interbedded with sedimentary rocks of the type characterizing the overlying formation, the contact at any one section may be recognized as conformable, though, regionally, it is likely to be diachronous.

A rubidium–strontium isochron age of 494 ±3 0 m.y. ($\lambda 1{\cdot}39 \times 10^{-11}$ year^{-1}) recorded by McCartney (1967, p. 50) is unlikely, as it implies an Early Ordovician age (Kulp, 1961) greatly at variance with all field relationships in southeastern Newfoundland that indicate an Ediacaran age.

Correlation

Field relations with neighbouring mapped areas to the north indicate continuity with the rock belts established there as the Bull Arm Formation. More recent mapping by King (1988) has demonstrated a lateral interdigitation between the upper part of the formation and the oldest sedimentary rocks assigned to the Big Head Formation in the northeast. This formation on Cape St. Mary's Peninsula was originally mapped as Unit 1 by Fletcher (1972a, 1984).

Plate 5. *Inaccessible strata of Big Head Formation on the eastern side of Cape St. Mary's looking towards the gannetry on Bird Island and the western side of False Cape.*

Big Head Formation (Unit 2)

Definition

The name Big Head Formation was proposed for the predominantly grey-green, fine-grained sedimentary rocks within the Musgravetown Group that overlie the Bull Arm Formation and underlie the redbeds of the Maturin Ponds Formation (McCartney, 1967, p. 50) at Big Head, north of Long Harbour in Placentia Bay. As thus defined, it was mapped into the northern part of the Cape St. Mary's Peninsula area by McCartney (1967), and extended farther south by King (1988), who correlated it with Fletcher's (1972a, 1984) map-unit 2a - Cape St. Mary's Siltstones Member.

Distribution and Thickness

The Big Head Formation is exposed in two separate outcrops in the map area. The sequence is best exposed in the high cliffs around the Cape (Plates 5 to 7), between the northern end of Brierly Cove in Placentia Bay (Plates 8 and 9) and the western side of Golden Bay in St. Mary's Bay. The main outcrop forms a belt around the Bull Arm Formation volcanic core of the north-central bifurcated domal area, where it is largely exposed in stream sections.

In the Whitbourne area to the north, McCartney's (1967, p. 51) measurements of this formation indicate a thickening from 460 m at Long Harbour to 2130 m in the south. Judging from the width and general dip values around its northern outcrop in the Cape St. Mary's map area, a

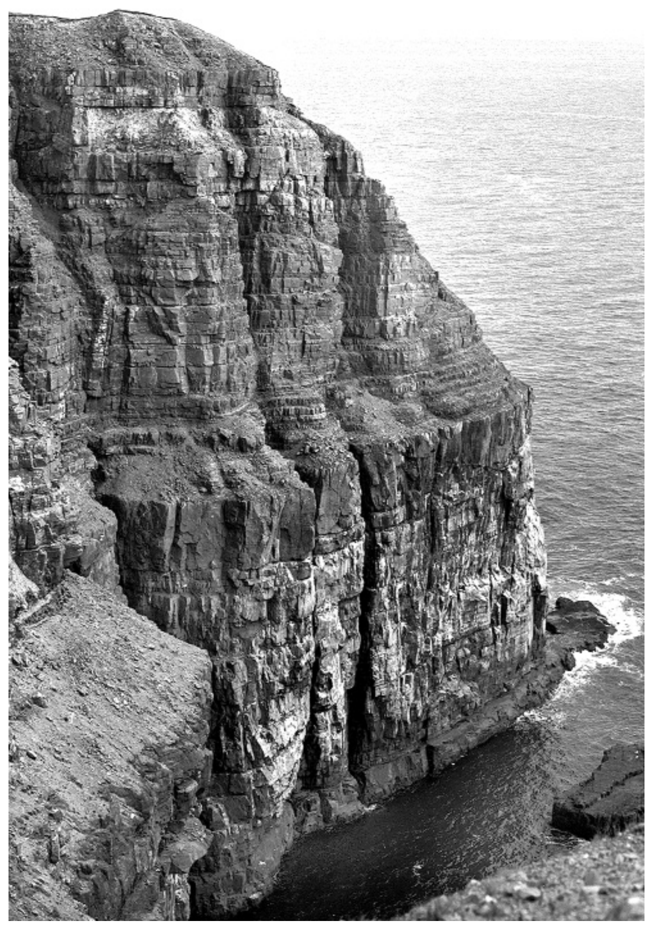

Plate 6. *Strata of the Big Head Formation on the western side of Cape St. Mary's headland.*

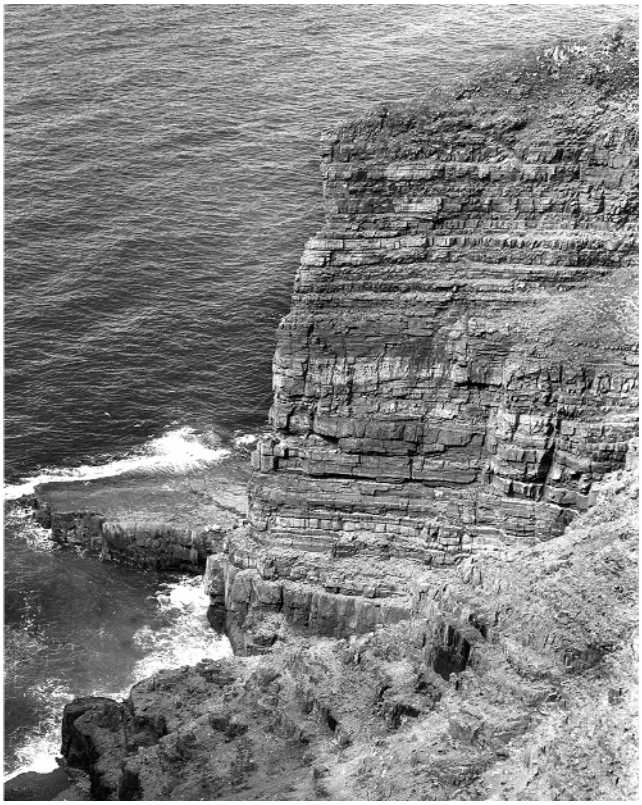

Plate 7. *Inaccessible cliff between Cape St. Mary's and Brierly Cove showing the typical thinner bedded sequence at the top of the Big Head Formation.*

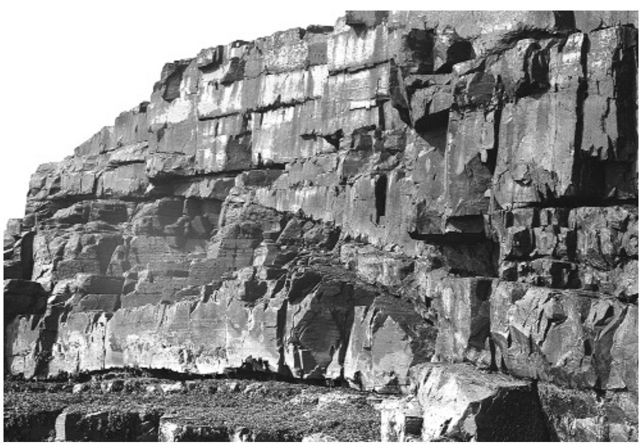

Plate 8. *Close-up view of channelling near the top of the Big Head Formation in Brierly Cove.*

thickness considerably less than 2130 m is evident. The southern outcrop in this map area represents only the top part of the formation, where about 180 m are exposed.

Lithology

A basal unit of redbeds, 30 m thick, characterizes this formation in the type section at Big Head (Jenness, 1963;

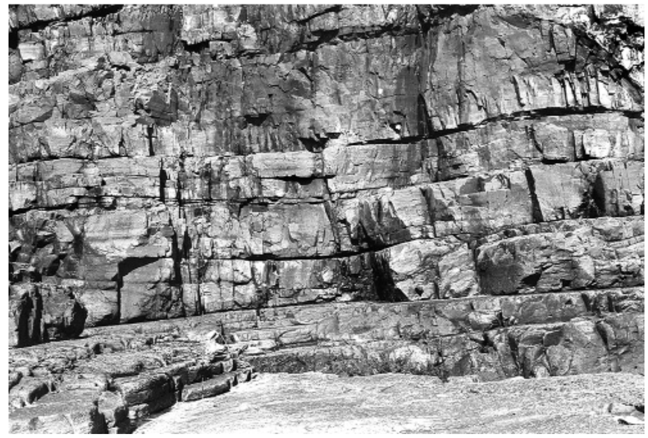

Plate 9. *Swaly beds near the top of the Big Head Formation in Brierly Cove.*

McCartney, 1967). According to McCartney (*op. cit.*), it may be over 300 m thick around Placentia, where it appears to transgress the basal contact as interbeds with basalt flows and breccias, below minor conglomerates in the sequence formerly referred to the Whiteway Formation (Hutchinson, 1953, p. 17). However, no trace of such a redbed unit at the base of the Big Head Formation has been recognized on Cape St. Mary's Peninsula and the situation in the Ship Cove stream noted by McCartney (*op. cit.*), where green sandstone and siltstone are interbedded with volcanic breccia at the basal contact, reflects the overall aspect of the Big Head Formation on Cape St. Mary's Peninsula.

In contrast to the predominant finer grained siltstones, slates and cherty argillite in the Whitbourne map area, the general aspect, in the inaccessible cliff sections of this map area to the south, is of greenish-grey, planar, arkosic sandstone units less than 3 m thick interbedded with thin gritty sandstone, siltstone or laminated mudstone; many beds have ripple-marked tops. Some hummocky crossbeds are evident along with numerous lensoid wedges. Most sandstones are feldspathic, slightly metamorphosed, and relatively well-sorted, with subangular grains having sericite films in a matrix of finer grained epidote and chlorite. Less common are arkosic greywackes, indicated by the overall whiteness of all weathered exposures that emphasize the predominance of feldspar grains. These rocks are more typical of the greenish strata in the higher parts of the formation in the type area to the north described by Jenness (1963) and McCartney (1967). Comparable coarse-grained arkosic facies occur southeast of Long Harbour, Placentia Bay in an unnamed upper member of the Big Head Formation (King, 1988).

Contact Relations

The basal contact throughout the map area is considered to be conformable, where its base is drawn on top of the highest volcanic rock of the Bull Arm Formation. Its upper contact is placed at the base of the first redbed in the False Cape Member at the base of the red Maturin Ponds Formation. In the type section of this basal member at the southern end of Lears Cove in Placentia Bay, it appears to be a conformable contact, where the redbeds rest sharply on apple-green argillite containing sandy wisps and rip-up rolls of coarse sand.

Correlation

The Big Head Formation extends throughout western Avalon Peninsula as a remarkably persistent unit. However, as noted by McCartney (1967), it varies greatly in thickness and also, as shown by King (1988), in lithic character. Its lower part exposed on the Bay de Verde Peninsula is transitional into the underlying Gibbett Hill Formation and its upper part is transitional with the Bay de Verde Formation of the Signal Hill Group (*see* King, 1988, legend/stratigraphical column).

Maturin Ponds Formation (Units 3a to 3c)

Definition

The Maturin Ponds Formation was proposed by McCartney (1967, p. 53) for the sequence of redbed arkoses and siltstones conformably above the green Big Head Formation and below the green Trinny Cove Formation.

In eastern Trinity Bay, King (1988) mapped a comparable sequence (up to 335 m thick) of red arkose and siltstone between Dildo and New Chelsea and correlated it with the Maturin Ponds Formation in the Dildo area, i.e., the sequence originally mapped by McCartney (1957) as unnamed Map Division 10 in the formerly recognized Hodgewater Group Snows Pond Formation. From Dildo, King (*op. cit.*) traced the same sequence through the Argentia map area (McCartney, 1956, Map Division 3) and correlated it with the three distinctive red clastic members mapped throughout the Cape St. Mary's Peninsula map area by Fletcher (1972, 1984, Map units 2b, 2c and 3a). On Cape St. Mary's Peninsula, the prominent mappable conglomerate marker bed (Fletcher, 1972, 1984, Lears Cove Conglomerate, Map unit 2c) in the middle of the Maturin Ponds Formation allows three redbed members to be delineated: False Cape Member, Young's Port Member and Lears Cove Member.

False Cape Member (Unit 3a)

Definition

The name False Cape Member is here proposed for the basal member of the Maturin Ponds Formation on Cape St. Mary's Peninsula, where it conformably overlies the green Big Head Formation and is conformably overlain by the conglomeratic Young's Port Member. The type section forms the cliffs on the southern side of Lears Cove (Plate 10).

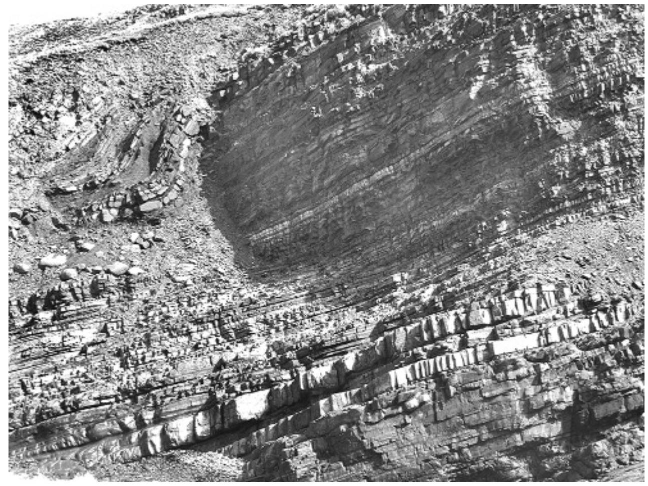

Plate 10. *Relatively thin, planar-bedded siltstone of the False Cape Member in the southern cliffs of Lears Cove.*

Distribution and Thickness

This member is variously exposed in three areas. In the south, it extends from the type section on Placentia Bay as an arcuate outcrop stretching around the nose of the northerly plunging Cape St. Mary's Anticline to the central part of Golden Bay. A small outcrop occurs as an outlier on a fault block at False Cape, where bedding-plane surfaces are well exposed inland of the cliffs. The main outcrop area lies around the bifurcated domal area in the northern part of the map area, but is largely covered by bogland and mainly exposed along the major stream beds. At the type section on Placentia Bay it is 61.2 m thick.

Lithology

The sequence comprises arkosic sandstone, siltstone and argillite, which in places, exhibit shallow-water structures, i.e., ripple marks and coarse channel-fills. Essentially dark red, in the type section, a thick greenish-grey argillite is conspicuous near the top and exhibits patches of soft-sediment deformation (*see* Table 3).

Contact Relations

The lower contact is sharply marked at the base of a prominent red siltstone bed resting on an apple-green arkose at the top of the Big Head Formation sequence. Its upper contact with the conglomeratic Young's Port Member is defined at the top of a gradational sequence marked by the

Table 3. False Cape Member, type section; on coast at the southern side of Lears Cove, Placentia Bay

Unit	Description	Thickness (metres)	Total from base (metres)
9	Gradational siltstone, red planar-bedded zone containing gritty sandstone lenses and soft-sediment deformation at top (Plate12)	2.5	61.2
8	Siltstone, apple green, characteristically rusty weathered	7.7	58.7
7	Slates, red and purplish dark red with silt laminae, typically with "vague streaks and swirls ("zebra-stripe bedding" is used as a field term) defined by gradational deepening of the purplish red colour in elongate patches subparallel with the inferred bedding" (McCartney, 1967, p. 53, facies in Maturin Ponds Formation)	3.1	51.0
6	Sandstone, quartzitic, micro- and mega-ripple marked with thin lensoid porcellanites, grading upwards into fine-grained argillites	15	47.9
5	Slate, dark red	1.3	32.9
4	Slate, bright red	3.1	31.6
3	Slate, very dark red, fine grained containing distinctive thin, yellow goethitic beds	6	28·5
2	Arkose, gritty, very dark red containing thin slate 10.7 m above base	21	22.5
1	Siltstone, very dark red, fine grained containing prominent gritty sandstone layer in middle and convoluted shale at base	1.5	1.5
Big Head Formation			
	Sandstone, arkose, siltstone, cherty argillite and mudstone, greenish-grey to light grey, regularly bedded, typically with conchoidal fracture, weathers very light grey	180+	

main well-cemented conglomerate containing no sandstone interbeds. The general lack of exposure of the Young's Port Member in the northern part of the map area renders it difficult to delineate the unit, but the scattered conglomeratic boulders typical of the member in that region are taken as evidence of the continuity of the member throughout the map area and the maintenance of three discrete members of the Maturin Ponds Formation.

Correlation

The False Cape Member is equivalent to the lower part of the Maturin Ponds Formation in its type locality north of Long Harbour, Placentia Bay, i.e., to redbeds underlying the 120-m-thick "massive conglomerate" noted by McCartney (1967, p. 53) south of Northeast Arm near Placentia. Some of McCartney's descriptions of that sequence are so succinct, that the same discrete environmental settings evidently extended as far south as Golden Bay. East of Trinity Bay, this member correlates with redbeds of the Maturin Ponds Formation extending from Dildo to New Chelsea (King, 1988). McCartney (1967, p. 41) drew attention to the "unusual mottled orange and green cherty beds" peculiar to the Whiteway Formation in the east and although comparable cherty beds also occur in the Bull Arm and Big Head formations (A. King, personal communication, 2005), such rocks resemble certain parts of the False Cape Member in this map area.

Young's Port Member (Unit 3b)

Definition

The name Young's Port Member is here proposed for the oldest conglomerate units in the Musgravetown sequence on Cape St. Mary's Peninsula. It is characterized by its redness. This unit lies in the middle of the Maturin Ponds Formation, conformably separating the False Cape Member below and the Lears Cove Member above.

Distribution and Thickness

The type section forms the small headland 250 m north of the mouth of Lears Cove Brook (Plate 11), close by the old abandoned home of the Young Family. There, it lies at the western end of an arcuate outcrop that stretches to the eastern side of the small promontory just east of the mouth of Golden Bay Brook. The northern outcrop is folded around the bifurcated domal structure, but is largely masked by bogland; it is exposed in stream sections and its continuity is inferred by its distinctive block-boulders scattered over a wide area.

At the type section it is 4.3 m thick and, in Golden Bay, has increased to 4.6 m. No detailed measurements in the northern outcrop have been made, but, in the Gooseberry Cove Brook, it is over 9 m thick. Assuming that the outcrop

Plate 11. *Typical blocky aspect of the conglomeratic Young's Port Member in Lears Cove.*

is continuous with the exposed "400 feet thick" massive red conglomerate in the Maturin Ponds Formation south of Northeast Arm, Placentia (McCartney, 1967, p. 53), a gradual northerly thickening toward the source area is indicated.

Lithology

The conglomerate is medium grained, thick bedded and well cemented. It mostly comprises rounded to subrounded pebbles averaging 2.5 cm in diameter, many of which have their coatings of bluish phosphate. These are mainly red felsite and milky quartz with subordinate mafic volcanic rocks and greyish green siliceous argillites. Three prominent smooth-surfaced joint planes that produce weathered, oblong-shaped boulders characterize the member (Plate 11) and the base is marked by prominent loading structures (Plate 13) pressed into the soft sediment of the underlying member (Plate 12).

Contact Relations

The basal and upper conformable contacts with the adjacent redbed members are sharply defined by the contrasting rock types. These contrasts are locally emphasized topographically by a conglomerate ridge.

Correlation

The Young's Port Member is the unit originally mapped as the Lears Cove Conglomerate in the Brierly Cove Formation (Fletcher, 1972, 1984, Map unit 2c) and it may correlate to the north with an unnamed, red and brown, pebble-conglomeratic interval within Jenness's (1963, p. 48) "Undifferentiated middle formation(s)" of the Musgrave-

Plate 12. *Soft-sediment deformation beneath the conglomeratic base of the Young's Port Member in the underlying False Cape Member in Lears Cove.*

Plate 13. *Loading structures on the conglomerate base of Young's Port Member in Lears Cove, due to pressure on the underlying soft sediment.*

Table 4. Lears Cove Member, type section. On northern coast of Lears Cove, southeastern Placentia Bay in cliffs between Young's Point and Norther Head Brook

Unit	Description	Thickness (metres)	Total from base (metres)
8	Siltstone, dark red, with arkosic gritty sandstone interbeds	76.0	190.3
7	Arkosic gritty sandstone, dark red	9.1	114.3
6	Siltstone, fine grained, pale green, with gritty sandstone interbeds	6.1	105.2
5	Siltstone, fine grained, grey-green, current bedded	30.5	99.1
4	Siltstone, fine grained, dark red, with gritty sandstone partings	45.7	68.6
3	Siltstone, grey-green, with dark red and brown siltstone partings	6.1	22 9
	Diabase sill with calcite veins	9.1	
2	Siltstone, fine grained, dark red	12.2	16.8
1	Siltstone, fining upward, dark red and greyish green	4.6	4.6
Young's Port Member		4.3	

town Group. It may be significant that the pebble sizes in the map area are generally smaller than in the Maturin Ponds Formation, south of Northeast Arm, Placentia Bay, where the likely correlative red conglomerate has pebbles averaging 2.5 cm, but up to 10 cm in diameter (McCartney, 1967, p. 53).

Lears Cove Member (Unit 3c)

Definition

The name Lears Cove Member is here proposed for the mainly red siltstone and coarse-grained arkose at the top of the Maturin Ponds Formation on Cape St. Mary's Peninsula. It rests conformably on the red conglomerate of the Young's Port Member and is overlain by green siltstones of the Golden Bay Member at the base of the Heart's Content Formation. The type section is the Placentia Bay cliff section between Young's Point and Norther Head Brook on the northern side of Lears Cove. This member was originally mapped as Map unit 3a by Fletcher (1972, 1984).

Distribution and Thickness

This member is exposed in two areas. The southern area forms an arcuate belt around the nose of the northerly plunging Cape St. Mary's Anticline between a faulted area near the type section and the eastern side of Golden Bay. The northern area forms a strip of varying width around the bifurcate domal structure. It is exposed in stream sections, but rarely exposed through the marshland cover. At the type section in the south, it is about 190 m thick.

Lithology

The Lears Cove Member is essentially a dark-red siltstone sequence containing thin, coarse-grained arkosic interbeds and partings and a prominent green siltstone interval in the middle (*see* Table 4). The thick arkosic beds have regular bedding, invariably defined by thin, darker red siltstone laminae along which the rock breaks. Crossbedding and ripple marks are commonly displayed. The excellent exposures in both Lears Cove and Golden Bay reveal a multitude of finer sedimentological details, e.g., flaser bedding, ripple-drift structures, scours and small-scale channelling, worthy of special study. Such features suggest deposition in a constant high-flow fluvial regime. Meagre palaeocurrent-direction readings indicate a northwestern provenance for the sediments. The detritus is largely feldspathic and its redness may indicate oxidizing conditions at the time of deposition.

Contact Relations

The conformable base of the Lears Cove Member is sharply defined by the top surface of the underlying Young's Port Member conglomerate; its top is similarly defined at the base of a dark grey and olive-brown, shaly Golden Bay Member at the base of the greenish grey Heart's Content Formation.

Correlation

Lithological correlation and continuity of each flank of the northern outcrop area indicates general equivalence of this essentially red arkose and siltstone member with greyish-green siltstone interbeds in the upper part of the Maturin Pond Formation.

Heart's Content Formation (Units 4a to 4c)

Definition

The name Heart's Content formation was applied by King (1988) to a distinctive 600- to 1000-m-thick sedimentary sequence in eastern Trinity Bay, consisting of grey to black shaly mudstone containing wispy, crosslaminae of siltstone and sandstone. The type area is Heart's Content Harbour (north and south sides), but no type section was established as components are best displayed at several reference localities. In that region, the Heart's Content Formation rests conformably upon the red Maturin Ponds Formation and was mapped by King southward from New Chelsea along the western side of Bay de Verde Peninsula, and correlated with a lithic unit mapped throughout the Dildo map area by McCartney (1957) as Map Division 11 within the Snows Pond Formation. The Heart's Content Formation in southern and eastern Trinity Bay gradually passes upward into a pinching and swelling sequence (up to 500 m thick) consisting of brown- to grey-weathering, olive-green sandstone and siltstone and named Heart's Desire Formation by King (1988). In places, olive-green sandstone and siltstone of the Heart's Desire Formation change vertically through abrupt gradation into an overlying unit, up to 200 m thick, of red and grey, trough-crossbedded arkose and interbedded red and green siltstone interpreted by King (personal communication, 2005) as an unnamed transitional member grading upward into mainly red pebble conglomerate and coarse-grained sandstone; this coarse sequence exposed on the coast between Heart's Desire and Hant's Head was assigned to the Crown Hill Formation (King, 1988). However, farther south, between Heart's Desire and Dildo, no contact with the red Crown Hill Formation is established, because the Cambrian Random Formation transgresses the Heart's Desire Formation to rest disconformably upon the upper part of the Heart's Content Formation.

In the Angel's Cove-Ship Cove area, McCartney (1967) mapped the strata between the red Maturins Pond Formation and the Random Formation as Trinny Cove Formation. The type section of this formation is well exposed in Trinny Cove, 30.6 km northwest of Long Harbour in Placentia Bay where, as noted by McCartney (1967, p. 55-56), mainly conglomerate and coarse arkose beds conformably overlie the Maturin Pond Formation and underlie the Crown Hill Formation. East of the type section, the Trinny Cove Formation changes laterally through gradation or intertonguing into different rock types (McCartney, 1967) and therefore, new formation names were proposed by King (1988). The name Trinny Cove Formation is not used in this map area, because it includes Kings' (1988) Heart's Content Formation and this writer's proposed Hurricane Brook Member of the Crown Hill Formation.

On Cape St. Mary's Peninsula, a "grey conglomerate" noted by McCartney (1967, p. 56) forms a prominent marker bed exposed in many places as a topographical ridge (Plate 2) and mapped by Fletcher (1972, 1984) as the "Norther Head Conglomerate (Map-unit 4a)". Although mapped by McCartney (1957, Map Division 12) in the Dildo map area, he did not give it formal status in his later Whitbourne map-area memoir (McCartney, 1967). Subsequently, this 10- to 20-m-thick, grey pebble conglomerate in the lower to middle part of the Heart's Content Formation on Bellevue Peninsula, southern Trinity Bay, was named Bellevue Beach Member by King (1988).

King (1988) traced the Heart's Content Formation (including the Bellevue Beach Member) and the Heart's Desire Formation (including unnamed red member at the top) southward and extended them into Cape St. Mary's Peninsula map area, utilizing the unnamed lithic units and their boundaries, as determined by McCartney (1956, Map Divisions 4a and 4b) in the Argentia map area. In this account of the lithostratigraphy of Cape St. Mary's Peninsula, the Heart's Content Formation is recognized as the greyish shaly mudstone–siltstone sequence conformably intervening between the redbed sequences of the Maturin Ponds Formation below and the Crown Hill Formation above; the distinctive characteristics of the conglomeratic Bellevue Beach Member [Norther Head Conglomerate] in the middle of the sequence readily allows three distinct members to be mapped in the map area: a lower Golden Bay Member, middle Bellevue Beach Member and an upper Cats Cove Member.

Golden Bay Member (Unit 4a)

Definition

The name Golden Bay Member is here applied to the greyish green siltstone and olive-brown and blackish shaly mudstone, at the base of the Heart's Content Formation, conformably overlying the red Lears Cove Member at the top of the Maturin Ponds Formation and conformably underlying the conglomeratic Bellevue Beach Member. In this map area, it was previously mapped as Map-unit 3b (Fletcher, 1972, 1984). The type section lies on the southeastern cliff of Placentia Bay between the mouth of Norther Head Brook and the southern side of Norther Head.

Distribution and Thickness

The Golden Bay Member is best exposed in cliffs at each end of its southern arcuate outcrop area that stretches over the axis of the northerly plunging Cape St. Mary's Anticline from the type section on Placentia Bay to the southeastern side of Golden Bay. In this region, it maintains a thickness of about 25 m as exposed at the type section and in the Golden Bay cliff. However, it appears to thin northward in the northern outcrop area. In the northwest, its narrower outcrop in Gooseberry Cove Brook is largely due to the local relatively steep dips characterizing the western flank of the Cape St. Mary's Anticline. However, the narrowness there is also due to reddening of beds that farther south, in the type section, are olive brown and green and demonstrate a diachronous colour contact between formations. In the east, the member is best exposed in the Beckford River section, where the outcrop area is wider due to shallower dips over the axis of the southerly plunging Branch Anticline. Farther northeast of Branch, the dips steepen to restrict the width of the outcrop area, but lack of exposures prevents any further demonstration of a diachronous formational boundary due to a migrating colour boundary.

Lithology

Two rock types distinguish the type section, namely, mudstone and siltstone. The basal unit comprises 9 m of olive-brown and blackish shaly mudstone and it is conformably overlain by 15 m of greyish-green, fine-grained, ripple-bedded siltstone (Plate 14).

Contact Relations

At the type section, the base is sharply defined at the bottom of a shaly mudstone resting on a dark red siltstone containing coarse-grained arkosic interbeds and is a contact regarded as conformable. However, as noted above, the basal contact in the northern part of the map area appears to be diachronous due to differential oxidation/reduction of the sediments. The upper boundary is conformable with the Bellevue Beach Member, although, in places, the latter may fill shallow channels along the contact (Plate 14).

Correlation

As defined above, the Golden Bay Member appears to correlate with the lowest unnamed member of the Heart's Content Formation, i.e., McCartney's (1957) lower Map Division 11 on the Bellevue Peninsula in the Dildo map area.

Bellevue Beach Member (Unit 4b)

Definition

The Bellevue Beach Member is a prominent sequence of distinctive grey conglomerate beds named by King (1988) within the Heart's Content Formation on the Bellevue Peninsula. The type section lies within the Bellevue Peninsula outcrop area originally mapped as the Snows Pond Formation of the Hodgewater Group by McCartney (1957). King (personal communication, 2005) traced the Bellevue Beach Member southward to the Villa Marie Syncline (King, 1988), where it forms a distinctive but rarely

Plate 14. *Conglomeratic channel fills at the base of Bellevue Beach Member in Cats Cove.*

exposed unit within the mid to upper part of the Heart's Content Formation.

Distribution and Thickness

In the Cape St. Mary's Peninsula area, the conglomerate of the Bellevue Beach Member is highly resistant to erosion and commonly forms topographical ridges in areas not masked by thick bog (Plate 2). The southern arcuate belt stretches from its faulted end around the Norther Head promontory on Placentia Bay, over the northerly plunging Cape St. Mary's Anticline to the southeastern cliffs of Golden Bay at Cats Brook. Its northern outcrop surrounds the northern bifurcated domal structure to connect with the conglomerate exposed (but not everywhere mapped) in the Whitbourne map area as noted by McCartney (1967). It is particularly well exposed around the nose of the southerly plunging Beckford Anticline and in all major streams crossing its outcrop; elsewhere, it is poorly exposed. At Norther Head and in Golden Bay, it is completely exposed and about 21 m thick.

Lithology

The Bellevue Beach Member comprises pale grey and greenish, compact, well-cemented, quartzose, pebble conglomerate beds each about 4.6 m thick, in channel contact with minor interbedded grey-green siltstones. The pebbles are subrounded and generally less than 5 cm in diameter. They are predominantly of vein quartz and dense, grey-green, cherty argillite cemented by light grey-whitish quartz. The well-cemented conglomerate characteristically weathers along strong joints to produce large resistant blocks, in contrast to thin conglomerates within the bounding members. In the north, it is slightly coarser, as may be inferred by McCartney's (1967, p. 56) observation that pebble sizes are up to 7.5 cm in diameter near Ship Cove.

Contact Relations

The contacts are sharply defined at junctions with conformable siltstones of the Golden Bay Siltstone Member below and the Cats Cove Siltstone Member above, where channel-fills are common.

Correlation

The continuity of the northern outcrop area with similarly described, but thicker, conglomerate beds in the Whitbourne map area indicates that the exposures mapped by the writer in 1959 (Fletcher, 1972, 1984, Map unit 4a) as the Norther Head Conglomerate represent the southern development of the Bellevue Beach Member recognized by King (1988).

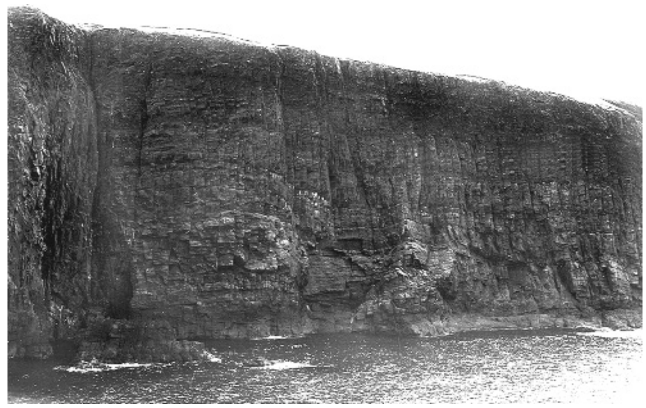

Plate 15. *Cliff section of the middle beds of the Cats Cove Member in Fish Cove south of Cats Cove.*

Cats Cove Member (Unit 4c)

Definition

The Cats Cove Member (Plate 15) is here named for the highest member of the Heart's Content Formation on Cape St. Mary's Peninsula. It is characterized as the green clastic sequence intervening between the conformable Bellevue Beach Member below and the upper colour change to red marking the base of the Hurricane Brook Member (Plate 16) at the base of the Crown Hill Formation. The type section is the cliff section on Placentia Bay between the northern side of Norther Head and the mouth of the stream just south of Island Head.

Plate 16. *Basal beds of the Hurricane Brook Member preserved in the axis of the St. Bride's Syncline on the southern side of Island Head.*

Distribution and Thickness

The Cats Cove Member has been mapped as one continuous unit throughout the map area. In the south, its lower boundary follows an arcuate track from the Norther Head environs over the northerly plunging Cape St. Mary's Anticline southward to Cats Cove and Redland Point at the southeastern end of Golden Bay. In the north, the lower boundary tracks around the southerly directed noses of several major folds and around the northern end of the intervening southerly plunging Point Lance Syncline. The upper boundary more or less parallels the lower boundary, but, due to differential erosion of the Musgravetown Group sequence prior to the deposition of the Cambrian Random Formation, the complete Cats Cove Member is largely preserved to the northwest of a line drawn from a point about 13 km due east of Perch Cove, in the headwater region of Branch River, to a point about 8 km due north of Bull Island Point (*see* Figure 3). It is well exposed in all the major stream sections. Small outcrops of the overlying Hurricane Brook Member farther north on St. Mary's Bay, underlying the quartz arenites of the Random Formation in the cliffs just north of the East Head of Red Head Cove and at Jonas Point indicate that the Cats Cove Member may be completely preserved in those regions. Note that these Hurricane Brook redbed outcrops were regarded by King (1988) as an unnamed red arkosic member at the top of the Heart's Desire Formation that he (A. King, personal communication, 2005) assumed to correlate with McCartney's upper red member (1956, Map Division 4b; 1957, Map Division 14).

In the southern cliff sections on Placentia Bay and at Cats Cove, the Cats Cove Member is about 177 m thick (Plate 15) and, where completely preserved in the north, it may be slightly thicker.

Lithology

Compared to other Musgravetown Group formations, the upper part of the Heart's Content Formation, as represented by the Cats Cove Member, is distinguished by conspicuous intervals of shaly mudstone. In the lower part, the

Table 5. Cats Cove Member, type section. On coast from Norther Head to Island Head Brook, southeast Placentia Bay

Unit	Description	Thickness (metres)	Total from base (metres)
7	Siltstone and silty mudstone, grey-green, characteristically thinly laminated and wavy bedded with wisps and discontinuous streaks	45.5	176
6	Mudstone, shaly, brownish olive and very dark grey	15	130.5
5	Gritty sandstone, arkosic, greyish green, containing thin dusky brown shale partings	30	115.5
4	Mudstone, shaly, greyish brown	15	85
3	Siltstone, greyish green, medium-fine grained, wavy bedded	9	70
2	Siltstone, brownish red, fine grained, containing minor interbeds of greyish green sandstone	30.5	61
1	Mudstone, shaly, silty, greyish green and brown	30.5	30.5
Bellevue Beach Member		21	

essentially grey-green, relatively thick, shaly mudstone units are interbedded with siltstone and rarer crossbedded, medium- to coarse-grained sandstone as indicated in Table 5, but the higher beds largely comprise thinly layered siltstone exhibiting ripple bedding (Plates 15 and 17). At Redland Cove, a thin conspicuous conglomerate bed lies 17 m below the upper unconformable contact with the Bonavista Formation. The constituent clasts include red jasper, which is also found in the basal conglomeratic quartz arenites of the Random Formation. Greene (1962a, b) reasonably regarded this to mark the local base of the Random Formation at Redland Cove, but, although the lithofacies has features in common with Facies 2 of the Random Formation (Hiscott, 1982), the lack of any trace of a quartz-arenite facies so near to its significantly thin occurrence just to the north, is considered by the writer to be sufficient evidence to regard this sequence as a typical part of the Cats Cove Member. In the Redland Point section, the top 4.6 m coarsens upward into a micaceous siltstone that may have been diagenetically reddened in the top 90 cm, below the basal, pink conglomeratic limestone at the base of the Bonavista Formation.

Contact Relations

The basal contact of the Cats Cove member is conformable on the thick, blocky, Bellevue Beach Member conglomerate. The upper contact, where the member is completely preserved, appears to be conformable with the Hurricane Brook Member redbeds as exposed in the cliff section on the southern side of Island Head (Plate 16). However, over much of the southeastern and eastern parts of the map area, the Random Formation transgresses an eroded Musgravetown Group sequence to rest on different levels within the Cats Cove sequence. At Redland Point, where the Random Formation is not preserved, the member is directly overlain by the transgressive base of the Bonavista Formation that here is marked by a complex pebbly limestone unit marking the base of the Cuslett Mudstone Member (Plate 17).

Plate 17. *Close-up view of the contact between the Cats Cove Member and the basal limestone of the Bonavista Formation in Redland Cove (hammer head on contact).*

Correlation

In the western part of the map area just south of Ship Cove, the Cats Cove Member is continuous with McCartney's (1967, p. 56) lower levels of the Trinny Cove Formation, whereas on the eastern side, it strikes into the highest unnamed member of the Heart's Content Formation mapped by King (1988); the latter is equivalent to the upper green beds of the formerly recognized Snows Pond Formation (Hutchinson, 1953, p. 18) and McCartney's (1957) upper Map Division 11 in the Dildo map area. King (1988, personal communication, 2005) restricts the Trinny Cove Formation to its type area in northeastern Placentia Bay and western parts of Trinity Bay and has established that its equivalent to the east is better subdivided into a lower Heart's Content Formation (with the Bellevue Beach Member) and an upper Heart's Desire Formation. King (personal communication, 2005) notes that, although the lithic characteristics of the Heart's Content Formation are relatively consistent throughout western Avalon Peninsula, those of the Heart's Desire Formation change both laterally and vertically from north to south. For example, between the Argentia and Cape St. Mary's Peninsula map areas, there is a relative thinning of the green sandstones and a thickening of the upper arkose and siltstone member of the Heart's Desire Formation to form a transitional unit upward into the Crown Hill Formation. In his compilation of the 1:250 000 geological map of the Avalon Peninsula, King (1988) correlated the Heart's Desire Formation with the upper part of Fletcher's (1972, 1984) "Cat Cove Siltstones Member" (Subunit 4b) and his unnamed redbed member at the top of the Heart's Desire Formation with Fletcher's "Hurricane Brook Redbeds Member" (Subunit 4c).

Near Ship Cove beach, King (personal communication, 2005) noted typical examples of wispy-laminated black shales of the Heart's Content Formation (Cats Cove Member) coarsening stratigraphically upward near the headlands into thick beds of greenish grey sandstone with decreasing shale interbeds. He interpreted the sandstones with their crossbeds and large internal load structures as broad channel-fill deposits of Heart's Desire Formation aspect and that they are conformably overlain farther south near Gooseberry Cove with abrupt gradation, by red sandstones, siltstones and mudstones (Hurricane Brook Member). Precise correlation of the Heart's Desire Formation with the Trinny Cove Formation near Ship Cove (*see* McCartney, 1967, p. 56) is difficult to establish despite the lithological similarities and relative stratigraphical positions of the Maturin Ponds and Heart's Content formations below and the Crown Hill Formation above. Therefore, because the lithofacies and boundaries of the Heart's Desire Formation in the Argentia map area are not clearly recognizable in the Cape St. Mary's map area, a local lithostratigraphical subdivision of this part of the Musgravetown sequence is desirable. Hence, the grey-green Cats Cove Member is recognized as the top member of the Heart's Content Formation, conformably overlain by the red basal unit of the Crown Hill Formation, here named Hurricane Brook Member. Consequently, the Heart's Content Formation as defined in this map area, i.e., the greyish sequence intervening between two prominent redbed sequences, fits the general diagnosis of part of the Trinny Cove Formation given by McCartney (1967) for the Ship Cove-Angel's Cove area.

Crown Hill Formation (Units 5a and 5b)

Definition

McCartney (1958, p. 8) first proposed the name Crown Hill Conglomerate Member for the red conglomerate sequence at the top of the Musgravetown Group that underlies the Random Formation. In the type area within the Deer Harbour Syncline, it comprises a lower unit characterized by up to 150 m of "unusually bright red siltstone and dull red arkose" below 450 m of red conglomerate beds. In a later account of the geology of the Terra Nova and Bonavista map areas, Jenness (1963, p. 49) raised its status to a formation. On Cape St. Mary's Peninsula, the formation is similarly subdivided, where the two facies are regarded as succinct members, namely the lower Hurricane Brook Member and upper Cross Point Member.

Hurricane Brook Member (Unit 5a)

Definition

The Hurricane Brook Member is here named for the lower member of the Crown Hill Formation on Cape St. Mary's Peninsula and in this area was originally mapped as Map unit 4c (Fletcher, 1972, 1984). It comprises relatively thick beds of arkosic siltstones and sandstones resting conformably upon the grey-green muddy siltstones of the Cats Cove Member at the top of the Heart's Content Formation. The lower boundary is drawn at the major colour change to red of this silty sandstone sequence that conformably underlies the dark red, coarser grained sandstones and conglomerates of the Cross Point Member.

The type section is the Placentia Bay cliff section between Island Head Brook, on the southern side of Island Head, and Hurricane Brook (incorrectly named Muskrat Brook on the Canada 1:50 000 National Topographic Series Sheet 1L/16 East Half).

Distribution and Thickness

The Hurricane Brook Member is completely preserved in outcrop only along the western flank of the St. Bride's Syncline between its contact with the Cross Point Member just south of Breme Point and about 1.6 km northeast of Angel's Cove (Figures 3 and 4). Due to the erosion, responsible for the removal of the younger conglomerate member prior to the deposition of the Random Formation, incom-

Table 6. Hurricane Brook Member, type section; on coast north of Island Head Brook, Placentia Bay

Unit	Description	Thickness (m)	Total from base (m)
3	Sandstone, arkosic, gritty, dark red, in beds about 3.7 m thick, interbedded with darker red siltstones and dark red mudstones resembling mudstones of the Adeyton Group	90	300
2	Sandstone, arkosic, graded bedded, dark red	60	210
1	Siltstone, dark red, with thinner beds of lighter red and green coarse-grained arkose	150	150
Cats Cove Member		176	

plete sequences crop out along both flanks of the syncline – on the eastern side from Island Head to Ship Cove (just north of the map area) and on the western flank to the closure of the syncline at Ship Cove. Small eroded remnants are preserved beneath the outcrops of the Random Formation farther east in three separate areas. The main remnant is preserved around the northern end of the Cambrian outcrop in the Point Lance Synclinorium, between a point about 13 km east of Perch Cove and a point about 7 km north of Bull Island Point. The ends of this faulted strip represent points where the member was completely eroded before the Random transgression. Similar eroded successions of these redbeds are preserved beneath the Random Formation along the shore of St. Mary's Bay. The more southerly succession lies between the East Head of Red Head Cove (mistakenly named Jigging Cove on the Canada 1:50 000 Topographic Series Sheet 1K/13) and Smith's Gulch, and the northerly succession around the Cambrian outcrop in the Cape Dog Syncline, where it is about 9 m thick. Although the whole sequence is not fully exposed in a measurable section, the type section is about 300 m thick and probably represents its fullest development.

Lithology

The Hurricane Brook Member is essentially a coarsening-upward, dark red siltstone to very coarse-grained sandstone sequence containing some interbedded, paler red and green coarse-grained arkoses and dark red mudstones, as outlined in Table 6.

Contact Relations

Both lower and upper contacts are conformable. A lithological and green to red colour change mark its junction with the Cats Cove Member of the Heart's Content Formation below and a prominent change to coarse-grained conglomerate delineates its contact with the overlying Cross Point Member.

Correlation

The western outcrop area of the Hurricane Brook Member, in the St. Bride's Syncline, appears to be an outlier of beds "probably equivalent" (McCartney, 1967, p. 57) to redbeds of the Crown Hill Formation in northeastern Placentia Bay and the Trinity Bay region, i.e., the basal sequence of "bright red siltstone and dull red arkose" in the lowest part of the formation. On the other hand, the more eastern outcrop areas (Figure 3), e.g., between East Head and Shag Roost and at Jonas Point, may represent reddened equivalents of the green siltstones of the variable Heart's Desire Formation mapped by King (1988) or to the unnamed red member at the top of the formation that he considers transitional to the Crown Hill Formation as previously discussed.

Cross Point Member (Unit 5b)

Definition

The name Cross Point Member is here proposed for the prominent sequence of dark red conglomerates and very coarse-grained pebbly sandstones forming the top beds of the Musgravetown Group succession on Cape St. Mary's Peninsula. There, it conformably overlies the Hurricane Brook Member and is unconformably overlain by the Random Formation.

The Cross Point Member is best displayed in the Placentia Bay cliffs between Cuslett Cove and the southern side of Breme Point, where the lower and upper contacts are exposed. However, the sequence is considerably faulted and no unbroken section of the whole succession has been detected, but it may stand as the type section. It was previously mapped as the Cross Point Formation (Fletcher, 1972, 1984, Map unit 5).

Distribution and Thickness

The Cross Point Member crops out only in faulted blocks on the western side of the St. Bride's Syncline (Figures 3 and 4). The most southerly outcrop forms the cliffs between the southern side of Cross Point and the southern shore of Perch Cove. A narrow outcrop of the highest beds lies along the shore to the south of Cuslett Cove and continuous northward below the waters of the cove with the main faulted outcrop stretching inland as far north as a point about 1.6 km northeast of Angel's Cove.

Due to differential pre-Random Formation erosion of the Musgravetown Group, the Cross Point Member is thickest in the southern outcrop area and the outcrops represent the meagre local remnants of a former widespread conglomerate cover, here preserved in a lensoid basin with its long axis plunging northeastward from the area immediately north of Hurricane Brook and plunging southwestward from a point just south of Patrick's Cove. As far as the evidence of the faulted blocks allows, the defined conglomerate member is at least 75 m thick around Cross Point.

Lithology

The Cross Point Member comprises well-cemented, interbedded quartz-pebble conglomerates and pebbly coarse-grained sandstone in beds about 3 m thick. The larger pebbles are generally less than 2.5 cm in diameter and are predominantly of subrounded vein quartz. An overall grain coating of hematite gives a pronounced redness; where fresh, it is dark red, but weathered surfaces generally display paler red hues. At the contact with the Random Formation on the southern side of Cross Point, the top 9 m exhibit the reducing effects of the pre-Random period of erosion and are pale green.

Contact Relations

The basal contact with the Hurricane Brook Member is conformable and coincides with the marked lithological coarsening to pebbly conglomerate. Its upper contact is everywhere unconformable with the Random Formation.

Correlation

The youngest rocks preserved in the Musgravetown Group of southeast Newfoundland are predominantly red and conglomeratic. Clearly representing relatively high-energy, shallow-water conditions, their former widespread cover evidently incorporated a considerable number of different interdigitating lateral facies. As a consequence, the complex lithostratigraphy at any one locality is now unlikely to be traceable over large distances and distinguishable in the numerous isolated remnants. Recognizing this, McCartney (1958, p. 8) assigned the name Crown Hill Conglomerate Member to accommodate the complexity of these coarse-grained redbeds in the Sunnyside map area. Although he recognized a basal sequence of "unusually bright red siltstone and normal, dull red arkose", he did not further subdivide the member. Later, he recognized its status as the Crown Hill Formation, but, despite his statement that "lithostratigraphic units tend to maintain their identity for long distances along the regional north-northeasterly trend", McCartney (1967, p. 57) considered that there was insufficient similarity of the redbeds in the southwestern corner of the Whitbourne map area to warrant the use of the name Crown Hill Formation for the highest redbeds on Cape St. Mary's Peninsula. However, on King's (1988) Avalon Peninsula map, they are shown as Crown Hill Formation, along with comparable coarse clastic lithologies exposed in two coastal strips between Heart's Desire and Hants Head in eastern Trinity Bay.

Having examined Crown Hill sections to the north as far distant as Hickman's Harbour, i.e., those described by Jenness (1963, p. 50), the writer does not consider the dissimilarities to those facies on Cape St. Mary's Peninsula are more than would reasonably be expected in a contemporaneous high-energy sedimentary sequence over 130 km distant. Considering this distance and the amount of "rapid facies changes" that have been postulated for older Musgravetown sediments, there would seem to be a remarkable match between McCartney's basal siltstones and the Hurricane Brook Member at the junction of the Whitbourne and Cape St. Mary's map areas, and between the upper conglomeratic sequence with the Cross Point Member farther down Placentia Bay, between Angel's Cove and Cross Point.

CAMBRIAN ROCKS

One of the marker sequences in the Dantzic Supergroup is the quartzose Random Formation, first described on Random Island on the western side of Trinity Bay (Walcott, 1900a). Over much of the areas north and east of the southern Burin Peninsula, it forms the local basal unit of the Cambrian, in contrast to its stratigraphical position well within the thick early Cambrian sequence preserved in the Fortune Valley Syncline between Fortune and Pieduck Point (O'Brien *et al.*, 1977; Bengtson and Fletcher, 1983) and on the nearby French island of Langlade (Rabu *et al.*, 1993a, b; Rabu and Chauvel, 1994). Its apparent conformity with the underlying Chapel Island Formation in those southern regions is debatable, but elsewhere, it clearly transgresses bevelled, eroded, Ediacaran sequences and is unconformably overlain by various Cambrian formations on the Avalon Peninsula.

Analyses of the scattered outcrops indicate that the Cambrian rocks of southeastern Newfoundland were deposited on a wide shelf experiencing differential subsidence over the sites of scattered, small, elongate, Late Neoproterozoic fault-bound basins. Four separate sub-basins can be differentiated. These are distinguished as unique sites where each succession is thickest for a particular interval of Cambrian time.

In the southern part of the Burin Peninsula, the rate of deposition in the Fortune-Dantzic sub-basin slowed down appreciably following the deposition of the Rencontre Formation-Random Formation sequence and later sedimentation was intermittently interrupted so that the post-Random Formation sequence there is considerably thinner and less complete than most contemporaneous sequences elsewhere.

The next interval of time, represented by the Bonavista Formation, saw the greatest accumulation of sediment in a sub-basin aligned along the Bonavista Peninsula (*see* Hutchinson, 1962, fig. 2) southward to Lawn Bay on the Burin Peninsula. An eventual decrease in the rate of sedimentation in this sub-basin and elsewhere is betrayed by a shallowing that eventually led to the development of the overlying stromatolitic limestones of the Fosters Point Member of the Smith Point Formation. Such shallowing continued until a time of non-deposition and possible emergence of the algal flats over a considerable area of this part of Avalonia. Later differential deepening of the marine waters gave rise to another episode of shallow-water limestone deposition now marked by the transgressive Broad Cove Member at the top part of the Smith Point Formation. With further deepening, the former mudstone environments were re-established. The consequent deposition of the Redland Cove Member of the Brigus Formation saw the greatest sedimentation rate in a sub-basin centred on the southeastern part of Trinity Bay. Note that Hutchinson's (1962, fig. 4) isopach map of the whole Brigus Formation is a little misleading, because the greatest thickness centred on Long Cove is due to the unusually thick Redland Cove Member in that region, where the developments of the overlying members were considerably thinner than farther south on Cape St. Mary's Peninsula.

Following deposition of the Redland Cove Member, there was a further shift in the centre of deposition to the southern part of Cape St. Mary's Peninsula, where the thickest and most complete Jigging Member-Beckford Formation sequence in the Avalon Zone accumulated. This latter fact emphasizes the importance of this report in documenting the lithological and biostratigraphical changes exhibited in the St. Mary's Peninsula area for the rocks deposited in the controversial interval of time within which a global "Lower-Middle Cambrian Boundary = Cambrian Series 2-3 boundary (Peng *et al.*, 2006, fig. 1)" is to be recognized.

The major unconformity between rocks of the Ediacaran Musgravetown Group and Cambrian Random Formation at the base of the Adeyton Group on Cape St. Mary's Peninsula accounts for the absence of the Fortune Group at the base of the Dantzic Supergroup in this map area.

ADEYTON GROUP (UNITS 6 TO 10)

Definition

The Adeyton Group represents the upper subdivision of the Dantzic Supergroup in southeastern Newfoundland. In this account, the Random Formation is regarded as its basal formation, as discussed above (p. 14). The group is an Early Cambrian shelf assemblage of weakly tectonized, quartz arenites and red, purple and green, carbonate-bearing mudstones, intervening between the generally more-inshore-shelf, Late Ediacaran–Cambrian, sedimentary rocks of the Fortune Group below and Late Cambrian, deeper water sedimentary rocks of the Harcourt Group above. Except for sections on the southern Burin Peninsula and Langlade, its transgressive base largely lies unconformably upon an eroded sequence of Ediacaran rocks and its upper limit is drawn at the base of the conformable Metabentonite Bed (*see* pages 77 and 78), i.e., the thin, whitish, unctuous clay (Howell, 1925, Bed 36, p. 50) marking the base of blackish shaly mudstones assigned to the Manuels River Formation (Hutchinson, 1962, p. 22).

Above the Random Formation, two prominent marker units serve to subdivide the other part of the group into four mappable formations (Hutchinson, 1962, p. 9); they are only mappable on scales of 1:25 000 and 1:50 000 (Fletcher, 1972, 1984) and cannot be differentiated on smaller scale maps (Jenness, 1963; McCartney, 1967; King, 1988). These units are in descending stratigraphical order: the Chamberlain's Brook Formation, the Brigus Formation, the Smith Point Formation, the Bonavista Formation and the Random Formation.

The lower marker unit is the thick pink limestone of the Smith Point Formation, extensively mappable as a resistant topographical feature separating the Bonavista and Brigus formations (*see* Cover and Plate 20), whilst the upper marker unit is very conspicuous in exposed sections as "a thin manganiferous member" (Hutchinson, 1962, p. 45) at the base of the Chamberlain's Brook Formation. When originally proposed, the base of the latter formation was drawn at the top of the "manganese formation" (Howell, 1925, Table 3, p. 56) in the famous Manuels River section, but, on the evidence at other localities, Hutchinson (1962, p.19) extended the Chamberlain's Brook Formation down to the base of the manganese sequence. The group is fossiliferous throughout, with trilobites the most common forms, first occurring in the top beds of the Smith Point Formation.

With the exception of the Smith Point Formation, the formations of the Adeyton Group comprise hundreds of metres of strata. It is the main concern, here, to further subdivide these into discrete members and to identify other conspicuous beds in the sequence. Generally, these subdivisions are not mappable, but are clearly differentiated in exposed sections and provide a guide to the chronology of both sedimentary and faunal events.

Random Formation (Unit 6)

Definition

The Random Formation is a prominent grey clastic sequence characterized by white-weathering, crossbedded, quartz arenites within the Early Cambrian succession of southeastern Newfoundland. In the southern Burin Peninsula and on Langlade (Figure 2), it is underlain by the Chapel Island Formation at the top of the Fortune Group, but farther north, and east as far as the eastern side of Trinity Bay, it rests unconformably upon pre-Fortune Group, Late Ediacaran sedimentary formations. Everywhere, the Random Formation is unconformably overlain by younger Adeyton formations as in the type section at Hickman's Harbour on Random Island (Figure 9).

Distribution and Thickness

On Cape St. Mary's Peninsula, the Random Formation occurs in faulted and folded outliers. The western outcrop area is continuous around the doubly plunging St. Bride's Syncline, where it overlies a truncated Crown Hill Formation. The main outcrop area surrounds the synclinorium of younger rocks centred on the southern end of the Point Lance Syncline and stretches from the McGill's Marsh (Figure 5) northeastwards to Branch River, then southeastwards along the Hare Hill Longstone, then northeastwards to Shag Roost on the St. Mary's Bay coast. Two other outcrop areas on the St. Mary's Bay coast occur around the northern ends of southerly plunging synclines at Little Salmonier Point and Jonas Point, Cape Dog. On structural grounds, a small outcrop of the formation is inferred to occur atop Lansecan Hill, but it has not been examined.

Differential erosion, preceding deposition of younger formations, has reduced the original thicknesses of the local sections of the Random Formation (Figure 9). The thickest section occurs on East Head at Red Head Cove, where it is a little less than 60 m thick and appears to be in the area where the formation was originally more thickly developed than elsewhere on the peninsula. However, such a thickness is considerably less than sections of the formation on the Burin Peninsula, where thicknesses over 177 m have been recorded (Hiscott, 1982, fig. 3). At Jonas Point, it is about 37 m thick; in Roche's Gulch, Branch, about 30 m thick; in Branch River about 18 m thick; but south of McGill's Marsh the formation thins out toward Redland, where there is no trace of it (Figure 10). In the St. Bride's Syncline, it is over 38 m thick on the southern side of Cross Point, 43 m thick on Cuslett Point and up to 12 m thick farther north on the shore of Placentia Bay (McCartney, 1967, p. 61).

Lithology

Hiscott (1982) has given analyses of the Random Formation lithologies and described the formation as a macrotidal sequence deposited at a time of global sea rise in muddy shoreline, near-shore and open-shelf settings prone to periodic storms. He identified the spatial relationships of a variety of associated sedimentary structures in four main lithofacies, *viz.*,

Facies 1: crossbedded quartz arenites deposited in an open-marine subtidal setting or as intertidal sand shoals in protected embayments;

Facies 2: thin-bedded sandstones and mudstones with shrinkage cracks indicative of high-intertidal ponds on mud flats;

Facies 3: mudstones with graded glauconitic sandstone beds representing recycled storm-disturbed, poorly oxygenated, muddy shelf deposits;

Facies 4: fine-grained, red, micaceous sandstones associated with crossbedded quartz arenites formed in lower-shoreface rip-current channels.

In earlier studies of the formation, Butler and Bartlett (1967, p. 11) and Butler and Greene (1976, p. 11) recognized three distinct mature quartz arenite members separated by a lower grey siltstone member and an upper greenish grey sandstone member; the quartz arenites were informally named "lower quartzite member", "middle quartzite member" and "upper quartzite member". On Cape St. Mary's Peninsula, though exhibiting some lateral changes, these five members are developed to varying degrees and appear to reflect a rhythmic sequence comprising three fining-upward units. In this account, these members are informally named.

Lower Quartz Arenite Member

The basal quartzose beds of such a rhythmic unit vary considerably in thickness and comprise coarsening and thickening-upward beds of Facies 1, in places, with thin representatives of Facies 4 or thin beds of Facies 3 (Plate 18). In the map area, the base of the informally named lower

Plate 18. *Lower quartz arenite member of the Random Formation as developed in the area of St. Mary's Bay north of East Head. (N.B. typical subsidiary folding associated with this formation)*

quartz arenite member is a conglomerate, 2.5 cm to 1.5 m thick, conspicuous as a continuous, dark, compact, recrystallized bed resembling a modern concrete. It is characterized by cobbles and pebbles of red and mauve jasper, felsite, black chert, grey, purple and blue-banded rhyolites, with lesser andesite and basalt in a matrix of gritty quartz sand, generally coarser grained than the overlying crossbedded quartz arenites. In places, pebbles are much less concentrated and may be scattered throughout a greater thickness of the quartz arenites. An exposure of the base in St. Bride's River lacks pebbles and it is assumed that the basal beds were channelled and washout conditions redistributed the clasts into the slightly younger beds of neighbouring districts.

The lower quartz arenite member alongside Jonas Point is not typical of contemporary sections in the map area, because the lower beds, although somewhat massive and planar, wedge out laterally into a greyish red, shaly mudstone sequence not seen elsewhere. In contrast, the top beds typically exhibit excellent examples of current-ripple marks in addition to asymmetrical wavy surfaces. Current directions at this locality indicate provenance from the southeast.

In Red Head Cove (Table 7A), some of the lowest beds of the 9-m-thick member are interlensed and the member is slightly thicker on the eastern flank of the syncline, due perhaps to differential tectonic effects. Farther south, the base is not exposed in Beckford River, but at nearby Roche's Gulch, this member is only 3 m thick, comprising a basal massive bed 2.4 m thick and two 30-cm-thick beds. Progressive thinning toward the east is indicated by the 1-m-thick Branch River section and, where last exposed as a quartz arenite on McGill's Marsh about 5.6 km east of Lears Cove, it is only 60 cm thick.

Around the St. Bride's Syncline, the lower quartz arenite member is similarly represented by the basal conglomerate, which may be up to 1.5 m thick. Although the member is much thicker in the eastern parts of the map area and current directions suggest a southeasterly provenance, the basal cobbles in the western sections are significantly larger, e.g., up to 25 cm in diameter on the southern side of Cross Point, indicating that they are not so far travelled and, therefore, likely to be nearer to the source area. On the other hand, the coarse sediments may merely reflect a local reworking of the underlying Ediacaran Cross Point conglomerates.

Lower Siltstone Member

The basal lower quartz arenite member is sharply overlain by muddy subarkosic siltstones of mixed facies, i.e., a combination of Facies 2 and 3 forming the top of the lowest rhythm. It is here informally termed the lower siltstone member. The member is generally greyish green and resemble similar beds in the Cats Cove Member of the Musgravetown Group. Some sections include horizons of large, discoidal silty carbonate concretions and weathered, small, goethitic ironstone nodules (? degraded glauconite), as on the southern side of Cross Point (Table 7B). A typical example of the flaser-bedded facies in this siltstone member at Gooseberry Cove has been illustrated by Hiscott (1982, fig. 6a) and closely matches the 17 m-thick, grey-green Cats Cove Member at Redland Point that displays 10 horizons of small thin lenses of pale coarser siltstone. Among some of the smaller graded units, phosphate-coated flattish pebbles of mudstone occur, e.g., in the Deadman's Cove coastal section on the southern side of Cross Point.

Middle Quartz Arenite Member

This informally named, "middle quartz arenites unit" (Hiscott, 1982, p. 2036) is well developed in all the exposed thick sections and marks the base of the second rhythm. It generally comprises "several coarsening and thickening-upward cycles" of crossbedded quartz arenite beds (Hiscott, 1982, fig. 10) with thinner, interbedded muddy siltstone and arkose layers (Plate 19).

Upper Siltstone Member

The middle quartz arenites are sharply overlain by siltstones and shaly mudstones of Facies 3 and, in places, e.g., at East Head of Red Head Cove, also contain sporadic discoidal silty carbonate concretions. This unit is informally termed the upper siltstone member; it is finer grained and brighter green in the western sections (Plate 19), but, in the east, drastic changes are marked along the outcrop. Exposures in the vicinity of Roche's Gulch on the Hare Hill Longstone are unusually red, coarsely sandy and crossbedded, but traced along the outcrop towards Branch River, it

Table 7. Random Formation, simplified sections on the eastern and western sides of Cape St. Mary's Peninsula

Unit	Description	Thickness (m)	Total from base (m)
A. Cliffs at and north of East Head of Red Head Cove, St. Mary's Bay			
5	*Upper quartz arenite member:* quartz arenites, white-weathered; comprising six main beds of which the lowest are very coarse and crossbedded and the highest thicker bedded	15.4	60
4	*Upper siltstone member*: siltstone, subarkosic sandstone and shaly mudstone, dark grey to dark greyish green, thinly interbedded; siltstone nodules and beds in lower more shaly beds	12.4	44.6
3	*Middle quartz arenite member* (15.2 m thick): quartz arenites, white-weathered, interbedded with thin siltstone and subarkose	6.2	32.2
	sandstone, dark grey to dark greyish green, interbedded with thin white-weathered quartz arenites	4.5	27
	quartz arenite, white-weathered, planar bedded	4.5	22.5
2	*Lower siltstone member*: siltstone, dark grey, and interbedded mudstone, dark grey and blackish, very thinly bedded and lenticular bedded with fine-grained quartzose sandstone lenses; some micro-crosslaminations, convolute laminae, sole structures and horizontal burrows	9	18
1	*Lower quartz arenite member*: quartz arenites, fine grained; comprises 15 quartz arenite beds varying from 22 cm to 1.1 m in thickness; at base, prominent 8-cm-thick, greyish green gritty conglomerate, with pebbles of jasper, felsite, chert and banded rhyolites; basal beds above conglomerate massively bedded with asymmetrical wavy upper surfaces and some washout structures; higher beds with quartz arenites interbedded with thin siltstone–mudstone commonly with straight-crested current and "ladder" or interference ripples and crossbedding	9	9
Total thickness of Random Formation		61 m	
B. Cliff and shore section on southern side of Cross Point, Placentia Bay			
5	*Upper quartz arenite member*: quartz arenites, greyish white (Plate 19)	1.5	53
4	*Upper siltstone member*: silty mudstone, slaty, olive green (Plate 19)	1.5	51.5
3	*Middle quartz arenite member*: quartz arenites, thinly bedded, white-weathered, interbedded with minor siltstone and mudstone, shaly, dark greyish green (Plate 19)	3	50
2	*Lower siltstone member*: mudstone, fine grained, thinly bedded, green, interbedded with thin, laminated, siltstone and arkose; with scattered small, goethitic ironstone concretions and prominent pale greyish yellow calcareous silty lenticular nodules 9 m above base	45.5	47
1	*Lower quartz arenite member*: quartz arenites, white-weathered, thinly massive bedded, with 0.3- to 1.5-m-thick conglomerate at base comprising cobbles and pebbles of jasper, felsite, chert and banded rhyolites in a recrystallized quartzose sand matrix	1.5	1.55
Total thickness of Random Formation		53 m	

Plate 19. *The middle, whitish arenite layers of the upper quartz arenite member of the Random Formation (rucksack circled) box folded with overlying green siltstone and uppermost quartz arenite layers in Deadman's Cove, St. Bride's; the latter in contact (marked x) with the Petley Member at the base of the Bonavista Formation.*

gradually changes to the grey and green sandy laminated siltstones more characteristic of the member.

Upper Quartz Arenite Member

As envisaged, the third rhythm is everywhere incomplete due to erosion of the upper, softer, mudstone part of the rhythm so that lower prominent, white-weathering, cross-bedded, quartz arenites typically mark the top of the formation (Plate 19). These quartz arenites are informally termed the upper quartz arenite member. The thickest development of this member occurs at the East Head of Red Head Cove, where the beds gradually thicken upward.

Contact Relations of the Random Formation

On the Avalon Peninsula, the Random Formation is highly transgressive over eroded, gently folded, Ediacaran rocks and, in the Cape St. Mary's Peninsula area, it unconformably rests upon the partially peneplaned surface of a tilted Musgravetown Group sequence. In the St. Bride's Syncline, it transgresses the redbeds of the Crown Hill Formation and, on its western flank, where the youngest Crown Hill member is preserved, cuts across the Cross Point Member-Hurricane Brook Member contact about 1.6 km northeast of Angel's Cove. Farther east, it transgresses the Crown Hill-Heart's Content formational contact at several places and, over a large area, rests unconformably on the grey-green siltstones and shaly mudstones of the Cats Cove Member. Thus, a considerable period of erosion preceding the deposition of the Random Formation sediments is indicated by the local removal of at least 380 m of the upper Musgravetown Group sequence. However, sporadic small lensoid bodies of the Hurricane Brook Member are preserved to the east beneath the quartz arenites along the western flank of the Point Lance Syncline between McGill's Marsh and the upper reaches of the Branch River, between the northern side of Red Head Cove and Smith's Gulch and at Jonas Point. These isolated remnants may represent either small synclinal pockets or raised areas of the Musgravetown Group surface.

Everywhere, the top contact of the formation is considered to be an eroded and channelled surface transgressed by younger Adeyton Group formations; south of McGill's Marsh, toward Redland Cove, the erosion was sufficient to completely remove any Random Formation sediments deposited in that area (Figure 9). In the map area, the overlapping transgression involved sequences from the west and northwest. In the southern region, the Bonavista Formation unconformably onlaps the Random Formation as far east as the western end of Hare Hill Longstone, where the feather-edge of the Bonavista Formation is overstepped by the Smith Point Formation and the Random Formation, for the greater part of that region, is also unconformably overlain by the limestone of the Smith Point Formation (Figure 10). In the northern region, the Bonavista Formation onlap is manifest in the synclinal sections around Cape Dog, where the Bonavista Formation is 8 m thick (Hutchinson, 1962, p. 138) and 5.8 m thick on the eastern side of Little Salmonier Point.

Fauna, Age and Correlation

Rusophycus avalonensis Zone: No skeletal fossil remains or floral elements have been recognized in the Random Formation on Cape St. Mary's Peninsula. Traces of life in the finer grained beds are represented by a selection of horizontal meandering burrows and bilobed tracks characterizing a *Rusophycus avalonensis* Zone (Crimes and Anderson, 1985; Narbonne and Myrow, 1988). An Early Cambrian age within the range of *Aldanella attleborensis* (Shaler and Foerste, 1888) as recognized on the Burin Peninsula (Bengtson and Fletcher, 1983, fig. 5) and in Trinity Bay (Landing and Benus, 1988, fig. 3) is indicated by regarding the Cape St. Mary's outcrops as local remnants of the former widespread cover of the formation in the Avalon Zone. Acritarchs collected by the writer and identified by Downie (1982, p. 281) from the Little Dantzic section on the Burin Peninsula include *Protoleisphaeridium* Timofeyev, 1960, *Granomarginata squamacea* Volkova, 1968 and *Archaeodiscina umbonulata* Volkova, 1968; in the Russian records, the first two occur in the Tommotian and the latter in the Atdabanian. Currently assigned to the Tommotian Stage, the Random Formation compares well with many other transgressive, relatively clean-washed, monomineralic, near-shore sediments at the base of Cambrian sequences, both in other regions of the Avalon Zone and beyond.

Bonavista Formation (Unit 7)

Definition

The Bonavista Formation is a mudstone sequence named by van Ingen (1914) for the oldest rocks he considered Cambrian in the areas of Conception and Trinity bays. Hutchinson (1962, p. 8) later selected the exposure on Smith Sound, Trinity Bay as the type section, designating the conformable base of the overlying limestones of the Smith Point Formation as its upper limit. In those regions, the Bonavista Formation rests unconformably upon the Random Formation which, as discussed above, is now recognized as Cambrian. The Bonavista Formation is a transgressive onlapping unit and is an easily mappable rhythmic sequence of brightly coloured mudstones and nodular limestones between highly distinctive whitish quartz arenites below and the prominent, feature-forming, relatively thick pink limestone forming the Smith Point Formation above (Plate 20).

In a more recent study of this formation, Landing and Benus (1988a, p. 65) have confused the stratigraphical nomenclature by using established lithostratigraphical names for sequence-stratigraphical units. Their relatively thin subdivisions of Hutchinson's (1962) Bonavista Formation (unmappable on 1:50 000-scale maps) have been treated as formations of a Bonavista Group and they altered Hutchinson's definitions by raising the upper limit of such a group into the Smith Point Formation to a regionally restricted sequence-break near the top of the limestone sequence. Clearly, a lithostratigraphical group boundary drawn within a prominent mappable limestone is untenable as it does not separate major stratigraphical divisions of different lithofacies and their sequence-stratigraphical nomenclature should be independent of the lithostratigraphical scheme.

In the lower part of the Bonavista Formation in the west, some thin, layered limestones relate to sediment-starved intervals. Two of these stromatolitic limestone units mark slight breaks in the sequence defining the top beds of Landing and Benus's (1988a) lower two "formations". In this account, Hutchinson's (1962) definitions of the Bonavista and Smith Point formations are retained and Landing and Benus's (1988a) three mudstone "formations", are regarded as members of Hutchinson's (1962) revised Bonavista Formation. The formal geographical names and

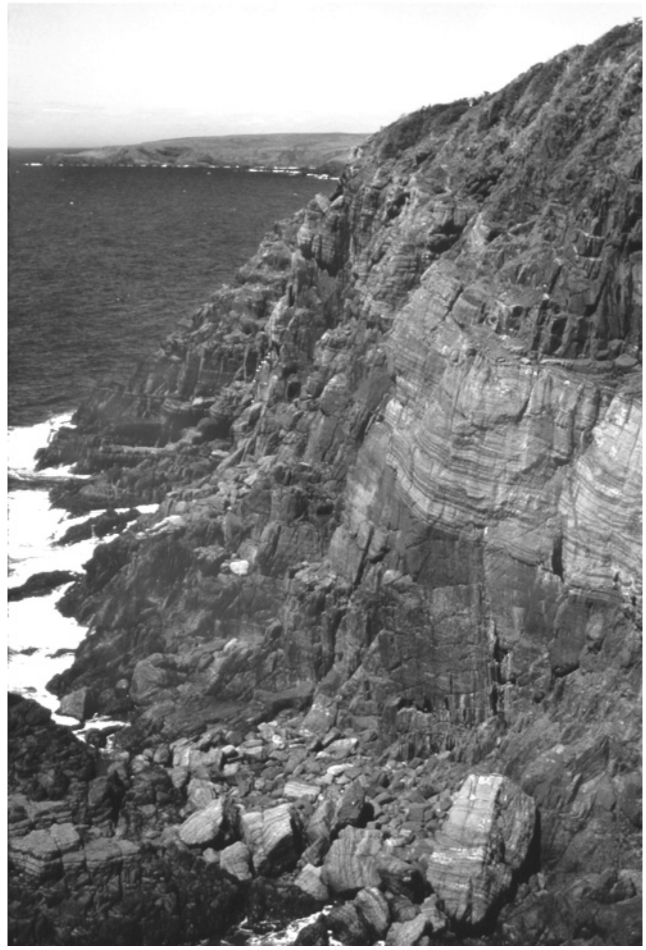

Plate 20. *Northerly view across Distress Cove to Cross Point from the cliff side of St. Bride's Harbour, where the prominent pale limestones of the Smith Point Formation intervene between the Bonavista and Brigus formations.*

type sections of Landing and Benus (1988b, fig.4) remain appropriate for lithostratigraphical units. Thus, the oldest unit is the Petley Member, the middle unit the West Centre Cove Member and the top unit the Cuslett Member. The type section of each member is established at a different locality, but the well-exposed section of the whole Bonavista Formation along the coast to the south of Cuslett on Cape St. Mary's Peninsula, can be considered a principal reference section for the formation.

Distribution and Thickness

Although Hutchinson's (1962, fig. 2) isopach map of the Bonavista Formation provides a guide to its overall disposition on the Avalon Peninsula, it requires some modification in the light of recent observations on the Burin Peninsula, where thicknesses in excess of those on the Bonavista Peninsula occur on the western shore of Little Lawn Harbour.

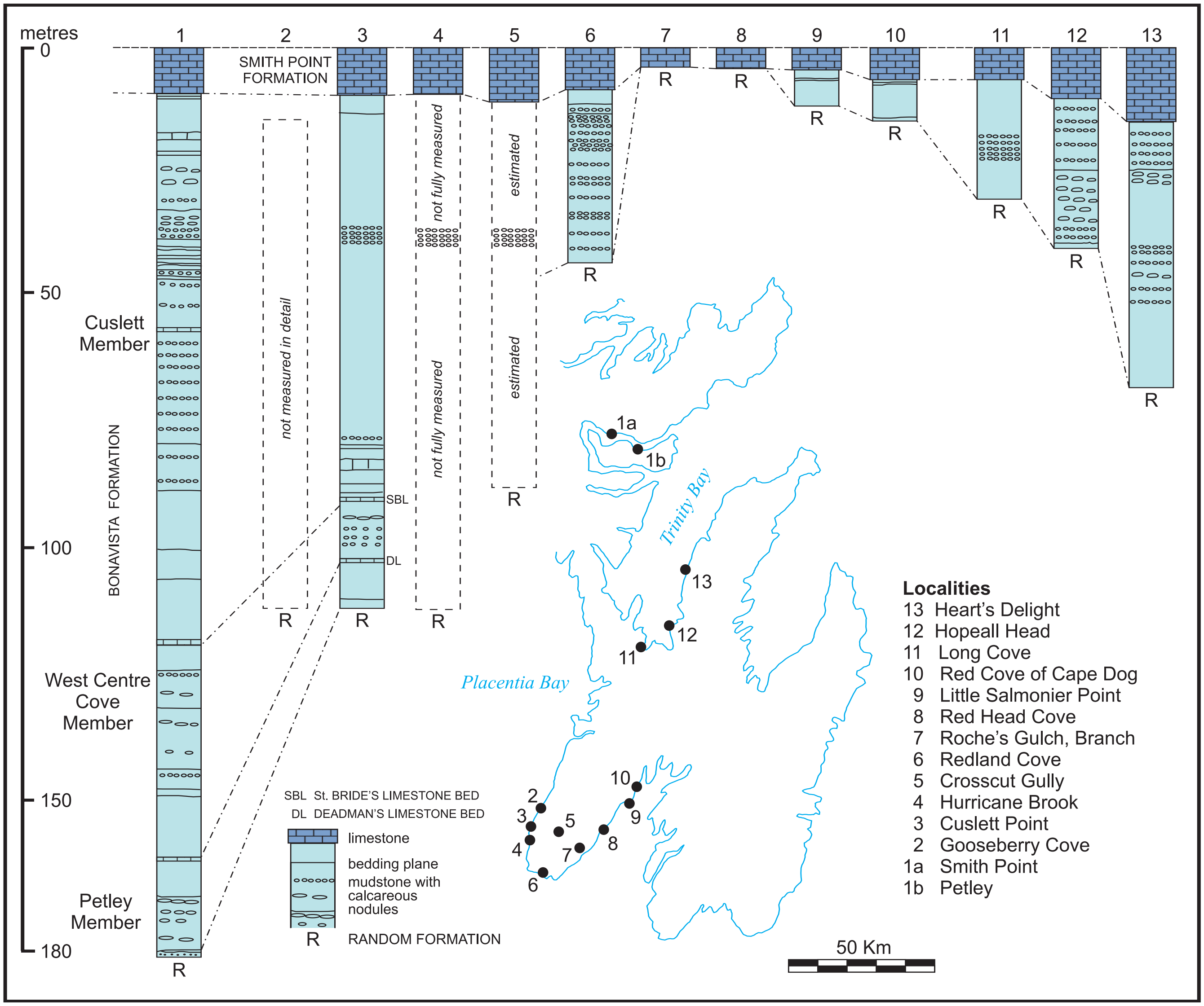

Figure 11. *Bonavista and Smith Point formations; comparative sections.*

On Cape St. Mary's Peninsula, the Bonavista Formation occurs in all the synclines of Cambrian strata and a gradual thinning eastward away from its thickest development on the western flank of St. Bride's Syncline is clearly marked (Figure 11). Landing and Benus's (1988a, p. 71) 110.4 m [362 feet] reported thickness of the western section at Cuslett Point on Placentia Bay seems to have been grossly overestimated if compared to the 215 feet [65.5 m] thickness recorded by Hutchinson (1962, p. 142) and the 42.7-m-thick section in Redland Cove, St. Mary's Bay farther east. Although individual beds may thin eastward, the main thinning of the formation is due to its transgressive nature as successive layers onlap the Random Formation to a feather-edge at the western end of Hare Hill Longstone, where the Smith Point Formation oversteps it (Figures 4 and 10). On the western coast of St. Mary's Bay, a southerly thinning is indicated by its decreasing thickness from the 8-m section in the coastal section in Red Cove of Cape Dog to the 5.8 m section at Little Salmonier Point and its absence in Red Head Cove (Figure 11).

Such thickness differences conform to the pattern of easterly transgression and onlap described by Landing and Benus (1988b, fig. 35) in Trinity Bay, where, due east of Come-By-Chance in Placentia Bay, only the highest Cuslett Member is developed.

Lithology

The formation generally comprises alternating dusky red, blackish red, greyish green and very dusky purple, layered, fine-grained and silty mudstones characterized by rare, thin stromatolitic limestone beds, some bedded calcareous wackestones and numerous bedding-parallel, small, somewhat laterally elongate, pink, whitish and rarer greenish grey, syndiagenetic limestone nodules. At certain levels, the nodules are so numerous as to coalesce as semicontinuous nodular layers similar to those typical of the younger Redland Cove Member at the base of the Brigus Formation. Two types of nodule may be recognized. The smaller, more common form described above, is characteristic of the finer grained reddest layers; the larger, millstone-type, silty concretionary disc is associated with siltier greyish green beds and is particularly well developed in the lower and upper levels of the formation in Trinity Bay and about 12 m above the base in the St. Bride's Syncline. Although not common, the latter form has no stratigraphical significance, because it characterizes similar lithofacies in the basal Cambrian Member 3 of the Chapel Island Formation in the Fortune Valley Syncline (Bengtson and Fletcher, 1983, p. 529) as well as green silty beds in the Random, Brigus and Chamberlain's Brook formations on the Avalon Peninsula.

As in other mudstone formations in the Adeyton Group, the Bonavista Formation has a rather massive aspect and bedding/separation planes are rare with bedding generally marked by sporadic manganese-coated erosion planes, subtle changes in grain size, limestone horizons and colour. However, not all colour changes are bedding-related and irregular patches, commonly astride detectable bedding, are evidently due to localized diagenetic reduction or oxidation of the high iron content.

Petley Member

Definition

The Petley Member is the basal unit of the Bonavista Formation and was originally named Petley Formation by Landing and Benus (1988a) for the sequence immediately overlying the Random Formation on the Petley foreshore of Random Island, Trinity Bay. A thin conglomeratic limestone marks the base and the member largely comprises alternations of red and greenish siliciclastic mudstones containing calcareous nodules, lenticular conglomerates, fine- to medium-grained quartz arenites and sporadic stromatolitic limestones. Its upper limit is prominently defined at the top surface of a distinctive stromatolitic limestone, which in the type section, lies 19.8 m above the base. This limestone is considered to indicate a break in sequence prior to the deposition of the overlying West Centre Cove Member and is here named Deadman's Limestone Bed (Plate 21).

Distribution and Thickness

In the Cape St. Mary's Peninsula map area, the Petley Member is only preserved in the St. Bride's Syncline and best exposed along the cliffline between Cuslett and Perch Cove and on the southern side of Cross Point in Deadman's Cove, where it is up to 8 m thick.

Plate 21. *The West Centre Cove Member and basal beds of the Cuslett Member of the Bonavista Formation in Deadman's Cove, St. Bride's. The Deadman's Limestone Bed marking the top of the underlying Petley Member is in the left foreground at sea level; the St. Bride's Limestone Bed marking the top of the West Centre Cove Member is the pale layer midway up the cliff.*

Lithology

A basal, stromatolite-layered, sandy, conglomeratic, pink, shelly limestone up to 1.5 m thick is well developed (Plate 19) and manganese-rich nodules are common in the basal layers, being especially noticeable in the Gooseberry Cove section. The report by Dale (1915, pl. xiv, pages 376 and 433) of a manganese locality near Ship Cove that McCartney (1967, p. 72) doubted, probably refers to these occurrences in Gooseberry Cove. The main body of the member comprises 6 m of bright red mudstone intermittently marked by thin bright green and purple streaks. In places, small calcareous nodules are developed and a prominent layer of nodules immediately underlies the characteristic limestone marking the upper limit of the member. In Deadman's Cove (Plate 21), this top limestone bed is 90 cm thick and comprises five layers with a capping of tightly packed, small manganese nodules. This is the Deadman's Limestone Bed and appears to be the limestone of similar thickness identified by Hutchinson as Bed 5 (1962, p. 142, section 15) in his section farther north near Cuslett.

Contact Relations

The Petley Member rests unconformably upon the Random Formation and is transgressed by the West Centre Cove Member.

Fauna and Correlation

Sunnaginia imbricata Zone (upper *Aldanella attleborensis* interval): No fossils have been collected from the member by the writer, but Landing and Benus (1988b, fig. 3) have identified the fauna as part of the "upper *Aldanella attleborensis* interval", correlative with other sections in the Avalon Zone assigend to the *Sunnaginia imbricata* Zone that are considered Tommotian in age.

West Centre Cove Member

Definition

The West Centre Cove Member is the middle member of the Bonavista Formation and was originally named and proposed as the "West Centre Cove Formation" by Landing and Benus (1988a) for the red, green and purple mudstone sequence exposed on the coast of Bull Arm at Sunnyside, disconformably intervening between the "Petley Formation" below and the "Cuslett Formation" above. In the type section, it is 32.4 m thick and its upper limit is defined along the top surface of a distinctive stromatolitic, hyolith-rich limestone that, in places, comprises two beds separated by a nodule-rich shaly mudstone. This bed is here named St. Bride's Limestone Bed (Plate 21).

Distribution and Thickness

In the Cape St. Mary's map area, the West Centre Cove Member is preserved only in the St. Bride's Syncline and best exposed in cliff sections just south of Cuslett and in Deadman's Cove, St. Bride's, where it is about 17 m thick.

Lithology

The West Centre Cove Member in Deadman's Cove comprises six distinct beds. A very red, thin basal mudstone bed, up to 15 cm thick containing a middle layer of small silty calcareous nodules rests on the manganiferous top of the Deadman's Limestone Bed. It is overlain by a prominent 8.2 m-thick sequence of green mudstone with numerous discontinuous layers of medium to large silty calcareous nodules. This bed is overlain by 2.4 m of dark red, purple-streaked, mudstone with green blotches followed by 1.5 m of bioturbated green, purple-streaked mudstone bearing numerous *Chancelloria* spicules. The uppermost mudstone unit is bright red and 3.4 m thick and underlies the prominent pink St. Bride's Limestone Bed that forms the top bed of the West Centre Cove Member. This marker limestone (Plate 21) is 1.8 m thick and is characterized by a basal green nodular zone. The limestone, therefore, is much thinner than described in Hutchinson's (1962, p. 141, section 15, beds 10 and 11) section to the north near Cuslett, which he records as 2.7 m [9 feet] thick.

Contact Relations

The West Centre Cove Member rests unconformably upon the Petley Member and is unconformably overlain by the Cuslett Member, i.e., it transgresses over the former and is transgressed by the latter.

Fauna and Correlation

A variety of hyoliths and *Chancelloria* spicules in the St. Bride's Limestone Bed has been noted. On the evidence available to Landing and Benus (1988b), this member falls within the top part of the Tommotian "upper *Aldanella attleborensis* interval" and within the *Sunnaginia imbricata* Zone.

Cuslett Member

Definition

The Cuslett Member is the uppermost mudstone unit of the Bonavista Formation and was originally proposed by Landing and Benus (1988a) as the "Cuslett Formation" with its type section along the shore immediately south of Cuslett in the Cape St. Mary's Peninsula map area. Here the Cuslett Member overlies the St. Bride's Limestone and is conformably overlain by the Fosters Point Member of the Smith Point Formation.

Distribution and Thickness

On the Cape St. Mary's Peninsula, the Cuslett Member is preserved in the St. Bride's Syncline and in the Point Lance Syncline as far east as a point near the eastern end of the Hare Hill Longstone. In the region between the latter point and a point a little south of Little Salmonier Point, the Cuslett Member is not preserved beneath the Smith Point Formation. Northward from Little Salmonier Point on St. Mary's Bay, the Cuslett Member thickens from 5.8 m to 8 m around Cape Dog. In both the Cuslett and Redland regions, it is about 40 m thick.

Lithology

Landing and Benus (1988b, p. 37; 1988a, p. 71) differentiated four informal subdivisions of the Cuslett Member at Sunnyside, but they appear to be of more local significance, because of the conspicuous lateral changes notable along the outcrops on Cape St. Mary's Peninsula. Certainly, the coloured subdivisions of the Cuslett Member sections in Distress Cove as far south as Hurricane Brook differ somewhat from those around the more northerly Cuslett coast. In general, two main sequences can be distinguished above the top of the St. Bride's Limestone Bed in the St. Bride's Syncline, i.e., a lower, 60-m-thick, streaked very dusky purple and green mudstone unit with thin red layers and one or two thin calcareous, stromatolitic wackestones near its base, overlain by about 4.3 m of bright red bioturbated mudstone containing three main thin nodular limestone beds and numerous scattered small calcareous nodules (Front Cover and Plate 20). Farther east in Redland Cove, where the Petley and West Centre Cove members have been overstepped, the Cuslett Member solely represents the Bonavista Formation and differs considerably from its type section. Here, there is a rhythmic pattern to the distribution of limestone and colour layering, manifest as a repeated association of streaked, very dusky purple and greyish green mudstone to dusky red mudstone to pinkish-white nodular limestone. Such a unit may reflect a shallowing/clearing-upward rhythm [not cyclic] and is most evident in the southern Redland Cove cliff section, where at least 15 distinct rhythms can be distinguished (Plates 22 and 23).

Plate 22. *Mudstone–limestone rhythms of the Bonavista and Smith Point formations in Redland Cove.*

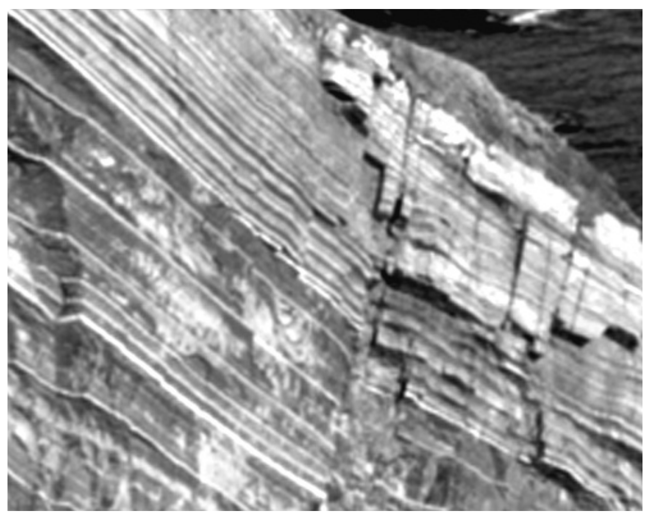

Plate 23. *Close-up view of the transitional prominent planar-bedded lithofacies of the Bonavista-Smith Point formational junction in Redland Cove indicative of the diminishing imputs of clastic material in the rhythmic sequence developed in the Cuslett Member.*

Contact Relations

The basal contact of the Cuslett Member is everywhere disconformable as successive beds onlap the underlying members to eventually cover the undulating top of the Random Formation in the southeast. The upper contact with the thick Smith Point Formation in this map area is conformable and is drawn in a continuous sedimentary regime, where the rhythmic influx of clastic sediment was drastically halted, at a level where the Smith Point limestone beds are separated by much thinner mudstone seams (Plates 22 and 23).

Fauna, Age and Correlation

Camenella baltica Zone: Apart from well-preserved specimens of the gastropod *Aldanella attleborensis* in Redland Cove and the problematica *Coleoloides typicalis* Walcott, 1889b from the top of the formation in Perch Cove, the writer has not collected fossils from the Cuslett Member in this map area. Such occurrences conformed to the biostratigraphical scheme proposed by Bengtson and Fletcher (1983, p. 532) in which the incoming of the latter species within the upper range of the former was considered to be a feature of possible global significance. However, closer scrutiny of the early Cambrian sections on the Burin Peninsula indicates that *C. typicalis* "first appears in much lower strata (member 4 of the Chapel Island Formation) and only undergoes an abrupt proliferation in the upper part of the Bonavista Group" (Landing *et al.*, 1989, p. 750). In the revised scheme of Landing and Benus (1988a, p. 69), a better defined zonal boundary was recognized at the base of the lowest limestone in the Cuslett Member. This level marks the junction at the top of the range of *A. avalonensis* between a lower *Sunnaginia imbricata* Zone (Landing *et al.*, 1989) and an upper *Camenella baltica* Zone (Landing *et al.*, 1989; Figure 12).

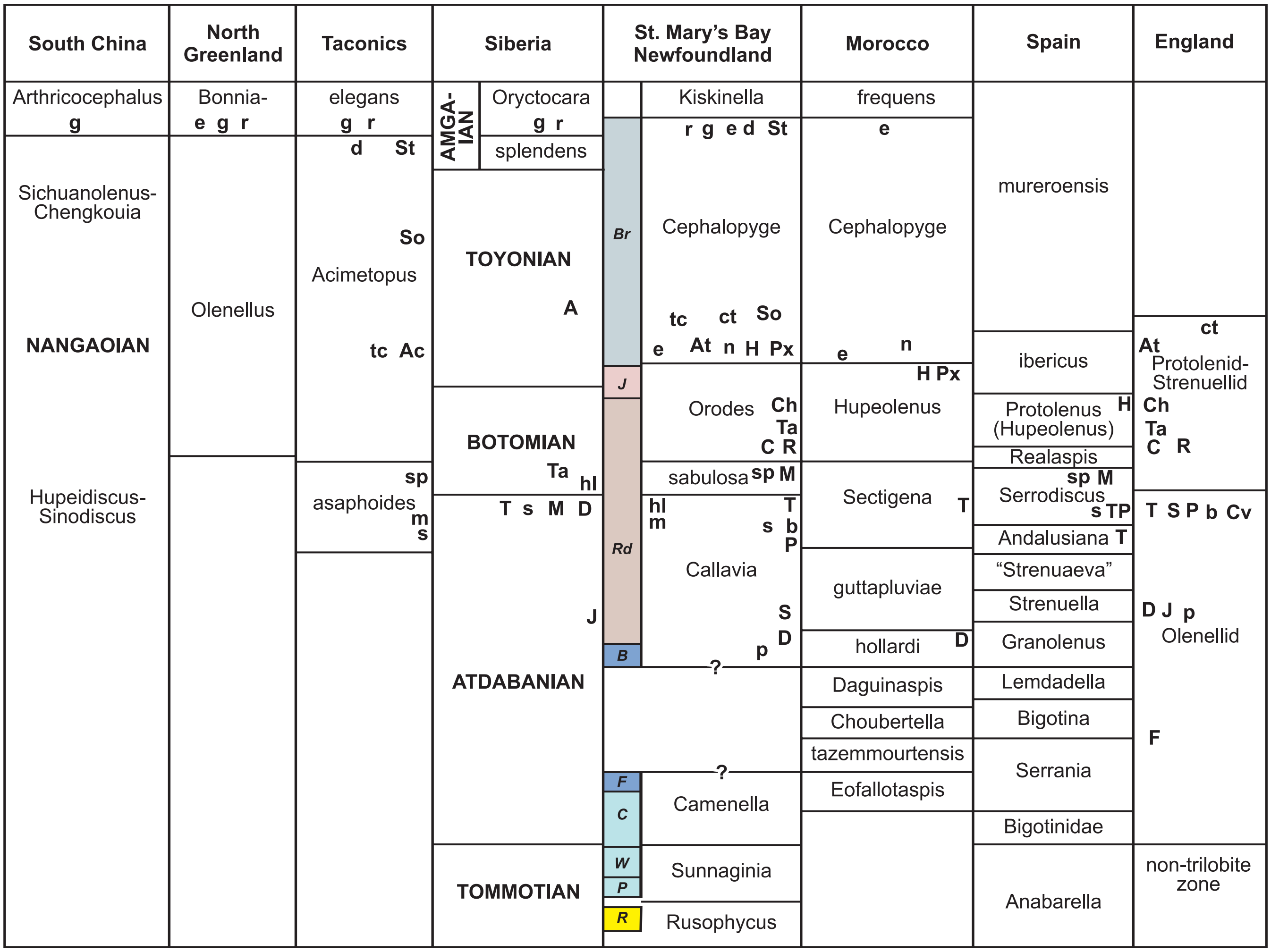

Figure 12. *Correlation chart of the biozones of the pre-Chamberlain's Brook formations (letters refer to taxa).*

On the faunal evidence of the Cuslett type section, the base of the "*Camenella baltica* (Bengtson, 1970) assemblage" rests upon a thin "upper *Aldanella avalonensis* interval" in the basal part of the Cuslett Member, possibly marked at the lowest nodular limestone in the member. The presence of *Aldanella attleborensis* (Plate 27, Figure 1) at the base of the Bonavista Formation in Redland Cove indicates that the whole Cuslett Member, as preserved in the St. Bride's Syncline, is preserved there and that the thin limestone at the top of the first rhythm likely marks the local base of the *C. baltica* Zone.

Bengtson and Fletcher's (1983, fig. 5) early correlation of the faunal elements of the early Cambrian Newfoundland sequence with the boundary beds of the pre-trilobitic Tommotian and the trilobitic Atdabanian stages have been supported by the more detailed micropalaeontological studies of Landing. On the evidence of a fallotaspid trilobite within the English equivalent *Camenella* Zone, it would appear that the Tommotian-Atdabanian (Cambrian Series 1 to 2) boundary on Cape St. Mary's Peninsula might lie within that zone in the top part of the Cuslett Member. See Landing *et al.* (1989) for a very comprehensive discussion on the faunas, and Landing (1996) for a correlation and comparative analysis of the sedimentary successions.

Smith Point Formation (Unit 8)

Definition

The Smith Point Limestone is a prominent unit of compact, pinkish limestone layers (some lower beds may be mottled pale green) conformably intervening between the brightly coloured, carbonate-bearing mudstones of the Bonavista Formation below and of the Brigus Formation above (Front Cover and Plate 20). First described by Walcott (1900a) as the only limestone of significant thickness on the northern coast of Smith Sound, Trinity Bay, the exposure, just east of Broad Cove, was later established as the type section of a formal lithostratigraphical formation by Hutchinson (1962, p. 12).

In some sections, the layers are prominently capped by thin stromatolites (Plate 24) and a lower member is separated by a non-sequence from an upper member characterized by the first appearance of trilobite remains. Landing and Benus (1988a, p. 67) regarded the lower unit as the top subdivision of a "Bonavista Group" and named it "Fosters Point Formation" below a trilobitic "Clifton Formation" with their type sections immediately east of the government wharf at Smith Point. Because such a subdivision is not everywhere apparent, e.g., in Redland Cove (Plate 23), Hutchinson's (1962, p. 12) concept of the "Smith Point Limestone" Formation should be maintained and, wherever two lithostratigraphical subdivisions are distinguishable, they may be treated as two separate limestone members, i.e., Fosters Point Member and Broad Cove Member [new name for preoccupied Clifton] of the Smith Point Formation (Fletcher, 2003, text-fig. 3 explanation).

Plate 24. *Top of the stromatolitic Smith Point Formation at Little Salmonier Point showing well-developed cabbage head-type algal growths.*

Distribution and Thickness

From the earliest days of mapping, the Smith Point Formation has been recognized as one of the main marker units in the Cambrian succession of southeastern Newfoundland (*see* Front Cover). "It has been successfully traced throughout many of the inland outcrop areas of the Cambrian, where the other formations rarely outcrop and has enabled the distribution and structure of these rocks to be easily determined in areas where such results would otherwise have been difficult" (Hutchinson, 1962, p. 15). In his formalization, Hutchinson (1962, fig. 3) figured an isopach map of the formation showing the localities of some major sections, four of which occur on Cape St. Mary's Peninsula.

The Smith Point Formation crops out in all the synclinally preserved Cambrian sequences in the map area, invariably exposed as a readily mapped, solution-weathered, hackly rock ridge devoid of soil. The best sections occur along the coastal outcrops at Perch Cove, Redland Cove, Red Head Cove, Little Salmonier Point and in the Red Cove of Cape Dog. Incomplete roadside exposures are well displayed at the top of the southern hill into Cuslett, on each side of the northern hill into St. Bride's and opposite St. Bride's Church in the river gorge. The limestone is thickest at Crosscut Gully in the central part of the peninsula (Figure 5), where it is 11.6 m thick. In the west, it is 9.8 m thick at Perch Cove and in the south in Redland Cove, 8.5 m thick: in the east, at Roche's Gulch, it is 3.8 m thick and farther north, in Red Head Cove, 4.3 m thick; at Little Salmonier Point, 4.6 m thick and, just south of Jonas Point, 5.5 m thick.

Lithology

The Smith Point Formation represents an interval of time when the supply of clastic material was considerably restricted during an important period of lowered sea level. The rhythmic shallowing/clearing-upward pattern of sedimentation, notable in the preceding Bonavista Formation, appears to have intensified in the near-shore regions until eventual extreme shallowing allowed the development of extensive algal carbonate flats and some resedimentation during storms (Plate 25). Numerous stromatolitic horizons indicate that, over large areas of the lagoonal shelf in southeastern Newfoundland, clastic-starved periods of emergence led to differential non-sequences in a tidal flat-shallow subtidal environment. However, only one such sequence-break is readily differentiated faunally. This is marked by the conspicuous fossil turnover from the non-trilobite regime in the Fosters Point Member to one dominated by trilobites in the Broad Cove Member. Apart from the limestone outcrop of the Smith Point Formation in Redland Cove, which is not stromatolitic, the sections on Cape St. Mary's Peninsula incorporate elements of both members of the type section on Smith Sound.

Except for the outcrops on the islands of Placentia Bay (Hutchinson, 1962, p. 13), most limestone layers are separated by thin interbeds of darker mudstone that are thickest in the basal and top parts of the formation; some mudstone partings contain small calcareous nodules. The limestones are predominantly red, having a range from moderate red to greyish pink. In any one bed, the colour is relatively uniform and always much paler than the associated mudstone interstices. Despite the dusky redness of the mudstones, an overall pinkish hue is produced when viewed from a distance (*see* Front Cover). Strong solution weathering is responsible for its hackly surface and emphasizes the essential concretionary character of most of the carbonates.

The limestones, where stromatolitic, have an overall nodular aspect and are generally less than 3 cm thick and capped by laminar, hematitic and manganiferous, cabbage head-shaped algal mats. Typically lensoid and, in places, conspicuously inclined (current bedded) (Plate 25), the limestone layers largely comprise hyolith and oncolith interclast-rich wackestones and packstones. Rare limestone beds are interspersed with lensoid, bird's eye-like, laminae of clear calcite due to diagenetic recrystallization, some of which are coarsely crystalline, others finer grained and "sugary".

Two distinct sedimentary structural developments occur and appear to have some geographical significance as well as probably reflecting original differences in the turbulence of the environment. As in the type section at Broad Cove, the sequence in Redland Cove is made up of successive planar-bedded limestones (Plate 23) that contrasts strongly with occurrences elsewhere in the map area, where bedding is highly irregular and the bulk of the formation comprises thinner lensing nodular beds that are commonly inclined (Plate 25). The latter facies suggests turbulent conditions and the association of so much algal material and clear calcite laminae is reminiscent of the intertidal facies of an algal-mat, carbonate sabkha environment described by Shearman (1966). Thus, evaporation and wind/storm turbulence may have been major influences in the development of the calcium and manganese carbonates of this formation (*see also* Bogert, 1939). As each stromatolitic layer signifies a sedimentary stage, the number of layers in a section may be an important guide to correlation, as in tree-ring chronology. Although of different aspect, the Perch Cove and Redland sections each comprise 29 limestone layers, the former section with layers between 90 and 5 cm thick, the latter section with layers between 53 and 10 cm thick. Some measure of the diachroneity of this formation may be gauged by the different numbers of layers elsewhere. At the type section at Broad Cove, the 32 layers may indicate incorporation of the top part of the Bonavista sequence as developed in the map area or, as the fauna suggests, incorporation of Redland Cove Member beds; on the other hand, the 16 layers at Hopeall Head and 14 layers at Brigus South Point possibly suggest that the topmost beds of the Bonavista Formation at these localities are equivalent to the lowest layers of the Smith Point Formation on Cape St. Mary's Peninsula and in western Trinity Bay.

Other subtle rock types noted by Landing and Benus (1988a, p. 67) at the Fosters Point-Broad Cove contact on Smith Sound occur in sections in the St. Bride's Syncline and in Red Cove, Cape Dog near Jonas Point. These include quartz sand and mudstone pebbles in lags on a phosphate or goethite-encrusted, planar, stromatolitic surface, where individual ooliths are truncated. In regions where the formation rests directly on the Random Formation, e.g., at the eastern end of Hare Hill Longstone, there is a basal quartz-pebble conglomerate or a discontinuous, basal veneer of phosphate-impregnated mudstone.

Plate 25. *Lensing stromatolitic lithofacies of the Smith Point Formation in cliffs south of St. Bride's Harbour that contrasts strongly with the planar-bedded lithofacies in Redland Cove (see Plate 23).*

Contact Relations

Very few sections on the Avalon Peninsula exhibit sharp interformational junctions with the Bonavista and Brigus formations and, like all those in the map area, the majority show gradational zones in which the alternating mudstone:limestone thickness ratio changes significantly. In describing the same section, various authors have differed in their placements of the contacts. As a general rule for delineating the formation at any section, the writer has excluded all beds of limestone that are thinner than their intervening mudstone beds (Plate 22). Although the contacts with the Bonavista and Brigus formations are locally conformable, lateral variations in the mudstone:limestone ratios indicate that both contacts are regionally diachronous. In the region between the Hare Hill Longstone and Red Head Cove, the formation rests directly on the Random Formation. The somewhat drastic biofacies change at the contact between the two members is commonly marked by shallow channel-fills indicative of a break in sequence, during which time differential erosion and subsequent onlapping sedimentation produced a widespread disconformity.

Fauna, Age and Correlation

Fosters Point Member

The faunas and widespread correlations of the *Camenella baltica* Zone in the Bonavista Formation and Fosters Point Member have been described and discussed by Landing (Landing *et al.*, 1989; Landing, 1996). Although the writer's collections add nothing further, the overall fossiliferous aspect of the lower member of the Smith Point Formation, in which a *Scenella* sp. and orthothecids with circular or broadly triangulate rounded cross sections are conspicuous, suggests that all the elements documented by Landing are present in the map-area. Although no trilobite remains have been recognized in the Fosters Point Member sequences, correlation with the English sequence in Shropshire implies that the *Camenella baltica* beds attributed to the pre-trilobitic Cambrian in Newfoundland are equivalent to fallotaspid trilobite-bearing strata elsewhere and are early Atdabanian in age (Figure 12).

Broad Cove Member

Callavia broeggeri Zone: The upper member of the Smith Point Formation is notable for the first appearance in Newfoundland of trilobites with small shelly species of *Coleoloides* and *Halkieria*. As pointed out by Hutchinson (1962), the overall denseness of the rock hinders the excavation of such remains. Their tests throughout the member are evident in thin section, but the only identifiable specimens have been recovered from the uppermost levels. The earliest trilobite assemblages in Newfoundland have yet to be established and the amount of diachroneity of this member is difficult to confirm. Relatively detailed work by the writer on the trilobites in the overlying basal member of the Brigus Mudstone Formation in Redland Cove indicates that two assemblages can be differentiated within the range of the trilobite *Callavia broeggeri*, i.e., the *Callavia broeggeri* Zone of Unit I (Fletcher, 2003, text-fig. 3; Figure 13). These have been assigned to the *Acanthomicmacca* and *Dipharus* subzones respectively. However, it should be pointed out that the relevant Redland section is less than 41 m thick and much thinner than sections on the eastern side of Trinity Bay, where the *Callavia* Zone is over 130 m thick, e.g., in Long Cove (Hutchinson, 1962, section 10). Unfortunately, the main discussions on the trilobites of the Smith Point Formation have focussed on collections from the type-area on Smith Sound, where *Dipharus attleborensis* occurs in the top of the formation (Hutchinson, 1962, p. 61). On the evidence of the Redland section, this change in thickness would indicate a much greater non-sequence in western Trinity Bay. Clearly, there is a need to substantiate the Redland trilobite subdivisions in the thicker sections of southeastern Trinity Bay, before an accurate assessment of the amounts of non-sequence at any one locality can be made.

The presence of *C. broeggeri* and a new species of *Acanthomicmacca* Hupé, 1953 (Plate 27, Figure 2) in the topmost bed of the Smith Point Formation at Redland Cove indicates a correlation with the lowest part of *C. broeggeri* Zone-deposits elsewhere in the North Atlantic region, notably near North Attleboro, Massachusetts, USA and at Comley, in England (Figure 12). Such beds are regarded as mid-late Atdabanian in age.

Brigus Formation (Units 9a to 9c)

Definition

The vagueness of van Ingen's (1914) original lithostratigraphical terminology for the Cambrian rocks of southeastern Newfoundland led Hutchinson (1962, p. 15) to redefine the limits of the Brigus Formation so as to include all beds "overlying the Smith Point Formation, and underlying the widespread manganiferous shale and limestone at the base of the Middle Cambrian". Since the problem of a global subdivision of the Cambrian is still under review (Robison *et al.*, 1977; Fletcher, 2001; Peng *et al.*, 2006) and formational terminology requires a lithological basis for subdivision, "Chamberlain's Brook Formation" should be substituted for "Middle Cambrian" in Hutchinson's definition.

The section at Brigus South Point on the western shore of Conception Bay was chosen as the type section, but, though a sequence between the defined limits is completely exposed there, it does not represent the full sedimentary record of this interval as developed elsewhere in Newfoundland. There is a diachronous basal contact and a significant upper unconformable contact due to local erosion or non-deposition of both the Brigus and Chamberlain's Brook formations. Therefore, whilst the concept of the formation is well demonstrated by the Brigus South Point section (*see* Hutchinson, 1962, section 3, p. 128, 129), there is a need to recognize other reference sections to accommodate the most complete sedimentary record.

The Broad Cove Member-Brigus Formation-Chamberlain's Brook Formation sequence on the southeastern side of St. Mary's Peninsula appears to be the most complete in southeastern Newfoundland, where the trilobite assemblages indicate that the oldest Brigus sediments are developed there and that there is no significant depositional/faunal break between the Brigus and Chamberlain's Brook for-

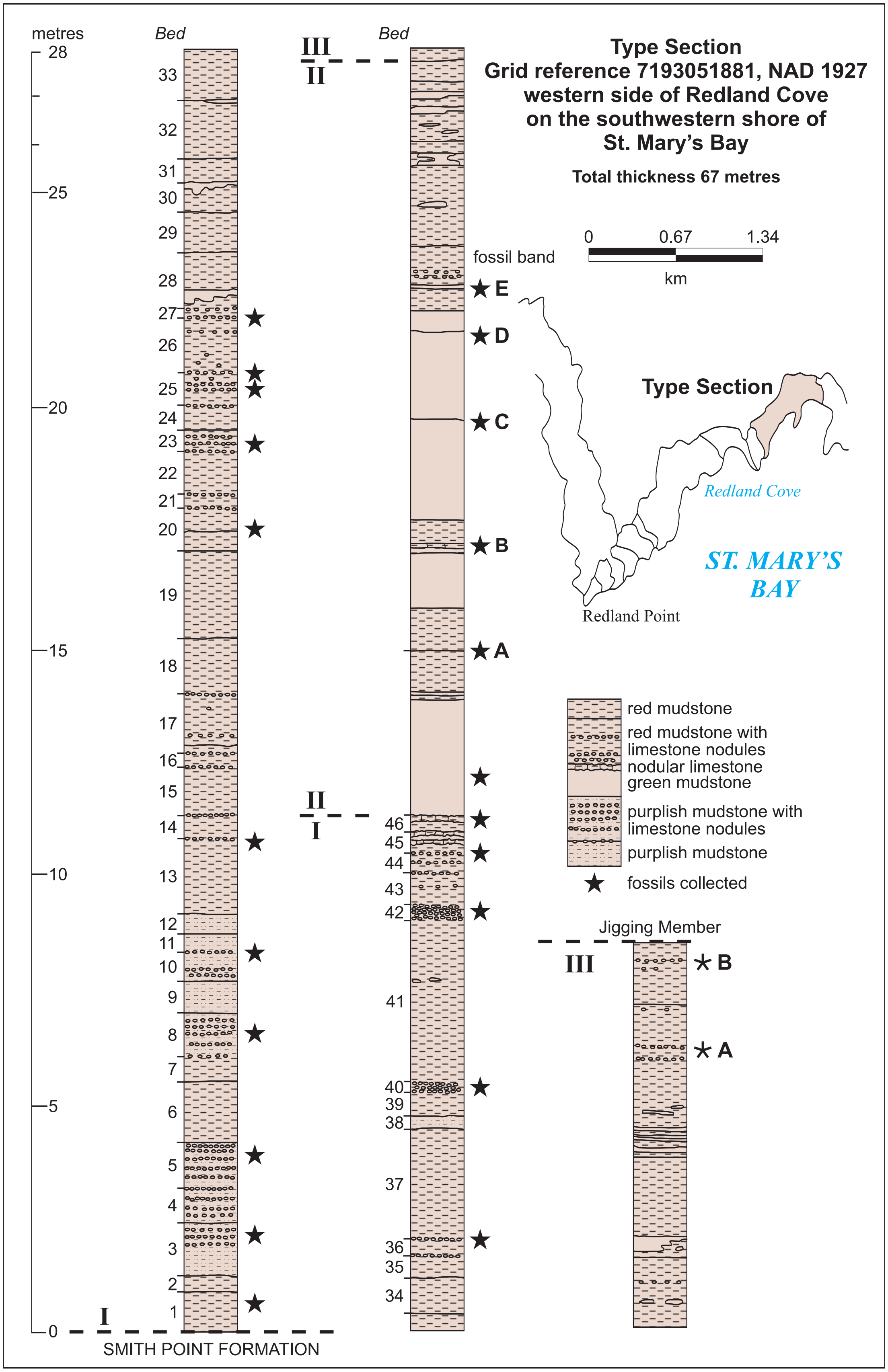

Figure 13. *Redland Cove Member; type section.*

Plate 26. *Cliff section of the Brigus Formation and lower members of the Chamberlain's Brook Formation in Redland Cove. [Scale: cliffs are 76 m high];* **s**, *top surface of the Smith Point Formation in the basal part of the* Callavia *Zone;* **c**, Triangulaspis *bed marking the top of Unit I of the Redland Cove Member and the top of the* Callavia *Zone;* **a**, *upper limit of the* Strenuella sabulosa *Zone in Unit II;* **o**, *upper limit of the Redland Cove Member above limestone nodules containing* Orodes howleyi; **b**, *junction of the Jigging Member and the Branch Cove Member at the base of the* Cephalopyge *Zone; note that thrust faulting, more or less coincident with the regional dip, has cut out the basal beds of the Jigging Member in the accessible beach section;* **1**, *fossil green-level 1a of the Branch Cove Member;* **k**, *base of the manganiferous Easter Cove Member of the Chamberlain's Brook Formation;* **m**, *Blister Bed at the top of the Easter Cove Member just below the top of the* Kiskinella *Zone,* **w**, *Waterfall Cove Member in the* Paradoxides (Eccaparadoxides) bennetti *Zone.*

mations. In all other regions, the absence of the youngest Brigus trilobite assemblage of St. Mary's Bay signifies the presence of a differential non-sequence immediately beneath the transgressive "manganese zone" of Conception and Trinity bays (Dale, 1915). In the absence of the characteristic form of the northern prominent, manganiferous, interbedded, jasper-like nodular bands, argillaceous and calcareous bed on Cape St. Mary's Peninsula, Hutchinson (1962, p. 21) tentatively regarded the formational junction as a gradational colour change "over several tens of feet of unfossiliferous beds". He provided two measured sections (1962, section 11, p. 137 and section 13, p. 139) from this region drawing the junction at a change to a darker olive-green colour. However, the ascribed basal beds of these sections are neither equivalent to each other nor representative of the base of the Chamberlain's Brook Formation as recognized elsewhere. Statements implying a lack of fossils in this part of the sequence are misleading since many important forms occur throughout the transitional Brigus Formation-Chamberlain's Brook Formation succession.

There are several completely exposed, accessible, fossiliferous sections of the Brigus Formation along the cliffs of St. Mary's Bay (Plate 26). A three-fold subdivision into formal members is evident on the basis of an abundance of nodular limestones in the lowest strata, the bright redness and lack of nodules in the middle part and an upper part of highly calcareous strata marked by thick green layers. Although laterally variable in thickness, each contains individual marker beds traceable to the Adeyton Group outcrops in the northern map areas. In this account, separate type sections at coastal localities for each of the three members are documented as new References Sections for the Brigus Formation. They are named Redland Cove Member, Jigging Member and Branch Cove Member.

Redland Cove Member (Unit 9a)

Definition

In all descriptions of the Brigus Formation, beds and nodules of pink limestone are noted as characterizing the red, purple and green mudstones in the lowest part. Here, this is recognized as the discrete stratigraphical interval from which all documented Brigus Formation fossils were obtained prior to 1972 and is here named Redland Cove Member. In the type section on the southern coast of Cape St. Mary's Peninsula (Plate 26), three less-formal subdivisions (Units I–III) are differentiated within this member (Figure 13).

The base of Redland Cove Member is conformable with the topmost beds of the Smith Point Formation that, as noted above, are regionally diachronous. The junction is drawn at the base of the lowest mudstone layer that is thicker than the intervening limestone layer within a transitional limestone-mudstone zone. At all localities, the upper limit of this member is conformable with the bright red Jigging Member and is defined by the prominently recessed bedding plane above the highest occurrence of limestone.

Stratigraphically different trilobite assemblages in the basal mudstones of this member in other regions of the Avalon Zone indicate the incompleteness of some sections. In the "classic" Smith Sound area of Trinity Bay, detailed by Matthew (1899a) and Walcott (1900b), the trilobite assemblage in the Broad Cove Member of the Smith Point Formation appears to be younger than that occurring in the Smith Point Formation and basal Brigus Formation beds on Cape St. Mary's Peninsula, and the Redland Cove Member in western Trinity Bay is considerably thinner. Although the Redland Cove Member around Long Cove in Trinity Bay is its thickest known development, the trilobite assemblages there are not as well described as in St. Mary's Bay and, for this reason only, the better-studied measurable section forming the cliffs of Redland Cove on the southern shore of Cape St. Mary's Peninsula (Plate 26; Figure 13) is currently more suited to be the type section.

Distribution and Thickness

The Redland Cove Member is extensively preserved in the Avalon, Bonavista and Burin peninsulas and reference to Hutchinson's (1962) measured sections shows that several complete sections are available for study.

The thickest section of the Redland Cove Member occurs along the Long Cove-Chapel Head coastal strip in Trinity Bay, where Hutchinson (1962, section 10, p. 135, 136, beds 11-53[in part]) measured about 165 m of strata that are referable to this member. Elsewhere in Trinity Bay, the Redland Cove Member at Hopeall Head is approximately 87 m thick (Hutchinson, 1962, section 7, p. 133, beds 7-19), at Heart's Delight it is perhaps as much as 148 m thick (Hutchinson, 1962, section 5, p. 130-131, beds 6-15) and at Smith Point is 68 m thick (Hutchinson, 1962, section 18, p. 144-145, beds 15-19 and "4 inches pink limestone at base" of Bed 20). In Conception Bay, at Brigus South Point, the Redland Cove Member is a little over 50 m thick and is considerably less than 30 m thick on the eastern side around Kelligrews and Manuels River.

On Cape St. Mary's Peninsula, the greatest thickness of the Redland Cove Member is about 90 m at Perch Cove in the St. Bride's Syncline and the isopach pattern of decreasing thickness into the eastern sections follows that for the Bonavista and Smith Point formations with a gradual reduction in thickness to the south and east; in Red Cove of Cape Dog, it is 88 m thick reducing to 71 m at Jigging Cove and 67 m in the type section.

The unusually thin sequences resting directly upon Late Neoproterozoic rocks at Manuels and on the Random Formation at Little Dantzic on the Burin Peninsula (less than 14 m, Hutchinson, 1962, sections 21 and 22, pp. 146, 147) are largely due to intermittent syndepositional erosion or non-deposition of the youngest sediments of this member in tectonic settings where the basal diachroneity is probably the most severe.

Lithology

The Redland Cove Member is lithologically similar to the Bonavista Formation, containing many limestone nodules in an essentially red mudstone sequence. The mudstones are very fine grained and massive with bedding generally marked by layers of thin shelly limestone, limestone nodules, red, purple and pale green irregular banding or sporadic separation/bedding planes. Three further, less-formal subdivisions are evident (Figure 13) in the Redland Cove Member, i.e., a lower Unit I (s to c in Plate 26) with the greatest concentration of limestone, a middle Unit II (c to a in Plate 26), characterized by relatively thick green bands containing rare nodules, and an upper Unit III (a to just above o in Plate 26) of brighter red mudstones containing bands of limestone nodules and thin shelly limestone beds [sampled fossiliferous beds and horizons are numbered in Figure 13].

In the type section at Redland Cove, basal Unit I is 40 m thick and is capped by a prominent nodular shelly limestone. The main nodular intervals tend to be associated with darker mudstone, in contrast to the thin, pink, commonly sugary, crystalline limestone beds in the top 8 m, where the red hues are much less dark. Along the margins of most separation planes, the iron-rich rocks have been reduced to give irregular, narrow, greyish-green bands and patches. In thinner sections elsewhere, nodule layers tend to be closer spaced and some coalesce to form nodular limestone beds. Extreme examples of such concentrated beds are the relatively thick trilobitic limestones at Brigus South Point, where van Ingen (1914) mistakenly regarded one as the "Smith Point Limestone", thus accounting for his record of *Callavia* Zone trilobites at a lower level than elsewhere (Hutchinson, 1962, p. 15). This unit is thickest in the St. Bride's Syncline and is only completely exposed in Perch Cove, where a relatively thick green layer about half way up the sequence is a characteristic of its western development. Such a green-bed feature seems to be associated with thick sections of this unit as is notable in those of eastern Trinity Bay.

In Redland Cove, Unit II is 17 m thick and rests conformably upon Unit I, i.e., upon the prominent nodular limestone (Bed 46 in Figure 13) whose steeply dipping, top bedding-surface allows access down to the shore (c in Plate 26).

Three, relatively thick, green mudstones and rare thin limestones in the intervening red bands distinguish the lower two-thirds of the unit. Wherever fossiliferous, the rocks (especially the limestones) are prone to deep weathering and occur as brown, steinkern-rich, goethitic, rotten stones. The top third is red with a very thin limestone bed containing nodules near the base and some small, laterally oriented, irregularly shaped green patches in the upper part. In the Trinity Bay sections, the correlative green beds contain relatively large, flattish, concretionary silty limestone nodules resembling the millstone-types characterizing the Chapel Island Formation Member 3 in the Fortune Valley Syncline on the Burin Peninsula (Bengtson and Fletcher, 1983), in the Random Formation at Hopeall Head and Distress Cove, St. Bride's, and in the basal mudstones of the Bonavista Formation on Random Island, clearly indicating similar environments of deposition.

Unit III is 9 m thick and separated from Unit II by a prominently recessed bedding plane. The unit is a brighter red mudstone sequence with sparse, laterally oriented, thin green patches, rare very dusky purple streaks and several thin, eodiscid-rich, nodular limestone horizons.

Contact Relations

The Redland Cove Member conformably overlies the Smith Point Formation, except in those areas of eastern Conception Bay and western Burin Peninsula, where it rests on a variety of older formations of both late Ediacaran and Early Cambrian age. In the most completely preserved sequences, the member is conformably overlain by bright red mudstones of the Jigging Member of the Brigus Formation, but there are regions where beds of the Chamberlain's Brook Formation disconformably lie upon it, because of a non-sequence involving both younger Brigus and Chamberlain's Brook formation rocks. In Redland Cove, the upper contact is somewhat obscured by scree material associated with small-scale thrust faulting affecting the contact rocks. However, well-exposed upper contacts are accessible in the core of the Beckford Anticline on the Easter Cove beach in Branch Cove and over the synclinal axis of the Red Head Syncline in the Easter Cove of Red Head Cove.

Fauna

Although brachiopods, bivalves and other associated taxa are conspicuous, trilobites are the main constituents of the faunas, and all listed fossils from the "Lower Cambrian" Brigus Formation of southeastern Newfoundland prior to 1972 were obtained from this member. Such forms are typical elements of a discrete faunal realm variously referred to as Atlantic, Acado-Baltic, Baltoscandian, and Perigondwanan, in which a succession of trilobite assemblages has been traditionally referred to, a lower "*Fallotaspis* Zone", a middle "*Callavia* Zone" and an upper "*Protolenus* Zone". As yet, the precise relationship between the lower and middle "zones" has not been established, because the temporal ranges of the two genera apparently overlap (*see* Age and Correlation below). In Newfoundland, England and Massachusetts, the *Callavia* Zone coincides with the stratigraphical range of the genus. However, recognition of a *Protolenus* Zone has been rather tentative, since it was first described from New Brunswick (Matthew, 1892) in a region where *Callavia* and its zonal associates do not occur. Today, protolenids are better understood and their stratigraphical associates above *Callavia*-bearing strata in Newfoundland, Massachusetts and England support such a faunal differentiation, though Geyer's (1990b) subdivision of the Moroccan protolenid succession into a lower protolenid *Hupeolenus* Zone and an upper eodiscid *Cephalopyge* Zone provides a more widely applicable standard of reference. In Morocco, the base of the *Hupeolenus* Zone is taken a little above the contemporaneous last occurrences of *Dipharus attleborensis* and *Triangulaspis* spp. Lermontova, 1940 at the first appearance of protolenids, e.g., *Orodes*. This is an interval of possible global significance (Robison *et al.*, 1977, p. 260) and is identifiable in Redland Cove, where the last appearances of *Dipharus* and *Triangulaspis* accompany that of *Callavia broeggeri* to mark the top of the *Callavia* Zone, a little below the first appearance of *Orodes* and *Protolenus* (*Protolenus*) species.

Callavia broeggeri Zone: Unit I, is replete with trilobite taxa, but only two genera are presently known to occur throughout, i.e., *Callavia* and *Acanthomicmacca*. The main faunal marker is the first appearance in Bed 20 (Figure 13) of the earliest eodiscid *Dipharus* Clark, 1923 and this allows a subdivision of a *C. broeggeri* Zone into a lower *Acanthomicmacca walcotti* Subzone and an upper *Dipharus attleborensis* Subzone.

Acanthomicmacca walcotti Subzone: The *Acanthomicmacca walcotti* Subzone represents the oldest Newfoundland trilobite assemblage, with its base, as noted previously, within the Broad Cove Member at the top of the Smith Point Limestone in Redland Cove and its upper limit defined at the base of the lowest bed containing *Dipharus*. In addition to *C. broeggeri*, three main forms occur, i.e., a new species of *Acanthomicmacca* (Plate 27, Figure 2), *A. walcotti* (Plate 27, Figures 4-7) and a species of *Comluella* Hupé, 1953 (Plate 27, Figure 25) close to *Micmacca protolenoides* Cobbold, 1931 (*see* Lake, 1932, pl. 22, figs. 12, 13).

Dipharus attleborensis Subzone: The *Dipharus attleborensis* Subzone contains numerous taxa, whose stratigraphical distributions are not yet fully known. Eodiscids are abundant, e.g., *D. attleborensis*, (Plate 27, Figures 8-11), *Delgadella plana* (Hutchinson, 1962), *Calodiscus lobatus* (Hall, 1847), *C. meeki* (Ford, 1876), *C. schucherti*

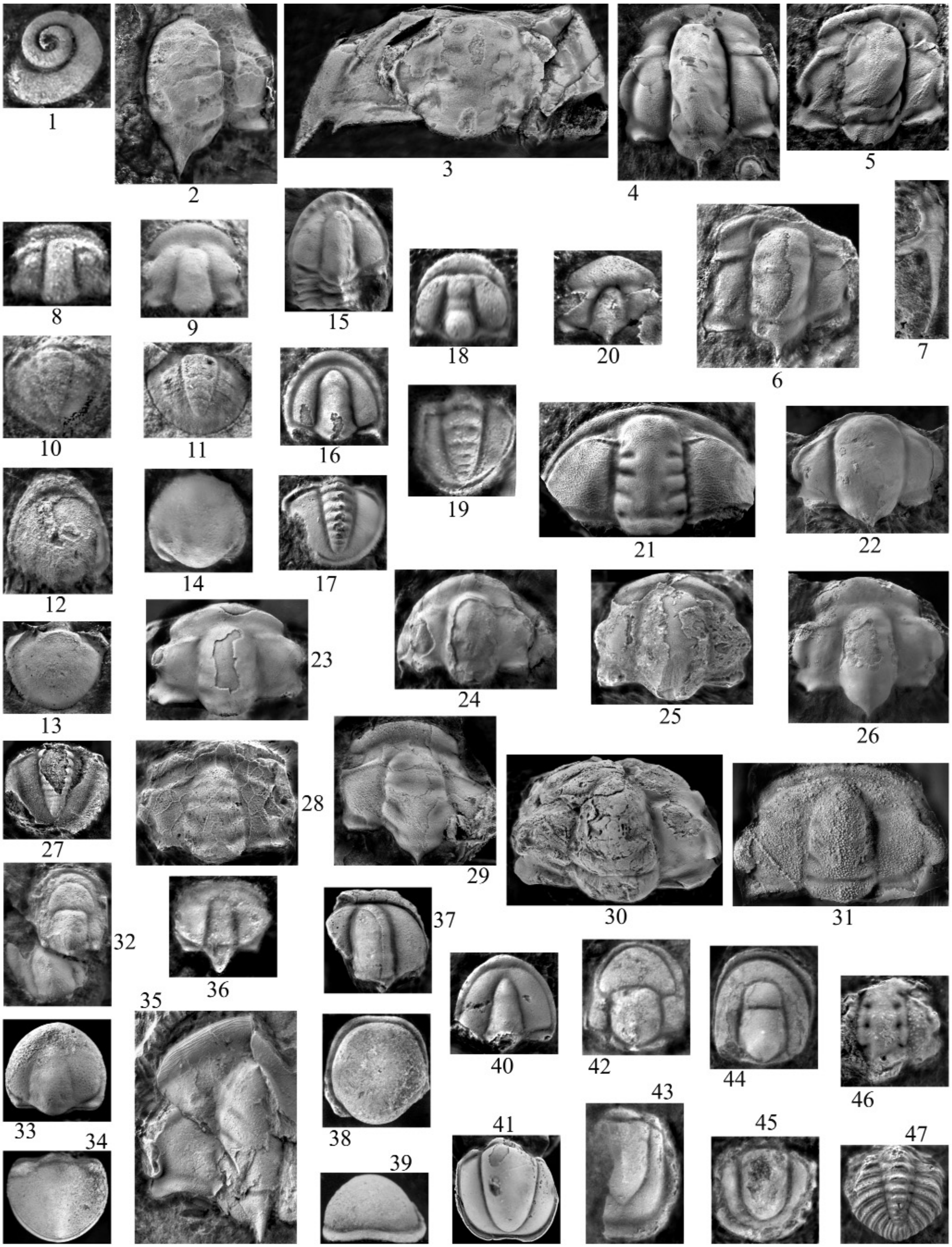

Plate 27. *Some fossils from the Bonavista, Smith Point and Brigus formations.*

Figure 1. *Aldanella attleborensis*, TPF 1641, x 7.7, from the basal bed of the Bonavista Formation in Redland Cove

Figures 2-26 from the *Callavia broeggeri* Zone

Figure 2. *Acanthomicmacca walcotti* (Matthew, 1899b), latex cast of a weathered external mould of partial cranidium TPF 590, x 2, from the top of the Smith Point Formation in Redland Cove

Figure 3. *Callavia broeggeri* (Walcott, 1890b), partial cephalon TPF 750, x 0.9, from the top of the *Dipharus attleborensis* Subzone in Redland Cove

Figures 4-7. *Acanthomicmacca walcotti* from the *Acanthomicmacca walcotti* Subzone in Redland Cove. 4-5, latex casts of external moulds of tectonized cranidia; 4, TPF 2642, x 4.6; 5, TPF 2503A, x 5.8; 6, cranidium TPF 2060, x 6.2; 7, latex cast of external mould of librigena TPF 2504, x 1.4

Figures 8-22, 24 and 26 from the *Dipharus attleborensis* Subzone in Redland Cove

Figures 8-11. *Dipharus attleborensis* (Shaler and Foerste, 1888). 8, immature cranidium TPF 2057A, x 12.7; 9, cranidium TPF 1969C, x 9.4; 10, pygidium TPF 2623A, x 8.5; 11, exfoliated pygidium TPF 2100A, x 12

Figures 12-13. *Weymouthia nobilis* (Ford, 1872). 12, damaged cephalon TPF 2018, x 3; 13, exfoliated pygidium TPF 2038, x 5.3

Figure 14. *Weymouthia* sp. nov., cranidium TPF 2418, x 9

Figures 15-17. *Serrodiscus bellimarginatus* (Shaler and Foerste, 1888). 15, cephalon TPF 2063, x 3.1, showing the intergenal spine and thorax; 16, cephalon TPF 1162, x 5.2; 17, pygidium TPF 3292, x 5

Figures 18-19. *Acimetopus helena* (Walcott, 1889b). 18, cephalon TPF 2000A, x 9.1; 19, pygidium TPF 2000B, x 9.5, from the top of the *Dipharus attleborensis* Subzone

Figure 20. *Triangulaspis vigilans* (Matthew, 1889), latex cast of external mould of cranidium TPF 2084, x 10.7, from the top of the *Dipharus attleborensis* Subzone

Figure 21. *Pseudatops reticulatus* (Walcott, 1890b), cranidium TPF 2121, x 1.9

Figure 22. *Myopsomicmacca* sp. aff. *M. ellipsocephaloides* (Cobbold, 1910), cranidium TPF 2006, x 1.6

Figures 23-24. *Comluella* sp. nov. from the *Dipharus attleborensis* Subzone. 23, cranidium TPF 596, x 1.9, on Mooney's Hill in the Easter Cove of Branch Cove; 24, incomplete cephalon TPF 2064, x 2.8

Figure 25. *Comluella* sp. cf. *C. protolenoides* (Cobbold, 1931), cranidium TPF 591, x 2.8, from the *Acanthomicmacca walcotti* Subzone in Redland Cove

Figure 26. *Strenuella strenua* (Billings, 1874), cranidium TPF 1987, x 3.3

Figure 27. *Mallagnostus llarenai* (R. and E. Richter, 1941), pygidium TPF 1010, x 2.3, from the *Strenuella sabulosa* Zone in Redland Cove

Figures 28-29. *Strenuella sabulosa* Rushton, 1966 from the *Strenuella sabulosa* Zone in Redland Cove. 28, decalcified cranidium TPF 1127, x 1.6; 29, latex cast of internal mould of exfoliated cranidium TPF 1081, x 1.6

Figure 30-31. *Orodes howleyi* (Walcott, 1889b) from the *Orodes howleyi* Zone. 30, cranidium TPF 464, x 1.2, from Jigging Cove; 31, latex replica of topotype cranidium USNM 18338, x 1.1, "from some short distance southwest along the railway track from the site of the former C.N.R. station" at Manuels

Figures 32-47 from the Branch Cove Member *Cephalopyge notabilis* Zone

Figure 32. *Condylopyge eli* Geyer, 1998, partial cephalon TPF 2698A resting on partial pygidium TPF 2698B, x 5, from Bed 1A in Jigging Cove

Figures 33-34. *Cephalopyge notabilis* Geyer, 1988, enrolled specimen ROM 56142 from Bed 1B in Easter Cove of Branch Cove. 33, cephalon ROM 56142A, x 5.8; 34, pygidium ROM 56142B, x 6,

Figure 35. *Hamatolenus (H.)* sp. aff. *H. (H.) marocanus* (Neltner, 1938), partial cranidium TPF 2301, x 2.6, from Bed 1B in Jigging Cove

Figure 36. Calodiscidae, gen. nov., cranidium TPF 2391B, x 7.7, from Bed 1 in Jigging Cove

Figures 37-47 from the top bed (Bed 6H) of the *Cephalopyge notabilis* Zone in Easter cove of Branch Cove

Figure 37. *Serrodiscus* sp. cf. *S. latus* Rasetti, 1966, partial cephalon TPF 289, x 3.7

Figures 38-39. *Bathydiscus taconicus* Fletcher, 2003, dorsal and anterior views of cephalon ROM 56141, x 3.7

Figure 40. *Serrodiscus occipitalis* (Rasetti, 1966), partial cephalon ROM 56159B, x 4.5

Figure 41. *Bathydiscus longifrons* (Rasetti, 1966), damaged pygidium ROM 56137, x 3.5

Figures 42-43. *Condylopyge eli* Geyer, 1998. 42, partial cephalon ROM 56125, x 10.7; partial pygidium ROM 56124, x 8.4

Figures 44-45. *Peronopsis roddyi* (Resser and Howell, 1938). 44, cephalon ROM 56122, x 7.2; 45, damaged pygidium ROM 56121, x 8.4

Figures 46-47. *Ovatoryctocara granulata* Tchernysheva, 1962. 46, partial cranidium ROM 56159A, x 6.2; partial pygidium ROM 56160, x 5.7

(Matthew, 1896), *Weymouthia nobilis* [*index* Rushton *in* Bassett *et al.*, 1976] (Plate 27, Figures 12-13), *Acimetopus helena* (Plate 27, Figures 18-19), *Mallagnostus llarenai* and *Serrodiscus bellimarginatus* (Plate 27, Figures 15-17). Among the polymerids, the following forms have been noted, *Callavia broeggeri*, *?Kjerulfia* sp. Kiaer, 1917, *Triangulaspis meglitzkii* (von Toll, 1899), *T. vigilans* (Plate 27, Figure 20), *Strenuaeva* cf. *S. spinosa* Ahlberg and Bergström, 1978, *Strenuella strenua* (Plate 27, Figure 26), *S.* sp. nov., *Comluella pustulata* (Cobbold, 1910), *C.* sp. cf. *C. protolenoides*, *C.* sp. nov. (Plate 27, Figures 23-24), *Acanthomicmacca walcotti*, *A.* sp. nov., *Avalonia manuelensis* Walcott, 1891, *"Bonnia" bombifrons* (Matthew, 1886) and *Pseudatops reticulatus* (Plate 27, Figure 21).

In addition to trilobites, relatively rare specimens of a *Fordilla* sp. and of *Microdictyon* Bengtson *et al.*, 1986 are associated with beds containing *Hyolithellus micans* (Billings, 1872), *Coleoloides typicalis*, *Helcionella* sp., *Latouchella paupera* (Billings, 1872), *Stenothecoides* sp., *Kutorgina labradorica* (Billings, 1861), lingulellids, obellelid brachiopods, e.g., *Obolella atlantica* Walcott, 1889b and bradoriids like *Indiana* cf. *I. lentiformis* (Cobbold, 1921). There are also well-preserved, calcitic, ostracod-like forms resembling aparchitids (M. Williams, personal communication, 2002).

In a recent publication, the author (Fletcher, 2003, table 3, txt-fig.3) proposed to differentiate a *Hupeolenus* Zone in Newfoundland comformably intervening between the *Callavia* Zone and the *Cephalopyge* Zone. The base of this Newfoundland Zone was to be taken immediately above the synchronous last appearances of *Callavia*, *Dipharus* and *Triangulaspis* and its top drawn at the base of the first occurrence of *Cephalopyge* Geyer, 1988. As thus defined, it closely corresponds to Geyer's (1990b, p. 62) Moroccan *Hupeolenus* Zone. However, the tentative reference of a new Newfoundland protolenid species to *Protolenus* (*Hupeolenus*) *mckillopi* (Fletcher, 2003, p. 97, pl. 3, figs. 18-20) was taken as support for the zonal name, but, because this protolenid is now considered to belong in the subgenus *Protolenus* (*see* Geyer and Landing, 2004, p. 195), this interval has been reviewed and a Newfoundland *Hupeolenus* Zone is no longer to be recognized. Instead, the interval is divided into two separate zones, a lower *Strenuella sabulosa* Zone containing some elements from the *Callavia* Zone restricted to Unit II, and an upper *Orodes howleyi* Zone, marked by the oldest protolenids in Newfoundland, extending through Unit III and the overlying Jigging Member into the base of the Branch Cove Member, where the succeeding zone fossil *Cephalopyge notabilis* Geyer, 1988 first appears. Such a revision better conforms to zonal subdivisions elsewhere that stress the significant first appearance of protolenid trilobites (Figure 12).

Strenuella sabulosa Zone: The *Strenuella sabulosa Zone* may be considered to be a short-lived buffer zone between beds with *Callavia* and beds with protolenids. The zonal fossil *S. sabulosa* (Plate 27, Figures 28 and 29) is the most conspicuous element of this assemblage. It accompanies a new species of *Strenuella*, *Delgadella plana*, *Calodiscus schucherti*, *Weymouthia nobilis*, *Mallagnostus llarenai*, (Plate 27, Figure 27) *Serrodiscus bellimarginatus* and *S. speciosus* (Ford, 1873) along with the brachiopod *Obolella atlantica* and bradoriids.

Orodes howleyi Zone: In addition to the zonal species, the protolenids are represented by *Protolenus (P.) mckillopi, Latoucheia* Hupé, 1953 and *Catadoxides harveyi* (Walcott, 1889b), but the most conspicuous elements are the eodiscids *Chelediscus acifer* Rushton, 1966 (Fletcher, 2003, pl. 1, figs. 25-26), *Tannudiscus balanus* Rushton, 1966 (Fletcher, 2003, pl. 3, fig. 2) and *Cobboldites* Kobayashi, 1943 accompanied by the agnostid *Condylopyge* sp. cf. *C. amitina* Rushton, 1966 (Fletcher, 2003, pl. 1, fig. 9) and phosphatic brachiopods, e.g., *Botsfordia* Matthew, 1889b and *Lingulella* Salter, 1859, as well as phosphatocopids possibly referable to *Falites* (M. Williams, personal communication, 2002). The top of Unit III is marked by the first appearance of tiny cones resembling *Salterella maccullochi* (Murchison, 1859) (Fletcher 2003, text-fig. 2, G-I). Note that the identification of these cones needs verification, because they also have features of *Volborthella* (*see* Fritz and Yochelson, 1988).

Age and Correlation

The Moroccan early trilobite succession acts as the standard for this faunal realm and the zonal scheme, initiated by Hupé (1953) and developed by Sdzuy (1967), has been refined by Geyer (1990b; Geyer and Landing, 2004). The earliest trilobite assemblages are characterized by fallotaspids and bigotinids, none of which is known in southeastern Newfoundland. However, the synchronous first appearances of the more cosmopolitan eodiscids *Delgadella* and *Dipharus* in the middle of the Moroccan *Antatlasia hollardi* Zone (Geyer *et al.*, 1995, p. 68), within the stratigraphical range of the fallotaspids (Geyer, 1996, p, 101), provide an important guide to correlation. Since these eodiscids occur within the *Callavia* Zone in Newfoundland, it would appear that the ranges of *Fallotaspis* and *Callavia* overlap and that the *Acanthomicmacca walcotti* Subzone of the Newfoundland *Callavia* Zone correlates with the lower part of the Moroccan *Antatlasia hollardi* Zone. In Morocco, the *Sectigena* Zone contains *D. attleborensis* and ends with the first appearance of *Protolenus* (*Hupeolenus*), a level a little above the last appearance of *Triangulaspis* (Geyer *et al.*, 1995, p. 69). Such a situation indicates that the Newfoundland *Dipharus attleborensis* Subzone is equivalent to the upper part of the *A. hollardi* Zone combined with the *A. gutta-pluviae* and *Sectigena* zones (Figure 12).

As in the Newfoundland sections (Figure 13, beds 42-46), there is evidence of shallowing associated with the extinction of *Triangulaspis* in Morocco and, in the classic Amouslek Section, conglomeratic sandstones separate *Sectigena* strata from the bed with the first protolenids, with no trilobites in common. This contrasts with the situation in Redland Cove, where several eodiscids of the *Callavia* Zone, continue their ranges into the succeeding *Strenuella sabulosa* Zone. In Morocco, *Orodes* Geyer, 1990a occurs at the base of the *Hupeolenus* Zone, whereas this genus has not been found in the lower *Strenuella sabulosa* Zone of Newfoundland. Two interpretations may be made; either the latter zone is to be correlated with the topmost *Sectigena* Zone or the conglomeratic interval in Morocco indicates a possible non-sequence to account for the absence of a *sabulosa* Zone equivalent, i.e., the interval between the last occurrence of *Triangulaspis* and the first appearance of *Orodes*. The presence of *Catadoxides* Matthew, 1899b in the *Orodes howleyi* Zone needs further attention, since this may be the senior synonym of *Myopsolenus* Hupé, 1953 necessitating some taxonomic revision.

Correspondence with contemporaneous faunas in England, Spain (Figure 12) and Massachusetts is also evident. In Shropshire, England, *Callavia broeggeri* [*callavei* Lapworth, 1888] with *D. attleborensis* and questionable *Kjerulfia* and *Judomia* Lermontova, 1951 occur in the Green *Callavia* Sandstone, above the fallotaspid-bearing Lower Comley Sandstone. *C. broeggeri* continues its range through the succeeding Red *Callavia* Sandstone [*Olenellus* Limestone], "*Eodiscus*" *bellimarginatus* Limestone and *Strenuella* Limestone units (Rushton, 1974) accompanied by *D. attleborensis*, *Calodiscus*, *Serrodiscus bellimarginatus*, *Triangulaspis vigilans* and *Pseudatops reticulatus* to suggest total equivalence to the *D. attleborensis* Subzone in Newfoundland. As in Newfoundland and Morocco, this assemblage is overlain by strata assigned to a protolenid zone, i.e., the *Protolenus* Limestone, but only follows Newfoundland in having some eodiscid elements continuing their ranges upward from the *Callavia* Zone, e.g., *Calodiscus*, *Serrodiscus* and *Weymouthia*; the presence of *Latoucheia* and *Cobboldites* in the *Protolenus* Limestone suggests correlation of this limestone with both the Newfoundland *Strenuella sabulosa* and *Orodes howleyi* zones.

In the Purley Shales of Warwickshire, England, Rushton (1966) collected three localities well above the base. His Localities 1A and 1B with *Serrodiscus bellimarginatus*, *Mallagnostus llarenai* and *Strenuella sabulosa* correlate with the *S. sabulosa* Zone of Newfoundland and Locality 2A, with eodiscids, e.g., *Chelediscus acifer*, *Cobboldites* and *Tannudiscus balanus*, together with an early form of *Condylopyge*, is diagnostic of the *Orodes howleyi* Zone.

The presence of *Callavia*, *Delgadella*, *Calodiscus schucherti*, *Mallagnostus llarenai* and *Triangulaspis meglitzkii* in the faunas of Cala, Llarena and Guadalcanal in Spain (Sdzuy, 1962) indicates some correspondence with the *Dipharus attleborensis* Subzone of Newfoundland and recordings of *Serrodiscus speciosus* in the '*speciosus-morenica* Band' from Guadalcanal suggest a correlation with the *Strenuella sabulosa* Zone.

Of what is known of the contemporaneous trilobites in the Weymouth Formation in Massachusetts, such as *Callavia broeggeri*, *D. attleborensis*, *Weymouthia nobilis*, *Serrodiscus bellimarginatus* and *Strenuella strenua*, only the *Dipharus attleborensis* Subzone is recognizable there.

Important correlations may be made also with Siberian sequences (Demokidov and Lazarenko, 1964, fig. 33, pls. 1, 4 and 5; Savitskiy *et al.*, 1972, tab. 1) containing *Delgadella*, *Dipharus*, *Calodiscus schucherti*, *Acimetopus helena*, *Mallagnostus* [*Ladadiscus* Pokrovskaya, 1959], *Triangulaspis meglitzkii* and *T. vigilans* to indicate that the top of the *Callavia* Zone of Newfoundland corresponds to the top of the *Dipharus-Judomia* Zone, i.e., the top of the Atdabanian [Aldanian] Stage. The occurrence of *A. granulosus* (Yegorova and Schabanov *in* Savitsky *et al.*, 1972, p. 52, pl. 1.1-1.4) – a form very close to *A. helena,* in the base of the Siberian Botomian Stage – seems to indicate a stratigraphical position in the *S. sabulosa* Zone and near the *Elliptocephala asaphoides-Acimetopus* faunal boundary in the Laurentian Cambrian (Rasetti, 1966), since a correlation of the *Dipharus-S. sabulosa* transitional sequence with the *Elliptocephala asaphoides* fauna in the Laurentian Taconic sequence (Rasetti, 1966, p. 16 17) within the tectonostratigraphical Humber Zone (Figure 1) is suggested by co-occurrences of *Calodiscus lobatus*, *C. meeki*, *C. schucherti* and *Serrodiscus speciosus* (Figure 12).

The correlations made above support the suggestion (Robison *et al.*, 1977) that the extinction level of *Triangulaspis*, lying at the base of protolenine sequences associated with *Dipharus*, *Serrodiscus*, *Calodiscus* and the earliest *Acimetopus*, is a potential candidate as a global Cambrian stage boundary, i.e., the base of Cambrian Series 3 (Peng *et al.*, 2006, fig. 1).

Jigging Member (Unit 9b)

Definition

The Jigging Member rests conformably upon the Redland Cove Member and is conformably overlain by the Branch Cove Member. It is distinguished as an especially bright red mudstone sequence lacking calcareous nodules and, in contrast to the adjacent members, generally lacks laterally extensive colour banding.

The type section forms the northern cliff of Jigging Cove in St. Mary's Bay (Figure 14), where the conformable relationships with the other members are well exposed. Its base is defined by a prominent, recessed separation plane immediately above the uppermost limestone nodules of Unit III of the Redland Cove Member and its upper limit is marked by a similarly conspicuous separation plane just below the lowest characteristic, calcareous, pellet-like, greyish-green mudstone layer of the Branch Cove Member.

Distribution and Thickness

The bright red Jigging Member is a characteristic component of the Brigus Formation as developed in St. Mary's, Placentia and Trinity bays, but, in Conception Bay, its iron-rich rocks have been reduced to an overall green colour most likely due to diagenetic changes related to the extensive local non-sequence between the Brigus and Chamberlain's Brook formations there. On the Burin Peninsula, this non-sequence is generally more pronounced and, in all but the section at Pump Cove (O'Brien *et al*., 1977, fig. 1; Figure 2), where the lower part of the Branch Cove Member is preserved, beds of the Chamberlain's Brook Formation rest directly upon the Redland Cove Member. Its greatest thickness is in the Cape Dog-Jigging Cove area of northwestern St. Mary's Bay, where the type section is 27 m thick (Figure 14). Thinning to south and north (Figure 14) is evident and its thickness in Trinity Bay is 19.5 m at Long Cove, 19 m at Smith Point and 18.5 m at Hopeall Head. Farther east in Conception Bay, it is 16.8 m at Brigus South Point and incompletely preserved in the Manuels-Kelligrews area.

In the map area, it is well exposed in Jigging Cove and in the Easter Cove of Branch Cove; in Redland Cove (just above o to b in Plate 26), the cliff section is generally inaccessible due to scree debris associated with local thrusting.

Lithology

The evenly fine-grained mudstones of the Jigging Member are bright, moderate red [*5R 3-4/7*] with relatively minor thin streaks and bands of purple and greyish-green coloured siltstone. A feature of the redbeds is the occurrences of small upstanding syndepositional pressure domes, some of which have been mistaken for trace fossils. Conspicuous recessed separation planes containing soft ashy clays of possible volcanic origin break up the sequence into three units (Figure 14).

At the type locality, Unit I is 9 m thick and the key correlative unit, because of its distinctive purple and green-striped bands and a base delineated by a thin, weathering-out tuffaceous layer. Unit II is 10 m thick and red throughout. Unit III is 7.6 m thick and less massive, but is marked by several minor separation planes encrusted with a dark manganese mineral and very thin green streaky bands, most of which represent marginal reduction zones to the separation planes.

Contact Relations

The lower and upper contacts of the Jigging Member with the Redland Cove Member and the Branch Cove Member are conformably drawn at prominent, recessive-weathering, bedding planes.

Fauna

As yet, no trilobites have been recovered from the Jigging Member. However, certain horizons in Unit 1 are replete with the same tiny cones provisionally referred to *Salterella maccullochi* [?*Volborthella*] occurring in the topmost beds of the underlying Redland Cove Member. In Unit II, some well-preserved, shiny black, beautifully ornamented bradoriid-like forms have been collected, along with one brachiopod specimen referred to *Lingulella*.

Age and Correlation

The member is considered to be part of the *Orodes howleyi* Zone, since it lies beneath the first occurrence of *Cephalopyge notabilis* marking the base of the overlying *Cephalopyge* Zone. In the absence of trilobites, the identifiable bradoriids may provide the best means of establishing a correlation with other trilobitic sequences (Siveter and Williams, 1997).

Branch Cove Member (Unit 9c)

Definition

The upper member of the Brigus Formation is here named the Branch Cove Member. This is a darker red mudstone sequence than below, marked by intermittent, weakly calcareous green layers containing a high proportion of minutely disseminated, whitish, angular carbonate pellets and shell fragments (Plate 28) as also developed in the overlying manganiferous Easter Cove Member (Plate 29). The base is defined by a prominently recessed bedding plane separating the bright red mudstones of the Jigging Member from the more fossiliferous green-layered sequence. The upper limit is that established for the top of the formation,

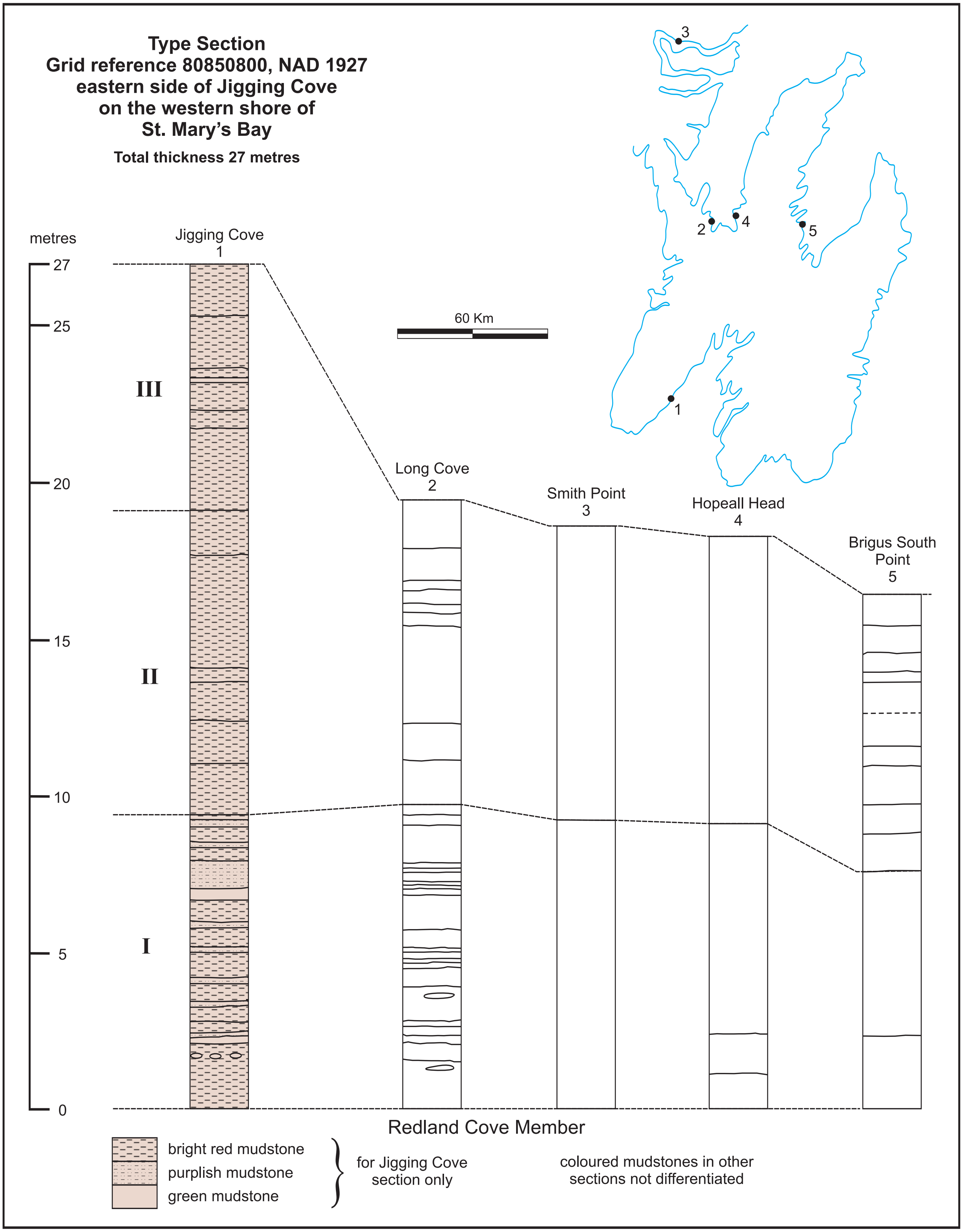

Figure 14. *Jigging Member; type and comparative sections.*

Plate 28. *Distinctive pale green reduction layers associated with fossiliferous calcareous debris typically occurring in the Branch Cove Member and the lower part of the Easter Cove Member of the Chamberlain's Brook Formation. These layers are in Bed 6 of the Branch Cove Member in Redland Cove, i.e., just below* **k** *in Plate 26.*

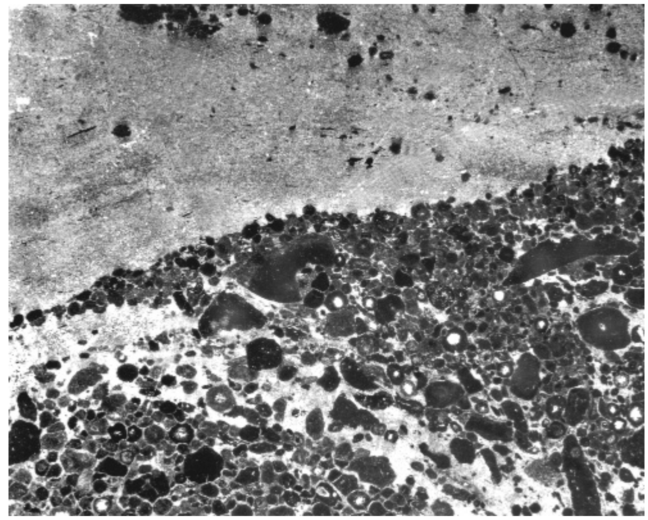

Plate 29. *Photomicrograph of mudstone from the upper part of the Easter Cove Member in the Wester Cove of Branch Cove. Wispy-bedded, fine-grained mudstone with streaked out lens of irregular fine calcareous debris. Main pocket includes degraded echinodermal ossicles and comprises a mosaic of tightly packed, nucleated and amorphous calcarenites, in places, showing solution contacts. [Magnification x 6]*

namely, the base of a conspicuous mudstone zone of manganese carbonate nodules characterizing the Easter Cove Member at the base of the Chamberlain's Brook Formation. The type section (Figure 15) in the Easter Cove of Branch Cove is well exposed and duplicated astride the axis of the pitching Beckford Anticline (Figure 3). Conformable and more or less gradational sedimentary relationships with the adjacent members indicate an unbroken sequence on Cape St. Mary's Peninsula. In areas where the Brigus-Chamberlain's Brook formational non-sequence is most pronounced, e.g., in northeastern Trinity Bay and Conception Bay, the considerable iron content has been reduced so that much of the underlying Branch Member is green.

Distribution and Thickness

The Branch Cove Member is only completely preserved in the Jigging Cove-Redland Cove region of Cape St. Mary's Peninsula and perhaps in the axial region of the St. Bride's Syncline to the west (Figure 3). Outside the map area, the member is not completely preserved, because the uppermost strata were either not deposited or were differentially eroded prior to transgression by sediments of overlapping members of the Chamberlain's Brook Formation. Therefore, when traced northward, the Brigus-Chamberlain's Brook formational boundary represents a differential non-sequence and the contact rocks of the Branch Cove Member are progressively older. In the northwest along Smith Sound, e.g., at Petley and to the northeast in Conception Bay, e.g., at Brigus South Point (Figure 16), only part of the Branch Cove Member is preserved and is almost completely overstepped by the increasingly thick manganiferous limestone marking the base of a thinning and incomplete sequence of the Chamberlain's Brook Formation. To the west, on the Burin Peninsula and on the French island of Langlade, the overstepping is even more severe and, in all areas except the Pump Cove area in the Fortune Valley Syncline (Figure 2), the Branch Cove Member is absent.

Differential subsidence over southeastern Newfoundland became more pronounced in late Brigus Formation times and, even in the map area, the thickness of the formation varies significantly (Figure 16). A reduction from 97 m in the Easter Cove of Branch Cove (where it is tectonically thinned over the axis of Beckford Anticline) to 66 m in Redland Cove is a measure of an original thinning. Measurements to the north through Jigging Cove and Red Cove of Cape Dog show the gradual attenuation of all beds in this member. At the latter locality, the first signs of the northerly non-sequence are discernible in the greater concentration of manganese nodules at the base of the Chamberlain's Brook Formation and a possible absence of the topmost layers of the Branch Cove Member.

Lithology

The Branch Cove Member is largely a dusky red, calcareous mudstone sequence, conspicuously layered in shades of greyish-green and minor dusky purple-blue [*5PB 2/2*]. Most green layers are essentially calcareous and char-

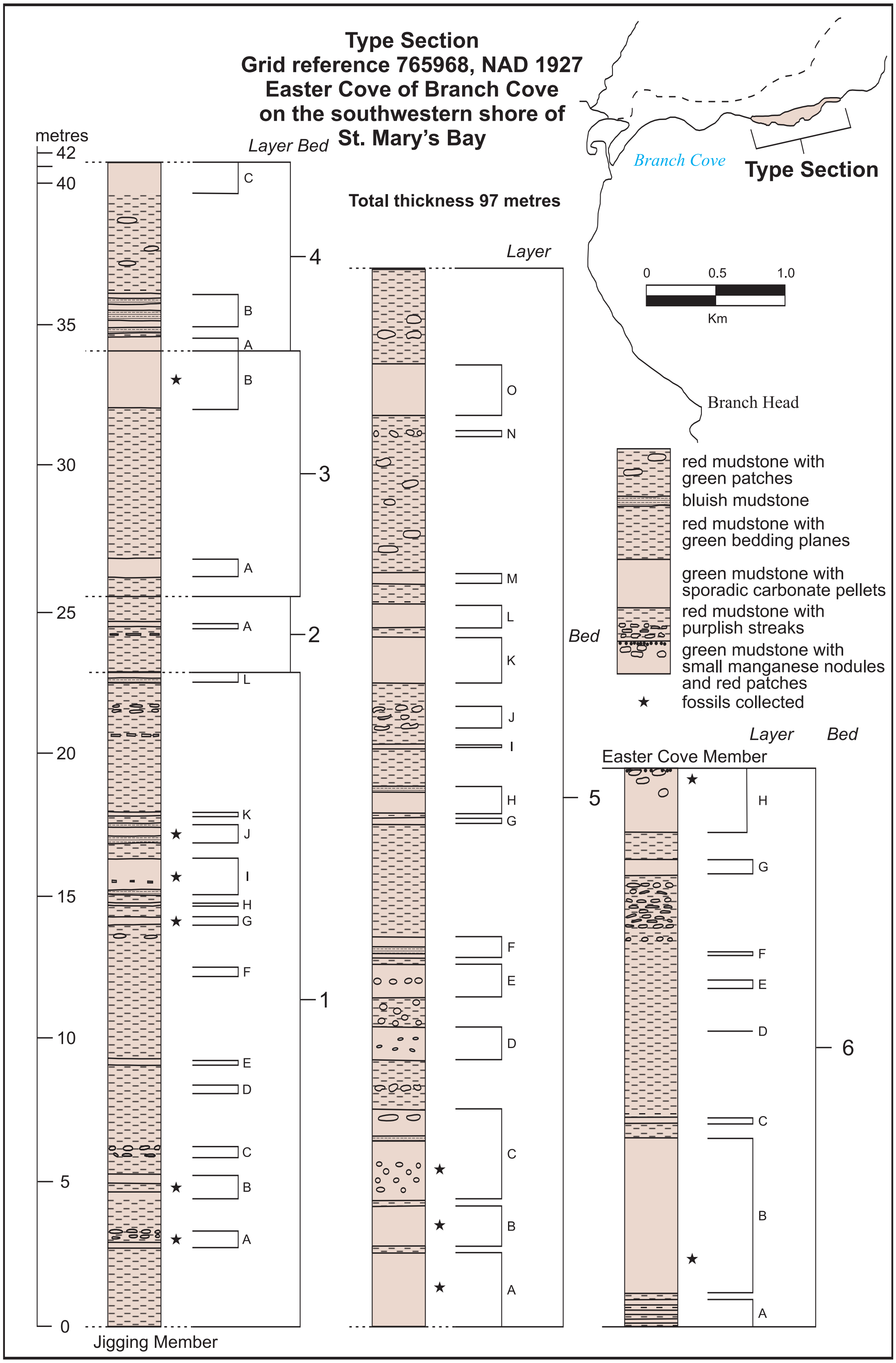

Figure 15. *Branch Cove Member; type section.*

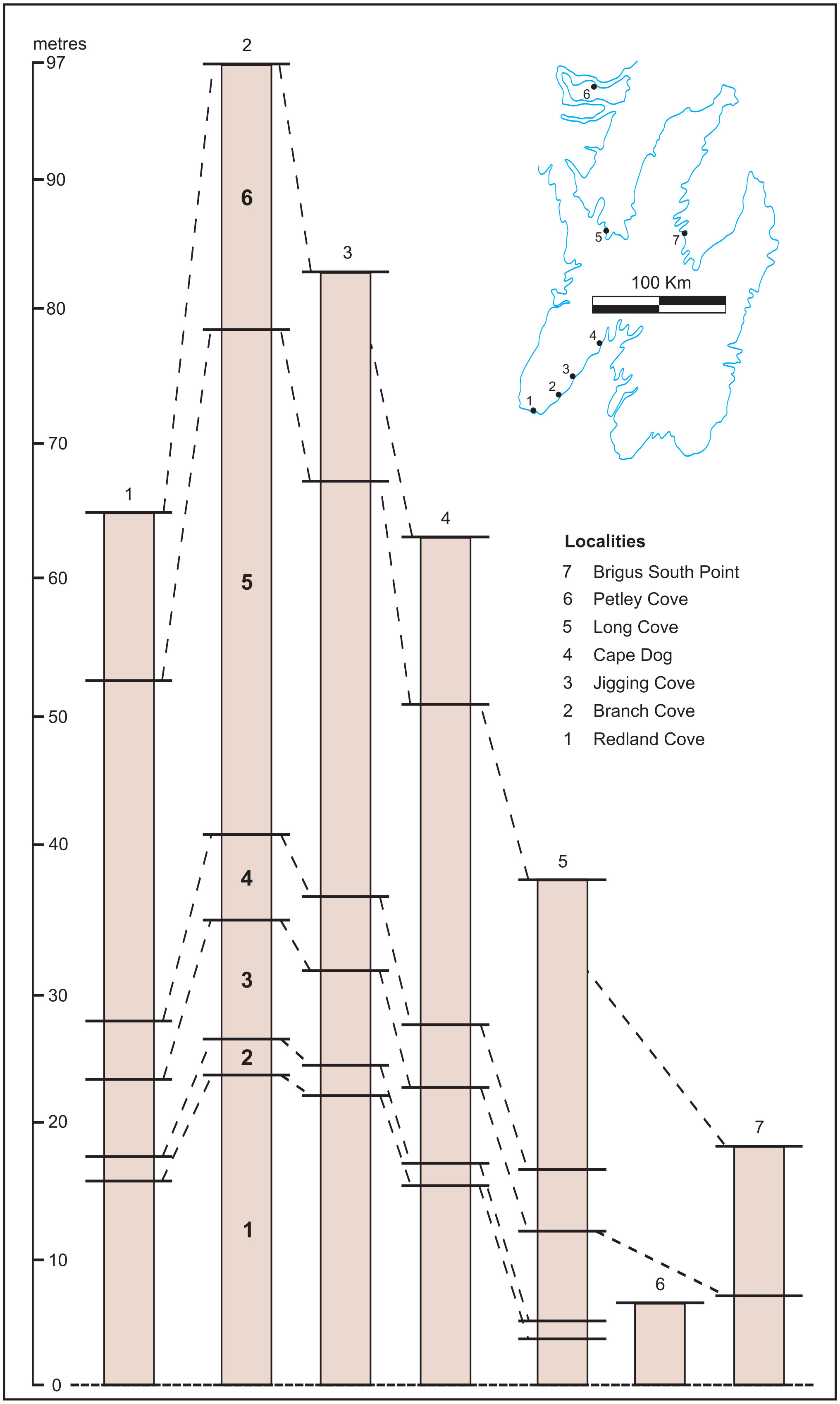

Figure 16. *Branch Cove Member (beds 1 to 6); comparative sections.*

acteristically associated with the more calcareous pelletty horizons, where the iron has been reduced (Plate 28); the purple-blue hues generally occur as layer margins or discontinuous horizontal streaks. Green layers are rarely thicker than the intervening redbeds and bedding-parallel green stripes are common, especially in the lower levels. The colouring and character of individual layers is remarkably uniform and the subtle differences between each are sufficient to allow them to be traced extensively. The presence and relative position of several specific major separation planes afford the best means of breaking down the member into easily traced beds (Beds 1-6, Figure 15), useful for establishing its biostratigraphy and correlation beyond the type area [individual green layers have been alphabetically coded to aid fossil collecting (Plate 15)]. Greenness of sediment, however, is not confined to the layers, since discontinuous elongate green, blotchy patches mark certain redbeds, particularly those in Beds 4 and 5; subsidiary, post-Cambrian, diagenetic green-reduced margins to joints, faults and igneous dykes are also common. Neither are carbonate-bearing strata always green, since there are larger discrete millstone-type discoidal, silty nodules in some of the darker red mudstones, similar to concretionary forms noted previously in the Bonavista Formation, indicative of shallower water conditions.

Much of the tiny, whitish carbonate debris in these green bands is concretionary in origin, and represents reworked material sifted from unconsolidated sediment by very gentle bottom currents. It occurs as tiny, tightly packed nucleated and amorphous nodules in a mosaic formed by solution of adjacent nodule boundaries (Plate 29); some of the more rounded particles appear to have a thin algal coating. These characterize the main fossiliferous horizons, yet in spite of a chaotic breccia-like aspect, tiny fossils like the eodiscids and eocrinoidal ossicles are beautifully preserved and exhibit no signs of abrasion or damaging effects of transport. In contrast, the associated larger, thin-shelled trilobites, e.g., *Hamatolenus* sp. (Plate 27, Figure 35), are almost entirely fragmental, though their delicate surface ornaments are generally preserved.

In the sections of Trinity Bay and Conception Bay, e.g., Long Cove-Chapel Head, Smith Sound, Cavendish [between Hopeall Head and Heart's Desire] (Figure 2), Brigus South Point and Manuels, tiny dark manganese nodules lie along the basal separation plane and form thin discontinuous layers close to the upper contact with the Chamberlain's Brook Formation. They appear to represent localized small-scale non-sequences. In the case of the upper layers, they lie within mudstones that have been completely reduced to the green colour associated with the main Brigus-Chamberlain's Brook formations manganese-bed non-sequence.

Contact Relations

The lower contact with the Jigging Member is conformably drawn at a prominent, recessive-weathering bedding plane and, at the type section, the upper conformable contact with the Easter Cove Member is drawn at the base of the lowest horizon bearing manganese nodules.

Fauna

Hutchinson (1962, p. 50) concluded that the "Lower Cambrian" fossils recorded by Walcott, not represented in his GSC collections, probably derive from a post-*Callavia* fauna in the Brigus Formation, "where fossils are extremely rare and generally fragmentary". However, all such forms described by both Walcott and Matthew and those assigned by Hutchinson to post-*Callavia* / pre-*Protolenus* and *Protolenus* faunas have been collected from the Redland Cove Member and the fauna of the youngest part of the Brigus Formation remained unknown until the Branch Cove discoveries in 1959 (Fletcher, 1972).

Genera and species have been recovered from the Branch Cove Member in the Easter Cove of Branch Cove, Redland Cove and Jigging Cove that hitherto have not been known to occur in the same assemblage. These include Acado-Baltic-type trilobites described from Warwickshire, England (Rushton, 1966) and Morocco (Hupé, 1953; Geyer 1988, 1990a, b), Siberian species (Tchernysheva, 1962; Romanenko and Romanenko, 1962) and Laurentian forms described from Taconic New England (Rasetti, 1966, 1967; Rasetti and Theokritoff, 1967). Ten separate fossiliferous beds (1 A, B, G, I and J; 5 A, B and C and 6 B and H in Figure 15) have yielded one main assemblage dominated by eodiscids, most prominent among which is the Moroccan zone fossil *Cephalopyge notabilis*. The stratigraphical distribution of the taxa in this member is given below:

Cephalopyge notabilis Zone:

Bed 1
Layer A. *Condylopyge eli* (Plate 27, Figure 32), *Strenuaeva nefanda* Geyer, 1990a (Fletcher, 2003, pl. 3, figs. 15-17) and a new calodiscid species (Plate 27, Figure 36)
Layer B. *Condylopyge eli*, *Cephalopyge notabilis* (Plate 27, Figures 33-34), *Strenuaeva nefanda, Acidiscus theristes* Rushton, 1966 (Fletcher, 2003, figs. 27-29), *Bathydiscus taconicus*, paradoxidid rostral plate, *Hamatolenus* (*H.*) sp. aff. *H.* (*H.*) *marocanus* (Plate 27, Figure 35) and ?bradoriids.
Layer C. ?bradoriids.
Layer D. bradoriids.
Layer G. *A. theristes*.
Layer I. *A. theristes* and *B. taconicus*
Layer J**.** *A. theristes*, *B. taconicus* and *Serrodiscus occipitalis* Rasetti, 1966

Bed 3
Layer B. *Indiana secunda* (Matthew, 1895) and *?Mononotella* sp.
Bed 5
Layers A and B. *C. notabilis*.
Layer C. *B. taconicus*, *B*. sp. nov. No. 1., *S. ctenoa* Rushton, 1966, *C. notabilis*, *S. occipitalis*, *Hamatolenus* sp., *Pelagiella* cf. *P. primaeva* (Billings, 1871), *Botsfordia* sp., *Beyrichona tinea* (Matthew, 1886) and *Indiana secunda*.
Bed 6
Layer B**.** *Bathydiscus taconicus*, *C. notabilis*, *S. occipitalis* and *H.* (*Myopsolenus*) sp. and numerous eocrinoid ossicles.
Layer H. *Condylopyge eli* (Plate 27, Figures 42-43), *Peronopsis roddyi* (Plate 27, Figures 44-45), *A. theristes*, *B.* sp. cf. *B. dolichometopus* Rasetti, 1966, *B. longifrons* (Plate 27, Figure 41), *B. taconicus* (Plate 27, Figures 38-39), *B*. sp. nov. No. 2, *B*. sp. nov. No. 3, *Cephalopyge notabilis*, *S*. sp. cf. *S. latus* (Plate 27, Figure 37), *S. occipitalis* (Plate 27, Figure 40), *Stigmadiscus* sp. nov. (Fletcher, 2003, pl. 3, fig. 1), *H*. (*M*.) *magnus* (Hupé, 1953), ? *Alanisia* sp. cf. *A. hastata* Sdzuy, 1958, *Strenuaeva nefanda* and *Ovatoryctocara granulata* (Plate 27, Figures 46-47).

Zonation and Correlation

The first occurrence of *Cephalopyge notabilis* just above the base and last occurrence at the top of the Branch Cove Member, provide the basis for the recognition of a C*ephalopyge notabilis* Taxon Range Zone as defined in Morocco (Geyer 1990b); Moroccan species like *Hamatolenus (M.) magnus* and *Strenuaeva nefanda* similarly characterize this zone and the specimen considered to be close to *Alanisia hastata* indicates a possible correlation with Spanish strata in the Sierra Moreno assigned to the late Lower Cambrian (Sdzuy 1961, p. 303, 1962, p. 185). *Condylopyge eli* continues its range up into this zone, but unlike Morocco, specimens are known throughout and the earliest forms are different from that described by Geyer (1990b), because slight stratigraphical changes in the pygidium precede the Moroccan form in the top of the Branch Cove Member.

The presences of the English forms *Acidiscus theristes* and *Serrodiscus ctenoa* are somewhat anomalous. These species were first recorded from a Warwickshire assemblage (Locality 2A of Rushton, 1966) that included species, which in Newfoundland are only known in the older *Orodes howleyi* Zone, e.g., *Chelediscus acifer* and *Tannudiscus balanus*; the possibility of earlier appearances in England, i.e., longer stratigraphical ranges, needs to be considered.

Probably, the most unusual aspect of this interval in Newfoundland is the occurrence of eodiscids first described from the Laurentian Cambrian sequence in the Taconic region of New York, where Rasetti (1966) established four faunal assemblages within the olenellid realm:

4. *Pagetides elegans* faunule with two *Olenellus* (*O.*) spp. and one *O.* (*Paedeumias*) sp.
3. *Neopagetina taconica* faunule
2. *Acimetopus* fauna with three *Olenellus* (*O.*) spp. and six *O*. (*Paedeumias*) spp.
1. *Elliptocephala asaphoides* fauna

As noted above and by Rasetti (1966), the *E. asaphoides* fauna has some affinity to faunas of the Acado-Baltic Realm, but the younger assemblages containing *Olenellus* Billings, 1861 clearly have more in common with the Laurentian early Cambrian in the tectonostratigraphical Humber Zone (Figure 1). The eodiscids, *Acidiscus*, *Bathydiscus dolichometopus*, *B. longifrons*, *B. taconicus*, *Serrodiscus latus*, *S. occipitalis* and *Stigmadiscus* in the Branch Cove Member indicate a close correspondence with Rasetti's *Acimetopus* fauna. Since these taxa are largely known from the very top of the *Cephalopyge notabilis* Zone in Newfoundland, it is evident that this paradoxidid-bearing zone appears to be coeval with Laurentian strata well within the range of *Olenellus*, thereby highlighting the problem of recognizing "Lower" and "Middle" subdivisions of the Cambrian based upon the concept that the stratigraphical ranges of *Olenellus* and younger paradoxidids do not overlap. Considerable discussion on this topic has taken place and the relative merits of the different provincial subdivisions remain a matter of contention. For some time, the extinction of the genus *Olenellus* of modern taxonomy has been regarded as the end marker of the Lower Cambrian and that *Paradoxides* does not replace *Olenellus* immediately in time. Öpik (1968) suggested that quite a long post-Olenellian and pre-Paradoxidian (Lower? or Middle?) Cambrian Ordian Stage interval intervened between them and that the presence of other genera is necessary for establishing the junction of the Lower and Middle Cambrian.

Probably the most useful correlative faunal element in the Branch Cove Member is the presence of *Ovatoryctocara granulata* in an *Acimetopus* assemblage at the top of the Newfoundland *Cephalopyge notabilis* Zone. This species is considered to be a marker for a possible global stage boundary (Fletcher, 2001, 2003) and is known in the earliest Siberian paradoxidid sequence, in the *Olenellus* and *Arthricocephalus* strata of Greenland, and with *Arthricocephalus* below *Bathynotus* strata in China. First described from the Siberian *Oryctocara* Zone, a correlation of the lower part of the Amgan Stage with part of the Laurentian olenellid *Acimetopus* fauna is indicated (Figures 12 and 18). Assuming, therefore, that the ranges of *Cephalopyge* are more or less contemporaneous in both Newfoundland and Morocco, it would appear that part of the Moroccan zone is also equivalent to at least part of the Siberian *Oryctocara* Zone [*Schistocephalus antiquus* Zone] and not post-*S. antiquus* strata as discussed by Geyer (1998, p. 377).

Other support for correlations made here is provided by the presence of *Peronopsis* [*Eoagnostus*] *roddyi*. First known from the *Olenellus*-bearing Kinzers Slate of Laurentia, it also occurs with *Ovatoryctocara granulata*, *Arthricocephalus chauveaui* Bergeron, 1899 and *Olenellus* in the Henson Gletscher Formation in Greenland (Blaker and Peel, 1997) and is part of the Taconic post-*Acimetopus* Fauna (Rasetti and Theokritoff, 1967) to indicate that the top of the *Cephalopyge* Zone coincides with a transitional *Acimetopus*-*Neopagetina*-*Olenellus*-bearing interval. On the evidence of its pygidium with a postaxial divided field, the Siberian *Peronopsis* form in the *Oryctocara* Zone assigned to "*P*. aff. *inarmata* Hutchinson, 1962" (Savitskiy *et al.*, 1972, p. 64, pl. 7, figs. 3-5; Yegorova *et al.*, 1976, p. 66, pl. 45, figs 1-3) appears to be *P. roddyi* and further supports the correlation of mid-*Olenellus* sequences with the paradoxidid basal Amgan Stage.

Chamberlain's Brook Formation (Units 10a to 10e)

Definition

The Chamberlain's Brook Formation is a largely calcareous, dark-red and pale olive-green mudstone sequence at the top of the Adeyton Group. In the southern part of Cape St. Mary's Peninsula, it conformably overlies the Brigus Formation, but in northern sections, its base is disconformable. Everywhere, it is conformably overlain by the white clay seam here formally named Metabentonite Bed (= Manuels Metabentonite *in* Fletcher and Brückner, 1974, fig. 9) at the base of the dark-grey, shaly Manuels River Formation, the basal unit of the Harcourt Group.

McCartney's statements (1967, p. 70), that the differentiation of the Chamberlain's Brook and Manuels River formations must be based upon the recognition of faunal zones, because "lithological variations within the Middle Cambrian Series are subtle and cannot always be relied upon in identifying the two formations" and a "lack of lithological marker horizons" are misleading and inconsistent with the observations of both Hutchinson (1962) and Jenness (1963).

The "Chamberlin's Brook formation" was first proposed by Howell (1925, p. 60) for what he considered the oldest paradoxidid sequence in southeastern Newfoundland. However, his "Middle Cambrian" formations were essentially biostratigraphical and any lithological differences were somewhat coincidental; his "Chamberlin's Brook formation" being synonymous with a "*Paradoxides bennetti* zone", the "Long Pond Formation" with a "*Paradoxides hicksi* zone" and the "Kelligrew Brook Formation" with a "*Paradoxides davidis* zone" (Howell, 1925, table 4). This being the case, a lithostratigraphical modification was left to Hutchinson (1962, p. 19). He corrected the name to Chamberlain's Brook Formation and accepted the type section in Manuel's Brook to include the "manganese zone" (Dale, 1915) / "manganiferous beds" that Howell (1925, table 3) considered to represent an "Unnamed formation". Since the two younger zones are confined to one lithological unit, the new name Manuels River Formation was substituted.

Undergraduate work by the writer on Cape St. Mary's Peninsula in 1959 indicated sedimentary continuity there between the Brigus and Chamberlain's Brook formations. The manganese deposits forming a prominent manganese limestone up to 4.6 m thick with "*Paradoxides bennetti*" Salter, 1859 elsewhere (Dale, 1915; Hutchinson, 1962, p.19) appeared to be represented by a considerable thickness of mudstone containing scattered manganese nodules. In addition, the contained paradoxidid was *P*. (*Hydrocephalus*) *harlani* (Green, 1834) (Plate 30 and Plate 34, Figures 1-2) and not *P.* (*Eccaparadoxides*) *bennetti* (Plate 31 and Plate 34, Figures 3-5); previously, all large paradoxidids in the formation were regarded as "*Paradoxides bennetti*". Further observations demonstrated that the *P.* (*E.*) *bennetti* Fauna of other sections on the Avalon Peninsula occurred high above the Cape St. Mary's manganiferous interval containing a distinct P. (*H.*) *harlani* Fauna close to that known from Braintree, Massachusetts (Fletcher *et al.*, 2005). The conclusion that the type section at Manuels only partially repre-

Plate 30. *Large specimen of* Paradoxides (Hydrocephalus) harlani *on highly cleaved bedding plane typical of the Wester Cove Member; shore section in the Wester Cove of Branch Cove.*

Plate 31. *Specimens of* Paradoxides (Eccaparadoxides) bennetti *on highly cleaved bedding plane typical of the Big Gully Member; shore section below Green Gulch in the Wester Cove of Branch Cove. N.B., in these beds, trilobites are common in concretionary carbonate growths largely unaffected by the cleavage.*

sents the formation led to the writer's graduate study of the Cape St. Mary's succession (Fletcher, 1972).

Although the type section of the Chamberlain's Brook Formation at Manuels stands, within the defined limits, this formation is most completely developed in the southwestern part of St. Mary's Bay (Plate 32), where it may be subdivided into six discrete coloured members, delineated by prominently recessed separation/bedding planes; at Cape Dog near the head of the bay, an areally restricted volcanic lentil occurs within the highest sedimentary member. In this account of Cape St. Mary's Peninsula, separate type sections at coastal localities for these members are documented. As shown in Figure 8, the Chamberlain's Brook Formation is subdivided into the following units:

Cape Shore Member containing the Cape Dog Basaltic Flow
Head Cove Member
Big Gully Member
Waterfall Cove Member
Wester Cove Member
Easter Cove Member

Easter Cove Member (Unit 10a - lower part)

Definition

The type section (Figure 17) of the Easter Cove Member in Easter Cove of Branch Cove incorporates all the red and green-streaked mudstones containing manganese nodules that conspicuously overlie the Branch Cove Member of the Brigus Formation. The top bed of the member is prominently marked as a 90 cm-thick limestone in which the largest manganese nodules are concentrated. The nodules occur as flattened spheres, generally less than 3 cm in diameter, in layers giving to each plane a blister-like appearance (Plate 33). At different localities, the limestone bed is variously coloured from red-purple-blue-green, and in the type section is remarkably blue. This is the same bed described by Hutchinson as Bed 28 (1962, section 11, p. 137) at Cape Dog and Bed 24 along the northern side of Jigging Cove (1962, section 13, p. 139), where the former was regarded as being 7.6 m above the base of the Chamberlain's Brook Formation and the latter, despite the presence of *Paradoxides*

Plate 32. *The cliff and shore exposures of the Chamberlain's Brook Formation on the eastern flank of the southerly plunging Beckford Anticline in the Wester Cove of Branch Cove showing the outcrops of the manganiferous Easter Cove Member (**ECM**) and the type sections of the Wester Cove Member (**WCM**), the Waterfall Cove Member (**WNM**), the Big Gully Member (**BGM**)-at the mouth of Branch Green Gulch (**GG**), and the Head Cove Member (**HCM**); in Head Cove (**HC**), the Cape Shore Member (**CSM**) forms Branch Head (**BH**), beyond which lie the black shaly mudstones and associated Hay Cove Basaltic Flow in the Manuels River Formation (**MRF**):* **WC** *=Waterfall Cove **F-F** = fault.*

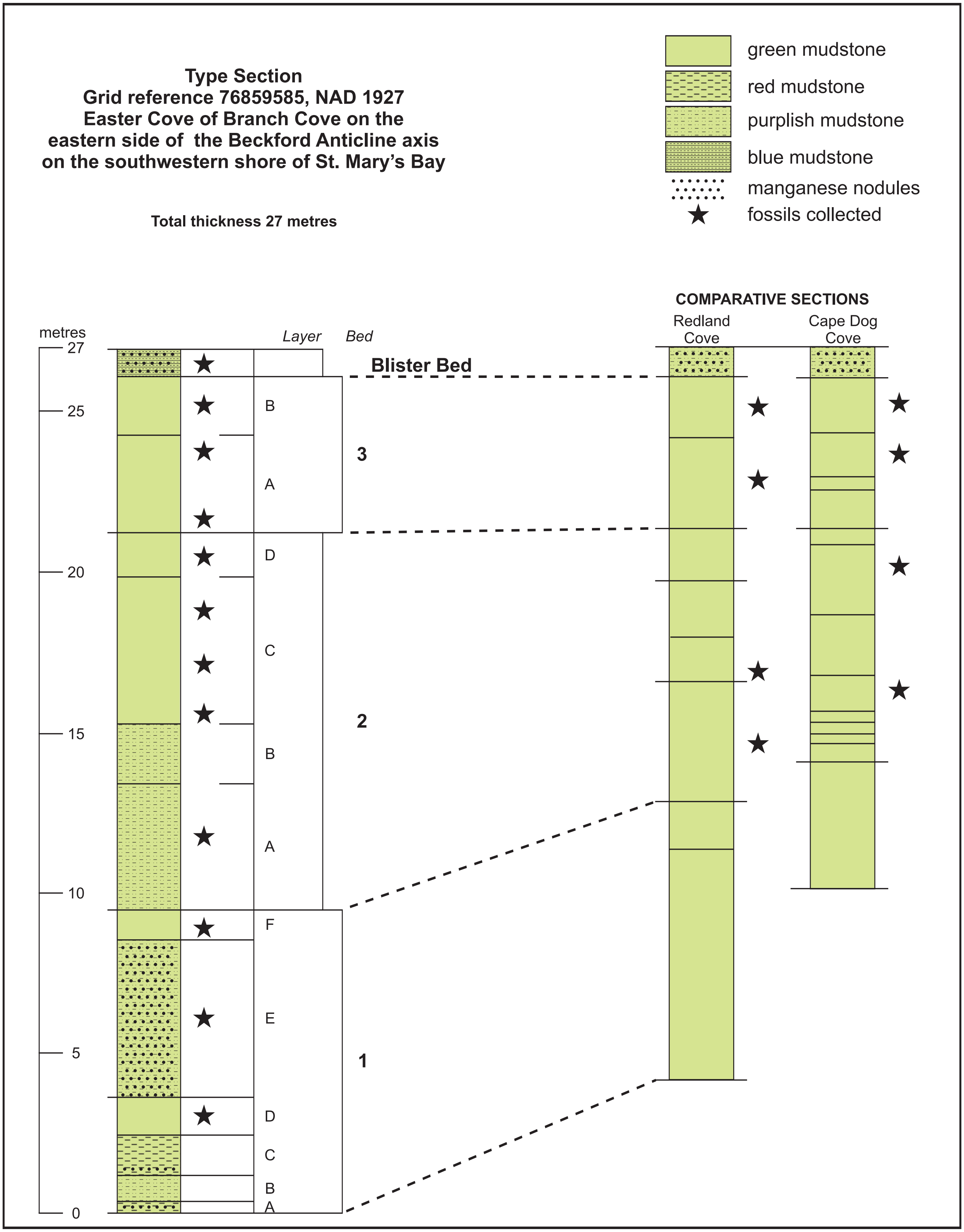

Figure 17. *Easter Cove Member; type and comparative sections.*

Plate 33. *Upper surface of the Blister Bed at the top of the manganiferous Easter Cove Member showing its characteristic, small, flattish manganiferous nodules. Type section in the Easter Cove of Branch Cove, where it is blue-grey, in contrast to exposures elsewhere in the map area that are reddish.*

(*Hydrocephalus*) in Bed 23, interpreted as the top bed of the Brigus Formation. Due to its prominence as a marker bed, it is here formally named the Blister Bed (informally referred to previously as the Blister band by Fletcher and Brückner, 1974, fig. 9).

Distribution and Thickness

The Easter Cove Member is fully developed only on Cape St. Mary's Peninsula and is well exposed at Cape Dog, Jigging Cove, in the Easter and Wester (ECM in Plate 32) coves of Branch Cove, and Redland Cove.

The greatest thickness of the Easter Cove Member is attained in Branch Cove, where it is 27 m thick (Figure 17), attenuating slightly toward Redland in the southwest. Traced northward, the reduction in thickness is due mainly to a gradual increase in both amount and number of small non-sequences within the member. At Cape Dog, this trend is demonstrated by a greater concentration of manganese-nodule horizons in the reduced 16.8-m-thick sequence and provides the guide to why the thinner sections farther north in Trinity and Conception bays are richer in manganese. In these regions, periodic arrests of sedimentation, also involving other members of the Chamberlain's Brook Formation, have concentrated not only manganiferous deposits, but also the faunal assemblages. However, such breaks in sequence in the southern part of Trinity Bay are of less magnitude than is inferred by the alleged presence of "*Paradoxides bennetti*" in the "manganese bed" (McCartney, 1967, p. 71), because the large paradoxidids have been misidentified and should be referred to the older *P.* (*H.*) *harlani*, the species characterizing the three members below the first appearance of *P.* (*Eccaparadoxides*) *bennetti* in the map area.

Lithology

The succession of the Easter Cove Member comprises fine-grained, marly mudstones with horizons of coarser calcareous debris interbedded with scattered flat-lying dark, ovoid, manganiferous nodules, some of which are coated with a thin film of phosphate. Except for the manganese content, the mudstones and calcareous debris are similar to those in the top member of the Brigus Formation, though the calcareous lenses are less numerous. The lower half is decidedly dusky red and streaked moderate olive brown along the calcareous bands. The upper half is exclusively greyish olive green with the Blister Bed being reddish-purple or, as in the type section, dusky blue.

The type section of the Easter Cove Member is made up of four main beds subdivided into units marked by colour changes or delineated by minor separation planes; the Blister Bed at the top, and three lower ones defined by major separation planes at 9.5 m, 21.3 m and 26 m above the base (Figure 17). Manganese nodules are especially numerous in Bed 1, where the sequence is sparsely fossiliferous. The lower levels of Bed 2 contain several fossiliferous layers of calcareous debris, but the association of greenness, carbonate content and fossil abundance is further emphasized by the nature of the higher layers that are notable for the preservation of large trilobites. Bed 3 is entirely green, richly fossiliferous and characterized by several horizons with horizontally meandering debris-filled burrows, commonly associated with wispy pockets of calcareous pelletty accumulations (Plate 29). The Blister Bed comprises a distinctive lithology. In places, it is red, in others bluish and is distinguished by jasper-like layers of green, brown and purple tightly packed, phosphate-coated manganiferous nodules.

Contact Relations

Structural relationships with the adjoining members are conformable being drawn at recessive-weathering bedding planes and no breaks in sedimentary and faunal sequences are apparent.

Fauna and Zonation

The agnostids *Condylopyge eli* and *Peronopsis roddyi* continue their ranges upward from the *Cephalopyge* Zone. However, the member is conspicuous for the presence of the Siberian pagetiid *Kiskinella cristata* and easily recognizable specimens of *Paradoxides (Hydrocephalus) harlani* on bedding planes (Plate 30). The whole member is assigned to the *Kiskinella cristata* Zone, whose base is taken above the last appearance of *C. notabilis* and its upper limit drawn at the last appearance of *K. cristata* in Bed 1E of the overlying Wester Cove Member (*see* Figure 19).

The stratigraphical distribution of taxa in this member is given below:

Kiskinella cristata Zone:

Bed 1
Layer D. *Condylopyge eli*
Layer E. *Parasolenopleura* sp. nov. aff. *P. tikasraynensis* (Geyer, 1998) and aff. *Braintreella rogersi* (Walcott, 1884) (Fletcher *et al.*, 2005, figs. 13-1, -2, -8-13), *Peronopsis* sp. nov. (Plate 34, Figure 17) and *Kiskinella cristata* (Plate 34, Figures 18-19)
Layer F. *C. eli*, paradoxididae gen. and sp. undet., *K. cristata* and *Parasolenopleura* sp. nov.
Bed 2
Layer A. *K. cristata*
Layers C and D. *C. eli, Peronopsis roddyi* (Plate 34, Figure 13), *P*. sp. nov., *K. cristata*, *Paradoxides (H.) harlani*, *Holocephalina* sp. aff. *H. leve* Gozalo and Liñán, 1996 (Fletcher *et al.*, 2005, fig. 10-4), *Parasolenopleura* sp. nov., *Agraulos quadrangularis* (Whitfield, 1884) (Plate 34, Figures 20-22), *Lingulella* sp., *Hyolithes shaleri* Walcott, 1884 and *Helcionella* sp.
Bed 3
Layers A and B. - as Bed 2, Bands C and D, but without *Peronopsis roddyi* and *Holocephalina*
Blister Bed
As Bed 3 and the bradoriid *Beyrichona tinea*.

Age and Correlation

The occurrences of *C. eli, K. cristata, Paradoxides (H.) harlani, Holocephalina* aff. *H. leve*, *A. quadrangularis* and *Hyolithes shaleri* clearly represent the early paradoxidid *P. (H.) harlani* assemblages of eastern Massachusetts (Fletcher *et al.*, 2005), of the Moroccan *Ornamentalis frequens* Zone and of the *mureroensis-sdzuyi* zones in Spain. However, occurrences of *Peronopsis* [*Eoagnostus*] *roddyi* and *K. cristata* allow wider correlations; the former with *Olenellus*-bearing Laurentia, the latter with Siberian sequences. As previously discussed (p. 61), *P. roddyi* occurs with *Olenellus* in Greenland and in the Parker Slate of northwestern Vermont, the Kinzers Slate of the Lancaster and York basins, Pennsylvania and in the *Pagetides elegans* Faunule of Washington County of New York (Bird and Rasetti, 1968, p. 42) to indicate the temporal overlap of *Olenellus* and paradoxidid ranges; *K. cristata* with *P. roddyi* supports the correlation made for the top of the Newfoundland *Cephalopyge* Zone with part of the Siberian *Oryctocara* Zone, which is mainly represented by the Easter Cove Member (Figure 18).

The synonymizing of "*Paradoxides Groomii*" Lapworth, 1891 as *P. (Hydrocephalus) harlani* implies some correlation with the Quarry Ridge Grit [*Paradoxides groomi* Grit] of Shropshire, England (Rushton, 1974). However, the English specimens lie within a conglomerate and, therefore, the "Grit" may be younger than the *K. cristata* Zone; indeed it may be as young as the Newfoundland *Agraulos affinis* Zone if the conglomeratic base represents substantial reworking. The association of differential non-sequence and the varied character of the basal manganese beds of the Chamberlain's Brook Formation suggest that the Welsh Manganese Grit (Matley and Wilson, 1946) and Ore-bed (Woodland, 1939) within the Haffoty Formation indicate substantial non-sequences in North Wales.

Wester Cove Member (Unit 10a - upper part)

Definition

The Wester Cove Member is a green and red, layered and striped mudstone member conformably intervening between the Blister Bed and the calcareous-nodule beds of the Waterfall Cove Member. The type section (Figure 19) in the Wester Cove of Branch is somewhat faulted (WCM in Plate 32), but correlation between blocks demonstrates that it comprises seven major beds as also exposed in the vertical cliffs of Easter Cove. The base is defined by the top surface of the Blister Bed and its upper limit delineated by the prominent separation plane underlying the conspicuous nodules at the base of the Waterfall Cove Member.

Distribution and Thickness

The Wester Cove Member is completely developed in the map area and in the southern part of Trinity Bay. The type section in the Wester Cove of Branch Cove is 46.28 m thick and appears to thin slightly toward Redland Cove in the south and thicken slightly northward through Jigging Cove to Cape Dog. However, differential tectonic stretching may account for these differences.

Lithology

The member comprises fine-grained massive mudstones throughout. In colour, three near-equisized parts are recognizable, i.e., a lower exclusively greyish olive green, a middle predominantly dusky red and an upper layered dusky red and very dusky red purple. Six major separation planes delineate seven beds, Beds 1 and 2 in the green part, Bed 3 in the middle part and Beds 4-7 in the layered part.

Beds 1 and 2 contain some weakly defined bedding planes and the greenness is associated with a high calcareous content. As in older green beds, there is much scattered carbonate debris and fossil abundance. Bed 3 is very distinctive and, in the lower half, contains two marker units (layers C and E in Figure 19) characterized by green spots

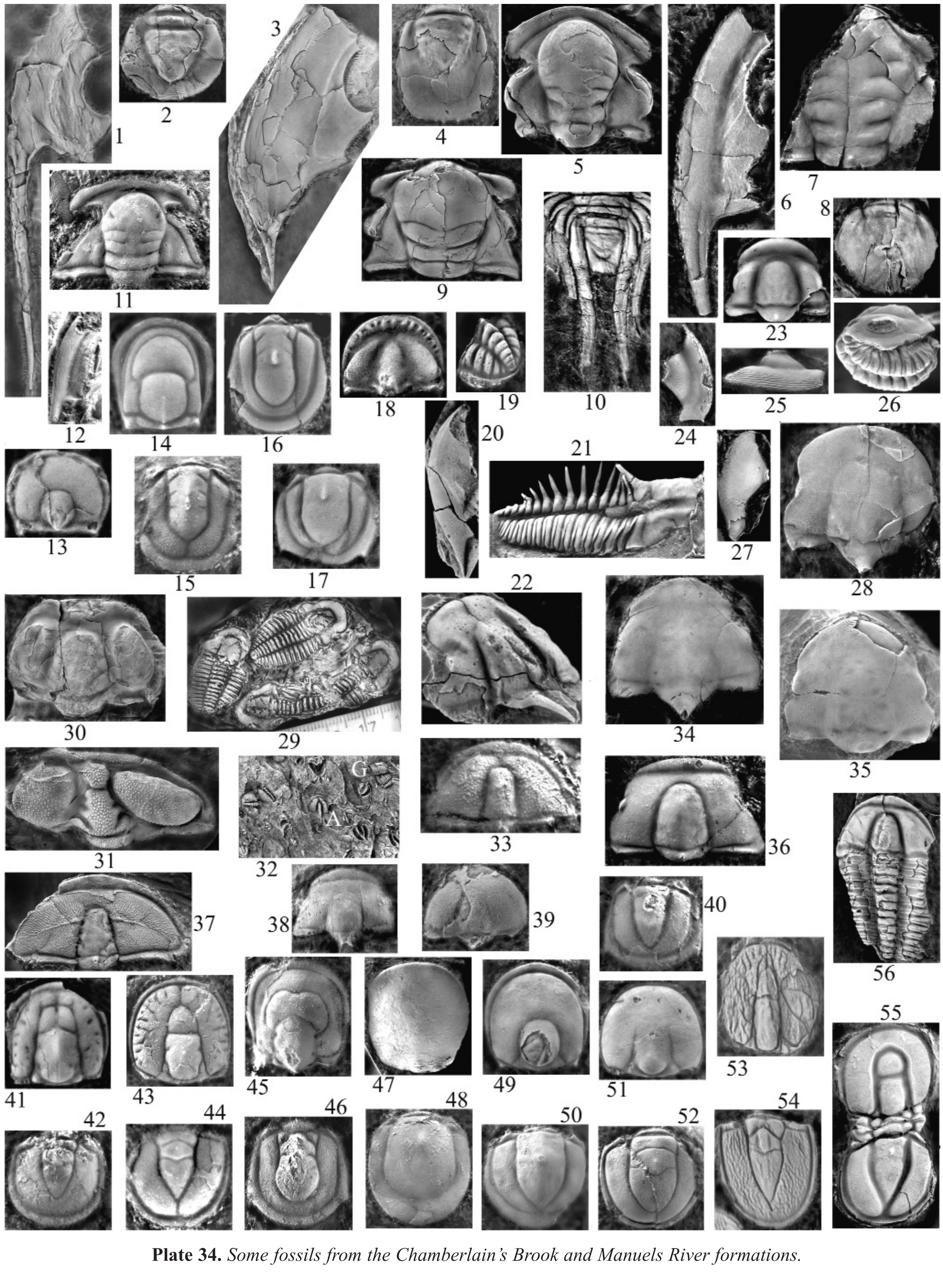

Plate 34. *Some fossils from the Chamberlain's Brook and Manuels River formations.*

Figures 1-2. *Paradoxides (Hydrocephalus) harlani* from the *harlani* Zone in Wester Cove of Branch. 1, librigena ROM 56407, x 0.5; 2; pygidium ROM 56406, x 1.2
Figures 3-5. *Paradoxides (Eccaparadoxides) bennetti* from the *affinis* Zone in Wester Cove of Branch. 3, librigena TPF 1546, x 0.5; 4, pygidium TPF 1561, x 1.6; 5, immature cranidium TPF 1518, x 2.1
Figures 6-8. *Paradoxides* (subgen. nov.) *hicksii* (Salter *in* Salter and Hicks, 1869) from the *hicksii* Zone in Deep Cove. 6, partial librigena TPF 1608, x 1.6; 7, partial cranidium TPF 1611, x 1.1; 8, pygidium TPF 3043, x 1.4
Figures 9-10. *Paradoxides (P.) davidis* Salter, 1863 from the *davidis* Zone in Deep Cove. 9, cranidium TPF 1622, x 0.5; 10; pygidium and basal thoracic segments TPF 1626, x 0.9
Figures 11-12. *Clarella venusta* (Billings, 1872) from the *hicksii* Zone in Deep Cove. 11, cranidium TPF 3172, x 1.8; 12, partial librigena TPF 3239, x 1.7

Figures 13-15 and 17-22 from the *cristata* Zone in Wester Cove of Branch

Figure 13. *Peronopsis roddyi,* cephalon ROM 56120A, x 5.8
Figures 14-15. *Condylopyge eli*. 14, cephalon ROM 56126, x 7.2; 15, pygidium ROM 56097, x 8.4
Figure 16. *Condylopyge carinata* Westergård, 1936 from the *affinis* Zone in Wester Cove of Branch, pygidium TPF 1304, x 4.1
Figure 17. *Peronopsis* sp. nov., pygidium TPF 1300, x 5.3
Figures 18-19. *Kiskinella cristata* Romanenko and Romanenko, 1962. 18, exfoliated cranidium ROM 56107, x 4.8; 19, latex cast of external mould of pygidium ROM 56153, x 1.6
Figures 20-22. *Agraulos quadrangularis* (Whitfield, 1884). 20, librigena ROM 56416, x 2.1; 21, latex cast of external mould of cranidium, thorax and pygidium ROM 56118, x 1.5; 22, cranidium ROM 56116, x 2

Figures 23-30 from the *affinis* Zone in Wester Cove of Branch

Figures 23-26. *Parasolenopleura gregaria* (Billings, 1865). 23, cranidium ROM 56579, x 1.3; 24, librigena ROM 56593, x 1.8; profile views of librigena ROM 56591, x 1.8; 26, enrolled specimen ROM 56596, x 2.4
Figures 27-29. *Agraulos affinis* (Billings, 1874). 27, librigena TPF 1399, x 1.3; 28, cranidium TPF 1393A, x 2.6; 29, rock slab with four exfoliated specimens TPF 1403, x 0.7
Figure 30. *Bailiaspis inflata* Lake, 1940, cranidium TPF 1638, x 1.2
Figure 31. *Hartella bucculenta* (Resser, 1937), latex cast of external mould of cranidium TPF 1450, x 1.4, from the *Hartella* Zone in Wester Cove of Branch
Figure 32. *Eodiscus punctatus* (Salter, 1864), cephalon TPF 1258A, x 1.4 and *Solenopleuropsis variolaris* (Salter, 1864), partial cranidium TPF 1258G, x 4, on latex cast of rock slab TPF 1258, from the *davidis* Zone in the Branch River section, approximately 4070 m northwest of Branch Church

Figures 33-36, 38, 40-52 from the *hicksii* Zone in Deep Cove

Figure 33. *Bailiaspis* sp. cf. *B. tuberculata* Lake, 1940, cranidium TPF 3126B, x 10
Figure 34. *Agraulos longicephalus* (Hicks, 1872), cranidium TPF 1433, x 6.4
Figure 35. *Agraulos ceticephalus* (Barrande, 1846a), cranidium ROM 56114, x 2
Figure 36. *Jincella applanata* (Salter *in* Salter and Hicks, 1869), cranidium TPF 1440, x 1.7
Figure 37. *Meneviella venulosa* (Salter *in* Hicks, 1872), cranidium TPF 1362, x 1.9, from the base of the *davidis* Zone in Deep Cove.
Figure 38. *Skreiaspis* sp. nov., cranidium TPF 3226 x 2.2
Figure 39. *Holocephalina* sp. aff. *H. incerta* Illing, 1916, cranidium TPF 1417, x 4, from the *davidis* Zone in Deep Cove
Figure 40. *Peronopsis fallax* (Linnarsson, 1869), pygidium TPF 1385B, x 11
Figures 41-42. *Tomagnostus fissus* (Lundgren *in* Linnarsson, 1879). 41, partial cephalon TPF 1420, x 9; 42, pygidium TPF 3283, x 8.5
Figures 43-44. *Acidusus atavus* (Tullberg, 1880). 43, cephalon TPF 3285A, x 6.7; 44, pygidium TPF 3291B, x 2.7
Figures 45-46. *Pleuroctenium granulatum scanense* Westergård, 1946. 45, cephalon TPF 3289A, x 6.6; 46, pygidium TPF 3290A, x 7.1
Figures 47-48. *Phalacroma scanicum* (Tullberg, 1880). 47, cephalon TPF 3286B, x 3.5; 48, pygidium TPF 3282A, x 5.4
Figures 49-50. *Hypagnostus parvifrons* (Linnarsson, 1869). 49, cephalon TPF 3287, x 6.3; 50, pygidium TPF 3286A, x 6
Figures 51-52. *Lejopyge barrandei* (Hicks, 1872). 51, cephalon TPF 1359, x 6.2; 52, pygidium TPF 3285C, x 5.4
Figures 53-54. *Ptychagnostus punctuosus* (Angelin, 1852) from the *davidis* Zone in Deep Cove. 53, cephalon TPF 1419A, x 5.6; 54, pygidium TPF 1419B, x 5.6
Figure 55. *Peronopsis scutalis* (Salter *in* Hicks, 1872), exfoliated specimen TPF 1350, x 3.5, from the *hicksii* Zone in Deep Cove
Figure 56. *Bailiaspis glabrata* (Angelin, 1854), cranidium and 13 thoracic segments TPF 1507, x 1.6, from the *davidis* Zone in Deep Cove

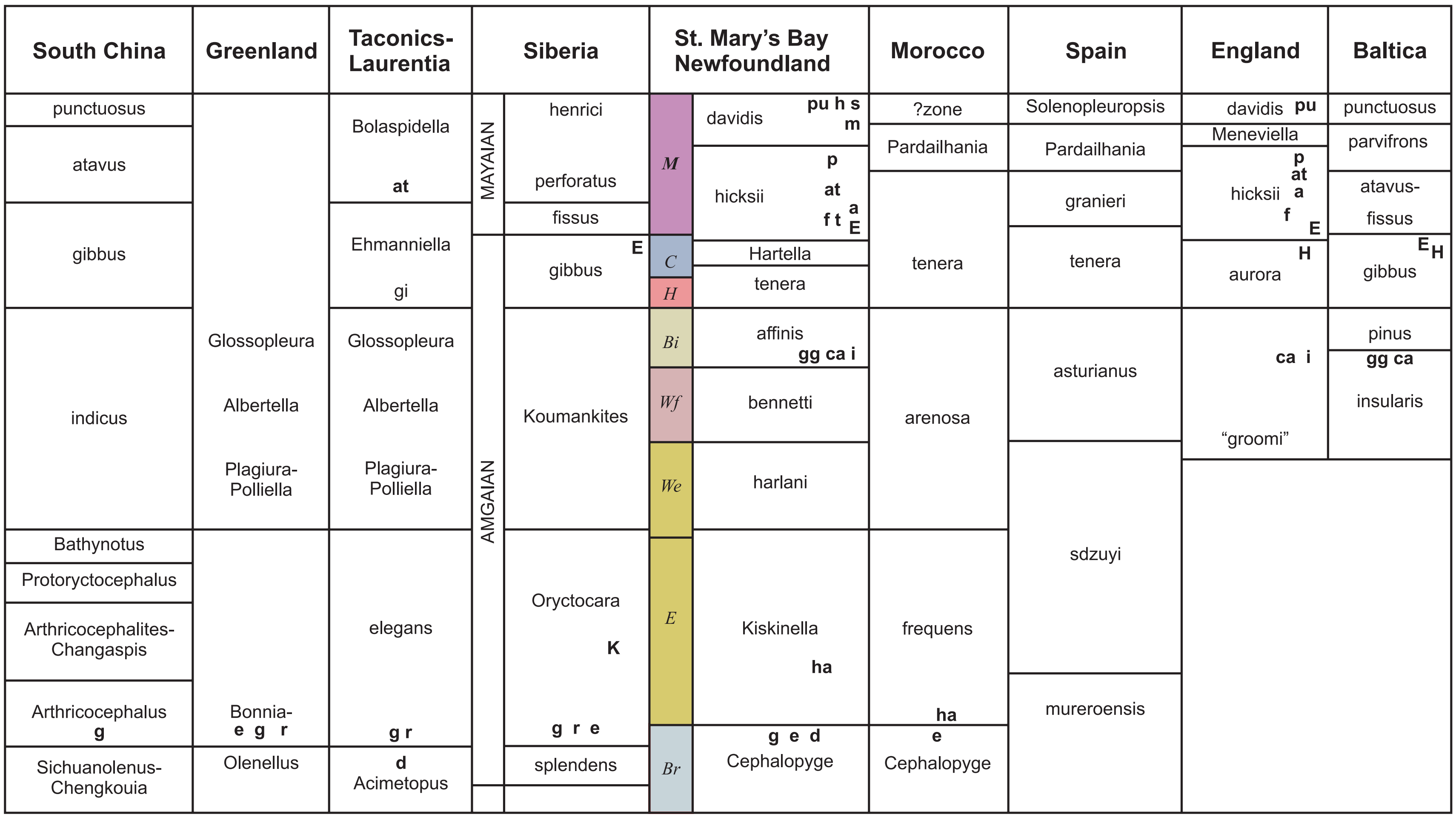

Figure 18. *Correlation chart of the trilobite zones of the Chamberlain's Brook and Manuels River formations in the Cape St. Mary's Peninsula map area (letters refer to taxa).*

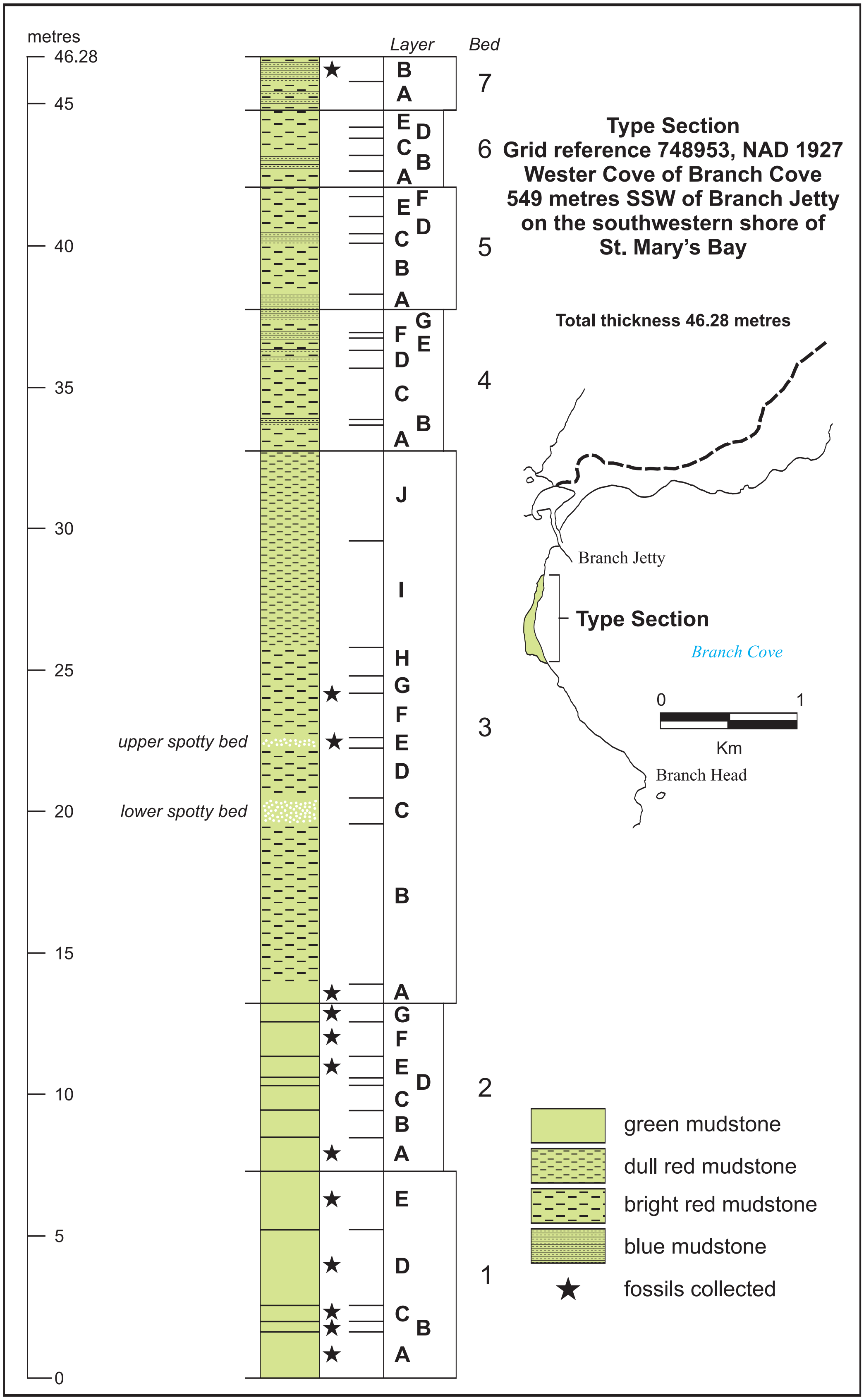

Figure 19. *Wester Cove Member; type section.*

associated with whitish carbonate fragments. Although essentially a dusky redbed, some thin green streaks along weak bedding planes are developed immediately above these marker units and, in the top 3 m, Beds 4 to 7 are strongly marked for their contrasting bright colour layering immediately beneath the nodule-bearing dull mudstones of the Waterfall Cove Member.

Contact Relations

The Wester Cove Member is conformable with the manganiferous Easter Cove Member below and the nodular mudstones of the Waterfall Cove Member above. The junctions are very sharply defined by bedding planes with no evidence to suggest significant breaks in deposition.

Fauna and Zonation

Paradoxides (*Hydrocephalus*) *harlani* Zone: Except for the presence of *Kiskinella cristata* in Bed 1, most of the trilobite elements of the underlying zone continue their ranges at least as high as Layer 3G. Since *Paradoxides (H.) harlani* occurs throughout the member, it gives its name to a zone whose base is drawn in the middle of Bed 1E at the highest occurrence of *K. cristata* and whose upper limit is marked by the first appearance of *P. (Eccaparadoxides) bennetti* in Layer 2E of the overlying Waterfall Cove Member. Thus the base of the *P. (H.) harlani* Zone is defined at the last appearance of *Kiskinella cristata* and its top at the first appearance of *P. (E.) bennetti*.

The stratigraphical distribution of the taxa in this member is given below:

Kiskinella cristata Zone:

Bed 1
Layer A–mid E. *Condylopyge eli*, *Peronopsis* sp. nov., *K. cristata*, *Paradoxides (H.) harlani*, *P. (E.)* sp. aff. *P. (E.) nobilis* (Geyer, 1998), *Parasolenopleura* sp. nov., *A. quadrangularis* and *Lingulella* sp.

P. (H.) harlani Zone:

Bed 2
Layers A, E G. as Bed 1, but without *K. cristata*.
Bed 3
Layer A. as in Beds 1 and 2.
Layers E and G. *Peronopsis* sp. nov., *Paradoxides (H.) harlani* and *A. quadrangularis*.
Bed 7
Layer B. *P. (H.) harlani*

Age and Correlation

The *P. (H.) harlani* Zone of this member represents younger parts of the correlative units noted for the *Kiskinella cristata* Zone. Of special interest is the presence of a pygidium here assigned to *P. (E.)* sp. aff. *P. (E.) nobilis*; this Moroccan paradoxidid apparently is a long-ranging form from "possibly uppermost *Hupeolenus* Zone" to basal *Ornamentaspis frequens* Zone (Geyer 1998, p. 390) and, in this case, a correlation of the Newfoundland specimen with forms in the *O. frequens* Zone may be assumed.

Waterfall Cove Member (Unit 10b)

Definition

The Waterfall Cove Member intervenes between the older Wester Cove Member and the younger Big Gully Member. The type section (Figure 20) is exposed in the Wester Cove cliffs around the waterfall south of Branch Gut (WNM and *WC* in Plate 32). The base is marked by the major separation plane beneath the lowest prominent discoidal carbonate nodule-bearing, dull brownish mudstone and is delineated above by a most distinctive black mineral-coated separation plane in the basal part of the thick green sequence so well displayed in the cliffs about the Branch Green Gulch waterfall.

Distribution and Thickness

The Waterfall Cove Member is fully developed within the eastern outcrops of the Chamberlain's Brook Formation of the map area and of southeastern Trinity Bay. Although generally maintaining its thickness over these regions, it appears to be thickest in the Wester Cove type section, where it is 45 m thick. Additional cliff sections occur in Redland Cove, on the northern side of Jigging Cove Head and on the eastern side of Cape Dog.

Lithology

Major separation planes define four main mudstone beds in the Waterfall Cove Member. In the St. Mary's Bay sections, the member differs from all others in its characteristic colour layering, but the most distinctive feature is the cyclic nature of the concretionary developments, where three cycles are recognizable. About 3 m above the base of Bed 1, small to medium-sized (2 to 15 cm wide), flat silty limestone concretions are conspicuous and resemble the millstone-types occurring in the Bonavista Formation that may indicate shallowing events. These are numerous and are associated with mudstones of dusky-dark reddish brown hues.

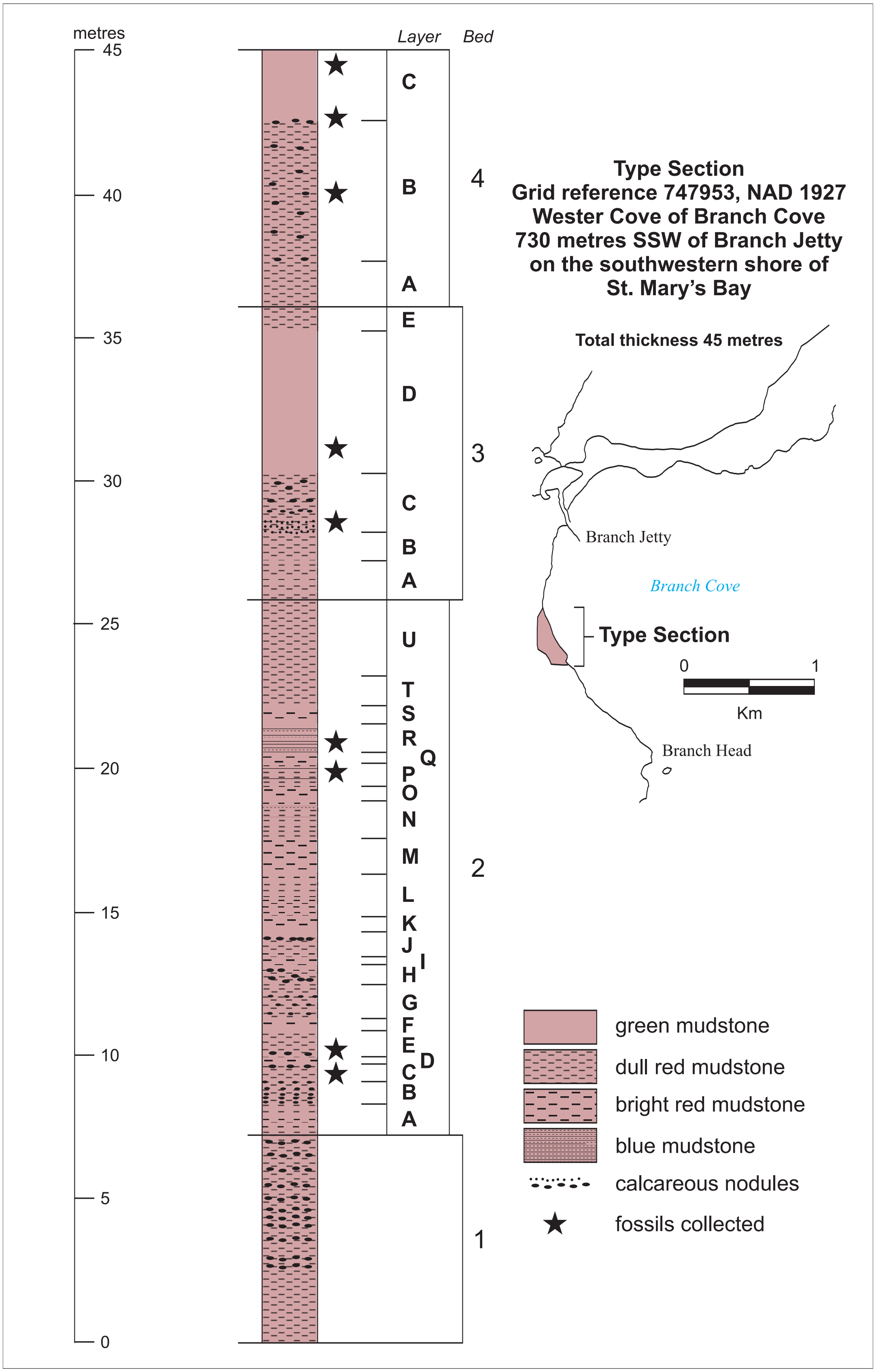

Figure 20. *Waterfall Cove Member; type section.*

Concretions also occur in the lowest 6 m of Bed 2, which is distinguished by nine, bright, dusky red layers (coded D, F, I, within J, K, M, O, Q and S in Figure 20) that contrast strongly with the predominant, duller dusky red and minor greyish olive green colours of this part of the member. The lowest concretions are relatively small and arranged in near-continuous stringers to be succeeded by larger ones that gradually become less numerous through Layer H.

Particularly silty nodules, containing cone-in-cone structures, appear again in Bed 3, concentrated as Layer C immediately beneath the thick olive green, highly fossiliferous marly Layer D; as in Bed 2, the lowest nodules are small and increase in size upward. The top of Bed 3 is marked as a 1-m-thick reddish mudstone.

Bed 4 is mainly red and contains many nodules scattered throughout its middle part forming Layer B. The largest nodules form a prominent horizon coinciding with a major colour change marking the base of green Layer C. Unlike the lower nodules, these are notably fossiliferous with large paradoxidid cranidia prominent.

Contact Relations

The Waterfall Cove Member in its type locality is conformable with the Wester Cove Member below and the Big Gully Member above; in areas beyond St. Mary's Bay, e.g., the Burin Peninsula and Conception Bay, it may not have been deposited.

Fauna and Zonation

As is commonly the case in the Chamberlain's Brook Formation, fossils are generally scarce in red mudstone layers and what is presently known of the fauna derives from greenish beds and a few nodules. The most important feature of the Waterfall Cove Member is the incoming of *P. (E.) bennetti* in Layer 2E to mark the base of the *Paradoxides (Eccaparadoxides) bennetti* Zone; the upper limit of the zone is drawn at the first occurrence of *Agraulos affinis* Billings, 1874, just above the base of the overlying Big Gully Member.

The stratigraphical distribution of the taxa in this member is given below:

Paradoxides (Hydrocephalus) harlani Zone:

Bed 2
Layer C. *Agraulos* sp. nov.

Paradoxides (Eccaparadoxides) bennetti Zone

Layer E. *P. (E.) bennetti* and *Parasolenopleura* sp.
Layers P and R. *P. (E.) bennetti*
Bed 3
Layers C and D. *P. (E.) bennetti* and *P. (E.)* sp. nov.
Bed 4
Layer B. *P. (E.) bennetti* and *P. (Hydrocephalus)* sp. nov. No. 1
Layer C. *P. (H.)* sp. nov. No 1, *P. (H.)* sp. aff. *P. (H.) harlani*, *P. (E.) bennetti* and *P. (E.)* sp. nov. No. 2.

Age and Correlation

The listed fauna indicates a transitional sequence between the Braintree *P. (H.) harlani* Fauna of Massachusetts (Fletcher *et al.*, 2005) and the *P. (E.) bennetti* Fauna formerly regarded as the oldest paradoxidid sequence in Newfoundland. Specimens of *P. (E.)* sp. nov. resemble a form figured from the Swedish *Paradoxides oelandicus* Stage by Westergård (1936, pl. 10), possibly suggesting some equivalence to some part of the upper *P. pinus* Zone [*Ptychagnostus praecurrens* Zone] of that stage. The last appearance of *P. (H.) harlani* may coincide with those ["*P. Groomi*"] in the Quarry Ridge Grit, if the Shropshire specimens are not reworked.

Big Gully Member (Unit 10c)

Definition

The type section of the Big Gully Member (Figure 21) is distinguished as the prominent, green, marly, calcareous mudstone sequence astride Branch Green Gulch waterfall in the southern cliffs of Branch Cove (BGM and *GG* in Plate 32). Its respective conformable contacts with the underlying Waterfall Cove Member and the overlying Head Cove Member are marked as strongly recessed separation planes. Two main beds are recognized.

The Big Gully Member is a highly calcareous, fossiliferous mudstone sequence and certain levels verge on limestone. Throughout, the member is greenish grey and is easily recognized around St. Mary's Bay as the thick green sequence forming the middle part of the Chamberlain's Brook Formation. Its upper boundary is drawn at the separation plane 61 cm below the top of the green colour, i.e., just below the prominent red mudstones typifying the cliffs of Head Cove (*HC* in Plate 32).

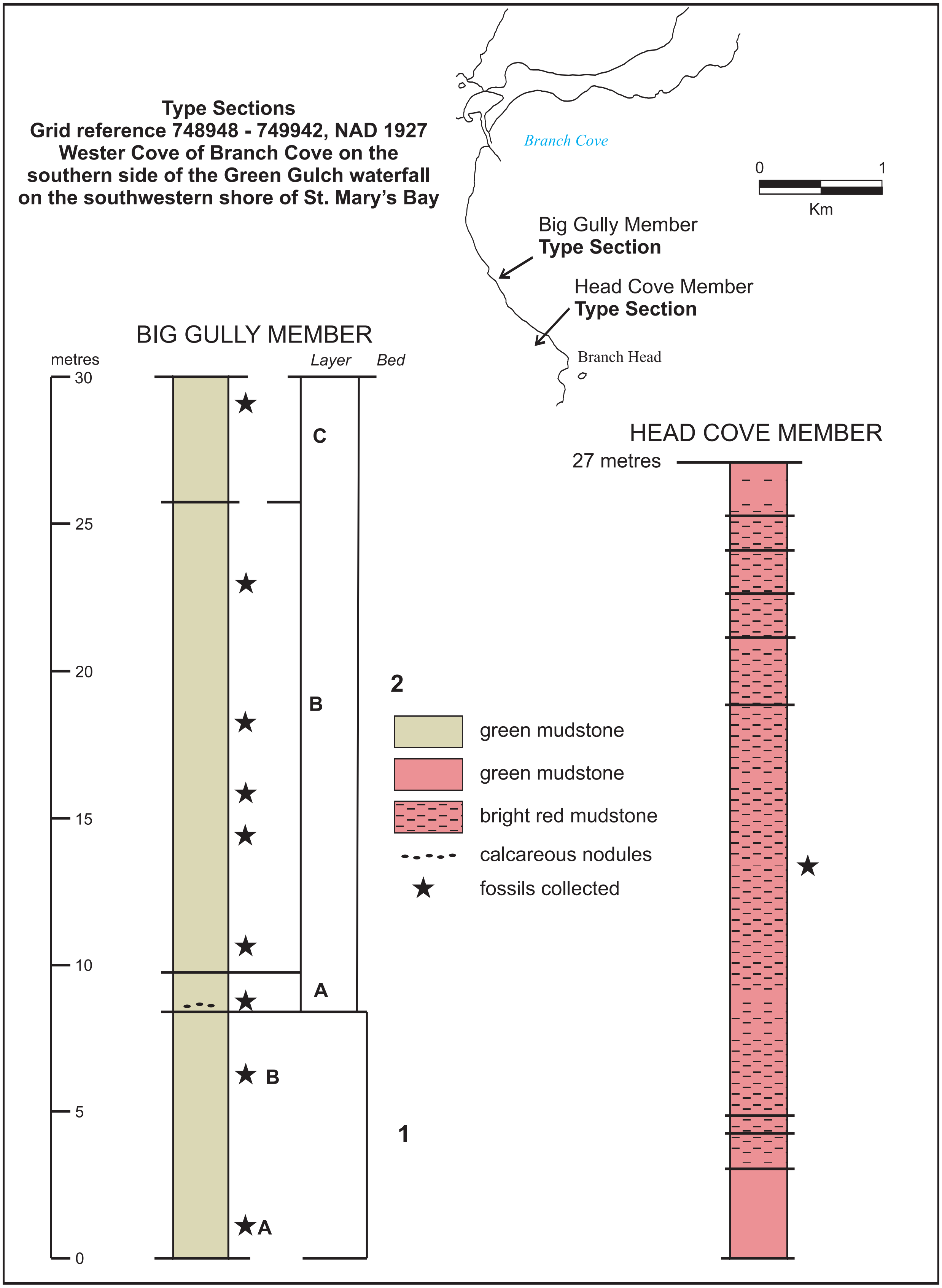

Figure 21. *Big Gully and Head Cove members; type sections.*

Distribution and Thickness

Marly mudstones are present within all the Chamberlain's Brook outcrops on the Avalon Peninsula, though only partially represented in the Manuels area, on the western side of Trinity Bay along Smith Sound and on the Burin Peninsula. The sequence is well disposed for collecting on both sides of Branch Cove, in eastern Redland Cove, on the northern side of Jigging Cove Head and at the eastern exposures of Cape Dog.

The only measured section is the type locality at the Branch Green Gulch waterfall, where it is 30 m thick (Figure 21).

Lithology

The distinctive medium greenish grey is a mark of the high calcareous content of this mudstone member and the lower half has the texture and composition of a muddy limestone [marl] in which fossils are beautifully preserved (Plate 31 and Plate 34, Figures 3-5, 23-26). Three prominent manganese-coated separation planes delineate four beds with small concretions also marking the base of Bed 2. In general, it is a homogeneous unit with little signs of layering or the typical micromozaic chaotic carbonate textures typifying some of the older major green intervals.

Contact Relations

The two bounding separation planes are considered no more than representing the slightest of breaks in sedimentary continuity between the mudstones of the Waterfall Cove and Head Cove members and both contacts are conformable.

The presence of *P. (E.) bennetti* and *Agraulos affinis* in the basal beds of the Chamberlain's Brook Formation in northern Trinity Bay and in the Manuels River section (Howell, 1925, p. 55) indicates that this member forms the base of the formation in those regions to emphasize the differential non-sequence of the Brigus-Chamberlain's Brook formational contact outwith the map area.

Fauna and Zonation

The trilobite fauna of this member is abundantly represented by undistorted, generally well-preserved specimens, many of which are complete or enrolled. The type section is also the type locality of *Paradoxides (Eccaparadoxides) bennetti*, *A. affinis* and *Parasolenopleura gregaria*. The latter solenopleurid was originally assigned to the Ordovician genus *Bathyurus*, but the revision of the species (Fletcher, 2005) indicates that it is evidently the senior synonym of *Solenopleura cristata* Linnarsson, 1877 described from Sweden, which Westergård (1953, p. 22) reassigned to his new genus *Parasolenopleura*. Although *P. (E.) bennetti* is common in this member, the greater variety of taxa contrasts strongly with the relatively impoverished fauna of the underlying *P. (E.) bennetti* Zone and, therefore, it is distinguished as part of the *Agraulos affinis* Zone, which has its base drawn at the lowest appearance of the zone fossil in this member and its upper limit delineated at the lowest occurrence of the distinctive *Parasolenopleura tenera* (Hartt *in* Dawson, 1868) in the overlying Head Cove Member.

The stratigraphical distribution of the taxa in this member is given below:

Agraulos affinis Zone:

Bed 1
Levels A and B. *Condylopyge carinata, Paradoxides (Eccaparadoxides) bennetti*, (Plate 34, Figures 3-5), *P. (H.)* sp. nov. No. 1 and *A. affinis*.
Bed 2
Layer A. *Peronopsis* sp. cf. *P.* sp. nov., *Paradoxides (E.) bennetti*, *A. affinis* (Plate 34, Figures 27-29).
Layer B. *C. carinata,* (Plate 43, Figure 16), *Peronopsis* sp. cf. *P.* sp. nov., *Paradoxides (E.) bennetti, P. (E.)* sp. nov., *P. (H.)* sp. nov. No. 2, *Bailiaspis* sp. cf. *B. inflata* (Plate 34, Figure 30), *Parasolenopleura gregaria* (Plate 34, Figures 23-26), *A. affinis* and a coiled molluscan.
Layer C. *C. carinata*, *P. (E.) bennetti* and *A. affinis*.

Age and Correlation

There is nothing in the above assemblages to suggest any direct correlation with other North American sequences, although part of the unexposed post-*Paradoxides (H.) harlani* Braintree succession of Massachusetts may have equivalence.

The presence of *Condylopyge carinata* and *Parasolenopleura gregaria* [*cristata*] indicates correspondence with the upper *pinus* Zone of the Scandinavian *Paradoxides oelandicus* Stage in which *C. carinata* first appears (Westergård, 1946, p. 98). Occurrences also of a similar stratigraphical stage of changing *C. carinata* form in Siberia allow correlation with part of the *Kounamkites* Zone. The species close to *Bailiaspis inflata* in this *A. affinis* faunal assemblage may indicate a slightly earlier occurrence than the type specimen in the Comley Breccia Bed of Shropshire, England, which is associated with younger faunal elements found in the *Hartella bucculenta* Zone of southeastern Newfoundland.

Recognition of a stratigraphical series of *Agraulos* (Fletcher *et al.*, 2005, fig. 12) indicates that *A. affinis* is an intermediate form between the oldest *A. quadrangularis* and the slightly younger *A. tosali* Sdzuy, 1967 occurring in the Spanish *P. (E.) asturianus* Zone. Therefore, a correlation of the *A. affinis* Zone with part of the Spanish zone (Sdzuy, 1967, table 4; Gozalo and Liñán, 1998, p. 100-101) is likely.

Head Cove Member (Unit 10d)

Definition

In the small cove (*HC* in Plate 32) between the Branch Green Gulch waterfall and Branch Head (*BH* in Plate 32), a sequence of reddish-layered mudstones conformably intervenes between the major green sequences of the Big Gully Member and the Cape Shore Member. It is delineated by conspicuous separation planes 3 m below the top of the lower green sequence and 61 cm above the uppermost red band. The cliff section in this cove is selected as the type section of the Head Cove Member (Figure 21).

Distribution and Thickness

The Head Cove Member is present in all areas of the Chamberlain's Brook Formation of Placentia, St. Mary's, Trinity and Conception bays. It is 27 m thick in Head Cove, but a thinning away from the type section is evident, though, in the absence of precise measurements, it is not possible to establish the rates or amounts of difference. It is also well exposed at the eastern end of Redland Cove, on the northern side of Jigging Cove Head, on the eastern side of Cape Dog and in various stretches along its folded strip in the bed of Branch River.

Lithology

The type section comprises only one main bed of homogeneous, fine-grained mudstone. Although predominantly greyish red, the sequence is distinguished by widely spaced greenish grey irregular, bedding-parallel, stripes and layers with closely spaced blackish red streaks at their bases. In general, striping is more widely spaced in the middle part and the broadest layers lie closer to the lower and upper limits.

Sections at Redland Cove and Jigging Cove are similar to that at Branch, but, farther north, thin limestone beds and sporadic very dark red layers are developed, as on the western side of Cape Dog and in Trinity Bay.

Contact Relations

The member is conformable with the adjacent members and the delineating separation planes do not signify significant sedimentary breaks.

Fauna and Zonation

Parasolenopleura tenera Zone: To date, only one horizon, just below the middle (★ in the Head Cove Member type section in Figure 21), has yielded fossils. None of the five species collected is known in the *A. affinis* Zone and, therefore, this level is chosen as the base of a younger zone. This zone is here named the *Parasolenopleura tenera* Zone, delineated at the base at the first appearance of *Parasolenopleura tenera* and, at the top, at the level of the first appearance of *Hartella bucculenta* (Resser, 1937) (Plate 43, Figure 31). The assemblage contains species of *Paradoxides (Hydrocephalus)* and *P. (Eccaparadoxides)* and a transitional *Parasolenopleura-Badulesia*-like solenopleurid. One of the paradoxidids resembles *P. (H.) sacheri* (Barrande, 1852), another resembles *P. (E.) asturianus* Sdzuy, 1967, though it is poorly preserved and might equally well be considered an early form of *P. (E.) lamellatus* (Hartt *in* Dawson, 1868).

The basic structure of *Parasolenopleura* and *Badulesia* is the same, but the solenopleurid in the Head Cove Member has fixigenal ridges not generally considered a feature of *Parasolenopleura* and lacks the diagnostic glabellar ridges of the Spanish *Badulesia* as indicated by its type-species *B. granieri* Thoral, 1935 (Sdzuy, 1967, p. 111). On the evidence of material in the higher Cape Shore Member, there is a complete merging of *Parasolenopleura* forms in which the prominent fixigenal ridges characterizing *P. tenera* seem to be variously developed from a typical ridgeless form, through types exhibiting a suite of incipient fixigenal ridges. Thus, such a difference might be taken as a reason for assigning the solenopleurid to a late group of *Parasolenopleura* forms (occurring at the same horizon) that herald the change to the younger *Badulesia granieri–Pardailhania–Solenopleuropsis* lineage (Álvaro and Vizcaïno, 2001, text-fig. 1). Certainly, it is easier to differentiate species of *Badulesia* s.st. with glabellar ridges from those with none. The writer (*in* Fletcher *et al.*, 2005) therefore, considers that fixigenal-ridged forms ex. gr. *tenera* better accommodated in the genus *Parasolenopleura* and that the Spanish form without ridges referred to *Badulesia* sp. A (*in* Álvaro and Vizcaïno, 2001, text-fig. 1) is a typical species of *Parasolenopleura*.

Age and Correlation

The scant paleontological information indicates a correlation of the Head Cove Member with the upper part of the Spanish *P. (E.) asturianus* Zone in which the ridgeless *Parasolenopleura* forms have been referred to *Badulesia* sp. A by Sdzuy (1971, p. 769) and Gozalo and Liñán (1998, fig. 2).

Cape Shore Member (Unit 10e) with Cape Dog Basaltic Flow (Unit 10ev)

Definition

The Cape Shore Member forms the top of the Chamberlain's Brook Formation and comprises dark greyish-green mudstones, i.e., the last of the sedimentary suite of colourful rocks characterizing the Adeyton Group. They are highly fossiliferous and delineated from the uppermost green layer of the Head Cove Member at a prominently recessed separation plane 61 cm above the base of that layer (Figure 22), and, at the top, by the prominent white Metabentonite Bed (Plate 35). Although the member (CSM in Plate 32) is completely exposed on the northern side of Branch Head and continuous with the type section of the underlying member, it mainly forms an inaccessible steep cliff unsuitable as a type section. The Cape Shore Member is accessible at Deep Cove, 4.6 km to the northeast, in the shoreline exposure of 45°-dipping strata, where it is completely exposed and is a suitable type section for the Cape Shore Member (Figure 22).

At certain localities on the Avalon Peninsula, short-lived volcanic episodes are manifest in this member and, at Cape Dog in the northeastern part of the Cape St. Mary's Peninsula, a localized thick volcanic sequence forms the Cape Dog Basaltic Flow (Unit 10ev) near its top (Plate 36).

Distribution and Thickness

The Cape Shore Member is present in all preserved sections of the Adeyton Group in southeastern Newfoundland and the French island of Langlade (Rabu *et al.,* 1993a, b), where the base of the Harcourt Group is preserved. In the map area, it is exposed at the top of the eastern cliff of Redland Cove, in Big Head Cove, on Branch Head, on the western side of Beckford Head, in Deep Cove, on the northern side of Jigging Cove Head, on the eastern side of Dog Cove, in Red Cove of Cape Dog and at various places along its folded outcrop in Branch River.

The type section (Figure 22) of the Cape Shore Member comprises eight beds delineated by recessed separation planes and is 32 m thick. This probably represents its maximum thickness; in the Manuels River section, where it was first fully investigated (Howell, 1925), it is about 30 m thick. This is a very complex unit and, outside the map area, intermittent differential arrests and rates of sedimentation associated with isolated areas of volcanic activity, e.g., at Cape Dog and Hopeall Head, along with the extensive diagenetic reduction of iron that resulted in a greening of older redbeds, have rendered it difficult to recognize the base of the member. Its unique fauna and sporadically developed nodular-microconglomeratic limestones best distinguish it. In Deep Cove, a solitary, prominent, 23-cm-thick, fossiliferous, nodular limestone lies 16.8 m above the base and 15.2 m below the top and is here named the St. Mary's Limestone Bed [previously mistakenly named Deep Cove Limestone by Fletcher (1972a, b), because the geographical title was preoccupied].

Lithology

The Cape Shore Member comprises medium greenish grey, fine-grained mudstones. The oldest beds are rather massive and less fossiliferous than slightly higher strata that are brighter green, marlier and weakly laminated. At the very top, the beds are conspicuously darker due to the development of dark grey streaky pyritic layers and this heralds the major facies change to the dark grey and blackish, pyritic, shaly, silty mudstone beds of the overlying Manuels River Formation. Weathering of these uppermost layers, and of shelly remains, produces an abundance of ochreous goethitic coatings. In some sections, e.g., in Redland Cove, a 90-cm to 1.5-m-thick, dusky red layer, some 7.6 m below the top, is also recognizable.

As noted above, the St. Mary's Limestone Bed is a prominent feature of the member in its type area and, in the northeast at Cape Dog, a lensoid, submarine, volcanic sequence also occurs in a similar stratigraphical position to the volcanic sequence at Hopeall Head in Trinity Bay. Unlike the latter volcanic sequence, which is little more than 4 m thick, the Cape Dog Basaltic Flow is over 61 m thick and is responsible for this very distinctive headland (Plate 3). Hutchinson (1962, p. 132) and Greenough (1984, p. 36-37) left the stratigraphical assignment of the basaltic flows and lapilli tuffs of Cape Dog and Hopeall Head in doubt and McCartney (1967, p. 72) incorrectly equated them to the volcanic Chapel Arm Member in the *Paradoxides (P.) davidis* Zone of the Manuels River Formation. Hutchinson (1962) described the section in the eastern Red Cove of Cape Dog, where the volcanics are faulted against the red mudstones of the Head Cove Member. However, on the eastern side of Dog Cove, the cherty, spilitic pillow-lava sequence is well exposed (Plate 36), where it represents the youngest strata in the trough of the Cape Dog Syncline (Plate 3). Here, there is no sign of the St. Mary's Limestone Bed and it may have been replaced by the volcanic rocks at an obvious period of sedimentary turbulence.

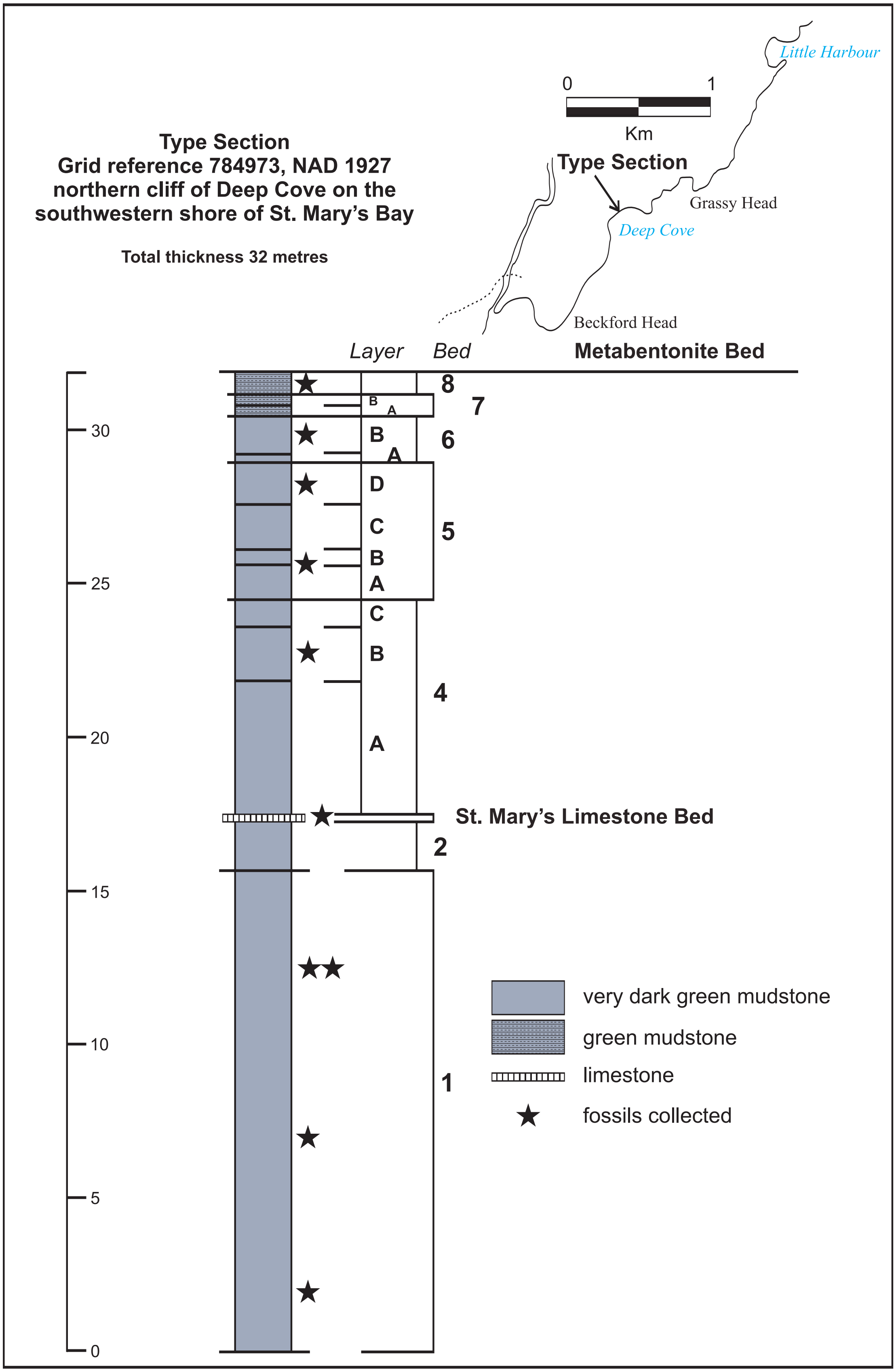

Figure 22. *Cape Shore Member; type section.*

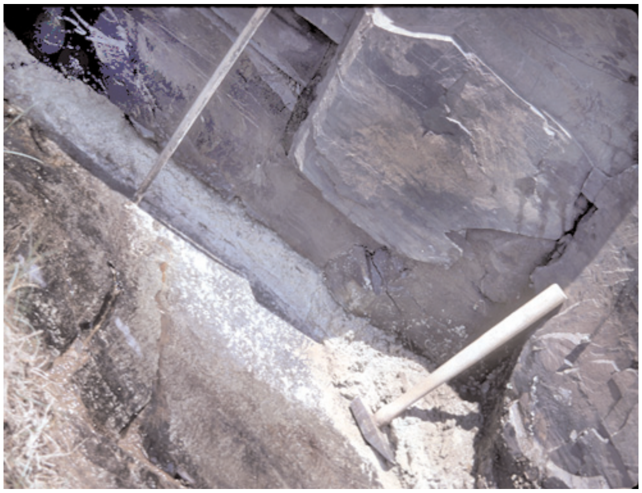

Plate 35. *The Metabentonite Bed – the distinctive white clay marking the base of the Manuels River Formation; section in Deep Cove, St. Mary's Bay.*

Similar limestones to the St. Mary's Limestone Bed occur in the Cape Shore Member outside the St. Mary's Peninsula area, but not all represent contemporaneous beds. For instance, there are older limestones containing the unique *Paradoxides (E.) lamellatus* in the Hopeall Head section (Hutchinson, 1962, section 7, bed 26, p.132) and on the northeastern shore of Cavendish, Trinity Bay. However, two closely spaced fossiliferous nodular limestones appear to coincide with the St. Mary's Limestone Bed in various sections along Smith Sound, Trinity Bay and, on the eastern side of Conception Bay, in the western pit on Red Bridge Road, Kelligrews and along the Manuels River valley (Howell, 1925, bed 19, p. 54). These limestones indicate at least two sequence-breaks, in contrast to the one in Cape St. Mary's map area, and reflect more marginal marine settings in the northern part of the Avalon Peninsula at this time.

The localized lensing nature of the Cape Dog Basaltic Flow (Unit 10ev) is emphasized by the fact that at Jigging Cove Head, only 24 km to the south and in Deep Cove (Figure 22), there is no trace of it in the Cape Shore Member.

Contact Relations

The basal contact of the Cape Shore Member appears to be conformable, with the delineating separation plane at the top of the Head Cove Member representing an insignificant break in sequence. Likewise, the upper contact is sharply defined at the base of the thin, extensively developed, unctuous, white, clay seam of the Metabentonite Bed representing the finer grained ashfall of some major volcanic episode, following the outpourings at Cape Dog and Hopeall Head. Although this clay prominently marks the base of the next group, it lies within a thin succession of gradually darkening, laminated, pyritic mudstones, transitional in type between the characteristic rock types of the varicoloured, blocky Chamberlain's Brook Formation and the monotonously dark grey, shaly sequences of the Manuels River Formation. The changing faunas, with several elements common to each formation, also match this gradation.

Plate 36. *Cliff section on the southern side of Cape Dog showing large basaltic pillow within the white chert-bearing Cape Dog Basaltic Flow.*

Fauna and Zonation

Although the St. Mary's Limestone Bed is a conspicuous lithostratigraphical marker, in the map area, the most significant biostratigraphical change is marked in the older Bed 1 by the sudden increasing variety of trilobite taxa, especially of the highly ornamented conocoryphids. This younger fauna, as presently recognized, lies 12 m above the base of the member (★★ in Figure 22) and is taken to be the zonal boundary between the *Parasolenopleura tenera* Zone below and the *Hartella bucculenta* Zone above. In the type section, the latter zone more or less corresponds to the range zone of *Hartella*, but the top of the zone in the type section is drawn 30 cm below the Metabentonite Bed at the first appearance of *Paradoxides* (subgen. nov.) *hicksii* (Salter *in* Salter and Hicks, 1869), which marks the base of the *Paradoxides* (subgen. nov.) *hicksii* Zone.

It should be noted that Kim *et al.* (2004) do not recognize *Hartella* Matthew, 1885 and follow the statistical analysis of Cotton (2001) by including it as a paraphyletic form of *Ctenocephalus* Hawle and Corda, 1847. However, since species of *Hartella*-form are limited to a stratigraphical interval well separated from the much younger stratigraphical occurrences of *Ctenocephalus*, without any intermediate linking species, e.g., in Britain, Scandinavia, southern France and southern Turkey (Dean and Özgül, 1981), its recognition as a distinct genus should not be abandoned especially since the roots of the prominent cranidial ridges are different; in *Hartella* they originate from the anterior lobe of the glabella in contrast to those of *Ctenocephalus* that stem from the anterior boss in the preglabellar area. Thus, in this account, *Hartella* is considered an important correlative genus and the reasoning given by Hutchinson (1962) for its distinction from *Ctenocephalus* is upheld.

The stratigraphical distribution of the taxa in this member is given below:

Bed 1

Parasolenopleura tenera Zone:
Basal 1.5 m. No fossils collected.

1.5 m above base. *Condylopyge* sp., *Peronopsis* sp., *Parasolenopleura tenera*.
6.7 m above base. *Paradoxides (Hydrocephalus) sacheri* (Barrande, 1852), *Parasolenopleura aculeata* (Angelin, 1852) [*ouangondiana* Hartt *in* Dawson, 1868]), *P. tenera* and *Agraulos* sp. aff. *A. tosali* (Sdzuy, 1967).

Hartella bucculenta Zone:

12 m above base. *Condylopyge carinata*, *P. tenera*, *Hartella bucculenta* [= *antiquus* Thoral, 1946] (Plate 34, Figure 31).
Bed 2
Middle. *H. bucculenta*.
Bed 3 St. Mary's Limestone Bed
Dawsonia dawsoni (Hart *in* Dawson, 1868), *Paradoxides (E.) lamellatus* (Hart *in* Dawson, 1868), *H. bucculenta*, *Parasolenopleura tenera*, *Lingulella ferruginea* (Salter, 1859), *Micromitra (Iphidella)* sp. cf. *M. (I) ornatella* (Linnarsson, 1869) and *Acrothele* sp. cf. *A. gemmula* (Matthew, 1893).
Bed 4
Layer B. *Paradoxides (Hydrocephalus) sacheri*, *P. (E.) acadicus* (Matthew, 1888), *Bailiella baileyi* (Hartt *in* Dawson, 1868), *B. ornata* Resser, 1937 [?=*Conocoryphe (Parabailiella) matutina* Sdzuy, 1967], *Hartella matthewi* (Hartt *in* Dawson, 1868) [*terranovicus* Hutchinson, 1962], *H. bucculenta*, *Parasolenopleura tenera* and *P. aculeata*.
Bed 5
Layer B. *Paradoxides* (*E.*) *eteminicus* (Matthew, 1893), *H. exsulans* (Linnarsson, 1879) [*solvensis* Hicks, 1871; *terranovicus* Resser, 1937].
Layer D. *Condylopyge carinata*, *Pleuroctenium pileatum* Rushton, 1966, *Bailiaspis dalmani* (Angelin, 1854) [*bufo* Hicks, 1869; *prominens* Resser, 1937] and *B. venusta* Resser, 1937 [*tuberculata* Lake, 1940].
Bed 6
Layer B. *Paradoxides (Hydrocephalus) regina* (Matthew, 1886), *P. (E.) acadicus*, *P. (E.) lamellatus*, *P. (H.)* sp., *Brunswickia robbii* (Hartt *in* Dawson. 1868) and *Parasolenopleura aculeata*.
Bed 8
C. carinata, *Peronopsis scutalis*, *Pleuroctenium pileatum*, *Diplagnostus lobatus* (Illing, 1916), *Eodiscus pulchellus* (Hartt *in* Walcott, 1884), *Paradoxides (H.) regina*, *Bailiaspis elegans* (Hartt *in* Dawson, 1868), *B. venusta*, *Hartella bucculenta*, *Parasolenopleura aculeata*, *P. tenera*, *Agraulos longicephalus*, *L. ferruginea* and *Acrothele matthewi* (Hartt *in* Dawson, 1868).
The *H. bucculenta* zonal assemblage corresponds to that extracted by Howell (1925, pp. 50-54) from Beds 19-35 in the Manuels River section, though his identification of "*Paradoxides bennetti*" in that faunule is erroneous.

Paradoxides (subgen. nov.) *hicksii* Zone:

Top 30 cm. *E. pulchellus*, *P. (*subgen. nov.*) hicksii* and *Agraulos holocephalus* Matthew, 1890).

Age and Correlation

Occurring a little below the local first appearance of *Tomagnostus fissus* in the overlying Manuels River Formation, the fauna in the Cape Shore Member may be considered late Amgan in age (Figure 18).

Parasolenopleura tenera is a well-distributed species and is known in the sequences of New Brunswick (Hartt *in* Dawson, 1868), Massachusetts (Stinson Lord Collection in the United States National Museum, Washington, D.C.), Rhode Island (Skehan *et al.*, 1978), Morocco (Sdzuy *et al.*, 1999), Montagne Noire (Álvaro and Vizcaïno, 2001) and Spain (Sdzuy, 1967). However, recent collecting has shown that, in Newfoundland, it has a relatively long stratigraphical range, extending from levels below the *Hartella bucculenta* Zone to as high as the *Eodiscus*-bearing sequence in the basal parts of the *Paradoxides* (subgen. nov.) *hicksii* Zone and, therefore, is not as precise a stratigraphical index fossil as generally considered.

It is an important fact that, in many of the Acado-Baltic Cambrian sequences, trilobite assemblages with conocoryphids and the eodiscid *Dawsonia* Hartt *in* Dawson, 1868 are directly associated with a lithofacies change from green, somewhat calcareous rocks to dark grey sulphurous rocks through the Zone of *Ptychagnostus* [*Triplagnostus (T.)*] *gibbus*, the basal zone of the Scandinavian "*Paradoxides paradoxissimus*" Stage (Westergård, 1946, p. 8). In Sweden, *Hartella exsulans* makes its first appearance at the base of that stage with *Parasolenopleura aculeata* and is succeeded by beds containing *Bailiaspis dalmani* and *Bailiella* spp. In Wales, *Dawsonia sculptus* (Hicks, 1871), *H. exsulans* [*solvensis*] and *Bailiaspis dalmani* [*bufo*] occur in the Solva Group (Rushton, 1974, pp. 88, 89), in Warwickshire, *B. dalmani* is a prominent component of the lowest Abbey Shales "*P. aurora* fauna" (Illing, 1916). In the French sequences of the Montagne Noire (Courtessole, 1973) and Herault and in the Iberian Chain, Spain, *Conocoryphe*, *Hartella* and *Bailiella* are well represented and they are important elements of the "zona *Eccaparadoxides pusillus*" in the Czech Republic (Šnajdr, 1958). All such occurrences match those assemblages in southeastern Newfoundland and New Brunswick (Hayes and Howell, 1937) that are associated with a lithofacial change.

The post-St. Mary's Limestone Bed faunule is an obvious duplicate of that in the earliest part of the New Brunswick paradoxidid sequence, i.e., the Fossil Brook Formation ("*Paradoxides eteminicus* zone" of Hayes and Howell, 1937, p. 56), which correlates with the "lower part" of the Trout Brook Formation of the Mira Valley Cambrian Basin (Hutchinson, 1952, p. 42) and the Bourinot Group of the McLeod Brook-Indian River Cambrian Basin (Hutchinson, 1952, pp. 8-20) in Cape Breton. For some time, the New Brunswick section influenced the belief that there are no older Middle Cambrian faunules in the Maritimes and that differences between the earliest paradoxidid assemblages in Massachusetts, Britain and Scandinavia were to be regarded as endemic equivalents of one and the same zone, a point even stretched to considering their different paradoxidid species as local variants of one contemporaneous form. Since this is not the case, the absence in New Brunswick of those older paradoxidid assemblages indicates the substantial non-sequence there at the protolenid Hanford Brook–Fossil Brook formational junction (Fletcher, 1972, fig. 21).

Since the base of the Westergård's (1946) *P. paradoxissimus* Stage is drawn at the base of the lower limit of the Exsulans Limestone, it seems reasonable to consider the *Hartella bucculenta* Zone and the pre-*Tomagnostus fissus* beds of the *P.* (subgen. nov.) *hicksii* Zone represent the *Ptychagnostus gibbus* Zone and, therefore, correlative globally with *P. gibbus*-sequences as far distant as Utah and Nevada (Robison, 1982, p. 139), Greenland (Blaker and Peel, 1997, p. 15), Siberia (Korovnikov, 2001, fig. 2), China (Lu Yanhao *in* Robison, 1982, p. 143), Australia (Öpik, 1979, p. 117) and Antarctica.

An important inter-realm correlation was made by Bird and Rasetti (1968, p. 40) when they equated the *P. gibbus* Zone of Scandinavia with the *Bathyuriscus-Ptychoparella* Zone of North America. Such a conclusion was based upon their studies of the Taconic sequence of New York that contains earlier Cambrian elements noted above in the Branch Cove Member of the Cape St. Mary's Peninsula succession. Thus, in Branch Cove, two of the New York faunule equivalents occur in one completely exposed section and a full sedimentary development from pre-*Acimetopus* to post-*Ptychagnostus gibbus* time can be demonstrated to clearly indicate that the Chamberlain's Brook Formation hereabouts is equivalent to those beds in the Laurentian Realm containing the *Bonnia-Olenellus*, *Plagiura-Poliella*, *Albertella* and *Glossopleura* zones.

HARCOURT GROUP (UNITS 11 TO 13)

Definition

The name Harcourt Group was proposed by Jenness (1963, p. 70) for the dark grey and black shale-siltstone-sandstone formations that overlie the red and green mudstones of the Adeyton Group. Such a lithofacial change was attributed to a significant turnover from a shallow-water oxidizing environment to one of deep-water reducing conditions.

The basal Manuels River Formation is a ubiquitous unit of sulphurous black shaly mudstones with its base well defined at the base of the Metabentonite Bed (Plate 35). However, fossils have shown that the top of this basal formation is regionally diachronous and, in general terms, may be drawn at the marked change to paler, more blocky, siltstone and shaly sandstone sequences.

Formations overlying the Manuels River Formation have not been widely established and the descriptions of these younger sequences in their type area on the western side of Trinity Bay do not readily correspond with the succession in the Cape St. Mary's map area. In keeping to a consistent subdivisional scheme, the Elliot Cove Group of Hutchinson (1962, p. 25), the Elliot Cove Formation of Jenness (1963, p. 72) and the Upper Cambrian Series of McCartney (1967, p. 74) should be subdivided into formations of similar scale to those already proposed earlier in this manuscript. Whereas it has not been possible to examine all contemporaneous sections in the Avalon Zone, it is obvious from the limited observations that the sequence does comprise several lithological units and that further work will establish a lithostratigraphical scheme of general application.

The youngest Cambrian succession on Cape St. Mary's Peninsula, i.e., that overlying the Manuels River Formation, comprises two main lithostratigraphical units, which are mappable and, to some extent, recognizable outside the map area. The older unit of light olive-grey siltstones is here named the Beckford Head Formation and is conformably overlain by a very thick sequence of interbedded, dark grey, sulphurous, shaly mudstones and sandstones that henceforth will be referred to as the Gull Cove Formation. Consequently, the Harcourt Group on Cape St. Mary's Peninsula comprises:

Gull Cove Formation
Beckford Head Formation
Manuels River Formation with Hay Cove Basaltic Flow

In addition to the lithological differences between the rocks of the Adeyton Group and this group, the latter do not show the major effects of tectonic stress so strongly manifest in the highly cleaved older sequence in which fossils are generally very distorted. In Harcourt Group sequences, fossils in limestones are invariably beautifully preserved in full relief and any distortion of a fossil appears to be due to synsedimentary compressive flattening in the mudstones.

Manuels River Formation (Units 11) with Hay Cove Basaltic Flow (Unit 11v)

Definition

The Manuels River Formation, as named by Hutchinson (1962, p. 22) comprises late paradoxidid-bearing grey to black shale or slate with numerous lenses and thin beds of grey or black fossiliferous limestones that overlie the greenish, more-blocky mudstones at the top of the Chamberlain's Brook Formation.

The section in the Manuels River valley on the eastern side of Conception Bay was chosen as the type section. Hutchinson (1962) took its base to coincide with the "abrupt change from grey-green shale to dark grey or black shale" and suggested that the upper contact coincided with the "Middle Cambrian–Upper Cambrian series boundary", a level he chose to be the base of his "Elliot Cove Group" (1962, pp. 22-25). As thus defined, it is a modification of earlier nomenclature by van Ingen (1915) and Howell (1925, tab. 1). In more precise terms, Hutchinson (1962) refers to Howell's (1925) section and states that the type section of the Manuels River Formation "includes beds 26 to 125". Quite obviously an oversight has allowed the publication of the number "26" for "36", because Howell's beds 26 to 35 form the top part of the older green formation and the "unctuous white clay" Bed 36 is a conspicuous marker for the base of the formation, occurring in all basal exposures of this formation in the Avalon Zone (Fletcher, 1972a) as far distant as Langlade in the St. Pierre and Miquelon archipelago (Rabu *et al.*, 1993a, b).

Walcott (1900a) had previously taken Howell's (1925) Bed 125 as the basal bed of the Upper Cambrian, but the problem of the upper boundary of the Manuels River Formation has been skirted somewhat, with vague references to "the contact", "the interval", the "boundary", etc., without referring to a significant widespread lithological marker in the succession. However, Poulsen and Anderson (1975) clarified the problems in the Conception and Trinity bay sections regarding the relationship between lithostratigraphy and chronostratigraphy, when they identified Howell's phosphatic conglomerate Bed 125 at Manuels and "an identical conglomerate of comparable thickness" on Random Island as marking a slight faunal break. In those sections, Poulsen and Anderson (1975) discovered fossils above that conglomerate indicative of later paradoxidid "Middle Cambrian" Scandinavian zones and concluded that the conglomerate signified a slight faunal break between beds equivalent to the Zone of *Goniagnostus (G.) nathorsti* and overlying strata containing elements of the zones of "*Solenopleura*" *brachymetopa* and *Lejopyge laevigata*. In all discussions relating to the top of the paradoxidid sections, an associated transitional lithofacies interval has been highlighted. No major lithological marker for the top of the Manuels River Formation has been proposed and Hutchinson's (1962, tab 1) boundary seems to be based on the upper limit of a "Middle Cambrian" fauna. In the absence of a widespread marker bed in such a position, locally relevant lithofacial boundaries need to be drawn. On Cape St. Mary's Peninsula, there is a transitional sedimentary sequence between the characteristic, blackish shales of the Manuels River Formation and the succeeding paler grey, more massive bedded siltstones. On Beckford Head and at the northern end of Deep Cove, this interval separates the highest *Paradoxides (P.) davidis*-bearing limestone from the lowest lenticular silty calcareous concretions in the overlying paler siltstones. For beds below and above this interval, there is no confusion as to which formation the strata belong, so one is left with an arbitrary decision on where to place the formational junction. In this map area, the top of the highest limestone bearing *Paradoxides (P.) davidis* has the aspect of a smooth, uneven eroded surface (Plate 37) and is taken to be the local horizon equivalent to the basal contact of Howell's Bed 125 and of its correlative conglomerate in Trinity Bay.

To conform most closely to Hutchinson's (1962) decision at the type section, the top of the highest *Paradoxides*-

Plate 37. *The contact rocks between the Manuels River and Beckford Head formations at the northern end of Deep Cove, St. Mary's Bay. Hammers on the highest limestone bearing* Paradoxides (Paradoxides) davidis, *the top surface of which is taken to mark a slight sequence break differentiating the two formations in the map area.*

bearing limestone is here defined as the upper boundary of the Manuels River Formation in the map area, thus recognizing the transitional zone described above to be the basal layers of the Beckford Head Formation.

Distribution and Thickness

The main area of the Manuels River Formation, in the St. Mary's Peninsula area, is continuous around the Point Lance Syncline, but only well exposed along its folded eastern limb in Branch River. The unit continues southward to the good section at Gooseberry Island in Branch River, where it is folded around the Gull Cove Syncline and continues down to Hay Cove. From the coastal cliff section, it kinks back over the Branch Anticline northward around the axis of the Hay Cove Syncline to the cliff exposure at Branch Head. From that headland, the formation is folded around the Beckford Anticline beneath the waters of Branch Cove to the faulted eastern limb that parallels the coast between the exposures at Beckford Head and the northern side of Jigging Cove Head. On the southeastern side of the Point Lance headland, a small coastal kinked outcrop occurs in Big Head Cove as the crinkled core of the Big Head Anticline.

The best section and thickest sedimentary development of this formation lies on the eastern limb of the Beckford Anticline on the northern side of Deep Cove. This section is 42.5 m thick and considerably thicker than the 21-m-thick type section at Manuels River (Figure 23). However, the intervening Hay Cove Basaltic Flow in the highest part of the sedimentary sequence is at least 60 m thick between Hay Cove and Branch Head and, therefore, has considerably increased the thickness of the formation to about 100 m in the Hay Cove Syncline on the southern side of Branch.

Lithology

The overall distinguishing aspect of this formation is of black, fissile, sulphurous mudstone interspersed with rare, thin, shelly, crystalline limestone lenses and unfossiliferous, bedding-parallel, septarian nodules. In contrast to earlier faunas, those of this formation are characterized by coquina levels of relatively tiny agnostid trilobites.

The formation in Deep Cove may be considered a major Reference Section and is here subdivided into four informal members labelled A-D (Figure 23):

Member D. Grey-black, "irony"-weathering, shaly mudstone containing thin black layers and some large fossiliferous calcareous concretions; interleaved with the Hay Cove Basaltic Flow.

Member C. Greenish grey siltstone containing numerous black shaly mudstone layers (Plate 38).

Member B. Black, "irony-weathering", shaly mudstone containing thin shelly limestone lenses, larger very rare fossil-coquina nodules and ovoid, septarian nodules.

Member A. Greenish, dark grey, shaly mudstone and basal Metabentonite Bed.

The lowest Member A is 7 m thick and comprises medium dark grey, greenish tinged shaly mudstones forming a transitional lithofacies between the green blocky Cape Shore Member and the darker grey, more fissile, shaly sequence above. Prominent throughout are numerous, closely spaced horizons of shell debris exhibiting a fine discrete bedding similar to the topmost, fossil-rich beds of the underlying Adeyton Group sequence. A prominent white clay bed, about 13 cm thick, identifies the base of the formation. First described as "unctuous white clay" by Howell (1925, in Bed 36, p. 50) in the type section, it is a slightly metamorphosed, montmorillonite-rich, bentonite traceable throughout the Avalon Zone in southeastern Newfoundland and St. Pierre-Miquelon and is known as the Metabentonite Bed.

Member B is 12 m thick and well differentiated as the pyritic, sulphurous, "irony-weathering", dark grey, papery shale sequence containing bedding-parallel, ovoid septarian nodules with vuggy or drusy calcite crystals, thin shelly limestone lenses and very rare, fossil-rich crystalline limestone nodules having an outward septarian appearance. Such a lithological association is apparently a significant lithofacies, since it is subsequently mirrored again as the youngest member of the formation.

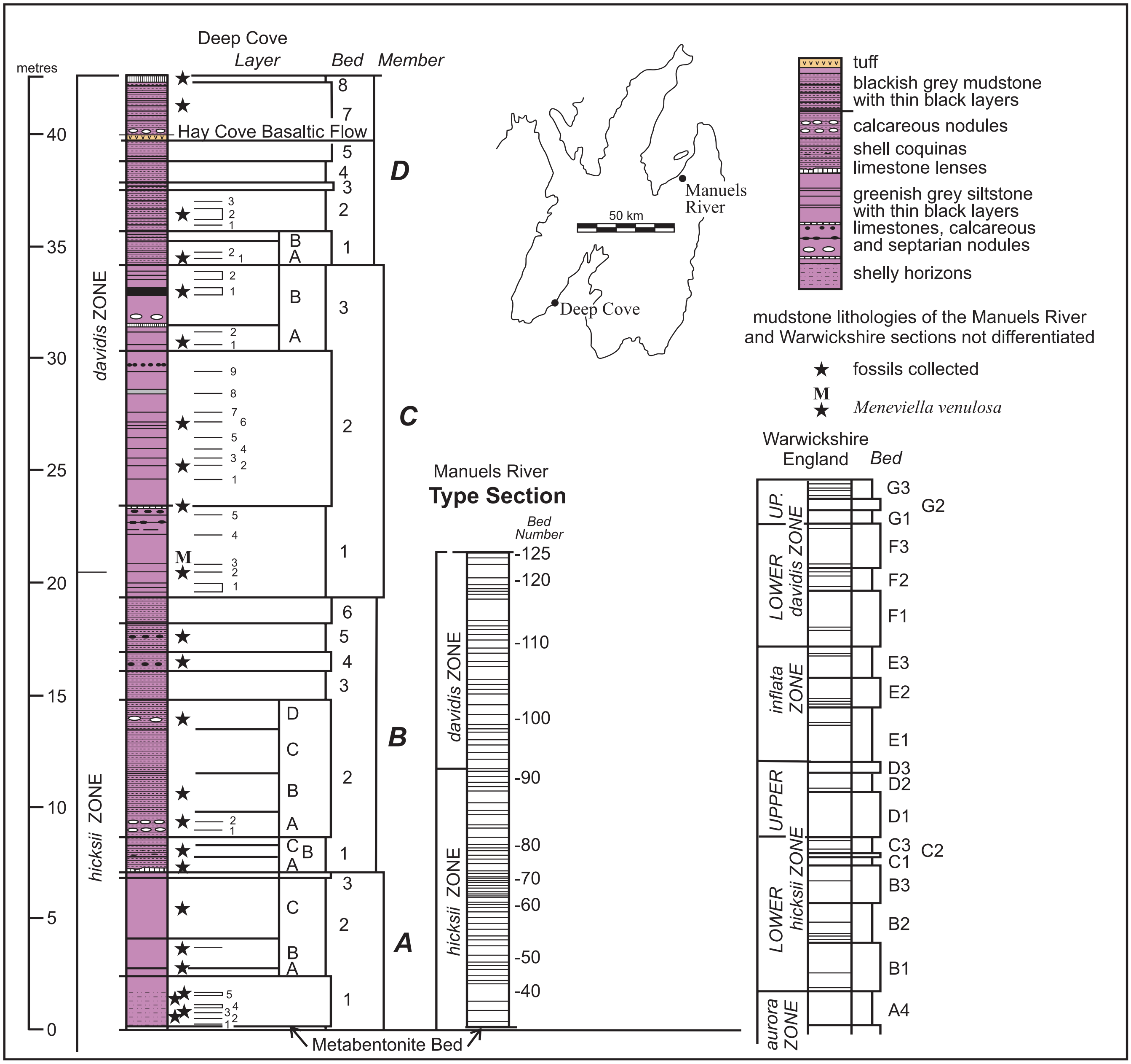

Figure 23. *Manuels River Formation; type and comparative sections.*

Member C is 15 m thick and contains sporadic cone-in-cone limestone lenses, some of which are fossiliferous. However, this member lacks limestone nodules and is characterized by a middle paler grey siltstone sequence, marked by numerous thin, black mudstone layers, that resembles the previously described transitional facies forming the basal layers of the Beckford Head Formation (cf. Plates 38 and 37).

Member D is 8.5 m thick and resembles Member B in that it is essentially shaly with an "irony-weathering" paper-shale at the base. Large rounded concretions are conspicuous and like the thinner limestone lenses are commonly packed with large paradoxidid remains. The top of the formation is drawn at the top of the highest limestone that forms a raised feature at the northern end of the Deep Cove beach (Plate 37; Bed D8 in Figure 23).

A prominent feature of Member D on Cape St. Mary's Peninsula is the interbedded lensoid body of submarine volcanic rocks in the top part of the sequence. This is named the Hay Cove Basaltic Flow (Unit 11v) and comprises highly calcitized hyaloclastites (lapilli tuffs) as waterlain tuffs and breccias associated with thin basaltic pillow lavas (Plates

Plate 38. *Blackish shaly mudstone layering in the greenish grey siltstone of Member C in the Manuels River Formation at Deep Cove; this lithofacies also resembles that forming the basal beds of the Beckford Head Formation.*

39-42). Centred on a 60-m-thick pile in the Hay Cove Syncline just south of Branch, a dramatic lateral thinning of the flow is conspicuous; at Beckford Head, it is represented by 70 cm of whitish aquagene tuffs (Plate 42) and farther northeast by similar tuffs in Deep Cove, where it is 29 cm thick on the southern side and 23 cm thick in the main northern section. Undoubtedly, there is a relationship to the apparently contemporaneous volcanic episode marked by pillow lavas and breccias in the *Paradoxides* (*P*.) *davidis* Zone-Chapel Arm Member (McCartney, 1967, p. 72) in southern Trinity Bay. However, there is no lateral continuity and the Hay Cove volcanic area is identified as one of several volcanic centres, developed in late stages of the *P*. (*P*.) *davidis* Zone, that reflect tectonic adjustments heralding a major change to a different sedimentary regime. At all localities examined, *P*. (*P*.) *davidis* Zone fossils occur above and below the volcanic sequence to indicate the relatively short-lived nature of such extrusions.

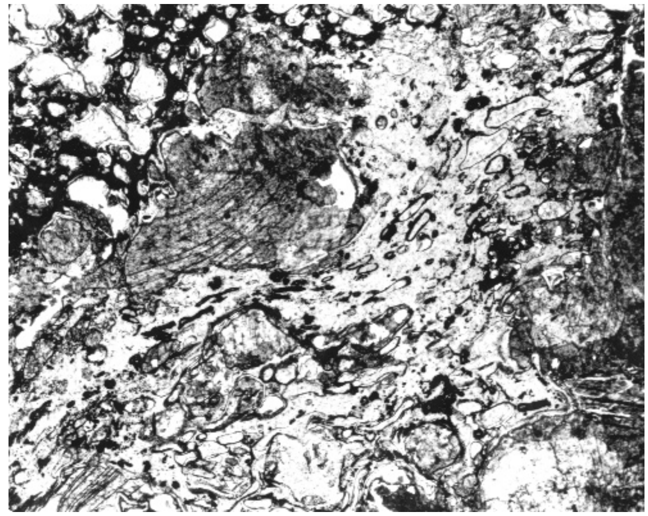

Plate 39. *Photomicrograph of a hyaloclastite flow within the Hay Cove Basaltic Flow in Hay Cove showing the stretched-out glassy globules indicative of mobility following their formation. [Magnification x 7]*

Plate 40. *Pillowed and wedging lapilli tuffs [hyaloclastites] in the axis of the Hay Cove Syncline in the type locality of the Hay Cove Basaltic Flow. [Scale: rucksack on pillows]*

Considering the great thickness of volcanic rocks at Hay Cove, it is noteworthy that the succeeding Harcourt Group sediments do not show any onlapping features or detectible non-sequences. Evidently, these bedded volcanics were built up upon the sea floor and rapidly reacted with the sea water. Typical hyaloclastites developed with calcite as the main interstitial cement; the latter is so dominant that some beds resemble crystalline bedded limestones. Each bed is variously coloured with pinks and pale greens predominant. Eruption was probably accompanied, or quickly followed, by depression of the volcano before sedimentation of the youngest Manuels River Formation strata continued on a more or less level sea floor.

Plate 41. *Block of highly calcareous hyaloclastitic flow containing variously sized cognate ejecta in the Hay Cove Basaltic Flow; shore section in Hay Cove.*

Plate 42. *Thinly bedded calcareous tuff within the* davidis *Zone on the western side of Beckford Head; a lateral extension of the northerly thinning Hay Cove Basaltic Flow.*

Contact Relations

The basal Metabentonite Bed reflects volcanic activity associated with tectonic movements accounting for a major environmental change. However, it does no more than mark a bed within the transitional Adeyton-Harcourt sedimentary sequence and the lower contact with the Cape Shore Member of the Chamberlain's Brook Formation is regarded as conformable. On Cape St. Mary's Peninsula, the top of the formation is drawn along the top surface of a prominent limestone bearing the highest occurrence of *P*. (*P*.) *davidis* Salter, 1863 and is considered an unconformable erosive horizon at the base of the overlying Beckford Head Formation. Sections to the north and east of the map area indicate that this horizon represents a differential non-sequence that, in some places, accounts for the absence of at least two zonal equivalents of the Scandinavian *Paradoxides forchhammeri* Stage (Westergård, 1946); in the Manuels River section, the zones of *Goniagnostus nathorsti* and "*Solenopleura*" *brachymetopa* are missing below trilobites of the *Lejopyge laevigata* Zone (Poulsen and Anderson, 1975, p. 2065).

Fauna

In most of its Newfoundland sections, the Manuels River Formation is abundantly fossiliferous with trilobites predominant. Howell (1925, p. 59) recognized two paradoxidid zones in his original description of the Manuels River type section, i.e., a lower "*Paradoxides hicksi* zone" and an upper "*Paradoxides davidis* zone" that he regarded synonymous with his now redundant lithostratigraphical units "Long Pond formation" and "Kelligrews Brook formation" respectively. An overlapping of the ranges of *P.* (subgen. nov.) *hicksii* and *P. (P.) davidis* has nowhere been demonstrated and in the Manuels type section, there is an 84-cm gap between positive identifications of these taxa, where the base of the *Paradoxides (P.) davidis* Zone must be drawn at the base of the undoubted specimen of *P. (P.) davidis* in Howell's Bed 94 (1925, p. 41).

Contemporaneous sequences in Britain (Illing, 1916) and Scandinavia (Westergård, 1936) have been further subdivided into more-restricted trilobite assemblage zones. In the North Atlantic region, equivalent sequences to Westergård's "*P. paradoxissimus* Stage" are distinguished by a surge of agnostid trilobites and various ranges of certain taxa within the stage have been used as the main criteria for zoning. At the present time, the writer has not yet completed the study of the faunas in the Manuels River Formation, but preliminary results suggest that Howell's two paradoxidid subdivisions may well be maintained as the best scheme. Howell's collection from the type section is unlikely to be bettered from any other Newfoundland section and any improvement will be due to a taxonomic review of his specimens. Certainly, sections in the map area will never compare as a fossiliferous sequence, because there are too many unfossiliferous intervals. For instance, the gap between the presently known ranges of the two zonal paradoxidids in Deep Cove is 15 m, but within that interval other trilobites occurring within the zones at Manuels have been collected and are used as evidence for drawing the local *hicksii-davidis* zonal boundary.

Within the stratigraphical range of *P*. (subgen. nov.) *hicksii* and before the first appearance of *P*. (*P*.) *davidis*, some important taxa make their first appearances to mark a series of important intervals of global significance. The first notable event is the incoming of *Eodiscus* Hartt *in* Walcott, 1884 (Plate 34, Figure 32), followed by *Tomagnostus* Howell, 1935 (Plate 34, Figures 41-42), then by *Acidusus atavus* (Plate 34, Figures 43-44), then by *Hypagnostus parvifrons* (Plate 34, Figures 49-50), and finally by *Ptychagnostus punctuosus* (Plate 34, Figures 53-54).

It should again be noted that the contentious *Parasolenopleura tenera* continues its range upward into beds with *Eodiscus* to indicate its presence in three Newfoundland zones. Other notable taxa are the agraulids accompanied throughout the post-*Eodiscus*, *Paradoxides* (subgen. nov.) *hicksii* Zone by the characteristic Welsh species *Jincella applanata* [*communis* Billings, 1874]. The position of the distinctive *Meneviella venulosa* (Plate 34, Figure 37) in the formation, known elsewhere at the base of *P*. (*P*.) *davidis* sequences, indicates that the bulk of the non-*hicksii-davidis* overlap interval on Cape St. Mary's Peninsula correlates with the *P*. (*P*.) *davidis* Zone, where best developed. In this report, therefore, the base of the latter zone is provisionally drawn at the lowest known occurrence of *M. venulosa*, i.e., at the base of Member $C1_2$ in Figure 23.

The stratigraphical distribution of the taxa collected from this formation in Deep Cove on Cape St. Mary's Peninsula is given below (for stratigraphical section see Figure 23):

Member A
Paradoxides (subgen. nov.) *hicksii* Zone:

Bed 1
Layer 1. *Parasolenopleura aculeata* and *Paradoxides* (subgen. nov.) *hicksii*.
Layer 2. *Eodiscus pulchellus* and *P*. (subgen. nov.) *hicksii*.
Layer 4. *Condylopyge rex* (Barrande, 1846) and *Parasolenopleura aculeata*.
Layer 5. *Ptychagnostus* sp. aff. *P. stenorrhachis* (Grönwall, 1902), *Peronopsis scutalis* (Plate 34, figure 55), *Cotalagnostus lens, Phalagnostus* sp. aff. *P. eskriggei* (Salter *in* Hicks, 1872), *P. nudus* (Beyrich, 1845), *E. pulchellus, Paradoxides* (subgen. nov.) *hicksii and Agraulos longicephalus* (Hicks, 1872) [*socialis* Billings, 1872].
Bed 2
Layer A. *Peronopsis scutalis*, and *Paradoxides* (subgen. nov.) *hicksii*.
Layer B. *Peronopsis scutalis*.
Layer C. *P*. cf. *P. howelli* Hutchinson, 1962, *C. claudicans* Westergård, 1946 and *Tomagnostus fissus*.

Member B

Bed 1
Layer B. *Ptychagnostus gibbus* (Linnarsson, 1869) and *Paradoxides* (subgen. nov.) *hicksii*.
Bed 2
Layer A2. *Acidusus atavus* (Plate 34, Figures 43-44), *Eodiscus scanicus* (Linnarsson, 1883), *Peronopsis fallax*, *C. lens* (Plate 34, Figures 51-52), *C. claudicans*, *T. fissus* (Plate 34, Figures 41-42), *Ptychagnostus* sp. cf. *P. ciceroides* (Matthew, 1896), *P. hybridus* (Brögger, 1878), *P. convexus* Westergård, 1946, *Phalacroma scanicum* (Plate 34, Figures 47-48), *Pleuroctenium granulatum scanense* (Plate 34, Figures 45-46), *Paradoxides* (subgen. nov.) *hicksii* (Plate 34, Figures 6-8), *Clarella venusta* (Plate 34, Figures 11-12), *Bailiaspis latigenae* Hutchinson, 1962, *B*. sp. cf. *B. tuberculata* (Plate 34, Figure 33), *Jincella applanata* (Plate 34, Figure 36), *A. ceticephalus* (Plate 34, Figure 35), *Agraulos longicephalus* (Plate 34, Figure 34), *Skreiaspis* sp. aff. *S. spinosus* (Jahn, 1895) and *S*. sp. nov. (Plate 34, Figure 38).
Layer B. *T. fissus*, *T. perrugatus* (Grönwall, 1902) and P. (gen. nov.) *hicksii*.
Layer C. *P*. (gen. nov.) *hicksii*.

Member C

Bed 1
Layer 2. *Bailiella aequalis* (Linnarsson, 1883).

Paradoxides (P.) davidis Zone:

Top. *Meneviella venulosa* (Plate 34, Figure 37).
Bed 2
Layer 2. *Eodiscus punctatus* (Salter, 1864) and *P. (P.) davidis and Ctenocephalus howelli* Resser, 1937.
Layer 6. *E. punctatus* (Plate 34, Figure 32), *Solenopleuropsis variolaris* (Plate 34, Figure 32).
Bed 3
Layer A1. *Ptychagnostus punctuosus*, *Anapolenus henrici* Salter, 1864.
Layer B1. *Paradoxides* (*P*.) *davidis* (Plate 34, Figure 10).

Member D

Bed 1
Layer A1. *Bailiaspis glabrata* (Plate 34, Figure 56).
Bed 2
Layer 2. *Ptychagnostus punctuosus* (Plate 34, Figures 53-54) and *Paradoxides (P.) davidis*.

Bed 7
Middle *P. (P.) davidis*.
Bed 8, i.e., the limestone marking the top of the formation on Cape St. Mary's Peninsula.
Ptychagnostus sp. cf. *P. ciceroides, ?Doryagnostus* sp., *Paradoxides (P.) davidis* (Plate 34, Figure 9) and *Holocephalina* sp. aff. *H. incerta* (Plate 34, Figure 39).

The sections at Branch Head and Jigging Cove Head are not conductive to bed-by-bed collecting and collecting is virtually restricted to the fossils in fallen blocks from the cliffs. However, unlike the limestone nodules in Deep Cove, those at these localities bear beautifully preserved specimens. The section at Beckford Head is wave-washed and barely collectable.

Age and Correlation

The Manuels River Formation preserved in this map area is the local equivalent of Howell's beds 36-124 in the type section and there is no evidence of a zonal equivalent of the Scandinavian Zone of *Goniagnostus nathorsti* at the top, as may be the case in the northern bays of the Avalon (Poulsen and Anderson, 1975, p. 2068).

In the absence of a detailed study of all the genera in this formation, little can be added to what has been said by Howell (1925) and Hutchinson (1962) concerning its age and correlation. The lower *Paradoxides* (subgen. nov.) *hicksii* Zone is equivalent to the bulk of the "*Paradoxides paradoxissimus* Stage" in Sweden incorporating the top part of the Zone of *Ptychagnostus gibbus*, the whole of the zones of *Tomagnostus fissus*-*Acidusus atavus* and *Hypagnostus parvifrons* and the lowest part of the Zone of *Ptychagnostus punctuosus* (Westergård, 1946, p. 8). The correlation of beds containing *T. fissus*, *P. punctuosus*, *Paradoxides* (subgen. nov.) *hicksii* or *Meneviella* with sequences as far afield as Warwickshire (England), Yakutia (Siberia), Queensland (Australia), New York State, Utah, Alaska (USA) and North Greenland can be made.

The *Paradoxides (P.) davidis* Zone in southeastern Newfoundland appears to represent the later parts of the same zone in Britain, which is equivalent to the late parts of the Scandinavian Zone of *Ptychagnostus punctuosus*. The presence of *Solenopleuropsis variolaris* in the zone not only strengthens the correlation with the high Menevian beds of Wales and Australia, but also with Sdzuy's (1967, tab. 2) Piso de *Solenopleuropsis* in eastern Asturias, Spain, beds in the Ferrals-Les-Montagnes in the Herault Region of southern France (Courtesole, 1973) and southern Turkey (Dean, 1982).

The suggested correlations for the Manuels River Formation are given in diagrammatic form on the correlation chart of Figure 18.

Beckford Head Formation (Unit 12)

Definition

The Beckford Head Formation is a sequence of thick-bedded, pale grey, blocky siltstones, containing sporadic calcareous silty nodules, unconformably overlying the Manuels River Formation on Cape St. Mary's Peninsula, where interbedded, dark grey shaly mudstones and thin sandstones of the Gull Cove Formation conformably overlie it.

The type section occurs at the southern limit of the eastern flanking outcrop belt of the Beckford Anticline at Beckford Head. Its upper contact with the Gull Cove Formation is exposed farther up the coast in Grassy Head Cove.

Distribution and Thickness

The Beckford Head Formation is continuous around the Point Lance Syncline from the Deep Gully Fault near Bull Island Point to the eastern side of Small Point, i.e., the eastern headland of Red (Wreck) Cove. Exposures may be examined in the upper reaches of the Lance River, along Branch River, on Big Head and along the coastal strips from Beckford Head to the southern point of Deep Cove and from the northern end of Deep Cove to the cove inside Grassy Head.

The overall inaccessibility of the formation in the Point Lance Syncline does not allow accuracy of measurement, but there is no reason to believe that the thickness differs to any great extent from the 46 m exposed in the type section.

Lithology

The Beckford Head Formation is distinguished as the non-shaly sequence that intervenes between the mainly fissile, sulphurous mudstones of the underlying Manuels River Formation and of the overlying Gull Cove Formation. The greenish tinged, grey, thick-bedded siltstones of Beckford Head are much paler than the neighbouring rocks and form ridges and promontories between the softer shale lowlands and embayments, as prominently manifest around Big Head and the cove at Grassy Head.

The rather blocky siltstone sequence of the Beckford Head Formation is essentially light olive grey and weathered-out separation planes delineate the main beds. In the somewhat transitional lithofacies at the basal and upper contacts of the formation, finer bedding is indicated by thin, continuous interbeds of dark grey silty mudstone (Plate 37). Diagnostic are scattered, lenticular, silty calcareous concretions weathering pale yellowish brown. Most of these are stretched out along the bedding and, on exposure, are commonly etched back into the rock face or exhibit cone-in-cone structure.

Contact Relations

Although the basal and upper contact rocks are marked as transitional facies from and to the adjoining formations, specific horizons are chosen as the boundaries of the Beckford Head Formation. As previously noted, the lower contact with the Manuels River Formation coincides with the eroded top of the youngest limestone bearing *Paradoxides* (*P.*) *davidis* (D8 in Figure 23), which is considered to mark a regional unconformity in the Avalon Zone of Newfoundland. The upper contact is taken to be conformable and drawn at the base of the contrasting, continuous, thin-bedded, shaly, silty mudstones typifying the Gull Cove Formation.

Fauna

No fossils have been found in this formation on Cape St. Mary's Peninsula, but the presence of so many dark layers in the basal beds might prove productive given sufficient time and patience, as Poulsen and Anderson (1975, p. 2067) have proved elsewhere in this part of the sequence.

Age and Correlation

Unnamed Cambrian Stage 7

Although a global Upper Cambrian unit is no longer to be recognized, the traditional base was drawn at the top of the Scandinavian *Lejopyge laevigata* Zone (Westergård, 1946) at the first appearances of *Agnostus* (*A.*) *pisiformis* (Wahlenberg, 1818) and *Olenus* Dalman, 1827. However, now the topmost series of the Cambrian is drawn at the first appearance datum (FAD) of the cosmopolitan trilobite *Glyptagnostus reticulatus* Angelin, 1852 and named Furongian Series (Peng *et al.*, 2006), i.e., at a level a little above the FAD of *A.* (*A.*) *pisiformis*. Therefore, as presently recognized throughout the world, the Beckford Head Formation represents the topmost beds of the traditional Middle Cambrian and possibly early *A.* (*A.*) *pisiformis* beds just below the base of the Furongian Series, i.e., in the yet unnamed Cambrian Stage 7 (Babcock *et al.*, 2005, fig. 1).

Lying above a sequence typical of the Manuels River Formation, this formation is likely to be the correlative of post-*Paradoxides* (*P.*) *davidis*-*Ptychagnostus punctuosus* zonal beds in a similar stratigraphic position described to the north and east of the map area (Hutchinson, 1962, p. 24; Poulsen and Anderson, 1975), i.e., above the unconformity at the base of equivalent phosphatic conglomerates to Howell's Bed 125 in the Manuels River section. In those regions, Poulsen and Anderson's (1975) researches have shown that the post-*Paradoxides* (*P.*) *davidis* sequence was transgressive eastward. On the western side of Trinity Bay, the basal beds contain elements of the Zone of "*Solenopleura*" *brachymetopa*, whereas at Manuels River, the basal beds have yielded a fauna no older than the Zone of *Lejopyge laevigata*. Accepting this as the case, the geographical position of the map area suggests that the potential fauna at the base of the Beckford Head Formation may yield a transitional *brachymetopa*-*laevigata* assemblage.

In contrast to the darker, more shaly rocks above the unconformity in Trinity and Conception bays, the siltstone lithofacies of the Beckford Head sequence may represent relatively uninhabited shallower water conditions. As also noted previously in the case of the Cape Dog-Hopeall Head volcanic episode, the significant change in sedimentary regime immediately following the Hay Cove Basaltic Flow event seems to reflect substantial fault movements affecting the stability of this local part of the basin. However, in other parts of the world at this time, significant lithofacial changes are recognized and may indicate more widespread eustatic changes in sea level.

Gull Cove Formation (Unit 13)

Definition

The main mass of the "Upper Cambrian" Furongian sedimentary pile of southeastern Newfoundland predominantly comprises dark grey to black sulphurous shaly mudstones with interbedded sandstones. In the map area, such a sequence conformably overlies the light greenish grey siltstones of the Beckford Head Formation and is best exposed in Grassy Head Cove. The formation is here named the Gull Cove Formation, because its features are well exposed in that cove, despite the folded and thrusted nature of the coastal exposures.

Although diabase and gabbroic sills occur within the lower Beckford Head Formation, the essentially interbedded character of the Gull Cove Formation has greatly facilitated the intrusion of the numerous sills so prominent within its outcrops. These intrusions are described later.

Distribution and Thickness

Hutchinson (1962) has indicated that the Harcourt Group sediments were probably deposited throughout the Avalon Zone of Newfoundland, but, because of erosion, the greater part of the sequence has been removed. Remnants of the former cover are preserved as isolated down-folded and faulted outliers with the most completely exposed sequence occurring in the Clarenville area of western Trinity Bay. However, the most completely preserved succession probably lies beneath the Ordovician rocks of eastern Conception Bay, where it is obscured below sea level.

On Cape St. Mary's Peninsula, the main sequence of the Gull Cove Formation forms a synclinorium in the southern axial region of the Point Lance Syncline, with its lower margin stretching northward from Bull Island Point to Branch River then southward to Red (Wreck) Cove. This sequence must continue northeastward, beneath the waters of St. Mary's Bay along a kinked margin, to join the coastal exposures between Grassy Head and the fault on the southern side of Jigging Cove Head. The southern coastal cliff sections expose the best vertical sections, but eroded stretches along the main river beds provide reasonable sections exhibiting its characteristic lithofacial features. Between the cove at Grassy Head and Jigging Cove Head, only the lowest member of the formation is exposed as the steeply dipping seaward beds underlying higher strata beneath the sea.

Estimation of the original thickness of the preserved Gull Cove Formation is virtually impossible, because of the numerous sills that have expanded the succession, some of which are as much as 46 m thick. Since no reliable estimate can be established, the geometrical relationship with contemporaneous sections beyond the map area cannot be ascertained with any measure of accuracy. A conservative figure for the combined sedimentary Gull Cove Formation and its intruded sills is 300 m, but, due to the lensing nature of the intrusions, the combined succession is unlikely to be of uniform thickness throughout the Point Lance Syncline and the above figure may be considerably exceeded in some parts.

Lithology

The middle part of the Gull Cove Formation succession is marked as a conspicuous interbedded sequence of shaly mudstone, siltstone and sandstone conveniently forming a mappable member between a lower dark grey shaly mudstone member and an upper blackish shaly mudstone member. Due to the nature of the writer's principal research in this map area, the post-Manuels River Formation sequence was less well considered and this vague subdivision was erected as an aid to mapping. With relatively little information available, no formal status can be proposed, but it is possible that future recognition of significant marker beds will allow type sections of these members to be established and reliable stratigraphical fossil collections made.

Lower shaly mudstone member. The beds overlying the Beckford Head Formation comprise prominent, dark grey, evenly bedded, shaly, silty mudstones. A common feature is the development of aggregates of crystalline pyrite and the consequent goethitic coating of the exposures.

Everywhere, the member is separated from the overlying member of shaly mudstone with interbedded siltstone and sandstone by diabase and gabbroic sills. These may occur as numerous discrete, relatively thin intrusions as developed along the Grassy Head-Little Harbour shore (Plate 43), or in a very thick sheet exhibiting gravity mineral layering, as along the headlands of Jigging Cove Head, Small Point and Point Lance (Plate 44). In the Grassy Head-Little Harbour outcrop, this member is about 45 m thick.

Middle interbedded member. The middle member is characterized by dark grey shaly mudstones with prominent interbeds of siltstone and sandstone. The sequence is best exposed in the cliffs of Red Cove below "Sill 2" at Fox Knob (Plate 45). At this locality, this member intervenes between the lower, layered "Sill 1" forming Small Point and "Sill 3" on the eastern side of the Gull Cove Head (*see* SILLS section) and contains thin sills interspersed with the siltstone and sandstone interbeds. The member is also well exposed along Bull Island Point shore and just north of the Point Lance Bridge, where it is more accessible for examination and fossil collecting. Inland, small waterfalls or stretches of rapids over ribs of sandstone generally betray the presence of this member in river and stream sections.

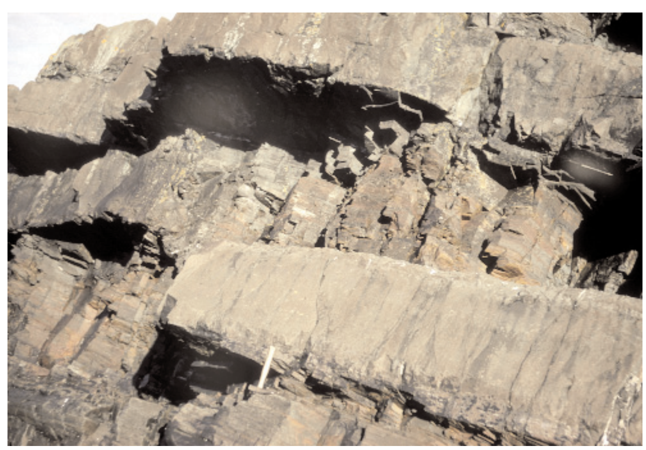

Plate 43. *Transgressive diabase sills in the well-jointed, irony-weathering shaly mudstones of the Gull Cove Formation. Cliff section on the southern seaward side of Little Harbour, St. Mary's Bay.*

Plate 44. *Very thick layered gabbroic "sill 1" at the base of the Gull Cove Formation on the eastern side of Point Lance. (N.B. pseudo-columnar jointing.) The metamorphosed shaly mudstones exhibiting well-developed hexagonal columnar jointing are well exposed on the western side of the headland.*

Upper shaly mudstone member. The beds of the upper member consist of finely layered, blackish shaly mudstone showing dark and light grey, ripple-bedded mudstone and siltstone. Pyrite is abundantly scattered throughout and siltstone lenses and concretions are common in the lower levels. In general, higher beds are darker and finer grained and include thin current-bedded siltstones. The prominently layered thick "Sill 4"separates the middle and upper members in Gull Cove.

Contact Relations

The Gull Cove Formation rests conformably on the Beckford Head Formation and contacts between the three members represent slight changes in lithofacies and are conformable.

Fauna

No fauna was collected from this formation. Fossils appear to occur throughout the shaly mudstone intervals, with small poorly preserved agnostids common on some bedding planes. Hutchinson (1962, p. 27) has recorded an *Olenus* specimen from an unspecified level in Gull Cove, and on the western side of the cove, in beds representing the transitional series at the top of the middle member, *Agnostus (Homagnostus) obesus* (Belt, 1867) is common.

Age and Correlation

Furongian Series

The known fossil occurrences indicate that the basal Furongian Series (Paibian Stage) *Agnostus* (*Homagnostus*) *obesus* Zone of Scandinavia (Martinsson *in* Holland, 1974,

Plate 45. *Thrust faulting and associated folding in the middle sandstone member of the Gull Cove Formation in the cliffs of Red (Wreck) Cove, St. Mary's Bay. Thrust plane is marked by the white dots and the sense of movement is indicated by the relative positions of bed x on each side of the plane.*

p. 206) is represented in the lower two members. If the middle member correlates with the "sequence of grey, silty shale and siltstone" above the "*Olenus*-bearing shales" noted by Hutchinson (1962, p. 27), then the shales of the upper member may contain elements of the succeeding Scandinavian *Parabolina spinosus* Zone (Martinsson *in* Holland, 1974, p. 206) as in the Elliott's Cove section on Random Island, Trinity Bay (Hutchinson *in* Jenness, 1963, p. 74).

Apart from the Gull Cove Formation being a local equivalent of the "Elliott Cove Group" (Hutchinson, 1962, p. 25), the lower and middle members must also correlate with the lower parts of the Salmonier Cove Formation (Howell *in* Widmer, 1950) in the Hermitage Bay area at the western limit of the Avalon Zone. Currently, unable to judge the thickness of the upper member, the presence of even younger Furongian faunal zones in the higher parts of the Gull Cove Formation will only be resolved by a more serious approach to fossil collecting.

Elsewhere in Newfoundland, Hutchinson (1962, p. 35-36) has identified *Ctenopyge* in the sequence to indicate faunas as young as the Scandinavian *Peltura* Zones (Martinsson *in* Holland, 1974, p. 206), thus allowing correlations of the youngest Cambrian formations of Newfoundland with rocks in Cape Breton Island, New Brunswick, Wales, Sweden, Denmark and Norway.

IGNEOUS ROCKS

Melanocratic, pyroxene-rich, extrusive and intrusive igneous rocks are a prominent component of the geology on Cape St. Mary's Peninsula and are of various ages. Chlorite and albite are the major alteration products and, on weathering, have facilitated the mechanical breakdown of the coarser rocks to produce exfoliating onion-skin surfaces and brown gritty soils.

EXTRUSIVE ROCKS (UNITS 1, 10ev AND 11v)

Four separate sequences of extrusive igneous rocks are preserved in the map area, the late Ediacaran Bull Arm Formation (Unit 1) at the base of the Musgravetown Group, the Metabentonite Bed at the base of the Harcourt Group, the Cape Dog Basaltic Flow (Unit 10ev) near the top of the Adeyton Group and the Hay Cove Basaltic Flow (Unit 11v) in the Manuels River Formation in the lower part of the Harcourt Group. The disposition and general characteristics of these units have been discussed in the stratigraphical section of this report.

Since the initial observations by Fletcher (1972) on the two Cambrian basaltic lentils, Greenough (1984) and Greenough and Papezik (1985a, b, 1986) have undertaken more detailed work on their petrology and geochemistry. They have shown that pillow lavas (Plates 36 and 40) and lapilli tuffs (Plates 39-42) are highly altered and have undergone two phases of alteration related to syndepositional basalt-seawater interaction that resulted in the formation of chlorite and carbonate (Greenough and Papezik, 1985a, p. 53). As previously noted, the rocks of the Hay Cove Basaltic Flow are particularly carbonate rich (Plate 39) to emphasize the high CO_2 activity in such reactions. The evolved basaltic to basaltic andesite flows (Plate 40) of both sequences have intermediate Mg' values and relatively high SiO_2 contents and their distinctive alkaline trace-element characteristics are those of some rift and oceanic-island basalts associated with tensional tectonic regimes. Although they resemble Cambrian basalts elsewhere in the Avalon Zone, they differ from the tholeiitic bimodal (basalt-rhyolite) rocks in Cape Breton and New Brunswick in their alkaline composition (Greenough and Papezik, 1985b, p. 1600).

INTRUSIVE ROCKS (UNITS 14 AND 15)

The intrusive igneous rocks are one of the highlighting features of this part of the Avalon Zone of Newfoundland, especially the Silurian sills that dominate the outcrop pattern of the youngest part of the Cambrian sequence and are responsible for the prominent indented coastline in the southeastern part of the peninsula. Much younger dykes, though numerous, are less obvious as topographical features.

Sills (Unit 14)

Silurian diabasic-gabbroic sills of varied thickness were injected into the sedimentary sequence prior to the period of major folding. No feeder pipes have been recognized in this map area, but a three-dimensional, spreading injection pattern is manifest by a number of interleaved bodies within the youngest strata. They are largely concentrated within the Point Lance Synclinorium and were first indicated in Murray and Howley's (1881b) map "Peninsula of Avalon showing distribution of formations" [reproduced in King, 1990, fig. 2], which incorrectly regarded them as part of a continuous wide body of "GRANITE TRAP" striking NNE from "Bull Cove" [= Lance Cove] to similar rocks near southern

Trinity Bay, i.e., the volcanic necks and sills forming the "Spread Eagle Gabbro Bodies" in the Whitbourne map area (McCartney, 1967, p. 73). On Baird's (1954) Geological Map of Newfoundland, the mistake was rectified and the less extensive synclinal disposition of an igneous layer forming the Point Lance headland was identified as of undifferentiated intermediate igneous composition. The overall nature of these igneous rocks was recognized by the writer during the initial 1959 undergraduate expedition and later mapped in detail as part of graduate studies (Fletcher, 1972). The name "Cape St. Mary's sills" was applied to these intrusives by Greenough *et al.* (1993), although their, and all subsequent references, e.g., Hodych and Buchan (1998), under this name refer to those occurring in the Harcourt Group, some distance from the Musgravetown Group sequence at Cape St. Mary's, where no sills occur.

Distribution, Thickness and Contact Relations

One thin sill is known in the Musgravetown Group and lies within the Golden Bay Member of the Heart's Content Formation at the mouth of a small gully in the middle of Lears Cove. Three sills have been noted in the Adeyton Group; a lenticular body 1.5 m thick, in the cliffs of Deadman's Cove, St. Bride's, lies within the upper part of the Cuslett Member in the Bonavista Formation, and two closely spaced sills, up to 3 m thick, in the topmost beds of the Cape Shore Member of the Chamberlain's Brook Formation are responsible for the Branch River rapids at each end of Gooseberry Island.

The main concentrations were injected into the Beckford Head and Gull Cove formations, although only that on Jigging Cove Head lies within the older formation. All sills appear to be lenticular and may wedge out completely. Some exceed 60 m in thickness and, where not masked by thick glacial deposits, form continuous ridges several kilometres in length that are well exposed where crossed by rivers like Lance River. However, due to the intense folding affecting the host shaly mudstones of the Gull Cove Formation and the thick glacial cover, it is difficult to identify with certainty the actual number of major sills. On the evidence of the coastal outcrops on either side of the Point Lance synclinal axis in Lance Cove, five main stratigraphically controlled bodies may be recognized; for present purposes they are informally numbered.

Some sills are transgressive and cut upward through different beds (Plate 43). Only the basal "Sill 1" is continuous around the synclinorium, but varies in thickness along the outcrop and transgresses from the top of the Beckford Formation on the eastern side of Small Point and on the southern flanks of the Big Head Anticline upward into the

Plate 46. *Section of the Branch Cove Member in the Easter Cove of Branch Cove showing the relationship of closely spaced cleavage and bedding on the western flank of the Beckford Anticline.*

Gull Cove Formation. It is particularly thick on the prominent headland of Point Lance (Plate 46), but at the extremities of the outcrop on the Bull and Cow islands south of Bull Island Point in the west and at Small Point in the east, it is much thinner; the bifurcate sill in the coastal Grassy Head and Little Harbour area (Plate 43) may represent the same sill. "Sill 2" is evidently lenticular and most extensive on the western flank of the synclinorium, in contrast to its much shorter length on the eastern side of Lance Cove. On Fox Knob, "Sill 2" is largely cut out by a thrust (Plate 45). "Sill 3" bifurcates at its southwestern extremity and forms a short outcrop on the eastern side of Lance Cove and the southwestern headland of Red (Wreck) Cove; it also forms the northern isolated arcuate body immediately to the west of Green Gulch, due north of Point Lance cutting Highway 100. "Sill 4" marks the hill at the western end of Point Lance settlement and on the western side of the lower reaches of Lance River, but it is best exposed as the prominently layered body about 46 m thick on the eastern side of Gull Cove. "Sill 5" is represented by the two outcrops astride the synclinal axis cutting through the settlement and seems to be at the same stratigraphical level as the prominent arcuate layered body a little farther north, straddling the synclinal axis.

Additional to these five main sills, numerous other thin ones are evidenced by exposures in well-exposed sections along the course of Lance River and the coastal sections in Gull Cove.

Outcrops of plugs, e.g., near Gull Cove, have figured on former maps and reports of this area, but their margins are conformable with weakly metamorphosed sedimentary bedding and may be regarded as isolated exposures of "Sill 1" along the crest of the Big Head anticline axis close to the Gull Cove Thrust.

Petrology and Geochemistry

The textures of the diabase and gabbro vary considerably in relation to the thickness of a sill and, in the thicker bodies, to its position within the sill; the bases and internal parts in such bodies are medium to coarse grained. Chilled, fine-grained margins are rarely more than 30 cm thick and may contain amygdules and pyrite, where they have reacted with the contact sedimentary rocks. A particular feature of the thicker sills is their layered appearance marked by upward changes in the whole-rock chemistry. The writer initially interpreted the very thick sills as gravity-layered bodies exhibiting early coarse crystal differentiates at their bases (Fletcher, 1972a, p. 215), but this view was later modified by Greenough and Papezik (1986), when they dealt more fully with the mineralogical associations and elemental analyses of “Sill 4” in Gull Cove and “Sill 2” on the western side of Lance Cove. Note that in Papezik (1986) and in a later one (Greenough *et al.*, 1993, fig. 1), the precise locality of the latter was not stated; in Hodych and Buchan (1998, fig. 1), the site is identified as the base of the upper bifurcate layer of “Sill 2” just south of the Point Lance Tilts, i.e., the former fish-landing stage. Greenough and Papezik (1986, p. 219) recognized that at the time of intrusion, olivine and possibly plagioclase were on the liquidus, but olivine was generally removed by fractionation and only rarely formed cumulus layers near the floor under gravitational influence, e.g., in their “Lance Cove sill”. However, subsequent “layering” evidently developed as a response to diffusive and thermogravitational transport processes as the melt gradually cooled, when particular elements were removed and locked up in new mineral growths. Some plagioclase grains are concentrically layered by augite, hornblende and biotite respectively and reflect such changes. As this process of upward-changing chemistry continued, there was a gradual relative enrichment in Si, Na and K and, in the final stages of cooling, volatile-related movements of the residual melt along restricted paths produced thin, sharply bound “veins” of quartz and granophyre up to 3 m thick, e.g., at the Point Lance Tilts.

Clinopyroxene, plagioclase and biotite mineral phases have been recognized in the gabbros. In their analysis of “Sill 4” in Gull Cove, Greenough and Papezik (1986, fig. 2) documented the upward-changing character of a thick sill, from basal chilled contact rocks up into a lower unit of coarse-grained gabbro containing poikilitic augite grains that “tend to increase in size up from the base. Local size fluctuations produce layering” to an enriched middle gabbro unit marked by the first appearance of thin sharply defined granophyre layers and where augite decreases in size and percentage, and biotite and apatite contents cease to rise. A feature of this unit not noted by Greenough and Papezik (1986) is the occurrence of veins with large euhedral crystals of a dark pyroxene associated with long thin, radiating feldspar laths. A depleted middle gabbro unit, cut by variously oriented thin granophyre layers, succeeds this unit and is separated from the upper gabbro (with upper chilled margin) by a 3-m-thick granophyre layer.

It should be noted that leucocratic, granophyre and quartz veining is not limited to the thick sills as evidenced by occurrences in the thinner sills along the Grassy Head-Little Harbour coast.

Details of the lowest gabbroic “Sill 1” at Small Point [not discussed by Greenough and Papezik] include serpentinized olivine crystals embedded in an ophitic matrix of coarse euhedral pyroxene and labradorite laths. The labradorite is zoned outward to calcic andesine and exhibits albite and carlsbad twinning; in some areas, fibrous, stellate accumulations are conspicuous and possibly represent replacement, since they appear to be bound by former crystal faces. In addition, a red-brown biotite is evident along with a non-hornblendic amphibole, chlorite and pyrite.

Compositionally, the sill-magmas of the Cape St. Mary’s Peninsula resemble alkaline rocks with high water content, but their whole-rock composition may indicate that the original magma was subalkaline. Fletcher’s (1973a, p. 215) original attribution to a “Plateau Type” was reassessed by Greenough and Papezik (1985b, p. 1600) and considered “transitional between those found in alkali basalts and those in tholeiites”.

Age and Correlation

Field evidence indicates that the sills were injected into existing late Cambrian rocks before the period of folding and metamorphism associated with the Siluro-Devonian Acadian Orogeny. A preliminary radiometric date of 425 ± 5 Ma, obtained from zircon and baddeleyite grains in “Sill 2” at the Point Lance Tilts by Krogh (*in* Greenhough and Papezik, 1986, p. 218), was later adjusted to give a U–Pb age of 441 ± 2 Ma indicative of a Silurian age (Greenough *et al.*, 1993).

Palaeomagnetism and Implication

In addition to providing a reliable age date for this intrusive episode, these sills also yield important data on the palaeolatitude position of this part of the Avalon Zone at that time. Hodych and Buchan’s (1998) stepwise alternating-field or thermal demagnetization of samples from 19 sites on Cape St. Mary’s Peninsula isolated a likely primary stable characteristic remanence carried by magnetite (not hematite) that predates an Early Devonian folding. According to their location map (Hodych and Buchan, 1998, fig. 1), samples 17, 18 and 19 were collected from “Sill 1”, 6, 7, 8, 9, 10 and 11 from "Sill 2", 1 from "Sill 3", 2, 12 and 13 from "Sill 4", 3, 4 and 5 from "Sill 5". Although their samples 14, 14S, 15 and 16 were considered to derive from a sill, the writer did not recognize a sill in this locality and mapped four separate dykes striking across the local bedding on this shore.

Hodych and Buchan (1998) gauge that the remanence was acquired on subsequent cooling below 550°C and indicates that a palaeolatitude for this part of West Avalonia at ~440 Ma was near to 32°S ± 8°. Although no palaeolatitudinal estimates for contemporary rocks elsewhere in Avalonia have yet been established, available palaeomagnetic data for slightly older and younger rocks (Tucker and McKerrow, 1995; Hodych and Buchan, 1998, fig. 5) imply that the Palaeozoic Iapetus Ocean was oriented east-west between Avalonia and Laurentia and, in its closing, was approximately 1000 km wide at about 440 Ma (Hodych and Buchan, 1998, fig. 6).

Basic Dykes (Unit 15)

Fine- to medium-grained diabase dykes are very common on Cape St. Mary's Peninsula, where they are associated with the joint and fault system that cuts across the whole folded succession.

Distribution, Thickness and Contact Relations

Dykes tend to be grouped in swarms close to fault zones and are particularly evident in exposed cliff and stream sections. They are especially common in the western part of the map area, where Murray (1868 Report *in* Murray and Howley, 1881a) first referred to their abundance and McCartney (1967, p. 95) noted that "five to ten dykes per mile are exposed. These dip steeply north or south, but are essentially vertical with remarkably uniform strikes of N60°W". His statements hold true for the remainder of the Placentia Bay coastline as far as Hurricane Brook, i.e., in the area coincident with the Cambrian outcrop in St. Bride's Syncline. Farther south toward Cape St. Mary's, they are much less common, though two abnormally wide dykes trend inland across the peninsula from Island Head and from near Young's Port.

All observed dykes have been plotted on the accompanying geological map. The trend on the eastern side of Cape St. Mary's Peninsula is much like that on the western side in that they are essentially normal to the main fold axes and rarely cut the subparallel faults.

The dykes average slightly over 2 m in width; those at Island Head and Young's Port may well be over 6 m wide. Multiple, closely spaced dykes are not uncommon and a good example of such is well exposed in the cliff just south of St. Bride's Fish Plant, where 8 dykes have cut through the Bonavista, Smith Point and Brigus formations. They range from 60 cm to 1.5 m in width and average 75 cm, while the intervening sedimentary rocks screens range from 30 cm to 6 m in width and average 2.5 m. About 30 percent of the 26 m width of the complex consists of diabase dykes. Evidence of cross-cutting relationships, e.g., around Patrick's Cove, indicate that dyke emplacement may have occurred at different times during episodes of faulting.

Along the coastlines, most dykes resist erosion and form narrow, commonly sinuous projections from the cliff face. Due to fracturing along cooling joints normal to their strike, others are so broken into small blocks that they are readily eroded by waves and are recessively weathered and commonly form narrow coves and niches along the cliffline.

Petrography

The majority of dykes examined are fine grained and are holocrystalline. Some wide examples have coarser grained interiors, but they are not layered parallel to the contact walls. Two particular dykes stand out from the rest. In Perch Cove, a porphyritic dyke cuts a fault and a similar dyke on the northern side of Patrick's Cove beach are unusually coarse grained containing phenocrysts of large euhedral laths of plagioclase, as much as 10 cm long, and pyroxene surrounded by a fine-grained basaltic groundmass containing scattered zeolite amygdules (Plate 47).

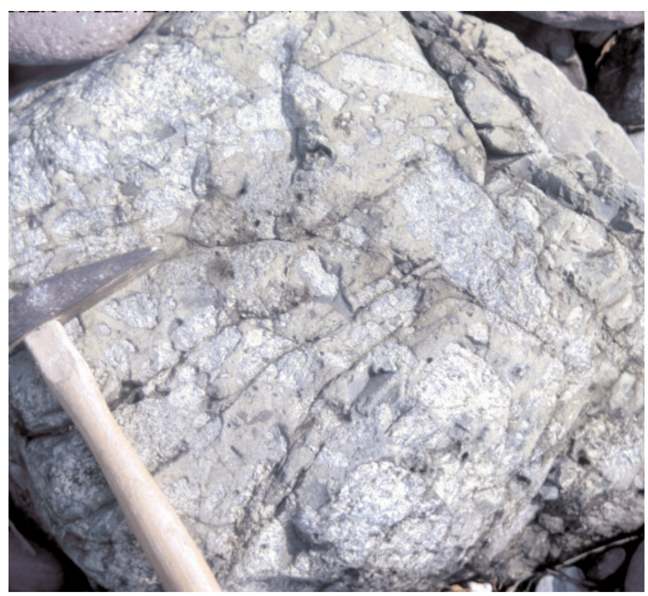

Plate 47. *Large boulder of a flow-differentiated, diabasic rock bearing extremely large euhedral plagioclase phenocrysts from the dyke-intruded fault at the southeastern corner of Perch Cove, Placentia Bay. N.B. This is from a similar megacrystic intrusive to that on the northern side of Patrick's Cove beach.*

The rocks are of olivine basalt magma type, though neither olivine nor its pseudomorphs have been recognized; the feldspar phenocrysts in the Perch Cove dyke are albite-twinned labradorite. They presumably derive from a deeper magma chamber and have continental tholeiite to weak alkaline characteristics.

Age and Correlation

All dykes in the map area appear to be related to one episode of injection that postdates the Silurian intrusion of sills and later period of folding. However, since they are associated with dilations of faults and joints that may have accompanied the folding, some may have formed in a late stage of the orogeny and so be as old as Devonian. The typical occurrences of calcite veining subparallel to the regional cleavage in many dykes less than 2 m wide suggest that they were emplaced during the period of folding. On the other hand, thicker dykes, like the porphyritic examples, are probably the same age as the “Younger Gabbroic Dykes” in the Terra Nova map-area (Jenness, 1963, pp. 102, 103) that cut a Middle-Late Devonian granite and relate to Late Triassic, or Early Jurassic, dykes known elsewhere in the Avalon Zone associated with rifting prior to the Atlantic opening (Papezik, 1980, p. 248; Hodych and Hayatsu, 1980; Hodych and Patzold, 1980; Hodych and Buchan, 1994, 1998; Greenough and Hodych, 2001).

STRUCTURAL GEOLOGY

INTRODUCTION

The outline of the Island of Newfoundland readily illustrates the influence of the Appalachian north-northeasterly fold pattern and the alignment of the Avalon Peninsula and its southeastern peninsula of Cape St. Mary’s conforms well to this trend. Prior to the deposition of the preserved rocks in the Cape St. Mary’s Peninsula map area, four tectonomagmatic and depositional events affected the underlying structure of the Avalon Zone of Newfoundland; these have been dated as 760 Ma, 685-670 Ma, 635-590 Ma and 590-545 Ma respectively. Such orogenic activity resulted in the amalgamation of distinctive tectonic packages preceding the deposition of a mudstone-rich platformal cover of terminal Neoproterozoic to Early Ordovician age in the eastern Avalon Zone of the Appalachian Orogen (O’Brien *et al.*, 1996). The oldest rocks on this part of the Avalon Peninsula relate to the 590-545 Ma complex volcanic, plutonic and structural event that was partly extensional and partly contractional in nature when the Ediacaran and younger sedimentary sequences accumulated.

During the Late Neoproterozoic and Cambrian, tilting movements related to incipient rifting and eustatic sea-level changes influenced sedimentation of the various groups in the Avalon Zone. In southeastern Newfoundland, the main break in sequence followed the deposition of the Musgravetown Group, prior to the latest Ediacaran-Cambrian transgression from the west. Subsequent, relatively minor, sequence-breaks during Cambrian times were caused by sea-level changes accompanying localized tectonic movements responsible for slight shifts in depocentres, some of which were associated with volcanic activity. In the Silurian, igneous intrusions in the form of sills heralded the Acadian Orogeny when all strata were folded and faulted during a reamalgamation of the periGondwanan terranes associated with the closure of the Iapetus Ocean. During this episode, rocks on the Avalon Peninsula were compressed along northeasterly trending axes against the more-stable foreland that lay to the east. Such stresses resulted in a series of elongate domes and troughs, together with cleavages, joints, normal tear faults and easterly directed thrusts. Later tectonic movements enhanced the old fractures, which largely controlled the disposition of numerous dyke emplacements and some mineral veining.

UNCONFORMITIES

On Cape St. Mary’s Peninsula, four significant breaks in sequence are marked as low-angular unconformities in the Ediacaran-Cambrian succession:

(4) break at the base of the Beckford Head Formation

(3) intra-Chamberlain’s Brook Formation break at the Blister Bed

(2) break at the top of the Random Formation

(1) break at the base of the Random Formation

The angular character and large-scale non-sequences at these junctions indicate tectonically controlled differential subsidence and differential erosion of the uplifted older sediments. The uplifted areas were extensive, but no cleavages associated tectonism at such times have been detected in the map area. Elsewhere on the Avalon Peninsula, these sequence breaks are considerably more, or less, conspicuous and account for the absence of parts only preserved or absent in certain areas, e.g., the *Kiskinella* Zone is only preserved in the map area, whereas the *Goniagnostus* (*G.*) *nathorsti* Zone is absent there. In addition, some limestones indicate periods of clastic starvation and, where they contain phosphate or manganese outside the map area, e.g., at the base of the Broad Cove Member at the top of the Smith

Point Formation, or at the stratigraphical level of the St. Mary's Limestone Bed near the top of the Adeyton Group, minor regional unconformities are recognizable.

FOLDS

The strata of Cape St. Mary's Peninsula are enveloped in open, large-scale, plunging folds and flexures with dips rarely steeper than 60° (Figure 4). Generally, the older exposed Musgravetown rocks are less internally deformed and the units trace out the broad open-crested plunging anticlines. In contrast, most Cambrian rocks are exposed in synclines and much more internally deformed. They are especially tectonized in the axial regions of these downfolds, where compression has been so intense that tight subsidiary folds and thrust faults have developed. Such structures are most intensely manifest at the southern end of the Point Lance Syncline, where the youngest Cambrian strata of the Gull Cove Formation comprise incompetent shaly mudstones and sandstones in a synclinorium, i.e., the Point Lance Synclinorium.

The rocks of the map area are essentially disposed around two major anticlinal axes striking north-northeast. Along the western Cape St. Mary's-Placentia Axis, the amount of uplift is not constant and two separate pitching rises are apparent, a northerly plunging Cape St. Mary's Anticline in the south and a doubly plunging Platform Hills Dome in the north. In the east, the doubly plunging Branch Anticline reaches the coastline on the western side of Hay Cove in the south and plunges northward beyond Great Gull Pond away from the domal crest forming Castle Ridge.

West of the Cape St. Mary's-Placentia Axis lies the much faulted, doubly plunging, periclinal St. Bride's Syncline striking between Gooseberry Cove and Island Head (Plate 16). On its western limb, several monoclinal flexures affect the Musgravetown Group sequence and are well exposed in the cliffs below Hurricane Brook and farther north near Angel's Cove and Patrick's Cove.

Intervening between the two anticlinal axes lies a major southerly plunging synclinorium that, in the north, has the effect of bifurcating the domal outcrop of the oldest rocks (Ediacaran Bull Arm Formation) on the peninsula. This synclinorium is centred on the Point Lance Syncline, which can be traced from a point just west of the Beaver Pond Hills down through the Point Lance settlement. The structure plunges southward to gradually preserve more and more of the youngest rocks (Late Cambrian Gull Cove Formation and Silurian sills), which become progressively more deformed by several minor plunging folds and thrusts; notable among these being the Big Head Anticline and the Gull Cove Syncline (Figure 3), the former largely arched by the influence of the eastern Gull Cove Thrust.

East of the Branch Anticline, lies a synclinorium largely hidden beneath the waters of St. Mary's Bay. Only the western crinkled margin of this structure is exposed on the peninsula, where the Hay Cove Syncline, the Beckford Anticline, the Red Head Syncline, the East Head Anticline, the Maggotty Cove Syncline, the Bear Head Syncline and the Cape Dog Syncline mark some subsidiary folds. Of these, only the Hay Cove Syncline has the features of a doubly plunging pericline.

On a much smaller scale, small open folds and box folds are commonly marked in compressed interbedded sequences of mixed lithology. In particular, they are characteristic of some exposures of contorted Random quartz arenites (Plates 18 and 19) and rocks of the Gull Cove Formation, where they are affected by thrust faults (Plate 45).

JOINTS

A well-defined joint system is developed throughout the peninsula and, apart from the cooling effects restricted to the igneous rocks and their immediate contact rocks, appears to have been established at the time of Siluro-Devonian folding. The system comprises three main sets of fracture [striking (a) 26°–56°E; (b) 112°E; (c) 126°–155°E] that have controlled the patterns of dyke emplacement and fault movements, as well as the present drainage pattern over the exposed bedrock surface (Figure 5).

FAULTS

Most of the documented faults on the accompanying map are exposed in the cliffs and their extension inland is marked either by lineaments seen in aerial photographs, by offsets of resistant rock ridges, or by the offset of mapped strata evident in correlating from one stream section to the next.

No faults developed prior to the period of folding have been recognized and, except for thrust faults, all faults are intimately controlled by the joint system (Figure 5).

Note that lineaments within the Bull Arm Formation outcrop, plotted on the accompanying map, are mainly oriented to the southeast, i.e., corresponding with Set (**c**). This, being the preferred trend of faults in the map area, suggests that most of these lineaments signify faults, some of which are rooted in the basement, as may be inferred from the aeromagnetic pattern (Figure 24).

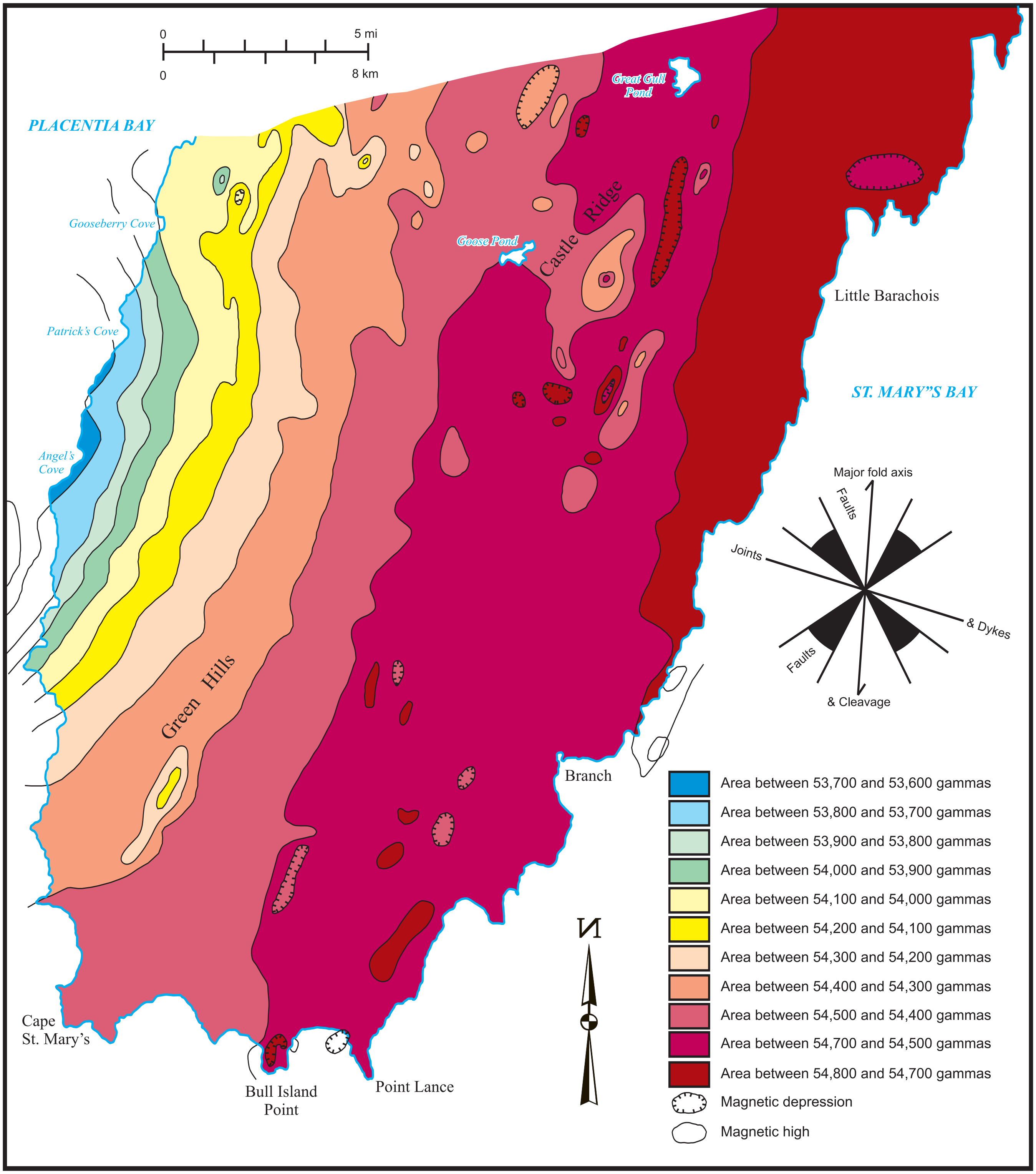

Figure 24. *Aeromagnetic map of the map area.*

Tear Faults

The main faults essentially form a complementary system of tear faults related to the stresses developed in the main period of folding. Most trend southeastwards (Set **c**), but there is also a conspicuous set oriented in a more east-west direction (Set **b**). Fault planes are nearly vertical, though some dip steeply to the south. The majority are unusually long and straight and can be followed for several kilometres.

Tear faults have cut the major folds into blocks with lateral and downdip movements. The sense of lateral movement and the degree of vertical throw of the faults cutting St. Bride's Syncline appear to be related to their position relative to the anticlinal Cape St. Mary's-Placentia Axis. Those block-bounding faults north of Perch Cove Fault, alongside the Platform Hills Dome, have the greatest lateral displacements and throw down to the south. In contrast, those between this fault and Hurricane Brook Fault, i.e., opposite the flattish saddle of the axis (Figure 4), throw down to the north as they near the margin of the Cape St. Mary's Anticline. Generally, the left-lateral movement on these faults has the effect of moving the St. Bride's Syncline closer to the axial saddle in the Green Hills region. Furthermore, the amount of lateral offset decreases as faults cut stratigraphically deeper from syncline to anticline. The left-lateral Angel's Cove Fault, passing through that settlement, extends across the St. Bride's Syncline and Cape St. Mary's-Placentia Axis to cut the Point Lance Syncline with the same sense, but it is a feature of most faults that the amount of vertical displacement varies along the length of the fractures as though hinged.

On the eastern side of the peninsula, most tear faults have very little movement and there are more east–west oriented (Set **b**) displacements than on the western side. Here, the dislocations are predominantly horizontal with throws less hinged.

The evidence of crosscutting dykes, associated with some offsetting, indicates that several episodes of faulting occurred, though they may not have been separated by much time.

Thrust Faults

Within the tightly folded Cambrian synclines, compression has been sufficient to rupture several folds, and small-scale overthrusting has occurred along the resulting highly inclined surfaces (Plate 45). Although movements on the thrust faults are relatively small, they not uncommonly extend considerable distances. However, mapping thrusts in poorly exposed inland areas is difficult, particularly where sills swell, pinch and disappear for reasons other than structural.

All recognized thrusts parallel fold axes, are steeply inclined and dip west, i.e., away from the stable foreland in the east. They have been observed to cut all Cambrian strata, though, because of their axial position within the syncline, they are most numerous within the Harcourt Group incompetent strata.

Rare thrusts in the Adeyton Group can be examined in Deadman's Cove (Plate 48), Redland Cove affecting the contact between the Redland Cove and Jigging members and on each side of Cape Dog, in contrast to the numerous ones affecting Harcourt Group sequences as in Gull Cove, Red (Wreck) Cove (Plate 45) and at The Falls along Branch River, below its junction with Crosscut Gully. Thrusts drawn within the Point Lance Synclinorium in the geological cross section (*see* Fletcher, 2006a) are symbolic of numerous dislocations evidenced by the intensely folded strata exposed along the course of the Lance River system.

CLEAVAGE

Only one cleavage has been detected on the peninsula and the degree of its development is controlled by the lithology of the strata. It was formed during the Siluro-Devonian period of folding and everywhere is axial-planar to the folds. As in the Whitbourne map area to the north (McCartney, 1967, p. 101), it strikes between north and 35°E and varies between vertical and 80° dips to the west.

For some unexplained reason, the Harcourt Group strata show very little sign of the slaty cleavage so characteristic of the older groups. Good slates are developed in some of the well-cemented, siliceous mudstones of the Musgravetown Group and mudstones and limestones of the Adeyton Group, for the most part, have been transformed into slates (Plate 46). Exposures of pre-Harcourt Group mudstones, generally, are typified by loose, needle-like, slaty flakes, which, in the case of Cambrian outcrops, render fossil collecting extremely difficult.

OROGENIC HISTORY

Stratigraphical evidence suggests that two major sedimentary breaks occurred during the accumulation of the sediments now comprising the Late Ediacaran-Cambrian sequence on Cape St. Mary's Peninsula. These are marked at the contact between the Musgravetown Group and the Adeyton Group, and at the top of the Random Formation.

Additional to these breaks, six particular limestones in the overlying succession signify short-lived periods of clastic starvation, minor localized uplift and/or sea-level fall; they are recognized as the Smith Point Formation, Deadman's Limestone Bed, St. Bride's Limestone Bed, Blister Bed, St. Mary's Limestone Bed in the Adeyton Group and the unnamed limestone containing *Paradoxides* (*P.*) *davidis* marking the top of the Manuels River Formation in the Harcourt Group. Due to periodic lateral changes in the rates of basinal subsidence, these limestones differ in character regionally and, outside this map area, fossil and lithostratigraphical evidence indicate significant differential faunal and lithological non-sequences at these levels.

During Cambrian times, small-scale tectonic adjustments in the Avalon Zone were accompanied by scattered volcanic activity indicative of rifting. These episodes marked basinal changes that were reflected by major lithofacial changes from the multicoloured, calcareous mudstones of the Chamberlain's Brook Formation to the blackish, pyritic, fissile shales of the Manuels River Formation and from the latter to the paler siltstones of the Beckford Head Formation.

All such breaks have been discussed in the preceding pages and it is concluded that they were not accompanied by deformation. Instead, regional tilting and erosion probably caused the differential removal of various amounts of rock prior to overlapping in subsequent periods of deposition.

Stratigraphical relationships indicate that the main deformational episode affecting this part of the Avalon Peninsula is younger than Early Ordovician and older than Late Devonian (McCartney, 1967, p. 80). However, a radiometric U–Pb Silurian age of 441 ± 2 Ma (Greenough *et al.*, 1993) for the Cape St. Mary's sills that were emplaced before the deformation indicates a Siluro-Devonian age characterizing a phase in the Acadian Orogeny.

This Acadian deformation was largely due to compression along an east to southeast direction that produced the upright folds and elongate domes and troughs of southeastern Newfoundland. A foreland area to the east acted as a buttress to give parallel, asymmetrical folds of north-northeasterly trend with steeper dips inclined to the east. During crustal shortening, joints and cleavages were formed and the tightest folds ruptured as steeply inclined thrusts; furthermore, tectonic adjustments to stress were transferred along cross joints to form tear faults.

Field relationships do not allow the age/ages of the dykes and mineral veins to be a readily gauged. Clearly they cut through the whole-rock sequence in the map area and largely follow the paths of dilated joints. They are also faulted, but, whether they are the same Acadian age as the joints, or whether they relate to the Triassic period of dykes associated with later extension, may only be resolved by radiometric dating.

FAUNAL SIGNIFICANCE

Most trilobites of the Avalon Zone are characteristic of the Acado-Baltic Faunal Realm, i.e., they are associated with a suite of taxa that dwelt on one specific continental shelf. There, the main variations in fossil assemblages are due to different environmental settings on that shelf, controlled by both geography and climate. Although the majority of elements are endemic to the shelf, communities inhabiting the outer shelf included some cosmopolitan forms from the open ocean with access to other continental shelves. Such forms are thus important for showing the time relationships between outer-shelf communities of different continents. Among these oceanic travellers are the agnostid, eodiscid and oryctocephalid trilobites, some of which are present in the Cambrian succession of the Cape St. Mary's Peninsula map area and allow important inter-realm correlations to be made.

One of the most important correlations possible is one that more or less settles a long-standing problem concerning the time relationships between the different assemblages characterizing Avalonia and Laurentia. Most notable among these was the olenellid:paradoxidid trilobite relationship that was a basis for originally differentiating the Lower and Middle Cambrian. The *Cephalopyge* Zone in the Branch Cove Member largely comprises eodiscids that were first described from outer shelf-continental slope deposits of Laurentia in the klippen setting of Taconic New York and Quebec, within the tectonostratigraphical Humber Zone (Rasetti, 1966; Figure 1). These indicate a previously unrecognized temporal overlapping of the Laurentian olenellids and Avalonian paradoxidids that now has to be considered by the Cambrian Subcommission in their deliberations on global subdivisions of the system.

Additional to the eodiscids, the top of the Branch Cove Member includes the oryctocephalid *Ovatoryctocare granulata* known elsewhere on the continental shelves of Siberia, China and Greenland, thus allowing another important correlation of global significance.

It is evident that the Branch Cove Member is one of global significance and represents a rarely preserved example of a Cambrian outer-shelf setting close to an oceanic basin. Generally, rocks of this origin were the first to be have been destroyed as oceans closed and continents collided.

ECONOMIC GEOLOGY

INTRODUCTION

At the present time, there is no mineral production in the Cape St. Mary's map area, nor, it seems, is there any confirmed history of such. Results of this study suggest that it is unlikely that there will be any major developments in the foreseeable future, because the known mineral occurrences are small and few. Nonetheless, most of the local stories of mineral discoveries in the past are from those areas of the Bull Arm Formation that have not been covered by the writer. Therefore, in view of the mineable lead, zinc and silver associated with the volcanic outcrop in the neighbouring Placentia district (McCartney, 1967, pp. 118-121), there is a need for a more detailed survey of the Platform Hills and Castle Ridge, e.g., the unpublished work carried out by Falconbridge (A. King, personal communication, 2004), especially if the plotted lineaments reflect significant faulting (Figure 24).

Glacial sand and gravel, peat, limestone and quartzite appear to be the immediate resources of the region.

Metallic Mineral Deposits

Copper

Copper is rumoured to have been extracted from the Hurricane Brook Fault zone, but no trace of the workings could be found. Copper minerals are commonly present in the brecciated fault zones cutting the Musgravetown Group and malachite is intimately associated with calcite gangue, e.g., along the Little Harbour Fault in the tributary of Beckford River, and at several places along Red Head River; malachite also occurs in some exposures of the Smith Point Limestone, e.g., at Roche's Gully, Branch. Murray (*in* Murray and Howley, 1881a) recorded copper in quartz veins at Cape Dog and native copper is sparsely distributed as evidenced in rock fragments on some Musgravetown outcrops.

Manganese

Manganese occurrences are limited to rocks of the Adeyton Group. They are sedimentary in origin and commonly represented by discrete carbonate nodules related to sea-level changes and periods of clastic starvation. They are typical of the main limestone beds in the Bonavista and Smith Point formations and are particularly associated with the contact rocks at the base of the Chamberlain's Brook Formation. In parts of eastern Trinity Bay, scattered tiny nodules occur in the top of the Brigus Formation below a significant break in sequence marked by the prominent "Manganese Bed" defining the local bases of the Chamberlain's Brook sequence in Trinity and Conception bays. On Cape St. Mary's Peninsula, manganese nodules are well dispersed throughout the Easter Cove Member and only concentrated at the top as the Blister Bed. Since the elements of the trilobite fauna continue their ranges upward into member above the Blister Bed in this map area, any break in sequence at this level is minimal.

Barite

Coarse, flaky, crystalline barite occurs in several veins on the western side of the peninsula. Commonly, the veins are several feet wide and near-vertical, and associated with tear and thrust faults. The most prominent exposures occur in a thrust cutting the Bonavista Formation in Deadman's Cove, St. Bride's (Plate 48) where the Bonavista Formation is thrown again a distorted Random Formation, in the Brigus Formation in Cuslett Brook tributary and in the Big Head Formation in the cliff just south of Brierly Cove.

Plate 48. *Barite veining in thrust-fault zone cutting through the Random Formation into the basal beds of the Bonavista Formation in Deadman's Cove, St. Bride's. [Scale: the cliff face is about 6 m high]*

Non-metallic Mineral Deposits

Crushed, Building and Decorative Stone

Should the need arise for large amounts of crushed, building and decorative stone, there are many ideal sites close by roads on the peninsula. Clearly, the finer grained, diabasic Silurian sills provide a source of hard material suitable for hardcore purposes and the hard green and red slaty/blocky Adeyton rocks compare well with attractive building stones so highly prized elsewhere as characterizing particular regions, e.g., in the English Lake District. The multicoloured nature and fine sedimentary bedding in many of the hard Musgravetown rocks, e.g., in the Maturin Ponds Formation in Lears Cove, would look well as polished decorative stone, as would the pink Cambrian limestones and the green and pink lapilli tuffs in the Hay Cove Basaltic Flow.

Quartzite

The "upper quartz arenite member" of the Random Formation is comparatively pure and thick in the Hare Hill Longstone area. Butler and Greene (1976, p. 35) reported some 3 000 000 tons of useable "quartzite" north of Branch, averaging 94.4% SiO_2, 2.1% Al_2O_3 and 1.7% Fe_2O_3.

Limestone

The Smith Point Formation may be suitable for the manufacture of cement, but undoubtedly its greatest potential would be in a crushed form for agricultural purposes were a local market to be developed. DeGrace (1974, pp. 27-29) compiled significant occurrences of this limestone on Cape St. Mary's Peninsula, and reported some analyses. Samples were collected from south of Cuslett, from St. Bride's and from Redland Cove. Unfortunately, most of these contained over 50 percent silica, in contrast to samples collected on Branch River that consist of 40% SiO_2, 49% $CaCO_2$ and 2% $MgCO_3$.

The highly calcareous lapilli tuffs in the Hay Cove Basaltic Flow may provide a local source for agricultural lime. The average of three samples collected and analysed by DeGrace (1974, p. 29) yielded approximately 32% CaO, 9% MgO, 14% SiO_2, 6% Al_2O_3 and 6.4% Fe_2O_3.

Sand and Gravel

Sand and gravel deposits are numerous and widely scattered throughout the map area. The important occurrences are of glaciofluvial origin in the form of eskers, kames and outwash, which are delineated on a map of the superficial deposits of the Avalon (Henderson, 1972). Numerous roadside deposits provided a constant source for grading the gravel roads in the days before paving, but they are now largely abandoned, e.g., the Green Hill Pit (Plate 49).

Plate 49. *Waterlain glacial sand and gravel in the Green Hill Esker. Former pit on the southern side of the St. Bride's–Branch road at Green Hill.*

Peat

Peat deposits form isolated, but commonly extensive areas on the peninsula. Pollett (1968, pp. 42-45) reported one peat bog near the St. Bride's-Branch road (McGill's Marsh) in the middle part of the peninsula, as 697 acres with an average depth of 4.9 feet and a maximum of 9 feet. However, he commented pessimistically on the low quality of the peat and its potential as a product worthy of export from the Province.

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APPENDIX 1
FOSSIL LIST

The following fossils have been collected from the Cape St. Mary's Peninsula:

CHANCELLORIIDS: *Chancelloria* sp.
HALKIERIIDS: *Halkieria* sp.
TOMMOTIIDS: *Camenella* sp. cf. *C. baltica* Bengtson, 1970, *Sunnaginia imbricata* Missarzhevsky *in* Rozanov *et al.*, 1969.
HYOLITHELMINTHS: *Hyolithellus micans* (Billings, 1872).
HYOLITHS: *Hyolithes shaleri* Walcott, 1884.
BRACHIOPODA: *Acrothele matthewi* (Hartt *in* Dawson, 1868), *A*. sp. cf. *A. gemmula* (Matthew, 1893). *Botsfordia* sp., *Latouchella paupera* (Billings, 1872). *Lingulella ferruginea* (Salter, 1859). *Kutorgina labradorica* (Billings, 1861). *Obolella atlantica* Walcott, 1889b, obelellids. *Micromitra* (*Iphidella*) sp. cf. *M*. (*I*.) *ornatella* Linnarsson, 1869).
MOLLUSCA: *Aldanella attleborensis* (Shaler and Foerste, 1888). *Fordilla* sp. *Pelagiella* sp. cf. *P. primaeva* (Billings, 1871). *Helcionella* sp. *?Salterella maccullochi* (Murchison, 1859) or *Volborthella* sp. nov. *Scenella* sp.
BRADORIID and PHOSPHATOCOPID ARTHROPODA: *Indiana* sp. cf. *I. lentiformis* (Cobbold, 1921), *I. secunda* (Matthew, 1895). *Beyrichona tinea* Matthew, 1886. *?Mononotella* sp. *?Falites* sp. *?aparchitids*.
CALCAREOUS PROBLEMATICA: *Coleoloides typicalis* Walcott, 1889a.
INCERTA SEDIS: *Microdictyon* sp.
TRILOBITA
Agnostus (*Homagnostus*) *obesus* (Belt, 1867). *Ptychagnostus* sp. cf. *P. ciceroides* (Matthew, 1896), *P. convexus* Westergård, 1946, *P. gibbus* (Linnarsson, 1869), *P. punctuosus* (Angelin, 1852), *P*. sp. aff. *P. stenorrhachis* (Grönwall, 1902).
Acidusus atavus (Tullberg, 1880). *Tomagnostus fissus* (Lundgren *in* Linnarsson, 1879), *T. perrugatus* (Grönwall, 1902). *Hypagnostus parvifrons* (Linnarsson, 1869). *Cotalagnostus claudicans* Westergård, 1946, *C. lens* (Grönwall, 1902). *?Doryagnostus* sp. *Peronopsis fallax* (Linnarsson, 1869), *P.* sp. cf. P. howelli Hutchinson, 1962, *P. roddyi* (Resser and Howell, 1938), *P. scutalis* (Hicks, 1872), *P*. sp. nov. *Diplagnostus lobatus* (Illing, 1916). *Phalagnostus* sp. aff. *P. eskriggei* (Salter *in* Hicks, 1872), *P. nudus* (Beyrich, 1845). *Phalacroma scanicum* (Tullberg, 1880). *Condylopyge* sp. aff. *C. amitina* Rushton, 1966, *C. carinata* Westergård, 1936, *C. eli* Geyer, 1998, *C. rex* (Barrande, 1846a). *Pleuroctenium granulatum scanense* Westergård, 1946, *P. pileatum* Rushton, 1966. *Dipharus attleborensis* (Shaler and Foerste, 1888). *Delgadella plana* Hutchinson, 1962. *Calodiscus lobatus* (Hall, 1847), *C. meeki* (Ford, 1876), *C. schucherti* (Matthew, 1896), *Calodiscidae*, gen. nov., sp. nov., *Calodiscid* sp. nov. *Chelediscus acifer* Rushton, 1966. *Weymouthia nobilis* (Ford, 1872). *Acidiscus theristes* Rushton, 1966. *Acimetopus helena* (Walcott, 1889b). *Bathydiscus* sp. cf. *B. dolichometopus* Rasetti, 1966, *B. longifrons* (Rasetti, 1966), *B. taconicus* Fletcher, 2003, *B*. sp. nov., No. 1, *B*. sp. nov., No. 2, *B*. sp. nov., No. 3. *Cephalopyge notabilis* Geyer, 1988. *Cobboldites* sp. *Mallagnostus llarenai* (R. and E. Richter, 1941). S*errodiscus bellimarginatus* (Shaler and Foerste, 1888), *S. ctenoa* Rushton, 1966, *S.* sp. cf. *latus* Rasetti, 1966, *S. occipitalis* (Rasetti, 1966), *S. speciosus* (Ford, 1873). *Stigmadiscus* sp. nov. *Tannudiscus balanus* Rushton, 1966. *Eodiscus pulchellus* (Hartt *in* Walcott, 1884), *E. punctatus* (Salter, 1864), *E. scanicus* (Linnarsson, 1883). *Dawsonia dawsoni* (Hartt *in* Dawson, 1868). *Kiskinella cristata* Romanenko and Romanenko, 1962. *Callavia broeggeri* (Walcott, 1890b). ?*Kjerulfia* sp. *Paradoxides* (*Eccaparadoxides*) *acadicus* (Matthew, 1888), *P*. (*E*.) *bennetti* (Salter, 1859), *P*. (*E*.) *eteminicus* (Matthew, 1883), *P*. (*E*.) *lamellatus* (Hartt *in* Dawson, 1868), *P. (E.)* sp. cf. *P. (E.) nobilis* (Geyer, 1998), *P. (Hydrocephalus) harlani* (Green, 1834), *P. (H.) regina* (Matthew, 1886), *P. (H.) sacheri* (Barrande, 1852), *P. (H.)* sp. nov., No. 1, *P. (H.)* sp. nov., No. 2, *P. (P.) davidis* Salter, 1863, *P*. (subgen. nov.) *hicksii* (Salter *in* Salter and Hicks, 1869). *Anapolenus henrici* Salter, 1864. *Clarella venusta* (Billings, 1872). *?Alanisia* sp. cf. *A. hastata* Sdzuy, 1958, *Triangulaspis meglitzkii* (von Toll, 1899), *T. vigilans* (Matthew, 1889). S*trenuaeva nefanda* Geyer, 1990a. *Strenuella sabulosa* Rushton, 1966, *S. strenua* (Billings, 1874). *Comluella* sp. cf. *C. protolenoide*s (Cobbold, 1931), *C. pustulata* (Cobbold, 1910), *C.* sp. nov. *Acanthomicmacca walcotti* (Matthew, 1889b), *A.* sp. nov. *Myopsomicmacca* sp. aff. *M. ellipsocephaloides* (Cobbold, 1910). *Catadoxides harveyi* (Walcott, 1889b), *Hamatolenus (H.)* sp. cf. *H. (H.) marocanus* (Neltner, 1938), *H. (Myopsolenus) magnus* (Hupé, 1953). *Protolenus (P.) mckillopi* (Fletcher, 2003). *Latoucheia* sp. *Orodes howleyi* (Walcott, 1889b). "*Bonnia*" *bombifrons* Matthew, 1886. *Ovatoryctocara granulata* Tchernysheva, 1962. *Bailiaspis aequalis* (Linnarsson, 1883), *B. dalmani* (Angelin, 1854), *B. elegans* (Hartt *in* Dawson, 1868), *B. glabrata* (Angelin, 1854), *B*. sp. cf. *B. inflata* Lake, 1940, *B. latigenae* Hutchinson, 1962, *B*. sp. cf. *B. tuberculata* Lake, 1940, *B. venusta* Resser, 1937. *Bailiella baileyi* (Hartt *in* Dawson, 1868), *B. ornata* Resser, 1937. *Hartella bucculenta* (Resser, 1937), *H. exsulans* (Linnarsson, 1879), *H. matthewi* (Hartt *in* Dawson, 1868). *Ctenocephalus howelli* Resser, 1937. *Brunswickia robbii* (Hartt *in* Dawson, 1868). *Holocephalina* sp. aff. *H. incerta* Illing, 1916, *H.* sp. aff. *H. leve* Gozalo and Liñán, 1996. *Meneviella venulosa* (Hicks, 1872). *Pseudatops reticulatus* (Walcott, 1890b). *Parasolenopleura aculeata* (Angelin, 1852), *P. gregaria* (Billings, 1865), *P. tenera* (Hartt *in* Dawson, 1868), *P*. sp. nov. aff. *P. tikasraynensis* (Geyer, 1998) and *Braintreella rogersi* (Walcott, 1884). *Jincella applanata* (Salter *in* Salter and Hicks, 1869). *Solenopleuropsis variolaris* (Salter, 1864). *Agraulos affinis* Billings, 1874, *A. ceticephalus* (Barrande, 1846a), *A. holocephalus* (Matthew, 1890), *A. longicephalus* (Hicks, 1872), *A. quadrangulari*s (Whitfield, 1884), *A*. sp. aff. *A. tosali* (Sdzuy, 1967). *Skreiaspis* sp. aff. *S. spinosus* (Jahn, 1895), *S.* sp. nov. *Avalonia manuelensis* Walcott, 1891. *Olenus* sp.
TRACE FOSSILS: *Rusophycus avalonensis* Crimes and Anderson, 1985.