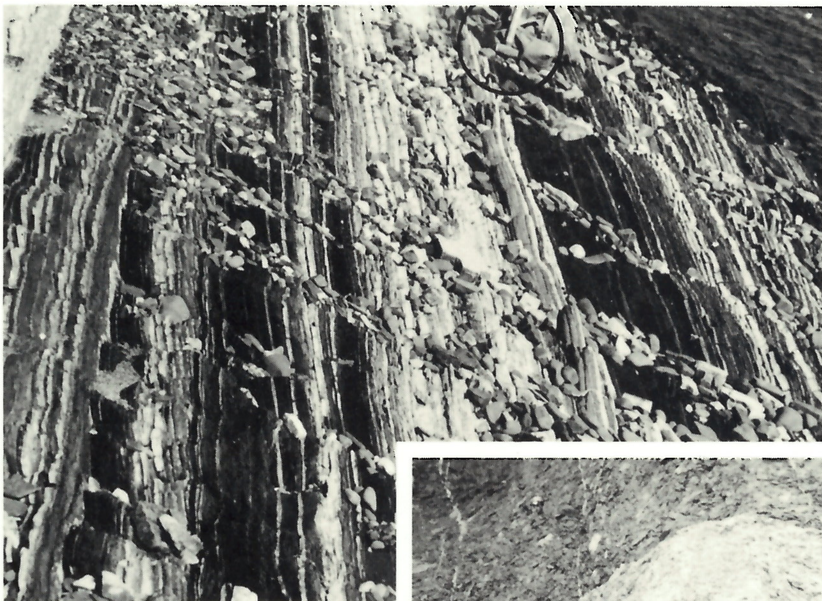
STRATIGRAPHY AND CORRELATION OF THE CAMBRO-ORDOVICIAN COW HEAD GROUP, WESTERN NEWFOUNDLAND



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See Figure 16a (p. 28) and Figure 28a (p. 42) for description.

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Critical Reader

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CONTENTS

Figures

Preface

The spectacular carbonate breccias in the Cow Head region of western Newfoundland have been a continued source of puzzlement and inspired interpretation since their discovery in the last century. Fossils from these famous deposits have been documented by many workers and detailed sedimentological studies have been attempted on parts of the sequence, yet there has been no coherent stratigraphy for these rocks. With the recent recognition that these conglomerates are sedimentary and not tectonic in origin, accumulated along an ancient continental margin, are allochthonous and have an interpretable tectonic history, it is now possible to study them from a stratigraphic viewpoint.

This report is a documentation of the stratigraphy, paleontology and sedimentology of these deep water sedimentary rocks. It provides the first description of this deformed yet surprisingly intact sequence deposited at the foot of a continental slope. A new stratigraphic nomenclature has been erected which reflects discernible proximal versus distal facies relationships. Intercalation of deep water graptolite and trilobite faunas with shallow water boulders containing trilobites and brachiopods permits correlation between quite different faunal realms, which is of international significance for early Paleozoic biostratigraphy. The sediments reflect changes in the depositional regimen of the adjacent shallow platform margin which accreted in response to the evolving community of carbonate producing organisms and eustatic fluctuations in sea level. The report includes an extensive appendix which details the stratigraphy and paleontology of all important stratigraphic sections.

R.A. Price
Director General
Geological Survey of Canada

Préface

Les spectaculaires brèches de carbonates situées dans la région de Cow Head (ouest de Terre-Neuve) ont toujours constitué un mystère pour les scientifiques et elles ont inspiré les interprétations les plus diverses depuis leur découverte au siècle dernier. Les fossiles provenant de ces célèbres dépôts ont été décrits par de nombreux chercheurs et des études sédimentologiques ont été tentées sur certaines parties de la séquence, mais il n'existe encore aucune stratigraphie cohérente au sujet de ces roches. Comme il a été récemment constaté, ces conglomérats sont d'origine sédimentaire plutôt que tectonique, ils se sont accumulés le long d'une ancienne marge continentale, ils sont allochtones et ils possèdent des antécédents tectoniques qu'il est possible d'interpréter, il est désormais possible de les étudier d'un point de vue stratigraphique.

Le présent rapport apporte des renseignements sur la stratigraphie, la paléontologie et la sédimentologie de ces roches sédimentaires formées en eaux profondes. Il fournit la première description de cette séquence déformée mais étonnamment intacte qui s'est déposée au pied d'un talus continental. La nouvelle nomenclature stratigraphique qui a été élaborée se veut le reflet de relations perceptibles opposant un faciès distal à un faciès proximal. L'intercalation de faunes de graptolites et de trilobites d'eaux profondes avec des gros blocs d'eaux peu profondes renfermant des trilobites et des brachiopodes permet de faire une corrélation entre des domaines fauniques bien différents, ce qui revêt une portée internationale pour la biostratigraphie du Paléozoïque inférieur. Les sédiments reflètent des changements dans les régimes d'accumulation par réaction à la communauté de carbonates en évolution qui produit des organismes et des variations eustatiques au niveau de la mer. Le rapport comprend une longue annexe qui donne en détails la stratigraphie et la paléontologie de toutes les sections stratigraphiques importantes.

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

STRATIGRAPHY AND CORRELATION OF THE CAMBRO-ORDOVICIAN COW HEAD GROUP, WESTERN NEWFOUNDLAND

Abstract

The Cow Head Group is an extensive deep water sediment apron deposit which formed at the foot of a low latitude, early Paleozoic continental margin. Although transported and deformed during Taconic and later orogenesis, a distinct NW - proximal (Shallow Bay Formation) to SE - distal (Green Point Formation) polarity is still intact. The complex shifting of facies through time produced seven distinct lithological units, now identified as members.

Fossils from the boulders, as well as from the shale and limestone interbeds, allow correlation with European and North American Cambrian trilobite zones, North American Ordovician trilobite zones and Australian graptolite zones. Juxtaposition of shallow water and deep water faunas in the same units permits assessment of the relative positions of different biostratigraphic zonal schemes defined in platformal versus basinal facies. Important sections are present through the Cambro-Ordovician boundary, the Tremadoc-Arenig series boundary and the base of the Whiterock stage.

The 300 to 500 m thick onlap sequence comprises five periods of deposition which reflect changes in the nature of the adjacent shallow water platform and local oceanographic conditions: (1) late Middle to early Upper Cambrian - an extensive series of limestone conglomerate debris sheets (Downes Point Member); (2) mid to late Upper Cambrian - a wide proximal quartzose calcarenite sediment apron (Tuckers Cove Member) and distal shale apron margin (Martin Point Member), both deposited under euxinic conditions; (3) early Lower Ordovician (Canadian/Tremadoc) - a series of proximal limestone conglomerate debris sheets (Stearing Island Member) and distal hemipelagic limestones (Broom Point Member) coincident with establishment of oxygenated deep seafloor conditions below an oxygen-minimum zone; (4) late Lower to early Middle Ordovician (Late Canadian - Whiterock/Arenig) - a narrow coarse grained sediment apron (Factory Cove Member) and wide onlapping slope of shale and limestone (St. Pauls Member) deposited under conditions of varying oxygenation and sediment supply and punctuated by spectacular mega-conglomerates; (5) Middle Ordovician (Whiterock/Arenig-Llanvirn) - basin deepening and burial by quartzose flysch (Lower Head Formation).

Résumé

Le groupe de Cow Head est une vaste nappe sédimentaire accumulée en eau profonde au pied d'une marge continentale de faible latitude au cours du Paléozoïque ancien. Bien que le groupe ait été transporté et déformé au cours de l'orogenèse du Taconique et d'autres orogenèses plus récentes, il conserve une polarité distincte nord-ouest (proximale) (formation de Shallow Bay) à sud-est (distale) (formation de Green Point). Le déplacement complexe des faciès dans le temps a produit sept unités lithologiques distinctes que l'on identifie maintenant comme étant des membres.

Les fossiles provenant des gros blocs et des interstratifications de schiste argileux et de calcaire permettent d'établir une corrélation avec les zones à trilobites cambriennes de l'Europe et de l'Amérique du Nord, les zones à trilobites ordoviciennes de l'Amérique du Nord et les zones à graptolites de l'Australie. La juxtaposition des faunes d'eau profonde et d'eau peu profonde dans les mêmes unités permet d'évaluer la position relative des diverses zones biostratigraphiques définies dans les faciès de plate-forme et les faciès de bassin. Des sections importantes sont présentes à la limite cambro-ordovicienne, à la limite de la série trémado-arénigienne et à la base de l'étage de Whiterock.

La série de transgression, dont l'épaisseur varie de 300 à 500 m, comporte cinq périodes d'accumulation qui traduisent les changements survenus dans la nature de la plate-forme contiguë en eau peu profonde

et les conditions océanographiques locales: 1) fin du Cambrien moyen au début du Cambrien supérieur — une vaste série de nappes de débris de conglomérat calcaire lithifié (membre de Downes Point); 2) du milieu à la fin du Cambrien supérieur — une vaste plaine sédimentaire proximale de calcarénite quartzeuse (membre de Tuckers Cove) et une marge distale d'un glacis de schiste argileux (membre de Martin Point), les deux s'étant accumulées dans des conditions euxiniques; 3) début de l'Ordovicien inférieur (Canadien/Trémadocien) — une série de nappes proximales de débris de conglomérat calcaire (membre de Stearing Island) et de calcaires hémipélagiques distaux (membre de Broom Point) dont l'accumulation a coïncidé avec l'établissement de conditions oxygénées sur le fond abyssal, sous une zone caractérisée par la présence d'un niveau minimal d'oxygène; 4) fin de l'Ordovicien inférieur au début de l'Ordovicien moyen (Canadien supérieur — Whiterock/Arénigien) — un glacis étroit de sédiments grossiers (membre de Factory Cove) et une vaste pente chevauchante de schiste argileux et de calcaire (membre de St. Pauls), accumulés dans des conditions variées d'oxygénation et d'apports sédimentaires et parsemés de méga-conglomérats spectaculaires; 5) Ordovicien moyen (Whiterock/Arénigien-Llanvirnien) — approfondissement du bassin et enfouissement sous un flysch quartzeux (formation de Lower Head).

SUMMARY

The Cow Head Group is a sequence of Middle Cambrian limestone, limestone conglomerate and shale deposited in deep water along a low latitude continental margin and now disposed as a series of stacked thrust sheets in western Newfoundland. This report is an account of the regional setting, stratigraphy, sedimentology, environments of deposition and macropaleontology of these rocks. Information is documented in 29 detailed sections and graphic logs, contained in the appendix, which are then used to construct interpretive cross-sections displaying original depositional arrangements.

The strata underlie a swampy coastal plain in front of Precambrian crystalline rocks of the Long Range Mountains in central western Newfoundland. The outcrop is sparse and isolated, mainly where resistant, NE-trending ridges intersect the sea or are cut by east-trending ponds and fiords.

The Cow Head is here recognized as the northern end of the Humber Arm Allochthon. It is now disposed as structural slices within the allochthon, which were formed prior to and during emplacement. These Taconic (Middle Ordovician) structures have been locally faulted and folded by later Acadian (Devonian) orogenesis.

The rocks were originally interpreted as continental margin deposits which had accumulated along the edge of a "paleoatlantic ocean" but were subsequently transported westward, an interpretation that is still held today. The sediments have variously been interpreted, however, as due to the ploughing action of sea ice on shallow water limestone beds, as crush breccias formed by advancing thrust sheets, and more recently as normal deep water sediments which accumulated at the base of the continental slope.

Stratigraphy. The stratigraphy has long been confused, partly because of poor outcrop, partly because of

SOMMAIRE

Le groupe de Cow Head est une séquence de calcaire, de conglomérat calcaire et de schiste argileux du Cambrien moyen mise en place en eau profonde le long d'une marge continentale à faible latitude et formant maintenant une série de nappes de charriage empilées dans la partie ouest de Terre-Neuve. Le présent bulletin décrit le milieu régional, la stratigraphie, la sédimentologie, les milieux de sédimentation et la macropaléontologie de ces roches. Les renseignements sont documentés à l'aide de 29 profils et colonnes lithologiques présentés en annexe et utilisés pour reconstituer des coupes transversales interprétatives qui exhibent l'organisation sédimentaire originale.

Les couches reposent sous une plaine côtière marécageuse située devant les roches cristallines précambriennes du chaînon Long Range dans la partie centrale de l'ouest de Terre-Neuve. Les affleurements sont épars et isolés et se présentent surtout là où des crêtes résistantes, à orientation nord-est, croisent la mer ou sont coupées par des étangs et des fiords à orientation est.

Dans le présent bulletin, le groupe de Cow Head est reconnu comme formant l'extrémité nord de l'allochtone de Humber Arm. Il est maintenant réparti sous forme de tranches structurales à l'intérieur de l'allochtone, la formation de ces tranches ayant en lieu avant et durant la mise en place. Ces structures taconiques (Ordovicien moyen) ont par endroits été faillées et plissées par l'orogenèse acadienne (Dévonien) plus récente.

À l'origine, on a cru qu'il s'agissant de dépôts de marge continentale mis en place en bordure d'un océan «paléoatlantique» mais par la suite transportés vers l'ouest; cette interprétation est encore valable aujourd'hui. L'origine de ces sédiments se prête toutefois à diverses interprétations; certains croient qu'ils résultent du rabotâge des couches de calcaire en eau peu profonde par la glace de mer; selon d'autres, il s'agit de brèches de friction formées par l'avancée des nappes de charriage; tandis que d'autres affirment qu'il s'agit de sédiments normaux d'eau profonde mis en place au pied du talus continental.

Stratigraphie. Le groupe présente depuis longtemps une stratigraphie quelque peu embrouillée à cause de l'absence d'affleurements, du changement rapide des faciès et de la tectonique et parce rapid facies changes, partly because of tectonics and partly because of similar autochthonous Middle Ordovician conglomerates (Cape Cormorant Formation) with which they were erroneously correlated.

The Cow Head Group is here divided into two new coeval formations and seven new members, but the old bed numbers are retained as subdivisions of the members.

Coarse grained, conglomeratic facies which occur in the northwest are named the Shallow Bay Formation. This formation is composed of four members. The lowest, the Downes Point Member is a series of conglomerates about 100 m thick that range in age from late Middle Cambrian to early Late Cambrian and contain Beds 0 to 5. The overlying Tuckers Cove Member is about 60 m of interbedded quartzose calcarenite conglomerate and minor parted to ribbon limestone, sandstone, siltstone and shale that are Middle to Late Cambrian in age and encompass all of Bed 6. The Stearing Island Member is a series of megaconglomerates about 80 m thick with minor interbedded limestone, quartzose calcarenite and shale. Composed of Beds 7 and 8, the strata range from uppermost Cambrian to Lower Ordovician or uppermost Tremadoc. The uppermost unit is the Factory Cove Member, a 100 m sequence of ribbon to parted limestone and minor shale punctuated by beds of boulder conglomerate and megaconglomerate, containing Beds 9 through 15, the rocks are as young as early Whiterock or late Arenig.

Contemporaneous, fine grained facies in the southeast are named the Green Point Formation. This formation comprises three members. The Martin Point Member, the basal unit, is green and black shale, partings and layers of ribbon limestone, siltstone and calcareous sandstone. It varies in thickness from 100 to 150 m and, on the basis of some fossils, is late Cambrian. The Broom Point Member, Early Canadian or Tremadoc in age, is an 80 m thick sequence of ribbon to parted limestone. The St. Pauls Member is a distinctive 130 to 150 m thick sequence of red, green and black shale with variable thicknesses of limestone, limestone conglomerate, siltstone and dolomite. The youngest beds are upper Canadian or lower Whiterock and uppermost Arenig.

The Cow Head Group is overlain by a distinctive sequence of green sandstone, minor conglomerate and shale newly called the Lower Head Formation. The top of this Middle Ordovician flysch is everywhere a tectonic contact.

Sedimentology. The deposits themselves are a mixture of fine grained hemipelagites and sediment gravity flows.

The hemipelagites are in the form of shales, siltstones and limestone rhythmites. Laminated black, dark grey and green shales are common throughout and represent deposition under anaerobic to dysaerobic

que les roches ont été mises en corrélation à tort avec des conglomérats autochtones similaires de l'Ordovicien moyen (formation de Cape Cormorant).

Le présent bulletin divise le groupe de Cow Head en deux nouvelles formations contemporaines et en sept nouveaux membres; les anciens numéros des couches ont été retenus et servent à désigner les subdivisions des membres.

Les faciès conglomératiques à grain grossier trouvés dans le nord-ouest portent le nom de formation de Shallow Bay, laquelle comprend quatre membres. Le membre inférieur, celui de Downes Point, présente une série de conglomérats dont l'épaisseur atteint environ 100 m et dont l'âge varie de la fin du Cambrien moyen au début du Cambrien récent; on y trouve les couches 0 à 5. Le membre sus-jacent de Tuckers Cove se compose d'environ 60 m d'interstratifications de conglomérat à fragments de calcarénite quartzeuse et de petites quantités de calcaire laminaire à rubané, de grès, d'aleurolite et de schiste argileux qui datent du Cambrien moyen à supérieur et qui englobent l'ensemble de la couche 6. Le membre de Stearing Island se compose d'une série de mégaconglomérats d'environ 80 m d'épaisseur qui contiennent de petites interstratifications de calcaire, de calcarénite quartzeuse et de schiste argileux. Les strates, formées des couches 7 et 8, varient du Cambrien le plus récent à l'Ordovicien inférieur ou au Trémadocien le plus récent. L'unité supérieure, appelé le membre de Factory Cove, exhibe une série de 100 m de calcaire rubané ou laminaire et de petites quantités de schiste argileux parsemée de couches de conglomérat blocailleux et de mégaconglomérat. Ces roches contiennent les couches 9 à 15 et datent du Whiterock inférieur ou de l'Arénigien supérieur.

On a donné aux faciès contemporains à grain fin dans le sud-est le nom de formation de Green Point, laquelle formation comporte trois membres. L'unité basale, sont le membre de Martin Point, se compose de schiste argileux vert et noir comportant des lamines et des couches de calcaire rubané, d'aleurolite et de grès calcaire. Son épaisseur varie de 100 à 150 m et, d'après certains fossiles qu'elle contient, daterait du Cambrien supérieur. Le membre de Broom Point, qui date du Canadien inférieur ou du Trémadocien, est une séquence de calcaire rubané à laminaire dont l'épaisseur atteint 80 m. Le membre de St. Pauls est une série caractéristique de 130 à 150 m d'épaisseur qui se compose de schistes argileux rouge, vert et noir avec diverses épaisseurs de calcaire, de conglomérat calcaire, d'aleurolite et de dolomie. Les couches les plus récentes datent du Canadien supérieur ou du Whiterock inférieur et de l'Arénigien le plus récent.

Le groupe de Cow Head repose sous une série caractéristique de grès vert, de petites quantités de conglomérat et de schiste argileux à laquelle on a récemment donné le nom de formation de Lower Head. Le sommet de ce flysch datant de l'Ordovicien moyen est partout un contact structural.

Sédimentologie. Les dépôts eux-mêmes se composent d'un mélange d'hémipélagites à grain fin et de sédiments provenant d'écoulements par gravité.

Les hémipélagites se présentent sous forme de schistes argileux, d'aleurolites, et de séquences rythmiques de calcaire. Des schistes argileux rubanés de couleur noir, gris foncé et vert, sont trés répandus et se sont accumulés dans un milieu anaérobie ou mal conditions. Bioturbated red shales with a distinctive ichnofossil assemblage record deposition in deep water, below the oxygen minimum zone, throughout the Ordovician. Buff weathering dolomitic siltstones and silty dolomites are partly detrital and partly diagenetic.

Limestone rhythmites, as parted to ribbon limestones, vary from planar bedded to lumpy to nodules in shale. They vary in texture from lime mudstone to graded calcisiltite to rippled calcarenite. The particles come from both shallow water (bioclasts, especially calcified algae) and deep water (radiolarians, sponge spicules). They may be partly silicified in Ordovician sequences. The sediments were lithified early, on or just below the sea floor, as demonstrated by their common inclusion in conglomerates. This facies is subject to synsedimentary deformation in the form of wrinkling, folding and overthrusting as well as the development of intraformational truncation surfaces.

Calcarenites are commonly quartzose and in Upper Cambrian deposits are sandstone. The quartz is coarse- to very coarse-grained, rounded and spherical, and interpreted to be mainly eolian. Carbonate allochems are mainly ooids and bioclasts, predominantly algal. Ordovician deposits contain more fossils and phosphate. These sands are either massive (grain flows) or graded (turbidites) or are caps on top of conglomerates.

The wide spectrum of conglomerates is divided into five types. Graded stratified conglomerates are grainy, commonly quartzose cobble to pebble conglomerates with cross stratification, ripples and laminated tops. These carbonate turbidites grade into calcarenites along strike. They are commonest in the Upper Cambrian Tuckers Cove Member. Limestone plate conglomerates are debris flows composed of cobble to boulder size pieces of parted and ribbon limestone identical to the intervening hemipelagites. Limestone chip conglomerates are deposits of small pebble- to cobble-sized clasts of both shallow and deep water origin. Boulder conglomerates are debris flows, like the plate and chip conglomerates, but contain abundant exotic, shallow water cobble to boulder size clasts, particularly calcified algae boundstone. Megaconglomerates are the thickest, muddiest and most chaotic muddy debris flows containing huge blocks of shallow water limestone and rafts of slope deposits up to 200 x 50 m. All deposits indicate a consistent NW to SE transport direction.

Dolomite and chert are both sedimentary and diagenetic. The matrix of many conglomerates, the pressure solution seams between limestones and the matrix in siltstones may be replaced by dolomite. Dolomite is also in part detrital, from shallow water, and in part formed early at or just below the seafloor as demonstrated by dolomite clasts in conglomerates. Chert is most common in Ordovician sediments, replacing limestone rhythmites, the tops of conglomerate beds

oxygéné. Des schistes argileux bioturbés de couleur rouge contenant un assemblage caractéristique d'ichnofossiles se sont accumulés en eau profonde, sous la zone caractérisée par un niveau minimal d'oxygène, tout au long de l'Ordovicien. Les aleurolites dolomitiques à surface d'altération chamois et les dolomies limoneuses partagent une origine en partie détritique et en partie diagénétique.

Les séquences rythmiques de calcaire ainsi que les calcaires laminaires ou rubanés forment des couches planaires, des mottes ou des nodules dans le schiste argileux. Leur texture varie d'une pélite calcaire à une aleurolite calcaire bien classée et à une calcarénite ondulée. Les particules proviennent d'eau peu profonde (bioclastes, notamment des algues calcifiées) et profonde (radiolaires, spicules d'éponge) et paraissent parfois partiellement silicifiées dans les séries ordoviciennes. Ces sédiments se sont consolidés tôt, sur ou immédiatement sous le fond marin, ainsi qu'en atteste leur présence dans les conglomérats. Ce faciès a subi une déformation synsédimentaire sous forme de plissotement, de plissement et de charriage, et on y trouve également des surfaces de troncature intraformationnelles.

Les calcarénites sont souvent quartzeuses et forment des grès dans les sédiments du Cambrien supérieur. Le quartz est grossier ou très grossier, arrondi et sphérique et aurait une origine surtout éolienne. Les allochèmes carbonatés sont principalement des oolites et des bioclastes, surtout algaires. Les dépôts ordoviciens renferment plus de fossiles et de phosphate. Il s'agit de sables soit massifs (écoulements de grains), soit bien classés (turbidites); ils peuvent également former des chapeaux sur les conglomérats.

La vaste gamme de conglomérats est divisée en cinq catégories. Les conglomérats stratifiés bien classés sont des conglomérats granuleux et souvent quartzeux, à gros cailloux et à galets, caractérisés par une stratification oblique, des rides et des sommets laminés. Ces turbidites carbonatées se transforment progressivement en calcarénites parallèlement à la direction. On les trouve le plus souvent dans le membre de Tuckers Cove du Cambrien supérieur. Les conglomérats à plaquettes de calcaire sont des coulées de débris composées de particules pierreuses ou blocailleuses de calcaire laminaire et rubané identiques aux hémipélagites intercalaires. Les conglomérats à éclats de calcaire sont des accumulations de petits clastes caillouteux ou pierreux formés en eau profonde et en eau peu profonde. Les conglomérats à blocs sont des coulées de débris, tout comme les conglomérats à plaquettes et à éclats, mais contiennent une quantité abondante de clastes exotiques pierreux ou blocailleux, accumulés en eau peu profonde, notamment des clastes de «boundstone» algaire calcifié. Les méga-conglomérats sont les coulées de débris les plus épaisses, les plus boueuses et les plus chaotiques; ils contiennent d'énormes blocs de calcaire d'eau peu profonde et des trainées de dépôts de pente pouvant mesurer jusqu'à 200 m sur 50 m. Tous les dépôts témoignent d'une direction de transport constante du nord-ouest vers le sud-est.

La dolomie et le chert sont à la fois d'origine sédimentaire et diagénétique. De la dolomie remplace parfois la matrice d'un grand nombre des conglomérats, la matrice des aleurolites et les couches formées entre les calcaires suite à la dissolution due à la pression. La dolomie, en partie d'origine détritique, est formée en eau peu profonde, et celle en partie d'origine précoce, est formée sur le fond and shales. Again rapid silicification is indicated by the incorporation of these components in conglomerates.

Paleontology. The key to unravelling the stratigraphy of the Cow Head is the abundant and diverse assemblage of fossils. Conglomerate horizons contain shelly fossils from strandline to deep slope environments while intervening shales and limestones host planktonic and deep water benthonic fossils. These juxtaposed faunas from different environments not only permit local correlation but regional and intercontinental correlation as well.

Emphasis in this report is placed on macrofossils, trilobites throughout with additional information from brachiopods and graptolites in the Ordovician. Cambrian biostratigraphy is based on trilobites, most of which come from the coarse, proximal Shallow Bay Formation. Representatives from shallow water (North American faunal province), deep water (Acado-Baltic faunal province) and platform margin environments occur in these sediments. A total of eight informal zones are recorded and correlated with both North American and Acado-Baltic faunal schemes.

Trilobites typical of most of the standard Utah/ Nevada Ordovician zones are present in boulders of the Cow Head. These trilobites can also be matched with faunas from contemporaneous shallow water carbonate strata in western Newfoundland and deep water strata in Spitsbergen.

Study of brachiopods has focussed on late Lower Ordovician — Mid-Ordovician conglomerates. The presence of *Orthidiella* in Beds 12, 13 and 14 indicates that the upper part of the Cow Head is Middle Ordovician.

The key to unravelling the Ordovician biostratigraphy, however, has been the prolific and diverse graptolite faunas. All zones of the standard Australian graptolite sequence from Lancefield to Darriwil 1 are present in the Cow Head.

Integration of all macrofaunal information allows precise definition of the Cambro-Ordovician boundary, the Tremadoc-Arenig boundary and the Canadian (Ibexian)-Whiterock boundary and suggests that the Valhallan Stage is equivalent to the lower part of the Whiterock Stage. These fossils also confirm that the Cow Head is entirely older than the autochthonous Table Head Group.

Correlation. Using the foregoing detailed lithostratigraphy and biostratigraphy, a detailed stratigraphy and correlation of the Cow Head Group is outlined. Members of the Shallow Bay Formation are subdivided and described in terms of the originally defined beds. Members of the Green Point Formation are not as easily subdivided, but where possible the original bed nomenclature is used. The same major beds occur in two coeval members.

de la mer ou juste en dessous, comme le révèle la présence de clastes de dolomie dans les conglomérats. Le chert est plus répandu dans les sédiments ordoviciens où il remplace les séquences rythmiques de calcaire et les sommets des couches de conglomérat et de schistes argileux. L'incorporation des ces éléments dans les conglomérats atteste également de la rapidité du processus de silicification.

Paléontologie. L'abondance et la diversité des fossiles permettent de reconstituer la stratigraphie du groupe de Cow Head. Les horizons conglomératiques contiennent des fossiles coquilliers d'organismes ayant vécu dans des milieux allant de la ligne de rivage jusqu'au talus profond; les schistes et les calcaires intercalaires contiennent des fossiles benthoniques abyssaux et planctoniques. La juxtaposition de ces faunes de milieux différents permet non seulement d'établir une corrélation locale mais aussi une corrélation régionale et intercontinentale.

Le présent rapport souligne les macrofossiles, plus précisément les trilobites, mais fait également mention des brachiopodes et des graptolites de l'Ordovicien. La biostratigraphie cambrienne est fondée sur les trilobites, la plupart provenant de la formation proximale grossière de Shallow Bay. Ces sédiments contiennent des organismes d'eau peu profonde (province faunique nord-américaine) et d'eau profonde (province faunique acado-baltique) ainsi que des organismes ayant vécu dans des milieux en marge de la plate-forme. En tout, huit zones sont décrites et mises en corrélation avec les schémas fauniques nord-américain et acado-baltique.

Les blocs du groupe de Cow Head contiennent des trilobites caractéristiques de la plupart des zones ordoviciennes standard de l'Utah et du Nevada. Ces trilobites peuvent également être mis en corrélation avec les faunes provenant des couches carbonatées contemporaines d'eau peu profonde dans l'ouest de Terre-Neuve et des couches d'eau profonde de Spitzbergen.

Les brachiopodes examinés proviennent surtout des conglomérats de la fin de l'Ordovicien inférieur et de l'Ordovicien moyen. La présence d'*Orthidiella* dans les couches 12, 13 et 14 indique que la partie supérieure du groupe de Cow Head date de l'Ordovicien moyen.

La présence d'assemblages prolifiques et variés de graptolites a permis de reconstituer la biostratigraphie de l'Ordovicien. Toutes les zones de la séquence de référence australienne de graptolites, de Lancefield à Darriwil 1, sont représentées dans le groupe de Cow Head.

L'intégration de toutes les données macrofauniques permet de définir avec précision la limite du Cambrien et de l'Ordovicien, du Trémadocien et de l'Arénigien, et du Canadien (Ibexien) et Whiterock, et semble indiquer que l'étage de Valhallan équivaut à la partie inférieure de l'étage de Whiterock. Les fossiles confirment également que l'ensemble du groupe de Cow Head est plus ancien que le groupe autochtone de Table Head.

Corrélation. La lithostratigraphie et la biostratigraphie détaillées permettent de présenter une stratigraphie et une corrélation détaillées du groupe de Cow Head. Les membres de la formation de Shallow Bay sont subdivisés et décrits en fonction des couches définies à l'origine. Il n'est pas aussi facile de subdiviser les membres de la formation de Green Point mais, dans la mesure du

The beds of each formation are described in terms of their distribution, paleontology and sedimentology. This information is integrated into a series of simplified cross-sections which in turn serve as a basis for an interpretation of the depositional history. This interpretation is presented within the framework of the general depositional setting, the basic tenants of early Paleozoic slope and basin sedimentation and the nature of the contemporaneous western Newfoundland carbonate platform.

Depositional history. The Cow Head is best interpreted as an onlap, toe-of-slope accumulation, deposited on a continental rise prism which evolved in response to a changing continental shelf and local oceanographic conditions. Five separate stages are recognized:

(1) Basal debris sheets. (Late Middle Cambrian to early Upper Cambrian) Extensive conglomerates, minor limestone rhythmites and thin shales (Downes Point Member) formed on a wide deep water sediment apron under generally anoxic conditions in front of a shallow water, rapidly accreting margin of ooid and skeletal sand shoals and calcified algal bioherms.

(2) Quartzose calcarenite sediment apron. (Upper Cambrian) This extensive deposit is composed of calcarenite grain flows and turbidites with minor conglomerates and shales (Tuckers Cove Member). The sand wedge changed through time, progressively narrowing so that by the beginning of the Trempealeauan the shales and siltstones of the Martin Point Member onlap significantly westward and upslope over the basal sands. Adjacent shallow platform facies are still ooid and bioclastic calcarenite sand shoals but deposition spans a period of arrested shallow water sedimentation, eolian sand bypassing and significant margin progradation. The top of the deep water package is marked by an increase in fine grained carbonate hemipelagites. The Cambro-Ordovician boundary is marked by a succession of massive, welded conglomerates in proximal facies representing a short period of oversteepening and erosion. The boulders are mostly fragments of calcified algal bioherms.

(3) Wide muddy carbonate sediment apron. (lower Canadian:lower Tremadoc) A period of extensive deep water carbonate sedimentation characterized by massive welded conglomerates and calcarenites in proximal facies (Stearing Island Member) and periplatform ooze in the form of limestone rhythmites in distal facies (Broom Point Member). Deposition is still on an unstable slope as illustrated by synsedimentary deformation and intraformational truncation surfaces in distal, fine grained carbonates. Contemporaneous platform carbonates are generally low energy muddy limestones and algal buildups. This phase of deposition represents a prolonged period of accretion and basinward progradation of the margin.

possible, on a conservé la nomenclature originale des couches. Les mêmes couches principales se présentent dans deux membres contemporains.

La description des couches de chaque formation se fait en fonction de leur répartition, de leur paléontologie et de leur sédimentologie. Cette information est intégrée en une série de coupes transversales simplifiées qui servent de base pour une interprétation de l'histoire sédimentaire. Cette interprétation est présentée dans le cadre du milieu sédimentaire général, des principes fondamentaux de la sédimentation du talus et du bassin au Paléozoïque ancien et de la nature de la plate-forme carbonatée contemporaine dans l'ouest de Terre-Neuve.

Histoire sédimentaire. Le groupe de Cow Head représenterait une accumulation transgressive au pied du talus, mise en place sur un coin de la pente océanique qui s'est formé suite à l'évolution de la plate-forme continentale et de la modification des conditions océanographiques locales. On y reconnaît cinq étages distincts:

(1) Nappes de débris basales (fin du Cambrien moyen au début du Cambrien supérieur). Il s'agit de vastes conglomérats, de petites quantités de séquences rythmiques de calcaire et de minces couches de schiste argileux (membre de Downes Point) accumulés sur une large plaine sédimentaire d'eau profonde dans des conditions généralement anoxiques devant une marge de bancs de sable squelettiques et oolitiques et de biohermes algaires calcifiés qui croissait rapidement en eau peu profonde.

(2) Nappe sédimentaire de calcarénite quartzeuse (Cambrien supérieur). Ce vaste dépôt se compose de turbidites et de coulées de grains de calcarénite ainsi que de petites quantités de conglomérats et de schiste argileux (membre de Tuckers Cove). Le coin de sable a varié dans le temps, devenant progressivement plus étroit de sorte qu'au début du Trempéaléanien, les schistes argileux et les aleurolites du membre de Martin Point chevauchaient fortement, vers l'ouest et en amont, les sables inférieurs. Les faciès contigus de plate-forme peu profonde se composent toujours de bancs de sable de calcarénites oolitiques et biosclastiques mais l'accumulation couvre une période de sédimentation interrompue en eau peu profonde, de transport éolien passager de sable et de progradation de la marge. Le sommet de l'assemblage d'eau profonde se caractérise par une augmentation de la quantité d'hémipélagites carbonatées à grain fin. La limite cambro-ordovicienne, elle, se caractérise par une succession de conglomérats massifs dans un faciès proximal qui représente une brève période de surraidissement et d'érosion. Les blocs se composent surtout de fragments de biohermes algaires calcifiés.

(3) Vaste plaine de sédiments carbonatés boueux (Canadien inférieur–Trémadocien inférieur). Il s'agit du résultat d'une période importante de sédimentation carbonatée en eau profonde, caractérisée par la présence de conglomérats massifs et de calcarénites dans les faciès proximaux (membre de Stearing Island) et de boue accumulée en marge de la plate-forme sous forme de séquences rythmiques de calcaire dans le faciès distal. La sédimentation a toujours lieu sur un talus instable comme le montre les surfaces de déformation synsédimentaire et de troncature intraformationnelle dans les roches carbonatées distales à grain fin. Les roches carbonatées de plate-forme contemporaine sont généralement des calcaires boueux et des masses construites par des algues, accumulés en un milieu à faible énergie. Cette phase de sédimentation

(4) Constricted sediment apron. (Middle Canadian to lower Whiterock-upper Tremadoc and Arenig) This complex deposit is a product of pronounced narrowing and westward shift of conglomeratic facies (Factory Cove Member) and upslope onlap of shale facies (St. Pauls Member). Proximal conglomerates change upwards in section from conglomerates to limestone rhythmites to shales while distal facies are mostly red, green and black shales with minor limestone rhythmites. Persistent megaconglomerates (Beds 10, 12 and 14, extend from proximal through distal facies. Superimposed on these trends are changes in local rates of sedimentation and oceanography which result in a further subdivision of this stage into (i) lower aerobic phase: narrowing of the carbonate sediment apron, onlap of red shales upslope in response to a rise in the oxygen-minimum zone; (ii) middle condensed phase: arrested carbonate deposition but silicification, redeposition of phosphate conglomerate and dolomite formation reflecting shelf inundation coincident with one of the highest eustatic stands of sea level in the early Paleozoic; (iii) upper euxinic phase: resumption of carbonate sedimentation but under dysaerobic conditions coincident with deepening of the oxygen-minimum zone and platform outbuilding. The megaconglomerate Bed 12 at the top of this phase represents wholescale collapse of the margin.

(5) Mixed carbonate and flysch. (lower Whiterock/upper Arenig) The top of the Cow Head records the gradual transition from a carbonate slope deposit to a submarine fan flysch complex. It is accompanied by a change in the oxygen-minimum zone and red shale deposition. This change to quartzose flysch took place during a period of extensive peritidal sedimentation, dolomite formation and synsedimentary faulting on the platform. Megaconglomerate Bed 14 is interpreted as a product of this period of general tectonic instability.

représente une longue période d'accrétion et de progradation vers le bassin de la marge.

(4) Plaine sédimentaire reserrée (Canadien moyen au Whiterock inférieur–Trémadocien supérieur et Arénigien). Le présent dépôt complexe résulte d'un resserrement prononcé et d'un déplacement vers l'ouest du faciès conglomératique (membre de Factory Cove) et d'un chevauchement amont du faciès de schiste argileux (membre de St. Pauls). Les conglomérats proximaux se transforment progressivement vers le haut de la section, passant de conglomérats à des séquences rythmiques de calcaire puis à des schistes argileux; les faciès distaux se composent surtout de schistes argileux rouges, verts et noirs qui contiennent une petite quantité de séquences rythmiques de calcaire. Des mégaconglomérats persistants (couches 10, 12 et 14) se prolongent des faciès proximaux aux faciès distaux. On y trouve superposées des variations de la vitesse locale de sédimentation et des conditions océanographiques qui permettent de subdiviser le présent stage en i) une phase aérobie inférieure: resserrement de la nappe sédimentaire carbonatée, chevauchement amont des schistes argileux rouges en réponse à une remontée de la zone caractérisée par la présence d'un niveau minimal d'oxygène; ii) une phase condensée moyenne: arrêt de la sédimentation carbonatée mais silicification, nouvelle sédimentation de conglomérat phosphatique et formation de dolomie traduisant une inondation de la plate-forme qui coïncide avec un des niveaux eustatiques les plus élevés du Paléozoïque ancien; et, iii) une phase euxinique supérieure: reprise de la sédimentation carbonatée dans des conditions mal oxygénées qui coïncident avec l'approfondissement de la zone caractérisée par la présence d'un niveau minimal d'oxygène et l'agrandissement de la plate-forme. La couche 12 du mégaconglomérat au sommet de cette phase représente l'effondrement général de la marge.

(5) Mélange de roches carbonatées et de flysch (Whiterock inférieur/Arénigien supérieur). Le sommet du groupe de Cow Head atteste de la transition progressive d'un sédiment de talus carbonaté à un complexe de flysch de delta sous-marin. Cette transition est accompagnée d'un changement dans la zone caractérisée par la présence d'un niveau minimal d'oxygène et de l'accumulation de schiste argileux rouge. Cette transformation au flysch quartzeux a eu lieu au cours d'une importante période de sédimentation péritidale, de formation de dolomie et de formation de failles synsédimentaires sur la plate-forme. La couche 14 du mégaconglomérat serait un produit de cette période d'instabilité tectonique générale.

INTRODUCTION

The Cow Head breccias are among the most famous elements of Newfoundland geology. Since their discovery in the middle of the nineteenth century, they have attracted the attention of geologists and paleontologists worldwide.

The rocks are part of the Humber Zone (Williams, 1978), a tectono-stratigraphic terrane along the western margin of the Appalachian Orogen (Fig. 1). Cambrian and Ordovician sediments in the Humber Zone accumulated in shallow water environments along a former low latitude continental margin and some distance from this margin in deep water oceanic settings. Four distinct lithological associations are now present; (1) a highly metamorphosed crystalline basement, (2) an autochthonous succession of shallow water sedimentary cover rocks, (3) a transported complex of deep water sedimentary rocks and (4) a transported sequence of mainly igneous and metamorphic rocks (Williams, 1978; James and

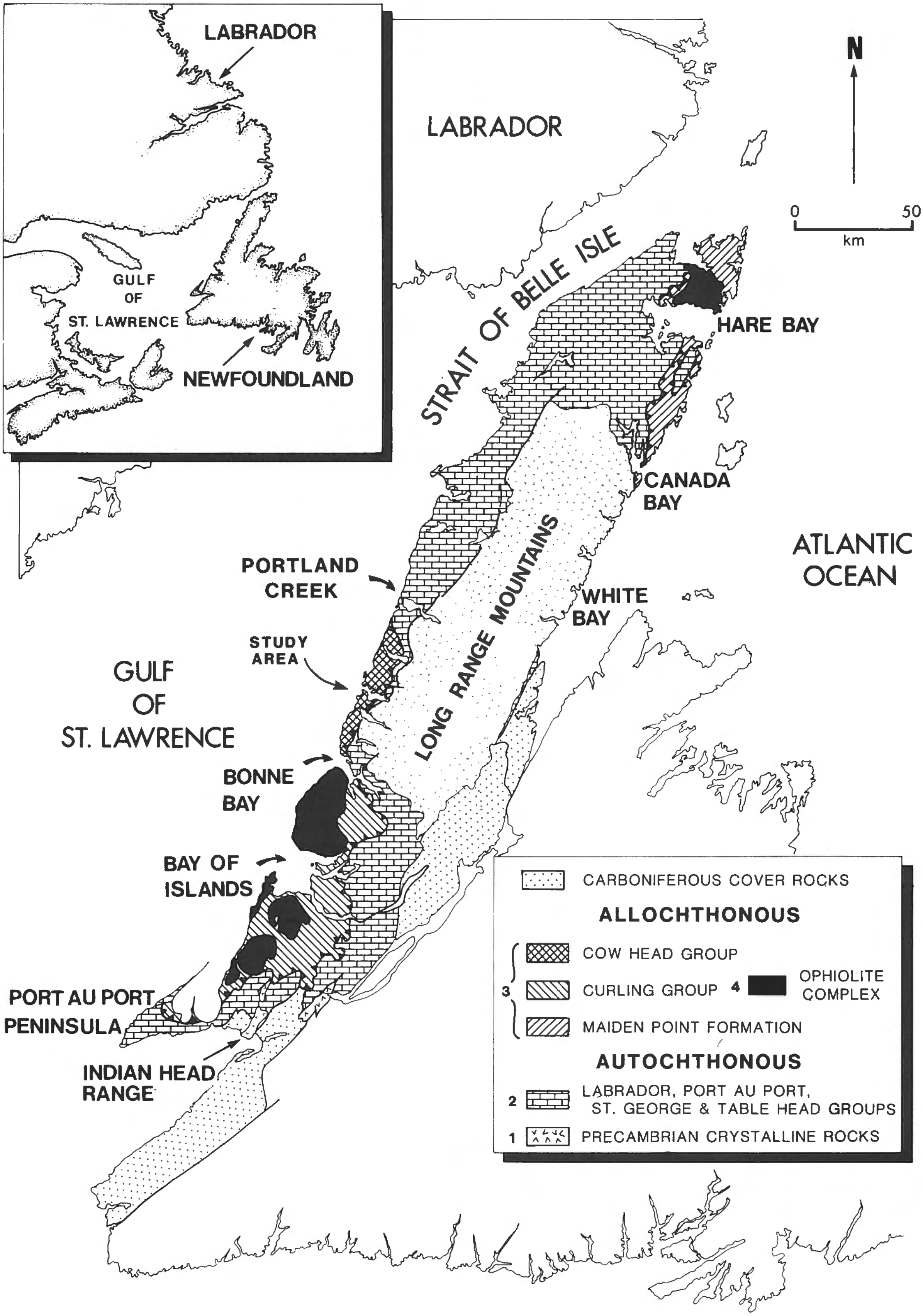

Figure 1. A simplified geological map of most of the Humber Zone in western Newfoundland.

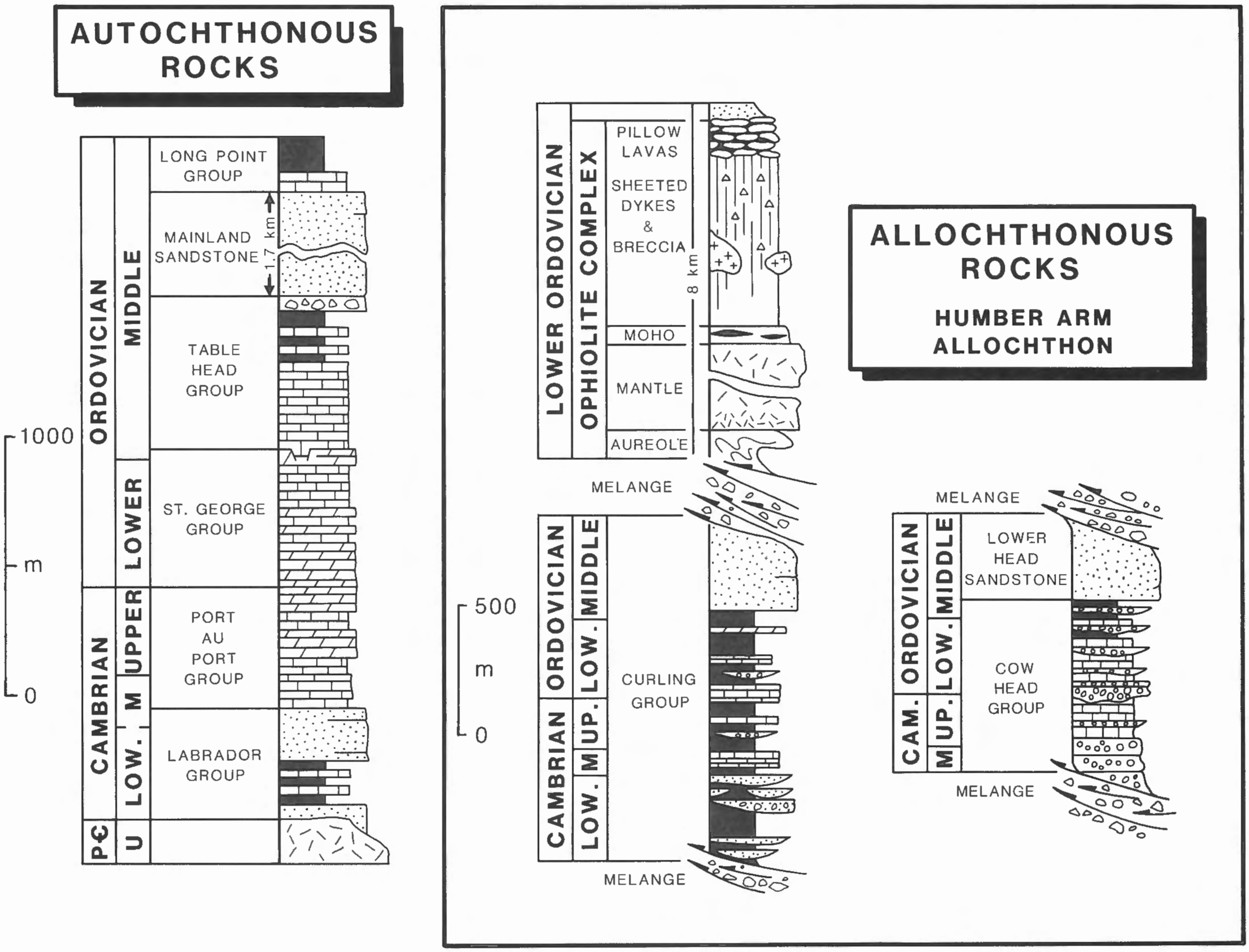

Figure 2. Simplified geological columns of autochthonous and allochthonous rocks in western Newfoundland.

Stevens, 1982). The transported rocks together comprise the Humber Arm Allochthon in the south and the Hare Bay Allochthon in the north (Williams, 1975; Williams and Smyth, 1983). The sedimentary rocks within the Humber Arm Allochthon are called the Humber Arm Supergroup (Stevens, 1970) and are divided into the Curling Group and Cow Head Group (Fig. 2).

The Cow Head Group underlies an area of about 600 km^2 and forms the coastal lowland of central western Newfoundland. Outcrop is sparse but spectacular. The rocks are of great interest because of their composition and the variety of early Paleozoic fossils they contain. The well washed coastal outcrops are beautiful examples of a now fragmented deep water carbonate slope deposit and illustrate an unusual array of sediments, sedimentary structures and diagenetic features. Of particular interest are the coarse, polymict limestone conglomerates. Although only about 500 m thick, the rocks span roughly 70 Ma, from late Middle Cambrian to early Middle Ordovician time, and representatives of virtually every early Paleozoic marine fossil group can be recovered from the strata. The juxtaposition of shallow water, bank edge, slope, pelagic and deep water faunas is an almost unique record of Cambro-Ordovician paleobiology.

In spite of their importance and repute, these rocks have never been documented in a systematic manner due to difficult access (until recently), lack of extensive outcrop and complex geological structure.

This report is a systematic description of the stratigraphy of the Cow Head Group and associated sediments. The text is accompanied by detailed stratigraphic sections, graphic logs and correlation diagrams for all important exposures. The resulting measured stratigraphic sections, sedimentology and biostratigraphy are integrated into a regional, correlated framework. This has resulted in a more refined stratigraphic nomenclature and the formulation of an actualistic depositional model for these deep water sediments. Correlation of the Cow Head Group with coeval shallow water sediments in western Newfoundland also suggests a linked history for all these rocks.

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DEVELOPMENT OF GEOLOGICAL THOUGHT

Introduction

The Cow Head Group underlies a swampy coastal plain between the Precambrian crystalline Long Range Mountains and the sea from Bonne Bay north to Portland Creek Pond (Fig. 1, 3). The lowland is covered by bogs, small lakes and dense growths of stunted spruce. This terrane is corrugated by northeast-trending wooded ridges of Cow Head rocks with less resistant sandstones and shales (Lower Head Formation) in the wide troughs between. Several elongate ponds trend east across the geomorphic and structural grain, with some extending into the Long Range Mountains as relic fiords. An account of the late Pleistocene glacial history was provided by Grant (1969). Outcrops formed by the intersection of these ponds and ridges of Cow Head rock are the only extensive inland exposures. This style is also present along the sea coast with outcrop present where rock ridges meet the coastline. The exposures are separated by long intervals of sand or boulder beach.

Much of the Cow Head lies in Gros Morne National Park and so is subject to federal collecting regulations of Parks Canada.

Interest in these rocks began in antiquity. Dorset Eskimos used cherts from Cow Head, Broom Point, and perhaps other localities to manufacture a variety of artifacts 21 to 25 centuries ago (J. Tuck, personal communication, 1983). Black chert, much like that from Bed 11 at Cow Head, seems to have been the main material used, but green, red, and brown radiolarites were also utilized. The material seems to have been of good quality since artifacts probably made from these cherts have been found as far away as northern Labrador.

The first European settlement began over 400 years ago. In 1783 the Treaty of Versailles gave France the right to fish along the west coast of Newfoundland and this region was long known as "The French Shore". That nation claimed fishing was an exclusive right while Britain maintained it was concurrent and the dispute was not resolved in Britain's favour until 1904.

Rocky headlands formed by resistant beds of the Cow Head Group provided the only natural shelter along this bleak shore and became sites for the first settlements. The largest was Cow Head (Fig. 4), first named Cap Pointu by Jacques Cartier in 1534 but subsequently called "Tete de Vache". The origin of the present name is obscure and there are several explanations current amongst the present day inhabitants. Some suggest that the name results from the resemblance of a weathered conglomerate at the Point of Head to a cow's head. Many of the boulders, the remnants of raised sea stacks and even the profile of the peninsula seen at a distance from the sea also resemble some part of the bovine anatomy. One local story has the mottled aspect of Bed 7 at Cow Head as the origin of the name (Fig. 5).

R. H. Flower (1978; personal communication, 1980) has suggested that during the French domination of west Newfoundland, curious French sailors collected fossils from the Cow Head Group and took them back to France from whence they were dispersed through various countries and some became important holotypes.

Past interpretations

The first North American interest in the Cow Head Group seems to have been shown by Sir William Logan who was concerned about the origin of the Quebec Group and its record of early Paleozoic history. He concluded that the

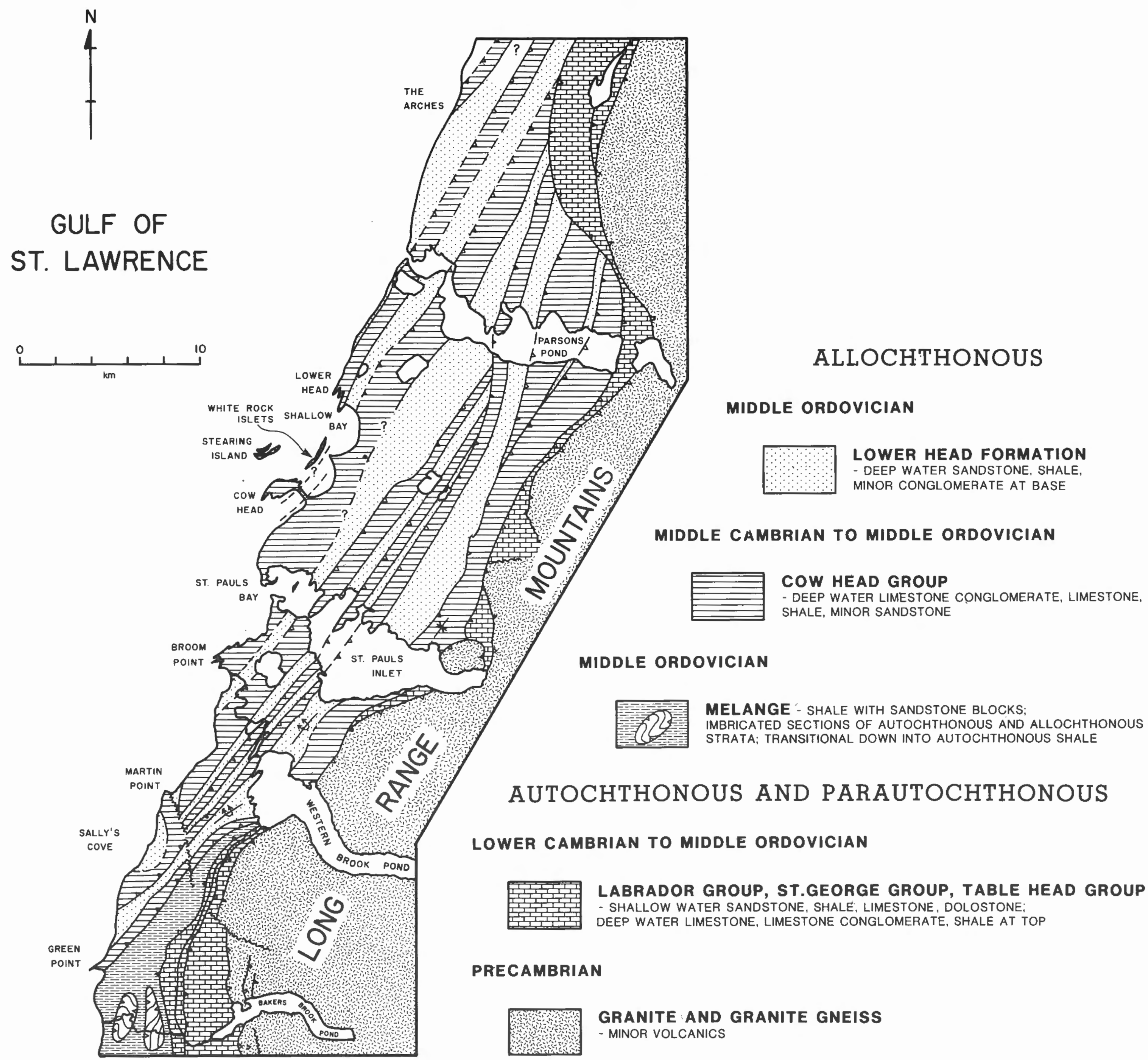
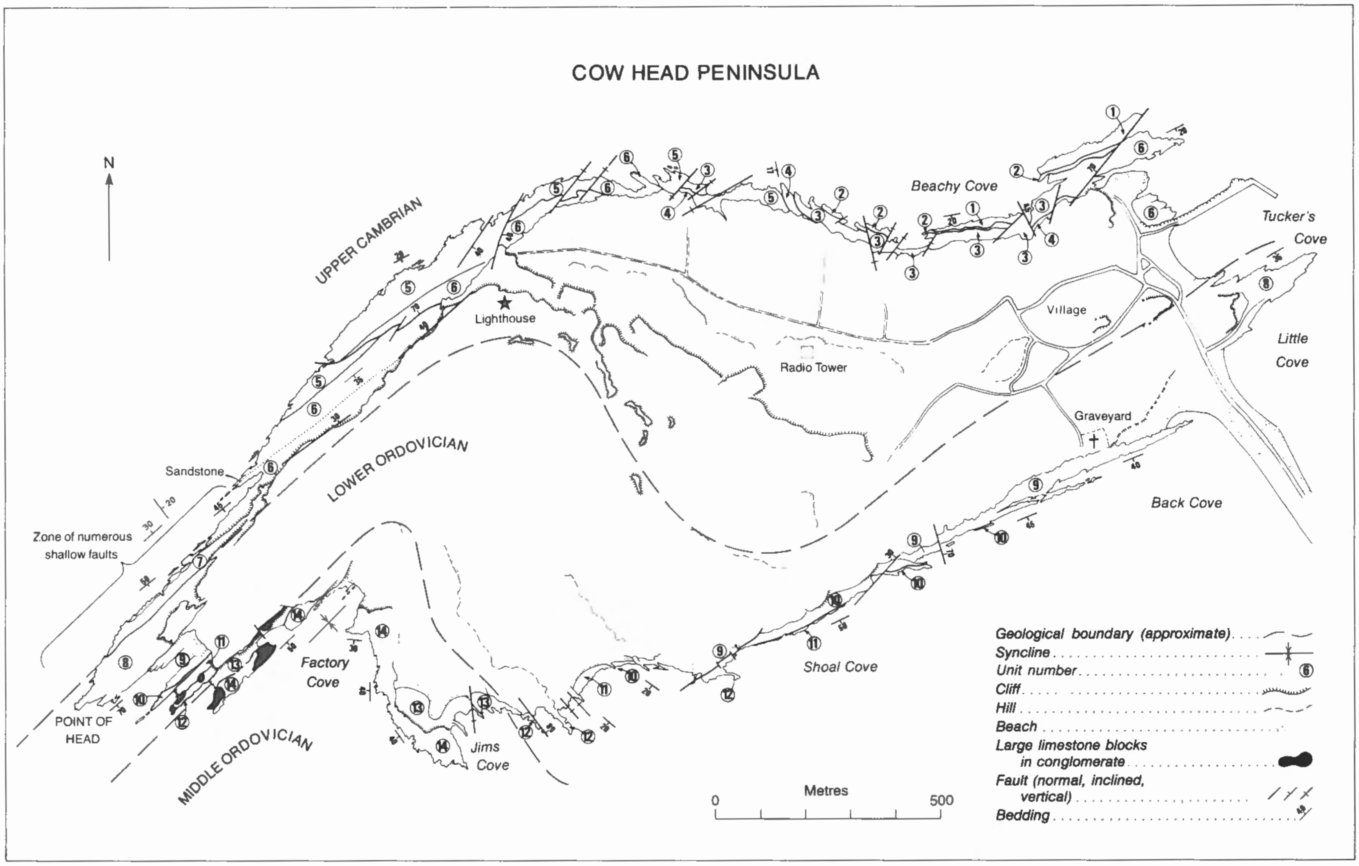


Figure 3. A geological map of the area in which Cow Head strata are found (after Williams et al., 1985).



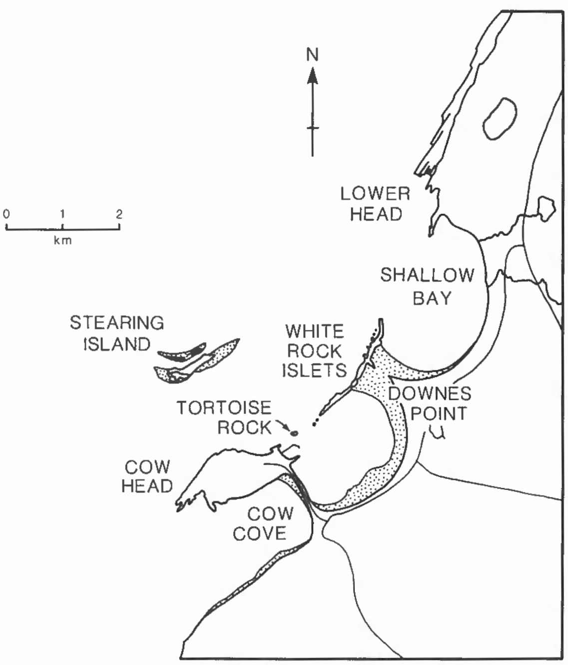


Figure 4. A map of the Shallow Bay region with a detailed map of Cow Head Peninsula.

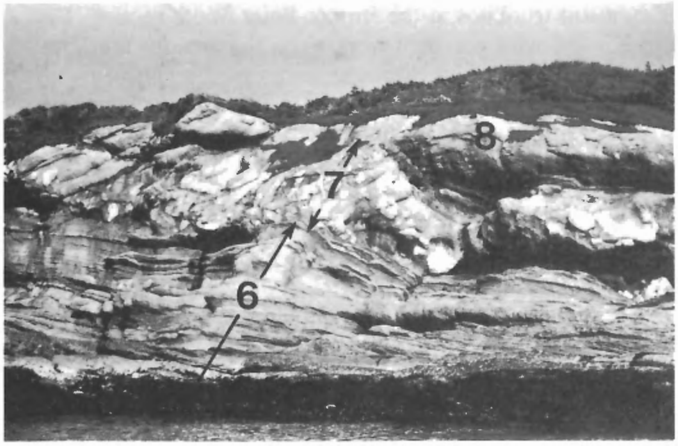


Figure 5. The northern shore of Cow Head Peninsula from the sea; the lower half of the 40 m cliff is interbedded Upper Cambrian calcarenite and conglomerates (Bed 6), the upper half is a megaconglomerate (Bed 7) with conspicuous white limestone boulders overlain by Bed 8 (GSC 191434).

Quebec Group had been deposited along the continental margin of North America bordering a "PaleoAtlantic" ocean but that it had been transported westwards along a "Great Dislocation" (Stevens, 1974). Logan sent James Richardson to west Newfoundland to investigate the northeastern extension of Quebec geology. Richardson's observations were included in Logan's "Geology of Canada" published in 1863 which contains the first detailed description of the Cow Head Group. Although Logan did not offer an explanation for the very coarse nature of the conglomerate (Logan, 1863, unit 15, p.291), he had no doubt that they were sediments in a normally bedded sequence. He was somewhat unsure, however, as to whether some of the larger masses were blocks or interbeds. The strong lithological and paleontological similarity between the west Newfoundland conglomerates and those at Levis, Quebec, suggested correlation of the two units (Logan, 1863, p.293). Both Ordovician and Cambrian fossils were found. It is not clear whether Logan regarded the Newfoundland conglomerates to be transported as he did the Levis rocks, but he did recognize that his "Great Dislocation" passed through the general vicinity of Bonne Bay, south of Cow Head (Logan, 1863, p.297).

Logan further decided that the conglomerates were both overlain and underlain by sandstone, a conclusion that seems to have been based on observations made at Lower Head (Logan, 1863, p.292). This interpretation lasted for over 100 years. More details are given in Harrington (1883) and the conglomerates are assigned to his division P. Fossils collected by Richardson and listed by Logan are figured and described by Billings (1865) who added to Logan's lists and gave more detailed localities.

Walcott (1894) included the Cow Head conglomerates in his discussion of similar rocks in the Appalachians and inferred that this type of sediment resulted from the ploughing action of sea ice on shallow water limestone beds, a hypothesis originally suggested by Dawson (1883).

Local inhabitants found several oil seeps in the area, reports of which led to the visit of several oil geologists, one of whom, Barrington-Brown (1938a), compared what seems to be the Cow Head conglomerates with sedimentary slide breccias that he had observed in South America (Barrington-Brown, 1938b).

An entirely different conclusion for the origin of the Cow Head rocks and an outline of the extensive fieldwork conducted by several expeditions from Yale University is given by Schuchert and Dunbar (1934). As part of their now classic "Stratigraphy of Western Newfoundland", these workers gave the first detailed account of the Cow Head Group or the Cow Head Breccia as they called it. They deduced that the breccia was polygenetic, some a crush breccia and some deposits of Middle Ordovician age derived from the erosion of advancing submarine thrust sheets. They discounted Walcott's and Dawson's interpretation of origin by ice action by noting the lack of faceted or striated blocks in the unit. Other important features they recorded include the lack of Lower Cambrian blocks, the presence of exotic limestones not known elsewhere in Newfoundland, and the fact "that at any one locality most of the blocks are of a single formation" (Schuchert and Dunbar, 1934, p.81). The presence of blocks of the younger Middle Ordovician (Caradoc) Long Point Group reported by Schuchert and Dunbar (1934) have not been confirmed by later workers, although calcareous sandstone blocks do occur in conglomerates not now correlated with the Cow Head Group. They agreed with Logan (1863) that the Cow Head rocks lay within a sandstone sequence and were younger than the Long Point rocks but older than the Humber Arm "Series".

It appears that the geological relationships at Cape Cormorant, well south of Cow Head at the western extremity of the Port-au-Port Peninsula (Fig. 1) played an important role in Schuchert and Dunbar's (1934) interpretation of the Cow Head. Their conclusions were based on observations made by Dunbar, Ingerson, and Leith in 1933 (Schuchert and Dunbar, 1934, p.84). The general concept is illustrated best in the textbook by Dunbar and Rodgers (1958, Fig. 91). At the Cape, limestone conglomerates, lithologically similar to those at Cow Head, are involved in folding and are apparently cut by two thrust faults. Two types of breccias occur in this section: one, a crush breccia, generated on a thrust; the other, a breccia interbedded with Middle Ordovician shale which they thought was derived from the limestone as it was being thrust and eroded.

The situation is complicated by the presence of an unconformity overlain by Carboniferous limestone conglomerates very similar to those of Cow Head which Schuchert and Dunbar (1934, Fig. 6 and p.111) do not seem to have recognized. Furthermore, they extrapolated the age of the conglomerates from Cape Cormorant to Cow Head where no such field relationships exist.

Another complicating factor is the occurrence, south of Cow Head, of the Green Point "Series" (Schuchert and

Dunbar, 1934, p.38-46). Strata referrable to this unit were seen at various localities in west Newfoundland, but the main outcrop area recognized by Schuchert and Dunbar runs from Green Point inland to Parsons Pond, via Western Brook Pond and St. Pauls Inlet (Fig. 3). During their field work, Schuchert and Dunbar regarded Green Point strata as part of the Humber Arm "Series" of middle Ordovician age, but the occurrence of Tremadoc graptolites recognized by Ruedemann (1947) forced a revision of this interpretation. They concluded that the Green Point was thrust into its present position and was somewhat older than the St. George "Series". Even though the Green Point contains limestone conglomerate beds, Schuchert and Dunbar made no correlation with the nearby beds at Cow Head.

One of the more important results of the Yale expeditions was the large collections of fossils obtained. These provided the basis for several papers and maintained interest in the Cow Head. Eventually, it was fossils from the Cow Head Group that led to its reinterpretation. Johnson, in a series of unpublished reports, maps, and a brief published note (1941), considerably modified the interpretation of Schuchert and Dunbar. Johnson found that an entire sequence of rocks in the Cow Head region could not be fitted into the Schuchert and Dunbar stratigraphic scheme. The Green Point "Series" was not an anomaly. He distinguished a Green Point Group, a Western Brook Pond Group, and a St. Pauls Group (for further discussion see Stratigraphic nomenclature). These he regarded as a broken but fairly complete section ranging from basal Ordovician (Schaghticoke) to middle Ordovician (Normanskill) age between 2000 and 2500 feet (645 and 806 m) thick. These conclusions were based on graptolites collected by his field assistant, C.H. Kindle (Kindle, personal communication, 1982). At the urging of G.M. Kay (personal communication, 1967) Johnson published his conclusion that these rocks "have been carried from a region to the east and subsequently broken up by later high angle faults" (Johnson, 1941, p.145).

The graptolite collections were studied in detail by Ruedemann and the results incorporated into his "Graptolites of North America" (1947). The Johnson/Kindle collection is now housed at the Smithsonian Institution. Ruedemann gave extensive lists but concluded that the Western Brook Pond and St. Pauls groups both contain Deepkill and Normanskill graptolites and are in part equivalent. Although Ruedemann (1947, p.60) listed Deepkill fauna from Cow Head, he did not draw any correlations between the Cow Head and Johnson's divisions.

Oxley (1953) described the terrane between St. Pauls and Parsons Pond and deduced that two distinct Cambrian and Ordovician facies existed and that Middle Ordovician thrusting was responsible for their juxtaposition. He concluded (Oxley, 1953, p.31) that the Cow Head, in its type area, was indeed a "thrust breccia" and following Schuchert and Dunbar interpreted the shale and limestone beds as large blocks. He emphasized (Oxley, 1953, p.33) that the breccias should not be treated as sedimentary rocks but as tectonic phenomena. One of Oxley's main contributions was the discovery of agnostid trilobites at the Broom Point South section. He told Kindle, who was then working in the area for the John Fox oil interests, of his discovery and, on closer inspection, Kindle recognized the trilobites as forms typical of the late Middle Cambrian. More importantly, it was at Broom Point South that Kindle recognized that the Cow Head contained bedded deposits and was not as chaotic as previously thought (Kindle, personal communication, 1983).

Nelson (1955) mapped between Portland Creek and Port Saunders, north of Cow Head, but included in his report some comments on the Cow Head Group. He emphasized its chaotic nature and described the lateral passage of Table Head Group strata into those of the Cow Head (Nelson, 1955, p.43). He broke from Schuchert and Dunbar by attributing the formation of the breccias "to localized earthquakes affecting semiconsolidated limestone muds" (Nelson, 1955, p.44). The Cow Head described by Nelson is not regarded as fully equivalent to the Cow Head in this report, but includes the younger Cape Cormorant Formation (Klappa et al., 1980).

A most significant advance in the understanding of the Cow Head area was the publication of Kindle and Whittington's "Stratigraphy of the Cow Head region, western Newfoundland" in 1958. Several important conclusions stem from this work. Kindle and Whittington demonstrated beyond a doubt that their redefined Cow Head Group was an orderly sequence of rocks. It was not of Middle Ordovician age exclusively, but ranged from late Middle Cambrian to Middle Ordovician. It was, like Johnson's groups, a facies equivalent of the platformal sediments exposed nearby. For the first time, the strata at Cow Head were systematically assigned to units; the 14 beds of Kindle and Whittington, and the paleontological data from the conglomerates and the interbedded shales and limestones were integrated into a stratigraphic scheme. They concluded that fossiliferous boulders from any one layer contain trilobites of the same limited age and are about the same age as the immediately underlying strata. The boulders were of shallow water origin but came to rest in deeper water at the foot of a long lived submarine scarp. They described the trilobite faunas known to them in great detail (Kindle and Whittington, 1958, 1959; Whittington, 1963; Kindle, 1982) and for the first time gave a stratigraphic account of the graptolite faunas (Kindle and Whittington, 1958). The shale and limestone interbeds, regarded by previous workers as blocks, yield graptolites that Kindle and Whittington could place in the Australian zonal scheme, thus allowing correlation between this and the shelly shelf faunas of the blocks. They regarded the Cow Head as a typical flysch deposit except that instead of siliciclastics, carbonate is the main component.

As noted by previous workers, the conglomerates of the Cow Head are overlain by sandstone. Kindle and Whittington (1958) referred to these as "the unnamed green sandstone" and regarded them as equivalent to the Humber Arm Group sandstones. They did, however, note that there is no evidence that green sandstone underlies the Cow Head. The ambiguous contact at Lower Head between the Cow Head Group and the green sandstone is shown as a fault (Kindle and Whittington, 1958, p.335).

The regional relationships of the Cow Head still presented problems. Since autochthonous carbonates crop out to the east of Cow Head, Kindle and Whittington (1958, p.339) tentatively concluded "to the east of the Cow Head Group facies a limestone-dolomite facies has been deposited during at least part of the same time". They evidently rejected Johnson's hypothesis of massive thrusting from the east to bring the two facies together. Furthermore, they correlated the unnamed green sandstone on top of the Cow Head with the Humber Arm and with the green sandstone at the top of the Table Head section (Whittington, personal communication, 1966). Since there is clearly no thrust between the sandstones and the Cow Head or Table Head it was difficult for Kindle and Whittington to accept the allochthonous nature of the Humber Arm and Cow Head (Whittington, personal communication, 1966).

Baird (1960a) mapped the west half of the Sandy Lake sheet in which the Cow Head occurs and gave an account of the Cow Head breccia (Baird, 1960b) with a discussion of its nomenclature and origin. He was the first to treat the rocks of the Cow Head Group as sediments. He concluded that the breccias represent submarine talus derived from fault scarps, and that movements on the scarps triggered the flow of debris into deeper water. Baird did not entertain Johnson's allochthonous hypothesis nor, in common with previous workers, did he separate the Cape Cormorant breccias from the Cow Head Group.

The basis of the interpretation of the modern Cow Head was formulated in an important paper by Rodgers and Neale (1963). They proposed that much of the Humber Arm Series and most of the Cow Head were not younger than the carbonate sequence but of the same age. To explain these relationships, they proposed long-distance transport of the Humber Arm and Cow Head from a site east of the Long Range to its present position. This interpretation, similar to that of Johnson (1941), was inspired largely by the paleontological work of Kindle and Whittington (1958, 1959) as well as an overall similarity between the geology of the Taconic region of New England and west Newfoundland.

The boundaries of the thrusted masses caused some concern to Rodgers and Neale. They appreciated that the carbonate-clastic contact was not the boundary of their proposed klippen and that some of the Humber Arm and Cow Head of previous workers did indeed rest conformably above the carbonate sequence. The sandstones, shales and limestone carbonates at Cape Cormorant were included in the autochthon (Rodgers and Neale, 1963, p.721) even though their Figure 1 (p.714) shows these rocks as transported. The northern boundary of the Humber Arm Allochthon depends on the interpretation of the limestone conglomerates at Portland Creek and Daniel's Harbour. Rodgers and Neale (1963, p.714) included these rocks in the allochthon but it seems more likely that these conglomerates are part of the autochthon and equivalent, though lithologically distinct, to the conglomerates of the Cape Cormorant Formation (Klappa et al., 1980). The northern limit of the allochthon is not yet determined with precision due to the lack of exposure in critical areas.

Stevens (1970) briefly reviewed previous interpretations of the Cow Head Group and suggested that all the transported rocks in west Newfoundland be referred to the Humber Arm Supergroup that might be divided into the Curling Group with minor limestone conglomerate and the Cow Head Group with much limestone conglomerate. He considered that the Cow Head Group had been deposited close to the continental margin whereas the Curling Group represents a more distal deposit. Stevens recognized three main occurrences of Cow Head strata: the main outcrops at Cow Head, conglomerates in the Curling Group, and an autochthonous sequence of conglomerates exposed near the top of the autochthon. He suggested the source of the conglomerates at Cow Head was a belt of carbonates deposited at the very edge of the carbonate platform that probably is nowhere exposed today.

Callahan (1974), Jansa (1974) and Fahraeus et al. (1974) discussed various aspects of the sedimentology of the Cow Head Group. Callahan's conclusion that the slope on which the Cow Head was deposited sloped to the south and southwest was later elaborated on by Hubert et al., (1977). After a detailed investigation of the main outcrop areas of the Cow Head, Hubert et al. (1977) concluded that it represented an allochthonous slope sequence transported from the southeast. They agreed with Kay (1969) that the Cow Head was a separate klippen to that containing the Curling Group and with Rodgers and Neale (1963) that the klippen was emplaced by gravity sliding during the Middle Ordovician. They differed from early workers, however, by suggesting a complex, pre-emplacement paleogeography for the Cow Head Group.

The allochthonous nature of the Cow Head

The Cow Head is only one of a series of Cambro-Ordovician carbonate conglomerates that occur at various localities in the Appalachian orogen (Rodgers, 1968; Keith and Friedman, 1977) and Cordilleran orogen (Cook and Taylor, 1977; McIlreath, 1977; Krause and Oldershaw, 1979). It would appear that this facies was a widespread, but now only rarely exposed, lithology along the margins of the ancient continental margin of North America. Unfortunately, in the northern Appalachians many of the occurrences are not well exposed and few have had modern paleontological attention. It is difficult to determine from the literature whether or not the conglomerates are analogous to the Cow Head and of Cambrian and Ordovician age, or if they are autochthonous or parautochthonous and related to the conglomerates of the Cape Cormorant Formation and of medial Ordovician age. Not all resemble the Cow Head in so much as any one conglomerate layer yields a majority of fossils of similar age.

According to Rodgers' (1968) concept, the conglomerates were deposited in relatively deep water near the edge of a shallow water carbonate bank. He drew an analogy with the Bahama Banks with their abrupt ocean-facing slopes. We accept this comparison, but with the reservation that there would be some differences, since the organisms living along the bank in Cambro-Ordovician time and the carbonate budget were quite different from those of modern platform margins.

There are only a few places in the Appalachians where the conglomeratic facies can be interpreted as interfingering with the carbonate bank (Rodgers, 1968, p. 144-145). Cow Head is not one of them. It is interesting to note that all of the possible examples of interfingering are of Cambrian age, a time when the edge of the bank was probably a sloping ramp rather than a steeply rimmed slope as it was during the Lower Ordovician.

Rodgers (1968, p. 146) presented two possible environments of deposition for the conglomerates. They may have been deposited in deep water embayments into the bank so that the bank edge was highly irregular, or they may have been transported into their present day positions from original sites of deposition oceanward of the bank. Rodgers prefers the second alternative but does suggest the possibility that the Conestoga limestone basin of Lancaster County, Pennsylvania, might represent an embayment of deep water deposits into the bank, somewhat like the Tongue of the Ocean or Exhuma Sound in the Bahamas today. He does, however, prefer the idea that in the Conestoga area an originally simple continental margin was tectonized to produce a new complex form.

In general, then, it would seem that in the northern part of the Appalachians four main styles of Cambro-Ordovician carbonate conglomerates are represented:

1) Conglomerates that interfinger with shallow water carbonates, with the whole assemblage either in place or transported as a unit.

2) Conglomerates transported to rest on top of the carbonate bank from a site oceanwards of the bank.

3) Conglomerates that were deposited in deep embayments into the bank and are now autochthonous or parautochthonous.

4) Autochthonous or parautochthonous conglomerates deposited over the bank during the early stages of the Taconic Orogeny as the bank foundered.

The conglomerates in the Cow Head Group, as defined by Kindle and Whittington (1958), fall into at least two of these categories.

Since the conglomerates around Daniels Harbour and Portland Creek and along the mountain front between Rocky Harbour and Western Brook Pond are of Table Head and perhaps younger age, we have removed them from the older conglomerates and equate them with the coeval autochthonous conglomerates of the Cape Cormorant Formation. These conglomerates contain only clasts of Table Head lithology, with minor green sandstones. They are unlike the type section at Cape Cormorant (Klappa et al., 1980) but are identical to massive conglomerates at Black Cove, northwest of Stephenville, northeast of Port-au-Port Peninsula (Fig. 1).

Johnson (1941) and Rodgers and Neale (1963) first suggested that some or all of the Cow Head had been transported from its original site of deposition at some distance to the east. The main evidence for allochthons used by these authors was the great facies contrast between the Cow Head and the coeval rocks of the platform. They argued that the rapid facies changes that represent outcrop patterns imply that an autochthonous interpretation is extremely unlikely. The Cow Head must therefore be transported.

It is well known that lateral changes from bank sedimentation to deep-water sedimentation are often startlingly abrupt (James and Mountjoy, 1983). It would seem that rapid changes are not *prima facie* evidence of transportation of deep water sediments; they are characteristic of carbonate bank margins.

Additional evidence used by Rodgers and Neale (1963) included the facies distribution within the Cow Head Group. They argued that since the coarsest conglomerates are confined to western exposures, the source of the limestone clasts must have lain to the west. It is difficult to refute this proposition, but it must be remembered that Precambrian basement is overthrust onto the Cow Head (Williams et al., 1985) and that the eastern half of an essentially autochthonous deep water basin could be now hidden under the basement (see following section). The evidence of facies distribution within the Cow Head, then, cannot be considered as absolute proof of the exotic nature of the Cow Head Group.

One major argument given by Stevens (1970) for the allochthonous nature of the Cow Head was the age of the first occurrence of green sandstone in the sequence. He assumed that since the sandstone contains detritus from ophiolite and island arc terranes it was derived from a source that lay oceanwards. The stratigraphic ages of the sandstone, determined by graptolites immediately beneath the various sequences, suggested that the sandstone was transgressive, appearing first in the Curling Group, then on top of the Cow Head, and finally on top of the Table Head. More recent work seems to confirm this. The basal beds of the flysch in the Curling Group contain graptolites equivalent to Castlemainian Zone 2 (Ca2; J. Botsford and S.H. Williams, personal communication, 1984). These beds are several graptolite zones older than the oldest flysch beds in the Cow Head which are equivalent to Darwillian Zone 1 (Da1). The flysch is not known above the Table Head before the third Darwillian Zone (Da3), usually correlated with the late Llanvirn (Finney and Skevington, 1979).

The early occurrence of the sandstone above the Cow Head as compared with the autochthonous sandstone strongly implies a larger paleogeographic separation of the two successions than exists now, and it is compatible with transportation of the Cow Head from the east, but does not prove it. It is possible that since the Cow Head facies reflects deposition in relatively deep water, turbidites depositing the sandstones reached these deeper basins first.

Current models for the emplacement of the Humber Arm Allochthon include the subduction of the ancient continental margin beneath an ophiolite sequence of rocks, probably a fore-arc basin (Searle and Stevens, 1984). Subduction of the margin with its thick sedimentary sequences would have resulted in the development of an accretionary prism much like that shown by Stevens (1970). Stevens (1965, 1970) speculated that a single sheet of ophiolite formerly covered the whole of the Humber Arm Allochthon and progressively accreted beneath it the various slices that compose the allochthon.

There is no evidence, on an outcrop scale, that any great thickness of rock has ever covered the Cow Head Group. It seems not to have been under an ophiolite sheet, at least not a very thick one, for any significant length of time. Evidence for shearing within the Cow Head is minor and cannot unequivocally be attributed to the emplacement of an allochthonous accretionary prism. Fossils such as graptolites, trilobites, and inarticulate brachiopods are moderately flattened, but only rarely sheared. Conodont colour alteration indices (CAI) are about 1.5 in the Cow Head Group compared with higher indices from carbonate rocks farther south in the Humber Arm Allochthon (Nowlan and Barnes, in press). It would seem that the Cow Head was not emplaced as part of a subophiolitic accretionary prism, at least not as presently envisaged.

Interpretation of the Cow Head is made still more difficult by the lack of any unambiguous outcrops of its basal contact. No single section demonstrates a tectonic juxtaposition of the Cow Head and undoubted autochthonous rocks. The only exposed contact of the base of the Cow Head are at Lower Head where Kindle and Whittington (1958) interpreted them as a fault against green sandstone. The other contact is exposed at the southern limit of the Cow Head Group where it tectonically overlies green sandstone but passes upwards into a similar green sandstone (James and Stevens, 1982, p. 43). This region is presently interpreted as poorly exposed mélange.

Despite the above discussion, we support the view that the Cow Head Group has in fact been transported from the east. Rodgers and Neale's (1963) argument of facies contrast between the Cow Head and the platformal carbonates is given more weight by the fact that many types of carbonate rock and fossils are not to be found in the nearby platformal carbonate rocks. In fact, some of the rock types and shelly fossils are not known in place in any of the carbonate bank sequences anywhere in the Appalachians. The platformal carbonates of the bank that outcrop near the Cow Head Group are no different than elsewhere. Furthermore, the similarity of the distal facies of the Cow Head and parts of the undoubtedly allochthonous Curling Group strongly suggest that the Cow Head is also allochthonous.

Present interpretation of regional geology

Since this study began in 1980 there have been several additional studies which have considerable bearing on the origin and deposition of Cow Head rocks. Of particular importance to regional geology is the mapping project by H. Williams, whose purpose is to document the whole Humber Arm Allochthon, and which has led to several recent reports (Williams and Godfrey, 1980; Schillereff and Williams, 1979; Williams, 1981; Williams et al., 1982, 1983; Quinn and Williams, 1983; Williams et al., 1984; Nyman et al., 1984). This work, which began in the south, is being completed in the Cow Head region in conjunction with the authors (Williams et al., 1985) and the following summary reflects current thinking (Fig. 3).

The Cow Head Group forms roughly the northern third of the allochthon. South of Bonne Bay (Fig. 1) the allochthon is complex, with individual slices of sedimentary and/or volcanic rocks separated by mélange. North of Bonne Bay, however, the sequence appears to be much simpler, composed only of structurally repeated sections of the Cow Head and overlying green sandstone (Lower Head Formation; Fig. 3). Here the allochthon appears to be separated from coeval autochthonous rocks by the mélange. This mélange extends along the foot of the Long Range, but becomes narrower northward as it is progressively overridden by crystalline rocks and autochthonous sediments that moved a few kilometres westward along steeply dipping reverse faults or thrust faults. From Western Brook Pond to Parsons Pond the Long Range complex abuts rocks of the Humber Arm Allochthon. The northern end of the allochthon is poorly defined, mainly because of poor outcrop.

In this area the Long Range Complex comprises Precambrian crystalline rocks that are mainly massive to foliated granite cut by mafic dykes. This basement is overlain, in the Gros Morne area, by the Lower Cambrian Labrador Group, which is composed of a thin basal sandstone of variable composition (Bradore Formation), a thick sequence of shale, siltstone and limestone (Forteau Formation) and a thick sandstone with minor shale and siltstone (Hawke Bay Formation; James and Stevens, 1982). These sediments, together with overlying carbonates of the St. George and Table Head groups, outcrop as a series of isolated, steeply dipping to overturned, structurally telescoped slivers in front of the Long Range crystalline rocks, along the eastern margin of the Humber Arm Allochthon. At the northern end, between Parsons Pond and Portland Creek Pond, the outcrop belt widens (Fig. 3) and these strata are upright and dip gently westward.

The shale and graded sandstone that overlie the Table Head limestone, and which are stratigraphically equivalent to the Black Cove Formation (Klappa et al., 1980) or Goose Tickle Formation (Cooper, 1937; Stevens, 1970), are informally called the Norris Point formation in this area. A prominent ridge of carbonate breccia south of Western Brook Pond is assigned to the Cape Cormorant Formation at the top of the Table Head Group (Klappa et al., 1980). Similar breccias occur at Berry Head and southward where they are interpreted as large blocks structurally incorporated in mélange. The Cape Cormorant also occurs north of Portland Creek and at Daniels Harbour, but the stratigraphic relationships there are uncertain.

The Rocky Harbour mélange, which overlies the Norris Point formation and forms the base of the allochthon in the Cow Head area, consists of grey scaly shale and clasts ranging from centimetres to kilometres in width. Most blocks are sandstone and siltstone, but limestone, limestone breccia and buff weathering dolostone are also common. The largest blocks are of Cape Cormorant Formation or Irishtown Formation (Curling Group) lithologies. The mélange is unknown north of Western Brook Pond and is absent or unexposed between repeated belts of the Cow Head Group north of Green Point (Fig. 3).

The rocks which form the ridges in the allochthon are remarkably undeformed. They consistently dip southeast and face southeast, except where locally folded and overturned. The repetition of northeast-trending belts of Cow Head-Lower Head rocks is currently interpreted as thrust imbrication of southeast-facing, southeast-dipping sections. Thrust contacts are exposed only in a few places. On the southwestern shore of St. Pauls Inlet, Lower Head sandstones dip southeast beneath Cow Head rocks. The contact is a confused zone of upright, folded green and red shale, green sandstone and minor dolomite, no more than 10 m wide. Cow Head strata above are tightly folded for another 10 m and the overlying beds are little deformed. Likewise, along the western shore of Lower Head, southeast-dipping sandstones of the Lower Head Formation are in structural contact with overlying Cow Head strata. The contact is a series of tight folds in shale and a 10 to 100 m wide fault zone (see following discussion).

The ridges can be grouped into separate belts.

1. *The Shallow Bay Belt.* This series of ridges in the northeastern part of the area comprises rocks on Cow Head Peninsula, Stearing Island, White Rock Islets, as well as Lower Head and extends northward to the tickle at Parsons Pond. Most strata dip to the southeast, but this simple picture is complicated locally by folding parallel to the trend of the ridges. The general style is illustrated both at Cow Head and Lower Head where southwest-plunging folds are bounded by high angle faults.

2. *The Broom Point Belt.* This belt has the poorest geomorphic expression, in large part because of an extensive Pleistocene and Holocene sand dune complex that parallels the coast in this area, obscuring much of the subtle relief. Extensive exposure at Broom Point disappears northward, is represented only by small outcrops in St. Pauls Bay and expressed by subdued relief between St. Pauls Bay and Parsons Pond.

3. *The Central Ridge Belt.* This wide and prominent series of narrow ridges runs from Martin Point in the south through the entrance to Western Brook Pond, across St. Pauls Inlet north to and across Parsons Pond. In outcrop they all have the same general style: each ridge is formed by eastward-dipping beds of Cow Head; the eastern side is a conformable succession passing up into Lower Head sandstone and shale; the western side is a small cliff and the contact with underlying strata is covered. This pattern is locally confused by folding on the southern side of St. Pauls Tickle. The outcrop at Martin Point is clearly structurally offset from this trend.

4. *The Inner Ridge Belt.* The easternmost series of outcrops, which extends from Green Point in the south all along the front of the Long Range, is more deformed than the other belts. From Green Point through Western Brook Pond, strata still dip to the southeast, but are overturned. This pattern changes across St. Pauls Inlet where they are overturned on the south shore but form a syncline on the north shore, a pattern which continues north through Parsons Pond.

The rocks have potentially been subjected to five phases of deformation: (1) during deposition by slumping, sliding or collapse of the continental margin; (2) during late stages of deposition by flexure and faulting of the foredeep; (3) during assemblage of the thrust slices prior to transport; (4) during transport westward to their present position in Middle Ordovician (Whiterock) time; and (5) during Devonian time by complex Acadian thrusting.

In general, however, most of the imbrication appears to be Ordovician whereas overturning and formation of steep, westerly inclined folds that increase in abundance from west to east are thought to be mainly Devonian (Williams et al., 1985).

Lower Head

Lower Head is one of the few places where the Cow Head Group (Shallow Bay Formation) and the Lower Head Formation not only outcrop together, but the structural relationships are also exposed. Because exposed structural contacts are rare, this has been regarded as a critical area ever since the earliest studies of Richardson (Logan, 1863). Previous interpretations have been presented in earlier sections and the general structure, which is basically correct, is outlined in Kindle and Whittington (1958, p. 335) as an eastern anticline and western syncline, whose axes trend northeast.

The anticline is complex (Fig. 6) and the cove is covered by beach sands. The eastern limb is apparently coherent, but the overlying Lower Head sandstones are nowhere seen in actual contact with the Cow Head; even at lowest tide they are separated by about 30 m of cover. The western limb is a vertical ridge of Bed 14 conglomerate with sheared sediments on either side. The sediments below, on the antiform side, are highly tectonized and barely recognizable as sheared phacoids. Nevertheless, graptolites have been recovered from the argillites, and are similar, but not identical to, those from Bed 11 beneath Bed 14 on the eastern limb. The vertical Bed 14 conglomerate on the western limb is different from that on the eastern limb; it is roughly 1/5 as thick and clasts are several orders of magnitude smaller.

The syncline is much more coherent as a small structure with a faulted eastern limb and a saddle of Lower Head sandstone in the core. The western limb, however, is truncated by a high angle shear zone oriented at a slight angle to the axis of the syncline so that progressively younger beds of the Cow Head are exposed northward along the shore. These beds exhibit parasitic folds which plunge to the southwest.

The western boundary fault lies in the intertidal zone and varies from a distinct crush zone against the conglomerate to a zone of deformation over 100 m wide when in contact with shale to the north. A few isolated blocks of Cow Head sit in this tectonized shale. West of this shear zone is a 200 to 300 m wide intertidal platform of well exposed, undeformed Lower

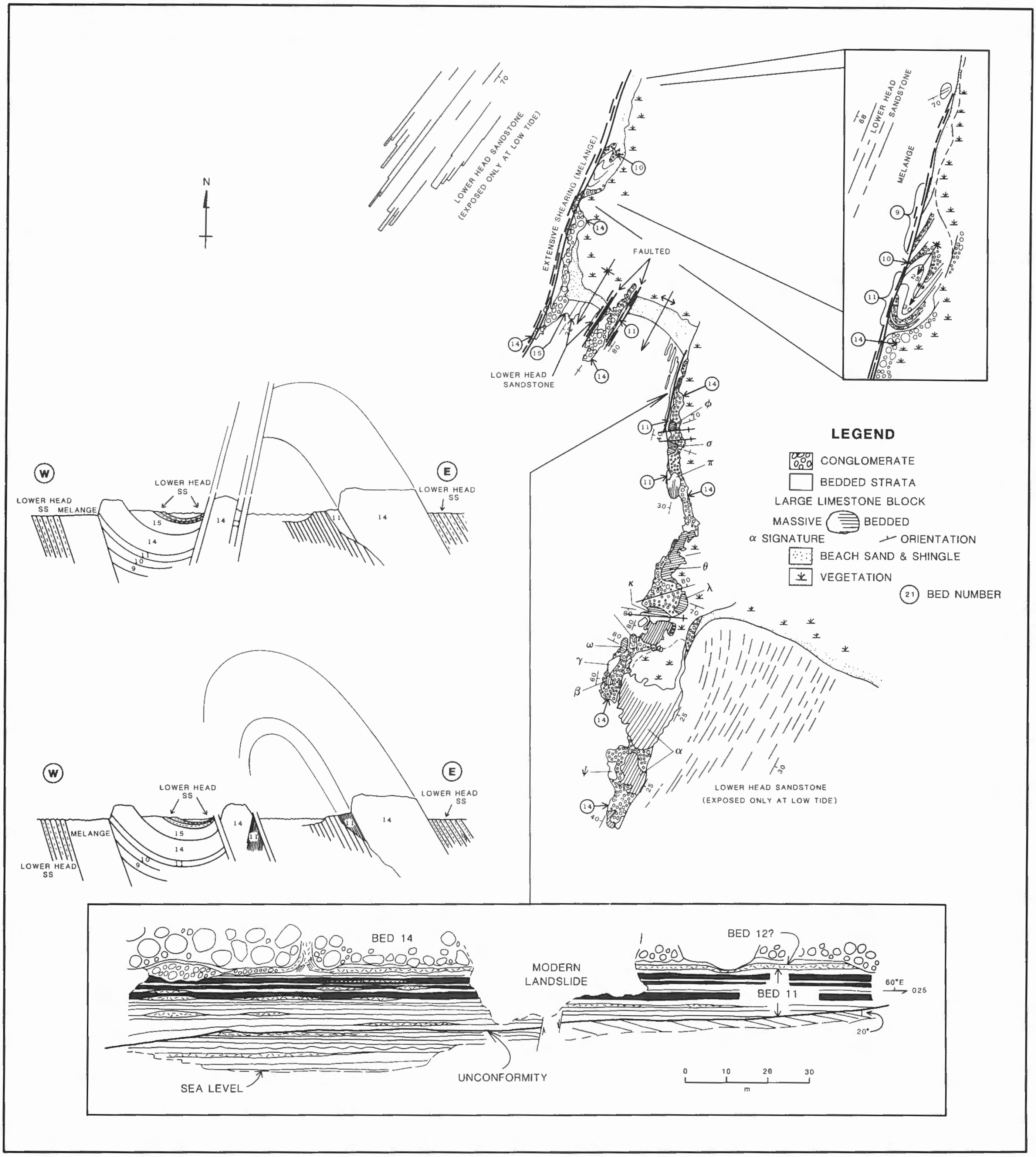


Figure 6. A geological map of Lower Head with an interpretation of the structure and a detailed sketch of the unconformity (inset).

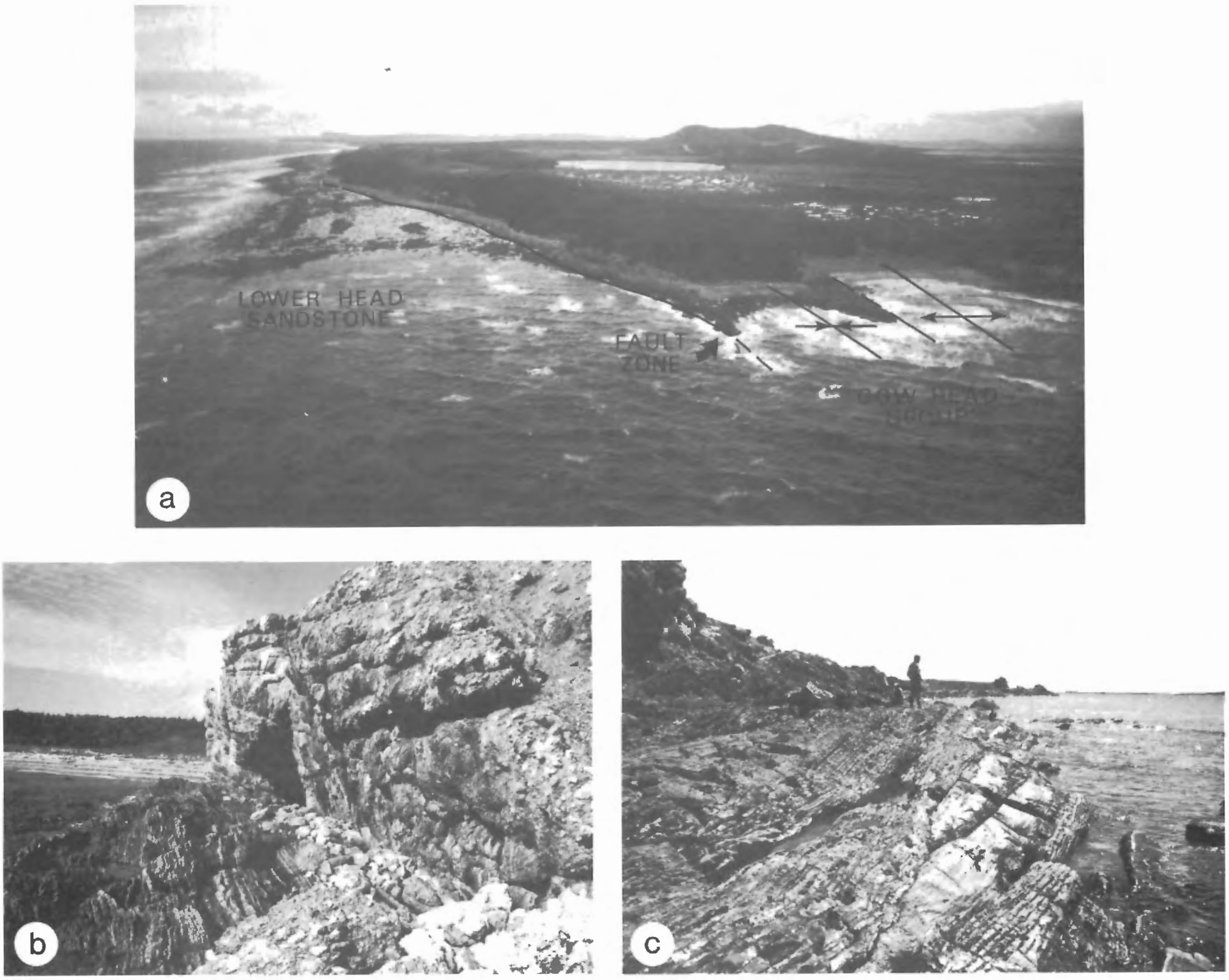


Figure 7. Lower Head.

a) An aerial view looking north of Western Lower Head illustrating the location of the syncline and anticline, as well as the extensive low tide platform of Lower Head Sandstone west of a major north-south fault. (GSC 191435)

b) A massive cliff 10 m high of Bed 14 conglomerates (right) and intertidal platform of thin-bedded limestones and shales (Bed 11) on the eastern side of the antiform (locality of detailed sketch in Figure 6. (GSC 191436)

c) The intertidal platform illustrated in (b), looking south and illustrating the unconformity (centre foreground) which separates Bed 11 strata (left) from strata of unknown age (right; GSC 191437)

Head sandstones (Fig. 7). The nature of this fault is unclear: in some places it looks like a high-angle reverse fault; in other places it resembles zones of mélange associated with thrust faults elsewhere in western Newfoundland.

This whole picture is further complicated by an hitherto unrecognized unconformity (Fig. 6, 7). The intact sequence of Bed 11 and Bed 14 on the eastern limb of the anticline is separated from green shale, buff siltstone and grey ribbon limestone of unknown age below by a pronounced angular unconformity (Fig. 6). The sediments beneath contain no macrofossils and do not yield conodonts, so, on the basis of negative evidence in an otherwise fossiliferous succession, are assumed to be Cambrian. Beds on both sides of the unconformity are truncated and strata beneath are deformed and fragmented, indicating that this is not a depositional unconformity but a surface of movement. No clear sense of movement direction can, however, be determined. It appears that the whole Bed 11 - Bed 14 complex which forms the eastern ridge of Lower Head is probably an enormous slide mass. Since Bed 14 here contains by far the largest blocks in the Cow Head Group it probably represents a detached fragment of very proximal, upslope facies that is nowhere else represented in the Cow Head. While this explains the dramatic difference in style between Bed 14 conglomerates on either side of the anticline (they are probably not the same unit), it raises the possibility that the structure is not an anticline at all.

At present two explanations seem possible (Fig. 6). The first is that the structure is much as Kindle and Whittington (1958) have outlined it, except that the limbs are much more faulted and tectonized than they realized. The second is that there is a syncline to the west but the sequence on the east is not an anticline but a completely unrelated east-facing sequence, faulted into place and fortuitously containing a coeval, but quite different, stratigraphic succession.

STRATIGRAPHIC NOMENCLATURE

Cow Head Group

Existing nomenclature

Strata corresponding to the present Cow Head Group were first assigned by Logan (1863), on the basis of field work by Richardson, to division P of the Quebec Group. The first detailed stratigraphy was given by Schuchert and Dunbar (1934) who, although incorrect in their assessment of the stratigraphic succession, recognized the presence of two separate units in the area, the Cow Head Limestone Breccia and the Green Point Formation.

The Cow Head Limestone Breccia, although containing both Cambrian and Ordovician clasts, was thought to be a Middle Ordovician deposit. The type area was defined as the Cow Head Peninsula and the section along the southern shore described (Schuchert and Dunbar, 1934, p. 74). They also mapped the breccia on Stearing Island, on White Rock Islets and at Lower Head. The conglomerates at Portland Creek (Cliffy Point and Portland Creek Head; Fig. 1) and at Daniels Harbour, because of their assumed similar age and their coarseness, were included in the Cow Head. These conglomerates are now recognized as part of the Cape Cormorant Formation (Klappa et al., 1980), an autochthonous Middle Ordovician unit.

The Green Point Formation (used interchangably with Series by Schuchert and Dunbar, 1934), a sequence of shales and limestones which outcrop at Green Point (Fig. 8), was thought to be wholly earliest Ordovician in age. The formation was not fully defined there because Schuchert and Dunbar felt that the recessive nature of the sediments together with structural complications meant the section was incomplete. Nevertheless, they recognized that similar strata occurred to the north along the shoreline to Broom Point and at Western Brook Pond, St. Pauls Inlet, Parsons Pond, Middle Arm of the Bay of Islands and at West Bay, Port-au-Port. The Green Point was described in a general way as a weak, shaly unit in which argillaceous and silty shales of olive-green to dark grey colour predominate, their percentage varying locally from perhaps 45 to 75% of the whole. Red shale is minor. In addition, there are thin interbeds of slabby light grey siltstone and earthy limestone and thicker interbeds of intraformational conglomerate made up of flattish fragments of these harder layers. A critical observation, that the strata at Green Point are overturned, was not made and this oversight has led to much confusion in subsequent publications on the stratigraphy.

Johnson (1941), recognizing that strata north from Green Point to Broom Point, although lithologically similar, were in large part younger than Early Ordovician, removed them from the Green Point Formation and called them the St. Pauls Group. It was not recognized that these same younger rocks are present but poorly exposed at Green Point and, because the section was thought to be the right way up, the beds "below" the basal Ordovician were never searched for graptolites. Johnson also first defined the greywackes that lie above both the Cow Head and the Green Point/St. Pauls as the Western Brook Pond Group. On his 1948 unpublished map, however, he abandoned Western Brook Pond Group in favour of the Humber Arm Group.

Oxley (1953) attempted to define more precisely the Green Point and St. Pauls by making them both groups and defining type sections. The type section of the Green Point was defined at Martin Point and is roughly equivalent to units 1 to 41 of this study. The St. Pauls was nowhere complete, but sections were described at Black Brook and St. Pauls Tickle. Unfortunately, the base of the St. Pauls was not defined on lithology but on the appearance of *Isograptus caduceus* or above the uppermost *Staurograptus* and even Oxley (1953, p. 16) recognized that "difficulties in separating the two amidst structural complexities and discontinuous outcrops in much of the area preclude mapping as discrete units".

Kindle and Whittington (1958, p. 335) used the term Cow Head Group for "about 1000 feet of limestones with interbedded shales and limestone conglomerates; the lowest strata are

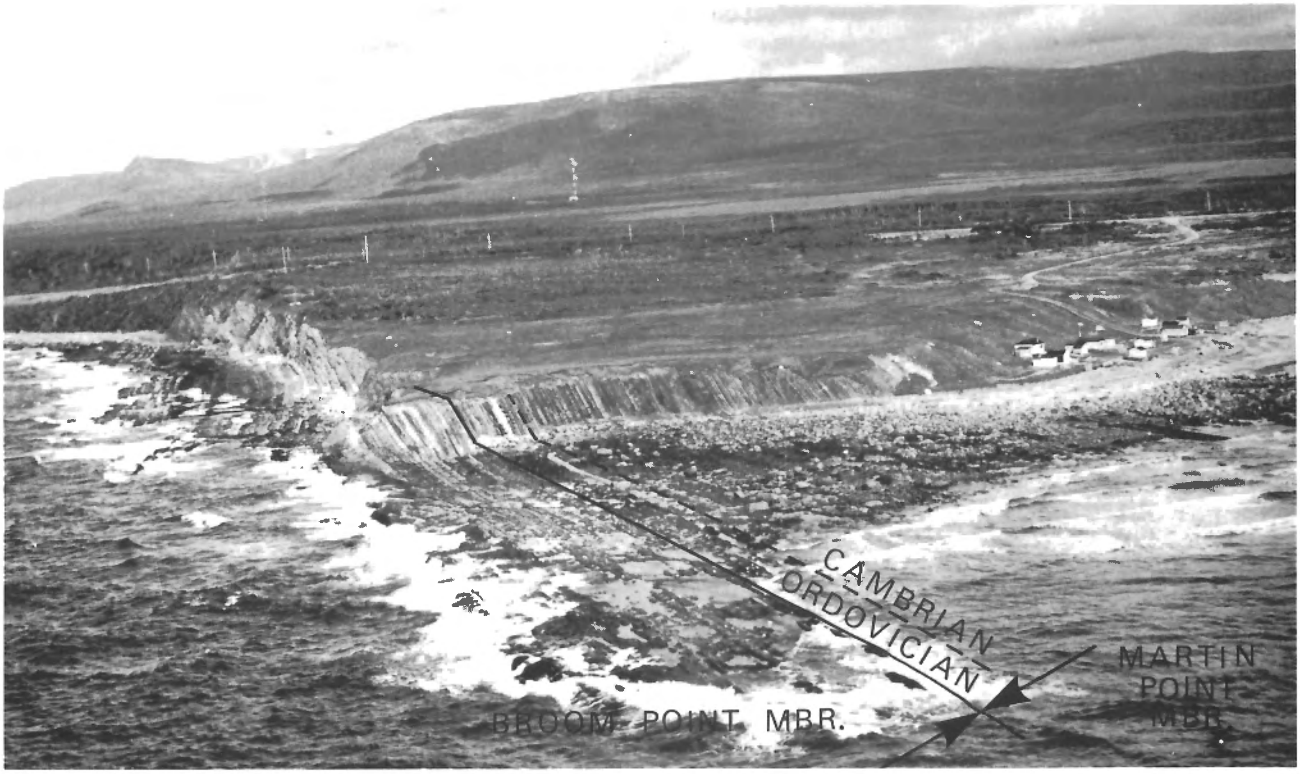


Figure 8. An aerial view of Green Point, looking east with the new stratigraphic units, Martin Point Member, Broom Point Member, as well as the Cambro-Ordovician boundary marked. The sequence is overturned, a fact not recognized by most previous workers (photograph J. Botsford; GSC 191438)

of Middle Cambrian age, the youngest early Middle Ordovician (Whiterock Stage)". They further proposed (ibid., p. 317) that pending "further studies which may give a more detailed picture of the stratigraphy, it seems simplest to use the name Cow Head Group (an emendation of Schuchert and Dunbar's Cow Head Limestone Breccia) for this Middle Cambrian to Middle Ordovician sequence, rather than introduce new names". They specifically did not use either an old or new name for the green greywackes that overlie the Cow Head but instead referred to them as the "unnamed green sandstone". At Cow Head Peninsula the sequence was subdivided into a series of 14 beds, with each bed characterized by specific paleontological and/or lithological characteristics (Fig. 4). These beds were not correlated away from the peninsula.

Kindle and Whittington (1958, p.336) assumed the sequence at Green Point was the right way up and not overturned and found fossils (Early Ordovician graptolites) only in the limestones at the point itself. They did not search the beds to the north because they thought these strata were Cambrian, whereas because of overturning, they are Ordovician. Similarly, they found only graptolite fragments in the shales south of the point, which they assumed were Ordovician, but which are Cambrian. They limited the Green Point Formation to the zone yielding the characteristic Early Ordovician fauna, roughly equivalent to units 23 to 29 of this study. Reinvestigating Oxley's defined section at Martin Point, they concluded that it was Upper Cambrian through Lower Ordovician in age and thus equivalent to a large part of the Cow Head Group. Even though this section contained the Green Point Formation as newly defined, it appeared to them to be an unwarranted extension of the Green Point as they had redefined it.

In summary, using the most recent nomenclature of Kindle and Whittington (1958), the Cow Head Group embraces all of the sediments under discussion with only one formation, the Green Point Formation restricted to several tens of metres of limestone and shale at Green Point proper and 14 beds defined at and applicable only to the section on Cow Head Peninsula.

Proposed nomenclature

The Cow Head Group is characterized by rapid facies changes, lenticular units and abundant evidence of synsedimentary erosion. These are attributes which mitigate against the establishment of units which can be mapped regionally at a scale of 1:50 000. The Cow Head could be subdivided into

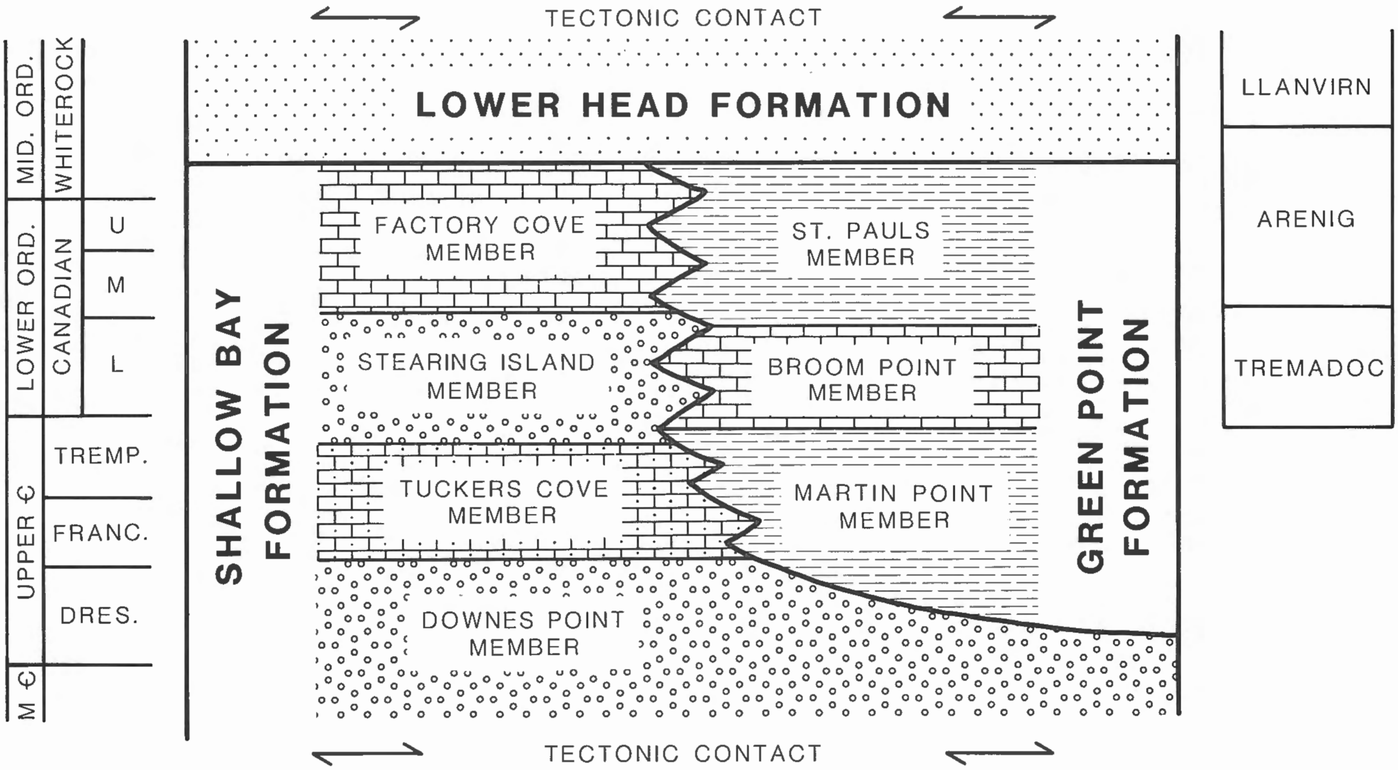


Figure 9. A simplified diagram of the different stratigraphic units which comprise the Cow Head Group.

numerous local formations, but it is felt that this would lead to unnecessary confusion and be contrary to the spirit of the Code of Stratigraphic Nomenclature.

Regardless, two major contemporaneous facies are mappable in the area, a northwestern coarse grained, conglomeratic facies and an eastern and southeastern fine grained shaly facies. These correspond in a general way to the Cow Head Limestone Breccia and the Green Point Formation, respectively, as described by Schuchert and Dunbar (1934). We propose that these regionally mappable and distinctive, though heterogeneous lithologies be recognized as formations (Fig. 9). Since the Cow Head Group is now used as the name for the whole sequence, the predominantly coarse grained lithologies will collectively be called the Shallow Bay Formation and the finer grained lithologies will be named the Green Point Formation. These names have been informally introduced by Williams et al. (1985). Distinctive packages of strata that have gradational boundaries and cannot be traced throughout the area are delineated as members; four in the Shallow Bay Formation and three in the Green Point Formation.

The definition of the Cow Head Group is as outlined by Kindle and Whittington (1958, p. 335-336), except that it is now made up of two formations as described below. The lower contact is nowhere unambiguously exposed. Where contacts are present between higher parts of the Cow Head and underlying green sandstones such as at Lower Head and Lobster Cove Head, they are faulted or lie in mélange.

Shallow Bay Formation

A sequence of limestone conglomerate and calcarenite with sections of interbedded limestone and shale in the upper part comprises the Shallow Bay Formation. The thickness of the formation ranges from 100 to 300 m. The formation stratotype is composite. The basal beds occur at Broom Point South (UTM Zone 21, 437700, 5520300) and comprise units 1 to 12 of that section (Fig. 10, in pocket). The bulk of the stratotype begins on White Rock Islets (UTM Zone 21, 441800, 5530300; Fig. 11a) and continues upsection along the north shore of Cow Head Peninsula encompassing both the Beachy Cove and Point of Head sections (UTM Zone 21, 443400, 5531500, Fig. 12, in pocket). The most extensive outcrop area is around Shallow Bay and the formation is named for this area. The basal contact is not exposed. The lowest beds at Broom Point form the eastern limb of an anticline whose core is eroded and now forms the beach at Sandy Cove (Fig. 10). The upper boundary with the Lower Head Formation is observable in Factory Cove, Cow Head Peninsula (Fig. 4) only at the lowest tides. The rocks are synonymous with the Cow Head Limestone Breccia of

Schuchert and Dunbar (1934) and the Cow Head Group as defined by Kindle and Whittington (1958) at Cow Head. The strata range in age from late Middle Cambrian to early Middle Ordovician. The formation, or parts of it, are recognizable at Cow Head Peninsula, Stearing Island, White Rock Islets, Lower Head, Broom Point, White Point, Gulls Marsh, Martin Point and Snug Harbour in St. Pauls Inlet.

The Shallow Bay Formation is subdivided into 4 members, which are described in ascending stratigraphic order below.

Downes Point Member. This unit is composed of the basal beds of the Shallow Bay, combining the lowest beds at Broom Point South (units 1 to 12; Fig. 10) the partly equivalent and succeeding strata at White Rock Islets (Fig. 11a) and Beds 1 to 5 of Kindle and Whittington (1958, p. 319-323) along the north shore of Cow Head Peninsula (Fig. 12). The strata, about 100 m thick, are mostly conglomerate with minor interbeds of ribbon to parted limestone and calcarenite. The member is named for Downes Point in Shallow Bay, about 100 m east of White Rock Islets (Fig. 4). There is, however, no exposure at Downes Point. Strata range in age from late Middle Cambrian to early Late Cambrian (Dresbachian).

Tuckers Cove Member. These strata are a 60 m thick series of interbedded quartzose calcarenite, conglomerate and minor parted to ribbon limestone, sandstone, siltstone and shale. The member is named after Tuckers Cove (Fig. 12), the main harbour on Cow Head Peninsula (Kindle and Whittington, 1958, Fig. 2, p. 320). Although the strata outcrop here, a better section is present along the northwest shore of the peninsula (Fig. 12) and is so designated as the stratotype. The rocks are equivalent to Bed 6 of Kindle and Whittington (1958, p. 323). Trilobites from these sediments indicate a medial to late Cambrian age (Franconian to Trempealeauan).

Stearing Island Member. This unit is an 80 m thick series of megaconglomerate with minor interbeds of ribbon to parted limestone, quartzose calcarenite and shale. The type section is on the north shore of Cow Head Peninsula (Fig. 12) and is equivalent to Beds 7 and 8 of Kindle and Whittington (1958, p. 323-325). The strata are named for Stearing Island (Fig. 4), just north of the type section where the rocks outcrop as well, but are less accessible and not as well exposed. The member straddles the Cambro-Ordovician boundary with the uppermost sediments as young as Lower Canadian, on the basis of shelly fossils, or uppermost Tremadoc on the basis of graptolites and conodonts.

Factory Cove Member. This upper member is a 100 m thick sequence of ribbon to parted limestone and minor shale punctuated by beds of distinct boulder and megaconglomerate. The member is named after Factory Cove on the southwest side of the peninsula (Fig. 12) where these strata form both sides of the cove. This cove, although called Deep Cove by Kindle and Whittington (1958, Fig. 2, p. 320) is called Factory Cove by local inhabitants and is also commonly referred to as Factory Cove in the archeological literature (Anger, 1982). The stratotype is on the western end of Cow Head at "The Ledge" of Kindle and Whittington (1958, p. 320) which forms the northern side of Factory Cove. The type section includes Beds 9 through 14 of Kindle and Whittington (1958, p. 325-326). At Lower Head additional sediments lie above Bed 14 and below the first green greywackes and are here designated as Bed 15. Shelly fossils from the Factory Cove Member indicate an age of middle to late Canadian to early Whiterock. Graptolites suggest an Arenig and perhaps earliest Llanvirn age.

Green Point Formation

The strata of this formation are predominantly green, red and minor black shale with scarce conglomerate and packages of ribbon to parted limestone of variable thickness. The stratotype is defined at Martin Point (Fig. 13) between units 31 and 64 (UTM Zone 21, 434300, 5513000). This is not an ideal locality, but is the best of several possibilities. The central part of the section is faulted and much of the upper part is covered, but both the top and the bottom contacts are exposed and it is relatively complete. The section at Green Point is inadequate as a stratotype because the upper third is in the intertidal zone and only partially exposed, and the upper contact is never exposed. The formation is tripartite, comprising a lower unit of mostly green and black shale, a middle unit of parted or ribbon limestone and conglomerate and an upper unit of mostly red shale, which are here named the Martin Point, Broom Point and St. Pauls members, respectively. Because of limited outcrop at the type section additional parastratotypes are defined at Broom Point and Western Brook Pond.

The formation ranges from 400 to 500 m in thickness. It overlies the lower parts of the Shallow Bay Formation at some localities, but is mainly the fine grained equivalent of the Shallow Bay. The Green Point is arbitrarily separated from the Shallow Bay by the presence of more than 50% siltstone and shale in the section. The lower contact is the first thick shale above a series of limestone and conglomerate at Martin Point (unit 33) but elsewhere is not exposed. The upper contact is the base of the first green greywacke of the overlying Lower Head Formation. Strata of Cow Head aspect occur above these green sandstones and the passage between the two is clearly transitional.

The formation is an expansion of the Green Point Formation as defined by Schuchert and Dunbar (1934), Oxley (1953) and Kindle and Whittington (1958), and includes the strata originally defined as the St. Pauls Group by Oxley (1953). The formation is widespread and recognizable along both sides of Parsons Pond, St. Pauls Inlet and Western Brook Pond, at Broom Point, Martin Point and at Green Point. Fossils indicate that strata range from late Cambrian to Middle Ordovician.

Martin Point Member. This basal member is green and black shale with partings of thin buff-weathering siltstone and calcareous sandstone, layers or packages of ribbon and parted limestone and a few thin conglomerate beds. The thickness varies from 100 m to over 150 m. The stratotype is exposed south of Martin Point and comprises units 33 to 36r (Fig. 13) of this study. Fossils are scarce but the strata are mostly late Cambrian.

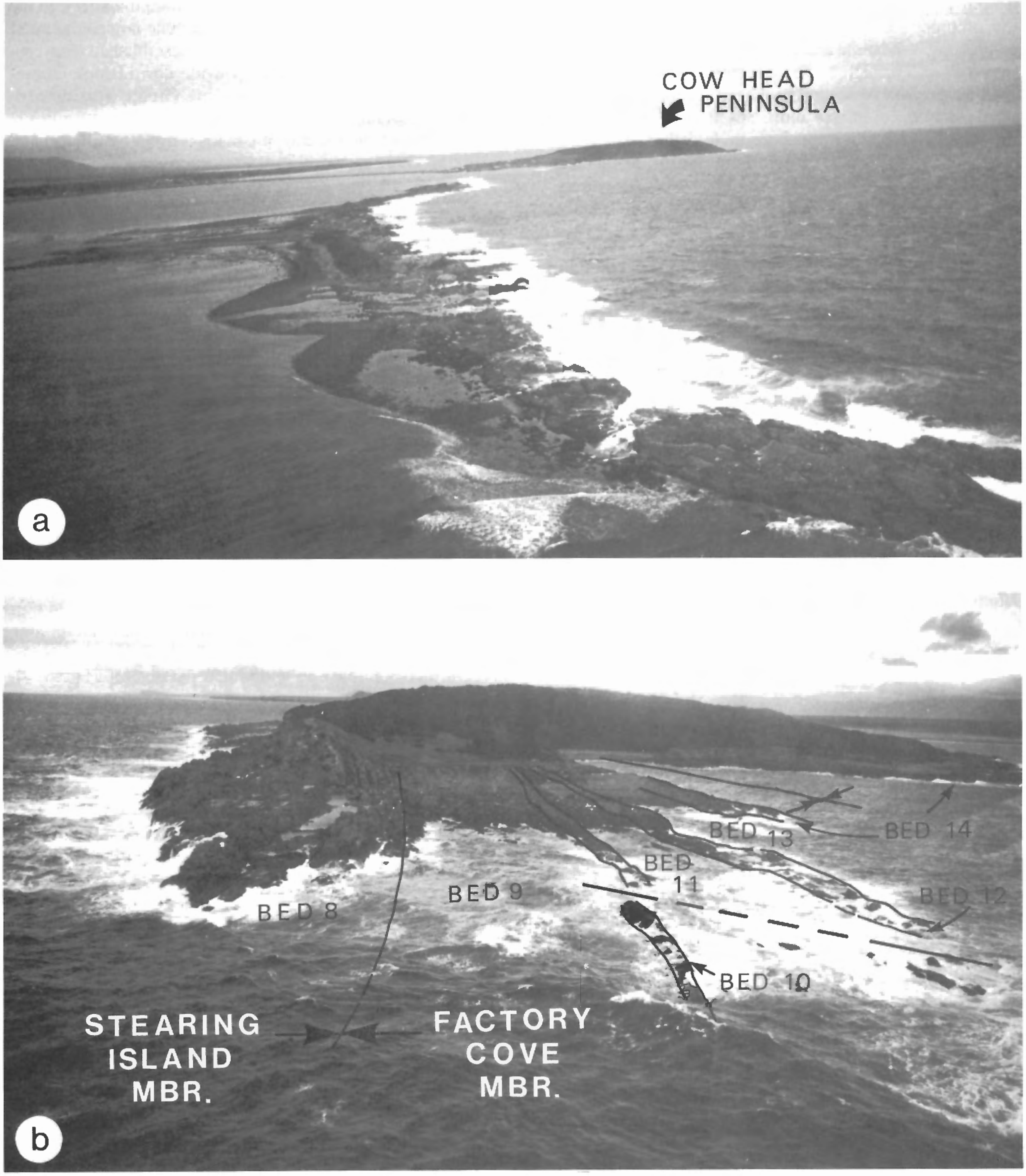


Figure 11. Shallow Bay Region.

a) Aerial view of White Rock Islets, looking south, with Cow Head Peninsula in the background. Aerial photo b) is taken at the western end of the Peninsula. (GSC 191439)

b) Aerial view of The Ledge on Cow Head Peninsula, looking east with the location of the major beds marked. (GSC 191440)

Broom Point Member. This member is an 80 m thick section of predominantly ribbon to parted limestone with minor siltstone, sandstone and conglomerate in the middle of the Green Point Formation. The parted to ribbon limestone may be a single unit or several packages separated by shale. The type section comprises units 36s to 42d inclusive at Martin Point. Because the strata here are folded and faulted, a parastratotype is defined at Broom Point North, to include units 73 through 110 (Fig. 10). Graptolites and conodonts indicate that the strata are mainly Tremadoc while shelly fossils indicate an Early Canadian age.

St. Pauls Member. The upper member of the Green Point is a 130 to 150 m thick distinctive sequence of red, green and minor black shale with variable sections of parted to ribbon limestone, thin conglomerate and buff-weathering siltstone and/or dolostone. These sediments are present in many sections but are difficult to define because they weather recessively and are commonly covered. These were informally separated as the St. Pauls Group by Johnson (1941) and this name is retained, but the strata are better designated as a member of the Cow Head Group. The type section comprises units 42e to 64 at Martin Point. Because much of this section is covered, a parastratotype is defined at Black Brook Point, St. Pauls Inlet between units 17 and 30 (Fig. 14). Strata are middle to upper Canadian to lower Whiterock on the basis of shelly fossils and Arenig on the basis of graptolites and conodonts.

Lower Head Formation

Although outside the immediate scope of this study the sandstones which overlie the Cow Head are important in terms of defining boundaries and in the overall interpretation of the depositional history. The name Lower Head Formation is proposed for these green greywackes and interbedded shales.

Existing nomenclature

The carbonate sequences in western Newfoundland, both autochthonous platform and allochthonous deep-water, are conformably overlain by flysch (Stevens, 1970). The sediments which overlie the autochthonous Table Head Group are about 1.8 km thick, mainly Llanvirn to ?early Caradoc, and called the Mainland Sandstone (Schillereff and Williams, 1979). The Mainland Sandstone conformably? underlies carbonates of Caradocian age between Cow Rocks and Low Point, Port-au-Port Peninsula (Stevens, 1970).

Nomenclature of the flysch which overlies the deep-water strata is not yet formalized. Within the Humber Arm Allochthon it presently outcrops in three areas, Port-au-Port Peninsula, the Bay of Islands at the mouth of the Humber Arm and in the Cow Head area north of Bonne Bay. In all areas the lower contact is conformable with underlying deep-water shale and carbonate of the Middle Arm Point Formation of the Curling Group (Fig. 2) or the Cow Head Group. The upper contact is always tectonic in thrusts or mélange. The strata are Arenig to Llanvirn and where substantial sections are present they commonly exceed 200 m in thickness. In the Bay of Islands area, where the stratigraphic nomenclature of the Humber Arm Supergroup was first established (Stevens, 1970), the flysch is called the Blow-me-down Brook Formation and is placed within the Curling Group. This nomenclature is presently under revision. On Port-au-Port Peninsula nomenclature from the Bay of Islands is used (Schillereff and Williams, 1979).

The flysch in the Cow Head region has been called either the Long Point Sandstones (Schuchert and Dunbar, 1934) or the Western Brook Pond Group (Johnson, 1941) or has been correlated with the Humber Arm Group to the south (Oxley, 1953, p. 337). The name Western Brook Pond Group was never used again after its introduction, even by Johnson. Kindle and Whittington (1958), pointing out that the name Long Point was wrong and that both Long Point and the Humber Arm lay far to the south of the Cow Head area, did not support any name for these sandstones. Instead they suggested no name be used and referred to the flysch as the "Unnamed Green Sandstones", separate from the Cow Head Group (ibid., p.317).

Proposed nomenclature

The new name Lower Head Formation is here proposed for these strata in the region north of Bonne Bay (Williams et al., 1985). The type area, Lower Head (UTM Zone 21, 4294480, 55123480), contains two thick sections of these strata, one along the northern shore of Shallow Bay and the other northwest of the shoreline as a wide intertidal outcrop (Fig. 6, 7). This is where Richardson (in Logan, 1863), as well as Schuchert and Dunbar (1934, p. 79-80) first noted these strata, and the sandstones are present both above and below the Cow Head. The base of the formation is taken at the base of the lowermost greywacke and the lower parts contain many beds of Cow Head aspect where they overlie the Green Point Formation. The base is unfortunately poorly exposed at both of the above localities but can be seen easily in the syncline between the central and western sections (Fig. 6).

SEDIMENTOLOGY

The Cow Head Group involves a spectacular array of sediments. Distal facies are long sections of black, green or red shale and brown siltstone interrupted only locally by thin grey limestone bands and conglomerate lenses. Intermediate facies are generally evenly-bedded grey limestone, buff dolostone and siltstone, variegated shale and grey limestone conglomerate. Proximal facies are mostly thick successions of chaotic welded boulder conglomerate. The sediments are a mixture of fine grained hemipelagites and sediment gravity flows of different types, some of which were reworked on the sea floor. Aspects of the fine grained sediments are discussed by Coniglio (1985). Some of the coarse grained deposits have been reported on by Hubert et al. (1977) and Hiscott and James (1985). This portion of the report is a summary of these deposits, beginning with the finer grained sediments and continuing with the conglomerates, which commonly contain clasts of the finer grained lithologies.

Hemipelagites

This term loosely refers to fine grained, deep water, mixed carbonate-siliciclastic sediments deposited by pelagic fallout and/or sediment gravity flows which may be reworked by bottom currents (McIlreath and James, 1984). In the Cow Head these are in the form of shale, siltstone, limestone rhythmites and dolostones. The sediments have variably been affected by dolomitization and silicification.

Shales

Shales (Fig. 15), the most abundant terrigenous sediments, vary from rare clay mudstones to common silty shales. Ordovician shales contain radiolaria and sponge spicules. While radiolaria are ubiquitous, spicules are restricted to specific layers. These sediments can broadly be divided into two types.

Laminated shales. These fissile shales to clay mudstones range from black to grey to various hues of green, form thick sequences with thin siltstones, are interlaminated with limestone rhythmites and in some Ordovician sections are intricately interbedded with burrowed shales. Lack of ichnofossils together with the organic nature of the black shales and reduced state of the iron in green shales suggest that bottom conditions during deposition were anaerobic to dysaerobic (Byers, 1977).

Bioturbated shales. Ordovician strata contain variable thicknesses of bioturbated red shale (Fig. 16) with a distinctive ichnofossil assemblage (Narbonne and James, 1984) deposited under aerobic conditions. They are in many cases interlaminated with thin black, dark green or light green shale. The light green shales are generally burrowed and some are clearly reduced former red shale. Buff-weathering silty dolomite and dolomitic siltstone, a few centimetres in thickness, are common associated lithologies. In contrast to the laminated shales these rocks are commonly silicified or cherty and contain abundant radiolaria.

Suchecki et al. (1977) recognized three clay-mineral suites in these shales; (1) a Middle Cambrian to basal Ordovician suite from laminated shales that is dominated by an illite-14A chlorite assemblage with high K_2O/Al_2O_3 ratio and low MgO/Al_2O_3 ratio, presumably from a continental cratonic source; (2) a transitional Early Ordovician suite from both laminated and bioturbated shales that is composed mainly of illite and expandable chlorite and (3) a late Early Ordovician to Middle Ordovician suite from laminated and bioturbated shales in both the Cow Head and overlying Lower Head formations that is dominated by a corrensite-illite-smectite assemblage in which the increased Mg is probably due to material from a newly formed Ordovician offshore volcanic island arc.

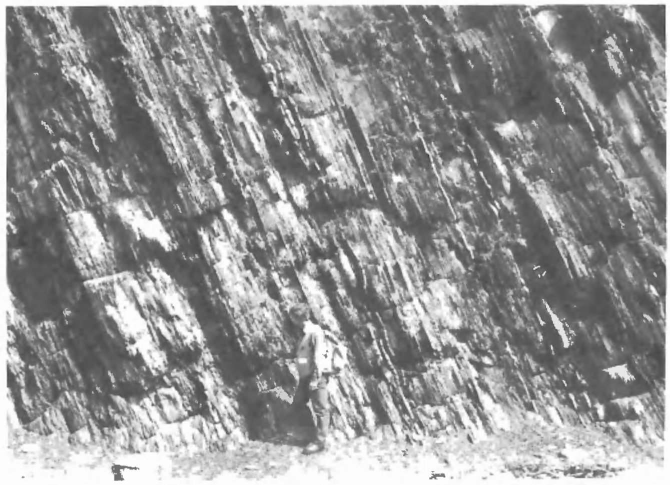


Figure 15. Laminated grey, black and dark green shale with thin light-coloured ribbon limestone, typical of the Martin Point Member (Green Point, Unit 17; GSC 191441)

Siltstones

Brown weathering siltstone is common throughout and varies from almost pure quartz silt to dolomitic silt to silty dolomite. The common mixture of quartzose silt and dolomite implies some as yet undetermined genetic or diagenetic link. Quartz ranges from medium to coarse silt to very fine sand grade. As true silt the grains are always angular, but as fine sand they are rounded. Individual layers are either finely laminated, or laminated and rippled with numerous ichnofossils.

Dolomitic siltstone is intimately interlaminated with shale (Fig. 16) in all lithologies from dark-laminated shale where bedding contacts are sharp to red bioturbated shale where it was reworked into the shale by the bottom fauna.

Limestone rhythmites

Terminology

The most common limestones in the Cow Head are remarkably evenly bedded, fine grained sediments separated by shale or argillaceous dolomite. If the limestones and argillaceous beds are roughly equal in thickness we have called them "ribbon limestones" (Fig. 17), but if the argillaceous or dolomitic layers are many times thinner than the limestones, we have named them "parted limestones" (Fig. 18).

Aitken (1966) proposed the term parted limestone for a distinctive widespread Cambrian lithofacies in the southern Canadian Rockies. It was applied to thin- and very thin-bedded limestones characterized by tan weathering partings of impure microcrystalline dolomite. The limestones in these rocks are calcisiltites, which commonly display crosslaminations. The parting material may be nearly pure dolomite,

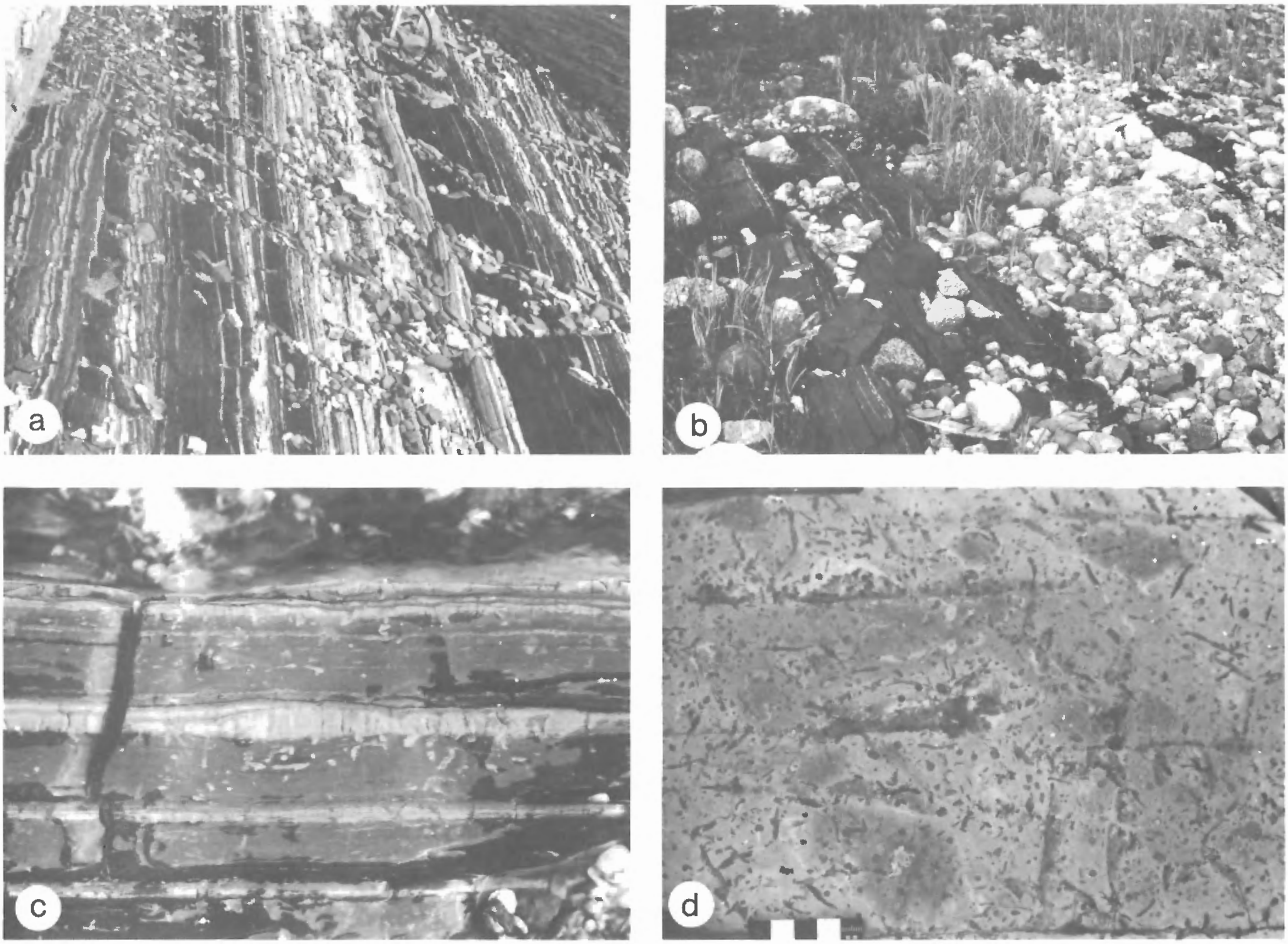


Figure 16. Bioturbated shale, St. Pauls Member.

a) Interlaminated red (black in photo) and green (light grey) shale, buff dolomite and grey limestone (white; Western Brook Pond North, Unit 23); hammer scale. (GSC 191442)

b) Blocky, siliceous red shale with light bands of silty dolomite (St. Pauls Tickle North, Unit 87), just below Bed 14; shale unit 1.8 m thick. (GSC 191443)

c) Interlaminated buff silty dolomite (2 cm thick) and dark red shale with numerous burrows filled by silty dolomite (St. Pauls Tickle North, Unit 84; GSC 191444)

d) A bedding plane of siliceous shale with numerous trace fossils (St. Pauls Tickle, Unit 84); centimetre scale. (GSC 191445)

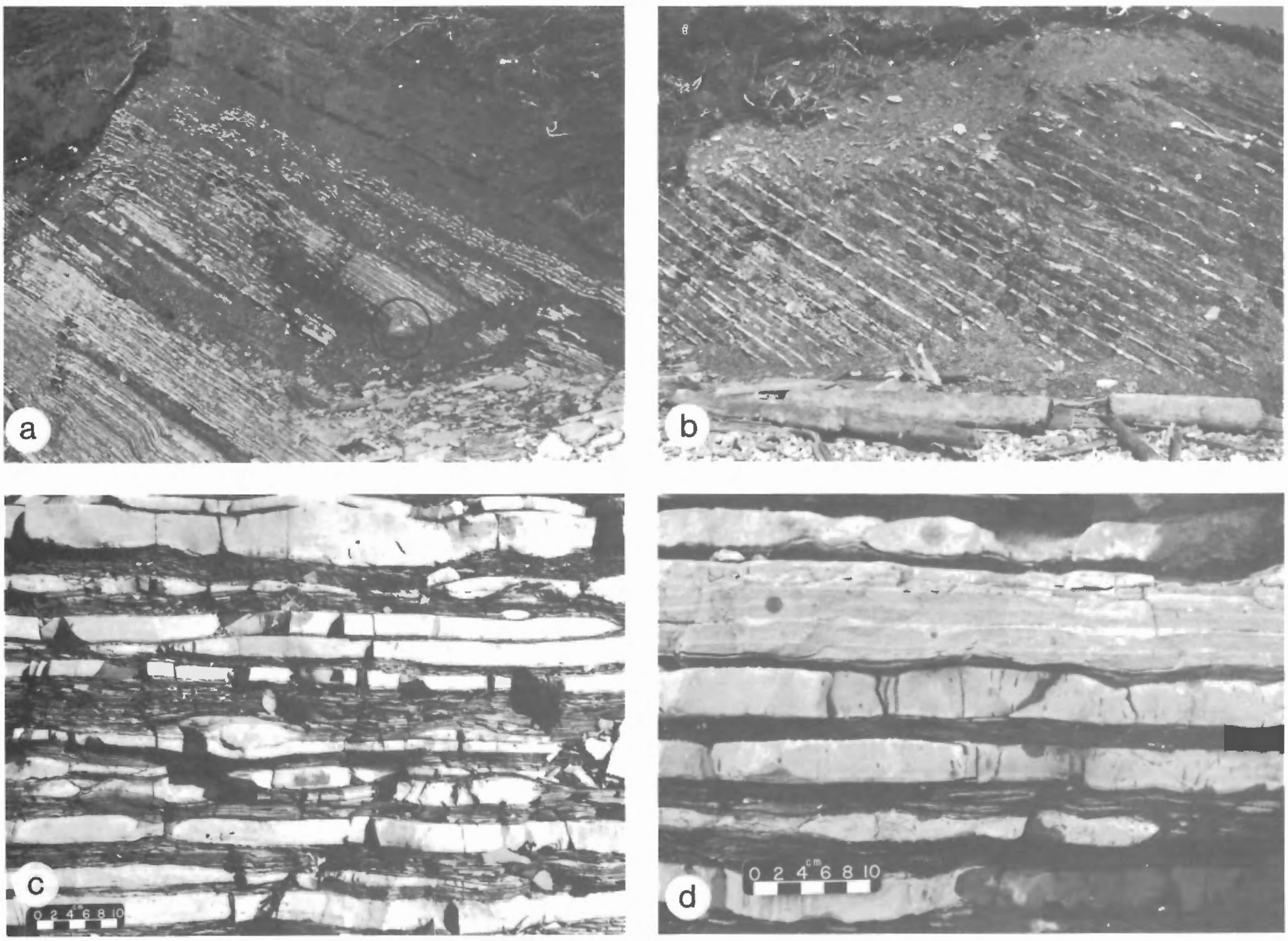


Figure 17. Limestone rhythmites.

a) Parted limestone (lower left) and ribbon limestone (centre) in the Broom Point Member (Martin Point, Units 36 t and u); packsack scale. (GSC 191446)

b) Planar-bedded and nodular ribbon limestone in the Martin Point Member (Martin Point, Unit 36m); section 8 m thick. (GSC 191447)

c) Ribbon limestone and green-grey laminated shale illustrating the variations in planar beds and nodules in the Factory Cove Member (Cow Head North, Unit 9.8; GSC 191448)

d) Ribbon limestone and laminated shale (lower half) and parted limestone (upper half) in the Factory Cove Member (Cow Head North, Unit 9.8). The ribbon limestone beds are penetrated by numerous vertical ichnofossils (*Skolithus* and *Diplocraterion*; GSC 191449)

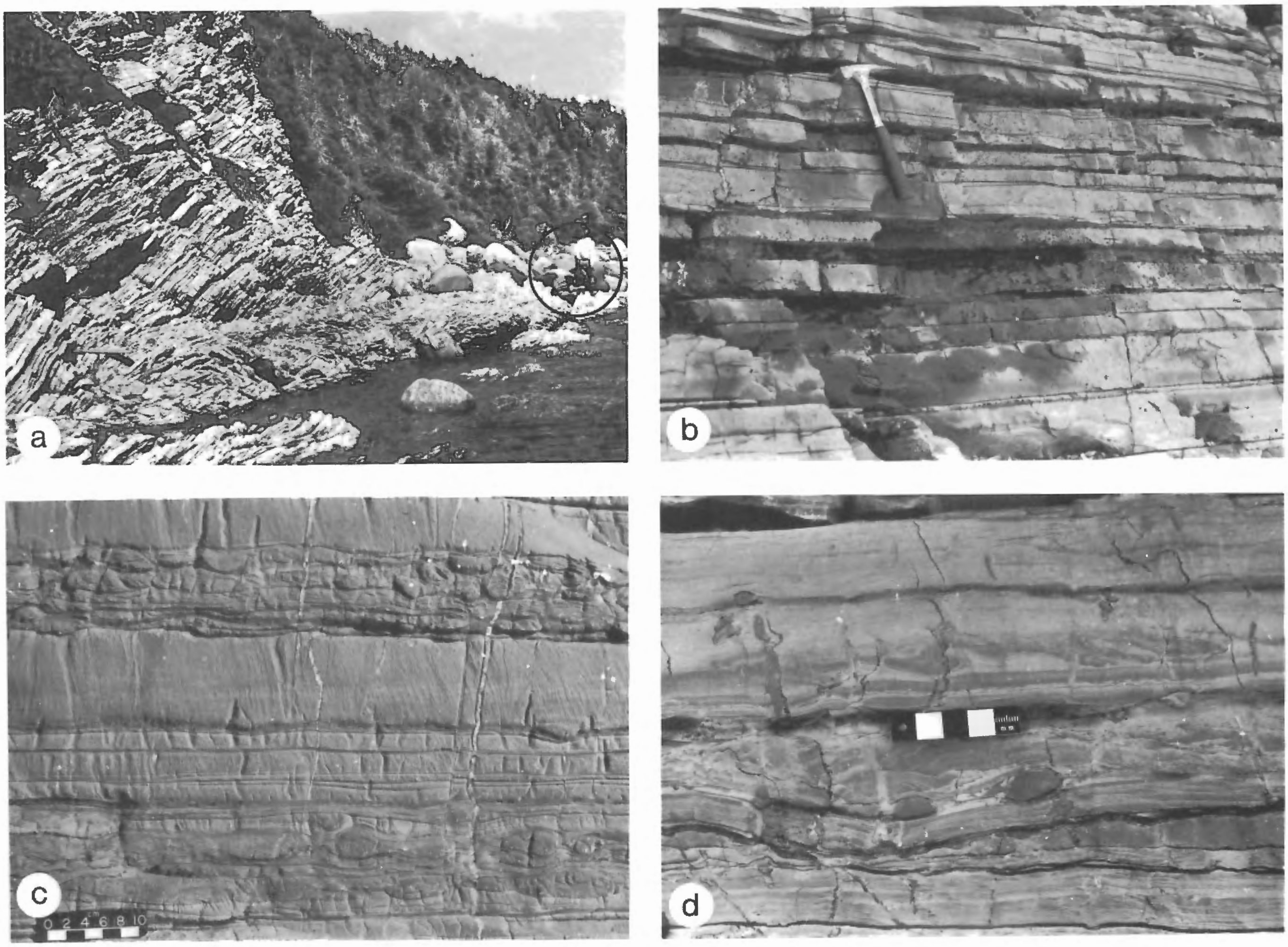


Figure 18. Limestone rhythmites, Broom Point Member.

a) Parted limestone, The Scrape, St. Pauls Inlet (Unit 5; GSC 191450)

b) Parted lime mudstone, characterized by extremely even bedding, rare parallel laminations and argillaceous dolomite partings (Green Point, Unit 28); bedding tops up. (GSC 191451)

c) Parted limestone composed of thick calcarenite beds (centre), thin lime mudstone beds (lower half) and nodules caused by soft sediment deformation (top and bottom; Long Point, St. Pauls Inlet, Unit 1; GSC 191452)

d) Parted limestone composed of laminated to crosslaminated fine grained calcarenite which has suffered minor soft sediment deformtion and was subsequently cut by vertical burrows (centre; St. Pauls Tickle North, Unit 52; GSC 191453) argillaceous and silty dolomite, calcareous and dolomitic shale, impure secondary silica or rarely, dolomitic siltstone. In this original definition the volume of the parting material may exceed that of the limestone beds but in this study we have separated out such strata as ribbon limestones.

The fabric of Cow Head rhythmites is in part depositional, in part the result of early lithification, in part due to compaction, and in part the result of pressure solution. Most beds are some combination of all four. This interpretation is in contrast to their explanation as sedimentary boudins by Hubert et al. (1977). Regardless, most of these sediments were lithified early, on or just beneath the seafloor, as illustrated by their common incorporation as broken clasts of platy limestone into overlying conglomerates (Fig. 19).

Argillaceous sediments between limestone layers are variable; shales are most common, generally dark green, grey or black, fissile and silty; green-grey dolomitic shale or argillaceous dolomite are not as prevalent. Lithological contacts are sharp or gradational and in Ordovician strata the contact is often marked by a green, grainy concentration of sponge spicules and/or radiolaria.

Limestones are commonly nodular and may change from slightly undulose layers to bands of true nodules to widely separated and isolated nodules along a single horizon. Concentrations of pressure solution insolubles such as clay, dolomite, radiolaria and sponge spicules can be traced between nodules.

In Ordovician strata the rhythmites are commonly silicified. Chert varies from nodules or ropes within layers to complete replacement of limestone and argillaceous interbeds. Some nodules may be silicified sponges.

Composition

The terms parted and ribbon limestone encompass a variety of limestone types: (1) dark lime mudstone; (2) very thinly interlaminated lime mudstone, graded calcisiltite and fine grained calcarenite; and (3) rippled, medium- to coarse-grained calcarenite.

Micrite occurs either as individual layers or as matrix in packestones or wackestones. Microscopically much of this micrite is 1/3 silt or sand-size peloids. Identification of original micrite is at times difficult because of aggrading neomorphism to microspar or pseudospar.

The most abundant carbonate particles are peloids and clasts, in two size grades. The largest are medium to very coarse sand size, ovoid to irregular, composed of uniform coarse micrite to microspar to pseudospar and are probably fecal pellets. They range from distinct grains to compacted blebs which give a wackestone to packstone fabric to grainy layers. The smaller and more common are coarse silt to very fine sand size, angular to subrounded and easily separated from other peloids by their dark, dense micrite nature that is never aggraded to coarse spar. These grains are probably algal in origin, derived from the calcified algae *Girvanella* and/or *Epiphyton* (Coniglio and James, 1984).

The alga *Girvanella* is also present as single tubules, twisted aggregates of tubules and small "rafts" of numerous subparallel tubules. There is a continuous spectrum from clear tubules to fragments of tubules which grade to the small clasts and peloids described above. Thus, together, calcified algae are the major contributors to these sediments.

The spectrum of other skeletal elements is not great, namely echinoderm plates with epitaxial overgrowths, pieces of brachiopod valves and whole to fragmented large trilobite carapaces and spines. Complete small trilobite skeletons and single and double ostracode valves are abundant in some layers. Monaxon sponge spicules and radiolaria, preserved either as calcite or as chert, are ubiquitous (Fig. 20).

There are, however, differences in composition between the Cambrian and Ordovician limestone rhythmites.

Cambrian. The finest grained carbonates are lime mudstones composed entirely of micrite probably originally periplatform ooze. These, in some cases, may have a few (ca. 10%) floating silt-sized peloids or have interlaminated micrite and silt-sized pelsparite on a scale of 1 to 2 m. Layers of pelsparite are just as common, but generally contain 1/4 to 1/2 quartz silt. These are well laminated to crosslaminated with layering due to open and close packing of the peloids. Dolomitization is variable within a single layer from 1/3 dolomite in a pelsparite with 20% quartz silt to a silty dolostone.

What appears in the field to be dolomitic siltstone invariably turns out to be coarse silt to fine sand-sized dolostone with up to 1/4 quartz silt. Others may contain variable amounts of clay and centimetre thick layering produced by clay-free silty dolostones and clay-rich (1/3 to 1/4) silty dolostones.

Ordovician. Ordovician limestone rhythmites are more varied than their Cambrian counterparts. Micrite lime mudstones, with up to 1/3 discernible small dark peloids, vary from pure carbonate to argillaceous limestone with clay micropartings. Pure lime mudstones generally contain a few scattered radiolaria. The mudstones, however, may range in composition from radiolarian micrites with up to 50% radiolaria to radiolarian spiculites with less than 1/3 micrite. These various lithologies occur in layers up to centimetres thick but also grade into the more grainy lithologies.

Grainy sediments composed of silt to very fine sand-size carbonate particles are characteristically well laminated into separate layers 0.1 to 2.0 m thick which are rarely graded. Layering is a function of variation either in texture or composition or both. The range in texture is from grainstone to packstone or wackestone with muddier sediments containing more clay. Laminae become coarser grained with the addition of larger sand-sized peloids. Sediments range in composition from those composed mostly of algal clasts and peloids to those with increasing amounts of other skeletal fragments such as echinoderms, trilobites, ostracodes, radiolaria and clay flakes, which generally occur together. In some layers spicules are more common than all other grains combined.

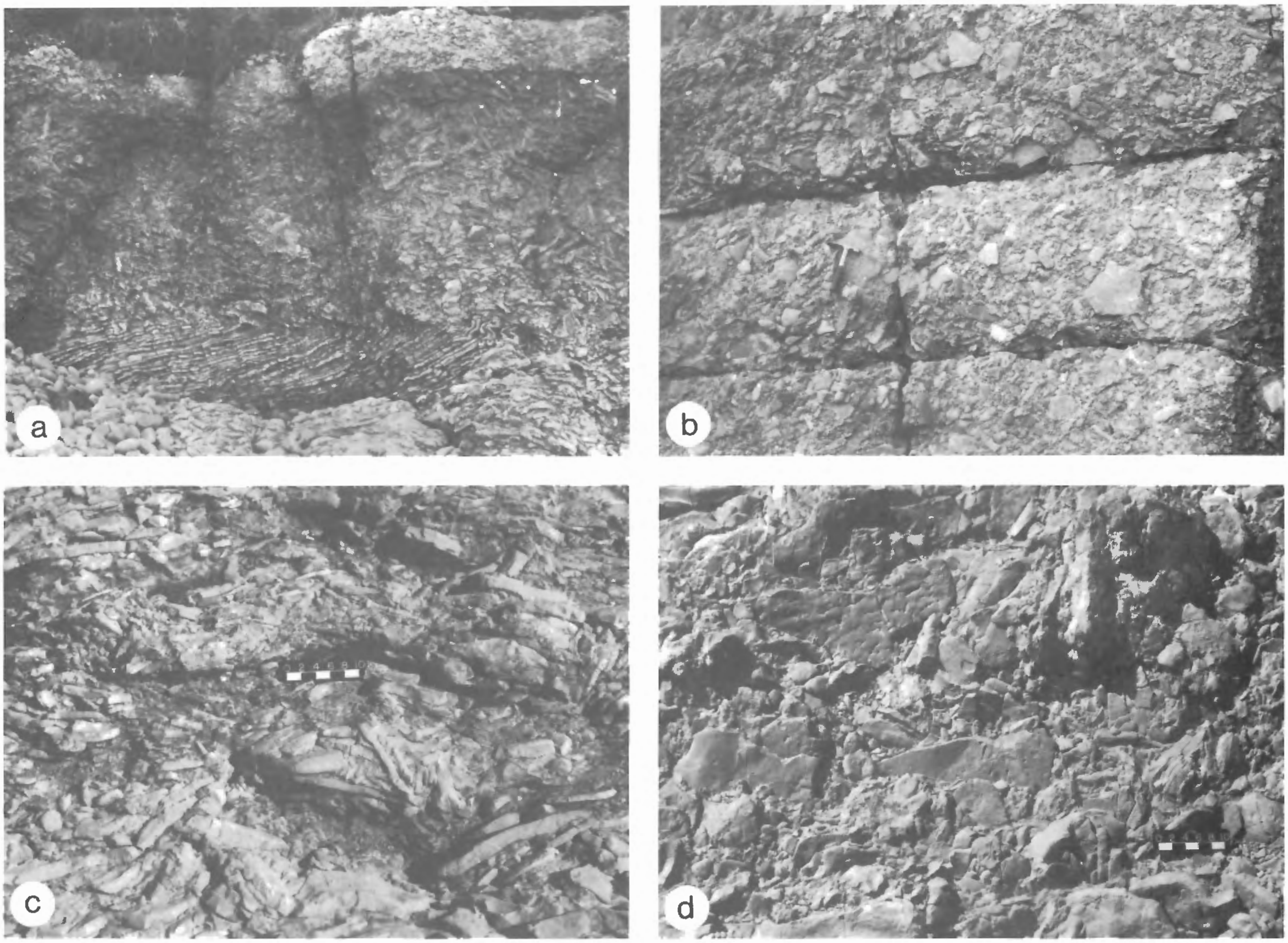


Figure 19. Limestone plate conglomerate.

a) Plate and boulder clast conglomerate with bed of ribbon limestone beneath ripped up to provide clasts for conglomerate; Tuckers Cove Member (Martin Point, Unit 5; GSC 191454)

b) Bedding plane view of a plate conglomerate composed of numerous angular plates; Factory Cove Member (Cow Head North, Unit 8.33; GSC 191455)

c) Close view of a plate conglomerate in which several clasts are bent; Factory Cove Member (Cow Head North, Unit 9.7; GSC 191456)

d) Bedding plane view of plate conglomerate in which many plates exhibit trace fossils (particularly *Diplocraterion*) identical to those in beds below; Factory Cove Member (Cow Head North, Unit 9.7; GSC 191457)

Deformation

Rhythmites are particularly susceptible to slight deformation or wrinkling and are commonly bent, folded, fractured and overthrust. In some instances it appears that deformation is due to the loading and/or sliding of the immediately overlying conglomerate, but where conglomerates are lacking some combination of slope creep, tectonic deformation and/or expansive recrystallization might be responsible.

Intraformational truncation surfaces

These parted to ribbon limestones, more than any other lithology, illustrate the instability of the overall depositional setting. This is manifest as shallow, bedding discontinuities which cut down through several metres of bedded limestone over distances of several tens of metres (Fig. 21). These surfaces are convex-down and can only be recognized in long strike sections. Local variations in bedding result in stepped discontinuities in several places, features identical to the surfaces described by Wilson (1969), Davies (1977), Smith (1977) and Yurewicz (1977) and likewise interpreted as slump or slide scars. The overlying beds are at first subparallel to the truncation surface, but with increasing distance upward away from the surface they become parallel to regional bedding (Coniglio, in press).

Although there is rarely evidence of the fate of the detached bedded limestone the presence of platy clast conglomerates throughout the Cow Head (see section on Conglomerate) suggests that such scars are the upslope source areas for these conglomerates. At Green Point, however, several slumped and contorted masses of parted limestone (Fig. 21) indicate only short-distance downslope movement. In addition, it is clear from the huge rafts of parted limestone in Bed 3 at Cow Head that large masses of limestone did detach and move downslope as coherent elements (Fig. 22).

Calcarenites

Medium- to very coarse-grained calcarenites and quartzose calcarenites occur as (1) thin beds in limestone rhythmites, (2) distinct, often lenticular, massive grainstone or quartzose grainstone beds, (3) layers in graded-stratified conglomerates, (4) caps of grainstone on boulder conglomerates or megaconglomerates.

Composition

Cambrian calcarenites

These sands are made up of the same components throughout: peloids, trilobite or echinoderm fragments, ooids, rare *Nuia* grains with less frequent quartz sand and silt and clay.

Peloids and clasts are the most ubiquitous and numerous of grains, comprising from 40 to 80% of the sediment. They come in two size modes, coarse silt to very fine sand and medium to coarse sand; range in shape from spherical to ovoid to irregular; are always rounded and commonly demonstrably detrital. Those in the finer size fraction appear to be uniform micrite and are the same as those in the fine grained rhythmites which are probably mostly algal in origin. Coarser grained peloids range from micrite to pelsparite to fossiliferous silty pelsparites. These pelsparites are polygenetic and difficult to characterize. In some instances peloids within clasts are of different sizes and packing so the clast is interpreted as an eroded, rounded fragment of limestone and should be properly classified as a lithoclast. In other cases it is clear that the apparent peloids in clasts are cross-sections of

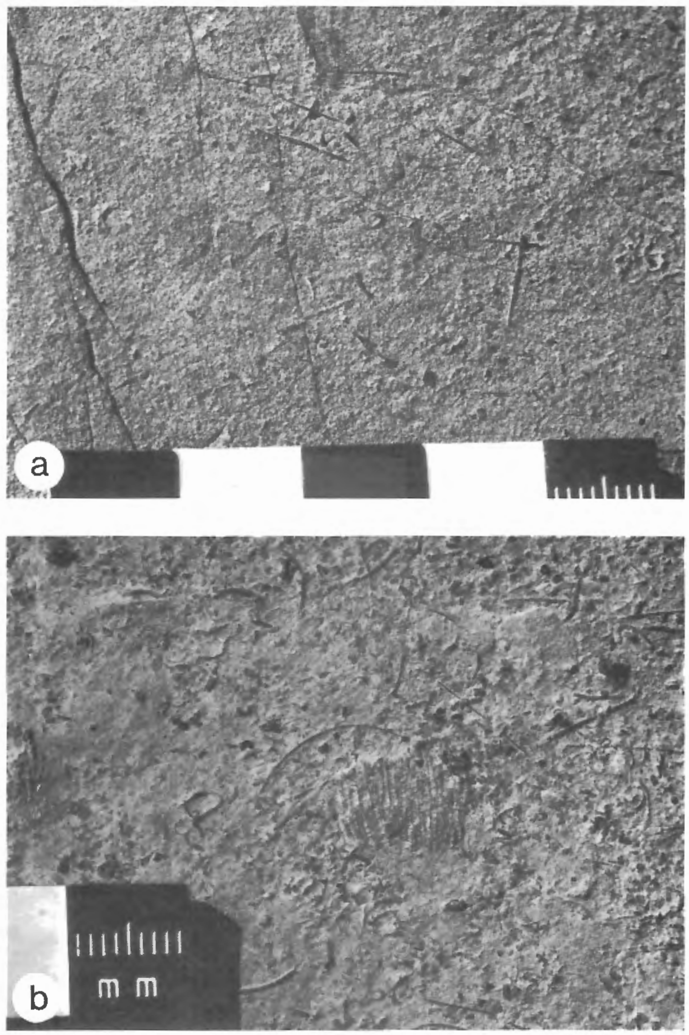


Figure 20. Spiculite.

a) Siliceous sponge spicules strewn on the surface of a parted limestone bedding plane; Factory Cove Member (Cow Head North, Unit 9; GSC 191458)

b) Same bedding plane as in (a) illustrating both spicules and whole fragments of the sponge network (GSC 191459)

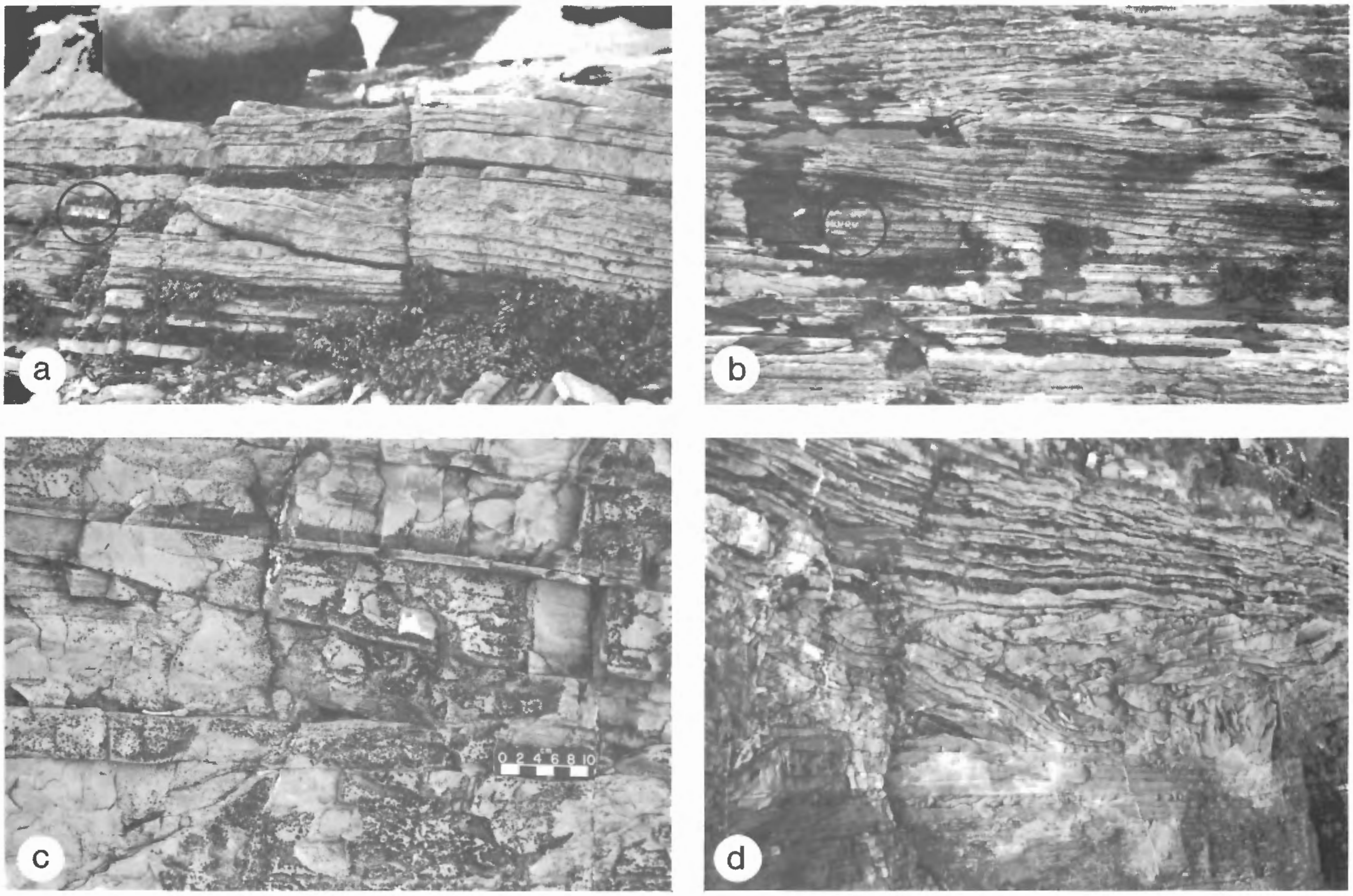


Figure 21. Intraformational truncation surfaces and deformation.

a) Planar intraformational truncation surface developed in parted limestone of the Broom Point Member (Broom Point North, Unit 96); 10 cm scale. (GSC 191460)

b) An irregular intraformational truncation surface in parted limestone of the Broom Point Member (Broom Point North, Unit 95; GSC 191461)

c) A close view of a planar intraformational truncation surface illustrating the clean surface with no encrustations; Broom Point Member (Broom Point North, Unit 94; GSC 191462)

d) A horizon of slumped and contorted parted limestone 1 m thick in the Broom Point Member (Green Point, Unit 28; GSC 191463)

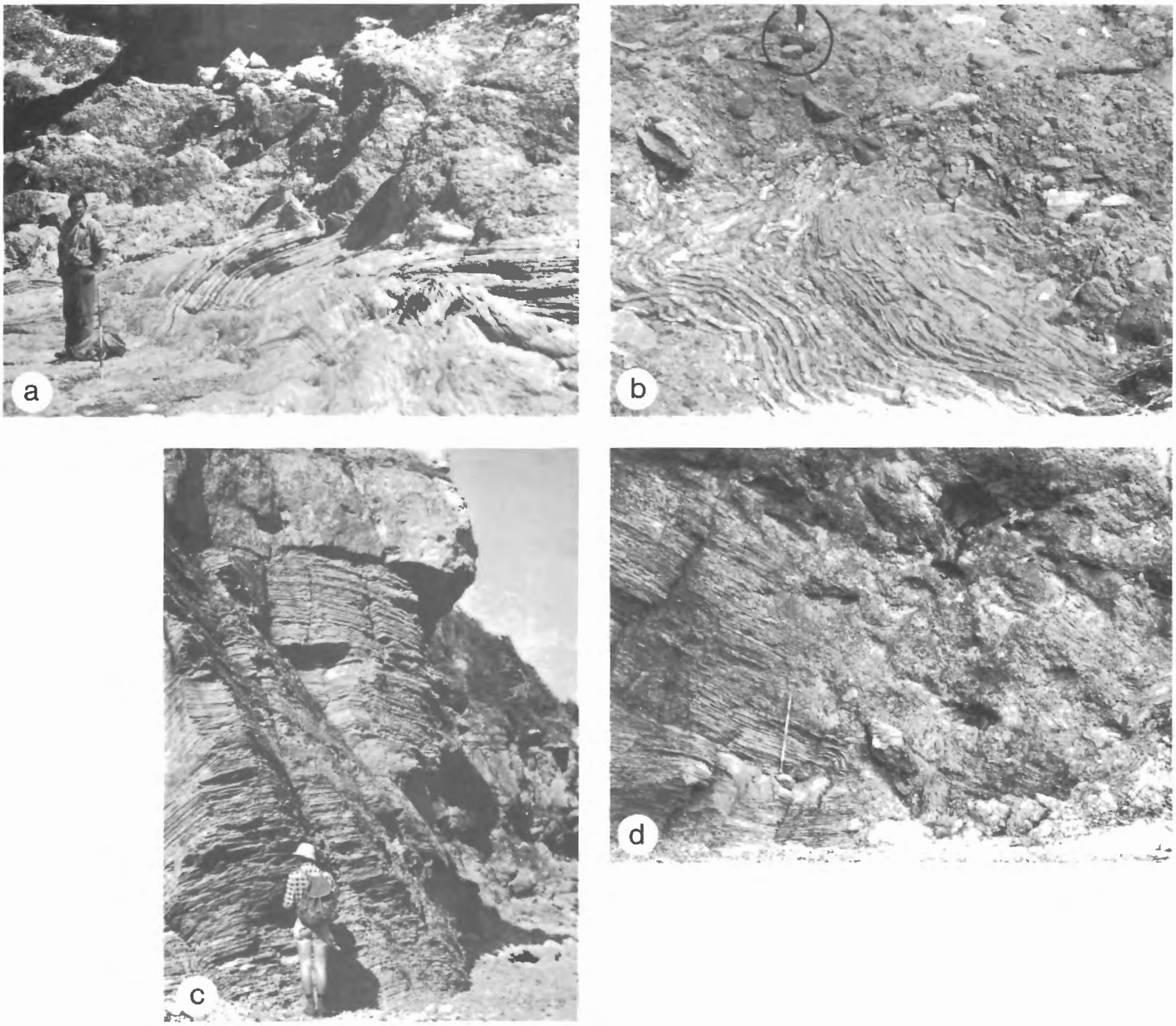


Figure 22. Limestone rafts.

a) Large raft of folded parted limestone in megaconglomerate; Downes Point Member (Cow Head North, Bed 3; GSC 191464)

b) Raft of folded parted limestone in megaconglomerate; Factory Cove Member (Cow Head North, Bed 14; GSC 191465)

c) Large raft of intact parted limestone and overlying conglomerate; Downes Point Member (Cow Head North, Bed 3; GSC 191466)

d) Margin of a large raft broken up into smaller rafts and clasts; Downes Point Member (Cow Head North, Bed 3): metre-stick scale. (GSC 191467)

Epiphyton branches and partial longitudinal sections can be seen in the same grain, so the particles are fragments of *Epiphyton* and cement. Thus the peloids are in part micrite (often with a grumulose texture, cf. Cayeux, 1935), in part pelsparite lithoclasts and in part algal fragments (Coniglio and James, 1985).

Ooids, which rarely exceed 20% of the grains in any one calcarenite, are absent in most sands. The grains invariably have a radial cortex and fragments of the cortex are almost as common as the whole ooids.

Iron-rich euhedral dolomite, which may comprise up to 50% of the rock, is diagenetic and of silt to fine sand size. It is found most commonly in the intergranular spaces and, with increasing abundance, first fills the spaces and then replaces the grains.

Ordovician calcarenites

The very coarse to granule Ordovician sands are intermediate in composition between the conglomerates and the finer sediments. The most abundant grains, which comprise 1/3 to 1/2 of the sediment, are fragments of limestone, mostly micrite or pelsparite. Also, like the conglomerates, they contain up to 10% rounded to angular phosphate fragments. Like the finer sediments, as much as 1/2 of the rock is particles of *Girvanella*, trilobites (often abundant), echinoderms and brachiopods. *Nuia* grains, often numerous, are restricted to this size range.

Quartzose sand

Quartz sand is an important component of most Upper Cambrian and some Lower Ordovician sediments. This sand is uniformly coarse- to very coarse grained. Particles are very rounded and highly spherical with heavily frosted surfaces and remnants of a thin hematite coating. As Baird (1960b, p. 15) described their occurrence "These grains may be scattered sparingly throughout a limestone cement and show as tiny dark eyes on light grey weathering surfaces", or they may form, in a few cases, true quartz arenites (Fig. 23) with a calcite cement. Some of the quartz is blue, like that from granulite terranes such as the Grenville Long Range.

Several factors point to an eolian origin for much of the quartzose sand and silt in the Cow Head. The rounding, sphericity and frosting of the sand grains all suggest a wind-blown source. In addition, when viewed in total the sand and silt-size terrigenous fraction is bimodal: coarse to very coarse rounded sand grains; medium to coarse angular silt grains. These particles are segregated into separate units in the Cow Head but the association is remarkably like Folk's (1965) bimodal, supermature quartz arenites, to which he ascribes an eolian origin. This bimodality is thought to be caused by the selective removal of the fine to medium sand fraction through saltation and accumulation as dunes, leaving the fine and coarse fractions as a deflationary reg on the desert floor. In addition, some quartz grains have red hematite rinds, a common eolian phenomenon.

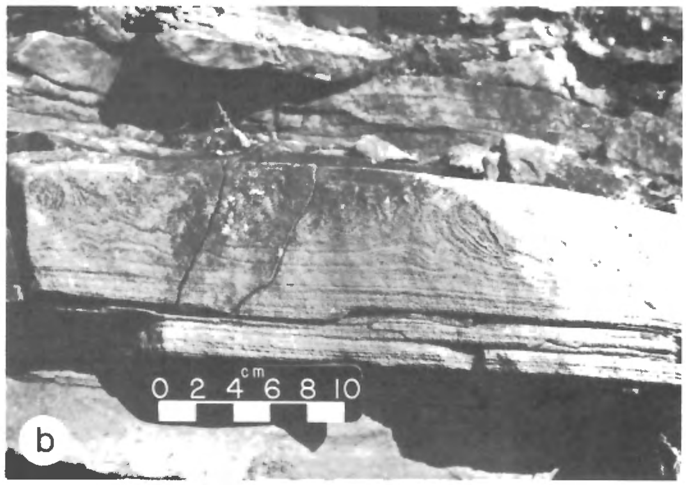


Figure 23. Sandstones.

a) Massive crosslaminated sandstone overlying quartzose calcarenites; Tuckers Cove Member (Martin Point, Unit 31d); resistant unit 2.0 m thick. (GSC 191468)

b) Thin sandstone with parallel and convolute laminations; Tuckers Cover Member (Martin Point, Unit 31c; GSC 191469)

Massive grainstones

These rocks, as isolated layers or lenses up to a metre thick, but generally less, occur in all facies. The sands are ungraded, range from uniform to laminated to crosslaminated and have sharp contacts with underlying and overlying strata (Fig. 24).

Quartzose grainstones

The high Upper Cambrian and, to a lesser extent, the basal Lower Ordovician are characterized by both graded and ungraded quartzose calcarenites (Fig. 23, 24). Hubert et al. (1977), in describing these graded beds, felt that they are identical to a typical Bouma sequence, with the addition of a

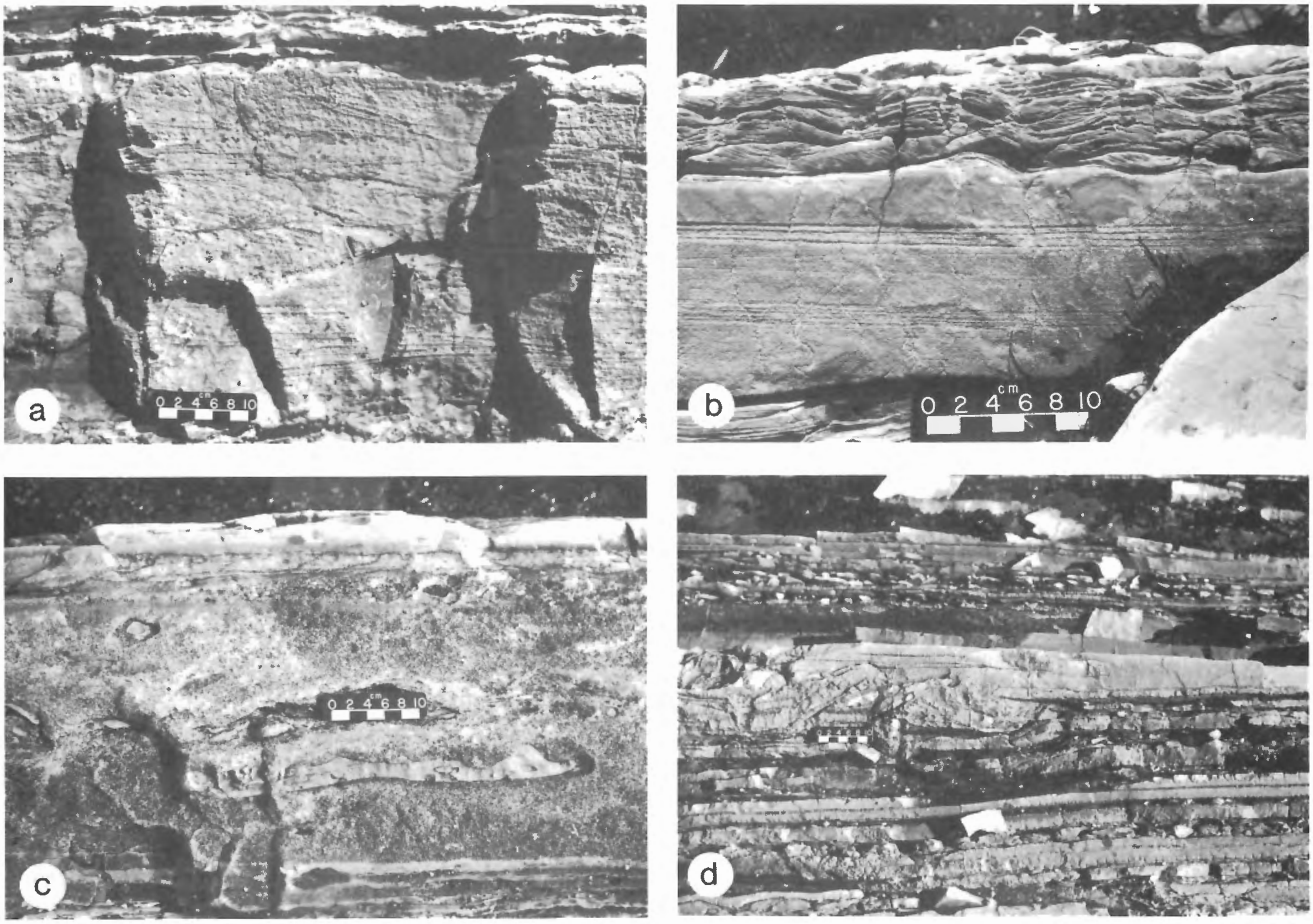


Figure 24. Calcarenites.

a) Crosslaminated calcarenite; Tuckers Cove Member (Broom Point North, Unit 22; GSC 191470)

b) Planar laminated and rippled calcarenite; Broom Point Member (St. Pauls Tickle North, Unit 52; GSC 191471)

c) Quartzose calcarenite with floating limestone plates and mudstone cap; Tuckers Cove Member (Unit 21; GSC 191472)

d) Edge of conglomerate lens, clasts in calcarenite (behind scale) grading to calcarenite (right); Broom Point Member (Broom Point South, Unit 37; GSC 191473) division of festoon crossbeds between divisions B (horizontal laminations) and C (ripples). They observed that most beds begin with divisions A or B in coarse grained calcarenites without a mud matrix and the bed soles illustrate flutes and grooves. These sands are also associated with coarser grained deposits as graded-stratified conglomerates. While confirming that these have all the attributes of turbidites, Hubert et al. (1977) interpreted them as the deposits of waning contour currents. In this report, these sediments are interpreted as turbidites flowing downslope (Hiscott and James, 1985).

Conglomerate caps

Many boulder conglomerates and megaconglomerates, regardless of age, have a layer of calcarenite, a few tens of centimetres thick, resting with abrupt contact on the upper surface, similar to those described by Krause and Oldershaw (1979) from deep water conglomerates of many different ages. These laminated to crosslaminated sands are irregular, thickening and thinning and at times completely disappearing along strike. These limestones were again interpreted by Hubert et al. (1977) to have formed by contour currents flowing parallel to the slope in a southeasterly direction, reworking the finer grained sediments in the upper parts of the conglomerate beds. They are here interpreted to be either separate turbidites or sands deposited with the flow itself.

Dolomite

Dolomite occurs in several settings: as metre thick beds in proximal facies (Fig. 25); as thin, quartz silt-rich beds in shales; as matrix in conglomerates; as pressure solution remnants in parted to ribbon limestones; and as boulders in conglomerates. Most dolostones, however, are silty and occur either as thin layers with shales between conglomerates or as thin laminated to crosslaminated layers in thick shale sequences, particularly red shales. They range in composition from dolomitic siltstones to silty dolomites. Most of this dolomite may be detrital (Hubert et al., 1977; Coniglio, 1985).

The thickest beds are buff-weathering, iron-rich, silt-size dolomite which is commonly laminated and burrowed. Their incorporation as clasts in conglomerates (Fig. 25), entombed in a matrix of argillaceous limestone and yet retaining all the same features as the in-place beds, suggests that dolomitization was rapid occurring on or just below the seafloor.

In the matrix of some conglomerates and in some dolomitic siltstones the dolomite clearly replaces micrite peloids of similar size. In pressure-solution seams, partings and internodule areas, dolomite is preferentially developed, as illustrated by Wanless (1979).

Chert

Chert is most common in the Ordovician part of the sequence, coinciding with the appearance of abundant radiolaria and siliceous sponge spicules.

The most common variety is brown-weathering, black chert, partially to completely replacing limestone (Fig. 26). This alteration occurs both downward from the top of a bed or upwards from the base of a bed. The whole bed may be replaced. Alternatively, nodules within a bed may be rimmed or completely replaced by chert. Although difficult to discern in uniformly fine grained limestone, the relic limestone structure can generally be seen with ease in coarser grained sediments.

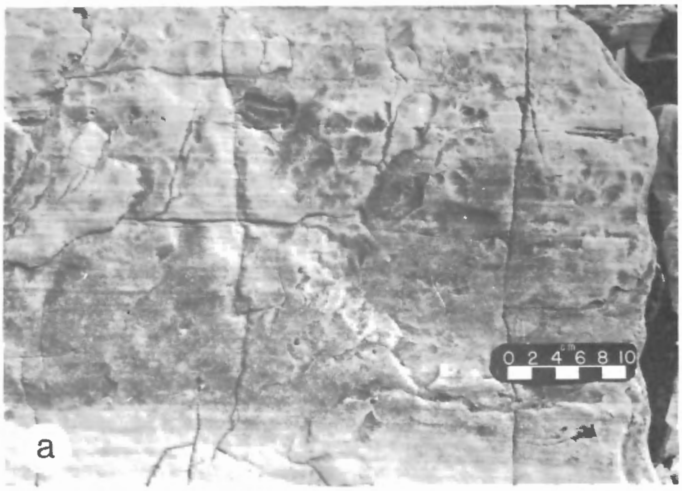


Figure 25. Dolomite.

a) Laminated to gently inclined, crosslaminated and burrowed massive dolostone; Factory Cove Member (Cow Head North, Unit 11.7; *see* Fig. 12 for location; GSC 191474)

b) Megaconglomerate Bed 12 with large clast of dolostone identical to dolomite illustrated in photograph (a); Factory Cove Member (Cow Head South; 10 cm divisions on stick; GSC 191475)

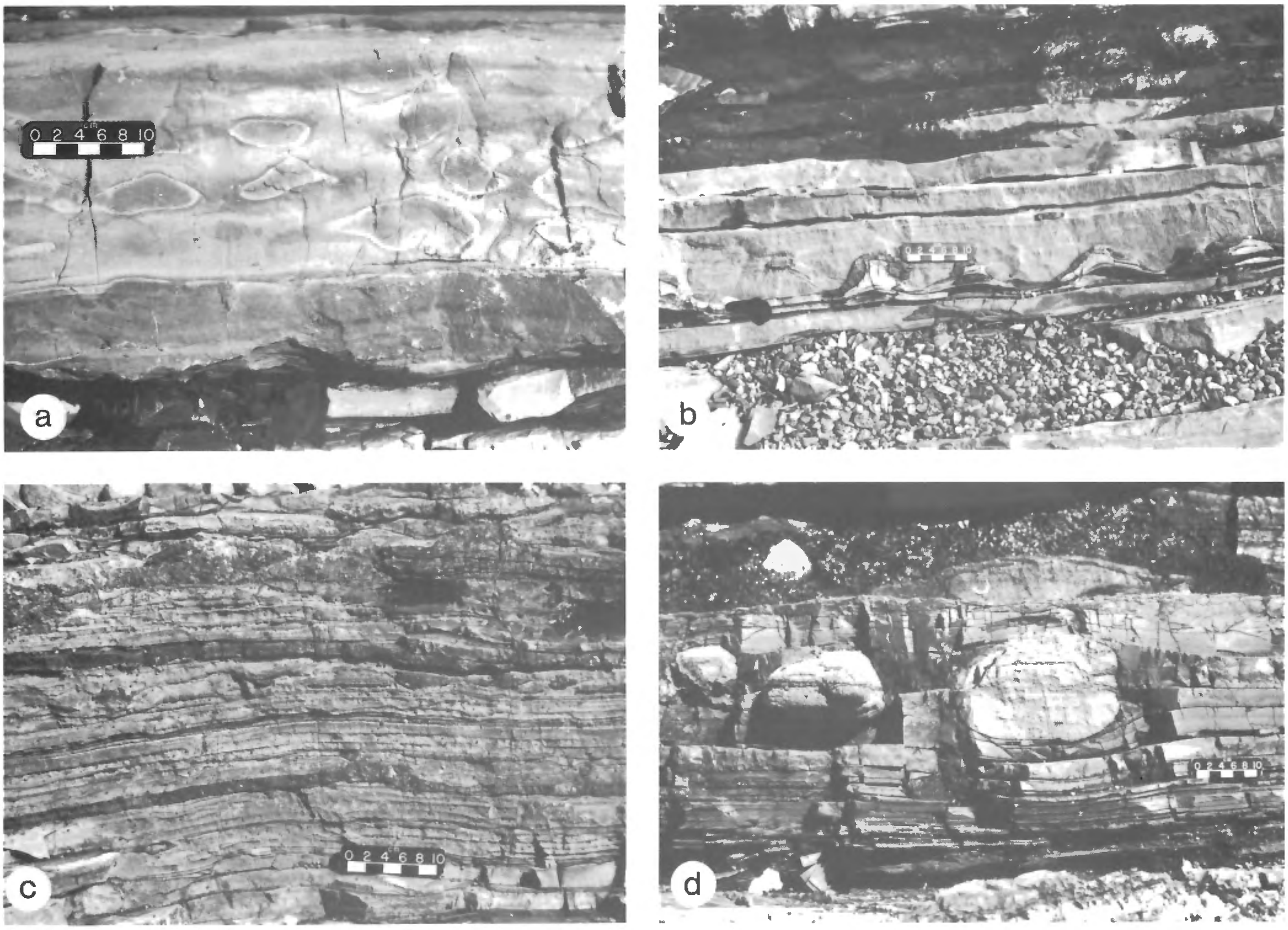


Figure 26. Chert.

a) A thick bed of lime mudstone with incipient nodules outlined by disseminated chert; Factory Cove Member (Cow Head North, Unit 9.6; GSC 191476)

b) Rippled calcarenite with black chert developed on ripple crests of underlying bed; St. Pauls Member (St. Pauls Tickle North, Unit 75; GSC 191477)

c) Black vitreous chert bands in parted limestone; Factory Cove Member (Cow Head North, Unit 11.5; GSC 191478)

d) Chert replacing limstone with nodules of relict limestone; Factory Cove Member (Cow Head North, Unit 11.4; GSC 191479)

Chert is also conspicuous as an impersistent top of many of the thick Ordovician conglomerates. It varies from silicified coatings around boulders in the upper levels of conglomerates to complete replacement of calcarenite caps and uppermost clasts in the conglomerate and results in a 10 to 20 cm chert layer that grades downwards into the limestone below. This style is so common that it can be used as a reliable "top" indicator for thick conglomerates in areas of sparse outcrop. Boulders at the top of some megaconglomerates are truncated and the bevelled tops are silicified. Conglomerates less than 20 cm thick may be completely silicified. Ropey chert is less common and developed as a three-dimensional network in thin limestone beds.

Silicifed shales are conspicuous in the Ordovician part of the succession with silicification affecting bright green, black or red shales in particular. Alteration ranges from blocky shale to chert that retains all the textures of the original shale, including colour. The presence of unflattened burrows in these replaced shales indicates silicification took place before significant compaction. Radiolaria can be easily seen in these cherts, particularly in the red varieties.

Clasts of chert, rafts of bedded limestone and chert, and partly silicified limestone, identical to lithologies in interbeds just below, are common in Ordovician conglomerates. These clasts are surrounded by an unsilicified argillaceous matrix in the conglomerates, suggesting either amazingly selective silicification in the conglomerates or rapid silicification on or centimetres below the Ordovician seafloor, prior to erosion.

Conglomerate

The Cow Head is best known for its spectacular limestone conglomerates. Although primarily carbonate, the deposits also contain a few clasts of chert, phosphate and shale, but unlike contemporaneous deposits in other parts of the Appalachians do not contain fragments of crystalline or volcanic basement.

The coarse beds in the Cow Head Group have been regarded as breccias for many years but should be called conglomerates. Most clasts are not angular but have rounded edges; many of the "exotic" clasts are rounded to well rounded; and it is usually only the extremely large blocks or platy clasts from adjacent ribbon limestones that are truly angular.

Individual units are distinctly lenticular, pinching and swelling dramatically along strike. They range from lenses less than a metre in length and centimetres in thickness loaded into underlying beds to layers tens of metres in length and 1 to 2 m in thickness, to beds of conglomerate several metres thick that can be traced a hundred or more metres along strike only to come to an abrupt end. Thus, correlation of conglomerate beds between sections with only a narrow band of coastal exposure is difficult.

Conglomerates composed of small clasts are often welded (i.e. two conglomerates on top of one another without intervening strata) and it is difficult to tell where one flow ends and the next begins when the only distinguishing character is a change in matrix or a recessively weathering notch which, when traced along strike, grades into thin parted limestone and shale, thus indicating slight erosion. The "50 foot conglomerate" described by Kindle and Whittington (1958, p. 322-333) from Broom Point, for example, seems to actually consist of about 15 welded flows (R.Hiscott, personal communication, 1982).

Limestone clasts

There are five different types of limestone clasts.

(1) Limestone plates. These clasts are broken cobble- to boulder-size pieces of ribbon to parted limestone lithologically identical to beds between conglomerates (Fig. 19). They are characteristically angular, commonly fractured and conspicuously bent tabular clasts 2 to 4 cm thick composed of lime mudstone and laminated to rippled grainstone. Some exhibit vertical burrows like those in the ribbon limestones. Quartzose calcarenite clasts like lithologies in underlying beds are also present as platy clasts in some Upper Cambrian conglomerates.

(2) Limestone rafts. These coherent clasts of ribbon to parted limestone (Fig. 22) are most commonly 1 to 2 m in size but may exceed 50 m in length and 10 m in thickness. Larger rafts are generally folded and contorted. All stages of incorporation into the conglomerates can be seen from individual ripped up plates, to partially fragmented beds, to thinly bedded rafts of contorted muddy limestone and shale. Some rafts appear to have been soft when incorporated, as smaller cobbles and pebbles are embedded in their periphery. Much of the matrix of some conglomerates was derived by the assimilation of similar clasts. Other large clasts illustrate wide variability in lithification with some layers broken in a brittle fashion while others were ductile and squeezed like toothpaste, while some are nodular.

(3) Limestone chips. These pebble-sized pieces of limestone, generally 4 to 6 cm long (rarely up to 20 cm) and 2 to 4 cm thick are the most common clasts in the Cow Head (Fig. 27). Lime mudstone is the most prevalent lithology, but together fossiliferous wackestone to packstone, silty wackestone, fine- to medium-grained peloid to ooid grainstone and dolomitic siltstone are just as abundant. They are derived from thin-bedded limestones of various compositions.

(4) "Exotic" limestone boulders. These most conspicuous of clasts (Fig. 28) exhibit the greatest range in composition and size and clearly originated outside the depositional environment.

Most common in Cambrian strata are subequant, angular to subrounded boulders of white limestone composed of calcified algae (Pratt, 1984), internal sediment and cement. These were interpreted by James (1981) to be fragments of algal mounds that grew along the shallow platform margin. Almost as common in some beds are boulders of ooid and peloid grainstone.

Similar clasts are also important and conspicuous in Ordovician conglomerates, but the wider variety of boulders also includes (1) dark grey fossiliferous lime mudstone, with molluscs, sponges, trilobites and brachiopods, (2) peloidal to fossiliferous wackestone or packstone with either conspicuous calcite spar and internal sediment (often green) or cut by numerous fractures filled by several generations of spar, and (3) dark rubbly weathering, bioturbated lime mudstone to wackestone. The largest boulders (up to the size of the alpha block at Lower Head, i.e. 50 × 200 m; Fig. 29) are either bedded limestone or biohermal or both in a single boulder. These larger clasts contain abundant trilobites, molluscs, ?stromatoporoids, sponges, bryozoans, worm tubes and calcified algae. There are also large boulders of rubbly limestone and rafts of interconglomerate strata.

(5) Conglomerate clasts. A minor but recurring component of the conglomerates are boulders of older conglomerate (Fig. 28). These are most commonly limestone chip conglomerates, but other types are also present.

Other clasts

While limestone predominates in Cambrian conglomerates, dolomite, chert and phosphate are distinctive elements of most Ordovician deposits.

Dolomite. Clasts of dolostone and dolomitic siltstone identical to and clearly derived from interconglomerate beds are found in most Ordovician conglomerates.

Chert. Brown-weathering, black chert clasts, generally pebble to cobble size, are found in most Ordovician conglomerates. More abundant, however, are partly silicified limestones and shales of all types, with the style of silicification identical to that in the enclosing interbeds.

Figure 27. Conglomerate composed almost entirely of limestone chips, clasts of muddy to grainy limestone generally less than 4 cm wide and 10 cm long, in a 5 to 10% matrix of argillaceous dolomite; Downes Point Member (Beachy Cove, Unit 5.4; GSC 191480)

Calcium phosphate. Blue weathering granules and pebbles of phosphate occur in most Ordovician conglomerates (Fig. 30) but are only major components in Bed 11. The phosphate occurs as peloids, ooid coatings and replaced limestone clasts.

Matrix

The matrix between clasts is highly variable in both amount and composition (Fig. 31). Some conglomerates may be as much as 1/3 matrix by volume; some may be filled with cement; while others have no discernible matrix at all. In those few beds least affected by diagenesis the nature of the matrix is clearcut, varying from (1) green argillaceous lime mudstone or calcareous shale to (2) intraclast/peloid or occasionally quartzose grainstone. In most units, however, it is difficult if not impossible to discern the original matrix because of neomorphism, pressure solution and dolomitization.

The most common alteration is the neomorphism of lime mud to microspar and pseudospar (Folk, 1965). This appears in the field as microcrystalline to coarsely crystalline calcite and can easily be mistaken for an original cement. When the matrix is argillaceous and silty the original fine grained carbonate has commonly altered to silt-sized, ferroan dolomite.

Definition of matrix is rendered most difficult, however, when stylolitized. It is unusual not to encounter some evidence of pressure solution, but all levels and degrees are present to the point where there is no identifiable matrix and all clasts are in stylolite contact.

In general, the matrix is similar in composition to underlying interbeds: if they are grainy the matrix will contain a high proportion of sand-sized particles; if they are muddy the matrix is generally argillaceous and calcareous mudstone. In some megaconglomerates extensive loading has resulted in injection of underlying sediment into the conglomerate, adding to the matrix and fracturing some of the larger clasts in the process. In others, matrix was acquired by erosion while moving downslope, coincident with the loss of large blocks.

Types of conglomerate

The conglomerates can be divided into five types (Fig. 32) based upon grading, sedimentary structures, matrix content, sorting, fabric and clast type.

(1) Graded-stratified conglomerates. These grainy, commonly quartzose, cobble to pebble conglomerates have cross-stratified and ripple-laminated tops. Layers range in thickness up to about 1 m. Particularly common in the Upper Cambrian and Lower Ordovician (Beds 6, 7 and 8), they range from calcarenites with 10 to 20% platy clasts floating in grainstone to true conglomerates made up of a variety of pebble- to boulder-size clasts with 10 to 20% calcarenite matrix. The conglomerates grade into calcarenites along strike. This facies is described by Hubert et al. (1977, p.141-145), but we

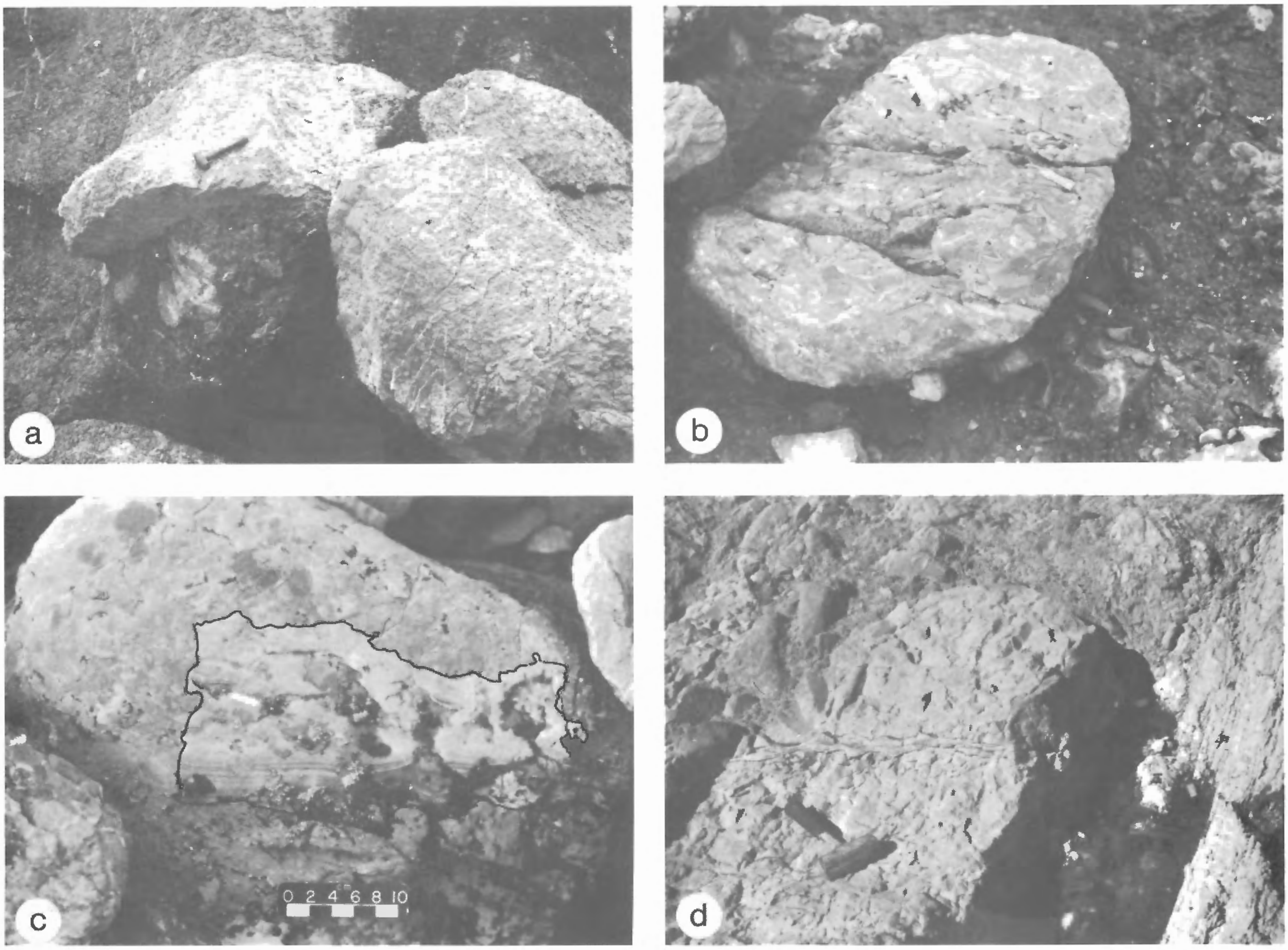


Figure 28. Exotic boulders.

a) Boulders of calcified algal limestone (James, 1981) which probably came from a biohermal facies at the shelf edge; Stearing Island Member (Cow Head North, Unit 7.1; GSC 191481)

b) Clast of plate and small boulder conglomerate about 1 m in long dimension in megaconglomerate; Factory Cove Member (Lower Head West, Bed 14; GSC 191482)

c) Clast of algal boundstone with a large cavity filled with geopetal internal sediment and cement; Factory Cove Member (Lower Head, Bed 14; GSC 191483)

d) Clast of calcarenite with a spar-filled crack that extends across the boulder, indicating formation and cement filling prior to erosion and transport; Factory Cove Member (Cow Head North, Bed 14; GSC 191484)

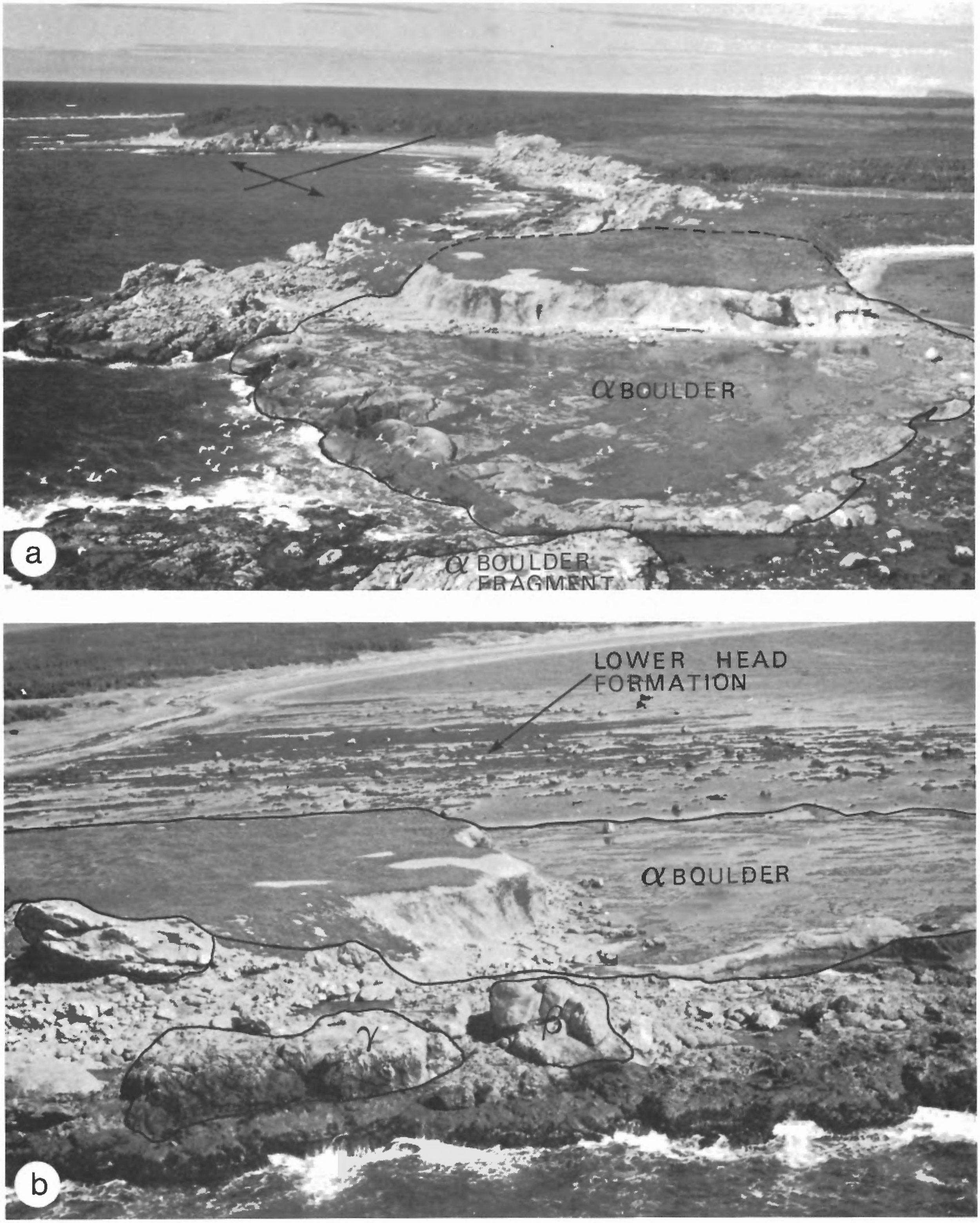


Figure 29. Megaconglomerate at Lower Head.

a) The eastern point of Lower Head, looking north and illustrating the largest clast in the Cow Head Group, Alpha boulder. This block, about 50 m across and fragmented into two, is composed of a biohermal facies which now forms the small grass-covered hill and an off-reef calcarenite facies which forms the low tide platform in the foreground. The core of the eastern anticline is in the cove to the west. (photograph J. Botsford; GSC 191485)

b) The eastern point of Lower Head, looking east across Alpha boulder and illustrating the intertidal platform of Lower Head Sandstone which overlies the Cow Head in the background and the conglomerate of Bed 14 in the foreground. (photograph J. Botsford; GSC 191486) believe that these graded layers, as with the graded calcarenites, were deposited by turbidity currents and not by contour currents.

(2) Limestone plate conglomerates. These practically oligomict deposits are composed entirely of limestone plates and rafts of parted to ribbon limestone (Fig. 19). Beds are less than 2 m thick and the tops are generally sharp. The matrix is characteristically argillaceous and/or carbonate mudstone similar to the partings between ribbon limestones in the adjacent interbeds, and comprises from 10 to 20% by volume of the deposit. Fabric appears generally chaotic in the field except that the upper parts of some beds illustrate a series of waveforms described by Hubert et al. (1977, p.133, 136). These waveforms range in wavelength from 1 to 6 m depending upon bed thickness and the conglomerate in the wave trough is more carbonate-rich and grainy.

(3) Limestone chip conglomerates. These common deposits (Fig. 27), generally less than 2 m thick and with sharp tops, are particularly conspicuous in the lower parts of the Cow Head (Downes Point Member, Shallow Bay Formation) where they form the bulk of the conglomerates. The matrix, generally less than 10% of a bed, is composed of either finely crystalline calcite, dolomite or argillaceous lime mudstone. There is no obvious fabric; clasts are oriented subparallel to bedding; they are not graded; only rarely is there a calcarenite cap. Clasts are mainly pebble- to cobble-size but may be as small as granules. These conglomerates locally contain large floating boulders, either tabular slabs of calcarenite or equant blocks of algal limestone, more than 0.5 m in size. In some instances these conglomerates support floating boulders which are bigger than the thickness of the whole bed (Fig. 33).

(4) Boulder conglomerates. These deposits are similar to chip conglomerates in terms of grading, fabric and matrix, but tend to be thicker (up to 5 m) and are distinguished by the large number of exotic cobble- to boulder-size clasts they contain. These boulders may be dispersed throughout the layer or may preferentially rest at the base. Some boulders project from the tops of layers. The matrix in these conglomerates is of different types and, although most is muddy, the upper parts may have a grainy matrix and a calcarenite cap which is crossbedded or laminated. In other beds, interstices in the uppermost parts appear to be devoid of mudstone matrix, even though matrix is present in the bulk of the layer. This lack of matrix and interparticle cement may account for the impression that these layers have a grainy cap.

(5) Megaconglomerates. These thickest, muddiest, and most chaotic of conglomerates (Fig. 29, 34) contain huge blocks, some of which are folded, up to 50 m across at Cow Head and 200 m across at Lower Head. Similar deposits have been called "megabreccias" by other workers (Mountjoy et al., 1972). The three thickest megaconglomerate layers are Beds 3, 12 and 14, which are up to 10, 20, and 100 m thick respectively. Platy-clast fabric is virtually random, but locally parallels the margins of large boulders. The matrix consists of green terrigenous mud like that of the underlying shaly facies; large blocks of thinly bedded shaly facies are also

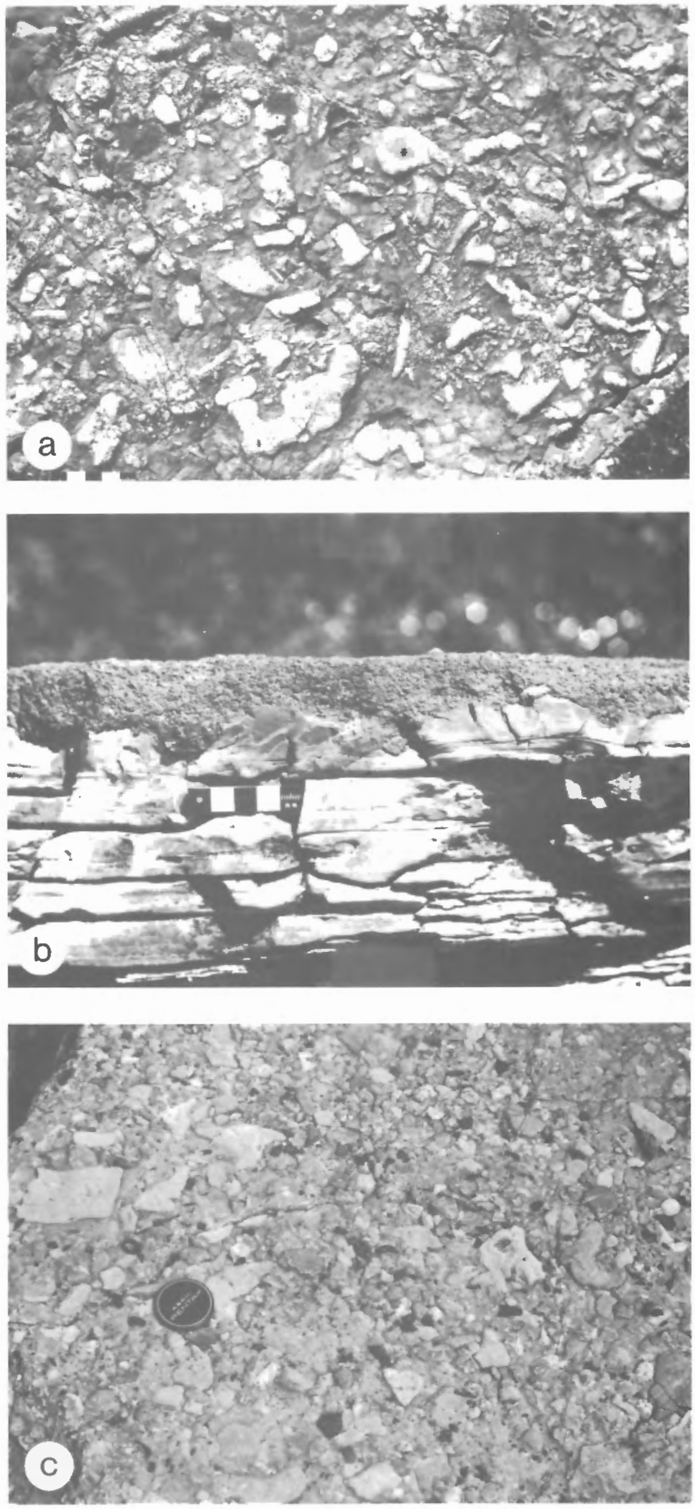


Figure 30. Phosphate.

a) Bedding plane view of coarse phosphate clast conglomerate; Factory Cove Member (Cow Head North, Unit 11.2; centimetre scale; GSC 191487)

b) Thin lens of phosphate granule conglomerate in a small channel eroded into parted limestone; Factory Cove Member (Cow Head North, Unit 11.4; GSC 191488)

c) Bedding plane view of a pebble conglomerate containing numerous black phosphate clasts; Factory Cove Member (Cow Head North, Unit 13.9; GSC 191489)

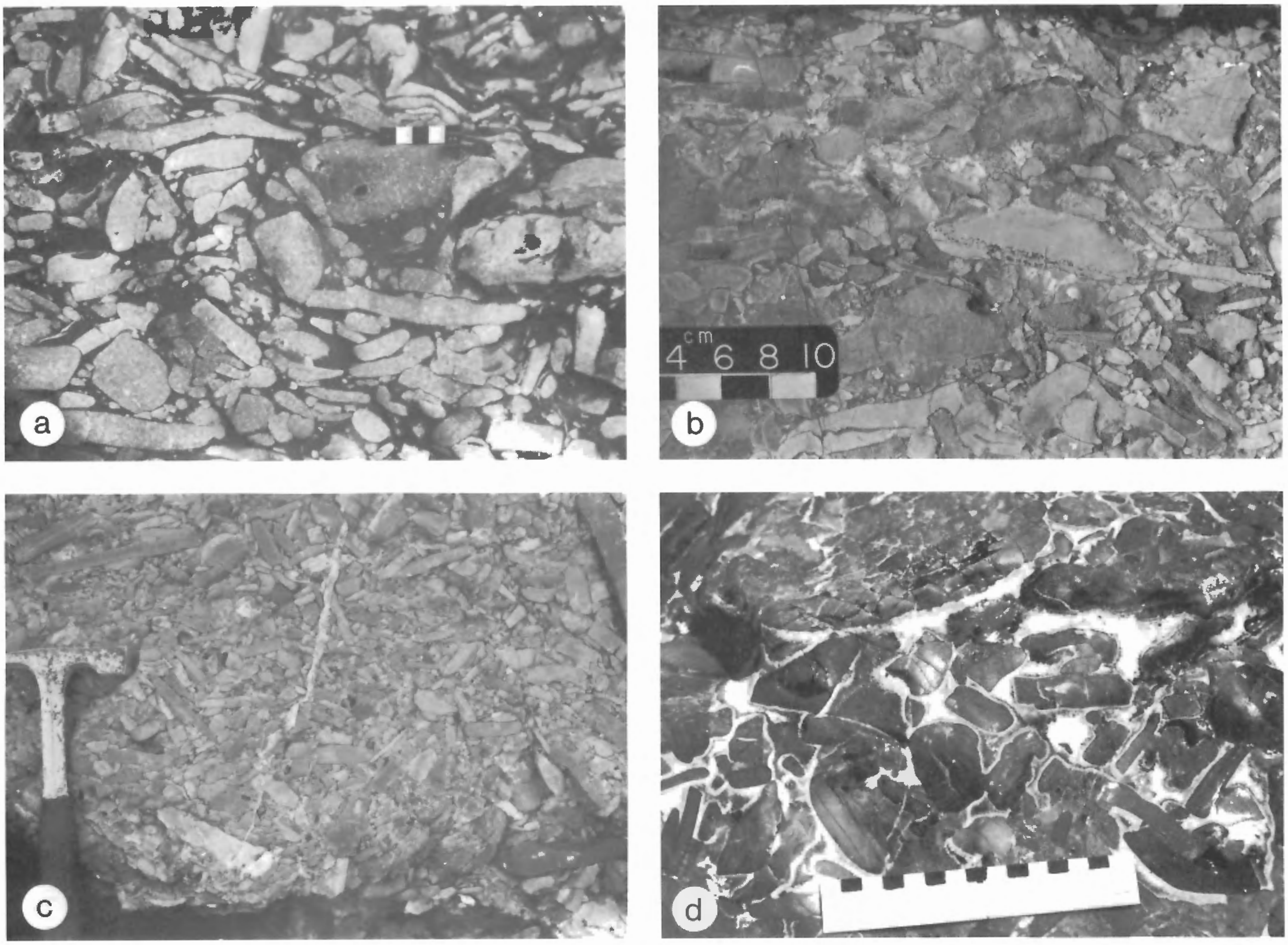


Figure 31. Conglomerate fabric.

a) Plate and small boulder conglomerate with argillaceous lime mudstone matrix; some clast contacts are stylolites; Broom Point Member (St. Pauls Tickle North, Unit 6; GSC 191490)

b) Plate and small boulder conglomerate with calcarenite matrix, much of which is stylolitized, with many clasts in stylolite contact; Broom Point Member (St. Pauls Tickle North, Unit 14; GSC 191491)

c) Plate conglomerate with no obvious matrix, all clasts in stylolite contact; Martin Point Member (Green Point, Unit 11; GSC 191492)

d) Conglomerate in which each clast is surrounded by an isopachous rind of synsedimentary cement and the remaining pore space is filled with sediment and a late stage cement; Downes Point Member (Cow Head North, Bed 2; GSC 191493)

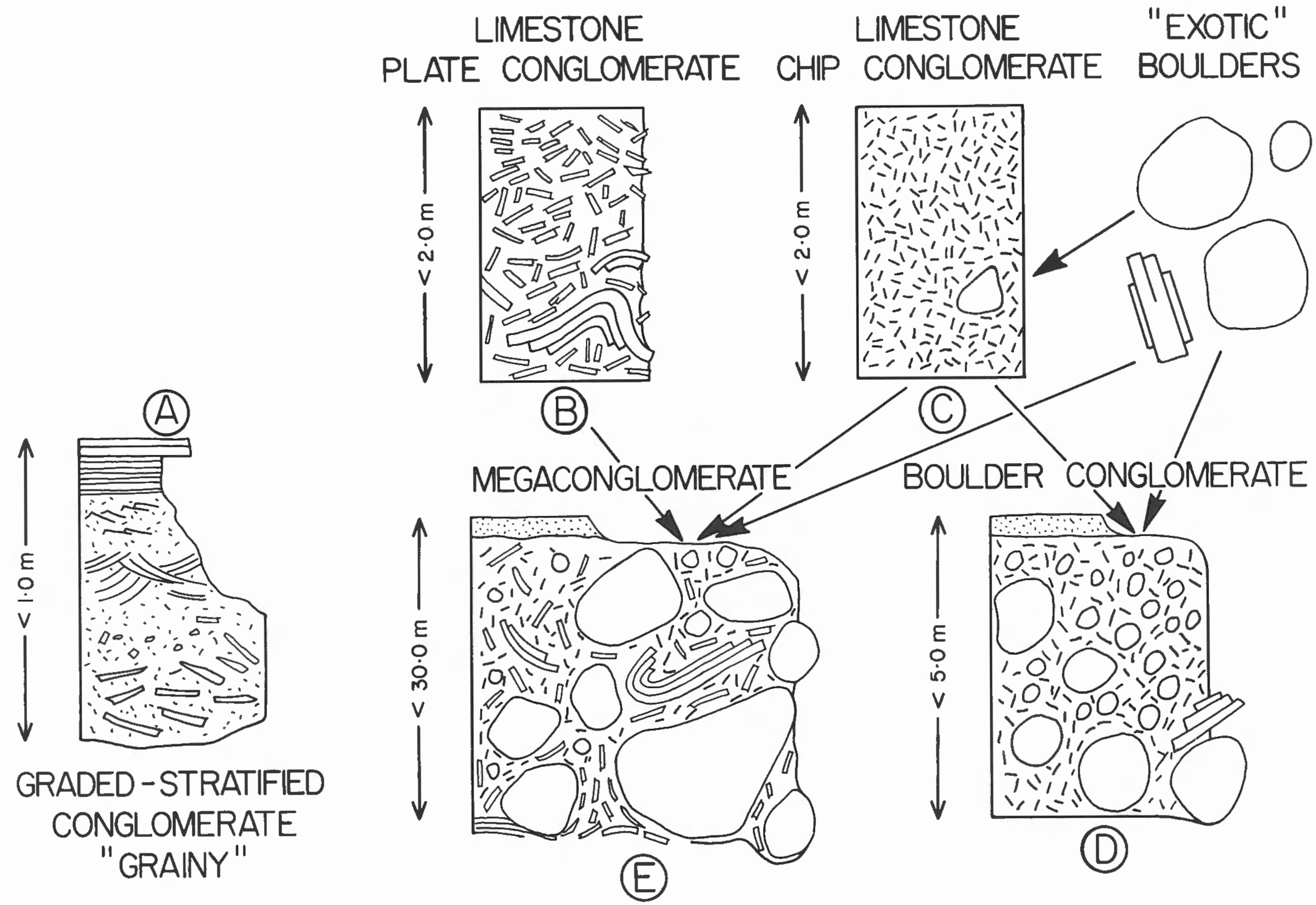


Figure 32. A sketch of the different types of conglomerate found in the Cow Head Group.

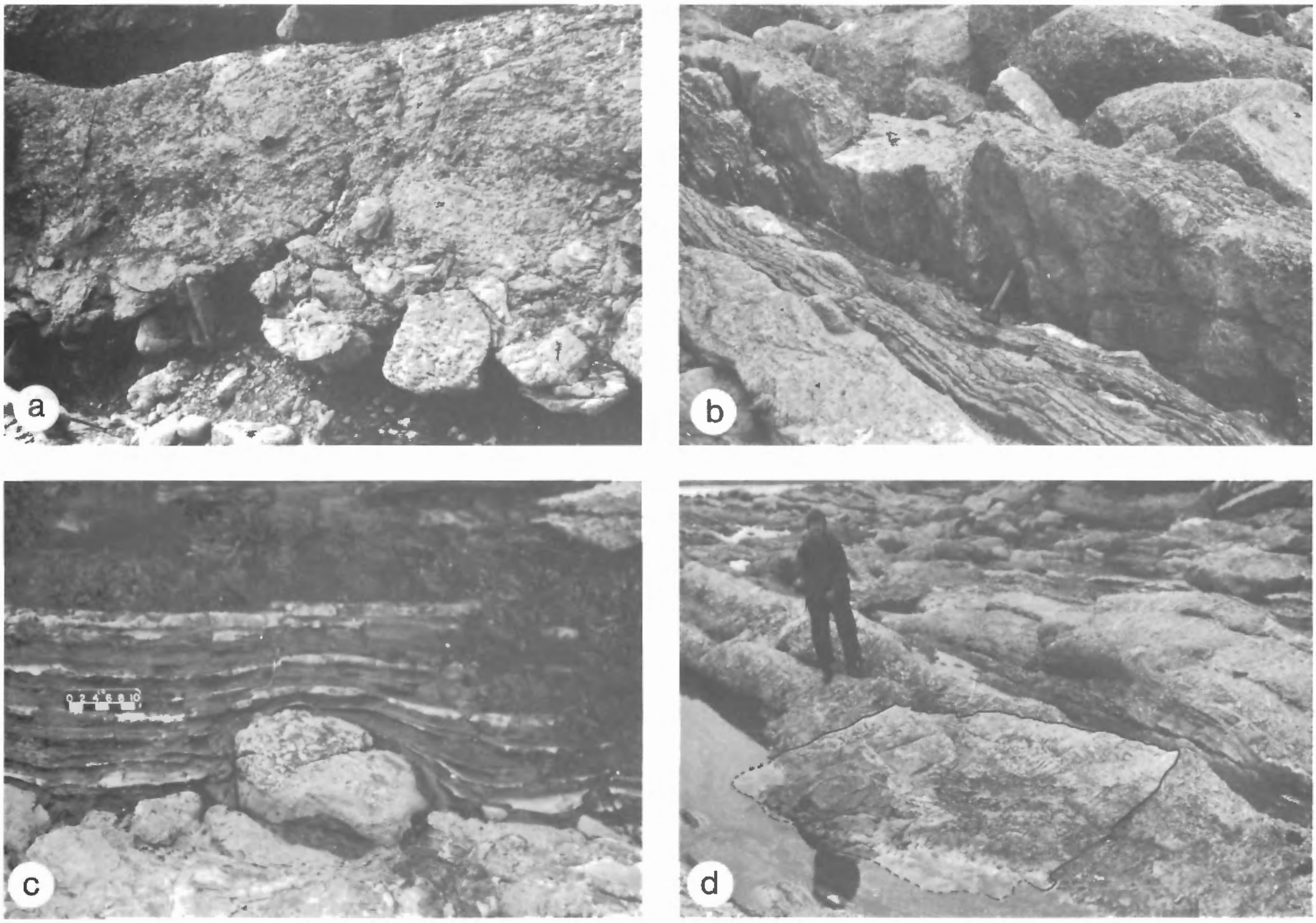


Figure 33. Conglomerate structure.

a) Plate and boulder conglomerate with largest boulders at base of debris flow; Downes Point Member (Broom Point North, Unit 18; GSC 191494)

b) Sole marks at base of conglomerate; Stearing Island Member (Cow Head North, Unit 8.25); hammer scale. (GSC 191495)

c) Clast of conglomerate sitting on top of flow and subsequently buried by shale and ribbon limestone; Downes Point Member (Broom Point North, Unit 8; GSC 191496)

d) Large clast of calcified algal limestone, much bigger than the thickness of the flow, extending down into shales and parted limestone below (below water); Downes Point Member (Broom Point North, Unit 16; GSC 191497)

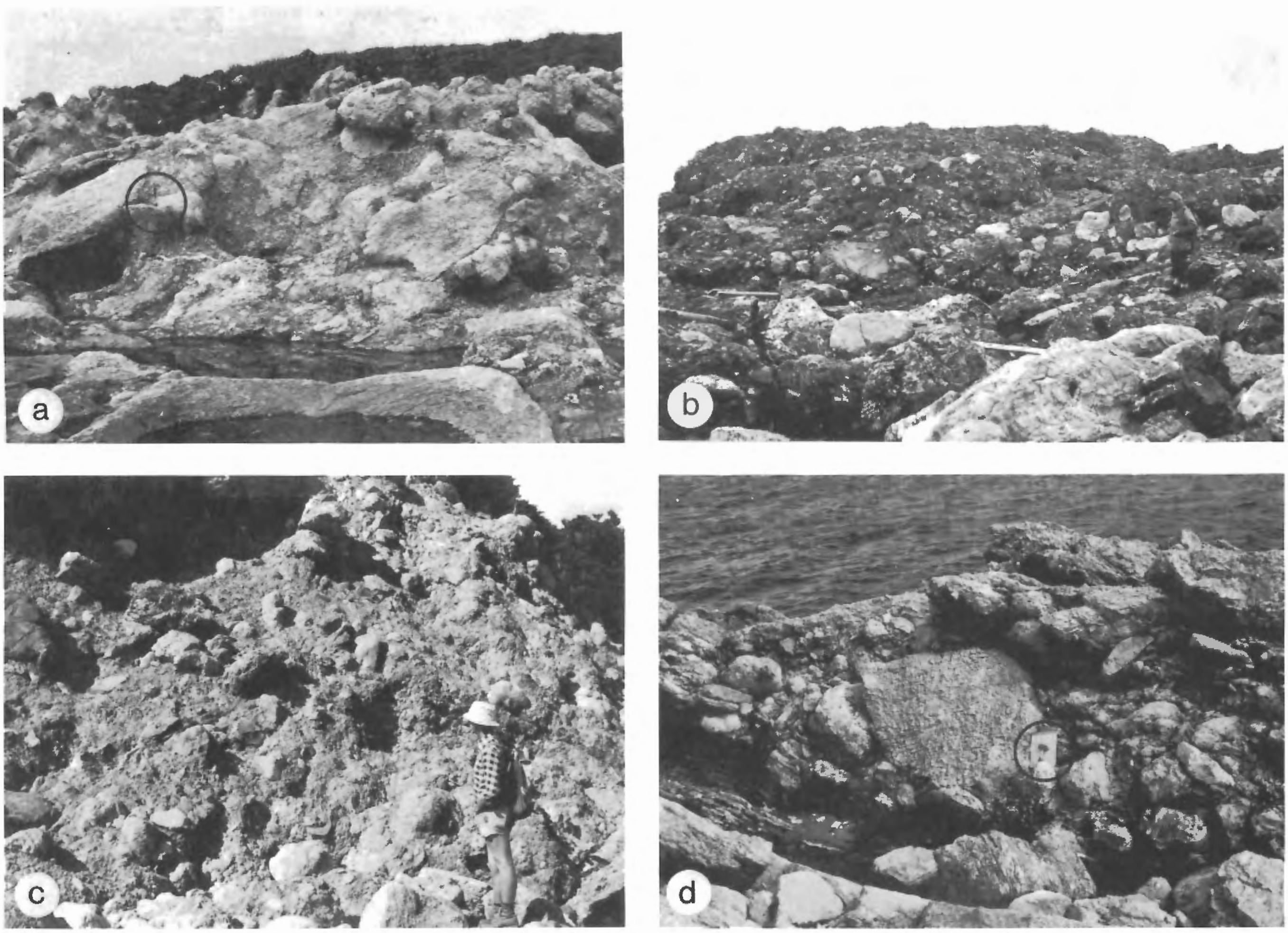


Figure 34. Megaconglomerates.

a) Bed 12, Stearing Island, Factory Cove Member; hammer scale. (GSC 191498)

b) Bed 14, Cow Head South; person for scale at right. (GSC 191499)

c) Bed 14, Cow Head North. (GSC 191500)

d) Bed 9, Cow Head South; hammer scale. (GSC 191501) present as clasts in these layers. Enormous load clasts, loaded boulders and deep injections of deformed, disarticulated thinly bedded substrate into the base of Bed 12 in particular suggest that much of the matrix may have been incorporated by injection and churning just prior to freezing of the flow. Some of these deposits have discontinuous calcarenite caps. Many Ordovician flows have a brown-weathering chert top and some of the uppermost clasts appear to have been planed off or bevelled subsequent to deposition.

Basal features

The bases of some type 4 and 5 conglomerates are erosive, but most type 2, 3, 4 and 5 conglomerates have flat bases showing no more than a few centimetres of downcutting into underlying beds, primarily by plucking of the underlying substrate. It is not clear how many of the limestone plates were derived by erosion (plucking) during flow and how many came from slope slide scars that probably provided the bulk of the clasts in the flows. Several conglomerate layers have basal tool marks with a northwest-southeast orientation. Lineation of plucked clasts also suggests a similar flow path.

Mechanisms and direction of flow

The graded-stratified conglomerates (type 1) appear to have the characteristics of turbidites, and paleocurrent measurements indicate transport and deposition toward the southeast (Hubert et al., 1977; Hiscott and James, 1985). All the other conglomerates exhibit features like those described for subaerial debris flows; i.e. flat sharp bases with only minor evidence of erosion, poorly developed clast fabric with tilting of platy clasts at right angles to the flow direction, boulders floating within flows or projecting above the tops of flows (Fig. 33), irregular flow tops indicating primary relief above the sea floor, and tapered flow margins (snouts; Hiscott and James, 1985).

Hubert et al. (1977) concluded, on the basis of orientation of slump fold axes, inferred extensional direction of synsedimentary boudins, and clast fabric of debris flows, that the paleoslopes dipped either northeast or southwest, depending upon the locality. Hiscott and James (1985) concluded on the basis of similar data, that the paleoslope consistently dipped to the southeast. The northwest-southeast flow path is also supported not only by the turbidite paleocurrent directions but also by sole marks at the base of conglomerate layers (Fig. 33).

PALEONTOLOGY AND BIOSTRATIGRAPHY

Introduction

The Cow Head Group has an abundant and diverse assemblage of fossils. Conglomerate boulders contain shelly fossils from shelf, shelf edge and slope environments, some of which are rare or unknown *in situ*. Intervening shales and interbedded limestones exhibit an almost unbroken record of early Paleozoic planktonic and deep water benthonic organisms. When adequately studied, these juxtaposed faunas from diverse environments will be of great use for local, regional and intercontinental correlation.

Although the importance of fossils from the Cow Head Group has been recognized since they were first collected by Richardson (in Logan, 1863) and described by Billings (1865), it is not until recently that any systematic attempts have been made to document them from measured stratigraphic sections (Kindle and Whittington, 1958; Whittington, 1965; Fahraeus, 1970; Erdtmann, 1971a, b; Fahraeus and Nowlan, 1978; Fortey and Skevington, 1980; Fortey et al., 1982; Kindle, 1981, 1982).

Presently, the trilobites are being studied by R.A. Fortey and R. Ludvigsen, the graptolites (Fig. 35) by R.K. Stevens, S.H. Williams and B.-D. Erdtmann, the conodonts by C.R. Barnes and L.E. Fahraeus, the radiolaria by R.K. Stevens and W.R. Iams, some of the Ordovician brachiopods by R.J. Ross and N.P. James and the trace fossils (Fig. 36) by G. Narbonne and N.P. James. The presence of acritarchs has been demonstrated by G. Bagnoli and a varied cephalopod fauna has been observed by B. Stait (both unpublished).

When these studies have been completed it may well be possible to define several important biostratigraphic boundaries in this area. Of particular interest are the Cambrian/Ordovician boundary (Fortey et al., 1982), the Trempealeauan/Gasconadian boundary, the Tremadoc/Arenig boundary, and the Canadian (Ibexian)/Whiterock boundary. A presumed equivalent to the Arenig/Llanvirn boundary may also be represented. Given the faunal abundances, the relative completeness of the sections, the eclectic nature of the faunas and good sections through rocks from greatly differing environments, it is clear that the Cow Head area will eventually become a key area in Lower Paleozoic biostratigraphy.

In this report most emphasis is placed on those fossils that were of use during field investigations. These include the graptolites, trilobites and brachiopods. In addition to the literature, trilobite data from Cambrian rocks were provided by C.H. Kindle and R. Ludvigsen, while R.A. Fortey visited most of the sections with us and has furnished almost all of the new data on the Ordovician trilobites. R.J. Ross, Jr. has supplied new brachiopod identifications from upper Cow Head horizons.

Graptolites have been a key to our correlation within much of the Cow Head Group. Excellent collections were originally made by Johnson's field parties and described by Ruedemann (1947). Although these collections are preserved in the Smithsonian Institution and have field numbers, there is no record of the collecting localities these numbers represent. They were therefore not examined during the present study.

Kindle and Whittington (1958) provided the first outline of the graptolite distribution and their results led to spot collecting by Erdtmann (1971a, b). More significantly, Fortey and Skevington (1980) recognized that the Broom Point sections are potential stratotypes for the Cambrian/Ordovician boundary and, as such, are important for the study of the early graptolite evolution.

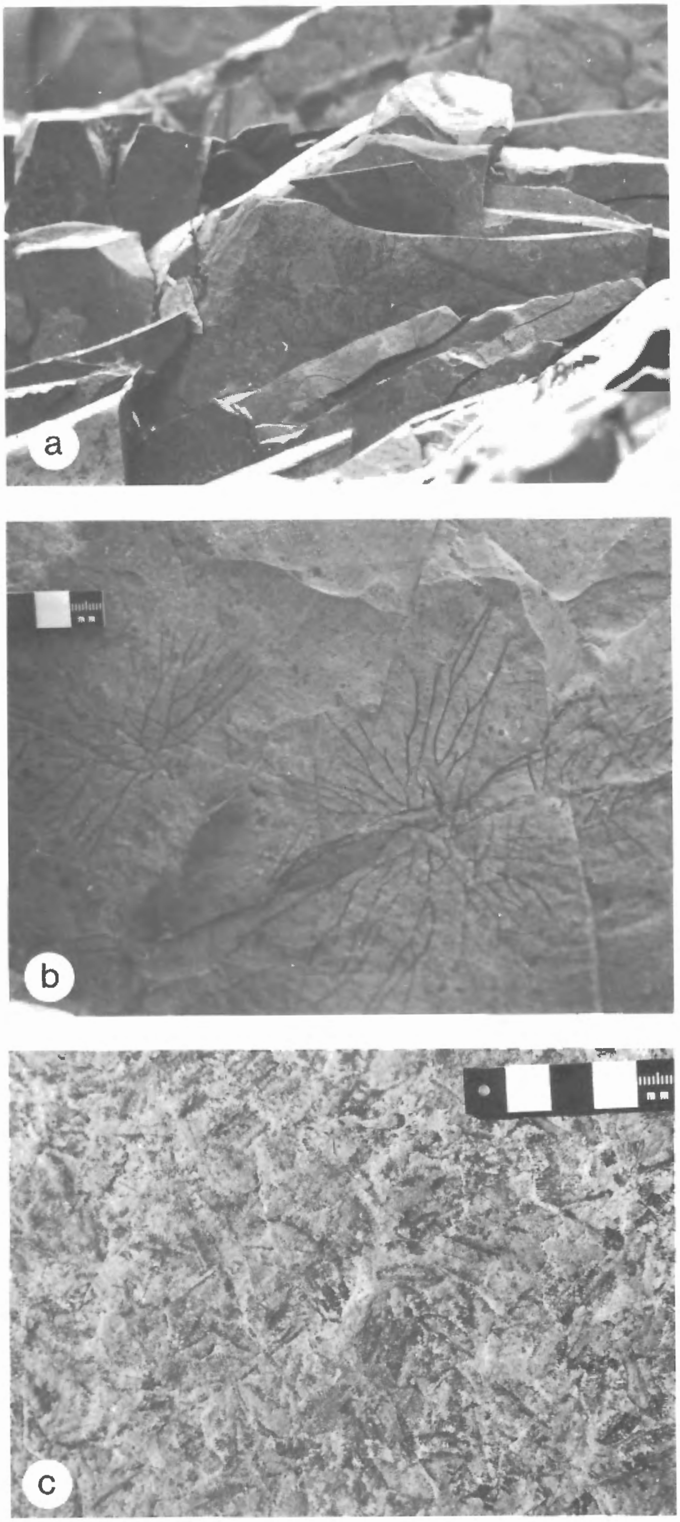


Figure 35. Graptolites, representative field examples.

a) Numerous *Dictyonema* sp. from basal Tremadoc strata in the Broom Point Member (Green Point, Unit 26; GSC 191502)

b) Large *Clonograptus* sp. in basal Arenig strata from the Factory Cove Member (Cow Head North, Unit 9.6; GSC 191503)

c) Prolific *Phyllograptus* sp. from Arenig strata in the Factory Cove Member (Cow Head South, Unit 11.1; GSC 191504)

Skevington first indicated to us (personal communication, 1967) that a key to understanding the succession of graptolites in west and central Newfoundland was to compare them with the Australian sequences (Thomas, 1960) rather than those regarded as standard for North America (Ruedemann, 1904,1908, 1947; Berry, 1960) or Europe (Elles and Wood, 1901-18). Almost every Australian standard graptolite zone between La2 and Da1 can be recognized from the Cow Head Group.

General Aspects

With newly acquired information and more detail on the distribution of previously reported taxa, several widely accepted aspects of Cow Head geology need clarification.

Contrary to previous interpretations not all of the boulders in any one conglomerate, even at any one locality, are of the same stratigraphic age. Boulders much older than the age of the conglomerates that contain them are most common in the coarse proximal facies as exposed at Lower Head and Cow Head. At Lower Head, for example, a large bedded boulder yields an earliest Tremadoc fauna of trilobites and conodonts, yet the conglomerate horizon was formed during latest Arenig (Da1) time. Correlation of faunas from the boulders is not as simple as previously thought.

Previously published correlation schemes for the Cow Head Group did not appreciate that the conglomerate beds, even the thickest, were emplaced almost instantaneously. They should be represented as lines and not areas on correlation tables. In extreme published examples well over half of the available time is occupied by the conglomerate horizons.

During the present study it was recognized that many of the conglomerates cut deeply into underlying beds, even though the basal contacts seem at first to be conformable. The age of the conglomerates is best restricted by the age of the immediately overlying shale and limestone. These, however, are usually condensed sequences so that care must be taken to locate the lowest fossiliferous layers.

Several graptolite taxa, formerly thought to be unrepresented in North America, have been collected and help clarify intercontinental correlations. On the other hand, the early appearance of several genera of shelly fossils in shelf edge derived boulders makes correlation more difficult. Apparently, several genera evolved in the shelf edge or slope environment and migrated onto the shelf where their main fossil record is preserved (Fortey, 1984).

Trilobites

Cambrian trilobites

Cambrian biostratigraphy worldwide is almost entirely based on the spatial distribution of trilobites (Palmer, 1977) and the Cow Head Group is no exception. The most widely used biostratigraphic stages in North America are a modification of those established by Howell et al. (1944) and progressively modified by Lochman-Balk and Wilson (1958), Palmer (1965) and Stitt (1971). This scheme is most applicable to those polymeroid trilobites which inhabited shallow water,

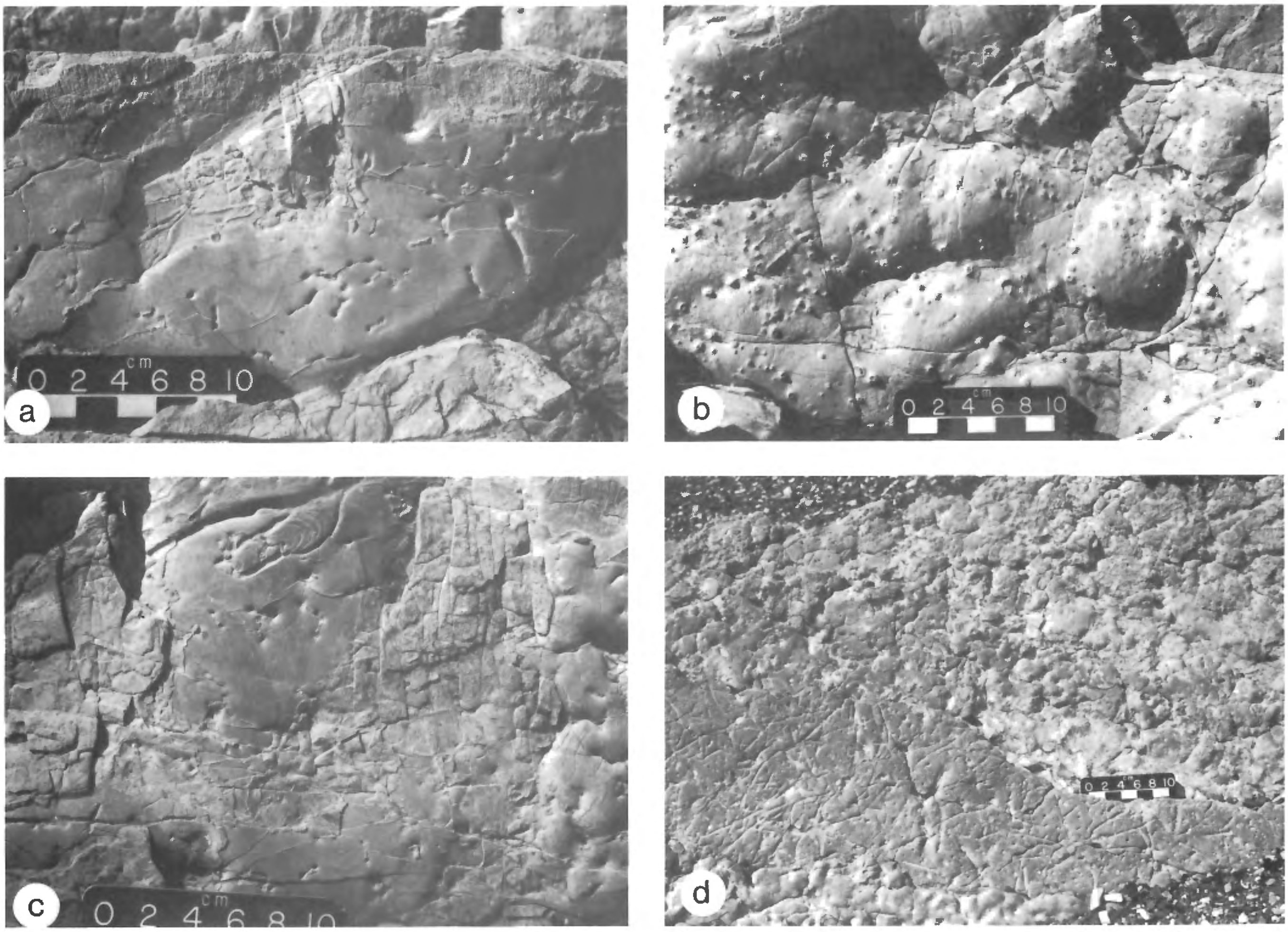


Figure 36. Trace fossils in limestone.

a) Bedding plane of ribbon limestone with numerous paired vertical burrows (*Diplocraterion* sp.); Factory Cove Member (Cow Head North, Unit 9.8; GSC 191506)

b) Bedding plane of calcarenite with lumpy bedding and numerous single (*Skolithos* sp.) and paired (*Diplocraterion* sp.) burrows; St. Pauls Member (St. Pauls Tickle South, Unit 1; GSC 191507)

c) Bedding plane of ribbon limestone with both vertical (*Diplocraterion* sp.) and horizontal (*Zoophycus* sp.) traces; Factory Cove Member (Cow Head North, Unit 9.8; GSC 191508)

d) Bedding planes with numerous vertical and horizontal ichnofossils; St. Pauls Member (St. Pauls Tickle South, Unit 1; GSC 191509) interior shelf environments, or the inner part of the Middle Carbonate Belt of Palmer (1960). It has become increasingly apparent, however, that this zonation is not applicable to outer shelf and deep water faunas. In fact, those agnostid trilobites in eastern (Acadian) North America have long been correlated with the Cambrian succession in Scandinavia (Westergard, 1946; 1947).

Whittington and Kindle (1969) recognized that Cambrian trilobites in the Cow Head were characteristic of three separate regions outside western Newfoundland: (1) shallow water facies from interior and western North America - the North American Faunal Province; (2) deep water facies from southeastern Newfoundland, Nova Scotia, New Brunswick and northern Europe - the Acado-Baltic Faunal Province; (3) from the St. Lawrence Lowlands (Levis) and other parts of the Appalachians and that they, as Rasetti (1944) surmised, were inhabitants of reefs or intermediate water depths. These faunas correspond in a general way to the faunas outlined by Ludvigsen (1982) for the uppermost Cambrian of the northern Cordillera. The nature of the intermediate faunas (3) is poorly understood, although they are becoming better known (Ludvigsen and Westrop, 1983). The most useful, therefore, in spite of their aforementioned limitations, are the North American and Acado-Baltic Zones, which are characteristic of the outer detrital and inner detrital to middle carbonate belts of Palmer (1960).

Most Cow Head Cambrian trilobites are found in the conglomerates and bedded limestones of the Shallow Bay Formation. Our present understanding is based almost entirely on the work of Kindle (1942, 1943, 1948, 1981, 1982) and Kindle and Whittington (1958, 1959, 1965), augmented by small collections by R. Ludvigsen and ourselves. The trilobites come mainly from boulders within the conglomerates, which have sampled a variety of shelf, shelf-margin and deep water environments.

Kindle (1981, 1982) has placed the Cambrian trilobites in eight informal zones. Each zone or grouping represents a mixture of boulders present at a given stratigraphic level. The relationship of these zones, as presently understood, is illustrated in Figure 37.

Middle Cambrian

Middle Cambrian trilobites fall into four zones. The basal Zones 1 and 2 are present only at Broom Point South, with trilobites from Zone 1 present in the lower two conglomerates (Units 1 and 2) and those from Zone 2 in the overlying Unit 4. North American forms are characteristic of the *Bathyuriscus-Elrathina* Zone whereas the presence of *Ptychagnostus* cf. *P. gibbus* is used to correlate the fauna with Zone B1 of the Acado-Baltic Faunal Province.

Zone 3 trilobites are more widespread and occur in overlying beds at Broom Point South (Units 8 and 11), White Rock Islets, the outer reefs of Stearing Island, White Point in St. Pauls Inlet and Snug Harbour in Western Brook Pond. This fauna contains elements characteristic of the *Bolaspidella* Zone in North America and Zones B2 and B3 in Sweden.

Trilobites from Zone 4 are found only in the thick welded conglomerates of Unit 11 at Broom Point South. The North American faunal province forms are similar to those from the uppermost part of the *Bolaspidella* Zone while agnostids are like those from Zone C2 in the Acado-Baltic Faunal Province.

Upper Cambrian

Zone 5 trilobites are found in Beds 1, 2, 3 and 4 on the north shore of Cow Head Peninsula and at Hickey Cove in the Broom Point North section. In terms of the North American Faunal Province these trilobites are characteristic of the *Cedaria* and *Crepicephalus* Zones, at the base of the Dresbachian Stage. The agnostids *Clavagnostus* sp. and *Baltagnostus*? sp. are also present, but are not diagnostic. Kindle (1948), however, recovered *Clavagnostus* cf. *C. sulcatus* together with a similar *Cedaria-Crepicephalus* fauna at Murphy Creek on the Gaspe Peninsula, Quebec, and on this basis correlated this Cow Head zone with Zone C3 of the Acado-Baltic Province. Zone C3, however, is regarded as Middle Cambrian (Westergard, 1946). The exact position of the Middle-Upper Cambrian boundary is a topic of ongoing discussion (Robison, 1976) and if placed at the top of the *Lejopyge laevigata* Zone then Zone C3 would lie well up in the *Cedaria* Zone in North America.

Trilobites from Zone 6 come primarily from Bed 5 along the north shore of Cow Head Peninsula, but also from Broom Point North, Martin Point and Gulls Marsh. These fossils are correlated with the upper part of the Dresbachian Stage or Acado-Baltic Zone 2.

Zone 7 is composed of faunas typical of the North American Franconian Stage or Zone 5 of the Acado-Baltic Province. Boulders containing these trilobites occur in the lower part of Bed 6 at Cow Head North, Broom Point North and at Martin Point.

The highest Zone 8 is defined on trilobites that come from boulders in the upper part of Bed 6 at Cow Head, at Broom Point North and South and from an isolated outcrop at Green Island in St. Pauls Bay. The oldest faunas in this zone come from boulders in the prominent sandstone bed in the middle of Bed 6. Similar North American trilobites can be recognized in the Trempealeauan Stage while Acado-Baltic trilobites are again typical of Zone 5.

Ordovician trilobites

The Ordovician has the advantage that with increased faunal diversity, several different taxa can be used for biostratigraphy, the most common being trilobites, brachiopods, graptolites and conodonts (see Ross, 1984 for a review). In this study we have relied on macrofossils; work on conodonts is in progress.

The reference area for North American Lower and Middle Ordovician trilobite biostratigraphy has, for the last 30 years, been western Utah and Nevada (Ross et al., 1982). There, 12 trilobite-brachiopod faunal zones were established and designated with the letters A through L. The Lower Ordovician

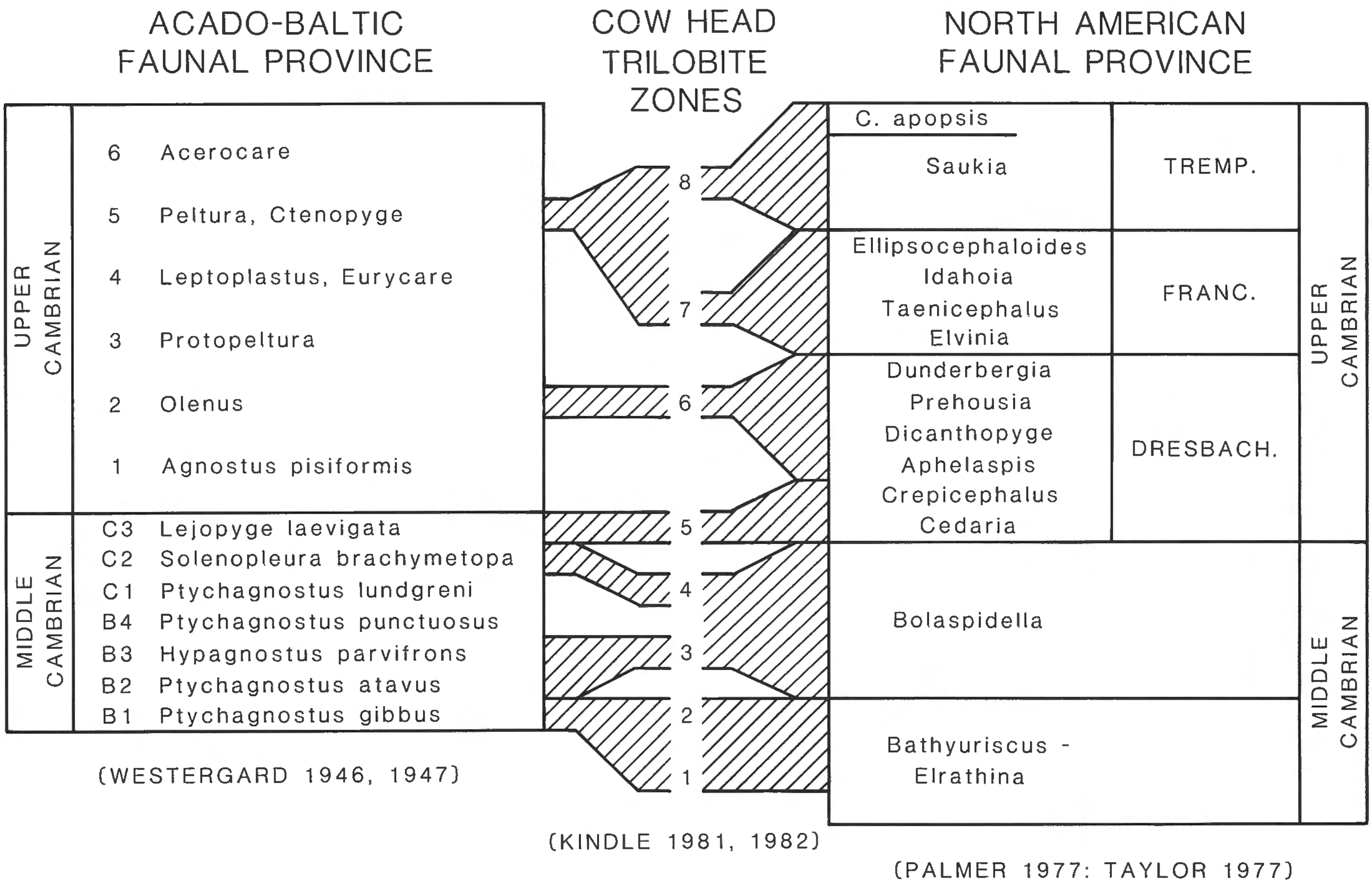


Figure 37. A diagram illustrating the zonal distribution of the different Cambrian trilobite zones within the Cow Head.

(Canadian or Ibexian) part of the section contains mostly shallow shelf, bathyurid trilobites while the Middle Ordovician (Whiterock) strata have a more diverse fauna. As in the Cambrian, there is now more emphasis on the importance of biofacies in zonation schemes (e.g. Shaw and Fortey, 1977). Four coeval post-Tremadoc faunal assemblages are now recognized: (1) a bathyurid biofacies on the inner shelf; (2) an illaenid-cheirurid community at the shelf edge, commonly amongst and within carbonate buildups; (3) a nileid community on the upper slope and (4) an olenid community on the lower slope in anoxic shales.

Several thousand shale horizons have been split searching for graptolites and scanned with a hand lens. Only five have yielded trilobites. Kindle (personal communication, 1982) has found only a few trilobites in Cambrian shales.

Information on Cow Head Ordovician trilobites comes from several sources. The faunas in general have been documented by Kindle and Whittington (1958, 1959), Whittington and Kindle (1969) and Whittington (1963, 1968). The trilobites near the Cambro-Ordovician boundary have been reported by Fortey et al. (1982) and Fortey (1984). The new trilobites reported on here were collected during the course of this study and all were identified by R.A. Fortey.

Ordovician trilobites, like their Cambrian counterparts, come mostly from conglomerates, and as the boulders sample a variety of environments, the flows characteristically contain trilobites recruited from several different communities.

Lower Ordovician (see Fig. 38)

Basal Ordovician trilobites have been described from Broom Point by Fortey (1984). Faunas typical of Zone A (*Missisquoia*) and Zone B (*Symphysurina*) are common. Conglomerates containing *Symphysurina* also occur at St. Pauls Inlet (Unit 6) and Green Point (Unit 25).

Trilobites in Bed 8, which forms most of the Stearing Island Member of the Green Point Formation, have been recovered at several localities. On Cow Head Peninsula the occurrences are complicated because those beds on the south side called Beds 8a and 8e (Kindle and Whittington, 1958) are best included in Bed 9. The only trilobites described from

Bed 8 here come from the ledge in the northern section and are characteristic of Zone B (Kindle and Whittington, 1958, p. 324).

The top of the more distal Broom Point Member is characterized by a thin conglomerate, and boulders in this conglomerate at St. Pauls Tickle North (Unit 31) and Broom Point North (Unit 109) contain *Leiostegium* which characterizes Zones D to E on the platform. The trilobites in Beds 7 and 8 then, in the Stearing Island and Broom Point Members, are typically Gasconodian and equivalent to Zones A to D and possibly E.

Trilobites in Beds 9 and 10 are found only in the conglomerates of the Factory Cove Member. Those from Cow Head (Back Cove) (Kindle and Whittington, 1958; Beds 8a and 8e; this study Beds 9.1 and 9.5) are mostly like those from the Catoche Formation, i.e. Zones G to H.

Middle Ordovician (see Fig. 38)

On the basis of the trilobites *Nileus* and *Kawina* cf. *K. vulcanus* in boulders from Bed 12, Kindle and Whittington (1958) suggested that these boulders were earliest Whiterock. Whittington (1968) further suggested that faunas from Bed 12 in the Cow Head North and South sections were equivalent to limestones in the autochthonous Table Head Group, and so equivalent to Zone M. It should be stressed, however, that this correlation was based on similar genera and not species.

In this study, Bed 12 on Stearing Island has yielded trilobites like those in the Catoche Formation equivalent to Zones H and I but also one boulder containing *Benthamaspis diminutiva* which characterizes Zone J. At Cow Head South similar Catoche Formation boulders are present, but in addition several boulders contain *Oopsites* cf. *O. hyburnicus*, *Gog catillus* and *Illaneus*, typical of Zone V2 in Spitsbergen which is correlated with Zone J by Fortey (1980a).

Conglomerate boulders in Bed 13 have not yielded any trilobites to date, but calcarenites at the base of Bed 13 at Cow Head and St. Pauls Tickle North contain *Endymionia clavaria*, which is typical of Zone V3b in Spitsbergen (Fortey, 1980a; Fig. 38). Fortey (1980b) suggested that this is equivalent to the thin *Hespronomiella* coquina of Zone K at Ibex, Utah, in the western U.S.A., the only known locality.

Conglomerates in Bed 14 characteristically contain boulders with trilobites as old as Upper Cambrian. Kindle and Whittington (1958) indicated that faunas in the Cow Head North section were similar to those from the large white boulder at Lower Head (Alpha Boulder) and equivalent to the Whiterock, especially the *Orthidiella* Zone in Nevada, having affinities to Zones M and N, but somewhat younger than N. Whittington (1968) suggested that the genera were similar to those in the Middle Table Head (Table Cove Formation).

Our studies confirm that most of the large white boulders at Lower Head are of the same age as Alpha Boulder and Fortey (1975b) indicated that this clast contains an illaenid-cheirurid, shelf-margin, bioherm assemblage "par excellence". Fortey (1980a) further suggested that these youngest conglomerates are older than any of the Table Head, a conclusion with which we agree (Fig. 38).

Bed 14 at Cow Head South contains some boulders with trilobites identical to those in the white limestone boulders at Lower Head, some boulders with a V2 Spitsbergen fauna, and some with nileids *Endymionia* and *Turgicephalus* which characterize Zones V3b to V4 in Spitsbergen, which Fortey (1980a) suggested is equivalent to Zone K and basal Zone M in the western U.S.A.

Brachiopods

Because the lower boundary of the Whiterock stage is based on the lowest occurrence of the fossils indicative of Zone "L" and particularly the brachiopod *Orthidiella* (Ross et al., 1982), the upper conglomerates in the Cow Head were searched for brachiopods. The trilobite genus *Ectenonotus* is also closely associated with *Orthidiella* and, when the brachiopod is absent, can be used to indicate the lower part of the zone (Ross et al., 1982).

Orthidiella has been recovered from Bed 14 at Lower Head and Cow Head South and from a conglomerate in the middle of Bed 13 at St. Pauls Tickle North. *Orthidiella* has also been identified in Bed 12 by R.J. Ross. Thus it appears that Beds 12, 13 and 14 are, by definition, Middle Ordovician (Whiterock; Barnes et al., 1981; Ross et al., 1982) and equivalent to some part of the *Orthidiella* Zone.

Graptolites

Cambrian graptolites are best seen at Cow Head itself. Dendroid fragments occur sporadically in Beds 1 to 6 and the first well preserved examples occur in the top of Bed 6 (Tuckers Cove Member) and at the base of Bed 7 (Stearing Island Member), as depicted in Figure 2 of Kindle and Whittington (1958). This fauna has been the source of some confusion. It is listed only from the top of Bed 6 (Kindle and Whittington, 1958, p. 323), but is used to correlate the whole of Bed 6. Furthermore, the boundary shown in the figure does not match the description of the beds given in the text. There is also some doubt as to the nature of the fauna.

Kindle and Whittington (1958) recorded *Staurograptus* sp. and *Dictyonema* sp. at this locality but we have resampled the locality and found no siculate forms. *Dictyonema* certainly occurs, but is asiculate. Radiate forms resembling *Staurograptus* are radiate, asiculate dendroids, not *Staurograptus* or *Radiograptus*. Ruedemann (1947) illustrated similar material from Cow Head, presumably from the same locality under the name of *D. johnsoni* (Pl. 4, Fig. 5 and 6. p. 533). Typical Cambrian trilobites occur, *in situ*, up to the top of Bed 7 (Fortey and Ludvigsen, personal communication, 1982).

Bed 8.2 at Cow Head yields a well preserved fauna comprising *Dendrograptus* sp. and *Callograptus* sp. We have in the order of 700 specimens, many unbroken, but there is no sign of any siculate form. It would seem that the horizon is Cambrian. Since there is no structural break between this

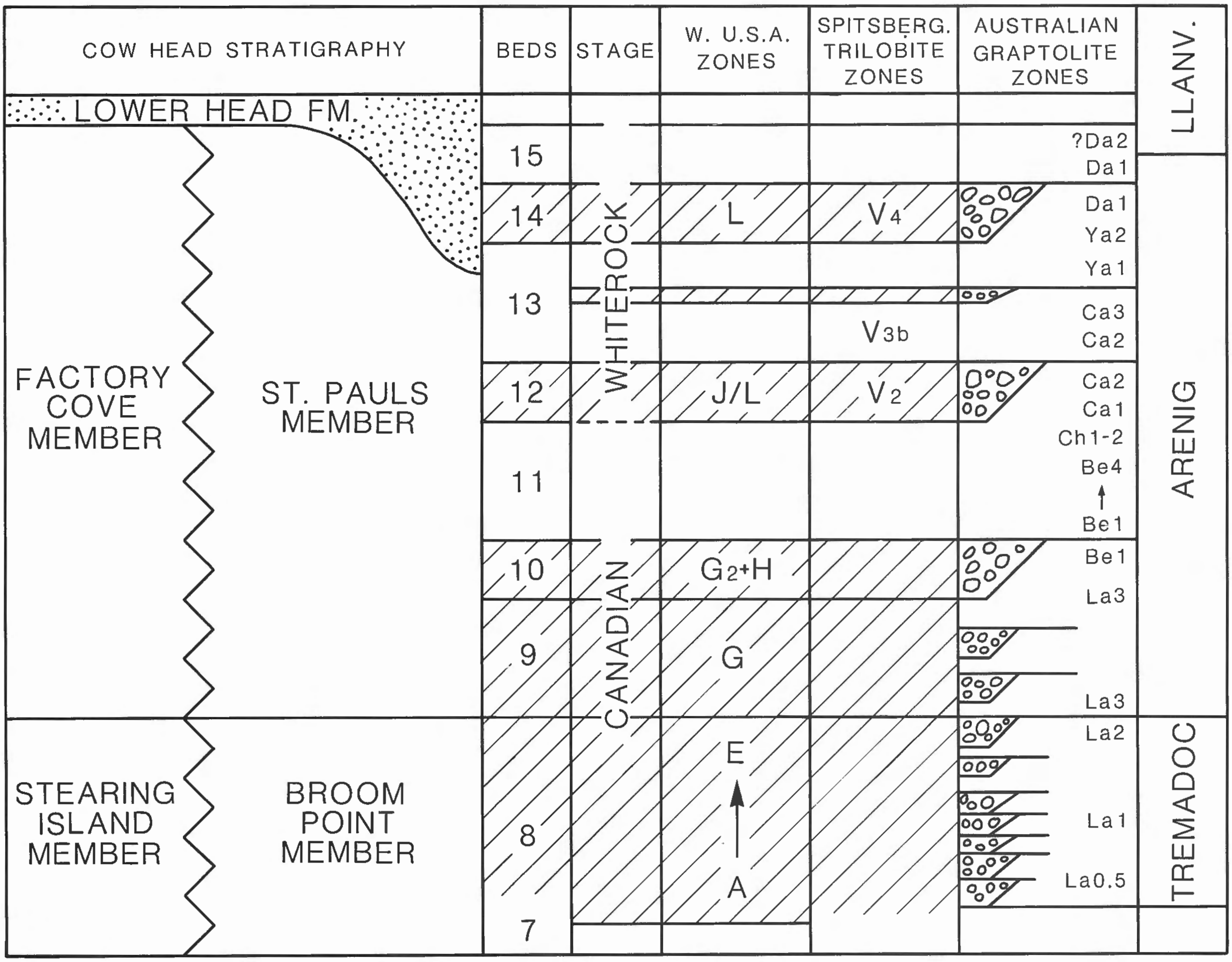


Figure 38. Correlation of the Ordovician units of the Cow Head Group, including beds, with the standard North American stages (Ross et al, 1982), trilobite/brachiopod zones of Utah and Nevada, trilobite zones of Spitsbergen, graptolite zones of Australia, and British stages.

occurrence and the underlying, "Tremadoc" fauna of Kindle and Whittington, we accept the trilobite evidence that Beds 6 and 7 at Cow Head are Cambrian.

The Cambro-Ordovician boundary is not clearly exposed at Cow Head itself. Extensive erosion by the conglomerate complex of Bed 8 seems to have removed the definitive horizons. *Dictyonema flabelliforme* has not been found. Nevertheless, the Green Point Formation provides several sections that are potential stratotypes for the Cambro-Ordovician boundary. This is mainly because the time span in these areas is characterized by limestone and shale and the resistance of the limestone to erosion leads to good outcrops of the critical sections.

Fortey et al. (1982) gave details of the succession across the boundary, but the placement of the boundary must await formal decision by the International Union of Geological Sciences Committee on the Cambro-Ordovician boundary. The best sections through the critical parts of the sequence are exposed on the shoreline platforms at Broom Point North and South. There, a rooted dendroid fauna apparently gives way upwards to a *Dictyonema* and *Staurograptus* dominated fauna. The role of *Radiograptus rosieranus flexibilis* (Fortey) during the evolution of graptolites across the Cambro-Ordovician boundary is still under discussion. It should be noted, however, that the genotype of *Radiograptus, R. rosieranus* (Bulman, 1950) is from a younger horizon that also contains *Staurograptus* ssp. and *Anisograptus* ssp. as well as an abundant *D. flabelliforme* ssp. assemblage and so is younger than *R. r. flexibilis* from Newfoundland (our unpublished data).

If the first appearance of *D. flabelliforme* subspecies is taken as indicating the Cambro-Ordovician boundary, then either of the sections at Broom Point would make a good stratotype. The best Tremadoc section occurs at Green Point. There, rooted dendroids in the lower part of the section are succeeded by a *Staurograptus* ssp. and *D. flabelliforme* ssp. assemblage. *D. flabelliforme* ssp. does not occur in isolation.

Above this assemblage the quadriradiate *Aletograptus* sp. occurs with *D. flabelliforme* ssp. This is the first recorded occurrence of *Aletograptus* sp. outside its type area in the U.S.S.R. Two distinct forms are present: one resembles *A. hyperboreus*, but mature specimens show stipe branching in the manner of *Staurograptus* and so this is probably a new species of *Staurograptus*; the second form has four stipes originating from a large sicular but the stipes are slender and lax. It resembles no described form.

This fauna is succeeded by an assemblage of triradiate graptolites that have been described as *Triograptus osloenis* mut. *minor* by Ruedemann (1947) and *T. canadensis* by Bulman (1950). On one bedding plane a strongly reclined triradiate graptolite resembling a reclined tetragraptid in superficial form makes an unheralded, short-lived appearance. No forms resembling *Psigraptus* have been recovered.

The best known Green Point fauna has been described by Bulman (1950). It consists of *Dictyonema canadense*, questionable *D. cristatlum* and *D. rusticum* and *Staurograptus dichotomus* var. *apertus*. In addition we have collected *Radiograptus rosieranus, Anisograptus richardsoni, A. matanensis, A. m.* var. *tetragraptoides*. The relationship between the *Dictyonema* species and *D. flabelliforme* is not yet clear. This assemblage occurs in most Tremadoc sections of the Cow Head Group except Cow Head. It is probably of Lancefieldian 1 age, equivalent to Cooper's (1979b) fauna 2.

A thin black shale in Unit 39 at Green Point yields an abundant fauna of La2 age. It consists of *Adelograptus victoriae, Bryograptus* sp., *Kaierograptus pritchardi, Clonograptus* cf. *C. tenellus, ?Triograptus* sp. (a large, robust form), *Tetragraptus bulmani*. Similar faunas occur at Cow Head, Western Brook Pond and Martin Point South. The Martin Point assemblage has been recorded by Erdtmann (1971a, b). *Tetragraptus decepiens* (Erdtmann, 1971b) seems to be a branching fragment of an exceptionally large, up to 40 cm across, new species of *Temnograptus*.

The next youngest Lancefieldian zone (La3) is usually taken as the oldest Arenig zone and coincides with the base of Bed 9. Its base is defined as the first appearance of *Tetragraptus approximatus*. Good sections through this zone occur at Cow Head, Western Brook Pond North and St. Pauls Inlet North. It also occurs at Lower Head, Broom Point and Martin Point. Common associates include *Clonograptus flexilis, C. rigidus, Tetragraptus* cf. *T. quadibrachiatus, T. pendens* and *T. acclinans*. Work in progress (Williams and Stevens) suggests that *T. approximatus*, as now understood, probably comprises a group of morphologically similar, but distinct, species.

T. approximatus, or a similar form, continues into the first zone of the Bendigonian where it is accompanied by *Tetragraptus fruticosus*. Although there is a trend through the Cow Head Bendigonian from a dominance of four-branched forms of *T. fruticosus* to a dominance of three-branched forms at the top, both varieties can be collected throughout. The distribution of the Australian Be2 and Be3 Zones, distinguished by the ratio of three and four-branch varieties, can only be made in the Cow Head sections. Be1 is characterized by a diverse fauna that is particularly well developed at St. Pauls Inlet North, Western Brook Pond and Cow Head Peninsula. *T. approximatus*, or a closely related form, occurs with *T. fruticosus, T. pendens, T.* cf. *T. acclinans, T. quadribrachiatus, T.* cf. *T. serra, T. phyllograptoides, Phyllograptus* ssp., *Kinnegraptus* sp., *Didymograptus hemicyclus, D. latus, D. similis, D.* cf. *D. similis, D. constrictus* and several genera of rooted dendroids. The confirmation of *D. latus* in Newfoundland reaffirms Thomas' (1960 p. 9) prediction. The assemblage is of early Bendigonian age.

The next distinctive fauna occurs at the base of Bed 11 and is dominated by extensiform Didymograptids, with Tetragraptid and Dichograptids and can be correlated with Zones Be2, Be3 and Be4. The best exposures occur at Cow Head and Western Brook Pond. Unfortunately, the section through this horizon described by Kindle and Whittington (1958) at Martin Point has been partially covered by a garbage dump. *T. fruticosus*, both three and four stiped forms, characterizes this assemblage. Other abundant forms include *T.*

serra, T. bigsbyi, T. pendens, T. similis, T. quadribrachiatus, Didymograptus extensus (Hall, non Ellis and Wood), *D. nitidus, D. similis, D. ensjoensis, D. pennatulus, Phyllograptus* ssp., *Goniograptus macer, G. thureau, Sigmagraptus laxus, Dichograptus octobrachiatus, G. geometricus*, and several dendroid genera. These are consistent with a Be2 to Be4 age.

T. fruticosus coexists with *D. bifidus* (Hall) over a few metres at Cow Head (Bed 11) and this association defines the first Chewtonian Zone (Ch1). Forms resembling *D. protobifidus* also occur in this horizon and slightly below it.

The Ch2 Zone is best exposed at Cow Head and Western Brook Pond where *D. bifidus* is associated with *Dichograptus octobrachiatus*, several *Didymograptus* species and *Phyllograptus* species.

Early Castlemainian (Ca1 and 2) assemblages occur towards the top of Bed 11 at Cow Head and Lower Head but are best exposed at Martin Point North where subconglomerate erosion beneath Bed 12 is least. *Isograptus primulus* is found with *I.v. lunatus* suggesting correlation with the Australian Ca1 Zone. Associated forms at Cow Head include *Pseudotrigonograptus ensiformis* and extensiform Didymograptids, Xiphograptids, *Acrograptus* sp., *Tetragraptus serra, T. quadribrachiatus*, T. *taraxacum*.

The second Castlemainian zone contains *I. v. victoriae, P. ensiformis* and *Xiphograptus* sp. at Martin Point North, where it occurs beneath the equivalent of Bed 12. This early occurrence of *Pseudotrigonograptus* is particularly noteworthy.

Bed 13 shows the radiation of the Isograptid stock in much the same manner as outlined by Cooper (1979a) from Australia. Basal beds at Cow Head (13.1) yield *I. v. victoriae* that give way to *I. v. maximus* and *I. v. maximodivergens*. *Pseudisograptus manubriatus* occurs near the top of Bed 13 at Martin Point South. Other *Pseudisograptus* species occur at lower horizons in Bed 13 at Cow Head. The upper Castlemainian Zone, Ca3, is characterized in the Cow Head sections by the association of *I. v. maximodivergens, I.* cf. *I. forcipiformis* (sensu, Cooper, 1979b), and *I. v. maximus*.

Although *Oncograptus upsilon, Cardiograptus morsus* and *Apiograptus crudus*, typical of the Australian Yapeen Zones in Australia, are not confirmed from Newfoundland, the occurrence of *D. v.-deflexus, I. v. maximodivergens* and *P. manubriatus* in Bed 13 confirms that at least the early Yapeen is present at Cow Head and St. Pauls. At Black Brook, St. Pauls Inlet, *Exigraptus* sp. (identified by X. Chen, personal communication, 1982) occurs at this horizon and is the first recorded find outside China. It suggests a correlation with the N6 Zone of South China (Mu et al., 1979, p. 10-11).

It is unlikely that late Yapeen graptolites occur in the Cow Head region. Most of the proximal sections show that Bed 14 has eroded deeply into the underlying Bed 13 and those more complete distal sections are in red and burrowed lithologies unsuitable for the preservation of graptolites.

Rocks yielding a sparse *Glyptograptus austrodentatus* fauna occur below and above Bed 14 at Western Brook Pond, north and south, indicating that the beds are of Darriwilian (Da1) age. *G. austrodentatus* also occurs above Bed 14 at Lower Head. Rocks in equivalent stratigraphic position from St. Pauls Inlet yield, in addition to *G. austrodentatus, T. ensiformis, Cryptograptus atennarius, Pseudoclimacograptus pungens, Isograptus* sp., and dendroids. St. Pauls South yields poorly preserved *Paraglossograptus tentaculatus* in addition to the previously listed species. Ruedemann (1947, p. 57) recorded some of this assemblage in Zone D2 at Levis and Zone 3, Bed 2 of the Deepkill section (ibid., p. 61-62). Rickards (1972) considered *P. tentaculatus*, to be of Da1 to Da2 age. Significantly he showed that *P. tentaculatus* is distinct and older than the form *Paraglossograptus etheridgei* of Berry (= *P. proteus*, Harris and Thomas).

Synthesis of Ordovician Biostratigraphy in the Cow Head Group

The Ordovician biostratigraphy of the Cow Head as determined in this study on the basis of macrofossils is given in Figure 38. The strata best correlate with the Australian graptolite-bearing sequences. Cooper and Fortey (1982, Fig. 2) give a correlation scheme of the Australian zones with other areas.

The brachiopods and trilobites are not nearly as well known but are important because they yield information as to the timing of platform-derived material. Boulder faunas from any one conglomerate are not of a single age, but careful searching usually reveals that the majority are of one age, with some older, often much older, and a few slightly younger. The youngest boulders are the most critical because they are probably contemporaneous with or slightly older than the flow itself. This is illustrated in some conglomerates by the soft, poorly cemented nature of the youngest clasts.

The Tremadoc/Arenig boundary

Although no graptolites of oldest Arenig age are known from the type area in Wales, the first appearance of *Tetragraptus approximatus* is usually taken as the base of the Arenig (Henningsmoen, 1973; Williams et al., 1972). In Australia, *T. approximatus* occurs in the La3 Zone. The Tremadoc/Arenig boundary then can be taken as the boundary between La2 and La3 in terms of graptolite faunas.

Several good sections through beds yielding La2 faunas are known from the Cow Head Group. These can be correlated with the upper part of Bed 8 at Cow Head. In the distal sections, such as Green Point and Martin Point, La3 graptolites are either unknown or rare because the shales are red and outcrop is poor. Only at Cow Head is there a good continuous section. There the boundary is marked by 3.3 m (Unit 9.1) of siltstone and green to minor brown shale.

The drastic change of sedimentation from reduced to oxidized across the boundary must reflect an equally dramatic change of ocean conditions more apparent in the deeper, distal sections than at Cow Head. The change is accompanied by one of the more important changes of graptolite faunas from one dominated by siculate dendroids to one dominated by true graptolites.

Correlation between the Cow Head Group and the Table Head Group

Most previous workers have correlated the younger beds of the Cow Head Group with at least part of the Table Head Group (e.g. Schuchert and Dunbar, 1934; Kindle and Whittington, 1958; Whittington and Kindle, 1963; Whittington, 1963, 1965, 1968). There are several reasons for this.

Early collections from boulders in the Cow Head Group were made on the assumption that it was stratigraphically higher than the Table Head. It was reasonable, therefore, to expect boulders from the Table Head to occur in the Cow Head. Sometimes collections were mixed. For example, several of the brachiopod genera listed by Cooper (1956, p. 11) from the Table Head were in fact collected from the Cow Head according to the localities given separately for the individual species. The correlation of the Cow Head Group with the post Table Head, Cape Cormorant Formation and equivalents north of Cow Head has also confused correlation.

Whittington (1963) has given the most detailed discussion of the correlation of Bed 14 from Lower Head. He observed that the trilobites are almost specifically unique and that 89% of the genera are new to North America. Nevertheless he (ibid., p. 15) concluded that the Lower Head Boulder, and hence a minimum age for the conglomerate as a whole, is generally equivalent in age to the Table Head. The Table Head yields a Llanvirn Da3 fauna (Finney and Skevington, 1979). Since the Table Head was deposited extremely rapidly, it is unlikely that the group as a whole is very much older than this. *Glyptograptus austrodentatus* has been obtained from rocks below and above the highest conglomerates in the Cow Head Group at several localities including Lower Head. *G. austrodentatus* (identification confirmed by S.H. Williams, 1984) is indicative of the Da1 Zone of Australia. Therefore, the Cow Head Group is entirely older than the Table Head Group, as suggested by Fortey (1980b). Beds 12 through 14 and equivalents seem to correlate with the *Orthidiella* Zone of the oldest Whiterock, while Cooper (1956, p. 127) suggested that the Table Head brachiopods have affinities with those of the *Rhysostrophia* Zone. Unfortunately, it is not clear if the brachiopods resembling *Orthidiella* from the "Table Head series" (Cooper, 1956, p. 126) were in fact collected from Table Head or from boulders in the Cow Head referred to the Table Head.

The Valhallan Stage

Fortey (1975a, 1976, 1980a, b) proposed that the Ordovician of Spitsbergen contains rocks older than the North American Whiterock Stage but younger than the uppermost Canadian. Fortey (op. cit.) suggested that these rocks, below the first occurrence of the *Orthidiella* Zone and above Zone J (*Carolinites genacinaca genacinaca*) can be referred to a new stage, the Valhallan Stage. Fortey (1980b) indicated that the Valhallan is represented by a stratigraphic break in all of the shallow-water North American sequences, but should be present in areas of deeper water sedimentation, such as Cow Head. Norford and Ross (1978), for example, described strata of probable Valhallan age from a graptolite and trilobite bearing sequence in British Columbia.

The occurrence of graptolites in the type Valhallan makes it possible to correlate the proposed stage with the standard Australian graptolite zonal scheme. Cooper and Fortey (1982) considered that the Valhallan graptolites correlate with the Ca2-3 Zones and probably with at least part of the Yapeen. Graptolites of this age occur low in Bed 13 of the Cow Head Group. Correlation of at least the lower part of Bed 13 with the Valhallan is also indicated by the occurrence of *Endymionia clavaria* (Fortey) in limestone interbeds. *E. clavaria* is restricted to the V3b or middle division of the Spitsbergen Valhallan (Fortey, 1980a). Elements of the Valhallan trilobite fauna occur in blocks from Bed 14 at Cow Head (Fortey, personal communication, 1980).

Brachiopods indicative of the Whiterock Stage are common in boulders from Bed 14. *Orthidiella* itself occurs from Unit 79 (Bed 13) at St. Pauls Tickle North. More importantly, a large boulder from Bed 12 at Cow Head (The Ledge) contains a silicified brachiopod fauna of Whiterock type (R. Ross, personal communication, 1984 and R.B. Newmann, personal communication, 1965). At this locality Bed 12 is overlain by shales that yield Castlemainian (Valhallan) graptolites.

Data from the Cow Head would seem, therefore, to suggest that the Valhallan Stage, as defined by Fortey (1980a), is equivalent to the lower part of the Whiterock. Nevertheless rocks of this age do seem to be wanting over the cratonic areas of North America as suggested by Fortey (ibid.) and indicated by Ross et al. (1982).

The Valhallan facies, as developed in Spitsbergen, would be farther up slope than even the most proximal Cow Head conglomerates at Stearing Island, because these conglomerates contain boulders with Valhallan trilobites.

The Arenig/Llanvirn boundary

The problem of identifying the base of the Llanvirn in North America and Australia is a difficult one since pendant didymograptids characteristic of the type Llanvirn, are unknown or of uncertain significance in these areas.

Strachan (*in* Williams et al., 1972) suggested that the Australian Da1 Zone is equivalent to the younger part of the *D. hirundo* Zone and this seems to be the generally accepted view (Thomas, 1960; Webby et al., 1981; Barnes et al., 1981; Ross et al., 1982).

If this correlation is correct then all of the conglomerates of the Cow Head Group are of pre-Llanvirn age since *G. austrodentatus*, a typical Da1 graptolite, occurs above the highest conglomerates.

Whittington's (1968) opinion that the Whiterock is equivalent to the Llanvirn was based in part on the assumption that the *D. bifidus* from Britain is the same as the *D. bifidus* of eastern North America, a view that has been disproved by Cooper and Fortey (1982). The correlation schemes for this part of the Ordovician by Skevington (1968), Jackson (1964) and Bulman (1958) are more reasonable. The younger parts of the Cow Head Group are of Arenig age but also of Whiterock facies type.

The occurrence of poorly preserved *Paraglossograptus tentaculatus* in the clastic rocks of St. Pauls south (Bed 15) suggests that the Arenig/Llanvirn boundary is present above the highest conglomerates of the Cow Head Group. It should be noted that the younger Table Head contains *P. proteus* (Rickards, 1972) that first occurs in Da2 (Webby et al., 1981, Fig. 2), not *P. etheridgei* as claimed by Morris and Kay (1966).

SYSTEMATIC STRATIGRAPHY AND CORRELATION

Introduction

The following is a systematic outline of the stratigraphy of the Cow Head Group. Description of the Shallow Bay Formation is followed by documentation of the coeval Green Point Formation. Members of the Shallow Bay Formation, because they outcrop mostly in the region of Cow Head Peninsula, are subdivided and described in terms of the beds originally defined by Kindle and Whittington (1958). It should be noted that in this context the term "Bed" is used in a stratigraphic rather than sedimentological sense. Members of the Green Point Formation are not as easily subdivided, but where possible, Kindle and Whittington's bed nomenclature is used. The same major beds occur in two coeval members. Although the Lower Head Formation is usefully separated from the Cow Head on the basis of the lowest sandstone unit, individual beds (e.g. Beds 13, 14 and 15), with their distinctive lithological character, pass laterally from the upper part of the Cow Head (Shallow Bay Formation) in the northwest through the basal part of the Lower Head Formation in the southeast. Since these beds are distinctive, they are described as separate units, regardless of the containing formation.

The stratigraphic sections and graphic logs upon which the following discussion is based are pocket items contained in Figures 10, 12 to 14 and 39 to 45 as are detailed correlation diagrams for the Cambrian, Lower Ordovician and Middle Ordovician. Simplified cross-sections for the Cambrian and Ordovician (Fig. 63, 64) appear later in the text.

Methods of Correlation

Just as there is a contrast in composition between Cambrian and Ordovician sediments, the quality of outcrop is significantly different. Exposure of Cambrian rock is sporadic and so control is relatively poor whereas just about every section exposes Lower and Middle Ordovician sediments, yielding a series of excellent sections.

Cambrian strata

Cambrian units are differentiated on the basis of trilobites in conglomerate boulders and in some instances on the basis of agnostid trilobites in the interbeds. Here we have relied almost entirely on the detailed work of Kindle and Whittington (1958, 1959) and Kindle (1981, 1982) and on recent studies by R. Ludvigsen (personal communication, 1980, 1982). Once the biostratigraphy was established more subtle lithological criteria were used to separate units. Since so many of the conglomerates are similar, however, this has been difficult. In the Tuckers Cove Member, distinctive quartzose calcarenites are easily traceable and have proven very useful in correlation.

Cambro-Ordovician boundary

All sections were searched for this interval by ourselves, by R.A. Fortey and D. Skevington, and more recently by C.R. Barnes and B.-D. Erdtmann, and several new localities have been discovered. Because of its potential biostratigraphic importance the boundary section at every locality has been scrutinized both in terms of macrofauna and more recently in terms of conodonts (Bagnoli et al., 1983). As a result, the correlation of this interval is particularly well defined.

Ordovician

This part of the sequence was originally investigated in conjunction with R.A. Fortey. Early work focussed on major conglomerate horizons and detailed their contained trilobite faunas and distinctive lithological character. A preliminary stratigraphic framework was then established, based on these observations, reconnaissance collections of graptolites from interbeds and previous work. More recent collecting by ourselves and S. H. Williams has concentrated on graptolite faunas in the interbeds. This, together with identification of thinner conglomerates and documentation of lithological changes away from Cow Head Peninsula, has resulted in a more precise correlation and a better stratigraphic framework.

Limitations of Correlation

In spite of locally excellent biostratigraphic control, the combination of sparse outcrop, rapid facies change, lenticular units, Paleozoic seafloor erosion and subtle multigeneration faulting makes exact correlation difficult. This is compounded in Cambrian shale by the lack of fossils and in bioturbated Ordovician red shales by the lack of graptolites.

The Middle Cambrian is represented by only a few short, mainly isolated sections (Fig. 46). The trilobites, except those from Broom Point, are poorly studied.

Biostratigraphic control is good for Upper Cambrian strata in the northwest (Shallow Bay Formation) but is poor in the southeast (Green Point Formation) because of short sections, fewer and finer conglomerates and less study. In the southeastern sections correlation is mostly lithostratigraphic.

The level of the Cambro-Ordovician boundary in the Shallow Bay Formation is difficult to place precisely because it lies in a series of welded conglomerates. In the Green Point Formation, however, the level can be fixed with much more certainty.

Likewise, the lowest Ordovician is a series of massive welded conglomerates (Stearing Island Member) at Cow Head, but limestones and shales (Broom Point and Martin Point members) to the southeast contain abundant and well-preserved graptolites.

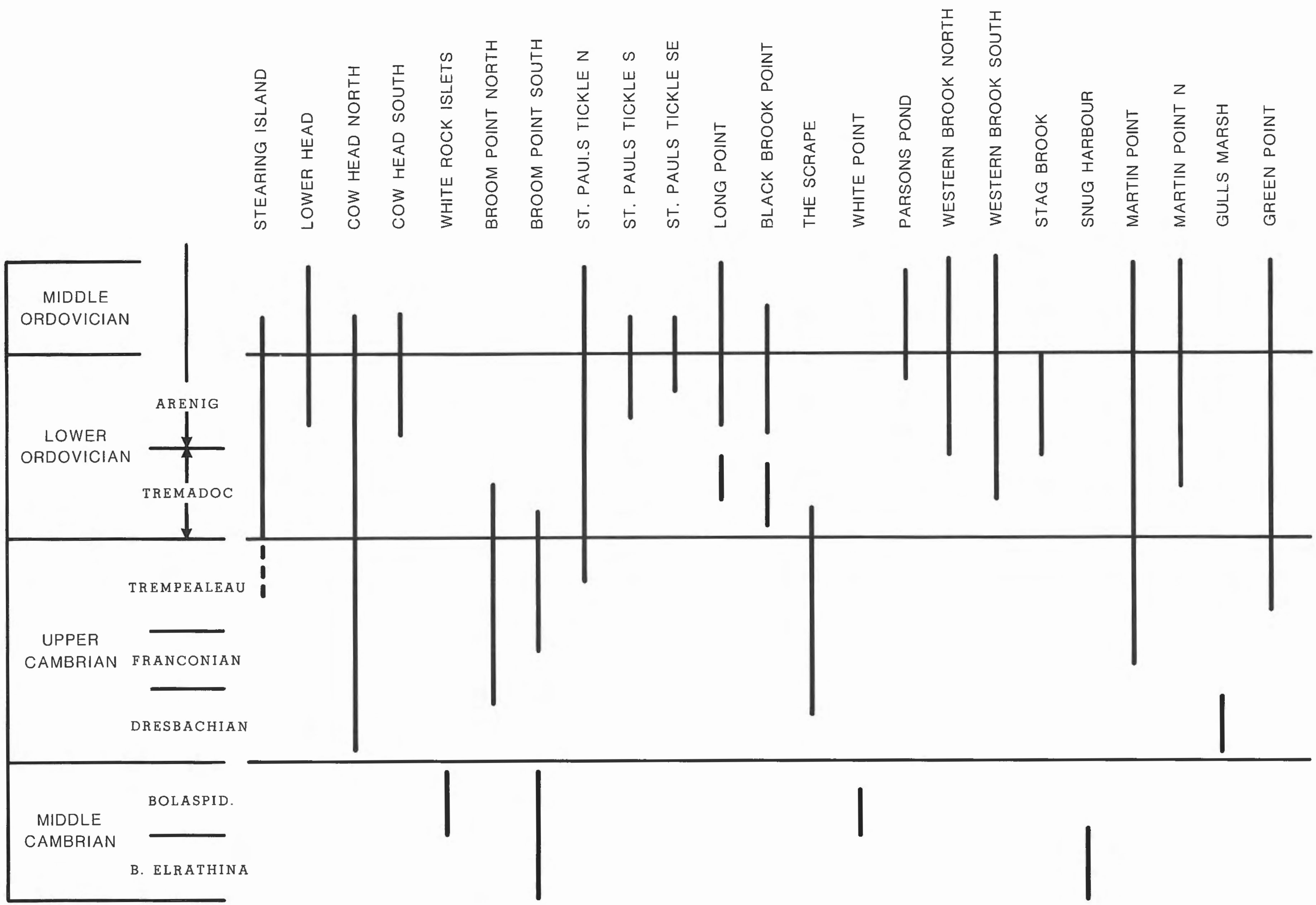


Figure 46. The age of strata represented in each of the stratigraphic sections in the Cow Head area.

Most sections of overlying Lower and Middle Ordovician, but still Arenig, strata contain graptolites. Active Ordovician seafloor erosion has, however, removed parts of some sections in the more proximal facies (Shallow Bay Formation), making correlation over short distances locally unreliable. Unfossiliferous red shales in more distal sections (Green Point Formation) have made establishment of precise correlation lines on the basis of graptolites alone in these strata difficult. Since conglomerate Beds 10, 12 and 14 are widespread traceable units, and were each emplaced at one specific time (except perhaps Bed 10) they can be regarded as time planes. On the whole, the stratigraphic framework is developed using a combination of biostratigraphy and lithostratigraphy.

Shallow Bay Formation

This unit comprises the coarser grained facies of the Cow Head Group. The basal, Middle Cambrian portion is widespread, occurring in most outcrop belts. Overlying strata become progressively more geographically restricted; coarse grained upper Cambrian sediments occur only in the northeast and central outcrop belts; coarse grained Ordovician sediments occur only in the Shallow Bay region.

Downes Point Member

The oldest strata in the Cow Head are not found on Cow Head Peninsula but at Broom Point, so Kindle and Whittington (1958) did not include them in their scheme of numbered beds. As they form an integral part of the sequence, and the overlying sequence begins at Bed 1, we have here designated these 40 to 60 m of strata as Bed 0. They are primarily a sequence of chip and boulder conglomerate and minor shale which outcrop in several widely separated localities. Beds 1, 2, 4 and 5 are similar, mostly chip and boulder conglomerates; Bed 3 is a megaconglomerate.

Bed 0 occurs in several widely separated sections. Beds 1, 2, 3 and 4 can only be recognized at Cow Head but the section at Gulls Marsh, of roughly the same age is probably equivalent to these beds. Bed 5 is exposed at Cow Head, Broom Point, Martin Point and probably comprises the upper part of the section at Gulls Marsh.

Bed 0

Distribution. There is a short, isolated section of these strata in each outcrop belt. In Shallow Bay they form White Rock Islets and a narrow curved rib of seaweed-covered reefs north of Stearing Island (Fig. 4, 47). White Rock Islets is an arcuate string of islands just off the southern shore of Shallow Bay (Fig. 4), separated from Downes Point by a narrow channel than can be forded only at spring low tide. The southeast-dipping conglomerate beds are eroded into a prominent cuesta (Fig. 47) whose strike swings so that the western end of the islets is on line with, but just south of, the basal beds on Cow Head Peninsula. Between these islands and the peninsula a small islet, Tortoise Rock (Fig. 4), is composed of chip conglomerates similar to those in Bed 1 at Cow Head. The basal conglomerates on Cow Head (Bed 1) are basal Upper Cambrian. Thus the whole sequence in probably conformable.

Equivalent strata of Bed 0 also occur on either side of Sandy Cove anticline at Broom Point, with the best section on the south side - the northern one is tectonized. Although no fossils have been recovered from the dolomitized conglomerates at The Arches (Fig. 3), an intact section of limestone and shale below these dolomites is lithologically similar to those on White Rock Islets.

In the Central Ridge Belt, they crop out only at White Point, on the southern shore of St. Pauls Inlet. In the Inner Ridge Belt these sediments occur in the faulted syncline at Snug Harbour, along the northwestern shore of Western Brook Pond.

Paleontology. The oldest and the only units that contain trilobites corresponding to the *Bathyuriscus-Elrathina* Zone are found at Broom Point (Kindle and Whittington, 1958; Kindle, 1982) where they comprise the basal 20 m of the section at Sandy Cove. These are overlain by a 20 m thick, distinctive white limestone and a further 30 m of conglomerate, limestone and shale from which a trilobite fauna characteristic of the *Bolaspidella* Zone has been collected. A matching latest Middle Cambrian fauna occurs in similar lithologies at White Rock Islets, Stearing Island, White Point and Snug Harbour (Kindle, 1982).

Sedimentology. The oldest beds at Broom Point are mostly conglomerate. The basal welded units are composed of limestone plates and subequant cobble to small boulders with little or no matrix. Some beds are massive, others are graded or have trough crossbedding, while still others have a green argillaceous carbonate mudstone matrix and calcarenite cap. Clasts range from lime mudstone to fossiliferous packstone to dolomitic siltstone, with the largest tabular clasts composed of bedded peloidal calcarenite. The upper beds, above a crossbedded calcarenite, are more massive and have a wider variety of clasts, namely (1) ooid/peloid calcarenite, (2) peloidal calcarenite, (3) white pisolitic calcarenite, (4) dark grey lime mudstone, (5) fossiliferous muddy calcarenite and, (6) calcified algal boundstone.

Deposition during subsequent *Bolaspidella* Zone time shows no real trend, except that the basal 10 to 20 m is everywhere a white limestone which gives White Rock Islets and White Point their names. At White Rock Islets it is a series of chip to boulder conglomerates (Fig. 47) that have been variably altered to fine or medium crystalline dolostone along strike. In the lower part both clasts and matrix are altered; in the middle only the matrix is dolomitized; in the upper 5 to 6 m all components are limestone. The most numerous exotic boulders are (1) white to grey calcified algal boundstone, (2) white pisolitic to oolitic grainstone, or (3) mottled porcellaneous white and dark grey lime mudstone. Other clasts include ooid grainstone in which the ooids have glauconite cores, ooid/peloid grainstone, trilobite-rich packstone, dolomitic siltstone, dark brown dolostone and fossiliferous grainstone. This conglomerate has a grainstone matrix. An almost identical conglomerate forms the base of the section at White Point.

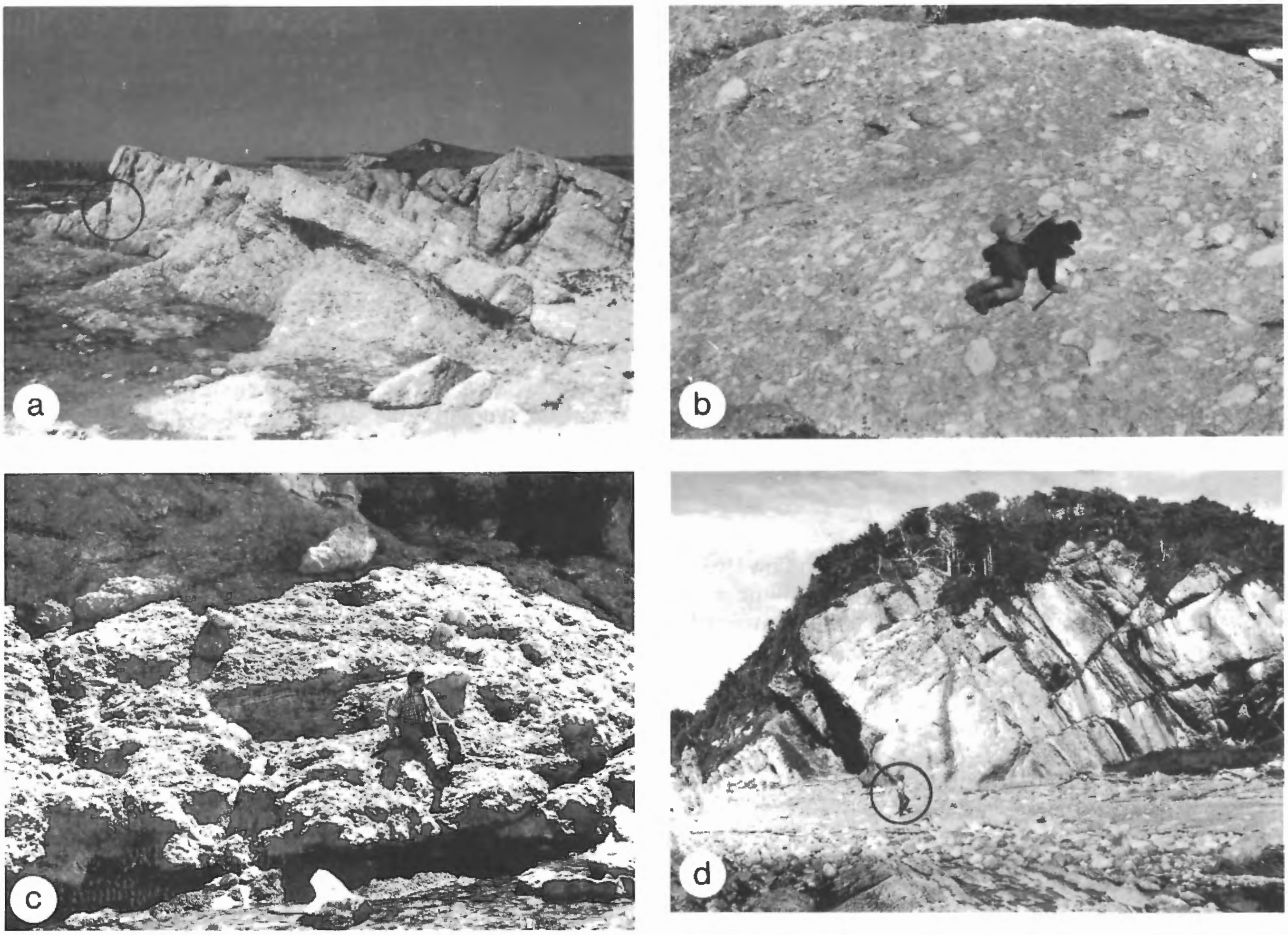


Figure 47. Downes Point Member.

a) Westward-dipping beds of Middle Cambrian welded conglomerates on the White Rock Islets, person for scale. (GSC 191510)

b) Bedding plane view of boulder conglomerate in which most clasts are white calcified algal boundstone or ooid/peloid calcarenite. (GSC 191511)

c) Megaconglomerate of Bed 3 (Upper Cambrian) at Beachy Cove with numerous rounded boulders and conspicuous rafts (behind person seated; GSC 191512)

d) The massive welded conglomerates which comprise the "50 foot conglomerate" of Kindle and Whittington (1958, p. 332-333; pl. 8, fig. 1; Broom Point South, Unit 11; this study); person for scale. (GSC 191513)

At Broom Point and Snug Harbour the white limestone is a series of massive to welded beds of white ooid-peloidal calcarenite and minor conglomerate.

The white limestone is everywhere overlain by conglomerates, calcarenites and shales with progressively fewer white limestone components and more limestone plates and chips upwards. At White Rock Islets and White Point the strata are dominantly conglomerates, sometimes welded, which vary from 1 to 9 m in thickness and have a distinctive green argillaceous matrix. At Broom Point and Snug Harbour the strata are bedded limestones and shales overlain by thinner-bedded conglomerates.

Beds 1 and 2

Paleontology. Trilobites from clasts in Bed 1 correspond to faunas from the lower Dresbachian *Cedaria* and *Crepicephalus* Zones of the North American Faunal Province (Kindle, 1982). No fossils have been obtained from Bed 2.

Sedimentology. This 10 m thick package is a series of 0.5 to 2 m thick welded conglomerates separated by thin discontinuous ribbon to parted limestone layers less than 0.4 m thick. The lower 8 m is mainly chip conglomerate with clasts of lime mudstone and fossiliferous wackestone or packstone together with lesser peloidal or ooid grainstone and silty wackestone. In several layers as many as 1/3 of the clasts are either (1) bedded, tabular-shaped boulders (up to 0.5 × 2.0 m) of lime mudstone or bioturbated wackestone or, (2) subequant cobbles of calcified algal boundstone. The approximately 10% matrix is very fine grained, dolomitized wackestone to packstone.

The upper 2.0 m thick layer (Bed 2) weathers as a resistant ledge because of pervasive calcite cement and is separated from underlying strata by an irregular ribbon lime mudstone averaging 0.4 m in thickness. This top layer contains clasts of pebble conglomerate similar in composition to Bed 1. Cement in the upper metre of this bed is isopachous calcite overlain by fine grained, geopetal, internal sediment.

Bed 3

Paleontology. Trilobites from both the boulders and the calcarenite cap of this bed indicate a lower, Dresbachian *Cedaria* and *Crepicephalus* Zones, age (Kindle, 1982; Ludvigsen, personal communication, 1982).

Sedimentology. This complicated 12 to 19 m thick unit varies dramatically along strike. Where most coherent it is composed of a basal green shale overlain by thick units of either parted to ribbon limestone or boulder conglomerate, both of which are capped by a calcarenite.

The thick middle part of the bed (Fig. 22a, c, d) is characterized by what appear at first to be separate units of parted or ribbon lime mudstone but which are in reality several huge rafts. These rafts, from 19 to 54 m in length and 6 to 10 m in thickness, lie at angles to bedding and some are intensively folded. The margins of these rafts break up into 2 to 3 m diameter clasts. Megaconglomerates laterally between rafts (Fig. 47) are composed of these smaller rafts and subequant exotic boulders in a matrix (30%) of green-grey calcareous shale derived from the underlying basal shale. These conglomerates cut down and removed much of this lower shale. The most obvious exotic boulders are up to 4 m across and are composed of: (1) calcified algal limestone; (2) peloidal to ooid calcarenite; (3) conglomerate similar to Beds 1 and 2.

Bed 4

Paleontology. Several abundantly fossiliferous boulders contain faunas indicative of the lower Dresbachian *Cedaria* and *Crepicephalus* Zones (Kindle, 1982).

Sedimentology. This 12 m thick bed is composed of two chip conglomerates of about equal thickness separated by a 1 m unit of parted calcarenite and thin lenticular conglomerate. The lower conglomerate contains about 10% large, floating, subequant exotic boulders of ooid to peloid grainstone and calcified algal limestone up to 3 m across while the upper conglomerate contains only a few. The matrix is buff-weathering finely crystalline dolomite.

Bed 5

Distribution. The true thickness of this bed is unknown. At Cow Head Peninsula it forms the top of the Beachy Cove section and base of the Point of Head section, but is extensively faulted between. A minimum thickness of 21 m is present here but it may be more than 40 m thick. Equivalent strata occur at the base of the Broom Point North section, the base of the Martin Point section and probably comprise part of the Gulls Marsh section.

Paleontology. Trilobites from larger boulders are correlated with the upper part of the Dresbachian Stage in the North American Faunal Province (Kindle, 1982).

Sedimentology. These rocks are distinguished at Cow Head by their uniform composition and relatively small clast size. They are a succession of numerous, welded chip conglomerates, each up to 1.0 m thick, that form 3.5 to 12.0 m thick packages. The tabular clasts of muddy, fossiliferous limestone or calcarenite are less than 10 cm long and in most units there is little obvious matrix, just rare microcrystalline calcite, except in the upper 10 m where some beds have a grainy matrix. Although the lower part contains few large clasts the upper half has some exotic boulders as large as 1 m in diameter of white calcified algal boundstone or brown ooid calcarenite. Some 2 to 4 m from the top there is a conspicuous and chaotic conglomerate with numerous large exotic clasts and a green argillaceous matrix. The conglomerates are in places separated by parted lime mudstone and dark grey shale which are discontinuous along strike, either squeezed out by, eroded by, or incorporated into the overlying conglomerate. Strata at Broom Point are virtually the same as those at Cow Head and do not appear to change thickness or composition between localities. Likewise the lithologies are the same at Martin Point but there is a green shale at the base which is not present at either of the other two localities. At Gulls Marsh there are more ribbon to parted limestone and shale interbeds then elsewhere.

Tuckers Cove Member

These strata are equivalent to Bed 6 at Cow Head Peninsula (Kindle and Whittington, 1958; p. 323-324).

Bed 6

Distribution. At the type section these strata form the wide shore platform and some of the cliffs along the northern shore of Cow Head Peninsula, just below the Crows Nest (Fig. 12). In the Shallow Bay outcrop belt they are also found along the northern shore of Stearing Island. Well exposed at Broom Point they form the lower half of the northern section, from Hickey's Cove to Broom Point itself (although deformed and faulted in places) and the middle part of the southern section (Fig. 48b), above a major fault. The west-facing cliff which forms Martin Point is also made up of these rocks.

Paleontology. Boulders from the lower half of the member at Cow Head, Broom Point North and Martin Point contain trilobites typical of Kindle's (1982) Zone 7 (Franconian) while those from the upper half of the member at Cow Head and Broom Point North as well as from the top of the section at Broom Point South are assigned to Zone 8 (Trempealeauan) with trilobites characteristic of the *Hungia magnifica* faunule (Kindle and Whittington, 1958).

Sedimentology. These sediments are quartzose calcarenites and graded stratified conglomerates (Fig. 24), quite different from the chip and boulder conglomerates of the underlying Downes Point Member. This style of sedimentation is similar in all three sections exposed except that the individual units thin somewhat and the conglomerates decrease in number and thickness from Cow Head southeast to Broom Point to Martin Point.

Lithologies include (1) thin, black, sooty shale; (2) parted limestone separated by green calcareous shale (Fig. 49); (3) buff-weathering, well-laminated or rippled dolomitic siltstone; (4) calcarenite; (5) graded-stratified conglomerate; to (6) occasional boulder conglomerate.

The ribbon to parted limestones are generally mudstone (now microspar) with occasional radiolaria and silt- to fine sand-size pelsparite microlaminations. A small proportion, estimated as less than 1/4, are rippled and crosslaminated, medium- to coarse-grained calcarenites. These beds are never wrinkled (i.e. gentle folding of individual layers of ribbon limestone or packages of parted limestone in an otherwise undeformed sequence: Fig. 50, 51).

The ubiquitous calcarenites are either massive or crossbedded units or thin layers in shales or small channels (Fig. 49a, b). They are composed of 1/3 to 2/3 medium- to very coarse-grained, rounded peloid/intraclasts, with up to 1/3 fossil fragments (especially trilobites, echinoids, *Nuia*, ooids, ooid fragments and rounded quartz). Most sediments are well sorted in individual layers but in some instances are very finely interlaminated or actively mixed with silt-sized sediments. Most sediments also contain trace amounts of dolomite, phosphate and clay flakes.

Some of the graded-stratified conglomerates grade laterally into calcarenites with floating clasts of either limestone plates or exotic algal limestone cobbles (Fig. 49c).

These strata, with all the characteristics of carbonate turbidites, were described by Hubert et al. (1977) who noted that the combination of conglomerate, quartzose calcarenite, lime mudstone, siltstone and shale gave the sequence a flysch-like appearance.

Well rounded, frosted quartz grains appear abruptly as a major constituent at the base of the Tuckers Cove Member and increase in abundance towards the middle of the bed where there is a conspicuous, resistant sandstone layer, above which they decrease again. Kindle and Whittington (1958, p. 323) reported two sandstone ribs but mapping during this study indicates that this is one bed, repeated by faulting.

The upper half of the Tuckers Cove Member is composed of essentially the same sediments as the lower half, with the addition of more parted and ribbon limestone units and more megaconglomerates with green calcareous shale matrix. The increased number of carbonate rhythmites is matched by a decrease in the number of quartzose calcarenites upwards. Conglomerate clasts, for the first time, contain numerous fractures filled with calcite spar. These subtle changes take place just above the sandstone bed at a megaconglomerate with large clasts of calcified algal limestone.

Stearing Island Member

This predominantly conglomerate unit (Fig. 52) is equivalent to Beds 7 and 8 of Kindle and Whittington (1958, p. 324-325) on Cow Head Peninsula. The member is recognized only on Cow Head Peninsula and on nearby Stearing Island.

Bed 7

Distribution. The thick conglomerates are exposed on the north shore of Cow Head Peninsula, at Tuckers Cove and as massive welded conglomerates on Stearing Island.

Paleontology. Boulders from conglomerates at Cow Head, where clearly exposed in sequence at the Point of Head, yield a late Cambrian, Trempealeauan Stage fauna. Where relationships are not as clear at Tuckers Cove and inland on the peninsula, clasts yield a mixed late Cambrian and early Ordovician fauna (Kindle and Whittington, 1958; Whittington, 1968).

The thick sequence of almost continuous Ordovician megaconglomerates on Stearing Island has not been studied in detail but on the basis of reconnaissance collections, the faunas appear similar to those on Cow Head Peninsula (R.A. Fortey, personal communication, 1980).

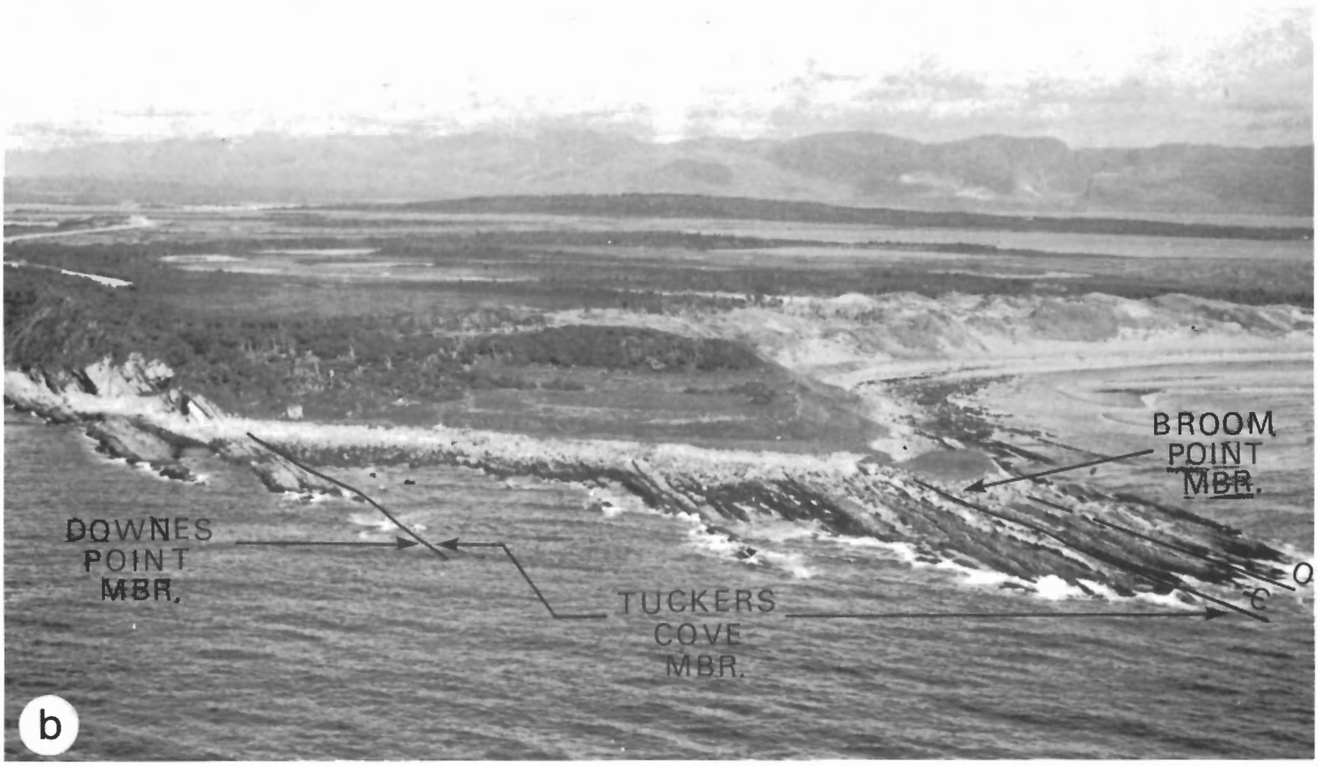


Figure 48. Broom Point.

a) Aerial view, looking northeast, of the upper part of the Broom Point North section, with the boundaries between members and position of the Cambro-Ordovician boundary illustrated; Long Range Mountains in background. (photograph J. Botsford; GSC 191514)

b) Aerial view, looking east, of the upper part of the Broom Point South section, with boundaries between members and position of the Cambro-Ordovician boundary illustrated. (photograph J. Botsford; GSC 191515)

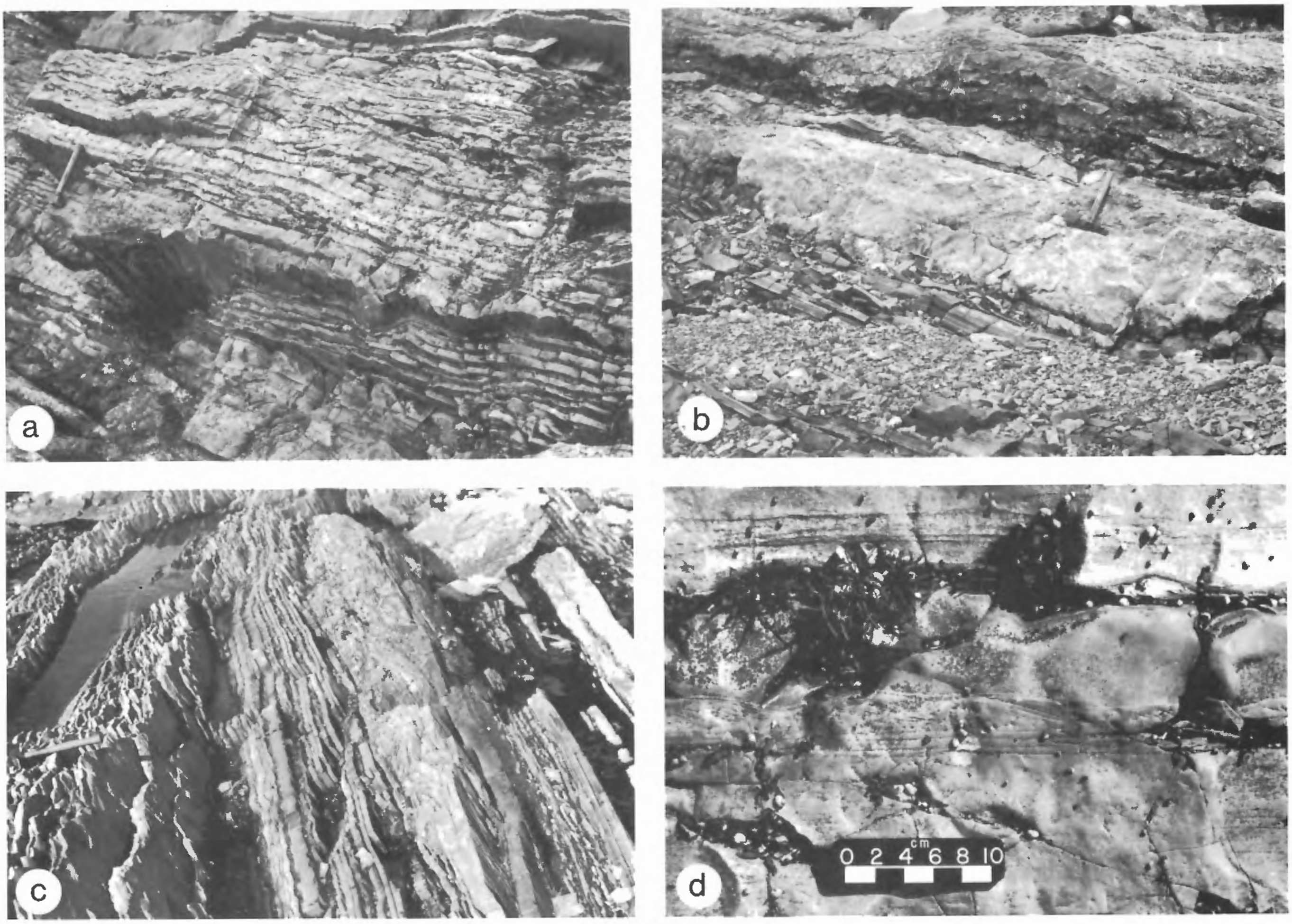


Figure 49. Tuckers Cove Member.

a) Parted to ribbon quartzose calcarenites and lime mudstones in upper part at Cow Head North (Unit 6.37; GSC 191516)

b) A channel eroded into dolomitic silty shale and filled with quartzose calcarenite conglomerate, at Beachy Cove (Unit 6.14; GSC 191517)

c) Parted to ribbon quartzose calcarenites and lenticular conglomerate (centre) in upper part, at Broom Point South, at about the same stratigraphic level as (a); Unit 43. (GSC 191518)

d) Quartzose calcarenite from units illustrated in (c). (GSC 191519)

Sedimentology. A massive-weathering series of welded conglomerates about 16 m thick is distinguished by numerous, exceptionally large boulders of white limestone (Fig. 28a, 52). The three megaconglomerates, each 4 to 5 m thick, are locally separated by centimetre-thick calcarenite, conglomerate or green argillaceous limestone layers. Since these interbeds are squeezed out or cut out by erosion along strike the conglomerates are commonly welded. Individual conglomerates resemble those directly below in Bed 6, they are bimodal with large exotic boulders in a "matrix" of limestone chips, which are in turn surrounded by 10% green argillaceous carbonate. The basal flow, which is 5 m thick and cuts down an additional 4 m into underlying bed 6, contains 1/3 large, rounded to slightly angular boulders of white algal boundstone ranging from 0.5 to 11.0 m in size. The majority of exotics are concentrated at the base with the rest scattered

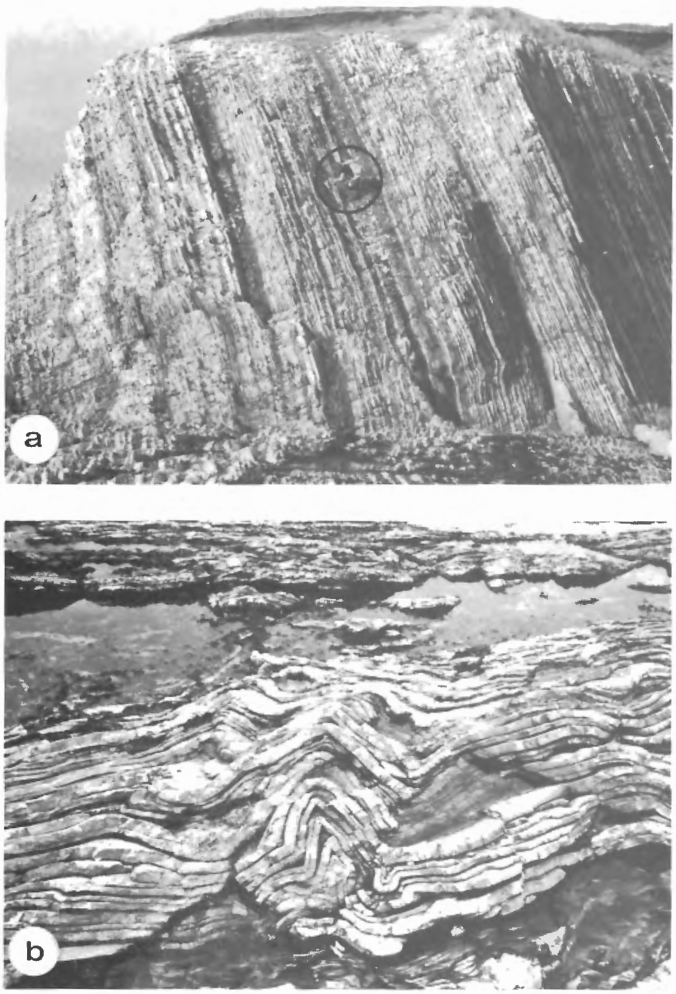


Figure 50. Broom Point Member.

a) Thick parted to ribbon limestones at Green Point, Unit 26; person for scale. (GSC 191520)

b) Deformed parted limestone, 1.8 m thick, at Broom Point North, Unit 60. (GSC 191521)

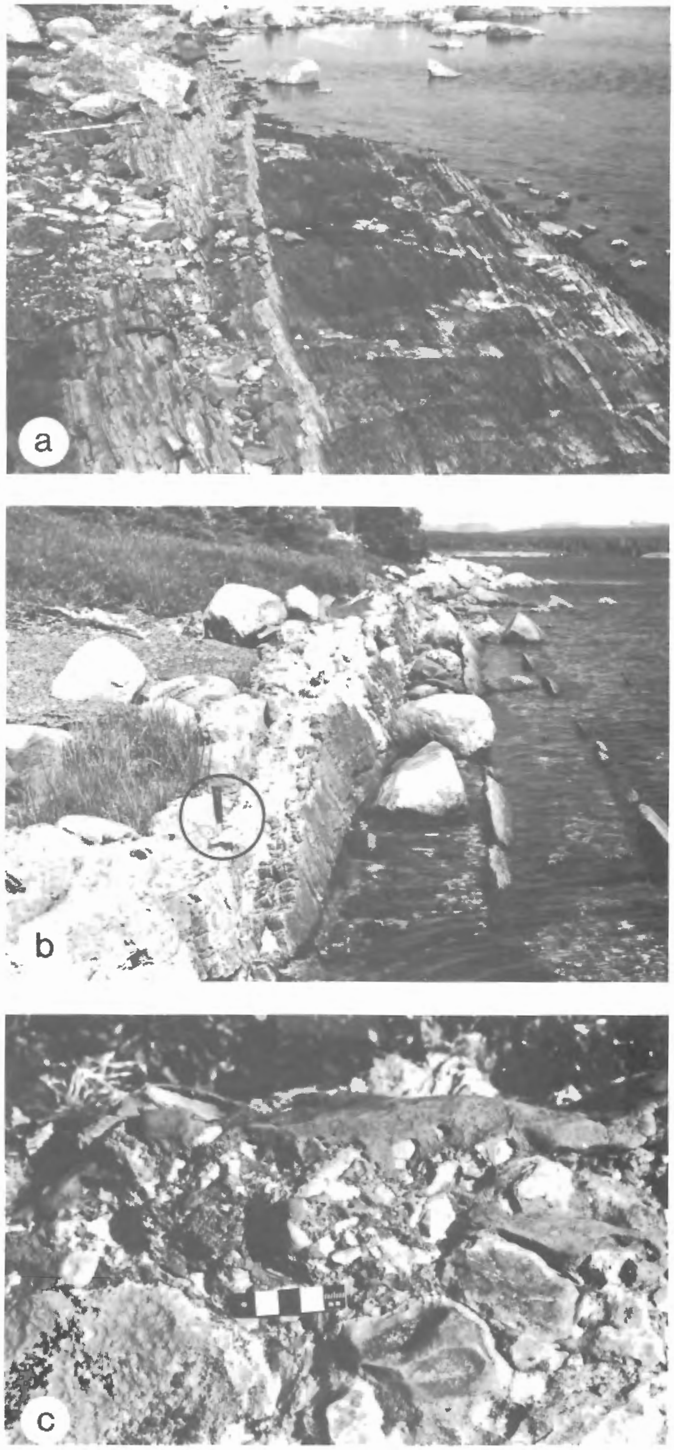


Figure 51. St. Pauls Member.

a) Typical low, recessive outcrop of dark red shale with resistant dolostone and limestone beds, Western Brook Pond South, Unit 23; metre stick scale at left. (GSC 191522)

b) Thin conglomerate with a pronounced brown chert cap, to right of hammer, St. Pauls Tickle North, Units 81, 82. (GSC 191523)

c) Bed 14, Black Brook Point, St. Pauls Inlet (Unit 38) in which overlying Lower Head Sandstone has filtered down between uppermost clasts. (GSC 191524) throughout the flow. The matrix in this basal flow is complex with the bulk being carbonate mudstone, while the upper metre is sandy calcarenite.

Bed 7 also occurs in Tuckers Cove where it is 14 m thick, contains roughly 1/3 large white limestone exotics, is capped by calcarenite and fills a channel which cuts down an additional 8 m into Bed 6.

Bed 8

This is a tripartite unit comprising a lower package of conglomerates and bedded sediments, a middle series of massive welded conglomerates and an upper succession of conglomerates and bedded sediments. Measurement of the lower beds is difficult because of numerous shallow-dipping faults.

Figure 52. Stearing Island Member.

a) The megaconglomerate of Bed 7 with large blocks of white calcified algal limestone (centre), limestone rhythmites of the Tuckers Cove Member below (Bed 6) and more conglomerates of Bed 8 above; person for scale. (GSC 191525)

b) Interbedded limestone rhythmites and chip, plate or boulder conglomerates at the top of the member at Cow Head North (Units 27-35); 9.0 m thick. (GSC 191526)

Distribution. The limestones and shales are exposed along the northern side of the peninsula where they form Point of Head at Tuckers Cove and on the northern shore of Stearing Island.

Paleontology. Trilobites from boulders in the lower part (ca. basal 30 m) of the section at Cow Head are mixed late Cambrian and early Ordovician with the youngest equivalent to Zone A, in western Utah. In the upper 1/3 of the unit faunas are also mixed but the youngest are the same as those found in Zone D in Utah. A trilobite fauna from the very top of the lower part, just below the thick conglomerates and in ribbon limestones is characteristic of the Tremadoc (cf. Rasetti, 1944; R. Ludvigsen, personal communication, 1980).

Graptolites in the lower part of Bed 8 at Cow Head are all rooted dendroids but those in the upper part are characteristically late Tremadoc and equivalent to the Lancefield 2 faunas of Australia.

Sedimentology. This 80 m thick unit is a complex sequence of lithologies, transitional in style between grainy Cambrian deposits and muddy Ordovician sediments. Chert occurs for the first time, both as beds and as clasts. Phosphate (collophane) sand grains and granules are dispersed throughout the sediments and trace fossils are found in abundance and brightly-hued shales separate carbonate beds.

The lower third is a succession much like the upper part of Bed 6; parted lime mudstone with green shale or green dolomitic siltstone separated by sequences of quartzose calcarenite and conglomerate. There is a complete gradation in composition from rippled calcarenites containing up to 20% quartz to calcarenites with floating tabular clasts to true clast-supported, graded-stratified conglomerates with a calcarenite matrix. These interbedded units are each generally less than 1 m thick. Equant to subequant clasts in these conglomerates as well as the thicker flows with a green argillaceous matrix range from sandstone to quartzose calcarenite to lime mudstone to calcified algal limestone to scattered chert.

The central 1/3 is roughly 30 m of massive, commonly welded conglomerate which forms the Point of Head. Individual 3 to 4 m thick conglomerates are locally separated by bright green calcareous, silty shales, calcarenites or ribbon limestones a few tens of centimetres thick. These interbeds are characteristically squeezed out or eroded and occur as coherent rafts within overlying conglomerates.

As with conglomerates in the lower part of Bed 8 and Bed 7, clast size is bimodal, roughly 2/3 are limestone chips and the remaining 1/3 are equant to subequant boulders 20 cm to 2 m, to occasionally 12 m in size. The largest boulders are in the middle of the bed where they make up over half the volume of the conglomerate. While some clasts are calcarenite or ribbon to parted limestone or conglomerate like those in the interbeds below, others are exotics such as: (1) white and brown calcified algal limestone, with and without numerous spar-filled voids and cracks; (2) laminated chert; (3) ooid calcarenite with cavities containing conspicuous green internal sediment. Matrix ranges from none with most intergranular contacts stylolitic, to 5 to 10% green dolomitic limestone and/or shale to calcarenite near the top of individual conglomerates.

The upper 1/3 (Fig. 52) is quite different: well-bedded, black to bright green shale, dolomitic siltstone, irregular to burrowed parted limestone, nodular to lenticular ribbon lime mudstone, and conglomerate in units less than 2 m thick. The evenly bedded carbonate rhythmites contain numerous burrows, either single vertical tubes (*Skolithos*) or paired vertical tubes (*Diplocraterion*), which are spar-filled. The periphery of discoid nodules is rimmed by coarse calcite spar or "beef" calcarenite, either as layers in parted limestone or as conglomerate matrix, containing both quartz and phosphate grains. Conglomerates are composed of tabular to equant pebbles or cobbles with up to 1/3 subequant to well rounded boulders as large as 2 m across. Chert is present both as laminated clasts and as silicified rinds on the more rounded boulders. Granules of phosphate are ubiquitous. Both normal and reverse size grading is present and a thin calcarenite cap is present on some conglomerates. Matrix varies both between conglomerates and within a single unit from grainstone to microcrystalline calcite to green, argillaceous, sometimes dolomitic lime mudstone and from less than a few percent to over 20% in the case of some calcarenites.

Factory Cove Member

This unit comprises Beds 9 through 14 on Cow Head Peninsula as defined by Kindle and Whittington (1958, p. 325-326). An additional unit, Bed 15, which forms the upper part of the member, is defined in this study and added to the original beds.

Bed 9

These strata, although shaly at the base, are mostly a succession of parted to ribbon limestones punctuated by boulder conglomerates.

Distribution. Strata are exposed both on Stearing Island and Cow Head Peninsula. This 50 m thick bed is the first one exposed extensively on both the northern and southern sides of the peninsula. On the south side most of these sediments were originally assigned to Bed 8 by Kindle and Whittington (1958, p. 324). Nowhere is there a complete section; in the north the middle of the bed is covered and in the south the lower part is not exposed. In the south small faults have repeated the upper portion of the bed three times.

Paleontology. Trilobites recovered from boulders on the southern side of Cow Head Peninsula and on Stearing Island, are shallow-water Late Cambrian and Early Ordovician forms as well as open marine agnostids. The youngest shallow water forms are equivalent to those from Zone G2 of the Nevada/Utah succession.

The carbonate rhythmites display numerous ichnofossils, particularly *Scolithos, Diplocraterion* and rare *Zoophycus*. Many layers contain abundant sponge spicules, while complete hexactinellid sponges are present on bedding planes. Muddy layers also contain radiolaria. Large phosphatic brachiopods (up to 3 cm in size) occur in some beds. Graptolites are common in both limestones and shales and are equivalent to Lancefield 3 faunas at the base and Bendegonian 1 faunas at the top.

Sedimentology. Conglomerates occur as welded, massive units on Stearing Island and as beds separated by carbonate rhythmites on Cow Head (Fig. 53). There are three types of conglomerates: (1) limestone plate conglomerate with a swirled fabric and green argillaceous matrix; (2) lenticular limestone chip conglomerate with limestone, phosphate and quartzose limestone clasts; and (3) boulder conglomerate, 6 to 10 m thick, with clasts and rafts over 1/2 of which are more than 1 m in diameter in a matrix of green argillaceous carbonate, and capped by calcarenite. The microcrystalline calcite spar matrix is in most instances pseudospar, often with considerable intercrystalline clay. Stylolitic contacts are common and dolomite occurs both along solution seams and in the pseudospar-clay matrix.

The conglomerates themselves vary in thickness both in individual sections and between sections. Lenses which vary from 0 to 40 cm over a strike length of 10 m are common. Thicker conglomerates range from 0.1 to 3.0 m or from 1.0 to 5.5 m in thickness between sections. These variations illustrate the characteristic heterogeneity of these proximal deposits.

Bed 9 is the first occurrence of relatively thick sequences of Ordovician carbonate rhythmites in the Shallow Bay Formation (Fig. 53) , and they persist in similar style and composition through Beds 11 and 13 (Fig. 53) to the top of the Factory Cove Member. The parted to ribbon limestones are separated by black to green shale, and vary from extremely evenly bedded layers (1 to 4 cm thick) to nodular layers in which brown-weathering chert outlines incipient nodules. These beds are mainly lime mudstone near the base of Bed 9 and rippled calcarenite near the top. There is little silt in the intervening shales.

The basal few metres at Cow Head North is a series of alternating 20 cm thick layers of dolomitic siltstone and bright-green or red-brown shale. These are the only red-hued shales in the Shallow Bay Formation.

Bed 10

This megaconglomerate bed (Fig. 53) is a widespread unit that varies in composition from northwest to southeast and can be recognized in both the Factory Cove and St. Pauls members.

Distribution. This unit occurs in all sections.

Paleontology. Most tribolites are Early Ordovician with the commonest similar to the Zone H and possibly Zone I faunas of Nevada and Utah.

Sedimentology. On Cow Head Peninsula this bed varies dramatically in thickness both along strike and between sections. In the northern section it thickens from 0.8 to 7.2 m

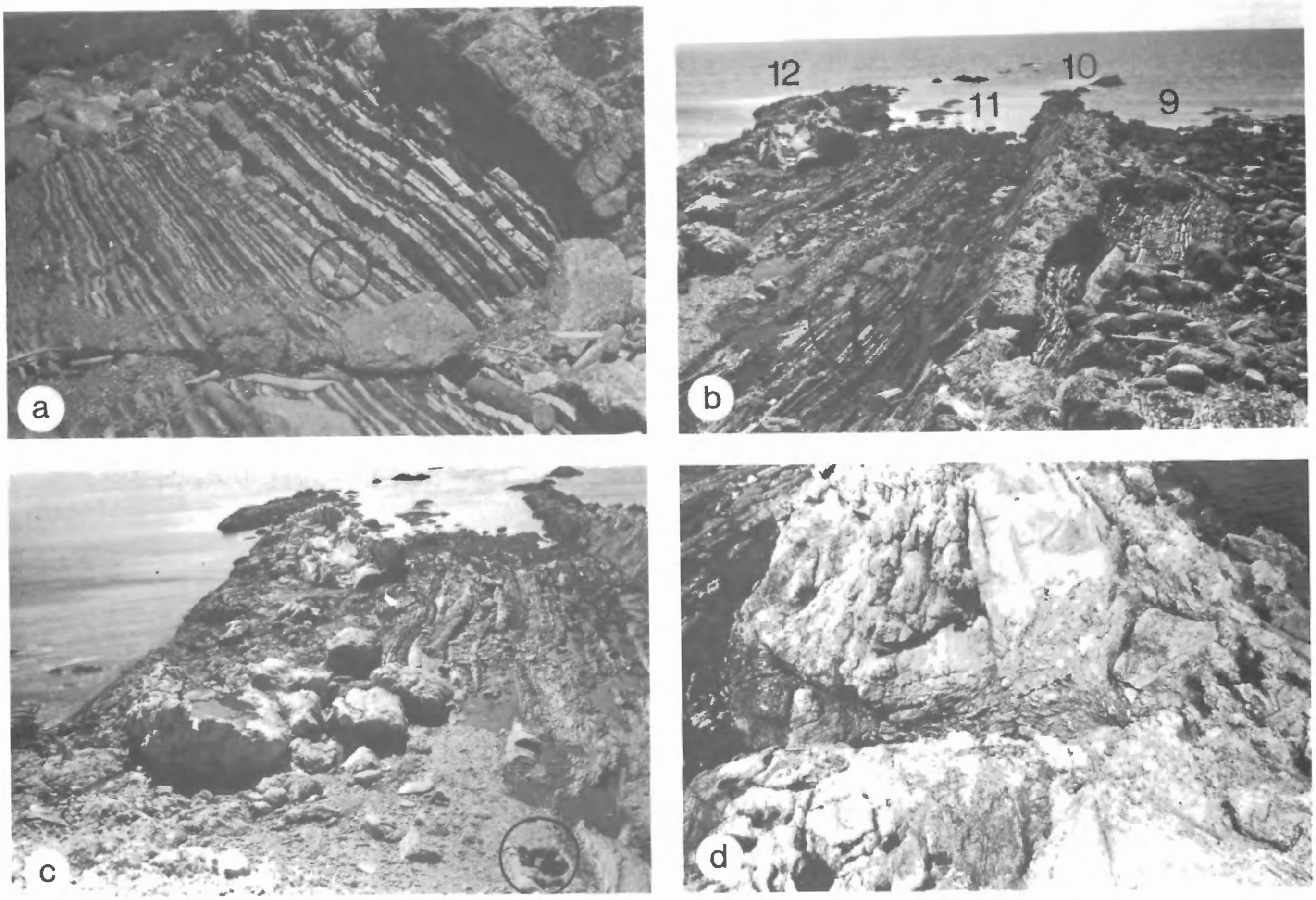


Figure 53. Factory Cove Member.

a) Typical Factory Cove lithologies, thick sections of ribbon to parted limestone punctuated by conglomerate horizons (Bed 9, Bed 10 conglomerate at upper right), Cow Head North, hammer scale. (GSC 191527)

b) Tidal platform at Point of Head illustrating Beds 9, 10, 11, 12; person scale. (GSC 191528)

c) Tidal platform at Point of Head illustrating Beds 10 (extreme right), 11 and 12. The large boulders are clasts in Bed 12, some of which have sunk down into the upper part of Bed 11; Person scale lower right viewing dolomite bed illustrated in Figure 25 (a). (GSC 191529)

d) Range pole (graduated in 10 cm increments) lies on limestone plates broken from underlying Bed 11 (left) and injected into Bed 12. (GSC 191530) over a distance of 50 m. Between the three faulted sections on the south coast it varies from 0.5 to 11.8 to 2.0 m. This variation is not entirely due to erosion of underlying strata but from deposition as a series of convex beds with slightly erosional bases.

Where thinnest, the bed is composed of limestone plates and subordinate subequant cobbles with a swirled fabric in a grey-green argillaceous carbonate matrix. As the deposit thickens the proportion of subequant and exotic clasts becomes greater and clast size becomes larger until in the middle there are a wide variety of boulders ranging from contorted rafts of underlying ribbon limestone to limestone and dolostone boulders averaging 30 cm, but commonly up to 3 x 4 m in size. The fabric is still chaotic and swirled with the matrix in the lower half brown to green argillaceous siltstone and in the upper metre calcarenite with phosphate granules. In the northern section, at the thickest part, there is a 0.3 m thick rippled and crosslaminated calcarenite cap. The uppermost surface also displays two aspects which are also found in Beds 12 and 14; a brown-weathering chert cap and boulders whose tops, where they once protruded above the top of the flow, were planed off. Chert replaces the calcarenite cap where present on the tops of uppermost boulders and intervening matrix.

On Stearing Island Bed 10 is a massive conglomerate and at Lower Head west a relatively thin series of mostly platy clast conglomerates.

Bed 11

This distinctive sequence of dark-hued shale, buff-weathering dolostone and cherty limestone (Fig. 53) is present at all sections and varies from 10 to 35 m in thickness. These thickness variations are due to erosion which accompanied emplacement of Bed 12, synsedimentary erosion and, as stressed to the authors by S.H. Williams, near bedding-parallel faulting, especially in the Point of Head section.

Paleontology. The rocks contain a rich graptolite fauna allowing, in most instances, good biostratigraphic control. Approximately the lower half contains faunas comparable to the Bendegonian Zones of Australia, with the bulk of the strata equivalent to Zones Be2, Be3 and Be4. This is clearly a condensed sequence. The upper part contains graptolites similar to the two Chewtonian Zones, Ch1 and Ch2. Castlemainian strata , Ca1 and Ca2, have been found only at Cow Head and Martin Point North.

Sedimentology. The cherty top of Bed 10 is overlain by a distinctive sequence of thin-bedded, dark red to black shale, brown-weathering chert partly to completely silicified ribbon limestone (Fig. 26) and 1 to 5 cm thick lenses of phosphate conglomerate (Fig. 30) . These lithologies change upward through laminated green and black shale to the top half of the bed which is composed of parted to ribbon limestone (with numerous vertical ichnofossils) and green-grey to black shale. The thin, grainy conglomerate lenses, which vary from 0.5 to 40 cm thick and are up to 4 m in length, contain phosphate and limestone clasts. The sequence is punctuated by numerous thin, distinctive, buff-weathering, bioturbated silty dolostones with spiculitic partings.

The dark-hued clay shales are up to 1/3 silt-sized ferroan dolomite and contain from 5 to 10% phosphate and usually 10 to 20% radiolaria and sponge spicules. In many thin layers radiolaria may make up 50% of the rock. Banding is due either to partial silicification or to the alternation of organic-poor and organic-rich layers. Silicification has altered many of the shales in the lower part of the bed to chert.

Limestones illustrate the same spectrum of texture and composition as those in Bed 9 with silicification more common in the lower layers. Calcarenites, however, contain more phosphate and more quartz than in Bed 9. The phosphate, as irregular rounded and microcrystalline particles, accessory phosphate skeletons (mostly brachiopods) and oolitically coated particles may comprise up to 1/3 of the grains. Even rounded quartz grains occasionally have oolitic phosphate coatings. The conspicuous dolostones are relatively pure, uniformly silt-sized, ferroan dolomite. Layers reflect alternating 0.5 to 1.0 mm thick laminae of pure dolomite or argillaceous dolomite. The layering is often disturbed by bioturbation.

At Stearing Island Bed 11 is thin, poorly exposed and similar to the middle part of Bed 11 at Cow Head. At the western section of Lower Head it is similar to the lower part of Bed 11 at Cow Head, but the basal layers have fewer phosphatic conglomerates and the middle part has more limestone conglomerates. In the eastern section at Lower Head (Fig. 7), where they rest on a major unconformity, sediments are like those at the western section except that there are fewer limestone conglomerates, thicker black shales and more phosphate-rich conglomerates.

Bed 12

This distinctive conglomerate, with its chaotic fabric, wide variety of rafts and limestone plates (Fig. 53) and matrix of olive-green calcareous shale is present in all sections.

Distribution. The conglomerate is most massive and erosive on Stearing Island and at Cow Head. It cannot be clearly identified at Lower Head and was likely incorporated into the overlying Bed 14.

Paleontology. Although trilobites as old at late Cambrian are found in some boulders, trilobites from most clasts, like those in Bed 10, are correlative with Zones H and I in Nevada and Utah, with a few more typical of the slightly younger Zone J fauna. One boulder also yielded numerous specimens of the brachiopod *Idiostrophia* sp. (RJR), again typical of Zone J in the Nevada sequence. Another boulder contains the brachiopod *Orthidiella* sp. suggestive of the basal Middle Ordovician (Whiterock Stage).

Sedimentology. A megaconglomerate with some clasts several tens of metres in size, this unit resembles Bed 10 in the chaotic nature of the fabric and wide variety of clasts. In contrast to Bed 10, however, extensive erosion and deformation of the underlying beds can be demonstrated. In the southern section at Cow Head, it is 3.5 to 5.0 m thick. In the northern section it is generally 10 m thick but in places downcuts an additional 20 m and so is a total of 30 m in thickness.

The 20% matrix is a mixture of olive-green calcareous shale and platy clasts of lime mudstone which were eroded from underlying ribbon limestones and injected up into the conglomerate during emplacement (Fig. 53). In the south section the conglomerate is capped by a discontinuous calcarenite which is not present in the north section. This calcarenite is partially silicified to brown-weathering chert and where absent, boulders near the top of the conglomerate are silicified instead.

Over 2/3 of the bed is composed of clasts larger than 0.5 m. They average 2.0 m in diameter and in the thicker parts clasts 5 to 6 m across are common. Occasional blocks are 20 × 5 m in size with the largest measured 8 × 67+ m (the actual size is unknown because it disappears into the trees and forms a small hill). White calcified algal limestone blocks are most conspicuous and some contain layers of nautiloids. Bedded clasts of burrowed, fossiliferous, rubbly weathering wackestone are also common and some are extensively fractured, with cracks and vugs lined by multigeneration calcite spar. Fractures or cavities in some of these clasts are filled with green geopetal sediment. Other distinctive boulders are: peloid or ooid calcarenite; "zebra" limestone; pelmatozoan calcarenite; green chert and obvious underlying lithologies such as calcarenite or brown dolostone.

Bed 13

This is a shaly sequence with a distinctive unit of parted to ribbon limestone at the base. It is 15 to 25 m thick, only half as thick as in most of the Green Point Formation. This is due to demonstrable erosion of the upper beds during emplacement of the Bed 14 conglomerates.

Distribution. The bed outcrops at both Cow Head sections and on Stearing Island, where it is faulted and mostly submerged, but it is not present at Lower Head where it was presumably eroded during emplacement of Bed 14.

Paleontology. The basal limestones and shales contain a graptolite fauna like that from the Castlemainian 2 Zone of Australia and the distinctive trilobite *Endymionia claveria* (RAF). The upper shales yield a distinctive Yapeen, Zone 1 graptolite fauna.

Sedimentology. The basal parted to ribbon limestones are mostly partially silicified spiculitic calcarenites in layers 4 to 10 cm thick. They are internally laminated, on a scale of 1 mm to 1 cm, with alternating layers of grainstone and wackestone. Particles are medium to coarse sand size, somewhat coarser than equivalent grains in Beds 9 and 11. They are mostly angular or scalloped clasts of pelsparite, resembling fragmented *Epiphyton*, grains or "minirafts" of *Girvanella*, trilobite skeletons and pelmatozoan plates. The muddier layers contain up to 1/3 clay, sponge spicules and radiolaria. Pure micrite layers contain scattered radiolaria and are punctuated by spiculite-rich laminae.

In the centre of the bed, separating the limestones below from the shales above, is a thin but persistent conglomerate composed of cobble-sized limestone clasts, conspicuous black chert fragments and phosphate granules. At Cow Head North erosion during Bed 14 emplacement cut down to this layer and some of it was incorporated into the overlying conglomerate.

Bed 14

This bed, the uppermost megaconglomerate in the Cow Head Group, is the thickest and most chaotic of all.

Distribution. The unit can be recognized at all localities. It is 15 m thick in the northern section at Cow Head with the top forming a small sea cliff and 12 m thick in the southern section. The base is demonstrably erosive and at least 4 m of downcutting can be seen along strike. On the western limb of the Lower Head structure it is 15 m thick, but over 100 m thick on the eastern limb (Fig. 29, 40), where it is probably part of a slide mass.

Paleontology. Conglomerates in Bed 14 have been of considerable paleontological interest because of the variety of fossiliferous clasts and the age of the strata, near the Lower to Middle Ordovician boundary. The most definitive work is that of Whittington (1963) who concentrated on the trilobite fauna from alpha boulder at Lower Head (the Lower Head boulder) confirming that it corresponds to the basal "Whiterock" trilobite fauna from Nevada particularly Zones L and M. This was confirmed by the discovery of the zonal brachiopod *Orthidiella* by R.J. Ross (personal communication, 1980) from soft green-grey fossiliferous limestones at both Cow Head and Lower Head. Although the largest and youngest clasts are middle Ordovician, large clasts with late Cambrian (R.A. Fortey, personal communication, 1980) and early Ordovician (R. Ludvigson, personal communication, 1983) trilobites are also present.

Sedimentology. At Cow Head the conglomerate is similar in style to Bed 12. It contains a remarkable variety of clasts (Fig. 34), the more conspicuous of which are: (1) subrounded blocks of calcified algal limestone and fossiliferous mudstone (Fig. 28); (2) tabular boulders of fossiliferous calcarenite, burrowed and mottled muddy limestone, peloid and ooid calcarenite, and partly silicified limestone or dolostone; (3) irregular clasts that are intensively fractured and infilled with spar; (4) twisted and contorted slabs and rafts of parted to ribbon limestone (Fig. 22). Boulders from which the youngest fossils have been obtained are green-grey argillaceous, fossiliferous, bedded calcarenite. The margins of these young boulders are studded with other pebbles that were pushed into their soft exterior during emplacement, implying that the limestones were only partly lithified. The largest measured clasts are 14 × 49 m in size. Although relatively uniform in composition the upper 0.5 m is a layer of tabular, pebble-size clasts which, in the southern section, is capped by a layer of brown-weathering chert. The 5 to 10% green-grey argillaceous limestone matrix is similar in composition to both the youngest clasts and underlying shale, implying that both may have contributed significantly.

On Stearing Island, the conglomerate is exposed in an upthrown fault block on the western end of the island and is very similar to the unit at Cow Head, although some 10 m thicker.

The unit at Lower Head is complex. Exposed in three sections on the limbs of an antiform and possible faulted syncline (Fig. 6), it varies both in composition and thickness. On the western limb it is similar to Cow Head, about 15 m thick and composed of roughly the same style, size and type of clasts. The central exposure is sheared and deformed, but appears roughly similar to that on the western limb. The conglomerate which forms the eastern exposure is, however, different from both of these exposures.

Measurements on the ground and on enlarged aerial photographs indicate that this unit is roughly 100 m thick. Although containing the same spectrum of clasts as at Cow Head, Stearing Island and the western exposure, at least half of the blocks are an order of magnitude larger, large enough to be seen on aerial photographs and be given specific names for future study. The largest clasts, tens to hundreds of metres across, are reefal, in the form of metre-size to decametre-size mounds composed of calcified algae, ?stromatoporoids, calcareous sponges and rare bryozoans surrounded by gastropod-rich sediment. In some blocks the bioherms are surrounded by clean, coarse grained algal calcarenites. Other large clasts are composed of eroded Cow Head strata including, in one instance, what appears to be a 20 m thick section of basal Factory Cove Member (Tremadoc) strata, including shales, grainstones and conglomerate beds. These clasts are all in a green argillaceous matrix.

The anomalous nature of this eastern section of Bed 14 may be explained, at least in part, by the relationships of underlying strata (see previous discussion of the Lower Head area). At the northern end of the outcrop Bed 11 strata rest on an angular unconformity. This unconformity cuts upsection to the south (Fig. 6, 7) until Bed 14 rests on the surface. In southern parts of the outcrop, strata from the ?Cambrian sediments below the unconformity are injected 6 to 7 m up into Bed 14. Thus, this whole Bed 11/14 complex which rests on the unconformity may be out of place. One possible explanation is that it is a huge mass of more proximal Cow Head from higher on the slope that detached and came to rest farther down the slope.

Bed 15

At Cow Head, where the original system of beds was designated, those strata above Bed 14 in the syncline at Factory Cove, which can only be seen at lowest tide, were not documented by Kindle and Whittington (1958). These sediments are a few metres of siltstones and shales capped by the first massive sandstones of the Lower Head Formation. These sediments are important, particularly from a paleontological point of view, and so we have designated them as Bed 15. Specifically, Bed 15 is the sequence of bedded strata that lies above Bed 14 and below the basal massive sandstones of the Lower Head Formation.

Distribution. This unit can be recognized only at Cow Head and the western section at Lower Head.

Paleontology. Graptolites recovered from above Bed 14 at Lower Head are similar to those found in the Darriwilian 1 Zone of Australia.

Sedimentology. In Shallow Bay the roughly 10 m of strata are thinly interbedded buff to green-weathering siliceous siltstone and green to black shale with 10 to 20 cm thick lenses of lime grainstone.

Green Point Formation

These strata are largely the fine grained equivalents of the Shallow Bay Formation. The basal Martin Point Member overlies the Downes Point Member of the Shallow Bay Formation and is mostly contemporaneous with the Tuckers Cove Member of the Shallow Bay Formation (Fig. 9). The Broom Point Member is equivalent to the Stearing Island Member, but in most areas cannot be separated into Beds 8 and 9. The widespread and sheet-like nature of the conglomerates which comprise Beds 10, 12, and 14, however, allows them to be distinguished in the St. Pauls Member, so beds can be separated in most sections.

At Broom Point (Figs. 10, 48) and Martin Point (Fig. 13) the upper members of the Green Point Formation overlie the lower members of the Shallow Bay Formation. At both Broom Point North and South, the Broom Point Member of the Green Point Formation overlies the Tuckers Cove Member of the Shallow Bay Formation. As both of these members are dominantly ribbon to parted limestone, differentiation is not straightforward. The boundary is therefore arbitrarily placed at the transition from dominantly quartzose calcarenites of the Tuckers Cove to the overlying, dominantly lime mudstones of the Broom Point (i.e. top of Unit 72 North and top of Unit 43 South; Fig. 10). At Martin Point the Martin Point Member overlies the Broom Point Member and the boundary is placed just above a distinctive quartz sandstone bed at the top of Unit 33 (Fig. 13).

Stratigraphic relationships at the top of the Green Point Formation are equally complex. At Cow Head, Bed 13 is defined as that sequence of sediments between the conglomerates of Bed 12 and Bed 14. The base of the Lower Head Formation is defined as the lowest green sandstone of lithic wacke composition in the section. In the Shallow Bay Formation these sandstones are all above Bed 14 but in the Green Point Formation they commonly occur in what would otherwise be Bed 13. This illustrates the erratic, yet time transgressive nature of the base of the Middle Ordovician flysch sequence and the mixing of sediments from two sources, the carbonate platform and an orogenic terrane. Thus, strata above Bed 12 are characteristically Cow Head in aspect, but stratigraphically upward become progressively less like the Cow Head and more like the Lower Head Formation. This part of the sequence is described under the heading of Green Point Formation to Lower Head Formation transition.

Martin Point Member

Distribution. Outside the type section at Martin Point, these sediments occur at St. Pauls Tickle, at the base of the section at Green Point and at The Scrape, the easternmost outcrop on St. Pauls Inlet.

Paleontology. Few fossils have been collected from this unit and so the precise age is unknown, but an approximate age can be assigned on the basis of some fossils, age of the overlying beds and correlation. At St. Pauls Tickle, the Cambro-Ordovician boundary lies in the basal beds of the overlying Broom Point Member so the underlying Martin Point strata are late Cambrian (Fig. 14). At Martin Point the basal beds overlie quartzose calcarenites containing the trilobite *Hungia magnifica* (R. Ludvigsen, personal communication, 1980) and the quartz sandstone here at the top of the underlying Broom Point Member is the same one as in the middle of the Tuckers Cove Member at Cow Head. Equivalent strata at Cow Head are Trempealeauan. The Cambro-Ordovician boundary lies in the uppermost beds of this unit, probably between Units 36r and 36t (Fig. 13), on the basis of conodonts and graptolites (Bagnoli et al., 1983).

A similar situation exists at Green Point (Fig. 13). Here the first diagnostic macrofossils above the base of the Green Point section are graptolites in Unit 25 (in the base of the Broom Point Member) which are equivalent to Lancefield 1 indicating that the Cambro-Ordovician boundary lies somewhere below. The thick conglomerate at the top of the Martin Point Member, together with preliminary conodont studies (Bagnoli et al., 1983), suggests that the boundary lies in the zone of wrinkled limestones that make up Unit 18, near the top of the Martin Point Member.

Trilobites from clasts in the thick conglomerate, Unit 19 (R. Fortey, personal communication, 1985), are *Symphysurina cleora* and *Tatonaspis* sp. The *S. cleora* appears to be a *Parakoldinioidia sitti* (= "*Missisquoia*" *typicalis*). The *P. sitti* and *Tatonaspis* sp. are a ?*Missisquoia* Zone fauna. The Unit 25 conglomerate above contains *Symphysurina* cf. *brevis*. Correlation of these faunas with Broom Point North suggests that the Cambro-Ordovician boundary lies somewhere in the interval between the two conglomerates. Fortey (personal communication, 1985) suggests that the Cambrian-type and Ordovician-type faunas in the same conglomerate may be genuine comtemporaries, with Cambrian genera having extended ranges in outer shelf to shelf-edge environments.

Thus the Martin Point Member is an Upper Cambrian unit, with the upper boundary being diachronous, Late Cambrian in age at St. Pauls Tickle and early Ordovician at Martin Point and Green Point.

Sedimentology. These fine grained sediments consist mainly of green, dark grey or black, fissile shale with thin interlayers of ribbon limestone, rusty-weathering siltstone and fine grained sandstone (Fig. 54). Siltstone units are intricately interbedded and interlaminated with the shale. Thinner partings, which may be up to 1 cm thick, are characteristically rippled and, in some cases, the ripples are isolated. Units more than a centimetre thick generally have a basal laminated layer and a rippled upper layer similar to a Bouma B-C couplet and are sharply overlain by shale. Surfaces of the siltstones and fine grained sandstones are textured by tracks and trails that are absent in the shales. The relatively few medium- to coarse-grained sandstone beds are always rippled.

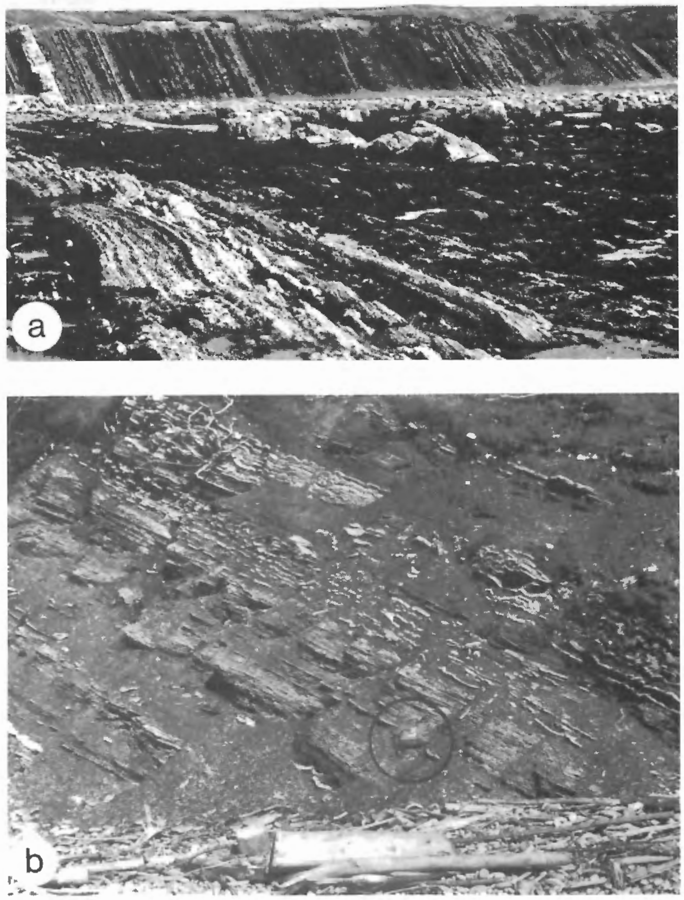


Figure 54. Martin Point Member.

a) Green Point with a well exposed section of the Martin Point Member, section illustrated here is roughly 80 m thick. (GSC 191531)

b) Typical green-grey shales and minor ribbon limestones at the type section at Martin Point, packsack for scale. (GSC 191532)

The siltstones contain as much as 1/3 ferroan dolomite, which replaces silt-size peloids. In some instances dolomite may comprise up to 2/3 of the sediment and so the sediments are silty dolostones.

The dark shales and brown dolostones are interrupted by striking, pale grey weathering ribbons of calcilutite or calcarenite (Fig. 54). These layers, generally 1 to 2 cm thick, vary from isolated limestone ribbons to packages of 6 to 8 ribbons each separated by 10 to 20 cm of shale, to packages of true ribbon limestones of equally thick limestone and shale. While most are evenly bedded some are nodular and some are isolated discoid nodules which, when traced from one to another several metres apart, lie along a single bedding plane. Some limestones are wrinkled and at the top of the Martin Point are characteristically deformed, particularly at Green Point where they are folded, cracked, split and overthrust.

Broom Point Member

This unit is dominantly ribbon to parted lime mudstone with conglomerate beds in proximal sections and shale beds in distal sections.

Distribution. The Broom Point Member is everywhere about 90 m thick. At Broom Point the rocks are a distinctive sequence of ribbon to parted lime mudstones (Fig. 50) with minor black to grey green shale and conglomerate. The section at St. Pauls Tickle is partly covered by bridge abutments, but piecing together partial sections in adjacent quarries and road cuts to the north suggests that most of the strata in this interval are like those at Broom Point, mainly parted to ribbon limestone. Similar lithologies are present at the base of the Long Point and Black Brook sections in St. Pauls Inlet, although with more shale, but they cannot be tied directly to overlying strata because of faulting in each case.

Tremadoc strata at the mouth of Western Brook Pond, which comprise the basal part of the section, are poorly exposed.

The sections at Green Point and Martin Point (Fig. 17) are similar, about equal portions of limestone and shale. Shales in the lower half are grey green and black, those in the upper half contain significant red units.

The section at the Scrape, in St. Pauls Inlet, ends in ribbon limestone at the centre of a syncline, with interbedded red-hued shales. The thickness of these strata is in doubt because of folding and faulting.

Paleontology. The trilobites, conodonts and graptolites from Broom Point have been documented in a series of recent reports because this locality is an excellent section across the Cambro-Ordovician boundary (Fortey and Skevington, 1980; Fortey et al., 1982; Fortey, 1984; Bagnoli et al., 1983). Here trilobites from the uppermost Cambrian *Corbinia apopsis* Subzone of the *Saukia Zone* are found in the basal conglomerate (Unit 73) which is succeeded by an overlying conglomerate with shallow-water boulders containing trilobites typical of the lowest Ordovician *Missisquoia* Zone. In this same interval the earliest planktonic dendroid graptolite, *Radiograptus* is found directly below and is apparently transitional into an abundant fauna of *Dictyonema flabelliforme* sensu lato. Both trilobites and conodonts indicate that there was significant seafloor erosion in this area.

The Cambro-Ordovician boundary lies several metres below the base of the Broom Point Member at Green Point and at Martin Point.

Graptolite faunas from the bulk of the unit are equivalent to the early Lancefield faunas in Australia, and equivalent to the Tremadoc in the United Kingdom. The polymict boulder conglomerate at the top at Broom Point and St. Pauls Tickle contains boulders with the trilobite *Leiostegium* sp. (R.A. Fortey, personal communication, 1980) typical of Zone D in Utah and Nevada.

Sedimentology. The coarser grained sediments, most common in the Broom Point and St. Pauls Tickle sections are either (1) packages of alternating chip conglomerate and calcarenite, each less than 1 m thick, (2) graded-stratified conglomerate, (3) limestone plate conglomerate, commonly lenticular, or (4) boulder conglomerate, with clasts up to 2 m in size, containing an argillaceous matrix which is often grainy in the upper part, and a sporadic calcarenite cap.

Parted to ribbon limestones are thicker and better developed in this unit than in any other (Fig. 50). The limestones are mostly lime mudstone with scattered radiolaria and fine- to very fine-grained, laminated to rarely crosslaminated peloidal calcarenites. Variations in compaction and pressure solution commonly result in irregular to nodular bedding. There is no evidence of bioturbation or ichnofossils in these lithologies except at the top of the sequence. Shales and partings range from green or dark grey to black shale to green-grey dolomite. Limestone is locally replaced by brown-weathering nodular to bedded chert.

These rhythmites contain abundant evidence of slope instability in the form of intraformational truncation surfaces (Fig. 21) and contorted, isolated masses of parted limestone (Fig. 50), especially in the lower part of the member. Intraformational truncation surfaces are only seen in long strike sections such as at Broom Point north, the partial section north of Martin Point and at Green Point, the outcrop band being just too narrow at other localities.

This period is also marked by the first appearance of bioturbated red shales indicating oxygenated bottom conditions. These rocks occur either as thick sections of brick-red shale or as thinner sections of interlaminated red, green and black shale. Sections of red shale rarely contain limestone but are banded by thin to thick buff, internally laminated or rippled dolomitic siltstone.

St. Pauls Member

This member is mostly a red to green shale with variable amounts of limestone rhythmites and conglomerates (Figs. 16, 51). It can be subdivided into the same beds as the Factory Cove Member, although most are lithologically quite different as they contain more shale and less limestone. Because Beds 13 and 15 contain green sandstones at several localities

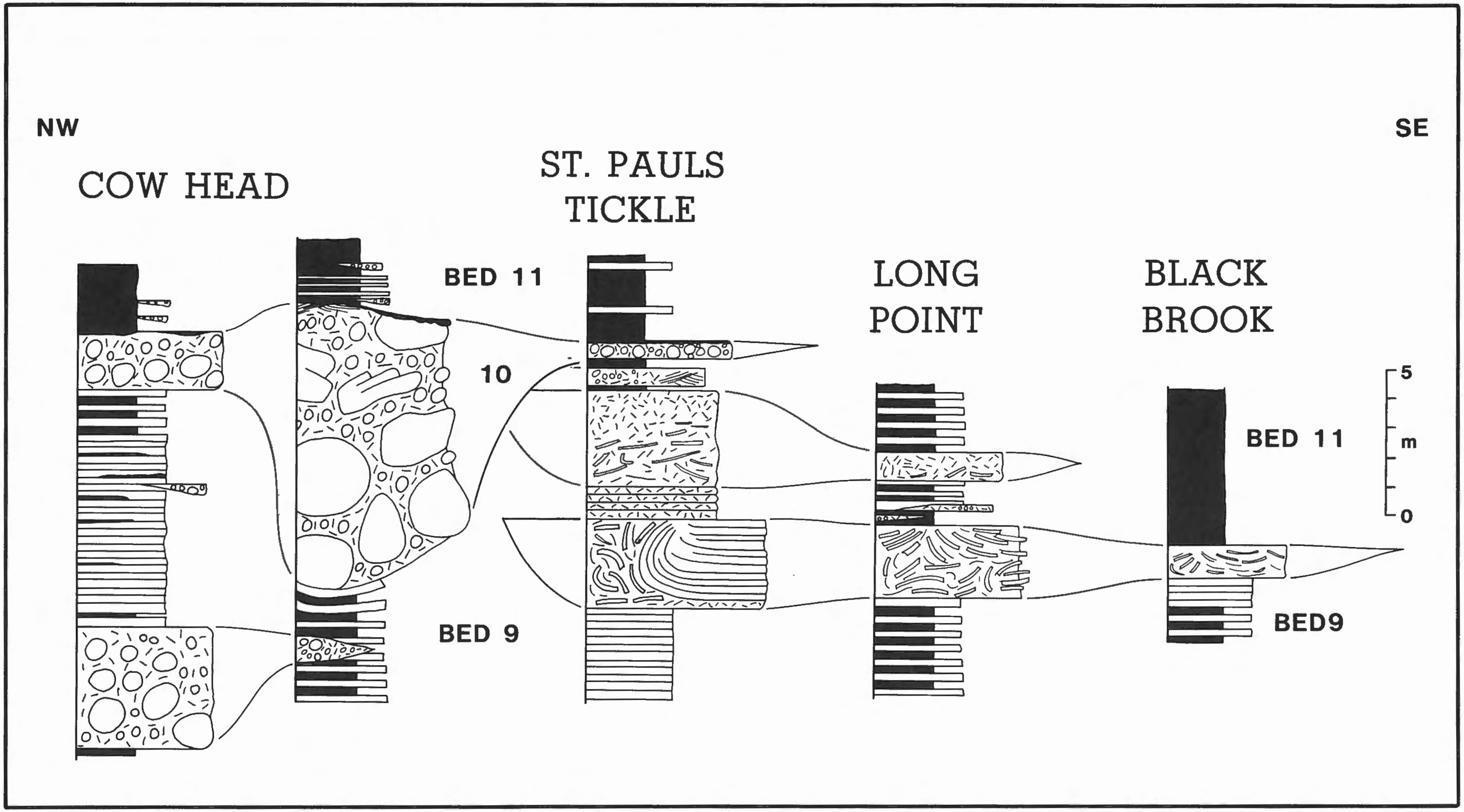


Figure 55. A diagram illustrating changes in the nature of Bed 10 across depositional strike.

they are sometimes included in the Lower Head Formation. These beds are therefore described in a separate section on the transition between the Green Point and Lower Head formations.

Bed 9

In most areas this is a unit of red shale with local packages of green shale and interbeds of green and black shale. Limestones are variable, a thick section is present at the top at St. Pauls Tickle, but elsewhere they are packages and isolated beds of ribbon to parted limestone or conglomerate.

Distribution. Only the lower half is exposed at Broom Point (Fig. 10); the top is faulted out. A complete section is exposed on the north side of St. Pauls Tickle, only the upper part occurs at Long Point, while the whole sequence crops out at Black Brook (Fig. 14). Only the upper part of the section is visible at Western Brook mouth and Stag Brook. Although partly covered by a garbage dump at Martin Point, the section is, save for a few beds, exposed along the shoreline in the cliffs and on the scraped top of the shoreline terrace (Fig. 13). At Green Point, the strata occur sporadically in the shoreline cliff and continuously amongst glacial erratic boulders in the low tide zone north of the point.

Paleontology. Graptolites from green and black shales are equivalent to those from Lancefieldian Zone 3.

Sedimentology. The thick sections of red shale indicate areobic bottom conditions. The presence of thicker red shale sections in more distal facies suggests that deeper waters were more commonly aerated.

The thick rippled grainstones at the top of the section in St. Pauls Tickle appear to represent a local sand apron accumulation.

Bed 10

Unlike the single conglomerate unit in the Factory Cove Member, this unit is either a single conglomerate or a series of conglomerates in the St. Pauls Member (Fig. 55).

Distribution. The unit can be recognized in all sections except Green Point.

Paleontology. No fossils have been collected from the conglomerates.

Sedimentology. At St. Pauls Tickle north, instead of one unit there are several conglomerates (Fig. 55). A basal plate-clast conglomerate with a green argillaceous matrix some 3 m thick is overlain by a series of welded granule to pebble clast conglomerates which together are about 3.0 m thick with a thin boulder conglomerate (ca. 20 cm) at the top which is the real equivalent of Bed 10 from Cow Head, with a chert cap. Across the tickle on the south side the basal plate-clast conglomerate contains a large raft of parted limestone 2 m thick and over 5 m long which is partly broken into plates suggesting a local source for this flow. To the east at Long Point this basal plate-clast conglomerate is 2.2 m thick, the overlying granule conglomerates are reduced to a series of lenses totalling 1.0 m in thickness and the boulder conglomerate with chert is no longer present. Likewise at Western Brook Pond this unit is about 3.0 m thick and composed mostly of tabular clasts and rafts of parted limestone up to 2 m in size while at Martin Point it is similar but only 1.0 m thick. At Black Brook Point it is only 1.0 m of plate-clast conglomerate.

Bed 11

These sediments are generally dark-hued green, red and black shales, and distinguished from other units by the abundance of chert which partially to completely replaces carbonate rhythmites and phosphate-rich conglomerates.

Distribution. This is probably the single most widespread unit in the Cow Head Group and is exposed at every locality except Broom Point where the sections do not reach this high. It is uniformly 50 to 60 m thick.

Paleontology. The lower half of the bed contains graptolites of Bendegonian age, the basal few metres above the Bed 10 complex of conglomerates equivalent to Be 1, the remainder similar to Zones Be2, Be3 and Be4. The upper half is equivalent to the two Chewtonian Zones, Ch1 and Ch2, with the uppermost beds containing a Castlemainian 2 fauna. This zonation can be recognized in all sections except Green Point and Martin Point whose sparse outcrop and predominance of red shales has so far precluded detailed collecting. The absence of a Castlemainian 2 fauna in uppermost Bed 11 strata in the Factory Cove Member is because these strata were removed by erosion during emplacement of Bed 12.

The same general sequence as in the Factory Cove Member is present in the St. Pauls Member, specifically: a lower part of red and green, commonly siliceous shale, rippled calcarenite and thin phosphatic conglomerate; a middle part of metre thick calcarenite with variable green and red shale as well as a persistent 0.1 to 0.5 m thick boulder conglomerate with a chert cap; an upper succession of interlaminated bioturbated green and red shale and buff-weathering dolostone with variable parted limestone and conglomerate lenses.

In general, the limestones become thinner and there is more red shale towards the southeast; at Green Point the sequence is red with some minor green shale and a few thin limestone layers.

Bed 12

This bed is the most widespread single conglomerate extending virtually unchanged from the Factory Cove Member, throughout the St. Pauls Member. No fossils have to date been collected from the clasts.

Transition between the Green Point Formation and the Lower Head Formation

The transition between these two units takes place either in Bed 13 or in Bed 15, depending upon the locality.

Bed 13

This is a sequence of black, green and red shales (Fig. 16, 51) with some conglomerate limestone beds and units of green sandstone.

Distribution. The unit can be distinguished in all sections except Green Point where it is poorly exposed and Bed 14 is not distinguishable.

Paleontology. Since the upper half of the bed is red shale in most places and thus contains no graptolites, close biostratigraphic control is restricted to the basal units. In most sections the lower half contains graptolites similar to those from Castlemainian 2, 3 and Yapeen Zone 1 in Australia. Where the upper 1/2 of the bed does contain graptolites such as at St. Pauls Tickle and Black Brook it is a distinctive fauna of biserial forms equivalent to the Darriwilian 1 fauna of Australia.

Since Bed 13 in the Shallow Bay Formation does not contain graptolites as young as the Darriwilian faunas, it appears that the upper half of Bed 13, as recognized in the Green Point Formation to the southeast, was either never deposited in the Shallow Bay region or was eroded during deposition of the overlying Bed 14.

The trilobite *Endymionia clavaria* (Fortey), characteristically occurs in the lowermost calcarenite beds. The brachiopod *Orthidiella* sp. (R.J. Ross, personal communication, 1984) has been recovered from the thin conglomerate in the middle of Bed 13 at St. Pauls Tickle.

Sedimentology. The bed is here 50 to 60 m thick. In western sections (St. Pauls Tickle, Long Point, Martin Point) the lower half of the bed, similar to the entire section in the Shallow Bay Formation, is green and black laminated to wholly green shale, with the basal calcarenites and chert beds present only at St. Pauls Tickle. In eastern sections (Black Brook, Western Brook Pond) the lower half is mostly bioturbated red shale.

The middle of the bed is characterized at St. Pauls Tickle by a series of boulder and plate conglomerates, each with a chert cap (Fig. 51) and less than 1 m thick, over an interval of 4 to 5 m. At this position in Western Brook Pond and Black Brook there are a few thin ribbon limestones and a lenticular conglomerate and at Martin Point there are some ribbon limestones. More distal sections do not have this unit.

The upper half of the bed is complex. In all areas it is mostly red bioturbated shale with buff-weathering dolomitic siltstone partings and thin beds. Green sandstones of the Lower Head Formation occur sporadically, but never at a consistent level in the bed; they vary considerably in thickness and do not appear to be traceable between sections. At St. Pauls Tickle thin, 1 m thick units occur in the upper half. At Long Point, however, a thin sandstone bed is present 10 m above Bed 12, and 15 m above that there is a massive sandstone unit which appears to be the base of the thick sandstone succession; there is no Bed 14. At Black Brook the lower 2/3 of the bed is bioturbated red shale but in the upper 1/3 there are also conspicuous dolomitic siltstone beds, thin conglomerates and green sandstone beds, green sandstone dykes and substantial red shale below Bed 14.

The only outcrops of the most distal facies are at Green Point where they are very poorly exposed in the intertidal zone, but appear to be red bioturbated shale and minor buff-weathering dolostone throughout.

Bed 14

This distinctive conglomerate is the same unit as Bed 14 in the Shallow Bay Formation, except thinner.

Distribution. The bed is present in all sections except Long Point in St. Pauls Inlet and Green Point.

Paleontology. No macrofossils have been obtained from this bed outside the Shallow Bay area.

Sedimentology. The thickness of Bed 14 varies from section to section; 3 to 6 m in sections along the shores of St. Pauls Inlet; about 2.0 m at Martin Point; always less than 0.5 m at Western Brook Pond.

The composition is similar from place to place with rounded, equant clasts recognizable even where it is thinnest. The matrix remains green calcareous shale in most localities but in more distal sections the upper half is calcarenite. In the section at Black Brook, the upper few centimetres are filled with green sandstone from above suggesting it was originally an open framework conglomerate (Fig. 51). Where thinnest, as at Western Brook Pond, both the top and bottom are chert or the whole conglomerate, except the clasts, is silicified.

Bed 15

This unit is recognizable as strata between Bed 14 and the first massive sandstones (+2 m thick) of the Lower Head Formation. It ranges from a thin, siliceous, red, radiolarian-rich shale to a series of limestones, dolostones, siltstones and shales. In some localities it is clearly a separate unit, but it generally loses its identity upwards, passing into massive sandstone.

Distribution. The bed is best developed in the south and southeastern sections at St. Pauls Tickle, where it is 25 m thick. At Western Brook Pond and Martin Point it is only a few metres of red siliceous shale below massive sandstone. It is not recognizable as a separate unit at Black Brook where sandstones lie directly on Bed 14, at Long Point where sandstones rest on mid-Bed 13 strata or at Green Point where the section is mostly shale and Bed 12 is not clearly identifiable.

Paleontology. Graptolites from the sections on the southern side of St. Pauls Tickle yield a similar fauna of diplograptids to that found in the Darriwilian 1 Zone of Australia.

Sedimentology. At St. Pauls the bed consists of two units. The lower unit is thin-bedded, crosslaminated, coarse grained parted calcarenite with abundant brown-weathering chert interbedded with medium-bedded shale. The upper unit is interbedded, medium-bedded, buff-weathering dolomitic siltstone, grey calcilutites and calcarenite and green sandstone. The sandstones are more common towards the top of the bed.

Lower Head Formation

The Lower Head Formation is a recessively weathering green greywacke that forms low-lying coastal exposures and surrounds or underlies the swampy terrain between ridges of Cow Head on the coastal plain. In general the basal 100 m of the formation contains a variety of shales, siltstones, limestones and conglomerates, although the main sediment is sandstone (Fig. 56). The main body of the formation above appears to be massive, well-bedded sandstone.

Distribution. Although outcrops are present in most inland areas the most extensive occur in Western Brook Pond, in Parsons Pond and along the coast at Lower Head, Martin Point north and south and at Green Point.

Paleontology. Graptolites from shales above Bed 14 are equivalent to Darriwilian 1 Zone while those from the massive sandstones may be as young as Darriwilian 2 faunule or basal Llanvirn.

Sedimentology. The sandstones are exposed, in the type area, on both the north and south sides of Lower Head. On the south side sediments outcrop in the intertidal zone of Shallow Bay. Outcrop is more extensive on the northern coast where it forms an extensive low tide platform. The basal contact is exposed only in the shallow syncline between the central and western ridges at Lower Head.

The sediments are a series of resistant, 0.5 to 1.0 m thick sandstone beds, separated by siltstone or shale. The sandstones are quartzofeldspathic lithic wackes and are graded with granule-rich erosional bases and sharp tops. Sole marks are common and indicate a NE to SW transport direction, opposite to Cow Head. Internally the beds exhibit dewatering structures, convolute laminations and rare dish structures. Granules or cobbles are predominantly shale, silicified shale, red chert and limestone. Shales become less common and sandstones more abundant upward. Lenses of conglomerate occur throughout.

The well-exposed section at Martin Point North (the Wreck) above Bed 14 is evenly interbedded, 0.5 to 2.0 m thick sandstones and shales. The sandstones are similar to those at Lower Head, with several beds slumped, disrupted and fragmented. This sequence is punctuated by occasional metre thick graded fine conglomerate - sandstone beds, ribbon lime mudstones, thin dolostones and lenticular limestone conglomerates.

A similar succession is present in the lower part of the formation at Western Brook Pond except that the shales are thicker, commonly red and many sandstones are planar-bedded and rippled.

The coarsest beds occur along the south side of St. Pauls inlet. Here the 2 to 4 m thick beds are graded, conglomeratic and have erosional bases. Some of the units are boulder conglomerates with a green sandstone matrix. Clasts are identical to lithologies in Beds 11 through 15 of the Green Point Formation with cherty, burrowed shale and dolomite, red and green chert, lime mudstone chips and small boulders of conglomerate particularly conspicuous.

Overall the coarsening-upward sequence suggests gradual southwestward encroachment of an external series of submarine flows. The lateral variability suggests a complex set of environments. The conglomerates indicate downcutting and incorporation of underlying Cow Head sediments in the basal units, confirming the implications from Long Point, St. Pauls Inlet, where massive sandstones occur in Bed 13 and Bed 14 conglomerates are missing.

Figure 56. Lower Head Formation.

a) The top of a graded sandstone bed (left) and the scoured base of an overlying graded granule conglomerate sandstone (right); Lower Head, western section, 10 cm scale at centre. (GSC 191533)

b) A conglomerate composed of typical St. Pauls Member clasts in a matrix of green lithic wacke, typical of the Lower Head Formation, unmeasured short section on south shore of St. Pauls Inlet. (GSC 191534)

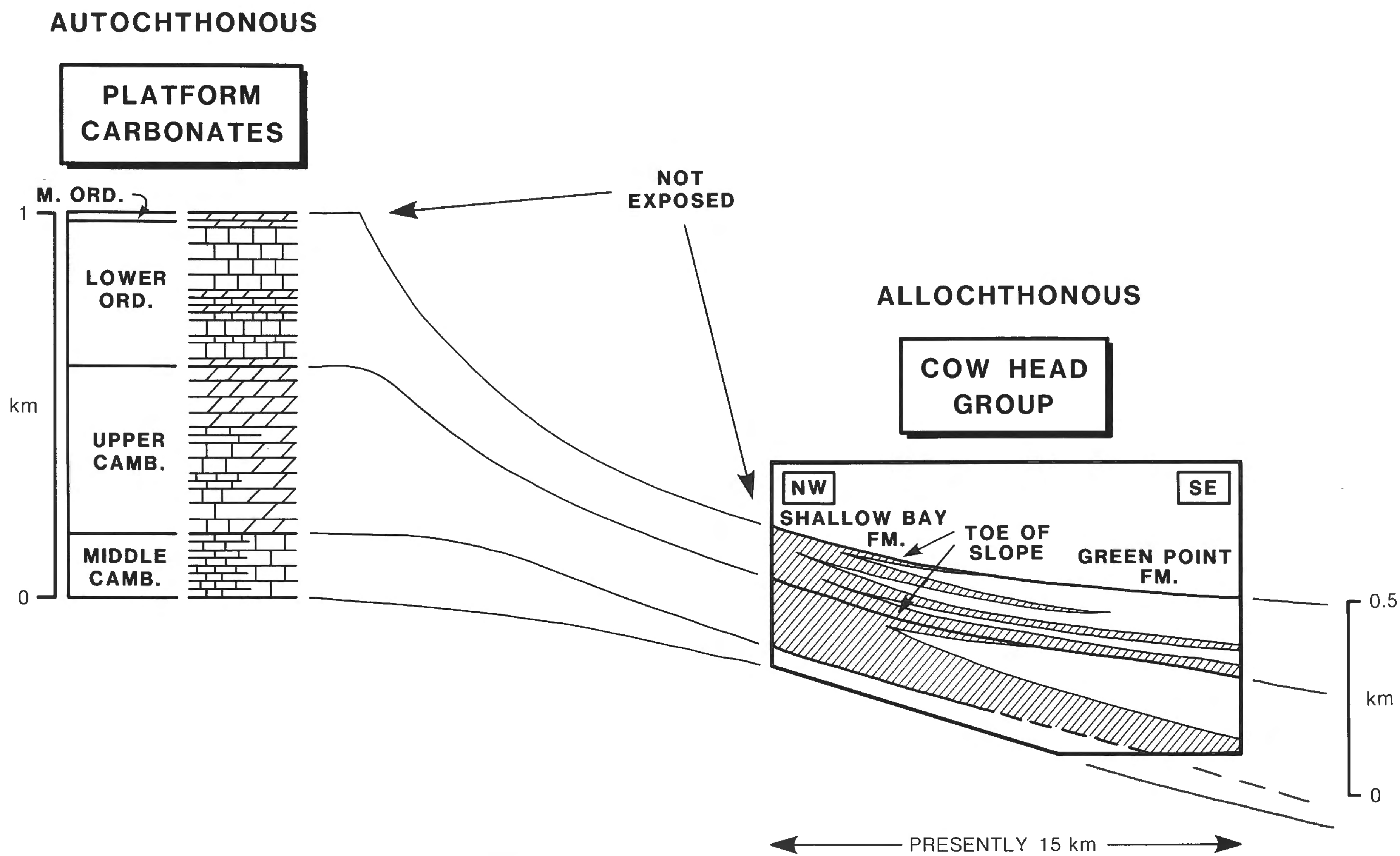


Figure 57. A sketch illustrating the approximate disposition of the Cow Head Group and contemporaneous platform carbonates at the time of deposition.

THE DEPOSITIONAL MODEL

The preceeding information is here integrated into an outline of the depositional history of the Cow Head Group. This is prefaced by an analysis of the general depositional setting, an outline of carbonate slope and basin margin sedimentation in general, with emphasis on the early Paleozoic, and a sketch of the contemporaneous western Newfoundland carbonate platform.

Depositional setting

The Cow Head Group, without doubt deposited in deep water, exhibits the characteristics of an accumulation formed somewhere in the zone between platform margin and basin floor, a setting that may range from forereef to carbonate slope to basin margin or, if facing a major ocean basin, continental slope to rise.

General facies trends and paleogeography

When viewed in total there is a recurring facies trend in Upper Cambrian through Middle Ordovician strata: relatively thin, conglomerate-dominated strata in the northwest, comprising the Shallow Bay Formation; thick, shale-dominated strata in the southeast, forming the Green Point Formation. This tendency is also reflected in a thinning of conglomerate units, general decrease in clast size, disappearance of ribbon to parted limestone and diminution in the modal sand size, all to the southeast. These attributes, together with the paleocurrent directions which are to the southeast, indicate a proximal-distal polarity in the overall facies from northwest to southeast.

In addition there appears to be a progressive, nonreversing trend in the above characteristics to the southeast, suggesting that, if faulted, more distal facies are not thrust over more proximal facies. This in turn implies that the present disposition of units is more or less similar to the way in which they were originally arranged during deposition.

The importance of later faulting in modifying or telescoping these trends is well illustrated in the two sections at Martin Point (Fig. 39), separated by a high angle tear fault. The northern section is similar to those more proximal sections exposed at Broom Point and St. Pauls Tickle, with thick parted limestones in the Broom Point Member and thin shales in the St. Pauls Member. The southern section, just across the fault, is more typical of distal facies and characterized by more ribbon limestone in the Broom Point Member and more shale in the St. Pauls Member.

When sections along the outcrop ridges are compared it is clear that, although generally similar, they are not identical. This suggests either that the ridges as now developed are at a shallow angle to the original depositional strike, or that there was originally considerable variation along strike over a distance of ca. 20 km. Given the relative paucity of outcrop this cannot be resolved with certainty but when considering the great lateral variability along modern carbonate margins it seems that a combination of both factors is likely.

Not only is there a northwest-southeast change in facies from proximal to distal, but upper Cambrian and Ordovician strata reflect a major change in facies style between the Shallow Bay region and the first extensive inland ridge at St. Pauls Tickle. Between these two areas conglomerate facies give way to finer grained limestone and shale facies. East and southeast of St. Pauls Tickle, although changes occur, they are gradual and progressive. We interpret this change to represent a break in slope somewhere between Cow Head and St. Pauls and have drawn it in this fashion on the Upper Cambrian through Middle Ordovician sections.

In summary, the Cow Head Group, as presently oriented, was deposited on a southeastward-dipping paleoslope in front of a carbonate platform which lay to the northwest (Fig. 57).

This interpretation is somewhat different from that proposed by Hubert et al. (1977) which envisages at least two NW-trending carbonate platforms, one between Cow Head and Lower Head and another near Martin Point. The conglomerates were shed to the northeast and southwest off these narrow linear platforms while contour currents flowed to the southeast, parallel to the platform, and deposited calcarenites. Since boulders of platform limestone in the conglomerates at Green Point, Parsons Pond and White Point could not have come from the platforms at Cow Head or Martin Point, because the platforms did not lie upslope, they surmised that there must have been other similar platforms elsewhere.

This alternative interpretation was based on extensive field work, but without detailed stratigraphy and without good biostratigraphic control. This resulted in the assumption, for example, that all red shales were deposited after the Cow Head conglomerates, whereas they are clearly contemporaneous with most in the Ordovician section. In addition, the conglomerates at Daniels Harbour and Cliffy Point were included as part of the Cow Head succession, whereas they are much younger and part of the Cape Cormorant Formation (Klappa et al., 1980) which is considered autochthonous and to lie above the Table Head.

Paleocurrent analysis of the Cow Head rocks, based mostly upon crossbeds, ripples, grain lineations and a few grooves or flutes, are consistent and in agreement with our data, indicating a flow to the southeast from Middle Cambrian through Middle Ordovician time.

The conclusion of Hubert et al. (1977) that the paleoslope dipped to the southwest was based on determinations obtained from slump sheets and synsedimentary boudins in bedded limestones as well as soft sediment folds in boulders in the breccias. This appeared to be corroborated by the dip of modal clast fabric in the breccias, but seems to dip upstream, the reverse of the more common downstream direction. The data upon which this interpretation is based have been challenged by Hiscott and James (1985).

Carbonate slope and basin margin sediments

Several examples of these accumulations are documented in the volume edited by Cook and Enos (1977) while their

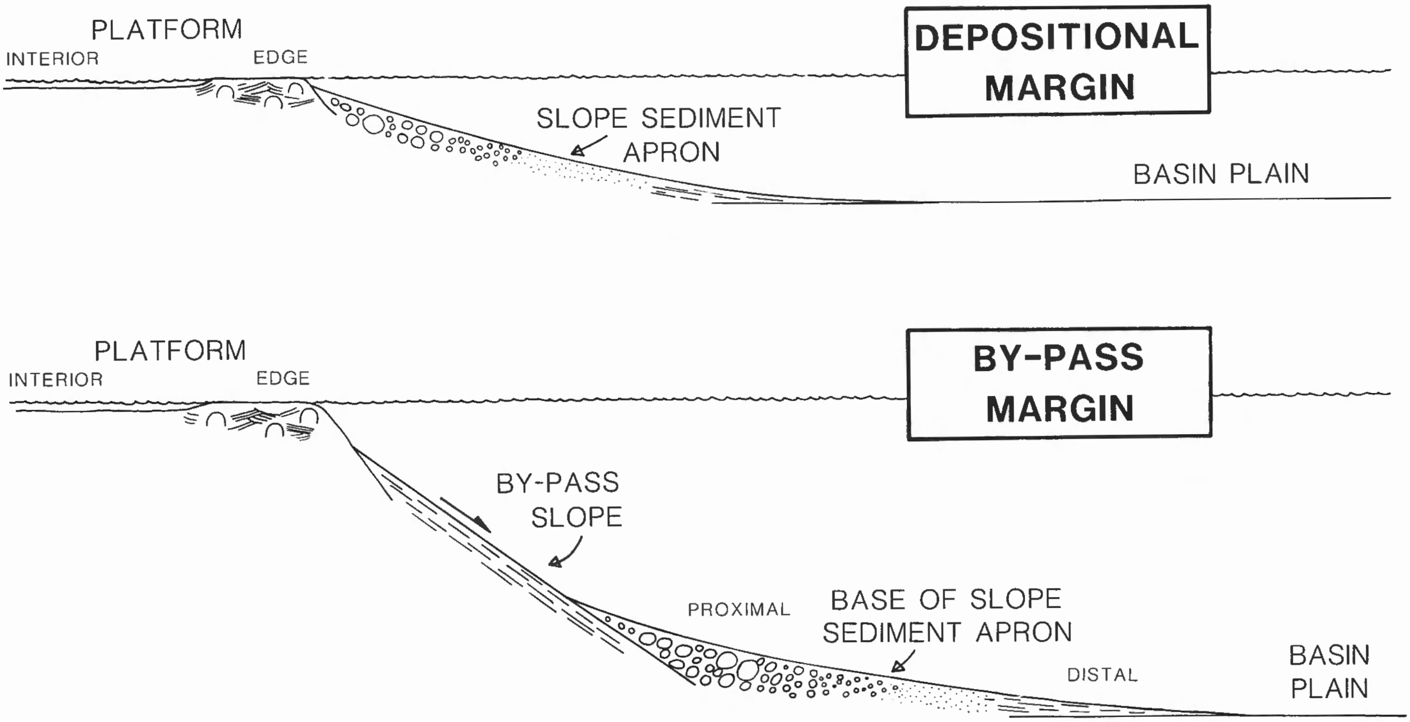


Figure 58. A sketch illustrating the difference between a depositional and by-pass margin.

attributes have been summarized by Wilson (1975), Enos and Moore (1983), Cook and Mullins (1983), Cook et al. (1983) and McIlreath and James (1984). The style of the shallow platform rim has been reviewed by James and Ginsburg (1979), James and Mountjoy (1983), and Read (1985) and one of the best studied modern areas, the Bahamas, has been summarized by Schlager and Ginsburg (1981).

The environment in general can be classified as either a depositional or bypass margin (Fig. 58). A depositional margin is a gently inclined slope that extends continuously from the shallow platform rim down to merge with the basin plain. Deposition may occur anywhere on this slope and so the full spectrum of periplatform deposits occur throughout; the deposit itself has been called the "carbonate slope apron" by Cook (1983). A bypass margin has a steep slope seaward of the shallow rim. Sediment flows down this slope, but bypasses and is deposited at the toe-of-slope, forming a wedge of sediment termed the "carbonate base-of-slope apron" by Cook (1983). The bypass slope itself is composed of fine grained periplatform carbonates.

The Cow Head, composed of proximal coarse grained sediments and distal fine grained sediments, is now not connected to the adjacent platform and so, on present evidence, could have been deposited in either of these settings. Some data, however, suggest that a bypass setting is the most likely. Many megaconglomerates contain large rafts of carbonate rhythmites, which must have been acquired on the way downslope, implying that a facies of fine grained periplatform sediments lay upslope. In addition, the carbonate portion of the deposit, at least in the Ordovician section, is not simply a distal tapering wedge as would be expected on a depositional slope. The thickest carbonate sections are at Cow Head; proximal of this section is welded conglomerate which is thinner than would be expected just upslope from the toe of slope.

Regardless, the Cow Head as a whole can be thought of as a platform margin carbonate debris apron. The interpreted break in slope near Broom Point probably represents a depositional toe-of-slope on this apron (Fig. 57). All deposition, however, took place on an incline, as demonstrated by intraformational truncation surfaces, as well as slumped and deformed strata even in the most distal Tremadoc facies.

Sediments on carbonate debris aprons in general are composed of interbedded fine grained periplatform sediments in the form of carbonate rhythmites and sediment gravity flows which range from fine- to coarse-grained silt and/or sand turbidites to carbonate debris flows. This deposition takes place against a background of continuous fallout of pelagic carbonate and/or clay. The sequence is punctuated by debris sheets and boulder to megaconglomerates representing major events that were widespread and contain huge volumes of debris. The Cow Head is distinguished by the relatively large number of debris sheets it contains.

Such sediments may be modified by geostrophic currents running parallel to the margin (Stow and Lovell, 1979), but there are very little data on such deposits from carbonate terranes. The resulting contourites are generally sandy, have near perfect sorting, lack a mud matrix, have sharp upper and lower contacts, exhibit laterally continuous and evenly spaced current ripples and, most telling, have transport directions parallel to well-established slope directions. In our examination of the Cow Head we find little evidence of contourites, but Hubert et al. (1977) concluded that much of the deposition was by this mechanism.

In contrast to deep water siliciclastic sediments which commonly exhibit organized facies sequences or associations, to date slope carbonates appear somewhat unordered. This is probably because, unlike terrigenous clastic deposits which generally issue from the point source of a submarine canyon and form large fans (Walker, 1984), carbonates come from a semicontinuous line source (Schlager and Chermak, 1979) along the margin. The only deep water carbonate deposit that has some aspects that resemble a deep sea fan is from the Cambrian of the western United States (Cook and Egbert, 1981).

While these attributes apply to platform margin facies in general, sedimentation adjacent to a specific carbonate platform also reflects: (1) the age of the deposit; (2) the type of sediments at the platform edge; (3) the sea level and tectonic history.

Early Paleozoic deep water carbonates

Present day deep water, periplatform carbonate deposits have two main sources, calcareous plankton in the water column and carbonate sediments on the adjacent platform. Both of these sources were different during the early Paleozoic compared to those of younger age.

Pelagic carbonate sediments. The bulk of modern deep water carbonates are from the fallout of calcareous plankton (McIlreath and James, 1984). These micro-organisms did not evolve until Mesozoic time (coccolithophorids during the Jurassic; planktonic foraminifers during the Cretaceous). Since there were no significant calcareous planktonic microfossils in the early Paleozoic, fine grained deep water carbonates were all of shallow water origin and platform-derived.

Thus, for the Cow Head, when the source of shallow water carbonate sediment was cut off there was no deposition of fine grained periplatform carbonate, instead shale, chert, phosphate and manganese prevailed.

Shallow water carbonate sediments. The spectrum of Cambrian and early Ordovician carbonate sediments is much smaller than those in younger Phanerozoic deposits. Cow Head skeletal particles are predominantly algal, from the disintegration of *Girvanella, Epiphyton* and *Renalcis* (Coniglio and James, 1985a), and the problematic alga *Nuia*. Invertebrate skeletons such as echinoid plates and spines, trilobite carapaces and to a lesser degree brachiopod valves are also significant. Of lesser importance are ostracode shells, gastropod shells and nautiloid cones. Nonskeletal grains such as ooids, peloids and lithoclasts make up a much larger component than they did later in the Phanerozoic when the benthic fauna was more diverse.

The origin of the mud-sized fraction is even more enigmatic than in modern carbonates where it appears to come from the breakdown of calcified algae and delicate epibionts, as well as direct precipitation from seawater (Bathurst, 1975). The abundance of calcified algae in the silt and sand-size fractions of the Cow Head suggests that as a source of fine sediment these plants may have been just as significant as they are today (Coniglio and James, 1985a).

Platform margin sediments

Since the source of periplatform sediment is the shallow margin, then the types of sediments will reflect the character of the margin. In general carbonate sand shoals tend to yield large amounts of sand to the slope while platforms rimmed by buildups have slopes made up of alternating fine grained sediments and conglomerates.

Particularly significant in terms of the Cow Head is the absence of large reef-building skeletal metazoans such as tabulate corals, stromatoporoids and bryozoans from Middle Cambrian through earliest Middle Ordovician time. Instead of being reef-rimmed the shallow margins of carbonate platforms during this time must have been formed by either ooid/skeletal sand shoals or bioherms and mounds in which calcified and noncalcified algae and/or calcareous sponges were the main biotic constituents, or some combination of the two (James, 1983).

Sea level and tectonic history

The relationship between the relative position of sea level and the type of slope deposition is difficult to predict (James and Mountjoy, 1983) because it depends upon rates, primarily the balance between the rate of carbonate sediment production and the rate of sea level change (Fig. 59).

Shallow platform flooding. When the platform is flooded by a shallow sea and subsidence is slow and constant then carbonate platform accretion is either: (1) vertical if the rate of sea level rise matches the rate of carbonate production; or (2) largely horizontal and seaward prograding if sea level rise is slow relative to carbonate production. In either case large amounts of sediment will be delivered to the slope. If carbonate sand shoals form the shallow rim the debris apron will be mostly calcarenite with lesser conglomerates and carbonate rhythmites. If reefs are along the shallow rim then finer grained carbonate rhythmites, shales and conglomerates should prevail.

Platform submergence. When sea level rises rapidly enough (or the shelf rapidly subsides) so that the outer part of the platform is below the depth of rapid carbonate sediment production, ca. 50 to 70 m, then the "carbonate factory" is virtually closed down. Since there is no pelagic carbonate source in Cow Head time then such a situation would result in cessation of carbonate sedimentation and formation of hardgrounds or deposition of noncarbonates such as shales, cherts or phosphates. If the cause of sea level rise is eustatic then carbonate sedimentation will eventually catch up, but if tectonic then it may lead to permanent drowning (Schlager, 1981).

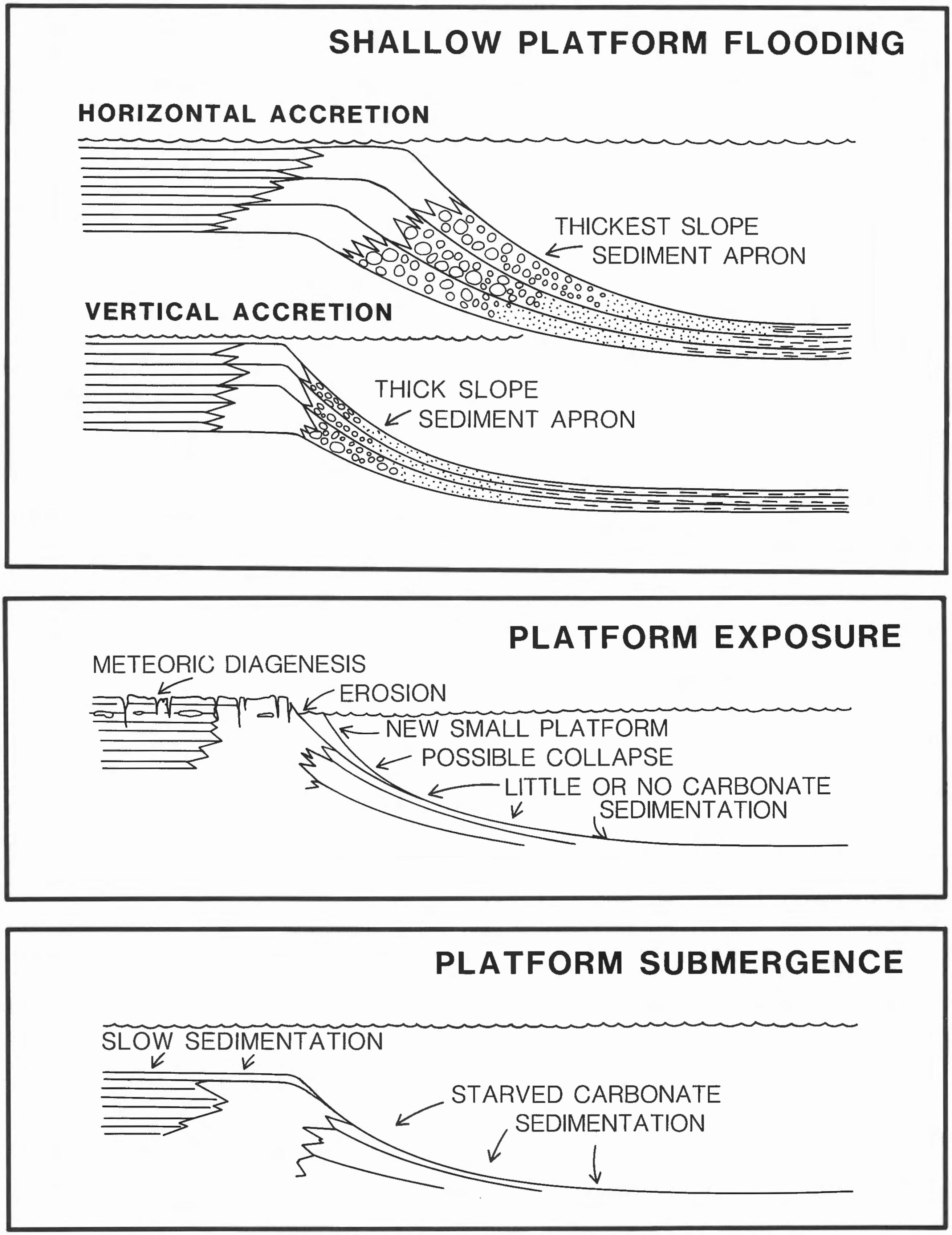


Figure 59. Sketches illustrating the response of carbonate slope sediments to changes in sea level.

Platform exposure. When sea level falls below the platform rim the source of carbonate sediment is again cut off and similar starved deep water sedimentation prevails. During the initial stages of sea level fall sediments may be eroded from the newly exposed rim and lead to sediment gravity flows. If prolonged, wave attack on a karst-weakened rim may result in collapse and formation of debris sheets. In general, however, subaerial exposure leads to carbonate lithification and so extensive erosion should not be expected. Again if prolonged a new, narrow shelf may develop at the lower sea level, rooted on older slope sediments. This structure may be inherently unstable on poorly lithified slope sediments and collapse, resulting in extensive debris sheets.

Carbonate debris sheets. These catastrophic events can result from several causes. Large storm waves or tsunamis may lead to erosion, but it is usually relatively minor and not on the scale of margin collapse. Erosion during subaerial exposure has already been outlined. Gravity, acting upon an unstable, oversteepened buildup margin, which may be fractured, can also cause collapse. This will be a common event during progradation and so be an expected part of the debris apron or it may be a rare event during a low stand of sea level when a narrow platform developed on an older unstable slope collapses and fragments (James et al., 1979). If a bypass margin, the oversteepened pile of periplatform talus high on the slope which has accumulated by rockfall may fail and move downslope as a sediment gravity flow.

Seismic activity is probably a major extrinsic cause. Earthquake shocks, which may be local or centered some distance away, can lead to collapse of large parts of the margin, especially if weakened or oversteepened. Faulting itself may detach parts of the margin, triggering mass wastage. As these events are unrelated to the sedimentary system they could occur at any time.

The west Newfoundland carbonate platform

An obvious source for the sediments that make up these strata is the contemporaneous, autochthonous, shallow water platform sequence also exposed in western Newfoundland around, and possibly beneath the Cow Head (Stevens, 1970). This platform would have lain to the west of the site of Cow Head deposition in Cambrian and early Ordovician time.

The autochthonous sequence, the main attributes of which have recently been summarized by James and Stevens (1982), is over 3 km thick and is composed of strata ranging in age from early Cambrian to Silurian. It reflects deposition on the outer part of a continental shelf which evolved from a narrow margin covered by siliciclastic sediments in early Cambrian time to a wide carbonate-dominated epeiric sea through early Ordovician time. This outer part of the shelf was transformed into a foredeep during Middle Ordovician time by ongoing orogenesis and buried by flysch and west-directed thrust sheets of which the Cow Head is part. The overlying Middle Ordovician to Silurian package records renewed shallow water deposition, which changed from shallow marine to terrestrial during late Ordovocian time.

Although shallow water outer shelf strata contemporaneous with the Cow Head are well exposed, the actual shelf edge facies does not crop out anywhere in western Newfoundland. Its only record are some of the exotic blocks in the Cow Head (James, 1981).

Cambrian

The Middle and Upper Cambrian carbonate platform is a sequence of interbedded limestones, dolostones, siltstones and shales about 600 m thick comprising the March Point Formation which is mostly Middle Cambrian, the Petit Jardin Formation which is mainly Dresbachian to Franconian and the Berry Head formation (informal) which is mainly Trempealeauan (Fig. 60).

The base of the Middle Cambrian is a massive orthoquartzite, the Hawke Bay Formation, whose lower half is latest early Cambrian, but whose upper part contains no fossils. The oldest Middle Cambrian strata of the March Point Formation contain trilobites characteristic of the *Bathyuriscus-Elrathina* Zone, almost precisely the same age as the oldest Cow Head sediments.

The Middle and Upper Cambrian platform strata are characterized by two distinctive and repeated facies: (1) sequences dominated by thin-bedded limestone, shale, argillaceous dolostone and stromatolites, and (2) sequences made up of thick-bedded limestone or dolostone as repeated shoaling-upward oolitic sand cycles.

A series of facies belts can be recognized in this succession (James et al., 1983): an eastern outer shelf belt of stacked ooid shoals; a central leeward belt of both ooid sand cycles and thin-bedded shales and limestones; and a poorly exposed western belt of shaly, thin-bedded or stromatolitic carbonates. The strata in the central belt are arranged in a sequence of three grand cycles (Chow and James, 1984; Fig. 60).

Lower Ordovician

The Lower Ordovician carbonate platform comprises the St. George Group, a succession of limestones and dolostones some 600 m thick which is subdivided into four formations (Knight and James, in press; Fig. 61). The sediments generally reflect lower energy conditions than the underlying Cambrian, are formed of more widespread and uniform lithologies, and contain a more diverse biota. They are characterized by mottled and planar laminated microcrystalline dolostone, dolomite-mottled limestone, abundant skeletal debris, algal-metazoan buildups and chert.

There are two distinct lithological associations within the St. George: (1) cyclic carbonates comprising numerous peritidal shallowing upward cycles grading from subtidal limestone to mottled dolostone to planar laminated, occasionally mudcracked dolostone and (2) thick sections of dark grey fossiliferous subtidal limestones or dolomitized subtidal limestone.

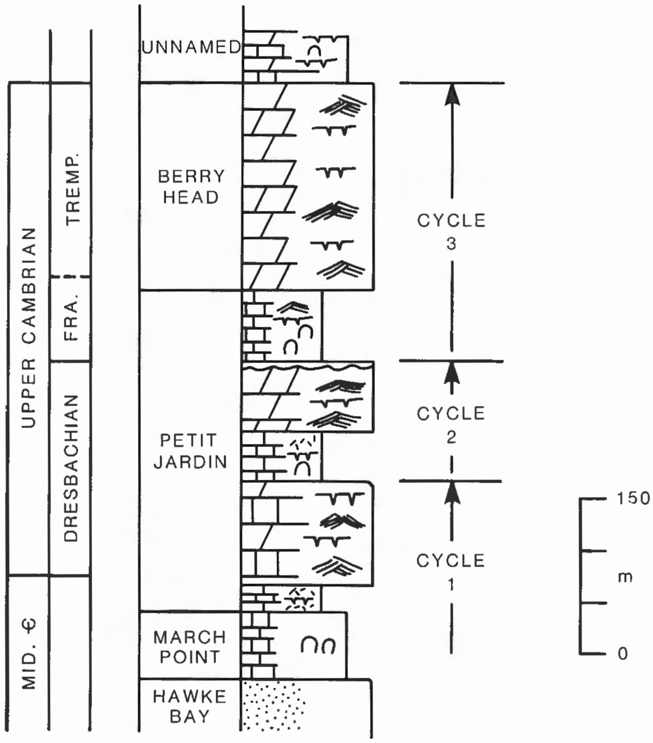


Figure 60. A simplified stratigraphic column of the Middle and Upper Cambrian platform strata in western Newfoundland.

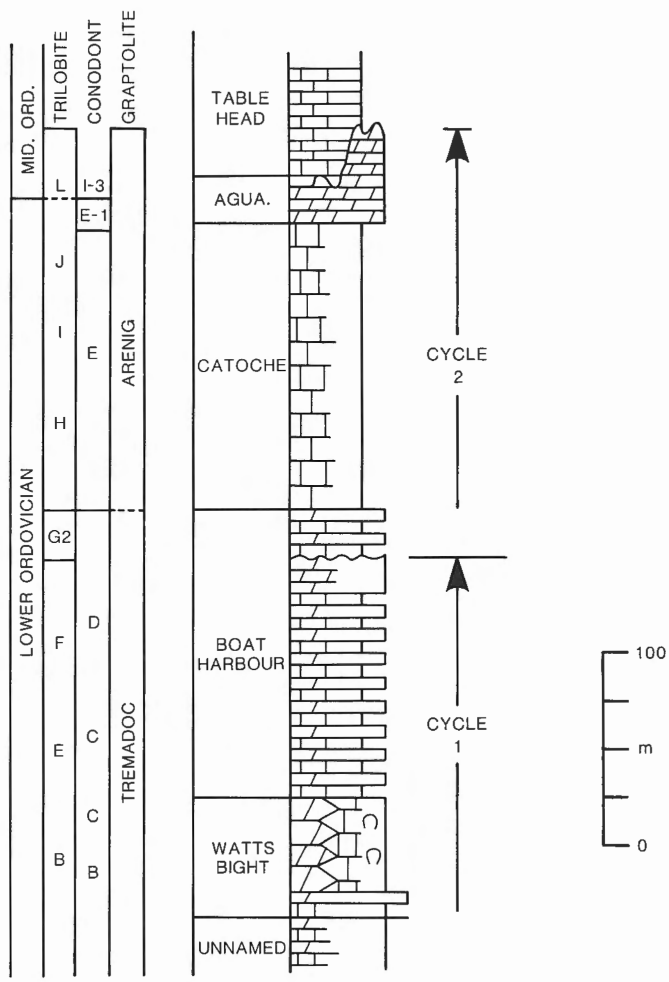


Figure 61. A simplified stratigraphic column of the Lower Ordovician platform carbonates in western Newfoundland.

Watts Bight Formation

Although peritidal limestone and dolostone are at the base, the Watts Bight is mainly a succession of subtidal carbonates which have been dolomitized over much of the area and which contain important sequences of mounds (Pratt and James, 1982). Conodonts from these strata confirm an early Ordovician age and are characteristic of faunas B and C of the midcontinent (Stouge, 1982) while trilobites from the middle are equivalent to Zone B of the western United States succession (Pratt, 1979).

Boat Harbour Formation

The overlying Boat Harbour is in contrast a succession of peritidal shallowing-upward sequences. Near the top of this sequence is a subaerial unconformity which can be recognized throughout western Newfoundland (Knight, 1978; Pratt, 1979; Boyce, 1979). Above this break carbonates are subtidal to peritidal, but coarser grained and higher energy. Conodonts from Boat Harbour lithologies correspond to faunas C and D of the midcontinent while trilobites are characteristic of middle Canadian Zones E, F and G with the unconformity corresponding to Subzone G1 and the uppermost part of the formation equivalent to Zone G2.

Catoche Formation

The upper half of the St. George is a sequence of mainly subtidal limestones some 300 m thick called the Catoche Formation, capped by a thin sequence of peritidal dolostone, the Aguathuna Formation. The widespread Catoche is Canadian (early Arenig) in age, contains conodonts equivalent to North American Zones E and E-1 (Stouge, 1982) and trilobites equivalent to Zones H, I and lower J (Fortey, 1979). In Hare Bay, where outer shelf facies are thought to occur, the Catoche is almost entirely algal-metazoan buildups (Stevens and James, 1976) similar to those found locally in the St. George elsewhere and described by Pratt and James (1982).

Aguathuna Formation

The uppermost beds of the St. George, are a widespread series of peritidal carbonates and associated lithologies, most of which are now buff dolostones, called the Aguathuna Formation (proposed, Knight and James, in press).

These strata contain several depositional breaks and were deposited during a time of synsedimentary faulting. The thickness of the unit varies from 6 to 84 m with the variation being accounted for by deposition on a faulted topography, local erosion of the upper beds and intrastratal dissolution (Knight and James, in press). The top of the formation is demonstrably erosional in many places (Schuchert and Dunbar, 1934; Levesque, 1977; Pratt, 1979) and conformable in others. Two widespread stratiform breccias as well as several thin sand layers suggest several, if not more, breaks in sedimentation and probably subaerial erosion.

Dramatic variations in the thickness of the overlying Table Point Formation (38 to 256 m) led Klappa et al. (1980) to conclude that there was a major period of faulting or folding during or following latest St. George (Aguathuna) deposition and prior to Table Head sedimentation. This is confirmed by the recent detailed work of Lane (1984) and I. Knight (personal communication, 1984). The actual event may be represented by the top of the St. George-Table Head unconformity or a thin conglomerate horizon within the upper third of the Aguathuna Formation.

The base of the formation is early Ordovician. The basal beds contain conodont faunas equivalent to midcontinent faunas E-1 (Stouge, 1982). They also contain graptolites equivalent to Bendegonian 2 to Chewtonian 2 faunas of Australia (S.H. Williams, personal communication, 1984). The upper beds are basal Middle Ordovician (Whiterock Stage) because they contain conodonts of North American faunas 1 to 3 or trilobite Zone L of Utah and Nevada. This is confirmed by the presence of Middle Ordovician trilobites typical of Zone L from these strata (R.A. Fortey, R.J. Ross, D. Boyce, personal communication, 1985).

The total St. George Group can be viewed as deposited in two megacycles (Fig. 61; Knight and James, 1985) each comprising a lower, relatively thin series of shallowing-upward cycles, a middle, thicker subtidal unit and an upper package of shallowing-upward peritidal sediments, capped by a subaerial unconformity. The lower megacycle 1 comprises the Watts Bight Formation and the Boat Harbour Formation, up to the unconformity near the top. The upper megacycle comprises the upper part of the Watts Bight, the Catoche and the Aguathuna formations (Fig. 62). These two cycles correspond roughly to the Tremadoc and Arenig portions of the Lower Ordovocian and are interpreted to represent deposition in response to eustatic sea level fluctuations (James, 1984a) and local tectonics (Knight and James, in press).

Middle Ordovician

Everywhere on the platform the St. George dolostones are overlain by the dark grey subtidal limestones of the Table Head Group (Schuchert and Dunbar, 1934; Whittington and Kindle; 1963, Klappa et al., 1980; Fig. 2). The basal Table Point Formation is a subtidal, bioturbated fossiliferous, grey, hackly limestone with minor dolostone containing horizons of small sponge bioherms (Klappa and James, 1980) and exhibiting disrupted bedding in the form of local slumped horizons. These subtidal carbonates are similar in age to the lower, but not lowest, Whiterock Stage (the upper part of Zone M; R.J. Ross, Jr., personal communication, 1984) and contain conodonts equivalent to North American fauna 4 (Stouge, 1982).

These strata are abruptly overlain by a 100 m thick succession of parted to ribbon limestones and black shales with many beds illustrating slump folding and breccia lenses called the Black Cove Formation. The prolific trilobite fauna from these beds (Whittington, 1965) indicates a middle Whiterock correlation or Zone N in the North American trilobite zonation, or, in European terms, Llanvirn. The Black Cove is overlain either by starved basin black laminated shales (Table Cove Formation) or complex, massive to bedded conglomerates (Cape Cormorant Formation). These sediments are in turn buried by the Mainland Formation which is similar to the older Lower Head Formation. This sequence records initial shallow water deposition on a carbonate platform periodically disturbed by faulting, followed by foundering and partial fragmentation of the platform margin, formation of a foredeep and initial deposition of synorogenic flysch (Stevens, 1970).

Depositional history and event stratigraphy

The Cow Head Group is interpreted as a toe-of-slope sediment apron complex. It is a series of stacked sediment wedges with an overall regressive, onlap, shaling-upward stratigraphy (Fig. 62). The sequence can be subdivided into five distinct stages of accretion which are tied to changes in the style of shallow platform margin sedimentation (Figs. 63, 64).

Stage 1: basal debris sheets

The basal Cow Head is everywhere characterized by extensive welded conglomerates, minor limestone rhythmites and thin shales. Deposition began in the *Bathyuriscus-Elrathina* Zone of the late Middle Cambrian, contemporaneous with carbonate deposition on the platform, and continued through to the top of the Upper Cambrian Dresbachian Stage.

The platform margin during this period was probably a series of stacked ooid sand shoals and calcified algal bioherms. In the Middle Cambrian this belt appears to have been narrow, grading rapidly shelfward into lime mudstones, stromatolites and shales of the March Point Formation. In the Late Cambrian, ooid sands were much more extensive, as illustrated by the Petit Jardin Formation. These sands accumulated rapidly, with almost all of the Petit Jardin deposited within the *Cedaria* and *Crepicephalus* Zones of the Dresbachian. The end of the Dresbachian is a period of slowed sedimentation (end of cycle 2), with the upper four trilobite zones represented in less than 20 m of strata. This arrested sedimentation is also marked by thin layers of quartz sand.

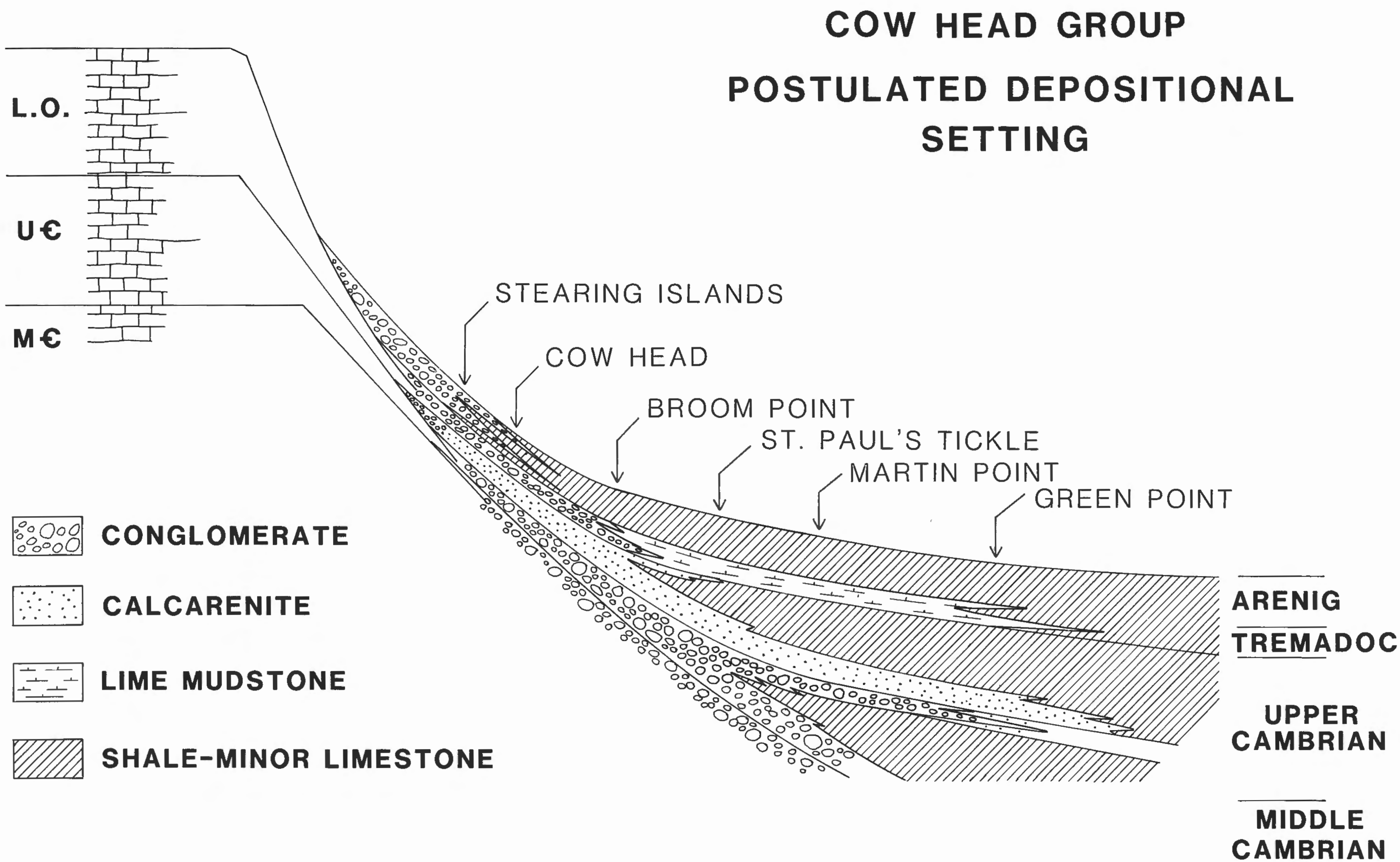


Figure 62. A simplified sketch of the Cow Head Group as a base-of-slope sediment apron with the location of present sections.

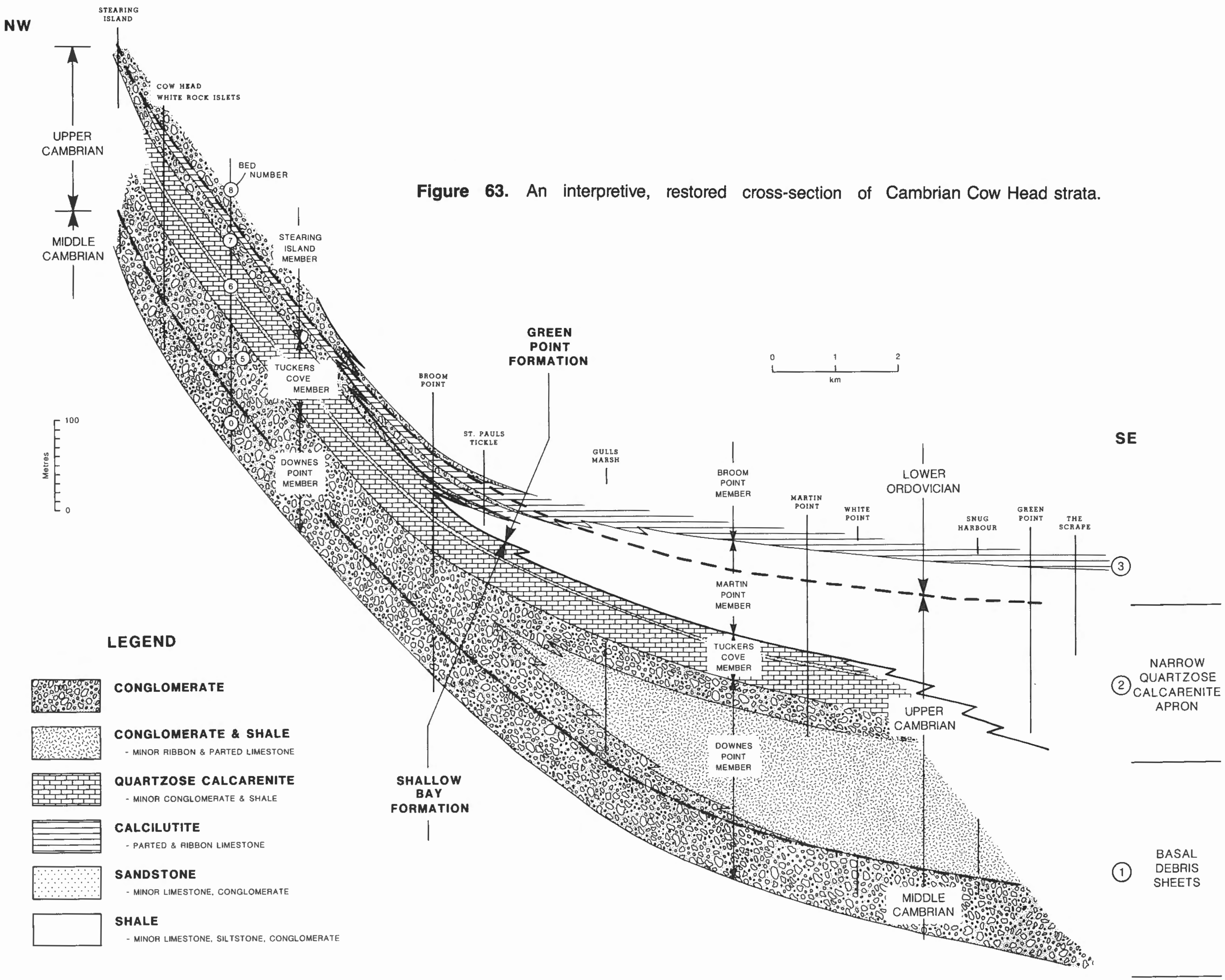


Figure 63. An interpretive, restored cross-section of Cambrian Cow Head strata.

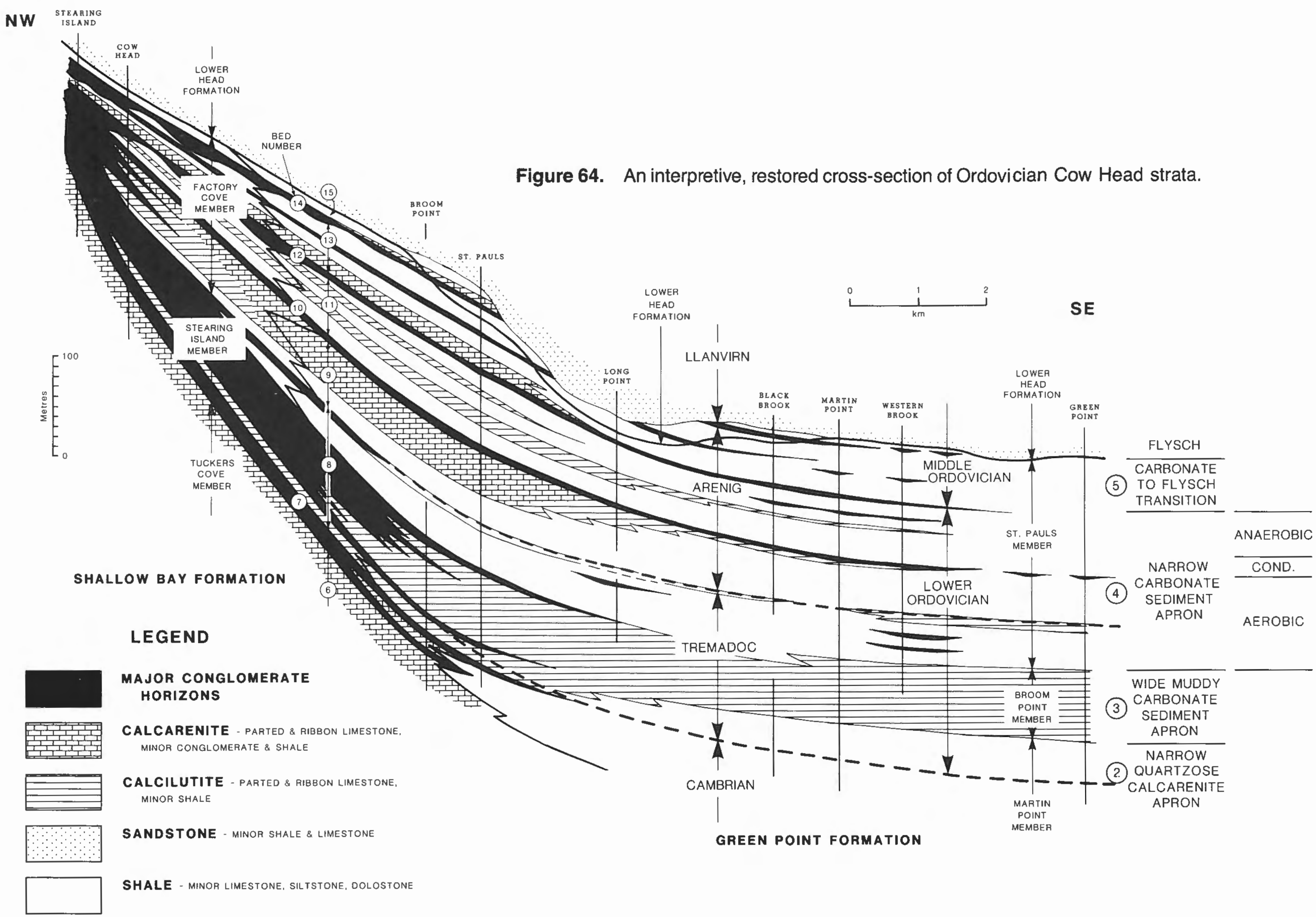


Figure 64. An interpretive, restored cross-section of Ordovician Cow Head strata.

The welded conglomerates in the Cow Head reflect these sources. The boulders are mostly chip and boulder conglomerates with the majority of clasts composed of calcified algal boundstone and ooid-peloid calcarenite. There is no clear information as to what facies lay basinward of these conglomerates, but if the Gulls Marsh section is any guide, they probably graded into shale and minor limestone. The lack of calcarenite, in spite of abundant ooid sand on the platform, suggests mostly on-shelf sand transport, rapid, extensive shallow water lithification and platform upbuilding. This is reflected in part by the numerous large chunks of bedded calcarenite in the conglomerates.

There are no obvious changes in the conglomerates to reflect the two cycles of deposition observed on the platform. There is, however, a marked change to chip conglomerates towards the top, which may reflect the arrested platform sedimentation in the upper part of cycle 2, with more material coming from the upper slope.

Overall the deep water setting is interpreted as a wide sediment apron in front of a sand-rimmed carbonate platform with local calcified algal bioherms (Fig. 63). Dark laminated shales indicate general anoxic conditions. The large rafts of limestone rhythmite in Bed 3 in the Downes Point Member, some of which are burrowed, indicate a contemporaneous, upslope, more oxygenated setting without conglomerate deposition. This, in turn, suggests a bypass margin with parts of the bypass slope rhythmites incorporated into the conglomerates which accumulated at the toe of slope. This conglomerate apron developed at a time of rapid shallow margin upbuilding, as evidenced by the lack of carbonate sand.

Stage 2: quartzose calcarenite sediment apron

The base of the Franconian Stage coincides with an abrupt change in the style of Cow Head deposition to quartz-rich calcarenites with minor shales and sporadic conglomerates, which together make up the Tuckers Cove Member. During early phases of deposition the sand wedge was extensive and can be recognized in sections as distal as Martin Point (Fig. 63). In the later phases, however, it becomes much narrower, and distal shale facies of the Martin Point Member onlap westward and upslope over the basal sands.

The lower broad sand apron

Calcarenites of this sand wedge are composed of peloids, ooids, algal fragments and eolian quartz. The quartz sand reached a maximum, and formed sand beds, in the late Franconian. Sediments were deposited primarily as turbidites and graded-stratified conglomerates. Boulder conglomerates punctuate the section throughout. Black and grey laminated shales together with minor muddy carbonate rhythmites and no trace fossils indicate a background of fine grained sedimentation under oxygen-poor, anoxic bottom conditions.

This period on the platform is represented by the upper beds (ca. 70 m) of the Petit Jardin Formation (base of cycle 3; Fig. 61). The condensed zone of ooid sands which coincides with the first quartz sand layers is followed by a diverse suite of mainly limestone lithologies, in particular ooid sands, flat-pebble conglomerates, shales and stromatolites, and rare quartz sand.

Similarity in depositional style of the deep water sediments throughout indicates a constant but episodic supply of sand from a prograding platform margin facies of sand shoals and algal bioherms. Episodic debris flows probably resulted from periodic oversteepening and slope failure.

The upper narrow sand apron

This is the first clear differentiation in the Cow Head into proximal carbonate (Tuckers Cove) and distal shale (Martin Point) facies. This package begins near the base of the Trempealeauan and extends upward through to just above the base of the Ordovician, about the top of trilobite Zone A. Deposition in proximal sections is the same as in underlying quartzose calcarenites, but with more boulder conglomerates and carbonate rhythmites. These strata grade distally into black, dark grey or green shale with thin siltstone, sandstone and ribbon limestone bands of the Martin Point Member.

The proximal carbonate rhythmites and distal ribbon limestones are fine pelsparite and radiolarian micrite. This is the first occurrence of these sediments in abundance, indicating a change from a sand-dominated platform margin to a significant amount of carbonate mud in the source region. Ribbon limestones around the Cambro-Ordovician boundary are everywhere deformed, implying a period of instability along the margin.

Siltstone and fine grained sandstone layers in the shale facies are distal turbidites with a distinctive trace fossil fauna which is lacking in the enclosing shales.

The abrupt change from calcarenite to shale takes place between Broom Point and St. Pauls Tickle implying that the toe of slope on the sediment apron lay somewhere between these two localities.

The contemporaneous platform sequence is a widespread massive dolostone, informally called the Berry Head formation composed of stacked ooid shoals and tidal flat dololaminates with minor stromatolites. Peritidal lithologies characteristically contain scattered quartz grains or quartz sand laminations.

The pronounced facies shift, with more distal shale facies (Martin Point Member) overlying more proximal sand facies, in the upper part of the package probably reflects an accompanying shift from progradation to upward accretion at the platform margin, with less sediment being shed into deep water.

Cambro-Ordovician boundary conglomerates

The Cambro-Ordovician boundary is poorly studied on the platform but where documented is a series of peritidal deposits with characteristics of both the underlying high energy, sandy Cambrian and the overlying, lower energy, muddy Ordovician.

Although the style of deposition above and below the Cambro-Ordovician boundary in the Cow Head Group is not significantly different in distal facies, in proximal sections, especially Cow Head itself, it is marked by a succession of massive welded conglomerates (Fig. 63). These conglomerates do not extend far into the basin and are accompanied by little other limestone deposition. In the Broom Point sections, there is indication of submarine erosion in the form of numerous intraformation truncation surfaces. There is, however, no evidence of condensed sedimentation such as hardgrounds, phosphate or manganese horizons.

The large clasts in these beds are almost oligomict, mainly boulders of calcified algal boundstone, suggesting erosion of a single facies as opposed to wholesale margin collapse, and therefore probably not of seismic origin. Instead a short period of oversteepening or erosion during small scale fluctuations of sea level along the rim is a more probable cause for these deposits.

There is no evidence to date from the platform of a major hiatus to explain these massive conglomerates except that the peritidal sediments may signal a slowed rate of subsidence and increased local margin progradation, leading to sediment oversupply.

Stage 3: wide muddy carbonate sediment apron

The basal Ordovician is a time of widespread deep water carbonate deposition (Fig. 64). In proximal sections it begins in the earliest Ordovician as the Stearing Island Member massive welded conglomerates, and by the middle part of the lower Tremadoc extends to the most distal sections as the Broom Point Member limestone rhythmites and shale. The sequence is about 100 m thick and terminates above the top of graptolite Zone La2 or roughly trilobite Zone D.

Proximal coarse grained sediments are mainly massive welded conglomerate with minor calcarenite layers. Distal limestone rhythmites are characterized by abundant evidence of slope instability in the form of intraformational truncation surfaces, slumps and slides, even in the most distal facies, indicating slope deposition throughout. Sediments are typical periplatform ooze, mostly carbonate muds with radiolaria and silt-sized pelsparites deposited from fallout and weak bottom currents. There is little macrofauna or microfauna.

These strata correspond to the mainly subtidal limestones of the Watts Bight Formation. The relative paucity of carbonate sand and abundance of carbonate mud in deep water reflects the lower energy conditions present on the platform during Watts Bight deposition.

The proximal to distal progression from massive conglomerate to fine grained carbonate in deep water facies, together with uniform distribution through a considerable thickness of strata, suggests that this phase of deposition was related to a long-lived platform event, most probably continued margin buildup and/or basinward progradation.

Stage 4: constricted sediment apron

This stage reflects pronounced narrowing or westward shift of conglomerate facies accompanied by expansion and progressive westward onlap of shale facies, beginning in the middle Tremadoc and continuing through the Arenig (Fig. 64). These sediments correspond to the largely peritidal deposits of the Boat Harbour Formation and subtidal limestones of the Catoche Formation on the platform. Proximal deep water facies grade rapidly from massive welded conglomerates to interbedded conglomerates, carbonate rhythmites and shales. Distal facies are predominantly red, green and black shale with minor limestone rhythmites. Several persistent conglomerate and megaconglomerate horizons in the Factory Cove Member (Beds 10, 12, 14), however, extend from proximal to distal facies. Superimposed on these trends are changes in the style and rate of sedimentation which allow the sequence to be subdivided into 3 phases, a lower aerobic phase, a middle condensed phase and an upper anaerobic phase (Fig. 64).

Lower aerobic phase

This phase is characterized by extensive red shale deposition and consists of three parts.

(1) Initial deposition corresponds roughly to the upper half of the Tremadoc (upper half of graptolite Zone La2, trilobite Zones E, F and G). In proximal facies there is a rapid change from massive welded conglomerate on Stearing Island to bedded sequences of boulder conglomerate, black shale, calcarenite and burrowed parted to ribbon limestone at Cow Head. There are considerably fewer grainstones than below, no graded-stratified conglomerates, abundant phosphate and chert. All distal facies are shale and by the end of the Tremadoc red shales extend as far west as Broom Point. The top of the package is marked by a short phase of renewed carbonate sedimentation, thick boulder conglomerates with cherty tops in proximal facies and widespread carbonate rhythmites in distal facies.

These sediments correspond in age to the peritidal carbonates of the Boat Harbour Formation. The reduced carbonate sediment supply to deep water probably reflects slowed subsidence and periods of subaerial exposure. The short phase of boulder conglomerate and sheets of carbonate at the Tremadoc/Arenig boundary may well be the deep water expression of the unconformity near the top of the platformal Boat Harbour Formation.

(2) The overlying basal Arenig (basal parts of graptolite Zone La3, trilobite Zone H) is, except on Stearing Island, dominated by shale deposition. At Cow Head the shales and siltstones are thickly interbedded black and green, except for an uppermost red-brown layer. East of Cow Head they are red and bioturbated with thin dolomitic siltstone partings. This marks the farthest westward encroachment of oxygenated bottom conditions, which began in middle Tremadoc, extended to Broom Point by upper Tremadoc and just reached Cow

Head by the Tremadoc/Arenig boundary. This short period is almost entirely without carbonate sediments. The most probable explanation is a short period of platform margin submergence reflected on the platform by the uppermost, high energy transgressive sediments of the Boat Harbour Formation.

(3) The upper beds which correspond to most of Bed 9 (graptolite Zones La3 and Be1, trilobite Zones H and I) grade in proximal facies from massive conglomerates on Stearing Island to interbedded carbonate rhythmites and boulder or plate conglomerates at Cow Head. Rhythmites are fine grained periplatform limestone at the base and calcarenite towards the top. The muddier sediments are burrowed and contain a deep water fauna of siliceous sponges and inarticulate brachiopods. In spite of the dark grey shales between limestone layers, the bottom fauna suggests dysaerobic bottom conditions. In the St. Pauls Member these sediments are much thinner red shales which continue basinward.

This entire phase is interpreted as a narrow carbonate sediment apron, probably resulting from both upward and basinward accretion of the margin. The abundance of mud and algae, together with blocks of calcified algal boundstone suggest a muddy platform with algal bioherms. At the nearest intermediate section, St. Pauls Tickle, the parted limestones are muddy at the base but most of the section is rippled calcarenite, composed predominantly of algal fragment sands. This calcarenite package is probably a local fan of carbonate sand.

This whole sequence is capped by Bed 10, a single megaconglomerate debris sheet in proximal facies but a series of boulder and plate conglomerates in distal facies of which only the upper one is equivalent to the megaconglomerate. This unit probably resulted from a series of events at this time which disturbed the platform margin, leading to collapse, not only of the edge, but of slope facies as well.

Middle condensed phase

Strata in the middle of this predominantly shale succession represent arrested deep water carbonate sedimentation. The lower half of Bed 11 is everywhere a distinctive sequence of interbedded shale, silicified shale, silicified limestone, radiolarite, chert, phosphate granule conglomerate lenses and dolostone. Less than 20 m of strata include most of the Bendegonian graptolite faunule (Zones Be2, Be3 and Be4) or trilobite Zone I.

The relatively thin sequence, sparse carbonate, abundant phosphate clasts and bedded chert all point to starved sedimentation. There is even a cessation of conglomerate deposition at the most proximal Stearing Island locality, for the first time. In the proximal sections at Cow Head and Stearing Island shales are black, unburrowed and deposited under anaerobic conditions; elsewhere red bioturbated shales indicate a widespread oxygenated sea floor.

These sediments correspond to the middle and upper part of the Catoche Formation and reflect maximum transgression together with temporary platform drowning. This is coincident with one of the highest stands of sea level in the Early Paleozoic (Vail et al., 1977).

Upper euxinic phase

The sediments in this phase, the upper part of Bed 11 and the lower part of Bed 13, are similar to those in Bed 9: in the aerobic phase, muddy to grainy rhythmites and lenses of conglomerate. The packages of intervening shale, however, are everywhere euxinic and green to black. These strata span the Lower to Middle Ordovician boundary through the Chewtonian, Castlemainian and Yapeen graptolite zones or the uppermost Canadian (Ibexian) to Whiterock Stages (trilobite Zones J, K and L). The sequence itself suggests normal accretion of the sediment apron, although somewhat slowly, probably in response to gradual platform buildup.

Deposition on the platform at this time is represented by the lower part of the Aguathuna Formation, the series of peritidal dolostones at the top of the St. George Group. This shallow water sequence has several breaks and intraformational polymict conglomerates suggesting both widespread subaerial exposure and instability.

The euxinic shales extend basinward and only those in the most distal sections, along the inner ridge belt at Green Point, are red. This eastward and basinward retreat indicates a significant and prolonged deepening of the oxygen-minimum zone. The top of this package is a thin, but widespread conglomerate.

The megaconglomerate debris sheet, Bed 12, punctuates the middle of this package. This unit, an isolated, albeit massive, deposit with little associated fine grained carbonate, is like Bed 10 but much more extensive. Clasts vary from shelf to shelf-edge to slope limestone to sediments from immediately underlying strata. This mixture, sourced from the entire margin facies together with immense clasts and a large volume of material, suggests wholescale collapse of the shallow shelf edge or upper slope.

Stage 5: mixed carbonate and flysch

This top package encompasses the uppermost units of the Cow Head, the upper half of Bed 13, Bed 14 and Bed 15, where they are transitional into the Lower Head Formation (Fig. 64). It begins at a point roughly equivalent to the base of the Darriwilian 1 graptolite fauna near the top of the Arenig and within Whiterock trilobite Zone L.

Strata are equivalent to the upper part of the Aguathuna Formation, deposited on a series of widespread muddy tidal flats. Numerous thin quartz and chert sand layers in the peritidal sediments indicate short periods of subaerial exposure. Karst horizons and irregular unconformities with up to 10 m of relief attest to longer exposure. This is also a period of faulting on the platform.

The base of the deep water succession (mid-Bed 13) is marked by a westward onlap and shallowing of the red shale facies so that all areas except the most proximal facies of the Shallow Bay Formation were again deposited under oxygenated sea floor conditions. The lower part is shale-dominated throughout indicating a reduction in carbonate delivery from the platform. The megaconglomerate sheet of Bed 14 with many of the same attributes as Bed 12, implies a collapse of the margin, and at this time tectonics on the shallow platform are a likely cause.

In proximal sections sandstones do not appear until after Bed 14 deposition. Likewise in distal sections the first sandstones directly overlie Bed 14. In intermediate sections, however, thin sand layers appear in Bed 13 and at Long Point, St. Pauls Inlet, massive sandstones appear in Bed 13, and Bed 14 is not present. This implies that the first tongues of sandstone, and then the major sandstone, may have moved down a shallow NE-SW trough whose axis is now in the region of the middle of the shale apron. The Cow Head sediments were either covered by the rapidly deposited sandstones or in some instances were eroded and incorporated into the lower layers of the flysch.

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APPENDIX[1]

Stratigraphic Sections of the Cow Head Group

The following description of stratigraphic sections is to accompany graphic logs reproduced on four separate panels (Fig. 10, 12-14, 39-45, in pocket). Sections are located on index maps within each panel.

Individual sections are located by area in the following sequence:

- White Rock Islets
- Cow Head Peninsula – Northern Shore
  - Beachy Cove
  - Point of Head
- Cow Head Peninsula – Southern Shore
  - Back Cove
  - Shoal Cove
  - Jims Cove
  - Tuckers Cove
- Stearing Island
- Lower Head
  - Eastern Section
  - Central Section
  - Western Section
- St. Pauls Inlet
  - Tickle – North
  - Tickle – South
  - Tickle – Southeast
  - Long Point
  - White Point
  - Black Brook Point
  - The Scrape
- Broom Point
  - North
  - South
- Gulls Marsh
- Parsons Pond
- Western Brook Pond
  - North
  - South
  - Stag Brook
  - Snug Harbour
- Martin Point
  - The Point
  - Martin Point North
- Green Point

Lithostratigraphy and most graptolite identifications have been done by the authors, but critical elements of the fauna have also been identified by the following colleagues, who are designated by initials in the text, though not necessarily collected by them.

RAF	Richard A. Fortey	British Museum
RL	Rolf Ludvigson	University of Toronto
DS	David Skevington	BNOC, Glasgow
BE	Bernard D. Erdtman	Gottigen University
RJR	Reuben J. Ross Jr.	Colorado School Mines
JKR	J. Keith Rigby	Brigham Young University
HW	Henry Williams	Memorial University of Newfoundland
XC	X Chen	Nanjing Institute of Geology and Paleontology

Other faunal elements previously reported in the literature have been located as precisely as possible. The key references, again abbreviated in the text, are:

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WHITE ROCK ISLETS

This string of islands, 2.5 km long, forms an arcuate cuesta some 300-400 m across in Shallow Bay, off Downes Point. The strata are broken by numerous small high angle faults, but a simple stratigraphy can easily be followed. The lower 10 m or so of section exposed along the western shore is dolomitized.

WHITE ROCK ISLANDS
49°56'N x 57°47'W

Unit	Description	Thickness (m) Unit	Total from base
	SHALLOW BAY FORMATION		
	Downes Point Member		
2	CONGLOMERATE - several fused beds of chaotic boulder conglomerate composed of 60% grainy limestone clasts and 40% others; tabular (1 cm to 20 cm; average 5 cm) = equant (average 30 cm); 10% green argillaceous matrix: 5% clasts up to 1.0 m.	20.0	37.0
	(f) conglomerate	2.0	
	(e) conglomerate	9.0	
	(d) conglomerate	3.0	
	(c) conglomerate	2.0	
	(b) conglomerate	1.0	
	(a) conglomerate	3.0	
	<u>Trilobites</u>: (3 boulders, K., 1982, p. 10) **Tomagnostus fissus** **Hypagnostus** sp. **Hypagnostus parvifrons** **Ptychagnostus atavus** **Peronopsis** sp. **Bailiaspis** sp. **Solenopleura**? sp. **Elrathia** sp. **Centropleura** sp. (pygidium) **Kingstonoides** spp. (2 species) **Bolaspidella** sp. **Catillicephalites** sp. **Alokistocare** sp. **Orria** sp. **Olenoides** sp. **Modocia** sp. **Spencella** sp. **Bathyuriscidella**? sp. **Corynexochides**? sp. **Bathyuriscus** sp.		
1	CONGLOMERATE - Several fused beds with conspicuous white clasts 2 to 40 cm, average 5 cm with 5% equant clasts up to 1 m, grainy matrix; lower 2/3 is a dolomitized chip conglomerate.	17.0	17.0

COW HEAD PENINSULA

Strata of the Cow Head Group are exposed almost continuously around the shoreline of the peninsula. Inland the southern half of the peninsula is heavily wooded while the northern half is pastureland with the old fishing village of Cow Head located on the northeast corner. The only outcrop inland is a discontinuous S-shaped spine of conglomerate equivalent to Beds 7 and 8 along the shore.

The shape of the peninsula reflects underlying structure, a well-defined, southwest-plunging syncline and adjacent irregular anticline, which has the same plunge. Both structures have faulted limbs. This structure results in repetition of much of the section around the peninsula.

NORTHERN SHORE

The section begins on the most seaward conglomerate ribs north of Beachy Cove and the Upper Cambrian strata continue west around the cove. The sequence is interrupted by a series of faults in Bed 5 but can be traced across the faults where the transition from Bed 5 to 6 is exposed. Faulting in Bed 6 further west repeats part of the sequence yet again so that the Bed 5 to 6 transition is exposed twice. The section above this series of faults is more or less continuous, though complicated by many shallow faults, along the northern shore and around Point of Head, across the ledge to Factory Cove.

The strata are documented in two sections, around Beachy Cove and along the northern shore around Point of Head.

COW HEAD NORTH - BEACHY COVE
49°55'N x 57°49'W

Unit	Description	Thickness (m) Unit	Total from base
	SHALLOW BAY FORMATION		
	Tuckers Cove Member		
	Top bounded by numerous faults.		
6.16	RECESSIVE SERIES OF UNITS -	5.3	106.8
	(g) dolomite, laminated.	1.2	
	(f) fault.	1.0	
	(e) dark grey mudstone, thin-bedded.	1.0	
	(d) thin-bedded grainstone.	1.3	
	(c) wrinkled ribbon lime mudstone.	0.4	
	(b) grainstone, fine grained.	0.1	
	(a) dark grey to laminated grainstone.	0.3	
6.15	CONGLOMERATE - several conglomerates each with lensoid conglomerate caps. Conglomerates are 60% grainstone and grainstones are cross-laminated.	2.0	101.5
6.14	RIBBON TO PARTED LIMESTONE - in 5 cm beds, 1/4 lenses of conglomerate that swell to 1 m in thickness over 5 m.	2.5	99.5
6.13	CONGLOMERATE - persistent along strike.	0.2	97.0
6.12	RIBBON GRAINSTONE.	0.2	96.8
6.11	CONGLOMERATE - massive, tabular (average 1x5 m) and equant (average 3x3 m) clasts in a quartzose grainstone matrix with a 0.1 m thick cross-bedded grainstone cap - 10% large (0.5x0.5 m) white limestone clasts.	1.6	96.6
6.10	GRAINSTONE - complex interlayered lenses and mudstone partings, parted quartzose grainstone in upper half.	1.0	95.0

Unit	Description	Thickness (m) Unit	Total from base
6.9	CONGLOMERATE - with grainstone cap.	0.4	94.0
6.8	PARTED LIMESTONE - lenses of grainstone.	0.2	93.6
6.7	GRAINSTONE AND CONGLOMERATE - coarse, quartzose, grainstone overlain and cut out by conglomerate.	1.0	93.4
6.6	GRAINSTONE - complex interlayered lenses and dark grey mudstone partings.	0.5	92.4
6.5	CONGLOMERATE -	1.0	91.9
	(b) coarse quartzose grainstone cap, steep cross-bedding and megaripples.	0.4	
	(a) 2/3 tabular (average 1x4) and few equant clasts in quartzose grainstone matrix. These are really 2 welded units and along strike one disappears and the other thickens - very lenticular.	0.6	
6.4	GRAINSTONE, LIMESTONE, SHALE - interbedded fine-medium-grained grainstone, parted limestone, and shale, each 2-10 cm.	2.1	90.9
6.3	GRAINSTONE - well-bedded, cross-beds, 10% floating mudstone clasts, slightly quartzose.	2.4	88.8
6.2	PARTED GRAINSTONE - medium-grained with black shale partings.	0.3	86.4
6.1	CONGLOMERATE - tabular (average 2x10 cm) clasts, 20% peloidal grainstone matrix.	1.0	86.1
	Downes Point Member		
5.5	CONGLOMERATE - generally small clasts as in unit 5.4 but a wide variety of compositions, bedded, mostly microcrystalline calcite cement.	21.0	85.1
	Section continues to the west, past zone of numerous faults.		
	A series of high-angle faults which repeat the upper part of the section.		
5.4	CONGLOMERATE - same as unit 5.2.	12.0	64.1
5.3	PARTED LIME MUDSTONE.	0-0.2	52.1
5.2	CONGLOMERATE - many small tabular mudstone clasts, microcrystalline calcite matrix.	6.3	51.9
5.1	RIBBON LIME MUDSTONE - less than 1 cm, dark grey calcareous shale.	0.3	45.6
5.0	CONGLOMERATE - with calcite spar matrix, 70% tabular (average 1x10 cm), 30% equant (average 3x3 cm) clasts.	3.6	45.3
4.4	PARTED GRAINSTONE.	0.3	41.7
4.3	CONGLOMERATE - as 4.1 but fewer large clasts, one large 2 m x 2 m clast, calcite cement in top meter.	5.5	41.4
4.2	PARTED GRAINSTONE - fine-grained, thin-bedded, average 1 cm, laminated, grainstone at top, and lens of conglomerate 0.4 m thick in center.	1.4	35.9

Unit	Description	Thickness (m) Unit	Total from base
4.1	CONGLOMERATE - with buff-green weathering; fine crystalline dolomite. Clasts, tabular/equant = 40/60, a wide range in size, average 5x5 cm, up to 2 m x 2 m down to less than a centimeter.	5.0	34.5
	Trilobites: (K&W, 1958, p. 322) **Catillicephala** sp. **Coosella** sp. **Kingstonia** sp. **Ithycephalus** sp. **Tricrepicephalus** sp. **Meteoraspis** sp. **Bienella** sp. **Millardia** sp. **Deiracephalus** sp.		
3.0	A complex bed that varies along strike, in the least disturbed portion it consists of 3 beds.	12.4-19.4	29.5
	(c) grainstone.	0.6	
	Trilobites: (RL) **Kingstonia** sp. **Coosella** sp. **Syspacheilus** sp. aff. **Cheilocephalus**		
	(b) massive conglomerate.	7.5	
	(a) shale, green with occasional ribbon limestone clasts.	4.3	
	These beds grade laterally into a massive conglomerate which in turn grades into coherent masses of parted limestone which may be intensively folded. Clasts in conglomerate - 1/2 are 60% tabular (average 2x10 cm) and 40% equant (average 5x5 cm) in 30% green argillaceous matrix; 1/2 are huge (2x2 m) clasts of underlying conglomerate.		
	Graptolites: **Dendrograptus** sp., in very large ribbon limestone clast.		
	Trilobites: (K&W, 1958, p. 322) **Meteoraspis** sp. **Catillicephala** sp. **Kingstonia** sp. **Blountia** sp. **Tricrepicephalus** sp. **Coosella** sp.		
	Erosion has removed much of underlying Bed 2 in places.		
2.0	CONGLOMERATE - predominantly small tabular clasts, because of crystalline calcite matrix it weathers are a resistant ledge; an irregular 0.4 m thick ribbon limestone base.	2.4	10.1
1.0	CONGLOMERATE - with a partly dolomitized mudstone to packstone matrix; 70% tabular (average 2x10 cm) and 30% equant (average 3x3 cm) clasts; 1/3 of clasts are large tabular grainstone blocks up to 0.5x2.0 m.	7.7	7.7
	Trilobites: (K&W, 1958, p. 322) **Tricrepicephalus** sp. **Crepicephalus** sp. **Deiracephalus** sp.		
	Section begins at point north of Tuckers Cove on northern side of fault and continues west along coast.		

COW HEAD NORTH - POINT OF HEAD
44°55'N x 57°50'W

Unit	Description	Thickness (m) Unit	Total from base
	LOWER HEAD SANDSTONE		
	SANDSTONE - covered except at very lowest tide, interbedded green siltstone and shale at base, resistant sandstone ribs in upper 1/2.	14.0	291.4
	SHALLOW BAY FORMATION		
	Factory Cove Member		
14.0	CONGLOMERATE - massive, chaotic unit that cuts down at least 4 m, a distinctive green argillaceous matrix; complete spectrum of clasts from contoured ribbon limestone to soft fossiliferous limestone, to huge (20x20 m) white limestone blocks, many blocks rounded.	15.0	277.4

Unit	Description	Thickness (m) Unit	Total from base
	Trilobites: (K&W, 1958, p. 326) (1) **Nileus** sp. **Presbynileus** sp. **Remopleurides** sp. an illaenid **Bathyurellus** sp. **Ampyx** sp. **Raymondaspis** sp. a harpid, a ceraurid **Ectenonotus** cf. **westoni** (2) **Illaenus** cf. **tumidifrons** **"Cheirurus" prolificus** **"Lichas" jukesi**		
13.10	SHALE - black and green, banded and burrowed. (cut out along strike by bed 14)	0.2	262.4

Unit	Description	Thickness (m) Unit	Total from base
13.9	CONGLOMERATE - 3 beds, lower conglomerate 0.2 m, middle grainstone 0.6 m, upper conglomerate 0.6 m, both conglomerates the same, 40% tabular (average 2x10 cm) and 60% equant (average 4x4 cm) clasts, conspicuous phosphate and phosphate-coated clasts and black chert fragments, matrix grainstone with minor granules. (cut out along strike by bed 14)	1.4	262.2
13.8	RIBBON GRAINSTONE - trilobite-rich, chert nodules and tops or bottoms of beds in layers up to 10 cm thick, occasionally nodular, synsedimentary dikes of grainstone. 1/3 black and green laminated shale. Graptolites: **Isograptus** cf. **forcipiformis** **I. victoriae divergens** **I.v. maximodivergens** **I.** sp. **Didymograptus v-deflexus** **Xiphograptus** sp. **Anomalograptus reliquus** **Tetragraptus headi** **T. rigidus** **Pseudotrigonograptus** sp. **Goniograptus** sp. (K&W, 1958, p. 326) **Loganograptus** cf. **logani**	1.9	260.8
13.7	SHALE - black, silty, occasional brown-weathering, cherty, sooty, 1/3 1-2 cm thick layers of nodular to irregular bedded lime mudstone.	2.8	258.9
13.6	CONGLOMERATE/RIBBON LIMESTONE - a disturbed bed, partly ribbon limestone, partly conglomerate, 0.2 m thick chert top, variable along strike.	1.1	256.1
13.5	SHALE - green and black laminated.	1.0	255.0
13.4	PARTED LIMESTONE - layers average 1 cm, separated by green-grey shale.	1.5	254.0
13.3	PARTED TO RIBBON GRAINSTONE - as 13.1.	2.3	252.5
13.2	PARTED LIMESTONE AND GREEN SHALE.	0.9	250.2
13.1	PARTED TO RIBBON GRAINSTONE - fine-grained, in layers 4-10 cm thick, commonly with silicified tops, cross-laminated, occasional spiculites, separated by black shale. Trilobites: (RAF) at 4.0 m **Endymionia clavaria**	9.0	249.3
12.0	CONGLOMERATE - massive with boulders averaging 2 m but often up to 5 m, largest clasts 5 m x 20 m, matrix derived from underlying bed by injection so it is green-grey dolomitic shale with floating tabular clasts of lime mudstone; no chert top. Fossils in clasts: Sponges: (JKR) **Anthaspidella** sp. **Archaeoscyphia** sp. **Psarodictyum** sp. Brachiopods: (RJR) **Orthidiella** cf. **o. castellata** **Pleurorthis?** sp.(aff. sp. 1 of Cooper, 1956) **Pleurorthis?** aff. **P. imbecilis** **Pleurorthis fascicostellata** **Orthidium?** sp. **Archaeorthis?** sp. **Idiostrophia valdari** **Leptella sordida** (R.B. Neumann) Gastropods: **Maclurites** sp. Trilobites: (K&W, 1958, p. 326) **Nileus** **Telephina** sp. **Kawina** cf. **vulcanus** an illaenid an agnostid (RJR) **Trinodus** sp. **Lonchodomas** sp. **Strototopis** sp. **Sphaerocoryphe** sp.	10.0	240.3
11.15	RIBBON MUDSTONE - minor grainstone, layers 2-10 cm thick, green-grey dolomitic shale of same thickness between layers, some distortion from overlying bed, upper part broken and incorporated into conglomerate above. Graptolites: 2.0 m above base **Didymograptus bifidus** s.l.	4.0	230.3
11.14	SHALE - buff-weathering, green, dolomitic, similar to 11.7, 11.11, a black band near top. thin lenses of tabular clast conglomerate.	0.6	226.3
11.13	PARTED MUDSTONE - layers 1 cm thick separated by green-grey calcareous shale, burrows at top.	1.4	225.7
11.12	SHALE - dark green, black bands, fissile, dolomitic.	0.3	224.3
11.11	DOLOMITE - same as 11.7.	0.5	224.0
11.10	SHALE - black, fissile, a 0.4 m thick conglomerate in center that extends laterally for 4 m.	0.9	223.5
11.9	PARTED MUDSTONE - layers 1 cm thick separated by black shale, occasional burrows, grainstone lenses, hummocky bedding.	1.0	222.6
11.8	SHALE - green and black, bright green top, dolomitic.	0.4	221.6
11.7	DOLOMITE - buff-weathering, greenish, silty, laminated flattened burrows, micro-laminations resembling starved ripples.	0.7	221.2
11.6	SHALES - laminated green and black, thin layers of grainstone, fine-grained. Graptolites: **Didymograptus bifidus** s.l.	1.0	220.5
11.5	PARTED LIMESTONE - parted lime mudstone, irregular to nodular bedded, paper thin green shale, black chert nodules, rare burrows, and no cross-laminations; basal 0-0.2 m is a lenticular grainstone with phosphatic clasts. Graptolites: **Tetragraptus fruticosus**, 3-stiped **Didymograptus extensus**	1.1	219.5
11.4	SHALE - dark green to black, siliceous, black, brown, and green chert layers ca. 2 cm thick, buff-weathering black cherty shale; at 0.6 m phosphatic conglomerate, at 3.3 m grainstone, upper 2 m is a prominent black shale, buff-weathering siltstone and chert. Graptolites: at 6.0 m: **Didymograptus extensus** **D. nitidus** **D. ensjoensis** **Tetragraptus quadribrachiatus** **T. fruticosus**, 3 and 4-stiped **T. serra** **Goniograptus** sp. **?Clonograptus** at 4.0 m: **Tetragraptus fruticosus**, 3 and 4-stiped **Dichograptus octobrachiatus** **D. maccoyi** **Goniograptus geometricus** **?Phyllograptus** sp. **Sigmagraptus laxus** at 3.5 m: **Didymograptus pennatulus** Tetragraptus fruticosus, 3-stiped at 1.0 m: **Didymograptus extensus** **D. nitidus**	6.6	218.4
11.3	SHALE - buff-weathering, green calcareous siltstone at base, burrowed.	0.6	211.8
11.2	SHALE - black siliceous, fissile, lenses of phosphatic conglomerate up to 5 cm thick. Graptolites: **Tetragraptus fruticosus**, 4-stiped **Phyllograptus typus**	0.6	211.2
11.1	SHALE - dark red to black, blocky, cherty, and siliceous, ribbon limestone bands 10 cm thick with chert top and bottom, nodular in places.	0.9	210.6

Unit	Description	Thickness (m) Unit	Total from base
	Graptolites: **Didymograptus constrictus** **Phyllograptus typus**		
10.0	CONGLOMERATE - chaotic, coarse, over a distance of 50 m it thickens from 0.8 to 7.2 m, average clast size 20 cm, largest tabular clasts 3x4 m, largest equant clasts 3.5 m, matrix in lower 1/2 10% brown-weathering dolomitic siltstone, grainstone in upper part, grainstone cap at thickest part of bed, brown weathering chert cap replacing grainstone, swirled fabric, top of large clasts bevelled flat.	0.8-7.2	209.7
	Sponges: (KR) **Archaeoscyphia** sp.		
9.17	RIBBON LIME MUDSTONE - layers 5-10 cm thick separated by equal thicknesses of black shale, some layers grainstone, fine-grained cross-laminated, rippled, some layers are graded, grainstone base, mudstone top, some layers contain sponge spicules, at 3.0 m is a conglomerate 1 m thick that wedges out over 40 m, clasts, 1x2 cm, spar matrix.	5.5	202.5
	Graptolites: in upper meter **Tetragraptus approximatus** **T. acclinans** **T. pendens**, 4-stiped **T. quadribrachiatus** **Bryograptus crassus** **Dictyonema** sp. (non siculate) **Desmograptus** sp. numerous other non-siculate dendroids		
9.16	PARTED TO RIBBON LIME MUDSTONE - in layers 1-2 cm thick, green-grey shale, occasionally nodular, generally well-bedded.	1.9	197.0
9.15	RIBBON LIME MUDSTONE - in beds 1-3 cm thick, shales green-black, a 0.2 cm thick conglomerate lens at top.	4.0	195.1
9.14	SHALE AND CONGLOMERATE -	1.4	191.1
	(b) conglomerate, lenticular, composed of equant (average 2x2 cm)=tabular (average 1x3 cm) clasts and a calcareous grainstone matrix.	1.0	
	(a) black shale and ribbon limestone.	0.4	
9.13	CONGLOMERATE - chaotic, clasts up to 2x2 m, equant=tabular clasts, composed of mottled limestone, chert, brown dolomite siltstone, parted and ribbon mudstone and grainstone, little or no matrix at base, variable matrix throughout, green argillaceous dolomitic calcareous grainstone matrix in upper 1/3 which becomes a grainstone cap.	2.8	189.7
9.12	GRAINSTONE - poorly exposed.	0.2	186.9
9.11	COVER - by beach, possibly shale.	9.8	186.7
9.9	RIBBON TO PARTED LIMESTONE - layers 1 cm thick, slightly nodular, green shale.	6.0	176.9
9.8	RIBBON MUDSTONE - 2-4 cm thick beds, irregular, hummocky, to occasionally nodular, laminated to cross-laminated, rippled, burrows, both vertical and Zoophycus-like, dark grey shale.	4.2	170.9
9.7	CONGLOMERATE - 80% tabular lime mudstone clasts up to 1x30 cm, 20% green argillaceous mudstone matrix; swirled fabric, cuts down into underlying bed.	3.2	166.7
9.6	PARTED LIME MUDSTONE - layers 5-10 cm thick, separated by 1-2 cm thick black shale, occasionally dolomitic and nodular; some thin beds (ca. 0.1 cm) rich in hexactinellid sponges, sponge spicules, silicified brachiopods, phosphatic brachiopods, trilobite fragments, echinoderm debris, minor ripples.	4.5-5.2	163.5
	Graptolites: **Clonograptus flexilis** **C. rigidus** **Tetragraptus approximatus** **T. acclinans**		

Unit	Description	Thickness (m) Unit	Total from base
9.5	SHALE - dark grey to black, sooty, conglomerate lenses at: (1) 0.4 m (0.6 m thick), (2) 1.8 m (0.3 m thick), and (3) 2.8 m; lime mudstone, often nodular; 10% thin graded grainstone bed with quartz and phosphate grains.	3.3	158.3
	Graptoiltes: near base **Clonograptus flexilis** **C. rigidus** C. sp. (small and slender) **Tetragraptus approximatus** **T. acclinans** T. cf. **quadribrachiatus**		
9.4	CONGLOMERATE - 10% green argillaceous matrix becoming more grainy upwards; clasts, tabular (average 1x3 cm, occasionally large 5x30 cm), composed of grainstone, mudstone, dolomitic siltstone, chert.	0.7	155.0
9.3	RIBBON MUDSTONE TO GRAINSTONE - laminated, fine-grained, vertical burrows 1 cm long, shale dark grey to black in beds 1 cm thick; 20% conglomerate lenses similar to bed 9.2.	1.4	154.3
9.2	CONGLOMERATE - basal 0.2 m downcuts into beds below, composed of boulders, 10 to 20 cm in size of grainstone, chert, mudstone, dolomite; upper 0.4 m clasts, 60% equant (average 2x2 cm, largest 15x15 cm), 40% tabular (average 1x2 cm, largest 2x15 cm); 20% grainstone matrix with phosphate and quartz.	0.6	152.9
9.1	SHALE-SILTSTONE - interbedded bright green shale and brown to buff-weathering dolomitic siltstone with rare shale clasts in beds 20 cm thick. The upper 20 cm is a red-brown shale.	3.3	152.3
	Stearing Island Member		
8.35	CONGLOMERATE - several beds.	1.8	149.0
	(c) conglomerate, green argillaceous matrix, wide variety of clasts, mostly equant up to 40x40 cm, abundant phosphate (average 0.2 cm) and brown chert clasts - not a chert cap but all clasts in upper layer are coated with brown chert.	0.2	
	(b) grainstone, cap to conglomerate succeeded by green dolomitic siltstone.	0.1	
	(a) conglomerate, matrix, grainstone at base, bright green shale in middle, to argillaceous mudstone and grainstone at top; clasts mostly equant, average 2x2 cm.	1.5	
8.34	PARTED TO RIBBON LIME MUDSTONE - in beds 2 cm thick, nodular, occasionally calcite "beef" spar; separated by shale and green dolomite, average 2 cm thick.	1.3	147.2
8.33	CONGLOMERATE - several layers.	2.2	145.9
	(c) conglomerate, reverse graded, 20% matrix, spar at base and top, argillaceous green mudstone in middle; clasts 2x2 cm at base, 15x20 cm in middle, 40x40 cm at top. Some clasts have chert rinds. Clasts of very varied composition, including green chert.	1.4	
	(b) shale green-black, parting.	0.1	
	(a) conglomerate - 20% matrix of calcareous grainstone surrounded and pushed into green argillaceous mud; top and bottom calcite spar; 60% tabular (average 1x3 cm, largest 2x20 cm), 40% equant (average 2x2 cm, largest 10x10 cm), clasts, phosphate, small black chert clasts.	0.7	
8.32	PARTED LIMESTONE AND SHALE - parted mudstone at base in disk-shaped nodules, overlain by 0.3 m of dark grey to black shale.	0.5	143.7
8.31	CONGLOMERATE - matrix 20%, calcite spar at base and top, argillaceous grainstone in center; clasts 70% tabular (average 1x5 cm up to 2x20 cm), 30% equant (average 2x2 cm).	1.0	143.2

Unit	Description	Thickness (m) Unit	Total from base
8.30	SHALE AND LIMESTONE - black and green banded shale and nodular, disk-shaped lime mudstone nodules. Calcite beef developed on upper and lower surfaces, lenses of conglomerate.	1.6	142.2
	<u>Graptolites</u>: **Dictyonema** sp. **Adelograptus** sp. **Bryograptus** sp. **Temnograptus** sp. **Clonograptus** sp. **Tetragraptus** cf. **bulmani** **T. decepiens** (BE) fragments resembling **Kaeierograptus**		
8.29	CONGLOMERATE - 40% matrix, calcareous grainstone with phosphate grains; 60% tabular clasts (average 1x5 cm), 40% equant clasts (average 3x3 cm).	0.4	140.6
8.28	RIBBON LIME MUDSTONE - calcareous green shale between; graptolites on partings.	0.2	140.2
	<u>Graptolites</u>: **Bryograptus** sp. **Clonograptus** sp. **Temnograptus** sp. **Tetragraptus decepiens** (BE)		
8.27	CONGLOMERATE - 10% matrix, crystalline calcite; clasts, 70% equant (average 2x2 cm, up to 15x15 cm), 30% tabular (average 2x5 cm, up to 1x10 cm).	1.2	140.0
	<u>Trilobites</u>: (K&W, 1958, p. 324) **Symphysurina** sp. **Stenopilus** sp. **Hystricurus** sp. **Pseudagnostus** sp.		
8.26	SHALE - black sooty, abundant graptolite fragments.	0.2	138.8
	<u>Graptolites</u>: **Bryograptus** sp. **Clonograptus** sp. **Temnograptus** sp. **Tetragraptus decepiens** (BE)		
8.25	CONGLOMERATE - 2 layers.	1.0	138.6
	(b) 20% grainstone matrix, clasts, tabular (average 1x5 cm)=equant (average 2x2 cm), largest 1x15 cm.	0.8	
	(a) matrix at base grainstone; calcareous to medium-grained.	0.2	
8.24	PARTED TO RIBBON MUDSTONE TO GRAINSTONE - the mudstone is burrowed to nodular, the grainstone contains tabular clasts up to 0.2 m in size.	1.0	137.6
	<u>Graptolites</u>: Indeterminate but siculate fragments.		
8.23	CONGLOMERATE - 20% matrix, calcareous top medium-grained grainstone, quartzose, phosphate; clasts subequant (average 2x3 cm, largest 15x30 cm).	0.9	136.6
8.22	RIBBON GRAINSTONE - beds 2 to 3 cm thick, calcareous green rounded clasts, quartzose, phosphate grains, separated by bright green shale partings.	0.4	135.7
8.21	PARTED LIMESTONE - to occasionally ribbon limestone, average 1 cm thick separated by green shale, hummocky to slightly nodular (hardground?). Good paired and single vertical burrows up to 2 cm long. Rare conglomerate lenses.	1.7	135.3
8.20	INTERBEDDED CONGLOMERATE AND RIBBON LIMESTONE -	0.8	133.6
	(b) ribbon limestone - 1 to 10 cm thick, grey calcareous shale interbeds. (a) conglomerate, average 0.1 m thick, equant to tabular clasts, average 1x5 cm, grainstone and phosphate pebbles.		
8.19	CONGLOMERATE - 2 layers.	9.1	132.8
	(b) small clasts as (1) but 30% grainstone matrix, no large clasts, phosphate grains in matrix.	3.5	
	(a) dark grey, 5% dark green argillaceous matrix, 70% equant, 30% tabular clasts, bimodal (1) 2-4 cm fine grainstone, mudstone, (2) 0.5-1 m calcified algae, oolite, spar-filled mudstone with green infill.	5.6	

Unit	Description	Thickness (m) Unit	Total from base
8.18	SHALE - bright green as 8.15.	0.2	123.7
	<u>Graptolites</u>: Indeterminate, but siculate, fragments.		
8.17	CONGLOMERATE - 10% fine grainstone matrix, 70% tabular clasts, 30% equant; trimodal size distribution, (1) 1x2 cm, (2) 2x10 cm, (3) up to 2 m (10%) both rounded and angular. (Clasts: mudstone, grainstone, siltstone, calcified algae, laminated chert.)	5.2	123.5
8.16	GRAINSTONE - thin-bedded, pinkish cast to grey colour, coarse to medium-grained.	0.4	118.3
8.15	SHALE - distinctive, bright green that is squeezed out along strike; also thickened and forced down into top of 8.14.	0.1	117.9
8.14	CONGLOMERATE - massive, similar to 8.13 but more large clasts, e.g. some 4x10 m, 5x12 m, generally rich in calcified algae, and 20% blocks 1 to 2 m in size. Becomes more chaotic towards top with larger boulders more common and comprising 1/2 of bed. Clasts with chert common.	7.7	117.8
8.13	CONGLOMERATE - massive, 5% matrix of green argillaceous mudstone, tabular (average 2x5 cm)=equant (average 2x3 cm) clasts and occasional large floating blocks up to 1 m across. Clasts of mudstone and grainstone often quartzose, calcified algae.	6.0	110.1
	Move to Point of Head and resume section.		
8.12	PARTED MUDSTONE - with grey calcareous shale partings, laminated, layers 1 cm.	2.0	104.1
	<u>Trilobites</u>: 0.5 m from top (RL) **Borthaspidella** sp. **Leiobienvillia laevigata** **Bienvillia** cf. **terranovica** agnostids		
	<u>Graptolites</u>: A small radial form either **Radiograptus** sp. (not **R. rosieranus**) or **Dictyonema** sp.		
8.11	CONGLOMERATE - massive, 10% grainstone matrix, medium-coarse grained, 1/3 equant (average 20x20 cm) clasts up to 1 m composed of grainstone, mudstone, siltstone, quartzose grainstone, calcified algae. Bright green argillaceous ribbon limestone at top.	3.8	102.1
	<u>Trilobites</u>: (K&W, 1958, p. 324, 8.11 to 8.14) **Theodenisia** sp. **Plethometopus** sp. **?Stenopilus** sp. **?Symphysurina** sp. **Rasettia** sp.		
8.10	GRAINSTONE - 1/3 floating clasts, mainly tabular, largest 1x15 cm, average 3x3 cm, scattered quartz.	0.3	98.3
8.9	PARTED MUDSTONE - finely laminated, dark grey shale, occasionally nodular, lenses of grainstone.	0.2	98.0
8.8	GRAINSTONE - medium-grained quartzose, 10% floating clasts.	0.2	97.8
8.7	GRADED LIMESTONE -	1.5	97.6
	(c) ribbon mudstone, dark grey calcareous shale, occasionally nodular.	0.1	
	(b) grainstone, thin-bedded, fine shale partings, slightly nodular, poor cross-laminations, occasional clasts.	0.3	
	(a) conglomerate, 10% matrix of coarse quartzose grainstone, 80% tabular mudstone and grainstone clasts (average 2x5 cm), largest 0.15x2 m.	1.1	
8.6	PARTED MUDSTONE - recessive, finely laminated lenses of conglomerate with 70% clasts, quartzose grainstone matrix.	0.3	96.1
8.5	INTERBEDDED CONGLOMERATE AND GRAINSTONE - 5% blocks white limestone, up to 2 m, clasts of clasts up to 1 m.	3.7	95.8
	(f) conglomerate, 80% clasts, grainstone matrix.	0.4	
	(e) conglomerate, argillaceous matrix, large clasts, occasionally chert, clasts of clasts.	0.7	

Unit	Description	Thickness (m) Unit	Total from base
	(d) conglomerate, clasts in medium grainstone.	0.5	
	(c) grainstone, same as (a).	0.4	
	(b) conglomerate, tabular clasts in grainstone (clasts average 2x15 cm).	1.1	
	(a) grainstone, thin-bed, cross-laminated, floating mudstone clasts.	0.6	
8.4	PARTED MUDSTONE - thin-bedded, irregular to hummocky bedded, occasional fine-laminated green argillaceous limestone partings - conglomerate lens (60% tabular clasts, grainstone matrix), upper 0.5 m grainstone layers, conglomerate lens, and dark grey shale, top layer dark grey shale.	1.3	92.1
	Graptolites: **Callograptus** sp. **Dendrograptus** sp. **Dictyonema** sp. (not siculate)		
8.3	GRAINSTONE - medium grained, thin-bedded, looks like sand waves.	0-0.5	90.8
8.2	DOLOMITE - buff to green-weathering, laminated to rippled, lenses of grainstone and conglomerate in center.	3.6	90.3
	Graptolites: **Callograptus** sp. **Dendrograptus** sp. **Dictyonema** sp. (not siculate) ?**Dictyonema** sp. (a radially preserved non-siculate form)		
8.1	GRAINSTONE - coarse-grained, beds 2 cm thick, laminated, peloids and calcified algal fragments.	1.0	86.7
7.6	CONGLOMERATE - massive, 60% tabular (average 1x5 cm), and 40% equant (average 2x2 cm) clasts, 10% large clasts (0.1-2 m) mostly at base; matrix grainstone at base (0.5 m), green mudstone in middle, top 1.0 m grainstone again. This could be several welded beds. The top 1.6 m grades laterally into well-bedded ribbon limestone, conglomerate and upper bed is grainstone.	5.1	85.7
7.5	RIBBON LIMESTONE - green dolomitic siltstone, varies greatly along strike.	0.1-0.6	80.6
7.4	CONGLOMERATE - massive, tabular (average 1x10 cm)=equant (average 3x3 cm) clasts, maximum size 0.4 m; green-grey fine grained calcareous matrix, never more than 10%, often difficult to find.	4.1	80.0
7.3	CONGLOMERATE - massive, tabular (2x15 cm) clasts=equant (3x3 cm) clasts; 10% large clasts of white limestone (average 0.5 m); matrix green, dolomitic argillaceous. This bed cuts down through 7.2 and 7.1 for maximum thickness of 3.0 m.	1.0	75.9
7.2	GRAINSTONE AND GREEN-GREY CALCAREOUS SILTSTONE - often cut out along strike.	0.4	74.9
7.1	CONGLOMERATE - massive, cuts down 4 m into underlying beds, graded, 80% large clasts at base, 20% at top; 2/3 tabular (average 2x10 cm), 1/3 equant (average 2x2 cm) clasts; argillaceous quartzose grainstone matrix; 1/3 huge white limestone clasts (average 4 m, range 1-11 m across).	5.0	74.5
	Trilobites: (basal boulders - RAF) (1) **Stenopilus** sp. **Saukia** sp. **Taenicephalus** sp. (2) **Saukia** sp. **Plethometopus** sp. **Stenopilus** sp.		
	Tuckers Cove Member		
6.48	PARTED TO RIBBON LIMESTONE - as bed 6.37.	1.0	69.5
6.47	PARTED LIMESTONE, FINE-GRAINED PELOIDAL GRAINSTONE - paper-thin partings of green shale to dolomitic siltstone, occasional lenses of grainstone and fine-grained peloidal grainstone.	1.4	68.5
	Graptolites: **Dictyonema** sp. (non-siculate) **Callograptus** sp.		
	Trilobites: (RL) **Parabolinella** aff. **argentina** (Kayser) **Idiomesus** sp. **Pseudosalteria howelli** (Raymond) ?**Aposolenopleura** sp. **Logananostus innocens** (Clark)		

Unit	Description	Thickness (m) Unit	Total from base
6.46	CONGLOMERATE - tabular clasts in a quartzose grainstone matrix.	0.2	67.1
6.45	RIBBON AND PARTED LIMESTONE - as 6.37 (identical)	1.2	66.9
6.44	CONGLOMERATE AND QUARTZOSE GRAINSTONE-	1.4	65.7
	(c) conglomerate, 1/3 tabular clasts.	0.6	
	(b) grainstone, cross-laminated.	0.4	
	(a) conglomerate, 1/3 tabular clasts.	0.4	
6.43	RIBBON TO PARTED LIMESTONE - as bed 6.37 with 50% lenses of quartzose grainstone and conglomerate.	0.5	64.3
6.42	CONGLOMERATE - basal portion contains 40% tabular (average 1x5 cm) clasts in a grainstone matrix while upper 1/2 is a very quartzose grainstone. In upper 0.5 m 20% large (0.5m) white limestone clasts.	1.0	63.8
6.41	SILTSTONE - thinly bedded with lenses of quartzose grainstone and lime mudstone.	0.1	62.8
6.40	CONGLOMERATE - tabular (average 1x3 cm) and equant (average 2x2 cm) clasts in quartzose grainstone matrix which increases from 30% at base to pure grainstone in top 0.4 m as a cap. Scattered large 0.5 m diameter boulders at top.	1.3	62.7
6.39	SHALE - silty, green.	0.1	61.4
6.38	CONGLOMERATE - tabular (average 1x10 cm) and equant (average 2x2 cm) clasts and a grainstone matrix with quartz, 20% at base, decreasing to 10% upwards. Several interbeds.	2.6	61.3
	(c) intermittent green shale.	2.0	
	(b) parted and ribbon limestone.	0.2	
	(a) green shale matrix.	0.4	
6.37	RIBBON TO PARTED LIME MUDSTONE - separated by green-grey laminated calcareous shale and siltstone, nodular in places.	1.0	58.7
6.36	CONGLOMERATE - 20% clasts in a grainstone matrix containing 20% quartz, scattered large 1x1 m boulders.	1.1	57.7
6.35	CONGLOMERATE - graded.	0.8	56.6
	(c) siltstone swirled and laminated.	0.1	
	(b) grainstone quartzose, cross-laminated and floating clasts.	0.3	
	(a) conglomerate tabular clasts, average 1x10 cm in 40% grainstone matrix.	0.4	
6.34	PARTED MUDSTONE - in layers 1 cm thick separated by green, banded calcareous shale.	0.8	55.8
	Graptolites: **Dendrograptus** sp. **Dictyonema** sp. (a radially preserved non-siculate form)		
6.33	THINLY INTERLAMINATED DOLOMITE AND SHALE - as 6.31.	0.5	55.0
	Graptolites: **Dendrograptus** sp.		
6.32	MASSIVE CLIFF-FORMING CONGLOMERATE - composed of 3 welded units.	7.8	54.5
	(c) conglomerate, mostly tabular clasts, 1 x 10 cm coarse quartzose matrix, lenticular.	3.5	
	(b) grainstone, coarse, quartzose, 20% tabular clasts.	0.5	
	(a) conglomerate, coarse quartzose grainstone matrix, huge 4x4 m clasts of calcified algae, numerous smaller 1x10 cm tabular clasts, cuts down into lower bed 1.1 m.	3.8	
	Trilobites: (RAF) **Rasettia magnum** **Saukia** sp. Catillicephalid (probably **Stenopilus** sp.)		
	Graptolites: **Dendrograptus** sp.		
6.31	DOLOMITE AND SHALE - thinly and intricately interlaminated dolomite - buff-weathering, cross-laminated, rippled and shale, green; gradational contacts, beds 1 mm to 1 cm thick.	1.9	46.7
	Graptolites: **Dictyonema** (a non-siculate radially preserved form)		

Unit	Description	Thickness (m) Unit	Total from base
6.30	CONGLOMERATE - tabular clasts (70%) of mudstone, grainstone and quartzose grainstone in a quartzose grainstone matrix - numerous partings of green shale.	0.6	44.8
6.29	CONGLOMERATE - thin layers with quartzose grainstone matrix and green shale partings.	0.2	44.2
6.28	SHALE - bright green, non-calcareous, non-dolomitic with stringers of lime mudstone.	0.2	44.0
	Graptolites: **Dendrograptus** sp. **Dictyonema** sp. (non-siculate) D. sp. (a radially preserved non-siculate form)		
6.27	CONGLOMERATE - grainstone and quartzose grainstone matrix and tabular lime mudstone clasts (60%), average 1x5 cm - the bed increases in thickness to 2.8 m along strike by downcutting.	1.5	43.8
6.26	DOLOMITE - buff-weathering dark green laminated, siltstone stringers.	1.3	42.3
6.25	CONGLOMERATE - with quartzose siltstone matrix and tabular clasts.	0.4	41.0
6.24	PARTED LIME MUDSTONE.	0.1	40.6
6.23	CONGLOMERATE - same as 6.21, with a 0.4 m sandstone cap - this bed laps up around a 6x6 m clast of calcified algal limestone in bed 6.21.	1.0	40.5
	Trilobites: (RL) **Keithiella** sp. **Pseudosaukia** sp. **Plethometopus** sp. **Buttsia** sp. **Rasettia** sp. **Loganellus** sp. **Menocephalus** sp.		
6.22	PARTED LIME MUDSTONE - 1 cm green dolomite shale partings.	0.4	39.5
6.21	CONGLOMERATE - compound.	2.6	39.1
	(b) upper 1.2 m, conglomerate, 50% quartzose sandstone matrix and cap which is cross-bedded.		
	Trilobites: (RL) **Rasettia** sp. **Keithiella** sp.		
	(a) basal 1.4 m, tabular clast conglomerate (average 2x5 cm - mudstone) with quartzose grainstone matrix and cap-base downcuts 1 m, interbedded lenticular conglomerates and cross-laminated to laminated grainstones.		
6.20	SILTSTONE - dolomitic, laminated and cross-laminated, 30% shale.	2.1	36.5
6.19	CONGLOMERATE - 50% tabular clasts (average 1x10 cm) and 50% quartzose grainstone - a series of 4 separate but fused beds each with conglomerate at base, grading up to grainstone and capped by a dolomitic siltstone.	3.6	34.4
6.18	PARTED MUDSTONE - in beds 1 cm thick, green shale.	0.8	30.8
6.17	GRAINSTONE - fine to medium-grained quartzose.	0.3	30.0
	Trilobites: (K & W, 1959, p. 9) **Keithiella** sp. **Loganellus** sp. **Loganopeltoides** sp. **Theodenisia** sp.		
6.16	BLACK SHALE AND SILTY DOLOMITE - interlaminated in beds 5-20 cm thick, rippled - at 3.5 m is a lens of quartzose grainstone that varies from 0.1 to 0.6 cm over 15 m.	4.2	29.7
6.15	RIBBON QUARTZOSE GRAINSTONE AND BLACK SHALE - cross-laminated, occasional layers of lime mudstone and lenses of conglomerate.	0.5	25.5
6.14	DOLOMITE - cross-laminated and shale and a 0.1 m thick conglomerate lens with a quartzose matrix.	0.5	25.0
6.13	GRAINSTONE - coarse-grained quartzose, occasional conglomerate lenses - appears to be several fused grainstone and conglomerate beds.	2.0	24.5
6.12	SHALE - black, sooty, dolomitic; siltstone, dolomitic, brown-weathering interlaminated in beds averaging 1 cm thick, rippled, cross-laminated.	0.4	22.5
6.11	CONGLOMERATE AND GRAINSTONE - 40% clasts of lime mudstone (average 1x5 cm), 60% coarse-grained quartzose grainstone; grainstone cap.	0.9	22.1
	Trilobites: (RL) (6.11-6.15) **Richardsonella** sp. **Levisella** sp. **Loganellus** sp. **Loganopeltoides** sp. **Keithiella** sp. **Pseudagnostus** sp. **Bienvillia** sp.		
6.10	GRAINSTONE - fine-grained massive, uniform.	1.0	21.2
6.9	SHALE - black sooty, very calcareous, thin-bedded to fissile.	0.5	20.2
6.8	GRAINSTONE - fine-grained, massive.	0.4	19.7
6.7	GRADED LIMESTONE -	0.6	19.3
	(c) dark grey argillaceous.	0.1	
	(b) fine grainstone, laminated.	0.2	
	(a) coarse grainstone, quartzose.	0.3	
6.6	SHALE - black, sooty, very calcareous, thin-bedded to fissile.	0.6	18.7
6.5	GRAINSTONE - fine-grained, laminated to cross-laminated rippled, 20% black shale partings, nodular.	2.9	18.1
6.4	SHALE - black, sooty, very calcareous, thin-bedded to fissile.	0.8	15.2
6.3	CONGLOMERATE AND PARTED LIMESTONE - interbedded in units 0.4 to 0.8 m thick.	3.1	14.4
	(c) conglomerate with quartzose grainstone matrix and tabular clasts 1x5 cm. (b) parted grainstone, laminated. (a) parted lime mudstone, 1 cm, green calcareous shale partings.		
	Trilobites: (K, 1982, p. 9) (RL) **Parabolinoides** sp. **Loganellus** sp. **Orygmaspis** sp.		
6.2	GRAINSTONE - coarse, quartzose, thin-bedded, cross-bedded, rippled, with 10% carbonate mudstone clasts.	2.3	11.3
6.1	CONGLOMERATE - similar to beds below but with a grainstone cap containing occasional quartz and pyrite grains.	1.0	9.0
	Downes Point Member		
5.6	CONGLOMERATE - with green-grey dolomite matrix, composed of several welded units with some grainstone partings. Conglomerates characterized by many chip clasts, like strata below fault, occasional large rafted clasts up to 2 m.	8.0	8.0
	Trilobites: (K&W, 1958, p. 322, 2 boulders) (1) **Taenicephalus** sp. **Parabolinella** sp. **Pseudagnostus** cf. **gyps.** (2) **Onchonotus** sp. **?Aposolenopleura** sp. **Talbotina levisensis** **Loganopeltoides** sp. **Pseudagnostus** cf. gyps.		
	(K&W, 1959, p. 9 - 4 boulders) **Glyptagnostus reticulatus** **Proaulacopleura** sp. **Cheilocephalus** sp. **Dunderbergia** sp. **Dytremacephalus** sp. **Blountia** sp. **Aphelaspis** sp.		

Unit	Description	Thickness (m) Unit	Total from base
	(K, 1982 - 3 boulders) **Aphelaspis** sp. **Dytremacephalus** sp. **Dunderbergia** sp. ?**Onchopeltis** sp. **Pseudagnostus communis** **Agnostus inexpectans** **Agnostus** cf. **pisiformis** **Homagnostus** cf. **obesus** **Tholifrons** sp.		
	Bathyholcus sp. **Cheilocephalus** sp. **Pterocephalops** sp. **Quebecaspis** sp. ?**Bellaspis** sp. **Acmarhachis** sp. Section begins along shoreline nor:Lwest of lighthouse and continues southwest along shoreline, around Point of Head and on to Factory Cove.		

COW HEAD PENINSULA - SOUTHERN SHORE

Faulting along the south shore has resulted in three short sections at Back Cove, Shoal Cove and Jims Cove which expose the upper part (Lower to Middle Ordovician) of the section.

A fault north of the Cow Head village has cut out the lower part of the section to the east so that the discontinuous section around the wharves and fish plant at Tuckers Cove is equivalent to Beds 6 through 8 exposed at Point of Head.

COW HEAD SOUTH - BACK COVE

49°55'N x 57°48.8'W

Unit	Description	Thickness (m) Unit	Total from base
	SHALLOW BAY FORMATION **Factory Cove Member** Disturbed zone in middle around Bed 10.		
9.7	CONGLOMERATE - at low tide partly covered with seaweed and periwinkles; a swirled conglomerate with a green calcareous matrix, clasts, 60% tabular (average 2x15 cm), 40% equant (average 10x10 cm), patchy brown-weathering chert top that extends down into matrix.	1.9	31.5
9.6	PARTED GRAINSTONE TO MUDSTONE - layers 5-10 cm thick separated by grey-black shale, beds pinch and swell along strike, laminated to cross-laminated and rippled; conglomerate lens 0.2 m thick and 4.0 m long, granule size clasts in grainstone matrix, occasional phosphate clasts and chert.	4.8	29.6
	Graptolites: **Desmograptus** sp. **Clonograptus**? sp. **Tetragraptus acclinans** **T. approximatus** **T. fruticosus**, 4-stiped **T.** sp. **Pseudophyllograptus** cf. **densus** (RAF) ?**Phyllograptus** sp.		
9.5	CONGLOMERATE - similar to 9.1 with occasional large clasts up to 3 m across and of very variable composition including clasts of conglomerate, large boulders in lower 1/2 only, dolomite argillaceous matrix at base, spar in middle and top, clasts trimodal: (1) 50% large, average 0.5 m and equant. (2) 30% tabular, average 1x15 cm, mudstone. (3) 20% small and equant, average 1 cm.	6.1	24.8
	Trilobites: (K&W, 1958, p. 324) (RAF) **Trinodus** sp. cf. **Protopresbynileus** **Petigurus** sp. **Ampyx** sp. asaphid remopleuridid n. gen. illaenids (2 species) aff. **Goniophrys** cf. **Glaphurina** ?**Selenoharpes** pliomerid **Keithiella** **Rasettia** **Leptopilus** cf. **Onchonotus** **Petiguris nero** **Benthamaspis gibberulla** large asaphid		
9.4	RIBBON LIME MUDSTONE - layers average 2 cm thick alternating with green black shale. evenly bedded; conglomerate lenses 0-10 cm thick and 10 m long or 0-40 cm thick and 30 m long.	3.1	18.7
	Graptolites: Dendroid fragments **Tetragraptus approximatus**		
9.3	CONGLOMERATE - variable along strike from 10 cm to 2 m, flat top, green argillaceous dolomite matrix at base, spar at top; 70% tabular clasts (average 2x10 cm, largest 10cm x 1 m), 30% equant clasts (average 3x3 cm, largest 20x20 cm); graded with largest at base.	0.5	15.6
9.2	RIBBON TO PARTED MUDSTONE - layers 1-2 cm thick, finely laminated mudstone, black at base.	5.0	15.1
	Graptolites: **Tetragraptus fruticosus** **T. approximatus**		
9.1	CONGLOMERATE - faulted in outcrop and extends into grass-covered hill; 10% matrix of green-grey dolomitic siltstone; clasts trimodal. (1) 50% large clasts, 1.5 m average equant some rounded, variable composition. (2) 30% medium-sized, mostly tabular mudstone-grainstone, average 2x15 cm. (3) small tabular clasts and spar cement forming cap in upper 0.4 m.	10.1	10.1
	Trilobites from clasts: (RAF) 3 boulders Upper Cambrian fauna, 3 boulders Arenig (St. George Group) age, 1 boulder composed almost entirely of agnostids, plus a Selenoharpid, Benthamaspis cf. conica, and an Isocoelid.		

COW HEAD SOUTH - SHOAL COVE
49°54.9'N x 57°49.0'W

Unit	Description	Thickness (m) Unit	Total from base
	SHALLOW BAY FORMATION		
	Factory Cove Member		
	COVE WITH DISTURBED STRUCTURE		
11.4	RIBBON LIMESTONE - layers mostly altered to black vitreous chert, 2 cm thick, alternating with black shale.	2.2	37.1
	<u>Graptolites</u>: **Goniograptus thureaui** **Tetragraptus fruticosus**, 3-stiped **T. pendens**, 3-stiped **T. reclinatus** **Phyllograptus typus** ?**Phyllograptus** sp.		
11.3	GRAINSTONE - calcareous, phosphate with abundant black and brown-weathering chert (50%) replacing limestone.	1.0	34.9
11.2	DOLOMITE - buff-weathering, laminated to cross-laminated, flattened burrows, abundant sponge spicules.	1.3	33.9
	<u>Graptolites</u>: **Phyllograptus typus** (prolific) **Tetragraptus fruticosus** 4-stiped		
11.1	SHALES - green, black, and red-weathering, siliceous and cherty, phosphate conglomerate layers.	2.0	32.6
	<u>Graptolites</u>: **Tetragraptus fruticosus**, 4-stiped **Phyllograptus typus** ?P. sp.		
10.1	CONGLOMERATE - massive, complex unit with a chert top, clasts up to 4.0 m across.	11.8	30.6
	<u>Trilobites</u>: (RAF) **Punka** sp. **Uromystrom** sp. **Gog** sp. nov.		
9.12	RIBBON LIMESTONE AND CONGLOMERATE -	10.8	18.8
	(i) one thin discontinuous bed of ribbon limestone, maximum 20 cm thick that is all but scoured away by overlying bed.	0.2	
	(h) conglomerate, 10% grey-green dolomite matrix, 70% tabular clasts (average 1x10 cm, largest 2x25 cm), 30% equant clasts (average 5x5 cm, largest 50x50 cm), one large 6 m clast of ribbon limestone.	1.8	
	(g) ribbon limestone as (e) on thin conglomerate lens. <u>Graptolites</u>: **Desmograptus** sp. **Tetragraptus fruticosus**, 4-stiped **T. approximatus**	2.5	
	(f) conglomerate, 2 layers separated by 0.1 m thick ribbon limestone, granule-size clasts.	0.7	
	(e) ribbon limestone, 2 cm thick layers alternate with black shale, common spicules.	0.5	
	(d) conglomerate, granule-size clasts, limestone and phosphate.	0.2	
	(c) ribbon grainstone, 5-10 cm layers alternating with dark grey shale, cross-laminated and hummocky along strike, black ropy and nodular chert. <u>Graptolites</u>: **Desmograptus** sp. **Tetragraptus acclinans** **T. approximatus** **T. fruticosus**, 4-stiped T. ssp.	3.8	
	(b) conglomerate, 1/3 granule matrix, inclined clasts, tabular average 1x5 cm, equant average 3x3 cm.	0.5	
	(a) ribbon grainstone and black shale.	0.6	
9.11	CONGLOMERATE - almost identical to 9.5 (Back Cove) and containing the welded granule-size conglomerate on top.	5.0	8.0
	<u>Trilobites</u>: from 7 clasts are Arenig in age and typical of the Catoche Limestone, St. George Group. (RAF)		
9.10	PARTED TO RIBBON MUDSTONE - laminated, layers 1-2 cm thick, paired vertical burrows, occasional spicules.	3.0	3.0
	Section begins at covered interval.		

COW HEAD SOUTH - JIMS COVE
49°54.8'N x 57°49.4'W

Unit	Description	Thickness (m) Unit	Total from base
	SHALLOW BAY FORMATION		
	Factory Cove Member		
14.0	CONGLOMERATE - massive, chaotic, with a green argillaceous matrix and many tabular clasts, a chert top.	12.0	92.3
	<u>Fauna in clasts</u>: <u>Brachiopods</u>: (RJR) **Petroria** sp. **Orthambonites**? sp. **Orthidiella** sp. <u>Trilobites</u>: (RAF) boulders indicate 3 fauna typical of: 1. Lower Head Boulder Fauna (Whittington, 1963) 2. Upper Cassinian (Gog) Fauna (Fortey, 1975) 3. Valhallan Fauna (Fortey, 1975; 1980)		
13.9	SHALE - green slightly calcareous, occasionally thin lime mudstone nodules.	2.0	80.3
13.8	CONGLOMERATE - poor exposure at low tide, green argillaceous dolomitic matrix with floating clasts, equant up to 20x20 cm = tabular up to 2x10 cm.	1.0	78.3
13.6/7	SHALE - green burrowed, grades up into green and black; black and silty at top, progressively more chert towards top in bands 2 cm thick, contact faulted.	4.1	77.3
	<u>Graptolites</u>: **Tetragraptus rigidus** **Didymograptus v-deflexus** **Xiphograptus formosus svalbardensis** **Isograptus victoriae maximodivergens** **Pseudotrigonograptus** sp.		
13.5	CONGLOMERATE - graded, large tabular clasts at base (average 2x10 cm, largest 4x40 cm) granule-size clasts in center, grainstone at top; phosphate pebbles; microcrystalline calcite matrix.	1.1	73.2
13.4	PARTED LIMESTONE - layers 10 cm thick separated by black shale partings, limestones in the middle are mudstone, at the top are grainstone, beds in lower part are capped by brown weathering chert.	9.4	72.1
13.3	PARTED MUDSTONE.	1.0	62.7
13.2	GRAINSTONE - peloid/intraclast with bright green chert grains, occasionally cross-laminated, brown chert nodules.	0.9	61.7
13.1	RIBBON LIMESTONE - layers 5-10 cm thick of mudstone or spiculitic, fine-grained, cross-laminated peloid grainstone, separated by siliceous black shale.	2.8	60.8
	<u>Graptolites</u>: 1 m above base **Pseudophyllograptus** cf. **angustifolius** **Isograptus victoriae victoriae** **Pseudotrigonograptus** sp. <u>Note</u>: A repetition of 13.1 occurs with a faulted upper contact in the small cove east of this locality. It yields Isograptus victoriae lunatus		
12.0	CONGLOMERATE - complex, conglomerate typical of bed 12, a 1 m thick grainstone cap which is silicified.	3.6-5.1	58.0

Unit	Description	Thickness (m) Unit	Total from base
	Fauna in clasts: (RAF) Trilobites: **Symphysurina** **Petigurus** **Oopsites** cf. **hibernicus** **Gog catilus** **Illaenus** sp.		
11.30	RIBBON LIMESTONE - layers of mudstone and grainstone 10-15 cm thick separated by dark grey shale, in the shale are 2-5 cm thick siltstone layers with phosphatic brachiopods, grainstone layers are cross-laminated with phosphate clasts.	1.0	52.9
	Graptolites: **Tetragraptus quadribrachiatus** **Phyllograptus** sp. **Isograptus primulus** **Didymograptus** cf. **hemicycalatus** **Tetragraptus serra** **Tetragraptus taraxacum** **Sigmagraptus** sp. **Dichograptus** sp. (slender) **Didymograptus** sp. (extensiform) **Didymograptus bifidus** s.l. **Dichograptus octobrachiatus** **Dichograptus maccoyi** **Dichograptus maccoyi** cf. var. **solidus** (RAF) **Acrograptus** sp. (?**ellisi**)		
11.29	CONGLOMERATE - 20% grainstone matrix with conspicuous phosphate clasts, 80% tabular grainstone clasts, average 2x10 cm up to 3x20 cm.	0.4	51.9
11.28	RIBBON MUDSTONE - layers 1 cm thick separated by brown to black shale of equal thickness.	0.7	51.5
11.27	CONGLOMERATE - 1/3 grainstone matrix, 90% of clasts tabular, average 2x15 cm, largest 4x35 cm.	0.9	50.8
11.26	RIBBON MUDSTONE - layers 4-10 cm thick separated by dark grey to black shale, occasionally nodular, rare burrows.	3.5	49.9
11.25	SHALE - green, burrowed.	0.7	46.4
11.24	PARTED MUDSTONE - layers 1-2 cm thick with green argillaceous partings, well-bedded, occasional nodules with grainstone centers.	1.1	45.7
11.23	SHALE - green and black banded, slightly dolomitic, one thin conglomerate lens 3 cm thick with phosphate clasts.	0.4	44.6
11.22	RIBBON LIMESTONE - evenly bedded in layers 1 cm or less in thickness, separated by argillaceous mudstone and green shale, minor conglomerate.	0.3	44.2
11.21	PARTED LIMESTONE - evenly bedded in layers 2 cm thick, prolific paired burrows.	2.9	43.9
	Graptolites: at top **Didymograptus** sp. (extensiform fragments)		
11.20	CONGLOMERATE - 10% dolomitic matrix, mostly tabular clasts, swirled fabric.	0.4	41.0
11.19	SHALE - dark grey to green.	1.8	40.6
	Graptolites: ?**Phyllograptus** sp. **Didymograptus extensus**		
11.18	CONGLOMERATE - green mudstone matrix, tabular clasts.	0.2	38.8
11.17	PARTED LIME MUDSTONE - thin-bedded average 1 cm thick.	2.0	38.6
	Graptolites: **Didymograptus bifidus** s.l.		
11.16	DOLOMITE - buff-weathering, flattened burrows, identical to bed 11.7 at Point of Head.	0.4	36.6
11.15	PARTED GRAINSTONE - dolomitic, with grey shale.	4.0	36.2
	Graptolites: 1 m above base **Tetragraptus serra** **T. fruticosus**, 3-stiped **Didymograptus bifidus** s.l. **D.** cf. **ensjoenis** 3 m above base **D. bifidus** a.l.		

Unit	Description	Thickness (m) Unit	Total from base
11.14	CONGLOMERATE - a lens that disappears along [illegible] 30% grainstone matrix, clasts up to 10 cm x 40 cm, most less than 5 cm, occasional equant clasts.	0.4	32.2
11.13	SHALE AND DOLOMITE -	5.0	31.8
	(b) cycles 0.4 to 0.8m thick of a green-black shale base grading up to a buff-weathering siliceous dolomite, occasional spicules.	4.0	
	Graptolites: **Dichograptus** sp. (a small slender form) **Tetragraptus fruticosus**, 3-stiped **T. serra** **T. quadribrachiatus** **Didymograptus ensjoensis** **D. deflexus** **D. pennatulus** **Phyllograptus typus**		
	(a) green shale.	1.0	
11.12	CHERT, SHALE AND DOLOMITE -	3.6	26.8
	(b) mostly chert which has replaced green shale, limestone with phosphate layers and dolomite.	2.0	
	Graptolites: **Didymograptus nitidus** **D.** ssp. (several extensiform types)		
	(a) buff-weathering dolomite, abundant chert and stringers of phosphate sand throughout, occasional limestone bands.	1.6	
11.11	SHALE - green-grey, phosphatic conglomerate layers, spiculite layers, some dolomite, chert.	1.1	23.2
	Graptolites: 10 cm above conglomerate **Phyllograptus typus** (RAF) **Phyllograptus angustifolius** (RAF) **Tetragraptus fruticosus**, 4-stiped		
10.0	CONGLOMERATE - silicified grainstone matrix, dark brown to black, many tabular clasts, largest 2x20 cm.	0.3	22.1
9.26	SHALE - green.	0.1	21.8
9.25	CONGLOMERATE - chaotic, calcareous grey-green matrix, tabular (average 2x5 cm, largest 2x20 cm)=equant (10x10 cm) clasts.	0.5	21.7
9.24	RIBBON LIME MUDSTONE/GRAINSTONE - layers 4-10 cm thick separated by green-grey shale; grainstone contains spicules.	3.5	21.2
	Graptolites: numerous dendroids including **Desmograptus** sp. **Tetragraptus approximatus** **T. acclinans**		
9.23	CONGLOMERATE - 10% dolomitic siltstone matrix equant (average 2x2 cm, largest 10x10 cm) = tabular (1x5 cm) clasts; grainstone matrix at top.	0.8	17.7
9.22	RIBBON LIME MUDSTONE - layers 1 cm thick, nodular, burrowed, green-grey shales between.	3.0	16.9
	Graptolites: **Tetragraptus approximatus** **Tetragraptus acclinans**		
9.21	CONGLOMERATE - 10% green dolomite matrix, wide variety of clasts, tabular (average 2x10 cm) =equant (average 2x2 cm), upper 20 cm has 20% grainstone matrix.	0.2-1.9	13.9
	Trilobites: (RAF) cf. **Presbynileus**		
9.20	CONGLOMERATE/RIBBON LIMESTONE - 2 lenses or wedge-shaped units, ca. 40 cm thick and 15 m in length with phosphate, sandstone and conglomerate, quartz grains.	1.0	12.0
	Graptolites: ?**Clonograptus** sp. **Tetragraptus** sp. (large) **Didymograptus** sp. (extensiform) ?**Phyllograptus** sp.		
9.19	RIBBON LIMESTONE - layers 2-10 cm thick and composite, with mudstone overlain by grainstone, large ripples length=10 cm, height=3 cm, separated by layers of grey gritty shale, sponges, chert.	2.7	11.0
	Graptolites: **Desmograptus** sp. **Tetragraptus acclinans** **T. approximatus** **T. fruticosus**, 4-stiped **T. pendens**, 4-stiped **Didymograptus** sp. (extensiform)		

Unit	Description	Thickness (m) Unit	Total from base
9.18	CONGLOMERATE - matrix of green calcareous and slightly dolomitic shale, tabular (average 2x15 cm) = equant (average 10x20 cm and 1x1 cm) clasts, a very swirled fabric, rare spicules in matrix, tabular clasts of mudstone and grainstone, a 3-4 cm thick grainstone plastered on top with phosphate clasts.	1.0	8.3
9.17	RIBBON TO PARTED LIMESTONE - identical to 9.10, at Shoal Cove, a conglomerate lens.	3.1-4.0	7.3
9.16	CONGLOMERATE - fine-grained grainstone matrix with calcite spar, 60% tabular and 40% equant clasts, bimodal size 2x10 cm and 1x2 cm.	0.6	3.3
9.15	CONGLOMERATE - 30% green argillaceous matrix, tabular (average 2x20 cm) = equant (average 3x3) clasts, very swirled fabric, tabular and flat clasts particularly conspicuous.	2.7	2.7

COW HEAD SOUTH - TUCKERS COVE
49°55.4'N x 57°48.7'W

Unit	Description	Thickness (m) Unit	Total from base
	SHALLOW BAY FORMATION		
	Stearing Island Member		
	Section ends at road		
8.10	CONGLOMERATE - a wide variety of clasts, 20% equant, 80% tabular (average 1x5cm), often rimmed with chert, very little matrix, base cuts down 2.6 m.	1.0-2.6	91.3
8.9	PARTED LIMESTONE - both mudstone and grainstone in beds 2-10 cm thick separated by argillaceous limestone, mudstone beds have numerous burrows.	4.6	88.7
8.8	CONGLOMERATE - predominantly tabular clasts which are often contorted (average 2x20 cm), a green-grey argillaceous matrix, swirled fabric.	2.7	84.1
8.7	COVER - with one thin 0.4 m bed of parted limestone at 3.0 m from base.	14.4	81.4
8.6	PARTED LIMESTONE AND CONGLOMERATE -	21.7	67.0
	(n) conglomerate.	0.4	
	(m) parted limestone.	6.0	
	(l) grainstone.	1.3	
	(k) parted limestone.	1.0	
	(j) grainstone, thick-bedded.	1.0	
	(h) parted limestone.	2.6	
	(g) conglomerate and parted limestone.	0.5	
	(f) parted limestone.	1.7	
	(e) conglomerate, grainstone matrix.	1.1	
	(d) parted limestone.	2.5	
	(c) conglomerate and parted limestone.	1.8	
	(b) conglomerate, grainstone matrix.	1.0	
	(a) parted limestone.	0.8	
8.5	CONGLOMERATE - a wide variety of clasts, 1/3 tabular (average 1x10 cm), 1/3 large (3x4 m) white limestone exotics, packstone matrix, erosive base.	7.0-14.5	45.3
8.4	RIBBON TO PARTED LIMESTONE - layers 1 to 2 cm thick, 1/2 green-grey argillaceous limestone interlayers, a thin conglomerate 0.2 m thick at 3.0 m.	12.2	30.8
8.3	CONGLOMERATE - a wide variety of clasts, 1/3 tabular (average 1x10 cm), 1/3 equant (average 3x3 cm), and 1/3 large (average 0.2 m) exotics up to 0.5 m, 30% matrix of quartzose grainstone, it cuts down through unit 6.2 and 6.1 and possibly lower.	2.0-10.3	18.6
8.2	PARTED LIMESTONE - calcarenite with 30% quartzose grainstone.	4.7	8.3
8.1	PARTED LIMESTONE - 1/3 cross-laminated fine-grained grainstone, 2/3 laminated silty lime mudstone, green-grey shale partings; at 2.8 m a 0.1 m thick bed of fine grained grainstone with floating quartz grains; at 3.6 m is a cro -laminated quartzose grainstone that grades laterally into conglomerate.	3.6	3.6
	Section begins at southeast side of Tuckers Cove amongst wharves.		

STEARING ISLAND

These low islands, which lie 1 km north of Cow Head Peninsula, are in the form of 2 concentric open crescents with an inner, northern string of small islets and, 200 m to the south, an outer arc of larger islands. At low tide intervening rock is exposed and they become two large arcuate islands. The strata in these islands differ from most other Cow Head exposures: although they span a considerable time period they are almost entirely conglomerate with few interbeds. Although the rocks which comprise the northern islets are younger than those to the south, all have the same dip and together may form a continuous section. Unit numbers correspond to Kindle and Whittington (1958) bed numbers on Cow Head Peninsula.

STEARING ISLAND
49°56.2'N x 57°50.0'W

Unit	Description	Thickness (m) Unit	Total from base
	SHALLOW BAY FORMATION		
	Factory Cove Member		
14	CONGLOMERATE -	25.1	145.0
	(a) large and varied clasts in a coarse granule to grainstone matrix, a 20 cm thick grainstone cap.	3.1	
	(b) chaotic conglomerate/breccia with massive and bedded limestone and dolomite clasts, large clasts 10 m in size common, some to 20 m, including large conglomerate clasts which resemble bed 12, green shale matrix.	22.0	
	Graptolites: in clasts **Isograptus victoriae maximus**		
	Trilobites: in clasts (RL) Valhallan fauna (Fortey, 1980)		
13.7	SHALE - olive green; 1/3 black laminations.	3.3	119.9
13.6	SHALE - with 1/4 thin (average 1 cm) lime mudstone layers.	1.3	116.6
13.5	SHALE - olive green and black, finely laminated.	0.6	115.3
	Graptolites: **Tetragraptus serra** **Isograptus victoriae victoriae**		
13.4	LIMESTONE - parted to ribbon in thin layers (average 1 cm) separated by grey shale.	1.2	114.7
13.3	SHALE - black, siliceous, 1/3 green spiculitic partings.	3.3	113.5
13.2	LIMESTONE - parted to ribbon in thin layers (average 1 cm) separated by grey shale.	1.3	110.2

Unit	Description	Thickness (m) Unit	Total from base
13.1	SHALE - hard, black, siliceous, to chert and three grainstone layers that are partly silicified.	1.5	108.9
	The upper part of the section is measured on the southeast part of the island on the other side of a major fault.		
12	CONGLOMERATE - a massive unit which forms most of the south shore of the islands: a megabreccia with a clearly erosive base, 2/3 of unit contains clasts greater than 0.5 m in size and at eastern end boulders are commonly 5-6 m, and occasionally up to 11 m across, a wide range of composition including pieces of underlying conglomerates, very little matrix composed of smaller clasts and green-grey argillaceous lime mudstone; at the thinnest point in center of island the basal 3 m is almost all tabular clasts, in other areas it is almost all equant, there is a sporadic thin chert cap.	12.0-31.0	107.4
	Fossils from clasts: Trilobites: (RAF) **Petigurus** sp. **Isoteloides** sp. **Catochia** sp. **Benthamaspis** sp. **Strotactinus** sp. One clast containing **Carolinites genacinaca, Oopsites hibernicus, Niobe ornata Sycophantia** sp. and nemopleurid.		
11	CONGLOMERATE AND RIBBON LIMESTONE - only visible in centre of islands, elsewhere has been eroded away by overlying conglomerate.	7.0	76.4
	(e) ribbon limestone, black shale.	4.0	
	(d) parted limestone, burrowed surface.	1.0	
	(c) conglomerate, tabular clasts, grainstone matrix.	0.6	
	(b) dolomite, buff-weathering.	0.4	
	(a) cover.	1.0	
	Graptolites: from (e) (RAF) **Tetragraptus fruticosus**		
10.5	CONGLOMERATE -	10.0	69.4
	(b) similar to 10.3.	8.0	
	(a) a conglomerate with a grainstone matrix, only small pebble clasts; above this in center of island, where bed 10 is thin, is another conglomerate (8a), very like unit 6, chert top.	2.0	
	Trilobites: (RAF) **Leiostegium** sp.		
10.4	CONGLOMERATE - a recessive cove; a granule to small pebble conglomerate with 1/5 large clasts; a very sparce grainstone matrix, sometimes as lenses; scattered large boulders at the top.	13.0	59.4
10.3	CONGLOMERATE - forms low, resistant cliff along the north side of island; a wide variety of clasts similar to unit 4, a welded unit with a conspicuous channel cut down into the lower unit and filled with many boulders larger than 2 m; almost no matrix.	5.2	46.4
10.2	CONGLOMERATE - a low, recessive area, covered by high tide; a granule to pebble-size conglomerate similar to unit 4, but only 1/5 are boulder-size clasts, like unit 4; a grainstone matrix.	7.0	41.2
10.1	CONGLOMERATE - a continuous mass that is probably three welded units and forms an irregular series of hillocks in the intertidal zone.	18.5	34.2
	(c) upper 1/3, very large boulders 2-5 m in size make up 4/5 of the clasts, rare blocks up to 8 m; green argillaceous matrix.		
	(b) middle 1/3, clasts slightly larger, calcified algae boulders up to 2 m; also rounded clasts of oolite and peloid grainstone; chert veneers on clasts; drusy calcite fillings; very little matrix.		
	(a) basal 1/3, very similar to unit 1 but also contains black chert; very little grainstone matrix.		
	Trilobites: (RAF) **Leiostegium** sp. **Symphysurina** sp. in upper 1/3.		
	Stearing Island Member		
8b	LIMESTONE AND SHALE - disappears laterally along strike, cut out by the bed above (10.1).	0.2	15.7
8a	CONGLOMERATE - a pebble to small boulder conglomerate in which 4/5 of the clasts are less than 10 cm; equal numbers of tabular and equant clasts; 1/5 clasts are rounded up to 0.5 m in size; a grainstone matrix which makes up no more than 5% of rock; appears to be two welded units with a 10 cm band of ribbon limestone between, but this is ripped up along strike to form rafts up to 3 m in size in the conglomerate.	6.0	15.5
	Trilobites: (RAF) (at base) **Hungaia magnifica** **Symphysurina** sp. **Hystricurus** sp.		
	Tuckers Cove Member		
6	LIME GRAINSTONE AND CONGLOMERATE - along the northeastern shore exposed at low tide; thin interbedded oolitic, intraclast lime grainstone with quartz and glauconite at base; thin layers of tabular-clast conglomerate.	9.5	9.5
	The main section begins along the central northwest shore of the island.		

LOWER HEAD

The exposures which form Lower Head are mainly from the upper part of the Group. The structure as envisaged by Kindle and Whittington (1958, p.335), is a gently southwest-plunging, tight anticline and syncline with west-facing limbs. The westernmost limb of the syncline, however, is intensively sheared and underlain by Lower Head Sandstone, which is extensively exposed at low tide. The Lower Head Sandstone also overlies the Cow Head in normal sedimentary contact in the core of the syncline in the small westernmost cove and likely in the easternmost corner of Shallow Bay although the contact is not now exposed.

The strata are exposed in three sections: a good western section along the limb of the syncline; a poor central section which is intensively tectonized; and a good eastern section along the limb of the anticline. The massive conglomerate which dominates the outcrop and forms Lower Head itself is difficult to measure precisely because of irregular exposure, synsedimentary deformation and structure. There is also a major disconformity present in the eastern section and much of the strata including the massive breccia and underlying beds rest with angular unconformity on strata of unknown age (see discussion in text).

LOWER HEAD - EASTERN SECTION
49°57.6'N x 57°46.2'W

Unit	Description	Thickness (m) Unit	Total from base
	LOWER HEAD FORMATION		
	SANDSTONE - green, thin to medium-bedded.	50+	242.1+
	COVER.	30.0	192.1
	SHALLOW BAY FORMATION		
	Factory Cove Member		
14.0	CONGLOMERATE - a chaotic and massive unit with a green argillaceous matrix; it is distinguished by the large size and variety of clasts (the largest blocks, those over 10 m in size, have been given Greek letter signatures); the huge blocks are either massive fossiliferous limestone (biohermal biostromal), bedded calcarenites, intact bedded limestone-shale-conglomerate lithologies, or twisted ribbon to parted limestones; most of the other clasts are equant and many are boulders of pre-existing conglomerate; the clasts grade down to granule size. The base of the bed is loaded into underlying strata and flames extend as much as 10 m up into the conglomerate and are composed of either tabular clasts or intact but folded limestone; large blocks are often fractured and matrix is injected into the cracks.	109.0	162.1
	<u>Fossils</u>: fossils have been collected only from clasts, some of which are outlined below.		
	1. Alpha boulder - this 350 m x 100 m clast which is fractured into two pieces is "The Lower Head Boulder" whose fauna has been described in detail by Whittington (1963).		
	2. Phi boulder of fossiliferous calcarenite which appears to have been soft when incorporated.		
	<u>Brachiopods</u>: (RJR) **Orthidiella** sp. **Orthidium** sp. **Petroria** sp. **Porambonites** sp.		
	<u>Trilobites</u>: (RJR) ?**Carolinites** sp. Pliomerid pygidium		
	3. White boulder of conglomerate between Pi and Sigma is late Cambrian in age (RAF) on the basis of contained trilobite fauna.		
	4. Lambda clast contains the trilobite **Parabolinella** sp. (RL) and graptolite fragments.		
	5. Theta clast has layers rich in ?thrombolites, which contain calcified algae (**Girvanella** and **Epiphyton**) probable stromatoporoids and between which are **Maclurites**-rich calcarenites.		
	6. Pi clast also contains ?stromatoporoids, bryozoa and a variety of brachiopods and trilobites.		
	In other clasts, cephalopods, sponges, and stromatolites have been found.		
13.1	RIBBON LIMESTONE - grainstone mudstone inter-bedded with 40% grey black shale, silicification common, spiculitic.	1.0	53.1
	<u>Graptolites</u>: **Isograptus victoriae lunatus** **Isograptus** cf. **primulus** **Tetragraptus** cf. **serra** **Phyllograptus** sp. **Dichograptus octobrachiatus** **Didymograptus bifidus**		
11.7	CONGLOMERATE - composed almost entirely of tabular clasts, often bent, lenticular, graded along strike to chaotic conglomerate.	1.1	52.1
11.6	SILTY SHALE TO ARGILLACEOUS LIMESTONE - black to dark grey, fissile with thin laminated to cross-laminated silty layers, lenses of phos-phatic granular conglomerate towards the top, dolomite also towards top, lenticular grainstone 10 cm thick at top, commonly with many phosphate grains, blocks of siltstone as in 11.5.	2.0	51.0
	<u>Graptolites</u>: **Phyllograptus** sp. **Didymograptus bifidus** **Tetragraptus bigsbyi** **Dichograptus octobrachiatus** Extensiform **Didymograptus**		
11.5	GRAINSTONE AND SHALE - irregularly interbedded rippled to massive grainstone in layers up to 10 cm and black fissile shale, thinner beds and ribbon to nodular mudstones at top, thin conglomerates, with isolated small blocks of green dolomitic siltstone whose layers are up to 30° to bedding.	2.7	49.0
11.4	CONGLOMERATE - predominantly tabular clasts, but also conspicuous dolomites, grainstone, ribbon limestone, chert, and occasional equant clasts, phosphate grains.	0-0.5	46.3
11.3	PARTED TO RIBBON LIME MUDSTONES - slightly recessive thin lumpy to nodular beds, average 2 cm thick, grey to black shale between.	2.7	45.8
11.2	PARTED TO RIBBON LIMESTONE - about 1/3 replaced by black vitreous chert which weathers brown, as nodules or whole layers; lime mudstone to cross-laminated grainstone in layers 1 to 2 cm thick, grainstone more common towards top, beds often nodular, green surfaces on some beds suggest spiculite, the top is a lenticular conglomerate which cuts down 10 cm and has phosphate, dolomite and green chert clasts; shale black; silicification disappears along strike, laps up against truncation surface southward.	2.2	43.1
11.1	RIBBON LIMESTONE - lumpy with black shale.	40.9	40.9
	(p) ANGULAR UNCONFORMITY OR SLIDE SURFACE - strata above are mostly conformable with the upper surface, strata below are removed; along the length of the exposure (140 m), a total of 10.6 m of underlying section is cut out at the sole of the surface, the strata below consist of rhythmically alternating green dolomitic siltstone (0.8 to 1.6 m) and thin ribbon lime mudstone separated by green to occasionally black shale (0.1 to 1.0 m), the siltstones in contact with the surface show slight brecciation, flowage and welding.	0-10.6	
	(o) RIBBON LIMESTONE - characteristically nodular in thin 1 to 2 cm thick beds separated by grey-green shale.	0.3	
	(n) SHALE AND CONGLOMERATE - green and grey shale (2/3) and 1 to 2 cm layers of buff-weathering grainstone (1/3); at base is a conglomerate layer, black shale band at top, wrinkled limestone at top.	0.9	
	(m) CONGLOMERATE - twisted limestone clasts in green siltstone.	0-0.3	
	SHALE AND SILTSTONE - dark olive green with light green and black laminations, occasional fine-grained, sandy layers, ribbon limestone.		
	(l) SILTSTONE - laminated.	0.3	
	(k) SHALE AND RIBBON LIMESTONE - with well-developed wrinkles.	2.8	
	(j) SILTSTONE - laminated.	5.6	
	(i) SHALE - green-grey.	2.9	
	(h) SILTSTONE - green, laminated.	0.8	
	(g) SHALE and minor siltstone with 1/3 widely separated lime mudstone layers average 2 cm thick.	1.0	
	(f) SHALE with resistant siltstone or fine grained sandstone layers.	1.1	
	(e) SHALE - with minor siltstone.	2.1	
	(d) SILTSTONE.	2.0	
	(c) COVER.	3.0	
	(b) SHALE, SILTSTONE, RIBBON LIME MUDSTONE.	3.2	
	(a) SHALE AND SILTSTONE - green, evenly laminated.	4.0	

Unit	Description	Thickness (m) Unit	Total from base
	Section begins in the first sandy cove north of the head in beds that are exposed only at spring low tide; the lower part of the section is measured east to the base of the massive conglomerate, the contact with which can be traced southwards as far as Phi boulder; the thickness of the conglomerate is estimated perpendicular to strike through Alpha boulder and the underlying conglomerate at the head. There is a 27 m covered interval between the top of the conglomerate and the first beds of the Lower Head Formation to the east.		
	A generalized diagram of the structure is contained in Figure 8, Kindle and Whittington (1958).		

LOWER HEAD - CENTRAL SECTION

49°57.9'N x 57°46.1'W

Unit	Description	Thickness (m) Unit	Total from base
	SHALLOW BAY FORMATION		
	Factory Cove Member		
	The conglomerate also forms a ridge which separates two sandy beaches in the cove north of the head. There it stands more or less vertically, as the western limb of an anticline whose eroded core forms the eastern beach. Although extensively sheared, remnants of lithologies like those on the eastern limb can be discerned below. From shales in contact with and 2 m below the conglomerate the following graptolites have been collected.		
	K & W, 1958, (p. 334): **Dichograptus octobrachiatus** **Tetragraptus** cf. **bigsbyi** **Phyllograptus** cf. **ilicifolius** **Didymograptus** sp. **?Isograptus** sp.		
	(this report): **Didymograptus bifidus** s.l.		
	Above the conglomerate, to the west, sheared remnants of lithologies similar to the shales and sandstones which overlie the westernmost outcrop of the conglomerate are recognizable.		

LOWER HEAD - WESTERN SECTION

49°57.9'N x 57°46.2'W

Unit	Description	Thickness (m) Unit	Total from base
	LOWER HEAD SANDSTONE		
	CENTER OF COVE, CORE OF SYNCLINE		
	SANDSTONE - green, medium to thick-bedded, massive, water-escape structures.	4.0	84.9
	SHALLOW BAY FORMATION		
	Factory Cove Member		
15.1	SHALE AND SILTSTONE - green shale with black interbeds, buff to green-weathering siltstone, siliceous in beds 1 to 2 cm thick, lenses up to 20 cm thick of lime grainstone.	9.0	80.9
	Graptolites: 2 m above base **Glyptograptus austrodentatus**		
14.0	CONGLOMERATE - massive, chaotic, a wide variety of clasts, mostly exotics or clasts of clasts, range 2 cm to 7 m, no obvious average, matrix green-grey argillaceous lime mudstone, an obvious cap of grainstone 0.5 m thick.	est. 16.0	71.9
11.10	COVER - by beach gravel or grass and trees.	3.0	55.9
11.9	(e) CONGLOMERATE - tabular clasts, range 2-4 cm, phosphate, 5-10% crystalline matrix.	0.5	52.9
	(d) RIBBON LIME MUDSTONE - in thin beds, average 2 cm, alternating with black shale.	0.6	52.4
	(c) SHALE - black.	0.4	51.8
	(b) RIBBON LIME MUDSTONE - in thin beds, average 2 cm, black shale.	0.2	51.4
	(a) CONGLOMERATE - 90% tabular clasts, average 4 cm, phosphate, 10% crystalline matrix.	0.4	51.2
11.8	DOLOMITE - buff-weathering green, silty burrowed, massive.	1.2	50.8
11.7	RIBBON LIME MUDSTONE.	0.5	49.6
11.6	CONGLOMERATE - 90% tabular clasts, 10% matrix.	2.0	49.1
11.5	(c) PARTED TO RIBBON LIMESTONE - often nodular to lumpy lime mudstone in beds (average 1 cm thick) and black shale.	2.8	47.1
	(b) GRAINSTONE - often lensoid.	0.2	44.3
	(a) SHALE - green silicified.	0.1	44.1
11.4	CONGLOMERATE - small tabular clasts (average 2 cm) with 10% silicified exotics, chert in many clasts near top.	1.0	44.0
11.3	SHALE AND SILTSTONE - green and black, siliceous to chert.	1.2	43.0
11.2	CHERT AND SHALE - silicified ribbon limestone, black, vitreous, brown-weathering; spiculite partings and where limestones are preserved they are grainstones, sparcely phosphatic.	3.9	41.8
11.1	RIBBON LIMESTONE -	7.2	37.9
	(b) beds 5-10 cm thick alternating with black calcareous and siliceous banded black and green shale.	3.2	
	Graptolites: (at base) **Phyllograptus** sp. **Tetragraptus fruticosus**, 4-stiped **?Clonograptus** sp. (abundant)		
	Trilobites: (RL) Odontopleurid hypostome		
	(a) same as (b), bu less siliceous, mainly mudstones, spiculite layers near base.	4.0	
	Fossils: phosphatic brachiopods		

Unit	Description	Thickness (m) Unit	Total from base
10.0	CONGLOMERATE - composed of 3 beds.	2.5	30.7
	(c) granule to pebble size, sparry grainstone matrix.	0.5	
	(b) tabular clasts, often contorted; rafts of broken beds.	1.5	
	(a) tabular clasts, average 10 cm, micro-crystalline matrix.	0.5	
9.8	RIBBON LIMESTONE -	6.5	28.2
	(b) nodular to lumpy well-bedded mudstone to grainstone, occasional coarse grainstone lenses with phosphate grains, black shale.	2.5	
	(a) grainstone, lensoid, with black shale.	4.0	
9.7	CONGLOMERATE - a lens more than 15 m in length, 90% pebble size but some larger, up to 20 cm.	0-3.6	21.7
9.6	SHALE - black, siliceous, well-laminated and equal amounts of buff-weathering dolomite, 1/3 10 cm thick lime grainstone layers, cross-laminated.	1.0	18.1
	Graptolites: **Tetragraptus approximatus**		
9.5	CONGLOMERATE - a lens, all tabular mudstone clasts.	0-0.8	17.1
9.4	(b) PARTED LIME MUDSTONE.	1.8	16.3
	(a) CONGLOMERATE - all tabular clasts.	0.3	14.5
9.3	RIBBON LIMESTONE - fine-grained grainstone or mudstone alternating with black shale, grainstone at 4.0 m, numerous thin layers of phosphatic grainstone in upper part.	6.0	14.2
9.2	CONGLOMERATE - a complex unit, comprising a basal conglomerate with numerous exotic clasts which is overlain by a buff-weathering dolomitic limestone, laminated; the conglomerate wedges out along strike; these two are overlain by a conglomerate with many large (up to 2 m) equant clasts that cuts down to the base of the lower conglomerate, incorporating the boulders and clasts within it, as well as clasts of the dolomitic limestone; the upper conglomerate has a cap of tabular clast conglomerate and there are boulders sticking up out of the top of the conglomerate as much as 0.5 m.	2.2	8.2
9.1	SHALE - green-grey with 1/3 lime mudstone or dolomite stringers average 0.5 to 1 cm thick. This can be recognized as a distinctive unit for 6 m, but below this it is extensively sheared and grades into melange.	6.0	6.0

This section begins at the lowest exposed folded strata along the coast northwest of the head and is measured southward through the folded strata, the thick conglomerate and then east to the core of the anticline in the first core.

At lowest tide a thickness of over 100 m of green sandstone is exposed and extends for several km along the shore. This is overlain by a zone of melange with blocks of green sandstone, limestone and conglomerate.

ST. PAULS INLET

The shores of St. Pauls Inlet from the Tickle east towards the mountain front contain several good sections of Cow Head Group strata and numerous other outcrops of both the Cow Head Group and Lower Head Sandstone. Headlands which project into the Inlet are usually Cow Head limestones while coves are eroded into the softer Lower Head Sandstones.

There are excellent sections along both sides of the Tickle with the most continuous on the north side. Part of the northern section, which exposes upper Cambrian through Middle Ordovician Strata, has been covered by bridge and wharf construction but equivalent strata have been exposed by quarrying and road construction and these are integrated into the measured sections.

Equivalent strata are also exposed on the south side of the Tickle and repeated by folding along the shore to the southeast, both of which are presented as sections.

Eastward into the Inlet, headlands along the north shore at Long Point, except at White Point, Black Brook Point and The Scrape (a local name), all expose Cow Head strata, but there is little continuous outcrop on the south shore. The succession at Long Point and Black Brook Point are Lower to Middle Ordovician in age. In contrast, the sequence at The Scrape is overturned and appears to be mostly late Cambrian in age.

ST. PAULS TICKLE - NORTH

49°51.2'N x 57°48'W

Unit	Description	Thickness (m) Unit	Total from base
	LOWER HEAD SANDSTONE		
91	SANDSTONE - green.	30.0+	433.4
90	COVER.	16.0	403.4
89	SHALE - red, thin dolomite laminations.	5.0	387.4
88	CONGLOMERATE - 20% green argillaceous lime mudstone matrix, partially calcified remnants of red mudstone matrix; chaotic fabric, 80% clasts, 2/3 equant, bimodal 2 cm and 10-15 cm, largest clasts 0.8 m, chert clasts.	2.8	382.4
87	SHALE - red.	16.0	379.6
86	SANDSTONE - green, water-escape structures.	2.0	363.6
	GREEN POINT FORMATION		
	St. Pauls Member		
85	SHALE - red and green.	2.5	361.6
84	SHALES AND DOLOMITE - shales, green to red with thin buff-weathering dolomite, burrowed; gradation from red to green along strike, thin grainstone and chert layers.	7.9	359.1
	Graptolites: small biserial forms, poorly preserved.		
83	SHALE - red, burrowed, siliceous.	4.0	351.2
82	SHALE - red and green, very thin parted lime-mudstone, and silicified conglomerate, shales are burrowed.	3.9	347.2
81	CONGLOMERATE AND DOLOMITE -	1.5	343.3
	(b) conglomerate, which cuts down to remove dolomite, 10% grey grainstone matrix, all tabular clasts (average 0.1 m, largest 1.5 m), dolomite clasts, chert top.	1.1	
	(a) dolomite, cross-laminated.	0.4	
80	SHALE - green and black with siltstone partings, a 0.1 m thick bed of conglomerate (similar to 79b) at 0.7 m above base.	2.0	341.8

Unit	Description	Thickness (m) Unit	Total from base
	Graptolites: **Pseudotrigonograptus ensiformis**, **Exigraptus** sp., **Tetragraptus** cf. **rigidus**, **Xiphograptus** sp., **Isograptus victoriae** cf. **maximodivergens**		
79	CONGLOMERATE - 2 layers with upper cutting down into lower.	1.3	339.8
	(b) silicified matrix, 2/3 equant clasts, obvious large dolomite clasts, some phosphate.	1.0	
	(a) 10% green argillaceous mudstone matrix, 2/3 equant clasts (average 2 cm, largest 25 cm).	0.3	
	Brachiopods: (RJR) **Orthidiella** sp.		
78	SHALE - green; conglomerate lens at 0.2 m, 5% grey mudstone matrix and mostly equant clasts (average 1 cm, largest 2 cm), minor phosphate.	2.3	338.5
	Graptolites: **Xiphograptus** sp., **Exigraptus** sp.		
77	PARTED GRAINSTONE - thin and hummocky bedded, laminated, green argillaceous partings.	2.9	336.2
76	SHALE - green.	2.7	333.3
75	PARTED GRAINSTONE - irregular bedded, cross-laminated, occasional burrows, folding perpendicular to bedding.	8.0	330.6
	Graptolites: **Didymograptus extensus**, **Tetragraptus serra**, **Tetragraptus bigsbyi**		
74	SHALES - green with chert layers at 1.8 m and 2.2 m.	5.0	322.6
73	CONGLOMERATE - chaotic 5% green-weathering mudstone matrix, 80% equant clasts, bimodal (large average 40 cm, small average 10 cm - largest 2.0 m), sporadic chert cap.	4.6	317.6
72	SHALES - green; a band of conglomerate and grainstone 0.4 m thick at 1.2 m above base, conglomerate similar to 69 but more phosphate clasts at top.	6.0	313.0
	Graptolites: **Didymograptus extensus**, **Tetragraptus serra**, **Tetragraptus bigsbyi**		
71	PARTED LIMESTONE - cross-laminated.	2.3	307.0
70	SHALE AND LIMESTONE - spiculitic, cherty. (c) shale, black. (b) parted limestone. (a) shale, black.	1.0	304.7
	Graptolites (from c): **?Phyllograptus** sp., **Didymograptus extensus**, **Tetragraptus serra** (large), **Sigmagraptus praecursor**		
69	CONGLOMERATE - 5% grainstone matrix, 90% tabular clasts (largest 25 cm, average 10 cm), chaotic to cross-laminated, chert.	0.9	303.7
68	SHALE - green.	3.6	302.8
67	PARTED LIMESTONE - paired burrows.	1.7	299.2
66	SHALE - green.	7.0	297.5
65	PARTED LIMESTONE - grainstone, very poor outcrop in central part, covered by water.	11.0	290.5
	Graptolites: **Didymograptus bifidus** s.l.		
64	SHALE AND DOLOMITIC SILTSTONE.	0.8	279.5
63	PARTED GRAINSTONE - fine cross-laminated.	1.0	278.7
62	SHALE AND CONGLOMERATE - lenticular, the conglomerates have grainstone and chert matrix, 1/2 equant clasts (largest 20 cm, average 10 cm), clasts are bored and chert fills borings, chert top.	0.8	277.7
	Graptolites: **Phyllograptus** sp., **Tetragraptus fruticosus**, 3-stiped		

Unit	Description	Thickness (m) Unit	Total from base
61	PARTED LIMESTONE - grainstone to mudstone, rippled, paired burrows.	4.5	276.9
60	SHALE - green and parted limestone, interbedded.	3.0	272.4
59	SHALE - green, poor outcrop.	2.0	269.4
58	SILTSTONE - green.	0.2	267.4
57	SHALE - red and green.	9.8	267.2
56	SHALE - red.	2.4	257.4
55	SHALE - green to dark green to black, brown-weathering chert layers at 0.8, 1.0, and 3.0 m from base.	3.0	255.0
	Graptolites: **Tetragraptus fruticosus**, 4-stiped, **Tetragraptus pendens**, 4-stiped, **Tetragraptus approximatus**, **Tetragraptus acclinans**, **Tetragraptus quadribrachiatus**, **Tetragraptus phyllograptoides**, **Didymograptus hemicyclatus**, **Didymograptus latus**, **Kinnegraptus** sp., **Clonograptus** sp., **Phyllograptus** sp., **Dendrograptus** sp., Dendroid fragments, **?Temnograptus** fragments		
54	CONGLOMERATE AND SHALE -	1.4	252.0
	(d) conglomerate, 90% tabular clasts (average 0.2 m, largest 0.4 m), green mudstone matrix, numerous chert clasts, chert top.	0.6	
	(c) grey-green shale.	0.3	
	(b) conglomerate, 90% equant clasts (largest 15 cm, average 1 cm), grainstone matrix - grades laterally into grainstone, minor chert.	0.3	
	(a) green, shale.	0.2	
53	CONGLOMERATE - a complex series of beds.	7.5	250.6
	(g) conglomerate, graded complex, base tabular clasts, top equant clasts, some chert and dolomite clasts, chert cap.	3.3	
	(f) conglomerate, 90% equant clasts (average 2 cm, largest 7 cm), grainstone top.	0.2	
	(e) conglomerate, as (a) (grainstone top).	0.5	
	(d) conglomerate, as (a).	0.7	
	(c) conglomerate, same as (a), slightly smaller clasts.	0.6	
	(b) conglomerate, same as (a) but very chaotic, curved base.	1.5	
	(a) conglomerate, mostly tabular clasts, (largest 40 cm, average 10 cm), green-grey mudstone matrix.	0.7	
52	PARTED GRAINSTONE - layers 5 to 15 cm thick with parallel- and cross-laminations and burrows; at top is a slightly chaotic silicified grainstone layer 0.5 m thick.	21.0	243.1
	Graptolites: 12 m above base **Tetragraptus approximatus**, **Tetragraptus quadribrachiatus**		
51	SHALE AND LIMESTONE - interbedded green shale, parted and ribbon limestone.	6.5	222.1
50	PARTED GRAINSTONE - burrowed, at 2.0 m above base is a bed whose fabric is inclined 45° to bedding.	4.5	215.6
49	PARTED LIMESTONE AND SHALE - nodular, interbedded with one thin lens of conglomerate composed almost entirely of tabular clasts (largest 15 cm, average 3 cm).	3.4	211.1
48	SHALE - green with interbeds of parted limestone 0.2 m thick at 2.0 m above base.	4.8	207.7
	Graptolites: at 3.0 m above base **Tetragraptus approximatus**, **Tetragraptus** cf. **harti**, **Tetragraptus quadribrachiatus**		
47	SHALE - red and green thinly interlaminated.	4.0	202.9
46	SHALE - red, intensively burrowed.	9.0	198.9
45	RED SHALE AND DOLOMITE - interbedded intensively burrowed red shales and cross-laminated dolomites; thin sand and conglomerate with phosphate pebbles.	7.0	189.9

Unit	Description	Thickness (m) Unit	Total from base
44	SHALE AND DOLOMITE - green shales which grade locally into red; brown-weathering silty dolomites, finely laminated, and thin conglomerate lenses.	5.6	182.9
43	PARTED LIMESTONES.	1.5	177.3
	Graptolites: **Tetragraptus quadribrachiatus** **Dictyonema** sp.		
42	CONGLOMERATE AND PARTED LIMESTONE - lenses of conglomerate and parted limestone; conglomerate made up of equal numbers of equant and tabular clasts, average 2 cm, largest 5 cm, in mudstone matrix.	1.0	175.8
41	PARTED GRAINSTONE - peloidal.	4.5	174.8
40	SHALE - green with a 0.1 m thick bed of green lime mudstone at 0.2 m.	0.8	170.3
39	PARTED LIMESTONE - green dolomitic shale partings, nodular, thin lenses of grainstone swelling to about 4 cm.	1.7	169.5
38	PARTED TO RIBBON LIMESTONE - green shale with conglomerate lens at top.	2.8	167.8
37	PARTED LIMESTONE.	0.4	165.0
36	SHALE - green.	2.6	164.6
35	PARTED LIMESTONE.	0.8	162.0
34	SHALE - much cover, green silty.	2.8	161.2
33	PARTED LIMESTONE.	0.4	158.4
32	COVER - abundant red and green shale debris but no outcrop.	38.6	158.0
	Broom Point Member		
31	CONGLOMERATE - 3/4 equant clasts, average 10 cm, largest 40 cm, 5% grainstone matrix, thin dolomite at top.	2.0	119.4
	Trilobites: (RAF) **Leiostegium** sp.		
30	COVER - occasional outcrops of parted limestone poking up out of gravel pit - equivalent to outcrop of parted limestone on road.	21.5	117.4
29	PARTED LIME MUDSTONE.	7.2	95.9
	(b) parted lime mudstone with deformation in lower meter, thin-bedded (1 cm), irregular bedded, nodular, lensoid; at 3.6 m grainstone layer, conglomeratic, coarse-grained, occasional quartz grains.	6.0	
	Graptolites: **Callograptus** sp. **Dictyonema** cf. **robustum**		
	(a) cover - in ditch.	1.2	
28	CONGLOMERATE - (exposed in ditch), argillaceous matrix at base, grainstone at top, and grainstone cap with tabular clasts.	1.2	88.7
27	COVER - includes road fill along shoreline and above quarry.	17.0	87.5
26	RIBBON LIME MUDSTONE AND GREY SHALE.	4.0	70.5
25	CONGLOMERATE - 15% grey-green siltstone matrix; 90% tabular clasts (average 5 cm, largest 15 cm).	0.5	66.5
24	PARTED LIME MUDSTONE - laminated and nodular, occasional chert partings and nodules.	7.0	66.0
	Graptolites: **Staurograptus** sp. **Dictyonema** sp. **Anisograptus** sp.		
23	CONGLOMERATE - lenticular to 0.5 m, identical to 21 but with chert scattered throughout.	0.4	59.0
22	RIBBON TO PARTED LIME GRAINSTONE - laminated to cross-laminated to rippled, 30% silty, slightly dolomitic mudstone.	0.9	58.6
	Graptolites: **Staurograptus** sp. **Dictyonema** sp.		
21	CONGLOMERATE - 1/4 grainstone matrix with 10% quartz; mostly tabular clasts (average 1 cm, largest 15 cm).	0.2	57.7
20	PARTED TO RIBBON LIME MUDSTONE - with rusty brown-weathering grey-green dolomitic shale partings, occasionally nodular, bedding 2-4 cm.	1.3	57.5
19	SHALE AND SILTSTONE - grey-green shale with 20% ribbon lime mudstone bands; at 2.0 m, a 0.2 m thick unit of parted limestone; at top a discontinuous 0.2 m thick lens of conglomerate.	3.4	56.2
	Graptolites: at 1.5 m **Dictyonema flabelliforme** s.l. **Dictyonema** cf. **scitulum** **Staurograptus** sp.		
18	CONGLOMERATE - 10% green siltstone matrix, 90% tabular clasts (average 1 cm, largest 15 cm).	0.3	52.8
17	DOLOMITE - brown-weathering, dark grey, finely laminated.	0.5	52.5
16	CONGLOMERATE - 20% grainstone matrix; 90% tabular clasts (average 5 cm, largest 50 cm).	0.6	52.0
15	RIBBON LIME MUDSTONE AND GREY-GREEN SHALE - conglomerate lens, silty dolomite partings.	3.5	51.4
	Graptolites: (BE) **Dictyonema flabelliforme** cf. **sociale**		
14	CONGLOMERATE - 10% grainstone (with scattered quartz); graded, more common at top; 90% tabular clasts (average 10 cm, largest 30 cm).	1.5	47.9
13	RIBBON LIME MUDSTONE AND GREY-GREEN SHALE.	1.0	46.4
12	DOLOMITE - silt to fine sand size, cross-laminated.	2.0	45.4
11	PARTED LIME MUDSTONE - dark grey shale.	1.0	43.4
10	SHALE - dark grey and olive green, brown-weathering dolomite and limestone.	1.0	42.4
9	PARTED LIME MUDSTONE - wrinkled, grey-green non-calcareous shale partings.	5.0	41.4
8	CONGLOMERATE - 10% grainstone matrix, almost all tabular clasts (average 10 cm, largest 25 cm).	0.5	36.4
7	PARTED LIME MUDSTONE - with rusty brown-weathering dolomite partings.	3.0	35.9
6	CONGLOMERATE - forms outer point of Tickle, varies laterally along strike to 1.5 m thick, cutting out interbedded shales, siltstones and thin conglomerate; 1/4 grainstone matrix, 80% tabular clasts (average 5 cm, largest 15 cm), occasional quartz grains (equal to basal conglomerate in quarry).	3.4	32.9
	Martin Point Member		
5	RIBBON TO PARTED LIME MUDSTONE AND OLIVE GREEN SHALE (70%).	5.2	29.5
4	RIBBON TO PARTED LIME MUDSTONE - grey-green shales in layers 2 cm thick.	3.2	24.3
3	SHALE - grey-green thin lenses of conglomerate up to 0.1 m thick, at 0.2 m, ribbon lime mudstones.	6.3	21.1
2	SHALE (90%) AND RIBBON LIME MUDSTONE.	1.3	14.8
1	SHALE -	13.5	13.5
	(c) parted lime mudstones, slightly nodular, grey-green calcareous shale partings.	7.0	
	(b) dolomitic and silty shales.	0.5	
	(a) (at lowest tide), grey shales (90%) and ribbon limestone.	6.0	

Section begins in St. Pauls Bay east of bridge at narrows and continues east and north along shoreline.

ST. PAULS TICKLE - SOUTH

49°51.1'N x 57°48.2'W

Unit	Description	Thickness (m) Unit	Total from base
	LOWER HEAD SANDSTONE		
33	SANDSTONE - green, forming the axis of a small anticline.	13.0	203.4
32	COVER - beach sand.	13.0	190.4
31	GRAINSTONE AND SHALE - similar to bed 28.	3.5	177.4
30	GRAINSTONE - with numerous small phosphate clasts.	0.1	173.9
29	GRAINSTONE, SILTSTONE, AND SHALE - equal parts of thin grainstone/siltstone beds and shale.	1.5	173.8
28	PARTED GRAINSTONE - cross-laminated, in layers 2-10 cm thick, 1/3 interbedded siltstone and shale, green chert grains.	3.0	172.3
27	SHALE AND DOLOMITE - green, 2/3 dolomite, siliceous.	4.0	169.3
26	COVER.	2.0	165.3
25	PARTED GRAINSTONE - cross-laminated in layers 2-20 cm thick, 1/3 brown-weathering chert.	4.5	163.3
24	CONGLOMERATE - chaotic, mostly equant clasts (average 2x2 m), green argillaceous matrix.	5.8	158.8
23	COVER - beach sand.	9.0	153.0
	GREEN POINT FORMATION		
	St. Pauls Member		
22	SHALE - green, cherty.	0.1	144.0
21	COVER.	0.6	143.9
20	GRAINSTONE - cross-laminated, 1/2 chert.	0.8	143.3
19	COVER - beach sand.	5.8	142.5
18	SHALE - red, burrowed; stringers of buff weathering dolomite.	8.0	136.7
17	SHALE - red, burrowed.	3.0	128.7
16	CONGLOMERATE - a wide variety of clasts, mostly equant (average 3x3 cm, largest 10 cm); green argillaceous matrix; chert top.	0.1-0.4	125.7
15	SHALE - green and black; 0.1 m thick buff dolomite (burrowed) at top (siliceous).	5.1	125.3
	Graptolites: **Isograptus victoriae** sp. (numerous) **Didymograptus nitidus** **Tetragraptus quadribrachiatus** **Didymograptus v-deflexus** **Pseudotrigonograptus ensiformis**		
14	SHALE - green, thinly laminated, cherty, and a resistant weathering dolomite layer.	0.6	120.2
13	SHALE - green, platey.	4.5	119.6
12	SHALE - green, with minor siltstone, dark chert and silicified shales.	0.5	115.1
11	FOLD - a zone of folded grainstone and abundant chert.	3.0	114.6
10	SHALE - green and black thin banded with 1/4 thin layers cross-laminated of brown-weathering dolomite, chert layer at top - a zone of faults and folds in red burrowed shale.	5.6	111.6
	Graptolites: **Phyllograptus** cf. **anna** **Isograptus victoriae** cf. **maximodivergens** Dendroids		
9	PARTED MUDSTONE - brown-weathering dolomite at top.	0.6	106.0
8	SHALE - dark brown and black, cherty throughout; 1/4 dolomite, buff-weathering.	3.9	105.4
7	PARTED GRAINSTONE - thick-bedded, laminated to cross-laminated to nodular with chert throughout, 10% black chert layers and nodules.	8.4	101.5
6	COVER.	2.8	93.1
5	CONGLOMERATE - a small outcrop poking up out of the sand; tabular clasts (average 2x10 cm) but with a wide range in sizes; phosphate clasts; grainstone matrix and a chert which has mostly weathered away.	0.1	90.3
4	COVER - beach sand.	64.0	90.2
3	CONGLOMERATE - composed mainly of granule-size clasts in a grainstone matrix and exhibiting a chert top; the uppermost 0.2 m is laminated chert.	3.2	26.2
2	CONGLOMERATE AND PARTED LIMESTONE - a complex bed, the northern end is a conglomerate composed entirely of parted limestone clasts and a swirled fabric; southward this passes through a folded zone into extremely evenly bedded parted limestone resting on a conglomerate layer; this limestone may be either in place or a large raft.	3.0	23.0
1	PARTED TO RIBBON LIMESTONE - irregular bedded, cross-laminated, hummocky numerous straight and paired burrows, green-grey shale partings.	20.0+	20.0
	Section begins on south side of tickle at narrowest part, east of bridge.		

ST. PAULS TICKLE - SOUTHEAST

49°50.8'N x 57°48.1'W

Unit	Description	Thickness (m) Unit	Total from base
	LOWER HEAD SANDSTONE		
35	AXIS OF FOLD SANDSTONE - green.	13.0	105.6
34	SANDSTONE - mostly cover but green sandstone ribs here and there.	4.0	92.6
33	SANDSTONE - green.	0.8	88.6
32	SANDSTONE AND SILTSTONE - green, sheared.	1.0	87.8
31	SANDSTONE - green, massive.	0.5	86.8
30	DOLOMITE - silty, brown-weathering, cross-laminated, loaded in beds 2 to 20 cm thick; 40% green silty shale; 10% green sandstone and ribbon limestone.	4.1	86.3
29	GRAINSTONE - cross-laminated and rippled, overlain by siltstone.	0.4	82.2
28	SILTSTONE AND LIMESTONE - similar to unit 26.	1.0	81.8
27	SANDSTONE - green.	0.2	80.8
26	DOLOMITE AND LIMESTONE - equal proportions in thin beds, sandstone, green; minor shale.	4.2	80.6
25	GRAINSTONE - siliceous, green clasts, well-laminated in beds 1-3 cm thick; buff-weathering.	3.0	76.4
	Graptolites: **Pseudotrigonograptus ensiformis** **Tetragraptus** cf. **quadribrachiatus** ?**Oncograptus** sp. small indeterminate biserial forms Dendroids		

Unit	Description	Thickness (m) Unit	Total from base
24	SHALE - red and green, siliceous.	6.0	73.4
23	PARTED GRAINSTONE - isoclinally folded, somewhat sheared at top and a phacoid of green sandstone; the basal layer forms the top of the underlying conglomerate; layers 5-10 cm thick, abundant chert; 1/3 dolomitic siltstone.	est. 6.0	67.4
	Graptolites: **Pseudotrigonograptus ensiformis** **Glyptograptus austrodentatus** Dendroids		
22	CONGLOMERATE - forms nose of a steeply plunging fold; chaotic, a wide variety of boulders, mostly equant, commonly 1 m across at the base and smaller upwards.	est. 2.5	61.4
21	SANDSTONE AND SHALE -	9.5	58.9
	(b) shale, red, 10% green, buff dolomite stringers.	9.1	
	(a) sandstone, green.	0.4	
	GREEN POINT FORMATION		
	St. Pauls Member		
20	SHALE - green, minor siltstone.	1.0	49.4
19	SHALE - red, blocky, siliceous.	1.3	48.4
18	CONGLOMERATE - mostly equant clasts, matrix in lower part green argillaceous, grainstone towards top with a 0.4 m thick grainstone cap, brown chert replaces much of grainstone cap.	2.1	47.1
17	SHALE - red, 20% buff-weathering dolomite stringers.	2.0	45.0
16	SHALE - red, 20% buff-weathering dolomite. The strike of the units now swings dramatically from 090° to 000°, but lithology remains the same.	8.0	43.0
15	SHALE - red, banded and burrowed in layers 2 cm thick.	4.0	35.0
14	GRAINSTONE-CONGLOMERATE - equal portions of clasts and matrix; small clasts, average 1-2 cm, numerous black phosphate pebbles; lenticular, cherty base and top.	0.2	31.0
13	SHALE - green and red, very fragmentary outcrop, silty dolomite at top.	4.0	30.8

Unit	Description	Thickness (m) Unit	Total from base
12	CONGLOMERATE - a complex of welded units.	3.5	26.8
	(d) conglomerate, swirled fabric, contorted and irregular clasts, tabular (average 2x10 cm)=equant (5x5 cm); 10% green dolomite matrix; locally there is a 10 cm thick grainstone cap beneath brown chert.	1.0	
	(c) dolomite, buff-weathering.	1.0	
	(b) shale, green.	1.0	
	(a) conglomerate, small, equant (3x3 cm) clasts; dark chert and phosphate common; 1/3 grainstone matrix.	0.5	
11	SHALE - green, cherty, burrowed, irregular bedded.	0.5	23.3
10	COVER - abundant green cherty shale on beach.	4.0	22.8
9	SHALE - blue-green to black, poor outcrop.	3.0	18.8
8	CONGLOMERATE AND GRAINSTONE - a lens with abundant phosphate.	0.2	15.8
7	SHALE - blue-green to black.	2.5	15.6
	Graptolites: **Isograptus** sp. **Didymograptus** cf. **nitidus**		
6	RIBBON LIME GRAINSTONE - thick-bedded, 1/2 black chert; thickness estimated because isoclinally folded.	4.0	13.1
	Graptolites: **Isograptus** sp. **Didymograptus extensus** **Phyllograptus?** **Tetragraptus quadribrachiatus** **Isograptus victoriae maximodivergens** **Didymograptus v-deflexus** **T. rigidus**		
5	RIBBON LIME MUDSTONE - thrown into a series of tight isoclinal folds.	2.0	9.1
4	SHALE - dark green, hard and cherty, vitreous brown chert.	3.2	7.1
3	CONGLOMERATE - chaotic, tabular clasts (average 5x20 cm)=equant clasts (average 10x10 cm); phosphate clasts, many chert coated; putty-green soft limestone (3x3 m); 20% green argillaceous matrix; brown chert cap.	2.3	3.9
2	SHALE - green cherty.	0.6	1.6
1	GRAINSTONE AND SHALE - brown to black vitreous chert replacing grainstone and green shale.	1.0	1.0
	Section begins at a prominent point which strikes eastward and continues west along the shoreline around another point to axis of anticline.		

ST. PAULS INLET - LONG POINT

49°51'N x 47°47'W

Unit	Description	Thickness (m) Unit	Total from base
	LOWER HEAD SANDSTONE		
25	SANDSTONE - green, only in water and scattered outcrop for a few metres, cover above.	0.5	189.4
24	SHALE - red, burrowed; 1 cm thick, buff dolomite layers; 20 cm thick, dolomite bed 1.0 m above base, poor exposure.	22.8	188.9
23	SANDSTONE - dark green.	0.5	166.1
	GREEN POINT FORMATION		
	St. Pauls Member		
22	SHALE - red siliceous, burrowed; 1/4 is 1 cm thick layers of cross-laminated dolomite.	0.5	165.6
21	SHALE - red; conglomerate lens with granule-size clasts and grainstone matrix 6.0 m above base.	7.5	165.1

Unit	Description	Thickness (m) Unit	Total from base
20	CONGLOMERATE - equal number of tabular and equant clasts, most less than 10 cm and a few over 20 cm in size, green argillaceous matrix, chert top, largest block 0.6 m.	2.5	157.6
19	PARTED GRAINSTONE - irregular bedded, rippled, paired burrows.	3.2	155.1
18	SHALE - dark green, a few ribbon limestones at base, burrowed towards top, occasionally covered.	16.8	151.9
	Graptolites: **Didymograptus bifidus** sl.		
17	PARTED GRAINSTONE - rippled, black shale partings.	7.0	135.1
	Graptolites: **Didymograptus ?indentus** (a pendent, large but slender type **Isograptus** cf. **primulus** (growth stages only)		

Unit	Description	Thickness (m) Unit	Total from base
16	PARTED LIMESTONE AND SHALE - green shale at base.	10.0	128.1
15	COVER - some scattered outcrop in the water, slabs of red shale, bright green shale towards top, buff dolomite 0.2 m thick at top.	3.0	118.1
14	RIBBON GRAINSTONE AND GREEN SHALE - beds of buff dolomite, brown chert on tops and bottoms of beds, conglomerate lenses with pebble-size clasts and grainstone matrix 2.0 m and 3.5 m above base.	12.0	115.1
	Graptolites: **Dictyonema** sp. **Desmograptus** sp. **?Clonograptus** sp. **Tetragraptus quadribrachiatus** **Phyllograptus typus** (prolific)		
13	RIBBON GRAINSTONE AND BROWN SHALE - cross-laminated.	1.5	103.1
12	RIBBON LIMESTONE AND SHALE - a lens of conglomerate 0.2 m thick, 2 m above base.	2.6	101.6
11	CONGLOMERATE - compound, composed of several layers.	3.2	99.0
	(d) small equant clasts with white crystalline calcite matrix.	0.6	
	(c) small equant to tabular clasts.	0.3	
	(b) small equant to tabular clasts.	0.3	
	(a) tabular clasts with a chaotic to swirled fabric and green calcareous mud matrix.	2.0	
10	RIBBON LIMESTONE AND GREEN SHALE - between 3.0 and 5.0 m the limestone is parted and burrowed.	6.4	95.8
9	CONGLOMERATE - tabular clasts.	0.8	89.4
8	RIBBON LIMESTONE AND SHALE - limestone very thin bedded, shale green; conglomerate at base, beds thicker and separated by wider shale bands at top.	12.6	88.6
7	SHALE - red, dolomite stringers in basal 4 m.	17.0	76.0
6	COVER.	6.0	59.0
5	CONGLOMERATE - numerous tabular clasts, small, 2-3 cm in size, spar matrix.	3.4	53.0
4	COVER - abundant red and green shale float in small cove, only outcrop is one thin dolomite bed and a 2 cm thick conglomerate stringer. Phyllocarids 8 m below conglomerate.	27.0	49.6
3	PARTED GRAINSTONE - rippled.	7.0	22.6
	Graptolites: **Dictyonema** cf. **pertextum** **D.** cf. **robustum**		
2	CONGLOMERATE - abundant platey to tabular clasts, little matrix, dolomitic.	3.6	15.6
1	SHALE AND RIBBON LIMESTONE - shale, brown limestone, thin platy, rippled grainstone to mudstone, occasional thin, 20 cm, dark green shale and siltstone stringers.	12.0	12.0
	Section begins at west side of point and continues east and north.		

ST. PAULS INLET - WHITE POINT

The long tree-lined southern shore of St. Pauls Inlet has few outcrops, the largest of which is a small promontory known locally as White Point. The low shoreline outcrops of Cow Head Group here strike 045° and dip eastward at 30°. The section is measured along the shoreline from west to east beginning in trees along the shore and ending at a small beach.

ST. PAULS INLET - WHITE POINT

49°48.5'N x 57°45.8'W

Unit	Description	Thickness (m) Unit	Total from base
	SHALLOW BAY FORMATION		
	Downes Point Member		
	Cover overgrown with trees along shore.		
15	CONGLOMERATE - chips to tabular clasts, 10% green dolomitic matrix, distinctive waves at top.	2.0	37.3
14	RIBBON LIMESTONE - green shale interlayers.	0.1	35.3
13	CONGLOMERATE - chips to tabular clasts, 10% green-brown dolomitic matrix, wave-like fabric in upper meter.	4.0	35.2
12	COVER - thin, poorly exposed small conglomerate layers.	2.0	31.2
11	CONGLOMERATE - chips to small tabular clasts, less than 10% dolomitic matrix.	1.0	29.2
10	CONGLOMERATE - same as bed 11.	0.5	28.2
9	CONGLOMERATE - same as bed 11.	0.4	27.7
8	CONGLOMERATE - tabular clasts with small subrounded boulders in upper meter.	2.0	27.3
7	CONGLOMERATE - 3 welded units which from base up are 0.2 m, 0.5 m, and 1.2 m thick, respectively, separated from one another by ribbon limestone and grey and black shale units 10 to 20 cm thick.	2.1	25.3
6	CONGLOMERATE - chip to tabular clasts, with scattered small subrounded boulders.	4.0	23.2
5	RIBBON LIMESTONE - grey shale interlayers.	1.0	19.2
4	CONGLOMERATE - chips to tabular clasts with scattered small subrounded boulders.	0.2	18.2
3	CONGLOMERATE - a chaotic unit with 10% green argillaceous matrix and whose clasts are 1/2 limestone chips, 1/4 tabular clasts averaging 5x20 cm and 1/4 large equant boulders up to 1 m across of white calcified algal limestone and/or large ooids which protrude above the top of the unit.	6.0	18.0
2	CONGLOMERATE - a mixture of 1/3 limestone chips and 70% subrounded boulders that range from 20 cm to 2 m in size and are composed of mudstone, calcified algal limestone, and lithified conglomerate in 10-15% argillaceous mudstone matrix.	5.0	12.0
1	CONGLOMERATE - about 1/3 limestone chips, 1/3 tabular cobble to boulder-size clasts, and 1/3 subrounded boulders, characteristically oolitic in about 10% calcarenite matrix.	7.0	7.0
	Trilobites: (probably from beds 1, 2; Kindle, 1982, p. 10, 12) **Orria** sp. **Kingstonoides** sp.		
	Cover, small sandy beach.		

ST. PAULS INLET - BLACK BROOK POINT

49°50.8'N x 57°45.0'W

Unit	Description	Thickness (m) Unit	Total from base
	LOWER HEAD SANDSTONE		
39	SANDSTONE - green, also thin shale stringers; beyond this covered by beach and wood chips in water.	1.0	244.5
38	CONGLOMERATE - varies in thickness along strike from 0.4 to 3.1 m, massive, chaotic texture, rounded clasts average 0.4 m, largest 2 m, wide variety of clasts; dolomite, chert, spar-filled limestones, numerous fossiliferous limestones, green soft limestone, clasts of clasts, often chert veneered, matrix red, argillaceous. sandstone from bed above forms matrix in top 2-5 cm.	3.1	243.5
37	SHALE - red, chert; green sandstone layers, average 20 cm thick.	3.6	240.4
36	SHALE - red, siliceous, good sandstone dikes, buff-weathering dolomite stringers.	2.8	236.8
35	SANDSTONE - green, shale chips, dewatering structures.	2.0	234.0
34	SHALE - green and red.	2.0	232.0
	<u>Graptolites</u>: dominated by biserials **Glyptograptus austrodentatus** **Paraglossograptus tentaculatus** **Isograptus** sp.		
33	SANDSTONE - green, flaggy.	1.0	230.0
32	SHALE - green, siliceous, thin dolomite layers.	0.2	229.0
	<u>Graptolites</u>: **Isograptus victoriae cf. divergens** Indeterminate biserial graptolites		
31	CONGLOMERATE - mostly equant, rounded clasts, largest 5 cm, 1/3 tabular clasts, grainstone matrix, brown-weathering chert at top and throughout, looks to be two welded units.	0.8	228.8
30	SHALE, DOLOMITE, SANDSTONE.	7.0	228.0
	(c) Shale, green, siltstone, black chert, and green sandstone which varies from 5 cm to 30 cm along strike.	1.0	
	GREEN POINT FORMATION		
	St. Pauls Member		
	(b) Interbedded green silty shale and brown-weathering dolomitic sandstone in beds 3-10 cm thick, cross-laminated, rare black chert.	4.0	
	<u>Graptolites</u>: **Pseudotrigonograptus ensiformis** **Pseudoclimacograptus pungens** **Cryptograptus antennarius** **Glossograptus echinatus**		
	(a) Shale, green.	2.0	
29	SHALE - a substantial part covered but good outcrops of red shale throughout, burrowed, occasional chert beds.	34.5	221.0
28	CONGLOMERATE - mostly tabular clasts, with the largest equant clast 20 cm, in part green argillaceous matrix, in part grainstone, swirled to chaotic fabric, brown-weathering chert top that extends down into grainstone, chert clasts.	2.2	186.5
27	SHALE - red and green, partly covered, occasional ribbon limestone, 10% burrowed dolomite.	36.4	184.3
26	RIBBON LIME MUDSTONE - beds 5 cm thick alternating with black shale, burrowed.	8.0	147.9
	<u>Graptolites</u>: many **Didymograptus** sp. extensiform many **Phyllograptus typus** **Clonograptus** sp. **Tetragraptus approximatus** **Dictyonema** sp.		
25	RIBBON LIMESTONE.	4.0	139.9
24	RIBBON LIMESTONE - both mudstone and cross-laminated grainstone in beds, average 10 cm thick, brown and black-weathering chert nodules and tops to grainstone beds, interbeds of black shale.	6.2	135.9

Unit	Description	Thickness (m) Unit	Total from base
23	SHALE - green.	3.8	129.7
22	SHALE - red.	1.0	125.9
21	CONGLOMERATE - dominantly tabular clasts of lime mudstone (average 2x10 cm, largest 30 cm), swirled fabric, 10% crystalline calcite matrix, grainstone near top.	1.0	124.9
20	SHALE - green, thin parted limestone layers, especially at the top, nodular, buff-weathering.	7.0	123.9
19	CONGLOMERATE - lensoid, calcite spar matrix, numerous tabular clasts, also chert and phosphate.	0.4	116.9
18	SHALE - green, nodules and ribbons of lime mudstone in upper part.	2.0	116.5
17	SHALE - red with 1/3 green layers, intensively burrowed, 10% siltstone stringers ca. 0.5 cm thick.	16.0	114.5
16	PARTED GRAINSTONE - excellent cross-laminated and rippled fine-grained grainstone, occasional brown ropy chert.	1.0	98.5
15	RIBBON LIMESTONES AND BLACK SHALE -	4.0	97.5
	<u>Graptolites</u>: Dendroids **Didymograptus** sp., a slender extensiform type **Dictyonema pertextum** **Tetragraptus quadribrachiatus** **Dictyonema** sp. **Bryograptus** sp. **Phyllocarids**		
14	SHALE - interbedded red and green.	10.0	93.5
	Fault.		
	Broom Point Member		
13	SHALE, LIMESTONE AND DOLOMITE - interbedded green shale and silty cross-laminated limestone and dolomite.	14.0	83.5
12	SHALE AND DOLOMITE - green-grey shale and brown-weathering dolomite, convolute bedding, cross-laminated and burrowed in beds 5-10 cm thick.	2.0	69.5
11	DOLOMITE - brown-weathering, fine crystalline, contorted.	0.1	67.5
10	SHALE - soft grey.	11.5	67.4
9	RIBBON LIMESTONE AND SHALE.	7.0	55.9
8	CONGLOMERATE - almost all tabular clasts, mostly from ribbon limestone, largest 10 cm in size, occasional phosphate at base, granule matrix, cross-laminated.	1.0	48.9
7	RIBBON LIMESTONE - wrinkled.	0.1	47.9
6	CONGLOMERATE - numerous tabular clasts, some phosphate, channeled.	0.2	47.8
5	PARTED TO RIBBON LIMESTONE - layers 1-2 cm thick separated by shale.	5.7	47.6
4	SHALE - black, sooty.	0.5	41.9
	<u>Graptolites</u>: (RAF) **Clonograptus sormentosus** **Clonograptus tenellus**		
3	SHALE - green-grey, black sooty layers and thin layers of ribbon limestone.	2.0	41.4
2	PARTED TO RIBBON LIME MUDSTONES.	1.5	39.4
1	SHALE/SILTSTONE - begins in shallow water at low tide, sporadic cover, green-grey and black, occasional layers brown-weathering siltstone, cross-laminated at 14 m and 17 m, at 35.2 m ribbon limestone layers.	37.9	37.9
	<u>Graptolites</u>: 3 m from top **Anisograptus** sp. **Staurograptus** sp. **Dictyonema** sp.		

Section begins on west side of point at low tide.

ST. PAULS INLET - THE SCRAPE

49°50.4'N X 57°43.0'W

Unit	Description	Thickness (m) Unit	Total from base
	GREEN POINT FORMATION		
	Martin Point Member		
12	SHALE AND LIMESTONE - red shale, dolomite and lime mudstone.	6.0	139.4
11	SHALE AND DOLOMITE - shale red, occasionally green.	6.0	133.4
10	SHALE AND DOLOMITE - interbedded green shale and buff-weathering dolomite.	2.0	127.4
	Graptolites: **Dictyonema flabelliforme** s.l.		
9	PARTED LIMESTONE.	0.1	125.4
8	RIBBON LIMESTONE.	2.0	125.3
7	SHALE - green.	2.0	123.3
6	RIBBON GRAINSTONE - interbedded green shale, grainstone, cross-laminated, thin conglomerate at top.	1.0	121.3
5	RIBBON LIME MUDSTONE - minor cross-laminated grainstone, brown-weathering chert bands and nodules, deformed.	12.0	120.3
	Graptolites: 2 m from base **Dictyonema** fragments		
4	SHALE - green and black.	4.0	108.3
3	RIBBON LIMESTONE - wrinkled lime mudstone.	0.3	104.3
2	SHALE - green and black, thin, brown dolomite interbeds.	76.0	104.0
1	SHALE - same as above.	28.0	28.0

BROOM POINT

INTRODUCTION

Broom Point is a series of rocky ledges and narrow coves which extends from the mouth of Western Brook around to Hickey Cove and exposes several sections of the Cow Head. The structure is a southwest-plunging syncline and anticline whose extensively faulted limbs are overturned to the west.

The strata are mostly Cambrian in age, from the lower half of the Group, and well exposed in two sections. The longest section extends along the northern shore from Hickey Cove upsection to Mudge Cove. Strata on the eastern side of Hickey Cove are deformed and a repetition of those on the western side. The section is not continuous but is broken twice by zones of complex folding, although strata can be traced through these zones and there does not appear to be much lost. The top of this section is a severely tectonized red shale on the south side of Mudge Cove.

The central section between Mudge Cove and Sandy Cove is severely tectonized and although discrete packages of strata are present there is no coherent sequence.

The southern section between Sandy Cove and Western Brook is continuously exposed but broken by a major fault. Visible only at spring low tide, this structure removes much of the Upper Cambrian part of the sequence so that Middle Cambrian strata pass across the fault into late Upper Cambrian strata.

BROOM POINT NORTH

49°50.2'N X 57°52.3'W

Unit	Description	Thickness (m) Unit	Total from base
	GREEN POINT FORMATION		
	St. Pauls Member		
121	TECTONIC BRECCIA - platey clasts of red shale, intensively deformed.	4.8	280.6
120	COVER.	5.0	275.8
119	SHALE - red, intensively burrowed.	5.5	270.8
118	SHALE - green and red.	2.1	265.3
117	SHALE - green.	3.0	263.2
116	COVER - beach gravel.	13.0	260.2
115	SHALE - green, 20% siltstone partings.	3.0	247.2
114	COVER.	3.0	244.2
113	SHALE - green and black, recessive weathering.	2.0	241.2
112	SHALE - green and buff weathering dolomite (20%) in layers 1-3 cm thick; at 5 m and 7.1 m are red shale stringers.	13.0	239.2
111	DOLOMITE - silty with black partings; 30% greenish grey shale.	2.0	226.2
	Broom Point Member		
110	CONGLOMERATE/GRAINSTONE - 40% small tabular clasts in grainstone; no quartz.	0.6	224.2
109	GRADED CONGLOMERATE. (c) grainstone, laminated. (b) grainstone, cross-laminated cap. (a) conglomerate, mostly small equant clasts (average 2x2 cm) or tabular (average 2x4 cm); 20% matrix of smaller clasts; larger clasts at base.	3.0	223.6
	Trilobite: (RAF) **Leiostegium** sp.		
108	RIBBON LIME MUDSTONE - thin bedded as in unit 106.	0.4	220.6
107	CONGLOMERATE - tabular clasts of mudstone (averaging 0.5 x 10 cm) in 50% grainstone matrix; 20% quartz in matrix.	0.8	220.2
106	RIBBON LIMESTONE - lime mudstone and cross-laminated grainstone in beds 2-8 cm thick separated by grey shale.	5.1	219.4
	(b) thin bedded (ca. 1 cm) mainly nodular, green and black shale separated in upper meter; beds rippled and burrowed.	4.1	
	(a) equal shale and limestone.	1.0	
105	PARTED TO RIBBON LIMESTONE AND CONGLOMERATE - main lithology is parted to ribbon mudstone, thin-bedded, burrowed irregular to nodular layers less than 1 cm thick, separated by green-grey shale; punctuated by (1) grainstone in lenses 2 to 20 cm thick with brown chert. (2) conglomerate, composed of tabular clasts and quartzose grainstone matrix.	1.9	214.3

Unit	Description	Thickness (m) Unit	Total from base
104	PARTED LIME MUDSTONE - thin-bedded, irregular layers to nodul-· 0.5-1.0 cm thick, green shale partings.	1.0	212.4
	Graptolites: **Dictyonema robustum** **D. pertextum**		
103	CONGLOMERATE - large tabular clasts (average 1x20 cm) in grainstone matrix; lenticular, grades to grainstone along strike; quartz grains in matrix.	0.3	211.4
102	RIBBON LIMESTONE - dark grey to green-grey shale in layers 1-2 cm thick alternating with equally thick lime mudstone or grainstone (medium-grained); occasional chert in grainstone.	0.7	211.1
101	CONGLOMERATE - 70% equant clasts (average 3x3 cm; largest 5x8 cm), 30% tabular clasts (average 1x4 cm, largest 5x8 cm); matrix grey wackestone, weathers recessively, grainy matrix at top.	2.0	210.4
100	PARTED LIMESTONE - similar to unit 96 but layers between are grey shale; vertical to paired burrows in upper meter.	5.2	208.4
99	RIBBON LIMESTONE - grades up into parted limestone, green shale.	1.1	203.2
98	COVER - a gravel-filled gully.	9.0	202.1
97	SHALE - green and black, layers of ribbon mudstone at base, chert at top.	2.0	193.1
96	PARTED LIME MUDSTONE - layers ca. 2 cm thick separated by paper-thin green-grey weathering argillaceous limestone; evenly bedded, occasional loads; nodules common.	17.3	191.1
95	RIBBON LIME GRAINSTONE - fine to medium-grained, in layers 4-10 cm thick which often exhibit loading separated by green-grey non-calcareous shale in layers 1-10 cm thick.	2.5	173.8
	Graptolites: **Dictyonema flabelliforme** s.l. **Anisograptus matanensis** **Staurograptus dichotomus** **Clonograptus** sp.		
94	PARTED LIME MUDSTONE - layers 1-4 cm thick very evenly bedded, separated by buff-weathering greenish grey argillaceous limestone ca. 1 cm or less in thickness; above 3.0 m a brown chert is common on tops and bottoms of layers and as nodules.	7.2	171.3
	Graptolites: (F, L and S, 1982, p. 100) middle 1 m, **Dictyonema flabelliforme** cf. **anglicum** basal 1 m, **Anisograptus** sp.		
93	RIBBON LIME MUDSTONE - layers 1 cm thick separated by 2-4 cm of calcareous shale.	1.2	164.1
92	GRAINSTONE - laminated; sedimentary dikes.	0.2	162.9
91	SHALE - dark grey, sooty, and silty; 10% layers of ribbon limestone.	2.0	162.7
90	PARTED LIMESTONE - mudstone to very fine-grained grainstone, green argillaceous limestone interbeds 2-4 cm thick; very wrinkled along strike and cannot determine whether this is sedimentary or tectonic.	1.4	160.7
89	SHALE - grey to black, calcareous, silty and sooty, one lime mudstone layer.	0.4	159.3
88	CONGLOMERATE - 70% tabular clasts (average 2x10 cm, largest 2x30 cm); 30% equant (average 3x3 cm); calcite spar matrix.	1.0	158.9
	Trilobites: (F,L and S, 1982, p. 100) as in bed 86.		
87	RIBBON LIMESTONE - mudstone to fine-grained grainstone in layers 2-8 cm thick, occasionally nodular; argillaceous interlayers dark grey.	1.5	157.9
	Graptolites: (F, L and S, 1982, p. 100) **Staurograptus dichotomus**		
86	CONGLOMERATE - 60% equant clasts (average 3x3 cm); 40% tabular clasts (average 2x5 cm); 20% large exotics up to 2 m across, especially at the base; matrix argillaceous lime mudstone, as between parted limestone below, more grainy towards top.	2.6	156.4
	Trilobites: (F, L and S, 1982, p. 100) **Symphysurina brevispicata** **Neoagnostus aspidoides** **Hystricuris** sp. nov. **Pseusohystricuris** cf. **obesus**		
85	PARTED LIME MUDSTONE.	1.0	153.8
	Graptolites: (F, L and S, 1982, p. 100) **Staurograptus dichotomus**		
84	CONGLOMERATE - 40% tabular clasts (average 1x10 cm); 60% very calcareous grainstone; this is only a lens which does not extend more than 10 m in any one direction.	0.6	152.8
	Trilobites: (F, L and S, 1982, p. 102) **Symphysurina** cf. **spicata** (in matrix) **Parahystricurus** sp.		
83	SHALE - green, grey.	0.1	152.2
82	PARTED LIME MUDSTONE - as unit 77.	1.3	152.1
81	LIME MUDSTONE - very thin, platy-bedded, brown to buff-weathering, dolomitic, laminated to cross-laminated.	1.2	150.8
80	PARTED TO RIBBON LIME MUDSTONE - layers 2 cm thick.	0.7	149.6
79	PARTED LIMESTONE -	0.9	148.9
	(c) grainstone.	0.1	
	(b) shale, black sooty.	0.4	
	(a) argillaceous limestone, buff-weathering.	0.4	
	Graptolites: **Dictyonema** sp.		
78	PARTED TO RIBBON GRAINSTONE - 60% fine-grained grainstone in layers 2-10 cm thick separated by 2-10 cm thick black sooty argillaceous limestone.	2.1	148.0
	Graptolites: (F, L and S, 1982) **Dictyonema flabelliforme flabelliforme** **D. f. rusticum** **D. f.** cf. **parabola**		
77	RIBBON TO PARTED LIMESTONE - layers 2-4 cm thick, evenly bedded to nodular, separated by green-grey argillaceous limestone; numerous trilobites.	3.9	145.9
	Trilobites: 2 m above base (F, L and S, 1982, p.101) **Missisquoia typicalis** **Missisquoia** cf. **nasta** **Segmentagnostus** sp. **Parabolinella "triarthroides"** **Leptoplastides** cf. **marianus** **Symphysurina** cf. **spicata** **Gymnagnostus ?mexicanus** **Lunacrania** cf. **trisecta** **Leiobienvillia terranovica**		
	Graptolites: 2 m above base (F, L and S, 1982) **Radiograptus rosieranus flexibilis** 1 m above base rooted dendroids		
76	CONGLOMERATE - 80% tabular clasts (average 1x5 cm, largest 2x20 cm), 10% grainstone matrix.	0.8	142.0
75	PARTED LIMESTONE - alternating grainstone and mudstone separated by green-grey argillaceous limestone; grainstone lens at top.	0.5	141.2
74	CONGLOMERATE AND PARTED LIMESTONE -	3.6	140.7
	(h) conglomerate, as unit (d) but dies out laterally in 20 m.	0.3	

Unit	Description	Thickness (m) Unit	Total from base
	Trilobites: (F, L and S, 1982, p. 100) **Stenopilus latus** **Plethometopus dubius** **Raymondina** cf. **immarginata** **Theodenisia falcata** **Acheilops** sp. nov.		
	(g) parted grainstone.	0.5	
	(f) conglomerate, as unit (d).	0.3	
	(e) grainstone, thick-bedded.	0.2	
	(d) conglomerate, 1/2 tabular clasts.	1.2	
	(c) parted grainstone.	0.3	
	(b) conglomerate, tabular clasts and little matrix.	0.3	
	(a) parted limestone as unit 73.	0.5	
73	CONGLOMERATE - a resistant bed along the water's edge; 60% tabular clasts (average 2x10 cm), 40% equant clasts (average 3x3 cm), 10% matrix of lime mud or microcrystalline calcite, scattered rounded clasts to 0.2 m.	1.1	137.1
	Trilobites: (F, L and S, 1982, p. 100) **Hungaia magnifica** faunules + **Symphysurina** sp.		
	SHALLOW BAY FORMATION		
	Tuckers Cove Member		
72	PARTED LIMESTONE - thin beds of mudstone and grainstone, separated by green-grey argillaceous limestone in beds 12 cm thick.	1.7	136.0
71	SHALE - black with one layer of wrinkled limestone ca. 2 cm thick.	0.2	134.3
70	PARTED GRAINSTONE - cross-laminated and well rippled, fine-grained grainstone, black shale partings.	1.3	134.1
69	PARTED LIMESTONE - irregular bedded on scale of 1-2 cm, partings of dark grey argillaceous limestone.	2.0	132.8
68	DOLOMITE - silty.	1.8	130.8
67	PARTED GRAINSTONE - fine-grained with black specks, argillaceous limestone; mostly in water.	2.1	129.0
66	RIBBON TO PARTED GRAINSTONE - similar to unit 65 but in water and partly covered at the head of the cove.	3.0	126.9
65	RIBBON TO PARTED GRAINSTONE - beds very irregular varying from lenses ca. 0.4 m thick to nodules 1x1 cm, grainstone very calcareous, 50% grey shale.	5.0	123.9
64	CONGLOMERATE - flat tabular clasts of mudstone and grainstone, 10% argillaceous matrix, clasts commonly 2x20 cm.	0.8	118.9
	Trilobites: (K & W, 1959, p. 10) **Idiomesus** sp. **Plethopeltis** sp. **Keithia** sp.		
63	PARTED GRAINSTONE - hummocky bedding 5-10 cm thick.	1.8	118.1
62	CONGLOMERATE - similar to unit 54, varies in thickness along strike.	0.8-2.6	116.3
	Trilobites: (K & W, 1959, p. 10) **Loganopeltoides** sp. **Onchonotus** sp. **?Plethometopus** sp. **Paranorwoodia** sp. **Leiocoryphe** sp. **Theodenisia** sp. **?Bellaspis** sp. **Idiomesus** sp. **Keithia** sp. **Plethopeltis** sp.		
61	RIBBON LIMESTONE - thin-bedded, green argillaceous limestone partings.	0.6	113.7
60	PARTED LIMESTONE - beds 1-5 cm thick with black shale partings, mudstone to fine-grained grainstone.	1.5	113.1
58-59	ZONE OF COMPLEX FOLDING - cannot carry individual beds through but it looks as though most of the deformation is taken up by one or two beds.	est. 9.5	111.6

Unit	Description	Thickness (m) Unit	Total from base
57	RIBBON TO PARTED LIMESTONE.	0.5	102.1
56	CONGLOMERATE - same as unit 54.	0.6	101.6
55	RIBBON TO PARTED GRAINSTONE - irregular bedded, cross-laminated, rippled, nodular beds 1-2 cm thick, 40% shale, lenses of grainstone up to 0.5 m.	3.0	101.0
54	CONGLOMERATE - 60% tabular (average 1x5 cm; largest 2x10 cm), 40% equant (average 2x2 cm), 10% medium to coarse-grained grainstone, thin 10 cm grainstone cap.	2.2	98.0
53	PARTED LIMESTONE - similar to unit 51 but more fine-grained grainstone and beds occasionally up to 10 cm thick.	2.8	95.8
52	RIBBON LIME MUDSTONE - equal shale and limestone.	2.2	93.0
51	PARTED TO RIBBON LIMESTONE - equal amounts of mudstone and grainstone and 1/4 black shale; 1 to 2 cm thick irregular beds, rippled and nodular, and occasionally lensoid.	2.0	90.8
50	CONGLOMERATE - a resistant rib; tabular clasts (average 1x10 cm; largest 2x20 cm) = equant clasts (average 5x5 cm - but commonly up to 40x40 cm, especially in lower 1/2); matrix of packstone/wackestone.	1.2-2.3	88.8
49	CONGLOMERATE - 60% tabular clasts (average 2x10 cm, largest 1x2 m) 40% equant clasts (average 10x10 cm) of both grainstone and exotics; 10-15% matrix of wackestone to packstone with floating quartz grains, many clasts parallel to bedding, a bar of conglomerate.	2.0	86.5
48	PARTED GRAINSTONE - rippled, very fine-grained to mudstone, beds 0.5 to 2 cm thick; 20% black shale.	1.5	84.5
47	DOLOMITE - silty.	0.4	83.0
46	GRAINSTONE - medium bedded, fine-grained, brown-weathering, quartzose.	2.0	82.6
45	CONGLOMERATE - a lens that grades along strike into parted grainstone.	0.2	80.6
44	DOLOMITE - buff-weathering, laminated to cross-laminated.	1.2	80.4
43	CONGLOMERATE - 60% tabular clasts (average 4x20 cm; largest 1x2 m), 40% equant clasts (average 5x5 cm but up to 20x20 cm), chaotic fabric, packstone to grainstone matrix; many rafts of parted limestone; tabular clasts commonly quartzose grainstone.	3.1	79.2
	Trilobites: (K & W, 1959, p. 10) **Bayfieldia** sp. **Onchonotus** sp.		
42	GRAINSTONE - fine to medium-grained, buff-weathering, cross-laminated, to cross-bedded.	1.1	76.1
41	GRAINSTONE - coarse to very coarse-grained 30-40% quartz, thick-bedded, lenticular, cross-laminated, trough cross-bedded.	2.1	75.0
40	SHALE - black, 1/3 ribbon limestone in layers and lenses ca. 2 cm thick.	0.4	72.9
39	GRAINSTONE - medium-bedded in layers 10-20 cm thick, 10% black shale.	0.4	72.5
38	RIBBON LIME MUDSTONE AND GRAINSTONE - 1/2 grainstone, rippled beds 2-10 cm thick, 30% black shale.	1.0	72.1
37	CONGLOMERATE - 40% large tabular grainstone clasts; 50% quartzose (10-20%) grainstone matrix; thin cross-laminated and rippled; grainstone cap.	0.4	71.1
36	GRAINSTONE - well bedded with shale partings, no quartz.	0.5	70.7
35	GRADED CONGLOMERATE -	1.0	70.2
	(c) dolomitic siltstone.	0.2	
	(b) grainstone rippled.	0.4	
	(a) conglomerate, 1/2 clasts, 1/2 quartzose grainstone.	0.4	

Unit	Description	Thickness (m) Unit	Total from base
34	SHALE - green-grey.	0.4	69.2
33	PARTED TO RIBBON LIMESTONE - lime mudstone to fine-grained grainstone; black shale beds to partings.	1.4	68.8
32	CONGLOMERATE AND SHALE -	1.1	67.4
	(c) conglomerate.	0.5	
	(b) shale, green.	0.1	
	(a) conglomerate, thin grainstone cap with scattered quartz grains.	0.5	
31	DOLOMITE - silty, cross-laminated, in beds 2-20 cm thick, 70% grey-green shale.	3.0	66.3
30	SHALE - green-grey.	2.0	63.3
27-29	ZONE OF COMPLEX STRUCTURE - a series of tight anticlines and synclines that plunge to the southwest and have faulted, west-facing limbs.	6.5	61.3
26	CONGLOMERATE, RIBBON LIMESTONE, GRAINSTONE AND DOLOMITE -	9.8	54.8
	(w) conglomerate.	1.0+	
	(v) ribbon limestone.	0.4	
	(u) grainstone - conglomerate lens.	0.2	
	(t) ribbon limestone.	1.0	
	(s) grainstone.	0.2	
	(r) ribbon limestone.	0.2	
	(q) dolomite siltstone.	1.0	
	(p) conglomerate.	0.8	
	(o) grainstone.	0.1	
	(n) grainstone.	0.4	
	(m) ribbon limestone.	0.2	
	(l) dolomite.	0.6	
	(k) grainstone.	0.4	
	(j) dolomite.	0.2	
	(i) grainstone.	0.2	
	(h) conglomerate.	0.1	
	(g) grainstone, cross-laminated.	1.4	
	(f) conglomerate.	0.4	
	(e) dolomite, siltstone, cross-laminated.	0.2	
	(d) conglomerate.	0.4	
	(c) grainstone, quartzose, cross-laminated.	0.1	
	(b) dolomite, silty, cross-laminated.	0.1	
	(a) grainstone, quartzose, cross-laminated.	0.2	
23	GRAINSTONE-CONGLOMERATE - similar to unit 21.	1.4	42.0
22	GRAINSTONE - 10% shale and siltstone partings up to 5 cm thick between beds; thick bedded and lenticular - grainstone lenses 0.6 m thick.	4.1	40.6
21	GRAINSTONE-CONGLOMERATE - 1/2 grainstone with 10-20% quartz, 1/2 tabular clasts, in layers ca. 20 cm thick.	0.8	36.5
20	PARTED GRAINSTONE - medium-bedded, occasional floating clasts, lenticular beds; 20% dark green shale.	1.4	35.7
	Downes Point Member		
19	CONGLOMERATE - similar to conglomerate unit 10 and forming a recessive unit, lenticular along strike.	6.2	34.3
	Trilobites: (K & W, 1959, p. 10) **Loganopeltoides** sp., **Taenicephalina** sp., **Phoreotropis** sp., **Parabolina** cf. **lobata lobata**, **Protopeltura** sp., **Irvingella** sp.		
18	CONGLOMERATE - 60% tabular (average 1x10 cm) and 40% equant (average 2x2 cm) clasts; occasional large exotics; fine crystalline matrix.	1.5	28.1
17	GRAINSTONE - fine-grained, thin-bedded.	1.0	26.6
16	CONGLOMERATE - tabular (average 2x5 cm) = equant (average 3x3 cm) clasts; matrix of fine-grained grainstone; this conglomerate contains one enormous boulder 2.3 m in size, bigger than the bed.	0.6-1.3	25.6
	Trilobites: (K & W, 1959, p. 12) **Irvingella** sp., **Oligometopus** sp., **Xenocheilos** sp., **Richardsonella** sp., **Homagnostus** sp.		
15	RIBBON GRAINSTONE - cross-laminated similar to unit 9.	1.2	24.3
14	CONGLOMERATE - composed of 2 layers, lenticular.	3.2	23.1
	(b) upper zone 60% tabular clasts (average 1x10 cm), green argillaceous matrix.	2.4	
	(a) lower zone of large clasts 80% equant (average 10x10 cm, largest 1x40 cm), dolomite cement.	0.8	
	Trilobites: (K & W, 1959, p. 10) **Dunderbergia** sp., **Onchopeltis** sp., **Pterocephalops** sp.		
13	RIBBON LIMESTONE AND CONGLOMERATE -	0.6	19.9
	(b) conglomerate with same shale matrix but clasts of ribbon and equant limestone.	0.4	
	(a) thin ribbon limestone and green calcareous shale.	0.2	
12	CONGLOMERATE - similar to unit 10 but less matrix (20%) and more equant clasts (50%).	1.3	19.3
11	PARTED MUDSTONE - layers 1 cm thick, slightly grainy.	0.8	18.0
10	CONGLOMERATE - wide variety of clasts; 40% tabular (average 1x20 cm); 60% equant (average 3x3 cm, largest 10x10 cm); 30% green calcareous argillaceous matrix, less towards top and grainstone cap; weather recessively.	2.2	17.2
9	RIBBON GRAINSTONE - 10 to 20 to occasionally 40 cm thick layers and lenses, cross-laminated and rippled, 30% green calcareous shale, layers 2 cm thick.	2.6	15.0
8	CONGLOMERATE - plastered on top of underlying unit; 70% tabular clasts, commonly bent (average 1x10 cm); 30% equant clasts; 30% green argillaceous matrix.	1.9	12.4
	Trilobites: (K & W, 1959, p. 9) **Cedaria** sp., **Crepicephalus** sp., **Tricrepicephalus** sp.		
7	CONGLOMERATE - massive and chaotic unit; 40% tabular clasts (average 1x5 cm); 60% equant clasts; tabular clasts are concentrated in lower 1/2 where they may get up to 1.5 m x 2 m and are clearly rafts of the underlying ribbon mudstones; 20% green argillaceous matrix.	3.8	10.5
6	RIBBON LIME MUDSTONE - 30% limestone, 70% green calcareous shale.	0.2	6.7
5	CONGLOMERATE - similar to unit 3.	0.4	6.5
4	PARTED LIME MUDSTONE - layers ca. 1 cm thick, black shale partings.	1.0	6.1
3	CONGLOMERATE - tabular clasts (70%) (average 2x10 cm) in a grainstone matrix; occasional large equant clasts up to 0.4 m.	0.8	5.1
	Trilobites: (K & W, 1959, p. 9) **Irvingella** sp., **Buttsia** sp.		
2	PARTED GRAINSTONE - very fine-grained, cross-laminated.	0.3	4.3
1	CONGLOMERATE - mainly small tabular (90%) clasts (average 1x5 cm) with less than 10% mudstone matrix.	4.0	4.0
	Trilobites: (K & W, 1959, p. 12) **Plethopeltis** sp., **?Keithiella** sp., **?Resseraspis** sp.		

Section begins at shoreline along rocky shoreline immediately south of Hickey Cove and continues southward.

BROOM POINT SOUTH

49°50'N X 57°52.0'W

Unit	Description	Thickness (m) Unit	Total from base
	GREEN POINT FORMATION		
	Broom Point Member		
66	PARTED LIME MUDSTONE - many beds mottled to nodular, occasional chert layers, grainstone lenses.	8.0	210.3
	Trilobites: probable location, K., pers. comm.1981, (O, 1953, p. 15; FR, 1954, p. 581) **Bienvillia terranovica** **Borthaspidella gaspensis** **Leiobienvillia laevigata** **Pareuloma brachymetopa** **P. impunctata**		
	Gastropods: (FR, 1954, p. 581) **Semicircularea** sp.		
65	CONGLOMERATE - an equal number of equant and tabular clasts, occasional chert clasts.	1.5	202.3
64	RIBBON LIMESTONE - scattered grainstone lenses, contoured beds in upper part.	1.0	200.8
63	COVER.	1.8	199.8
62	PARTED LIMESTONE - very evenly bedded layers 2-4 cm thick, separated by dark grey argillaceous limestone, or calcareous shale; 30% of beds in upper 1/2 are replaced by brown-weathering chert, along the top and bottom of beds, as nodules or as whole beds.	9.1	198.0
61	PARTED LIMESTONE - mudstone and fine-grained grainstone in layers ca. 2 cm thick alternating with black shale.	1.0	188.9
60	RIBBON LIME GRAINSTONE - layers of fine to coarse-grained grainstone 4-10 cm thick which are lenticular and sometimes nodular with chert tops alternating with layers of dark grey argillaceous limestone to calcareous shale 2-20 cm thick.	2.9	187.9
	Graptolites: **Dictyonema flabelliforme** s.l.		
59	CONGLOMERATE - similar to unit 57(a).	0.4	185.0
58	RIBBON GRAINSTONE - a lenticular unit with black shale separating grainstone layers.	0.2	184.6
57	CONGLOMERATE (B1, of Fortey & Skevington, 1980) - a compound, welded unit.	1.9	184.4
	(b) similar in composition to (a) except for somewhat larger clasts (ca. 10x30 cm).	1.4	
	Trilobites: (F, L and S, 1982, p. 98) **Hystricuris millardensis** **Neoagnostus aspidoides** **Symphysurina** spp. **brevispicata** **Parabolinella** cf. **hecuba** **Pseudagnostus** ssp.		
	(a) mainly tabular clasts (average 2x10 cm) of both grainstone and mudstone; less than 10% grainstone matrix; there is a 5 cm thick grainstone cap which is partially eroded by the overlying unit.	0.5	
56	RIBBON LIMESTONE - similar to unit 54, layers of grainstone at top, cross-laminated and rippled.	0.4	182.5
	Graptolites: (F, L and S, 1982, p. 98) **Staurograptus** sp. **Dictyonema flabelliforme** s.l.		
	Trilobites: (F, L and S, 1982) **Symphysurina spicata** **Parahystricuris** cf. **obesus** **Symphysurina** cf. **cleora**		
55	RIBBON LIMESTONE - mostly mudstone in layers 2-4 cm thick; 70% green argillaceous limestone or calcareous shale.	1.4	182.1
	Graptolites: **Staurograptus** sp. **Dictyonema flabelliforme** s.l.		

Unit	Description	Thickness (m) Unit	Total from base
54	RIBBON LIMESTONE - both mudstone and grainstone, laminated to cross-laminated in layers 1-2 cm thick separated by light green-grey, brown-weathering argillaceous limestone to calcareous shale; similar to unit 50.	3.1	180.7
	Graptolites: (F,L and S, 1982) **Radiograptus rosieranus flexibilis** **Dictyonema flabelliforme sociale** **D. f. parabola** D. ssp.		
53	CONGLOMERATE AND NODULAR MUDSTONE - a complex unit with erosion and redeposition of conglomerates, in 3 units, upper contact an unconformity.	1.7	177.6
	(c) conglomerate (B2 of Fortey and Skevington, 1980), mainly tabular clasts with a grainstone matrix - a small erosional unconformity separates this unit from the one above.	0.3	
	Trilobites: (F and S, 1980) **Missisquoia typicalis** **Highgatella cordilleri** **Highgatella** sp. **Symphysurina** cf. **minima** (F, L and S, 1982, p. 98) **Symphysurina** cf. **cleora**		
	(b) parted to nodular mudstone.	0.2	
	(a) conglomerate (B3 of Fortey and Skevington, 1980), a lens of mostly tabular clasts but 10% equant exotics and clasts of clasts; matrix identical to bed 42 below.	1.2	
	Trilobites: (F and S, 1980) **Lecanthopygae** spp. **Bienvillia corax** **Leiobienvillia** sp. (F, L and S, 1982, p. 98) **Yukonaspis kindlei** **Liostracinoides texanus** **Bienvillia terranovica** **Leiobienvillia** sp.		
52	PARTED GRAINSTONE - dolomitic, fine-grained; brown and buff-weathering, finely laminated; rarely cross-laminated, massive, some flattened burrows.	2.6	175.9
51	SHALE - grey-green calcareous with 3 grainstone layers ca. 5 cm thick that are lensoid to nodular and disappear along strike; conglomerate lens in upper part.	1.0	173.3
50	RIBBON LIMESTONE - very evenly bedded, lime mudstone to very fine-grained laminated grainstone in layers 1-2 cm thick; occasionally cross-laminated; lenses of grainstone up to 10 cm thick in upper part; separated by layers of brown-weathering argillaceous limestone.	3.6	172.3
49	CONGLOMERATE - varies along strike from one unit to separate lenses; mainly tabular clasts (average 1x10 cm), matrix in lower 75% is silty dolomite but is never more than 5% of rock, in upper part the matrix is grainstone, sole of unit is an unconformity.	0-0.4	168.7
48	RIBBON LIMESTONE - alternating with green-grey shale, limestone layers 1 to 2 cm, shale layers 2-4 cm.	3.5	168.3
47	DOLOMITE - recessive, silty, laminated to cross-laminated.	1.5	164.8
46	PARTED LIMESTONE - equal proportions of mudstone and grainstone separated by either black shale or green-grey argillaceous limestone, often dolomitic; grainstone rippled and cross-laminated in layers 2 cm thick, often nodular and lensoid.	3.7	163.3
	Graptolites: Dendroid fragments		
45	RIBBON LIME GRAINSTONE - 2/3 black shale and 1/3 grainstone, as nodules and occasional persistent beds ca. 2 cm thick; grainstone at top of bed in lenses.	3.0	159.6

Unit	Description	Thickness (m) Unit	Total from base
44	PARTED LIME GRAINSTONE - cross-laminated and rippled, in layers 2 cm thick separated by black and green-grey shale; often nodular and lenticular.	0.4	156.6
43	CONGLOMERATE - (B4 of Fortey, Landing and Skevington, 1982) 70% tabular clasts (average 2x10 cm, up to 5x20 cm) composed of equal parts grainstone (quartzose) and mudstone; 30% equant clasts; 1/3 grainstone matrix; conspicuous thickening and thinning along strike.	0.3-1.3	156.2
	Trilobites: (K, pers. comm., 1981) **Jujuyaspis** sp. **Eutychaspis** sp. **Heterocaryon** sp. **Stenopilus** sp. **Leiocoryphe** sp. **Idiomesus** sp. **Theodenisia gibba**		
	(F, L and S, 1982, p. 98) **Leiocoryphe platycephala** **Stenopilus latus**		
42	RIBBON TO PARTED LIMESTONE - equal parts of mudstone and grainstone; cross-laminated, rippled, layers separated by green-grey argillaceous limestone, ca. 2 cm thick; a few conglomerate lenses ca. 0.5 m x 1 m thick; a 0.1 m thick grainstone just above the base that grades laterally into conglomerate.	2.9	154.9
	SHALLOW BAY FORMATION		
	Tuckers Cove Member		
41	CONGLOMERATE - mostly small tabular clasts less that 20 cm in size, rare equant boulders; matrix calcareous green grainstone with rare quartz grains.	2.1	152.0
	Trilobites: (K & W, 1958, p. 333) **Theodenisia** sp. **Plethometopus** sp. **Stenopilus** sp. **Leiocoryphe** sp. **Richardsonella** sp. **Stigmametopus** sp. "**Acidaspis**" cf. **ulrichi**		
	(K, 1981, pers. comm.) **Ambonolium** sp. **Stenopilus** sp. **Leiocoryphe** sp. **Phoreotropis** sp. **Idiomesus** sp.		
	(RL) **Stenopilus latus** **Leiocoryphe platycephala**		
40	PARTED TO RIBBON LIMESTONE - ribbon limestone looks to be soft sediment deformed; grainstones have scattered quartz, separated by green shale; two conglomerate lenses at 1.5 m (0.4 m thick) and 2.9 m (1.0 m thick), matrix in both quartzose grainstone.	7.6	149.9
39	CONGLOMERATE - graded with no obvious matrix at base, 20-30% matrix in center, and quartzose grainstone at top, very chaotic and swirled; tabular clasts of mudstone and grainstone, less than 10 cm in size; minor equant exotic clasts up to 20 cm; graded and cross-laminated cap 0.4 m thick, erosional base.	2.0-3.8	142.3
38	PARTED GRAINSTONE - interlayers of green shale.	1.8	138.5
37	CONGLOMERATE - a series of conglomerate lenses up to 0.2 m thick.	1.8	136.7
36	PARTED TO RIBBON LIME MUDSTONE - along strike is a lens or wedge of conglomerate up to 0.5 m in thickness.	1.8	134.9
35	PARTED TO RIBBON LIMESTONE - recessive, layers 1-4 cm, 60% limestone, dolomitic, rippled, cross-laminated; shales grey, platy calcareous.	5.2	133.1
34	GRAINSTONE - 40 to 50% quartz, cross-bedded, 20% floating clasts of mudstone.	0.8	127.9

Unit	Description	Thickness (m) Unit	Total from base
33	PARTED LIME MUDSTONE TO RARE GRAINSTONE.	0.9	127.1
32	GRAINSTONE.	0.2	126.2
31	DOLOMITE - silty.	1.0	126.0
30	GRAINSTONE.	0.5	125.0
29	DOLOMITE - silty.	1.0	124.5
28	CONGLOMERATE.	0.2	123.5
27	PARTED MUDSTONE.	0.8	123.3
26	CONGLOMERATE.	0.4	122.5
25	GRAINSTONE AND DOLOMITE - layers 0.1-0.2 m thick of quartzose grainstone and silty dolomite.	4.2	122.1
24	PARTED LIME MUDSTONE.	1.6	117.9
23	CONGLOMERATE AND GRAINSTONE - basal conglomerate (1.0m) with 40% quartz matrix, upper grainstone (1.1m), minor quartz.	2.1	116.3
	Trilobites: (21-23) (K&W, 1958, p. 332-333) **Theodenisia** sp. **Plethometopus** sp. **Stenopilus** sp. **Leiocoryphe** sp. **Richardsonella** sp. **Stigmametopus** sp. "**Acidaspis**" cf. **ulrichi**		
22	SHALE - pale green; silty.	2.4	114.2
21	CONGLOMERATE - grainstone, parted limestone and dolomite in graded beds. Conglomerate mainly tabular clasts in a matrix of quartzose grainstone; grainstone, cross-laminated, same composition as in conglomerate; dolomite, cross-laminated, silty; parted mudstone.	8.3	111.8
	(j) conglomerate.	3.2	
	(i) grainstone.	0.1	
	(h) parted limestone.	0.1	
	(g) dolomite.	0.4	
	(f) grainstone.	0.2	
	(e) conglomerate.	1.8	
	(d) a complete cycle conglomerate (0.4), grainstone (0.2), dolomite (0.1), parted limestone (0.1).	0.8	
	(c) parted limestone.	0.2	
	(b) grainstone.	0.3	
	(a) conglomerate.	1.2	
	(a), (b), (c) are very quartzose.		
20	PARTED LIMESTONE.	1.0	103.5
19	DOLOMITE - thin to medium-bedded; a few small channels of tabular clast conglomerate, rippled to cross-laminated, occasional quartz sand.	2.2	102.5
18	CONGLOMERATE, QUARTZOSE GRAINSTONE AND SHALES - conglomerates are mainly tabular clasts in a grainstone matrix; grainstones are fine to medium-grained quartzose, cross-laminated and rippled.	12.3	100.3
	(n) conglomerate with grainstone matrix, 60% clasts.	2.0	
	(m) grainstone fine-grained cross-laminated to rippled with dolomitic siltstone cap.	1.0	
	(l) conglomerate.	0.3	
	(k) conglomerate with grainstone cap.	0.4	
	(j) conglomerate with small clasts.	0.2	
	(i) conglomerate.	2.0	
	(h) parted lime mudstone.	0.4	
	(g) conglomerate.	0.9	
	(f) grainstone, grades laterally into conglomerate.	0.4	
	(e) conglomerate tabular clasts in quartzose grainstone matrix.	0.9	
	(d) grainstone cross-laminated, quartzose.	1.0	
	(c) conglomerate with grainstone cap.	0.6	
	(b) parted lime mudstone.	0.2	
	(a) grainstone cross-laminated quartzose.	2.0	
	Layers (e) to (m) very quartzose.		
17	COVER - covered by water.	2.0	88.0

Unit	Description	Thickness (m) Unit	Total from base
	Tuckers Cove Member		
16	CONGLOMERATE AND PARTED LIMESTONE IN GRADED BEDS - the conglomerates have small rounded tabular clasts less than 10 cm, a microcrystalline spar matrix, near top they have a grainstone matrix; grainstone layers are deformed by slumping.	6.6	86.0
	(g) conglomerate grainstone matrix.	0.3	
	(f) ribbon limestone and shale.	0.1	
	(e) conglomerate microcrystalline calcite matrix.	2.1	
	(d) ribbon limestone and shale.	0.6	
	(c) conglomerate.	0.4	
	(b) ribbon limestone and shale.	0.1	
	(a) conglomerate mudstone matrix at base, grainstone at top.	3.0	
	Trilobites: (K & W, 1959, p. 11) **Cheilocephalus** sp. ?**Drumaspis** sp.		
15	SHALE - mostly cover, olive green dolomitic siltstone and shale; thin contorted layers of lime mudstone.	1.8	79.4
14	CONGLOMERATE - tabular and equant clasts, less than 10 cm in size; argillaceous matrix; numerous stylocontacts.	0.6	77.6
13	LIMESTONE/SHALE - thin-bedded to fissile green-grey argillaceous limestone to calcareous shale, platy.	4.6	77.0
	COVER - large glacial boulders; at spring low tide a zone of chaotic tectonic deformation is exposed.	22.0	72.4
	Downes Point Member		
12	PARTED LIMESTONE - thin-bedded, slightly nodular, grey shale partings.	2.9	50.4
11	CONGLOMERATE - massive, thick, cliff-forming unit, composed of these obvious units, which in turn may be composite.	22.2	47.5
	(i) conglomerate, 95% clasts, 60% tabular (average 4 cm, largest 15 cm), grey-green mudstone and spar matrix.	3.0	
	(h) ribbon limestone and grey-green shale.	0.1	
	(g) conglomerate, 95% clasts, 60% tabular (average 4 cm, largest 10 cm) grey-green matrix.	2.0	
	(f) parted limestone and green shale, lenticular mudstones.	0.1	
	(e) conglomerate, 95% clasts, lenticular average clasts 15 cm, largest 10cmx3m.	0.4	
	(d) ribbon limestone and grey-green dolomite shale.	0.1	
	(c) conglomerate lenticular, 95% clasts, 70% tabular clasts (average 5-10 cm, largest 25 cm), grey-green grainstone matrix.	5.0	
	(b) conglomerate, recessive, 95% clasts 80% tabular (average 10 cm, largest 50 cm) green-brown dolomitic matrix.	0.5	
	(a) conglomerate, 95% clasts 70% tabular (average 5 cm, largest 20 cm), grey-green grainstone matrix.	11.0	
	Trilobites: (K, 1981, p. 107 - two faunas) (1) 2 boulders **Peronopsis** sp. **Tomagnostus** sp. **Meneviella venulosa** **Bailiaspis** sp. **Eodiscus** sp. ?**Hypagnostus** sp. **Ptychagnostus atavus** **Alokistocare** sp. **Spencella** sp. (2) 6 boulders **Ptychagnostus aculeatus** **Phalacroma glandiforme** **Onchonotopsis** sp. ?**Bynumia** sp. **Lecanopleura** sp. **Corynexochides** sp. **Hemirhodon** sp. **Blountia** sp. **Modocia** sp. **Bolaspidella** sp. **Arapahoia** sp. ?**Aposolenopleura** sp. **Kormagnostus** sp. ?**Homagnostus** sp. ?**Liostracinoides** sp. **Brassicicephalus** sp. **Bolaspis** sp. ?**Lonchocephalus** sp. **Kingstonoides** sp. **Bathyuriscidella** sp.		
10	SHALE - grey-green, dolomitic, with interbeds of ribbon limestone at the base, layers 10 cm thick.	3.2	25.3
9	GRAINSTONE - lenticular and cross-laminated.	0.8	22.1
8	PARTED LIMESTONE - mostly mudstone, laminated, some cross-laminated and lenticular layers.	1.5	21.3
	Trilobites: (K, 1981, p. 107) **Tomagnostus fissus** **Hypagnostus parvifrons** ?**Ptychagnostus atavus** ?**Cotalagnostus** **Meneviella venulosa** ?**Alokistocare** sp.		
7	RIBBON LIMESTONE - very finely laminated, two conglomerate lenses, cross-laminated, clasts 3.5 cm in size.	1.8	19.8
6	CONGLOMERATE AND PARTED LIMESTONE - interbedded conglomerate composed of parted limestone clasts, cross-laminated and laminated parted limestone.	1.5	18.0
5	LIMESTONE AND SHALE -	1.7	16.5
	(c) grainstone, cross-laminated, conglomerate with tabular clasts.	0.7	
	(b) parted lime mudstone, lenticular, layers, 3-5 cm thick.	0.6	
	(a) shale, black silty.	0.4	
4	CONGLOMERATE - 90% clasts, 70% tabular (average 60 cm), 10% green mudstone matrix, 1/2 clasts are same size, 10 cm.	1.8	14.8
	Trilobites: (K, 1981, p. 107, 3 boulders) **Elrathia** sp. **Onchocephalites** sp. **Kootenia** sp. **Bathyuriscus** sp. **Corynexochus** sp. **Ptychagnostus** cf. **gibbus** **Peronopsis** sp. **Alokistocare** sp. **Zacanthoides** sp.		
3	GRAINSTONE - trough cross-bedding, 3-10 cm in size.	1.6	13.0
	Trilobites: (K & W, 1958, p. 333) **Corynexochus** sp.		
2	CONGLOMERATE - chaotic, 60% clasts (average 10 cm; largest 80 cm), green mudstone matrix with grainstone cap.	5.2	11.4
1	CONGLOMERATE - three separate layers.	6.2	6.2
	(c) conglomerate, graded, mostly clasts 60% equant, top composed of cross-laminated granule-size clasts.	1.9	
	(b) conglomerate, again little matrix, 60% equant clasts, largest at base (5 cm x 1.5 m to 2.0 x 10 cm at top), 1/2 the clasts are less than 1 cm, trough cross-bedding.	3.1	
	(a) conglomerate, almost all (80%) equant clasts (average 10 cm, largest 50 cm); no obvious matrix.	1.2	
	Trilobites: (K, 1981, p. 106, 4 boulders) **Bathyuriscus adaeus** **Peronopsis** sp. **Zacanthoides** sp. **Chancia** sp. **Tonkinella** sp. **Oryctocephalus** sp. **Pagetia** sp. **Peronopsis** sp. **Ptychagnostus** cf. **gibbus** **Kootenia** sp. **Elrathia** sp. **Onchocephalites** sp.		

Section begins at base of cliff on west side of cove.

GULLS MARSH

A series of low outcrops that trend more or less parallel to the shoreline for 1 km (strike 050°, dip 50°W). The section begins at the north end in a small indentation of the coastline and continues south to the small harbour and fishing huts of Gulls Marsh. The strata at the top have swung and are oriented 035° and dip 40° west.

GULLS MARSH

49°47'N X 57°53'W

Unit	Description	Thickness (m) Unit	Total from base
	SHALLOW BAY FORMATION		
	Downes Point Member		
	Top of section covered by boulders along shoreline near small harbour and fishing huts.		
36	CONGLOMERATE - chaotic, recessive weathering, 60% tabular (average 1x20 cm) and 40% equant (average 10x10 cm) clasts in 30% green argillaceous matrix.	3.0	60.4
35	RIBBON TO PARTED LIMESTONE - 2-4 cm thick, cross-laminated calcarenites separated by 20% shale.	2.1	57.4
34	CONGLOMERATE - a lenticular unit of 70% tabular (average 2x10 cm) and 30% equant (average 5x5 cm) clasts in 10% argillaceous matrix at base and grainstone matrix at top.	1.9	55.3
33	PARTED LIMESTONE - 2-4 cm thick beds of cross-laminated calcarenites with channelized and loaded bases separated by 20% shale.	4.5	53.4
32	RIBBON LIMESTONE - equal proportions of 2 cm thick layers of lime mudstone and green-grey shale.	2.6	48.9
31	CONGLOMERATE - similar to unit 28 but calcarenite matrix; thins along strike to 0.2 m.	1.2	46.3
30	PARTED LIMESTONE - 2-4 cm thick irregular beds separated by green shale.	0.6	45.1
29	RIBBON LIMESTONE - 2 cm thick nodular layers separated by green shale.	0.5	44.5
28	CONGLOMERATE - chaotic, all tabular clasts (average 2x20 cm) in green matrix; wave fabric.	2.0	44.0
27	SHALE - green with 1/3 layers of lime mudstone 1 to 2 cm thick.	4.7	42.0
26	PARTED LIMESTONE - 4 cm thick, slightly nodular layers separated by grey shale.	0.8	37.3
25	CALCARENITE-CONGLOMERATE - a basal 0.3 m calcarenite overlain by a chip conglomerate with a grainstone matrix; lenticular along strike.	0.8	36.5
24	RIBBON LIMESTONE - green shale partings.	0.8	35.7
23	CALCARENITE - 1/4 floating tabular clasts.	0.6	34.9
22	RIBBON LIMESTONE - separated by green shale.	0.4	34.3
21	CONGLOMERATE - all tabular clasts (average 1x20 cm) in 20% green argillaceous matrix and a resistant calcarenite cap.	0.8	33.9
20	CALCARENITE - lenticular.	0.2	33.1
19	SHALE - green, 1/3 nodular ribbon limestone in layers 2 cm thick.	2.7	32.9
18	CONGLOMERATE - three welded units of equal thickness, the basal and upper units having a calcarenite matrix and the middle unit a green shale matrix.	0.7	30.2
17	SHALE - green 40% ribbon limestone layers 1 cm thick.	0.4	29.5
16	CONGLOMERATE - 2/3 tabular clasts (average 2x10 cm, up to 4x20 cm) and 1/3 equant clasts (average 5x5 cm, up to 10x10 cm) in 10 to 15% green argillaceous matrix; rafts of green ribbon limestone and shale weathering as holes up to 0.5 x 1.0 m.	2.2	29.1
15	SHALE - green, 1/4 thin limestone partings, the unit is cut out along strike.	0.4	26.9
14	CONGLOMERATE - a resistant rib that extends along the shoreline; basal 1.2 m is a recessive weathering unit of 3/4 tabular clasts (average 2x20 cm) and 1/3 equant clasts (average 5x5 cm) and rafts of ribbon limestone up to 1.0 m in size in 20% green argillaceous matrix; upper 1.0 m is resistant, has a grainstone matrix and the uppermost 40 cm is a cross-laminated grainstone cap.	2.2	26.5
	Trilobites: (K, 1982, p. 15) Upper Dresbachian trilobites.		
13	RIBBON LIMESTONE.	0.3	24.3
12	CONGLOMERATE - 2/3 tabular clasts (average 1x5 cm, up to 2x20 cm) and 1/3 equant clasts (average 4x4 cm) in 10% green dolomitized matrix.	1.0	24.0
11	RIBBON LIMESTONE - 2/3 blue-green shale and alternating mudstone, 10% cross-laminated grainstone layers, commonly loaded, calcarenite dikes, wrinkled in upper meter.	3.0	23.0
10	CONGLOMERATE - limestone chips (average 1x5 cm) in 10% green-brown argillaceous dolostone matrix; lenticular varying from 0 to 0.6 m over 40 m.	0.6	20.0
9	RIBBON LIMESTONE - 2/3 blue-green shale with nodular mudstone layers; numerous 1 mm thick limestone layers in the shale.	2.6	19.4
8	CONGLOMERATE - limestone chips (average 1x5 cm, up to 1x20 cm) in 10% dolomite matrix, irregular and lenticular along strike, green shale clasts at base.	0.4	16.8
7	PARTED TO RIBBON LIMESTONE - 4 cm thick beds irregular and lenticular along strike, black shale between.	0.5	16.4
6	CONGLOMERATE - limestone chips (average 1x10 cm), 5 to 10% equant clasts, 5% green argillaceous dolostone matrix, forms persistent ledge along shore.	2.4	15.9
5	RIBBON LIMESTONE - equal proportions of 2-4 cm thick lime mudstone layers and green shale, wrinkled in upper 1/2 m.	4.6	13.5
4	CALCARENITE - cross-laminated and lenticular, 10% floating clasts.	0.3	8.9
3	SHALE AND RIBBON LIMESTONE.	0.2	8.6
2	CONGLOMERATE AND RIBBON LIMESTONE -	4.4	8.4
	(c) conglomerate, limestone chips (1x5 cm) in 5-10% argillaceous matrix, cuts out (b) along strike.	1.9	
	(b) parted to ribbon limestone with thin conglomerate in center.	0.4	
	(a) conglomerate, chaotic fabric, 70% tabular clasts (average 2x10 cm), 30% equant clasts (3x3 cm), rafts of green shale and ribbon limestone.	2.1	
1	PARTED LIMESTONE - 2-4 cm thick mudstone layers separated by black shale.	2.0	4.0
0	CONGLOMERATE - limestone chips.	2.0	2.0
	Base of section is buried by glacial till which is being eroded by the sea.		

PARSONS POND

There are several points composed of Cow Head Group strata along the north shore, but only the one about 8 km east of the narrows exhibits a significant section.

PARSONS POND

49°59.5'N X 57°37.5'W

Unit	Description	Thickness (m) Unit	Total from base
	LOWER HEAD SANDSTONE		
38	SANDSTONE - green, in poor outcrop along shoreline.	20.0+	176.5
	GREEN POINT FORMATION		
	St. Pauls Member		
37	SHALE - red, blocky conspicuously burrowed; occasional buff-weathering dolomite layers.	10.0	156.5
36	SHALE - red.	4.0	146.5
35	SHALE - red siliceous, cherty, occasional red chert bands, ca. 2 cm thick.	1.0	142.5
34	GRAINSTONE - cross-laminated, cherty.	0.1	141.5
33	CONGLOMERATE - tabular and equant (rounded) clasts in about equal amounts; slabs and rafts of ribbon limestone up to 1 m long, largest equant clast 15 cm, green argillaceous matrix.	4.0	141.4
32	SHALE - red with dark green layers, black at top.	2.0	137.4
	Graptolites: (RAF) **Tetragraptus** sp. **Isograptus** sp. **Yushanograptus separatus**		
31	SHALE - green.	2.0	135.4
30	DOLOMITE - buff-weathering, silty.	0.1	133.4
29	SHALE - green-grey.	2.2	133.3
28	DOLOMITE - buff-weathering, silty.	0.2	131.1
27	SHALE - grey.	1.0	130.9
26	DOLOMITE.	0.2	129.9
25	SHALE - grey with very thin-bedded parted limestone.	2.0	129.7
24	DOLOMITE - buff-weathering.	0.1	127.7
23	SHALE - green and red, rare dolomite stringers.	4.0	127.6
22	SHALE - red with minor green, dolomite layers.	14.0	123.6
21	RIBBON LIMESTONE - very thin-bedded, alternating with green shale.	3.0	109.6
20	SHALE - interbedded green and red.	2.0	106.6
19	SHALE - red.	10.0	104.6
18	PARTED AND SILTY DOLOMITE.	4.0	94.6
17	SHALE - red.	4.0	90.6
16	SHALE - green-grey, occasional thin limestone beds, silty, some chert layers at base.	4.0	86.6
	Graptolites: ?**Clonograptus** (large) **Tetragraptus quadribrachiatus** **Didymograptus** of extensus group		
15	PARTED GRAINSTONE - thin-bedded, rippled, cross-laminated.	1.0	82.6
14	SHALE AND DOLOMITE - as above but more shale.	4.0	81.6
13	SHALE AND DOLOMITE - dolomite, buff-weathering, thin-bedded; green and red shale.	4.0	77.6
12	DOLOMITE AND SHALE - buff-weathering, cross-laminated silty dolomite with interbeds of bright green shale.	3.0	73.6
11	PARTED LIMESTONE AND GREEN SHALE.	1.0	70.6
10	CONGLOMERATE - small tabular clasts.	1.0	69.6
9	GRAINSTONE - cross-laminated.	0.2	68.6
8	PARTED LIMESTONE.	4.6	68.4
7	RIBBON LIMESTONE.	1.8	63.8
6	COVER - grey shale on beach.	5.0	62.0
5	SHALE - grey calcareous, thin layers and lenses of dolomite siltstone, brown-weathering, cross-laminated.	16.0	57.0
4a	Extensive folding and faulting of parted limestone - beds above vertical.	est. 10.0	41.0
4	CONGLOMERATE - 2 layers, each 2 to 3 cm thick, of mostly tabular clasts.	4.0	31.0
3	COVER - one buff-weathering dolomite.	15.0	27.0
2	SHALE - grey-green and ribbon limestone.	10.0	12.0
	Graptolites: **Didymograptus** (extensiform) large dendroids.		
1	CONGLOMERATE - all clasts of tabular limestone.	2.0	2.0
	Section begins at eastern edge of point.		

WESTERN BROOK POND

The outcrop along the shores of Western Brook Pond is similar to that in St. Pauls Inlet with headlands of Cow Head limestone and coves eroded into Lower Head Sandstone. There are three areas which display good sections, the mouth of the pond, a point halfway between the mouth and the mountain front and the inner part of the pond.

The pond is easily accessible by a Parks Canada trail and the longest and most continuous sections are exposed at the end of the trail, along the shoreline where the pond empties into Western Brook. There are two sections here, one on either side of the Brook, and although occasionally broken by small faults and obscured by covered intervals, the upper, Ordovician, part of the succession is well exposed.

A second section is present along the southern shoreline east of Stag Brook which is again accessible by trail. Exposing roughly the same part of the sequence as at the Pond mouth, the strata are, however, overturned to the west. A headland on strike across the pond on the northern shore is also composed of Cow Head strata which are overturned, but exposure is poor and not continuous.

The easternmost section is exposed on the northern side, at Snug Harbour.

WESTERN BROOK POND NORTH

49°47.2'N x 57°50.0'W

Unit	Description	Thickness (m) Unit	Total from base
	LOWER HEAD SANDSTONE		
46	SANDSTONE - minor shale, a few limestone bands; a massive unit that continues for at least 100 m up section.	100+	230.15
	Graptolites: **Glyptograptus austrodentatus**		
	GREEN POINT FORMATION		
	St. Pauls Member		
45	SHALE - green.	0.05	130.15
44	CONGLOMERATE - 80% clasts, 20% grainstone and granule size matrix, many stylolites, chert top and base.	0.3	130.1
43	SHALE - red interbedded with buff cross-laminated dolomite layers and thin ribbon limestone.	17.2	129.8
42	SHALE - red and green burrowed in 0.2 m thick units alternating with pale resistant units of dolomite with thin platy limestone about 0.5 cm.	3.1	112.6
41	SHALE - red and green interlaminated at a scale of 2 cm.	2.0	109.5
40	SHALE - red, and parted limestone.	0.8	107.5
39	SHALE - dark green, 20% red, dolomite (20%), cross-laminated.	15.2	106.7
	Graptolites: at 12 m **Isograptus victoriae victoriae** **Pseudotrigonograptus ensiformis** **Xiphograptus formosus svalbardensis**		
38	CONGLOMERATE - chaotic, graded with grainstone cap and then 2 cm thick chert layer; clasts of all shapes, both single and compound lithologies including other breccias; largest 0.5 m; 10% green argillaceous matrix, very swirled.	2.6	91.5
37	SHALE - green (70%) and red (30%) blocky weathering, siliceous; 0.1 m-thick conglomerate at 2.4 m.	6.1	88.9
36	PARTED LIMESTONE - as unit 34.	0.8	82.8
35	SHALE - green.	0.2	82.0
	Graptolites: **Didymograptus extensus** **Tetragraptus serra** (large form) **Phyllograptus anna**		
34	PARTED LIMESTONE - layers separated by light green shale; 10% lenticular cross-laminated and rippled grainstone.	4.5	81.8
33	SHALE - dark green with rare dolomite layers which are rippled, cross-laminated, and loaded; occasional black chert nodules.	2.0	77.3
32	SHALE - red with green shale partings.	2.5	75.3
31	CONGLOMERATE - tabular and equant clasts, mostly grainstone; some large clasts up to 2x50 cm; 30% peloid grainstone matrix; 10% chert clasts.	0.1-0.4	72.8
30	SHALE - red, burrowed with 25% cross-laminated, buff-weathering, burrowed dolomite.	3.1	72.4
29	SHALE - green blocky; 20% ribbon limestone.	2.0	69.3
28	PARTED LIMESTONE.	0.4	67.3
	Graptolites: **Tetragraptus fruticosus** (3-stiped) **Sigmagraptus** sp.		
27	SHALE - green.	0.2	66.9
26	SHALE - green.	0.9	66.7
	Graptolites: **Tetragraptus fruticosus** (3-stiped) **Sigmagraptus** sp.		
25	SHALE - red and green with minor parted limestone; nodular.	1.0	65.8
24	DOLOMITE - burrowed.	0.1	64.8
23	SHALE - green and red.	1.0	64.7
	Graptolites: **Tetragraptus fruticosus** (3-stiped) **Phyllograptus** sp. **Tetragraptus serra** **Dictyonema** sp.		
22	PARTED LIMESTONE.	0.4	63.7
21	SHALE - as unit 19.	1.6	63.3
20	DOLOMITE - buff, burrowed.	0.1	61.7
19	SHALE - green, red, and minor black, very siliceous, thin bedded and laminated, 20% bright red and green chert layers 20 cm thick; burrowed, alternating lime grainstone and spiculite near base.	12.6	61.6
	Graptolites: at 12.5 m **Tetragraptus serra** (prolific small forms) **Tetragraptus fruticosus**, 4-stiped **Tetragraptus fruticosus**, 3-stiped **Dictyonema** sp. at 9.0 m **Tetragraptus fruticosus**, 4-stiped **Tetragraptus fruticosus**, 3-stiped **Didymograptus ensjoensis** **Didymograptus nitidus** at 4.0 m **Tetragraptus pendens** **Didymograptus extensus** **Didymograptus nitidus** **Tetragraptus fruticosus**, 3-stiped **Tetragraptus** cf. **acclinans** **Phyllograptus typus**		
18	SHALE AND LIMESTONE - green, blocky weathering, cherty, occasional bright green 20% parted mudstone with black chert nodules, 20% cross-laminated coarse-grained grainstone, lenses that grade laterally into conglomerate with phosphate grains, conspicuous high-angle cross-bedding.	6.4	49.0
	Graptolites: **Tetragraptus approximatus** **Tetragraptus fruticosus**, 4-stiped		
17	CONGLOMERATE - tabular to equant clasts, stylolite to spar matrix, 10% green chert clasts; largest clast 3x20 cm.	0.1-1.0	42.6
16	SHALE - green with minor ribbon limestone, siliceous, and spiculitic.	0.8	41.6
	Graptolites: **Tetragraptus approximatus** **Tetragraptus fruticosus**, 4-stiped **Clonograptus** sp.		
15	CONGLOMERATE - tabular and equant clasts in green chert matrix, largest 2x10 cm.	0.5	40.8
14	PARTED TO RIBBON LIMESTONE - layers 1 cm thick, green shale.	2.2	40.3
13	CONGLOMERATE - mostly tabular clasts of grainstone, often cross-laminated, and rafts of ribbon limestone up to 2 m, as well as previous breccia; 10% green argillaceous matrix, very swirled fabric.	2.8	38.1
12	SHALE - same as unit 10.	1.0	35.3
	Graptolites: **Bryograptus** sp. **Desmograptus** sp. **Tetragraptus approximatus** Dendroids		
11	CONGLOMERATE - same as unit 9, but mostly tabular clasts of shallow water grainstone.	0.4	34.3
10	SHALE - light green with 30% lenses and nodules of cross-laminated grainstone ca. 2 cm thick.	1.0	33.9

Unit	Description	Thickness (m) Unit	Total from base
9	CONGLOMERATE - equant and tabular clasts of a wide variety of limestones, largest 10x20 cm, minor argillaceous matrix.	0-0.2	32.9
8	SHALE - red, with 20% green and grey partings ca. 2-3 cm thick.	7.2	32.7
7	COVER - buried by beach gravel, looks like green shale in water.	16.0	25.5
6	DOLOMITE - buff-weathering, cross-laminated, in beds 10 cm thick, 20% green and red shale.	1.6	9.5
5	SHALE AND PARTED LIMESTONE - red (30%) and green (60%) shale interbedded with parted limestone; red shale, occasionally cherty in upper 1/2 occasional cross-laminated, dolomite beds and conglomerate lenses.	2.4	7.9
4	PARTED LIME MUDSTONE AND BRIGHT GREEN SHALE - interbedded in three units, limestone ca. 0.3 m thick.	1.8	5.5
	Graptolites: **Tetragraptus** cf. **quadribrachiatus** **Temnograptus** sp. **Kaeierograptus** sp. (fragments) **Bryograptus** sp. numerous Phyllocarids		
3	PARTED LIME MUDSTONE - as unit 1.	0.5	3.7
2	CONGLOMERATE - tabular clasts identical to parted limestone, basal layers grade down into parted limestone, dolomite matrix.	0.8	3.2
1	PARTED MUDSTONE - layers 2 cm thick separated by laminated dolomite, commonly nodular; 2 cm thick bright green shale at 2 m.	2.4	2.4

Section begins on north side of outlet to Western Brook Pond and continues along the shoreline.

WESTERN BROOK POND SOUTH

49°47.0'N x 57°50.5'W

Unit	Description	Thickness (m) Unit	Total from base
	LOWER HEAD FORMATION		
65	SANDSTONE - green, massive minor shale; top of section contorted and faulted.	22.0	284.1
64	SHALE - green with interlaminated dolomite, 10% red shale and 10% sandstone.	5.6	262.1
63	SANDSTONE - green, well-laminated and rippled throughout.	0.8	256.5
62	SHALE - red siliceous (50%); green siliceous (30%), sandstone in even beds 2-10 cm thick (10%); at 4.4 m is a 0.4 m thick lens of conglomerate with clasts up to 15 cm across; the matrix, which is grainstone in at least the upper 1/2, is all silicified, but clasts are limestone.	10.2	255.7
	Graptolites: **Glyptograptus austrodentatus**		
61	SANDSTONE - green, granular.	0.5	245.5
60	SHALE - red and green as unit 58.	2.0	245.0
59	SANDSTONE - green, granular, soft sediment deformations.	1.1	243.0
58	SHALE - red blocky to fissile (60%), green siliceous (30%); 10% dolomite partings.	1.4	241.9
57	SANDSTONE - green granular, massive.	10.2	240.5
56	SHALE - green and red as unit 52.	0.9	230.3
55	SANDSTONE - green, a lens with soft sediment deformation.	1.0	229.4
54	SHALE - green and red as unit 52.	2.3	228.4
53	SANDSTONE - green, granular at base.	9.1	226.1
	GREEN POINT FORMATION		
	St. Pauls Member		
52	SHALE - green (60%) and red (30%), commonly silicified to chert (50%); 10% buff-weathering cross-laminated, dolomite; thin 0.1 m grainstone lens just below next unit.	3.3	217.0
51	CONGLOMERATE - thickness variable along strike; graded, largest 20x20 cm clasts at base; granule-size at top; chert base and top; argillaceous matrix at base, grainstone at top.	0.1-0.5	213.7
50	SHALE AND DOLOMITE - banded red shale (50%); buff-weathering, burrowed, cross-laminated dolomite partings (40%); green shale (10%); all often siliceous; burrowed throughout.	11.1	213.2
49	SHALE - banded red shale (60%) and buff-weathering dolomite (40%) in beds less than 1 cm thick.	4.7	202.1
48	SHALE - red shale at base grading up into green dolomite, sharp contact at top.	1.4	197.4
47	SHALE - same as 48.	0.9	196.0
46	DOLOMITE - grey to buff-weathering and red shale, dolomite at top, sharp contact.	1.4	195.1
45	DOLOMITE - same as 46.	2.2	193.7
44	DOLOMITE - shale at top of unit.	0.9	191.5
43	SHALE AND DOLOMITE - red shale at base grading up into dolomite at top; all burrowed.	0.8	190.6
42	SHALE - red and green, burrowed; at 1.0 m is a conglomerate lens 8 m in length and 0.4 m thick at maximum; clasts average 3x3 cm; 30% grainstone matrix, green chert top; at top shale grades into burrowed dolomite.	3.0	189.8
41	DOLOMITE - pale green to brown laminated to cross-laminated, shale, red, burrowed near base.	1.0	186.8
40	SHALE - red and green, with 50% chert replacement.	0.5	185.8
39	SHALE - dark green; 10% ribbon limestone and 10% dolomite.	1.5	185.3
38	SHALE - dark green, with 20% ribbon limestone and 20% parted limestone.	3.1	183.8
37	SHALE - dark green and black, banded with 10% dolomite and a 0.01 m thick band at top.	1.4	180.7
36	RIBBON LIME MUDSTONE - layers 1 cm thick, nodular and 30% green shale, at 0.1 m is a thin unit of parted limestone.	1.1	179.3
35	SHALE - green, siliceous blocky; at 0.8 m is a conglomerate that varies from 0-0.4 m over 5 m; tabular (average 1x5 cm) = equant (average 3x3 cm) clasts, numerous phosphate clasts.	1.0	178.2

Unit	Description	Thickness (m) Unit	Total from base
	Graptolites: **Tetragraptus rigidus** **Isograptus v. victoriae** **I. v.** cf. **maximodivergens** **Isograptus** sp. **Didymograptus v-deflexus** **Xiphograptus formosus svalbardensis**		
34	DOLOMITE - silty, in beds 1 cm thick separated by green shale, burrowed.	1.4	177.2
	Graptolites: (RAF) **Isograptus v. maximodivergens** (abundant) **Isograptus** sp. **Tetragraptus serra** (?**rigidus**) **Didymograptus nitidus**		
33	SHALE - dark green, black siliceous.	2.0	175.8
32	SHALE - red with black and occasionally green partings.	3.2	173.8
31	SHALE - green and 20% red, siliceous, blocky; thin grainstone at top.	1.9	170.6
30	CONGLOMERATE - graded in clast size from base where there are equal proportions tabular (average 2x20 cm) and equant (average 3x3 cm) clasts to the top where all clasts are less than 1 cm; 1/3 grainstone matrix; chert base and top; 20% cherty, siliceous, red chert or dolomite clasts weathering in relief; grades into grainstone along strike.	1.0	168.7
29	SHALE - red and green equally; vitreous chert bands.	1.1	167.7
28	SHALE AND DOLOMITE - dark green shale (60%) and buff-weathering, cross-laminated to rippled dolomite in layers up to 10 cm thick (40%); red shale bands, shales siliceous towards the top, fault near base.	6.0	166.6
	Graptolites: **Phyllograptus** sp. **Tetragraptus serra**? **Goniograptus macer**		
27	PARTED MUDSTONE AND SHALE - interbedded very thin (ca. 1 cm) parted limestone and green shale layers at top cross-laminated and burrowed rare thin chert layers.	1.6	160.6
26	SHALE - banded red and dark green; grainstone lens at 3.1 m (0.1 m thick).	4.2	159.0
25	CONGLOMERATE - tabular (average 1x20 cm)= equant (5x5 cm) clasts; chert clasts and top; cuts down into parted limestone and lenses out along strike; muddy argillaceous matrix at base, grainstone matrix at top, grainstone cap.	0-1.5	154.8
24	PARTED LIME MUDSTONE - argillaceous, partings, very nodular.	1.5	153.3
23	SHALE AND LIMESTONE - interbedded, fault in upper meter.	12.9	151.8
	(1) red, burrowed shale with buff-weathering dolomite layers; (2) dark green shale; (3) parted to ribbon limestone, very thin bedded, in which layers are almost all nodules; (4) thin lenses of grainstone - as follows:		
	(j) shale, red and minor green. Graptolites: **Didymograptus bifidus** **Didymograptus octobrachiatus**	2.0	
	(i) shale, green and red, black at base, 1/3 dolomite stringers. Graptolites: **Phyllograptus** sp. **Tetragraptus quadribrachiatus** **Tetragraptus fruticosus**, 3-stiped	3.1	
	(h) parted limestone, nodular, burrowed.	1.2	
	(g) shale, green.	1.1	
	(f) parted limestone nodular.	0.5	
	(e) shale, green.	0.1	
	(d) parted limestone nodular.	0.8	
	(c) shale, red at base, green at top. Graptolites: **Phyllograptus** sp. **Tetragraptus pendens**, 3-stiped **Tetragraptus** sp. ?**Sigmagraptus** sp. **Dichograptus** sp. (slender)	1.0	
	(b) red shale and green shale, burrowed dolomite at top.	2.0	
	(a) red shale, siltstone at top.	1.1	

Unit	Description	Thickness (m) Unit	Total from base
22	COVER - No outcrop along shoreline, which is a sandy beach with boat-dock. At low water on a windless day it is possible to see through the water that the dock is built on a 6 m thick chaotic conglomerate which is underlain by 6 m of shale and minor ribbon limestone. The rest of the section is not visible.	50.0	138.9
	Broom Point Member		
21	PARTED MUDSTONE - very nodular separated by buff-weathering argillaceous limestone up to 2 cm thick; 20% grainstone; 20% green shale in lower part.	9.3	88.9
	Graptolites: at 6.0 m **Temnograptus** sp. **Dictyonema** sp. **Clonograptus** sp. (large) **Tetragraptus** cf. **acclinans** **Didymograptus**? sp. fragments at 1 m **Dictyonema flabelliforme** s.l. **Clonograptus** sp. **Bryograptus** sp. (or **Adelograptus**)		
20	PARTED LIMESTONE AND SHALE -	6.4	79.6
	(c) shale, green, 20% grainstone.	1.8	
	(b) grainstone, coarse-grained, cross-laminated, cherty, rippled, green silty shale.	1.8	
	(a) parted limestone (30%), grainstone (cross-laminated) (20%), green shale (40%), and dolomite (10%).	2.8	
19	PARTED LIMESTONE -	3.6	73.2
	(c) conglomerate, granule to very coarse sand-sized clasts, spar matrix.	0.5	
	(b) shale, green-grey.	1.1	
	(a) parted mudstone, beds 0.5 to 2 cm thick, green-grey argillaceous partings irregular bedding, nodular; 20% grainstone layers.	2.0	
18	SHALE - green, buff-weathering dolomite interbeds 0.1 m thick.	3.0	69.6
17	GRAINSTONE - cross-bedded, graded with buff-weathering top.	0.1	66.6
16	SHALE - green and grey.	3.5	66.5
15	CONGLOMERATE - granule-sized clasts, largest 4 cm, occasional chert, grainstone matrix.	1.0	63.0
14	SHALE - green-grey.	0.2	62.0
13	CONGLOMERATE - granule size clasts and grainstone matrix.	1.8	61.8
12	GRAINSTONE - cross-laminated and graded with thin conglomerate.	2.1	60.0
11	GREEN SHALE AND DOLOMITE - partly covered.	6.0	57.9
10	CONGLOMERATE - granule-size clasts in a grainstone matrix.	1.0	51.9
9	COVER.	3.2	50.9
8	CONGLOMERATE - granule-size clasts and grainstone matrix.	5.2	47.7
7	SHALE - green with dolomite partings.	7.0	42.5
6	SHALE, SILTSTONE AND DOLOMITE - red and green shale (30%) and cross-laminated silty dolomite (70%).	4.0	35.5
5	PARTED GRAINSTONES.	4.5	31.5
	Fossils: graptolite fragments of Tremadoc aspect.		
4	COVER.	11.0	27.0
3	SHALE - light green and dolomite.	2.0	16.0
2	COVER.	7.0	14.0
1	PARTED LIMESTONE.	7.0	7.0
	Section begins just west of the outlet to Western Brook Pond along the river bank.		

STAG BROOK

49°45.6'N x 57°50.5'W

Unit	Description	Thickness (m) Unit	Total from base
	GREEN POINT FORMATION		
	St. Pauls Member		
	SECTION OVERTURNED - 050°, 45°E		
27	SHALE - green, very siliceous and cherty as unit 25.	0.5	87.4
	Graptolites: (RAF) **Isograptus v. maximodivergens**		
26	GRAINSTONE - cherty layers.	0.1	86.9
25	SHALE - green, very siliceous and cherty, thin to medium-bedded; 20% dolomite layers 5-10 cm thick, cross-laminated.	2.8	86.8
24	CONGLOMERATE - a wide variety of clasts, largest are equant 4 cm x 10 cm boulders; ribbon mudstone, skeletal mudstone, shale (10% chert clasts); 20% green argillaceous matrix; a graded top.	2.1	84.0
23	SHALE - dark green and red interbedded.	3.6	81.9
22	RIBBON LIMESTONE - thin-bedded (ca. 1 cm thick).	0.4	78.3
21	SHALE - blocky weathering red (40%), green (40%) and grey (20%).	4.0	77.9
20	SHALE - green (60%) and dolomite (40%).	2.8	73.9
	Graptolites: (RAF) **Didymograptus bifidus**, **Didymograptus** cf. **protobifidus**, **Phyllograptus** sp., **Tetragraptus serra**		
19	CONGLOMERATE - tabular and equant clasts floating in a grainstone matrix; 1/3 chert clasts; a chert cap.	0.8	71.1
18	SHALE - green, siliceous with 20% thin-bedded brown-weathering dolomite and 10% black chert.	5.2	70.3
	Graptolites: (RAF) at 2.8 m **Phyllograptus typus**, **Didymograptus** cf. **bifidus**, **Tetragraptus serra**, **Tetragraptus similis**, **Didymograptus** sp. (extensiform)		
17	RIBBON LIMESTONE AND GREEN SHALE.	1.8	65.1
16	SHALE - red and green, both fissile and blocky, interbedded; 30% buff-weathering dolomite in beds up to 0.2 m thick.	7.2	63.3
15	PARTED LIMESTONE AND GREEN SHALE.	1.1	56.1
14	PARTED LIMESTONE - very thin beds (ca. 0.5 cm) separated by brown-weathering dolomite; limestone is cross-laminated grainstone.	0.3	55.0
13	SHALE - red (60%) and green (40%), thin, interbedded, siliceous.	4.8	54.7
12	RIBBON LIMESTONE - thin-bedded, blocky, fine-grained, cross-laminated grainstone (20%); dolomite (20%); shale, green (50%); two thin conglomerate bands; rare thin chert layers.	5.4	49.9
	Graptolites: (RAF) at top prolific **Phyllograptus** sp.		
11	CONGLOMERATE - similar to unit 9 but with chert matrix.	0.2	44.5
10	SHALE - green and red (10% chert).	0.6	44.3
	FAULT		
9	CONGLOMERATE - mostly tabular clasts of laminated lime mudstone and fine-grained grainstone, very swirled and contorted, very little matrix and when seen is grey-green and argillaceous; some compound ribbon limestone clasts up to 1 m in length, others average 1x20 cm.	3.2	43.7
8	SHALE - green, 50% cross-laminated, fine-grained lime grainstone.	2.0	40.5
	Graptolites: (RAF) **Didymograptus** sp. (extensiform), **Tetragraptus fruticosus**, 4-stiped, **Tetragraptus approximatus**		
7	SHALE - green, 20% ribbon limestone at top.	4.8	38.5
	Graptolites: (RAF) **Tetragraptus approximatus**, **Didymograptus patulus** type, Dendroids		
6	CONGLOMERATE - equant-tabular clasts, largest 5 m, green argillaceous matrix.	0.2	33.7
5	SHALE - red, sporadically burrowed, 30% green shale, 10% buff-weathering dolomite.	18.6	33.5
4	DOLOMITE - cross-laminated.	0.3	14.9
3	SHALE - green, with 2 to 5 cm thick beds of cross-laminated dolomite.	3.8	14.6
2	PARTED LIMESTONE AND SHALE - alternating layers 20 cm thick of green shale (occasional red at base) and parted limestone in beds 2-4 cm thick.	5.8	10.8
	Broom Point Member		
1	PARTED LIMESTONE - layers separated by green siliceous shale, often nodular.	5.0	5.0
	Section begins at second prominent point east of Stag Brook, beds sheared and deformed, section overturned.		

SNUG HARBOUR

This locality is the easternmost headland on the north shore of Western Brook Pond before the mountain front. The headland protects a small cove called Snug Harbour by local residents because it opens to the southeast, offering protection from the strong westerlies that prevail during summer months. The headland is composed of Cow Head Group limestones folded into a tight syncline whose faulted, northwest-southeast axial plane dips eastward. The main body of the section is flanked on both limbs by outcrops of white limestone, which form a separate headland on the western limb, and an area of scattered outcrop on the beach in Snug Harbour on the eastern limb, both of which are separated from the main section by cover. Across the cove, some 200 m from the easternmost outcrops of Cow Head, the eastern shore of Snug Harbour is composed of Precambrian granite and granite gneiss with numerous mafic dikes.

The section described here is from the eastern limb of the syncline.

SNUG HARBOUR

49°46.2'N x 57°48.0'W
Core of a faulted syncline

Unit	Description	Thickness (m) Unit	Total from base
25	CONGLOMERATE - turning point and steep cliffs east of bay; composed of beds of chip to small tabular clast conglomerate with a dolomite matrix 1.0-1.5 m thick separated by 10-20 cm thick layers of green siltstone and shale.	7.0	69.2
24	SHALE AND BEDDED LIMESTONE - a recessive unit similar to unit 22 but with 2/3 green shale and thinner limestone.	2.4	62.2
23	CONGLOMERATE - chip clasts with 15% dolomite matrix.	2.2	59.8
22	SHALE AND BEDDED LIMESTONE - a recessive unit composed of 1/2 green shale beds, 1/4 calcarenite turbidites with dolomitic caps in beds 2-4 cm thick, 1/8 buff-weathering rippled siltstone and 1/8 black shale.	2.4	57.6
21	CONGLOMERATE AND CALCARENITE -	1.5	55.2
	(b) grainstone, with shale partings.	0.3	
	(a) conglomerate, similar to unit 10.	1.2	
20	GREEN SHALE AND CALCARENITE.	0.2	53.7
19	CONGLOMERATE - chip clasts and dolomite matrix.	0.3	53.5
18	CONGLOMERATE - a recessive core formed by a unit with 1/3 green argillaceous matrix and 2/3 subrounded to tabular lime mudstone or conglomerate clasts 5 - 20 cm in size.	4.4	53.2
17	CONGLOMERATE - a series of welded conglomerates composed predominantly of chip clasts.	1.2	48.8
16	SHALE AND NODULAR LIMESTONE - green shale and equal proportions of nodules or layers of fine-grained calcarenite about 4 cm thick.	0.4	47.6
15	CONGLOMERATE - a series of welded chip clast conglomerates with scattered rounded boulders in 10 to 15% stylolitic dolomite matrix.	3.5	47.2
14	CONGLOMERATE - similar to unit 10, but sheared and faulted.	3.1	43.7
	SHALLOW BAY FORMATION		
	Downes Point Member?		
13	COVER - scattered outcrops of shale and calcarenite.	0.8	40.6
12	CONGLOMERATE - chip clasts in 10% dolomite matrix.	1.3	39.8
11	COVER - occasional outcrops of grey shale.	4.0	38.5
10	CONGLOMERATE - forming a prominent headland this unit is chaotic composed of: (1) 30% tabular clasts (1 cm x 2-4 cm) and equant clasts (1 cm); (2) 30% subequant clasts up to 20 cm; (3) 10% rafts of parted limestone and; (4) 20% tabular clasts up to 4x30 cm of conspicuous green-hued dolomitized limestone, all in 10% brown-weathering dolomite matrix.	6.3	34.5
9	LIMESTONE AND SHALE - alternating beds of the following lithologies: (1) 20% dark grey fissile shale; (2) 40% green shale with nodular or wrinkled lime mudstones; (3) 20% buff-weathering dolomitic, rippled siltstone in mm to cm layers; (4) 20% calcarenite turbidites which grade up into rusty-weathering siltstone tops; 2 m from the top is a 0.5 m thick conglomerate with tabular clasts floating in grainstone.	8.8	28.2
8	COVER - small outcrops suggest that it is the same lithology as unit 6.	2.1	19.4
7	CALCARENITE - very coarse grained turbidite with conglomerate clasts at the base and scattered quartz.	1.3	17.3
6	LIMESTONE AND SHALE - interbedded, 40% dark grey fissile shale in layers 5-10 cm thick with thin, brown-weathering mm-thick siltstone partings, 10% green shale and 50% calcarenite turbidites 5 to 20 cm thick and a siltstone shale cap.	1.4	16.0
5	CALCARENITE - coarse-grained.	1.1	14.6
4	CONGLOMERATE - similar to unit 1.	4.8	13.5
3	SHALE - forms a narrow cleft in section, dark grey with minor dolomitic siltstone partings.	1.2	8.7
2	CALCARENITES - welded to top of conglomerate, coarse-grained.	1.3	7.5
1	CONGLOMERATE - forms the easternmost headland and shear cliffs and is composed of clasts 2-4 cm in size in a stylolitized dolomite matrix.	6.2	6.2
	Trilobites: collected from similar bed on western limb of syncline (K, 1982, p. 10, 12, fig. 2) **Bolaspidella**? sp. **Pagetia** sp.		
	The more continuous section begins in the steep cliff which forms the western shore of Snug Harbour; faulting can be seen along cliff; thick bedded (2-6 cm) conglomerate units can be seen beneath the water underlying the basal unit.		
	On both sides of the syncline an area of no exposure estimated at 40 m separates the basal white limestone unit from the main part of the section.		
	WHITE LIMESTONE - a massive unit of small clast conglomerate, calcarenite and mudstone with several meters of ribbon limestone at base which forms a small headland on western limb and a series of outcrops on the beach on eastern limb.	est. 10.0	10.0

MARTIN POINT

There are two sections of Cow Head exposed at Martin Point, the well-known section at the Point and a shorter section to the north, here called Martin Point North.

The main section runs south from the cove north of the point, around the promontory and along the shoreline to the contact with the Lower Head Sandstone. Although exposed in past years, the upper part of the section is now partly covered by a garbage dump. The section is underlain by Lower Head Sandstone and although the contact is covered in the small harbour, it is clearly faulted, as at Lower Head.

MARTIN POINT

49°46.2'N x 57°54.6'W

Unit	Description	Thickness (m) Unit	Total from base
	LOWER HEAD SANDSTONE		
65	SANDSTONE - with green siltstone and shale.	70.0	498.8
	GREEN POINT FORMATION		
	St. Pauls Member		
64	SHALE - red, red chert with radiolaria.	2.0	428.8
63	CONGLOMERATE - irregular to rounded boulders in a green argillaceous matrix; chert top; outcrop on shoreline and in cliff.	2.0	426.8
62	SHALE - red and buff-weathering; siltstone, dolomitic, a few burrows.	14.0	424.8
61	SILTSTONE - green dolomitic.	0.2	410.8
60	SHALE - red, blocky, burrowed.	5.0	410.6
59	RIBBON LIMESTONE - green-grey, burrowed; red shale interbeds.	7.0	405.6
58	SHALE - red and green, burrowed, a 0.2 m thick conglomerate outcrops in cliff at 6.0 m.	13.0	398.6
	<u>Graptolites</u>: **Isograptus** sp. (manubriate) **Isograptus victoriae maximodivergens** **Didymograptus v-deflexus** **Tetragraptus** cf. **rigidus**		
57	SHALE - green siliceous, banded, blocky.	0.3	385.6
56	SHALE - green, outcrop between glacial pebbles on the beach.	11.0	385.3
	<u>Graptolites</u>: (K & W, 1958, p. 330 - location approximate) **Dichograptus octobrachiatus** **Isograptus v. victoriae** **Didymograptus** ssp. **?Glossograptus** sp.		
55	CONGLOMERATE - large rounded boulders up to 5.0 m, some ribbon limestone clasts; green argillaceous matrix, chert cap.	1.0	374.3
54	SHALE AND THICK RIBBON LIMESTONE.	3.0	373.3
53	SHALE - green-grey.	2.0	370.3
52	SHALE - green, occasionally blocky.	13.8	368.3
51	CONGLOMERATE - similar to unit 47.	0.5	354.5
50	COVER - shale float.	3.0	354.0
49	RIBBON LIME MUDSTONE.	1.0	351.0
48	SHALE - red and occasional green, good outcrop in cliff.	28.5	350.0
47	CONGLOMERATE - 90% clasts, most tabular, largest 3x15 cm; some phosphate pebbles; green argillaceous matrix, chert matrix at top.	1.0	321.5
46	SHALE - red and green.	1.1	320.5
	<u>Graptolites</u>: (BE, 1971, pers. comm., 1984) **Tetragraptus approximatus**		
45	CONGLOMERATE - 95% tabular clasts, largest clasts 40 cm, almost all ribbon limestone clasts, green-grey mudstone matrix.	0.4	319.4
44	SHALE - green.	0.1	319.0
43	CONGLOMERATE - 2/3 clasts, 3/4 tabular, average 2 cm, largest 5 cm, almost all ribbon limestone; grainstone matrix.	0.2	318.9
42	PARTED TO RIBBON LIMESTONE AND SHALE -	64.7	318.7
	(g) shale, red and green, parted lime mudstone in upper 2 m.	8.4	
	(f) shale, red.	17.0	
	(e) shale, red and green with black partings, dolomite partings in upper 4 m.	16.0	
	Broom Point Member		
	(d) parted limestone and black, red, dark green shale; ribbon limestone in upper 1/3.	17.0	
	<u>Graptolites</u>: **Bryograptus** sp. **Adelograptus** sp.		
	(c) ribbon and parted limestone, grainstone to calcareous siltstone, rippled to cross-laminated occasional paired burrows, occasional nodules.	1.6	
	<u>Graptolites</u>: **Temnograptus** sp. **Bryograptus** sp. very abundant **Adelograptus** sp. **Clonograptus** sp. (BE, 1971) **Tetragraptus** cf. **decepiens**		
	(b) ribbon limestone, cross-laminated; 75% bright green shale, occasional minor conglomerate lenses.	2.7	
	(a) parted lime grainstone, laminated to cross-laminated, irregular bedded, rarely more than 2 cm thick.	2.0	
	<u>Graptolites</u>: **Clonograptus** sp. (small)		
41	CONGLOMERATE - 95% clasts, 80% equant (average 8 cm, largest 30 cm), wide variety in composition including chert, grainstone matrix, upper meter has spar matrix.	1.7	254.0
	<u>Trilobite</u>: (RAF) **Leiostegium** sp.		
40	SHALE - parted to ribbon limestone.	16.8	252.3
	(f) parted lime mudstone, 2-3 cm thick, irregular bedded to brecciated.	0.4	
	(e) shales, black and grey-green laminated siliceous.	0.6	
	(d) parted to ribbon mudstone, 2-3 cm thick, irregular bedded to brecciated, 0.3 m ribbon limestone, 2.0 m parted limestone.	2.3	
	(c) shale, dark green and brown-weathering, cross-laminated siltstones.	1.4	
	(b) shale, red (60%) and green (10%), interbedded 30% brown-weathering dolomite siltstone in lower half.	10.2	
	(a) shale and dolomite, olive green weathering, calcareous shale (60%) and ribbon dolomitic siltstone.	1.9	
39	CONGLOMERATE - 95% clasts, bimodal and graded with pebbly grainstone top, 80% tabular clasts (average 2x8 cm, largest 3x80 cm); grey-green mudstone matrix.	1.5	235.5
38	PARTED TO RIBBON LIMESTONE AND SHALE -	3.6	234.0
	(b) ribbon limestone, mudstone and grainstone in beds 5-10 cm thick, grainstone rippled and cross-laminated.	3.0	
	(a) shales, dark grey-green, recessively weathering, occasional nodules.	0.6	
	<u>Graptolites</u>: **Dictyonema** cf. **pertextum** Dendroids abundant Phyllocarids		

Unit	Description	Thickness (m) Unit	Total from base
37	CONGLOMERATE - 90% clasts, 85% tabular, grey-green, brown-weathering dolomitic matrix, average clast 5 cm, largest clast 3x25 cm, swirled, clasts of clasts, occasional chert clasts.	1.6	230.4
36	RIBBON LIMESTONE AND SHALE -	140.4	228.8
	(z) parted to ribbon limestone-mudstone and fine-grained grainstone, 2 cm thick; loads; 10% grey-green shale.	3.4	
	(y) conglomerate, 1/3 clasts, 90% tabular (average 3 cm, largest 15 cm), grainstone matrix, basal flute marks.	0.4	
	(x) parted limestone and 40% grey-green shale; conglomerate lens at 2.0 m of tabular clasts and grainstone matrix.	5.5	
	(w) parted limestone, basal 2 cm irregular bedded mudstones - upper 3 m grainstone, chert layers at 2 m.	5.0	
	(v) ribbon limestone and grey-green shale nodular, chert layer at 3.0 m, 85% grey-green shale; conglomerate lens, 0.2 x 3 m, 2 m from top; 70% clasts, 90% tabular, grainstone matrix, quartz and phosphate grains. Conspicuous bright green and black banded shale in basal 2 m.	10.0	
	Graptolites: in basal 1 m **Adelograptus hunnebergensis**		
	(u) ribbon to parted lime mudstone and minor grainstone, occasionally nodular ca. 1 cm thick or less and 30% grey-green shale.	6.0	
	Graptolites: **Dictyonema flabelliforme**, **Staurograptus dichotomus**, **Anisograptus richardsoni**		
	(t) ribbon lime mudstone (wrinkled) ca. 1 cm thick alternating with grey-green shale, thin layers of rusty-weathering dolomitic siltstone.	7.8	
	(s) ribbon lime mudstone to fine-grained grainstone, laminated and cross-laminated, up to 10 cm thick.	2.2	
	Graptolites: 1.0 m above base (BE) **Dictyonema flabelliforme**, **Staurograptus dichotomus**		
	Martin Point Member		
	(r) shale, grey-green with 10% parted lime mudstone (wrinkled) and 30% rusty weathering siltstones.	11.0	
	(q) parted grey-green lime mudstone, nodular and wrinkled, rippled, graptoloid fragments.	1.8	
	(p) shale, grey-green.	3.0	
	Graptolites: **Dendrograptus** sp.		
	(o) parted limestone and 80% grey-green shale.	3.2	
	(n) conglomerate, 80% clasts all tabular (average 3 cm, largest 8 cm), grey-green grainstone matrix.	0.3	
	(m) ribbon limestone (often nodular) and grey-green shale, wrinkled limestone at 4.0 and 8.1 m; lime mudstone; conglomerate lens at 8.4 m, tabular clasts with a grey-green grainstone matrix.	28.3	
	(l) shale, grey-green with 20% brown-weathering grainstone.	4.4	
	(k) ribbon lime mudstone, nodular and rippled fine-grained grainstone; 70% grey-green shale.	4.0	
	(j) shale (60%) grey-green, and rusty, brown-weathering dolomitic siltstones.	1.5	
	(i) ribbon lime mudstone, nodular and 70% grey-green shale.	10.5	
	(h) ribbon grainstone (40%) finely laminated; 60% grey-green shale; upper meter is rusty brown-weathering, fine interlaminations of grainstone and dolomitic siltstone.	2.4	
	(g) conglomerate, 80% clasts, all tabular (average 3 cm, largest 8 cm) mudstone.	0.2	
	(f) ribbon limestone (40%) mudstone; 60% shale.	1.0	
	Graptolites: **Dendrograptus** sp.		
	(e) ribbon limestone (1/4), nodular, mudstones, quartzose, rare conglomerate lenses, 3/4 shales.	0.7	
	(d) grey-green shale and brown-weathering silty dolomite, 1-10 cm thick, flaggy, rippled, burrowed (**Planolites** sp.), current lineations.	6.0	
	(c) ribbon limestone (30%), finely laminated mudstone to grainstone; shale (70%).	10.8	
	(b) shale, green-grey, thin grainstone partings, graptoloid fragments.	7.0	
	(a) ribbon limestone (30%), rippled, nodular, quartzose grainstone; shale (70%).	4.0	
	Graptolites: **Dendrograptus** sp.		
35	GRAINSTONE, CONGLOMERATE, RIBBON LIMESTONE AND SHALE - ribbon lime mudstone and green shale with quartzose grainstone lenses; quartzose grainstone grading laterally into conglomerate with 1/3 grainstone matrix (average clasts 10 cm, largest 2x20 cm); conglomerate, 60% clasts, all tabular, grey-green quartzose grainstone matrix.	3.2	88.4
34	CONGLOMERATE - 3/4 clasts, all tabular, grey-green grainstone matrix; lenticular 0.3 to 0.6 m.	0.6	85.2
33	RIBBON LIME GRAINSTONE - parallel to cross-laminated, lenses of conglomerate, 85% clasts, quartz-rich grainstone matrix, clasts (average 10 cm, largest 2x25 cm), imbricated; interbedded lime mudstones, wrinkled and occasionally broken.	3.0	84.6
	SHALLOW BAY FORMATION		
	Tuckers Cove Member		
32	GRAINSTONE - grey to brown-weathering, dolomitized, parallel to cross-laminated, loads; upper 0.4 m is a conglomerate in grainstone matrix, floating quartz grains, clasts of bed 31.	2.2	81.6
31	LIMESTONE, SANDSTONE AND SHALE -	10.9	79.4
	(f) parted mudstone, wrinkled.	0.2	
	(e) sandstone, very calcareous, grainstone clasts, finely cross-laminated to planar bedded.	0.6	
	(d) sandstone, finely cross-laminated, good ripples, occasional clasts; upper part finely intercalated grainstone, mudstone, sandstone - brecciated along strike.	0.6	
	(c) grainstone, quartzose, small trough cross-beds.	0.4	
	(b) ribbon lime mudstone and green calcareous shale, very wrinkled.	2.3	
	(a) irregular layered grainstone (3/4), cross-laminated (current direction from NW), and interlayered green calcareous shales; conglomerate lens 0.3 m thick at 2.6 m (30% clasts) quartzose grainstone matrix.	6.8	
30	CONGLOMERATE - a welded bed of 2 units separated by green shale parting: both units have ca. 80% clasts (average 10 cm, largest 25 cm), most of which are tabular; the more resistant upper 0.8 m has a grainstone matrix, the lower unit has an argillaceous matrix.	2.5	68.5
	Trilobites: (K, 1981, p. 109) **Bathyholcus** sp., **Quebecaspis** cf. **coniforns**, **Richardsonella** sp., **Tholifrons** sp., **Xenocheilos** sp., **Oligometopus** sp., **Oligometopus** cf. **xenocheilos** (RL), **Levisella** sp., **Loganellus** sp.		
29	PARTED TO RIBBON LIMESTONE AND SHALE -	6.4	66.0
	(c) same as (a), dendroids.	0.8	
	(b) parted grainstone, rippled to cross-laminated; rare burrows, vertical to subhorizontal to horizontal.	3.8	
	(a) ribbon limestone and calcareous green-grey shales; laminated mudstone and cross-laminated grainstone.	1.8	
28	CONGLOMERATE - 80-85% clasts, 90% tabular (average 2x8 cm, largest 2x20 cm), green-brown grainstone matrix.	0.8	59.6
27	RIBBON LIME MUDSTONE - 2/3 limestone separated by green, slightly calcareous shales.	0.8	58.8

Unit	Description	Thickness (m) Unit	Total from base
26	CONGLOMERATE - 3/4 clasts, all tabular (average 5 cm, largest 2x15 cm), of mudstone and grainstone and clasts of clasts of underlying lithologies; a brown-weathering green, partially dolomitized grainstone matrix.	0.5	58.0
25	RIBBON LIME MUDSTONE - bright green slightly calcareous shales; 2 conglomerate bands, each 0.2 m thick at 0.3 and 0.6 m composed of ribbon limestone clasts.	1.2	57.5
24	CONGLOMERATE - 2/3 ribbon limestone clasts (average 5 cm, largest 10 cm); grey-green calcareous mudstone to fine-grained grainstone matrix.	0.1-0.3	56.3
23	RIBBON TO PARTED LIMESTONE -	8.8	56.0
	(d) parted limestone, very fine-grained graded grainstone, cross-laminated, grey to grey-green.	2.8	
	(c) 3/4 green slightly calcareous shale; fine-grained cross-laminated grainstone.	2.6	
	(b) parted sandy grainstone, planar to cross-laminated, lenticular; bright green shale partings.	1.6	
	(a) ribbon limestone and green shale, irregular, finely laminated 5-10 cm thick beds.	1.8	
22	PARTED LIME GRAINSTONE - undulatory bedding; at 1.4 m is a 0.3 m thick welded conglomeratic unit, equal numbers of tabular and equant clasts, cross-laminated; at 1.8 m is a 0.2 m unit of strongly folded lime mudstone.	2.4	47.2
	Trilobites: (RL) **Hungaia** sp.		
21	CONGLOMERATE - 90% clasts, 80% tabular (average 4 cm, largest 15 cm) rusty brown-weathering dolomitic grainstone matrix.	0.5	44.8
20	RIBBON LIMESTONE - green, 2/3 shale; limestones vary from mudstone to silty grainstones which are cross-laminated; a lens of conglomerate 0.2 m thick and 3 m long.	2.0	44.3
19	CONGLOMERATE - 90% clasts, almost all tabular (average 3 cm, largest 15 cm), brown-weathering dolomitic grainstone matrix.	1.4	42.3
18	SILTSTONE AND SHALE - brown-weathering, green dolomitic siltstone, cross-laminated and green shale.	1.8	40.9
17	CONGLOMERATE - 95% clasts, all tabular (average 5 cm, largest 30 cm); brown-weathering dolomitic siltstone matrix.	0.5	39.1
16	RIBBON LIMESTONE - green shales with a lenticular interbed of grey-brown dolomitic siltstone 0.3 m thick at 0.9 m which is rippled and cross-laminated.	1.9	38.6
15	CONGLOMERATE - 90% clasts, 3/4 of which are tabular (average 5 to 8 cm, largest 15 cm); grey-green siltstone matrix; highest conglomerate in cliff and is folded to form nose of point.	5.0	36.7
14	RIBBON LIME MUDSTONE - interlayers of green shales; forms part of a folded sequence at nose of Martin Point.	1.8	31.7
13	CONGLOMERATE - 2/3 clasts, 90% tabular (average 10 cm, largest 15 cm), grey-green dolomitic grainstone matrix.	1.4	29.9
12	GRAINSTONE - parallel-laminated, green.	0.3	28.5
11	GRAINSTONE - dolomitic, grey-brown weathering massively bedded with a few tabular clasts; grades laterally westward into flat-pebble conglomerate with 70% grainstone matrix.	0.5	28.2
10	SILTSTONE - rusty brown-weathering, calcareous; finely parallel to cross-laminated.	0.3	27.7
9	CONGLOMERATE - 95% clasts of which 90% are tabular (average 5 cm, largest 40 cm); green mudstone matrix; unit cuts down as far as unit 7; a 0.1 m shale seam at 1.8 m.	2.5	27.4
8	DOLOMITE - brown-weathering, silty; parallel to cross-laminated, rippled; cut out westward by conglomerate above.	1.5	24.9
7	CONGLOMERATE - small pebble conglomerate, 90% clasts, equal numbers of tabular and equant (average 4 cm, largest 25 cm); lower half has green mudstone matrix, upper half grainstone matrix; upper part cut out along strike by unit 9.	1.8	23.4
	Trilobites: (K, 1981, p. 109) **Levisella brevifrons**, **Hungaia** cf. **burlingi**, **Simulolenus** sp., **Liostracinoides** sp., **Loganopeltoides kindlei**		
6	RIBBON LIMESTONE - alternating beds of limestone and green dolomite, slightly calcareous shales; unit thins to 1.0 m, recessively weathering.	1.4	21.6
5	CONGLOMERATE - lenticular; 3/4 small, rounded pebbles but several large clasts of ribbon limestone and shale up to 0.4 m, clasts become more tabular westward along strike; dolomite and shale matrix; bed thins to 0.8 m southwestward.	2.3	20.2
4	PARTED TO RIBBON LIMESTONE - parted limestones are grainstone, ribbon limestones, and mudstones; 1/2 green shale; lenses of conglomerate 0.1 to 0.6 m thick; all units contorted westward.	2.5	17.9
3	CONGLOMERATE - chaotic, 95% clasts, 3/4 of which are equant (average 8-10 cm, largest 25 cm); tabular clasts clearly from underlying bed; matrix green-grey argillaceous, same as the bed below, top 20 cm spar matrix and so resistant.	2.3	15.4
	Trilobites: (K, 1981, p. 108) **Aphelaspis** sp., **Dunderbergia** sp., **Dytremacephalus** sp., **Pterocephalops** sp.		
2	CONGLOMERATE AND RIBBON LIMESTONE -	0.9	13.1
	(b) ribbon lime mudstone, alternating with 2/3 grey-green shale in layers 1 cm thick.	0.6	
	(a) conglomerate, 80% small equant clasts (average 2 cm, largest 4 cm) green mudstone and spar matrix, lenticular in (b), disappears in 30 m along strike into small lenses.	0.3	
1	SHALE - green, fissile, non-calcareous; at 4.3 m a 0.1 m bed of grainstone and conglomerate; at 9.0 m a 10.0 m bed of ribbon lime mudstone; at 10.6 m and 11.9 m a 0.1 m layer of ribbon limestone.	12.2	12.2
	Section begins at base of cliff in southeastern corner of cove; lowest beds exposed only at low tide.		

MARTIN POINT NORTH (THE WRECK)

These strata are exposed at the base of the cliff and along the shoreline north and south of the wreck north of Martin Point. The section begins about 800 m north of the wooden stairs and continues south past the wreck of S.S. Ethie to the man-made harbour and fishing huts below the cliff at Martin Point. The section is separated from the Gulls Marsh section to the north by a 1 km stretch of beach. As these rocks are wholly younger than those to the north and bedding is more or less concordant they may represent the top of the sequence that begins at Gulls Marsh.

MARTIN POINT NORTH (THE WRECK)

49°46'N x 58°54'W

Unit	Description	Thickness (m) Unit	Total from base
	LOWER HEAD SANDSTONE		
70	SANDSTONE - green in ribs about 0.6 m thick alternating with equal amounts of cover, excellent dewatering structures.	16.0	200.1
69	COVER - small outcrops of green shale between boulders.	4.0	184.1
68	SANDSTONE AND SHALE - alternating green sandstone beds 0.4 m thick and red and green shale beds 0.6 m thick.	2.0	180.1
67	SHALE - green at base grading upward into red.	4.0	178.1
66	SANDSTONE - green soft sediment deformation, lumps and clasts.	1.0	174.1
65	CALCARENITE - laminated to cross-laminated.	0.4	173.1
64	SANDSTONE - green, dikes, nodules and clasts, grading to green shale in upper 0.6 m.	2.6	172.7
63	SILTSTONE - green laminated.	1.1	170.1
62	SANDSTONE - green, with dikes, nodules and clasts.	3.0	169.0
61	SANDSTONE - green, irregular outcrop between boulders on shoreline, strata above exposed only on shoreline.	5.5	166.0
60	COVER.	5.0	160.5
59	SANDSTONE - green, massive.	4.0	155.5
	GREEN POINT FORMATION		
	St. Pauls Member		
58	SHALE - red.	0.4	151.5
57	CONGLOMERATE - exposed both on backbeach in cliff and on shoreline; poor exposure; a wide spectrum of clast size and composition (max. 0.4 m), 10 to 20% green argillaceous matrix at base, upper 1/4 silicified calcarenite, sporadic silicified cap.	1.8	151.1
56	SHALE - red, 1/4 green.	2.1	149.3
55	SHALE - well-exposed in cliff as small brook tumbles down slope over outcrop, red, 1/3 buff dolomite and green shale, intensively borrowed.	9.2	147.2
54	SHALE - green, blocky, siliceous.	2.0	138.0
53	COVER.	1.0	136.0
52	SHALE - green, blocky, siliceous.	1.5	135.0
51	COVER.	1.0	133.5
50	SHALE - green and red.	0.5	132.5
49	CONGLOMERATE - calcarenite matrix.	0.4	132.0
48	PARTED LIMESTONE - thin bedded, green shale partings.	0.5	131.6
47	COVER - conglomerate on beach (0.2 m).	5.0	131.1
46	SHALE - green.	0.4	126.1
45	COVER.	8.0	125.7
44	SHALE - base of stairs and wreck; green.	1.0	117.7
43	COVER.	5.0	116.7
42	SHALE - green, blocky.	1.0	111.7
41	COVER.	1.8	110.7
40	CONGLOMERATE - most prominent outcrop both in backbeach cliff and as rib out to sea (000°, dip 27°W); chaotic fabric of large subrounded boulders as large as 2.0 m (average 0.4 m) and rafts of parted limestone in 20% green argillaceous matrix in lower recessive-weathering half and tabular clasts with 1/3 subequant clasts in upper resistant-weathering half; an irregular chip conglomerate with calcarenite matrix in lenses up to 0.6 m thick along top; brown chert replaces calcarenite matrix at top.	2.3	108.9
39	SHALE - green, siliceous, blocky with minor thin beds of siltstone and spiculitic limestone.	2.8	106.6
38	CONGLOMERATE - chip to small tabular clasts 2-4 cm in size, phosphate clasts as well, calcarenite matrix, silicified top and bottom, grades to completely silicified bed.	0.4	103.8
37	SHALE - green, blocky, siliceous, 1/3 ribbon limestone in layers 2 cm thick in lower 1/2.	5.3	103.4
	Graptolites: **Pseudotrigonograptus ensiformis** **Isograptus victoriae victoriae** **I. v. lunatus**		
36	SHALE - green with red interbeds in lower 1/3.	3.5	98.1
	Graptolites: **Pseudotrigonograptus ensiformis** **Isograptus victoriae victoriae** **I. v. lunatus**		
35	CONGLOMERATE - small clasts 2-4 cm in size, phosphate clasts, stylolitized calcarenite matrix; silicified top and bottom.	0.2	94.6
34	SHALE - 3/4 red, 1/4 green, burrowed.	13.5	94.4
33	COVER.	2.0	80.9
32	SHALE - red and green.	2.0	78.9
31	CHERT - silicified shale.	0.2	76.9
30	SHALE - 2/3 dark red, 1/3 red.	2.0	76.7
29	CONGLOMERATE - small tabular clasts in green shale matrix.	1.5	74.7
28	SHALE - red.	2.0	73.2
27	COVER.	2.0	71.2
26	SHALE - green and black.	0.2	69.2
25	CONGLOMERATE - all tabular clasts; swirled and chaotic fabric with some waves; occasional rafts; 30% green argillaceous matrix.	3.1	69.0

Unit	Description	Thickness (m) Unit	Total from base
24	COVER - uppermost 2.0 m green shale, section above in backbeach cliff.	5.0	65.9
	Graptolites: (HW) **Tetragraptus approximatus**		
23	COVER - scattered green shale amongst boulders.	2.0	60.9
22	SHALE - green.	1.0	58.9
21	COVER.	1.5	57.9
20	SHALE - red, burrowed.	6.0	56.4
19	SHALE - red, 1/4 green interbeds.	1.8	50.4
18	SHALE - alternating green and red, 1/4 limestone and dolostone bands less than 1 cm thick.	2.0	48.6
17	SHALE - green, 1/3 thin calcarenite to conglomerate layers.	4.0	46.6
16	SHALE - dark green, amongst boulders on beach.	2.0	42.6
15	SHALE - pale green, 1/3 limestone bands.	1.0	40.6
14	PARTED LIMESTONE - beds 2-4 cm thick with green-grey shale partings; occasional thin lenses of granular conglomerate.	4.8	39.6
13	COVER.	2.1	34.8
12	PARTED LIMESTONE - forms a promontory which is wholly exposed at low tide; layers of lime mudstone 1-4 cm thick separated by grey shale, irregular and slightly nodular, may be up to 10 cm thick in centre; numerous intraformational truncation surfaces.	11.2	32.7
11	COVER.	2.0	21.5
10	PARTED LIMESTONE - 1-2 cm thick layers separated by grey shale.	1.0	19.5
9	COVER.	1.5	18.5
8	PARTED LIMESTONE - 1-2 cm thick layers separated by grey shale, all below water at low tide.	11.0	17.0
7	COVER.	0.5	6.0
6	CONGLOMERATE - graded, clasts up to 0.5 m at base, granule-size at top, white microcrystalline calcite matrix.	1.4	5.5
5	PARTED LIMESTONE - very thin-bedded.	0.4	4.1
4	CALCARENITE - cross-laminated.	0.8	3.7
3	CONGLOMERATE - chip-sized clasts.	0.4	2.9
2	COVER - scattered outcrops of parted limestone.	0.5	2.5
1	CONGLOMERATE - subequant clasts up to 0.5 m (average 0.3 m) in 10% green argillaceous matrix.	2.0	2.0

Section begins amongst boulders along shoreline 0.5 km north of the steps leading down to the wreck of S.S. Ethie.

GREEN POINT

The strata exposed here are overturned to the north, a fact not recognized by some earlier workers. The sequence is mostly Ordovician with some Upper Cambrian exposed at the base.

The base of the section is exposed on the low tide platform south of the small harbour, but most of the strata are in rapidly eroding sea cliffs. The upper third of the section to the north is poorly exposed in sporadic outcrops along the shoreline but can be seen at lowest tide.

GREEN POINT

45°43.4'N x 57°41'W

Unit	Description	Thickness (m) Unit	Total from base
	LOWER HEAD SANDSTONE		
	SECTION OVERTURNED		
51	SANDSTONE - green, massive, dewatering structures; interbedded green shale for first 30 m.	140+	600.6
50	COVER - scattered outcrop of shale, finely laminated siltstone and green sandstone.	40.0	460.6
	GREEN POINT FORMATION		
	St. Pauls Member		
49	SHALE - red, blocky, upper 10 m siliceous, scattered outcrop along shoreline.	54.0	420.6
48	SHALE - red, buff-weathering, cross-laminated, rippled dolomite.	5.0	366.6
47	SHALE - red, siliceous; 1/3 cross-laminated dolomite interbeds less than 2 cm thick.	26.0	361.6
46	CONGLOMERATE - limestone clasts in a green argillaceous matrix.	1.0	335.6
45	SHALE - red with 1/3 cross-laminated, buff-weathering siliceous dolomite layers less than 2 cm thick.	4.0	334.6
44	SHALE - alternating red (burrowed), green, and black; at 1 m above base is a 10 cm thick conglomerate layer with phosphate and chert clasts and a chert top, much cover in upper part.	12.0	330.6
43	SHALE - bright red and buff-weathering dolomite (30%), none greater than 2 cm thick, most common in lower 1/2; almost continuous exposure along beach.	12.0	318.6
	Graptolites: (HW) **Tetragraptus approximatus**		
42	SHALE - green and red.	2.0	306.6
41	RIBBON LIMESTONE AND CONGLOMERATE - the conglomerate layer is ca. 10 cm thick and mostly tabular clasts.	1.0	304.6
40	SHALE - green and red.	2.0	303.6
39	RIBBON LIMESTONE - thin layers, ca. 1 cm separated by green shale.	2.0	301.6
	Graptolites: **Adelograptus victoriae** **Bryograptus** sp. ?**Triograptus** (a large robust form) **Tetragraptus bulmani** **Kaierograptus pritchardi** **Clonograptus** cf. **tenellus**		

Unit	Description	Thickness (m) Unit	Total from base
38	SHALE - red with green layers in the upper 2 m, parted limestone in center.	5.0	299.6
37	RIBBON LIME GRAINSTONE - layers of finely cross-laminated grainstone with occasional chert at base ca. 2 cm thick separated by dark green shale.	2.5	294.6
36	SHALE - green and red equally with minor black interbeds; in upper 8 m are scattered buff-weathering dolomite layers.	46.0	292.1
35	SHALE - green.	8.0	246.1
	Broom Point Member		
34	SHALE - green and black with 1/3 buff-weathering dolomitic limestone, thin sandy calcarenite layers, conglomerate lens with tabular clasts at 7.0 m.	9.0	238.1
33	PARTED LIMESTONE - limestone in layers less than 1 cm thick, some synsedimentary folding, thin lenses of quartz sandstone and conglomerate, 40% green shale.	8.2	229.1
32	RIBBON LIMESTONE - layers 2 cm thick, cross-laminated interlayered with equal units of green or black shale.	1.5	220.9
31	PARTED LIMESTONE - similar to unit 33.	5.0	219.4
30	SHALE - alternating black, bright green, and red in beds 10 cm thick, siliceous, 5% sporadic ribbon limestone; forms base of cliff and inner part of low tide platform.	15.2	214.4
29	SHALE AND RIBBON LIMESTONE - 70% black and bright green shale, 30% thick (1-5 cm) beds of ribbon limestone and siltstone, some red shale.	6.8	199.2
	<u>Graptolites</u>: **Dictyonema** sp. (fragments of a large slender form with sparse dessepiments. See unit 26). **Adelograptus hunnebergensis** **Bryograptus** sp. ?**Clonograptus** sp. (a small slender form)		
28	PARTED LIME MUDSTONE - grey-weathering, grey-green limestone, very evenly bedded, occasional layers of parallel to cross-laminated grainstone, synsedimentary deformation, forms prominent bed along shore.	7.8	192.4
	<u>Graptolites</u>: **Anisograptus** sp. (small form near top of bed) **Anisograptus richardsoni** **Radiograptus rosieranus**		
27	SHALE AND RIBBON TO PARTED LIMESTONE - green shale (75%) with lime mudstone; synsedimentary deformation including a contorted slump mass 4.0 m thick that continues along strike for 107 m.	2.6	184.6
26	PARTED TO RIBBON LIMESTONE - interbedded with 20% calcareous grey-green and black shale and occasional parallel to cross-laminated siltstone.	10.8	182.0
	<u>Graptolites</u>: at 9 m **Dictyonema canadense** (B, 1950, p. 67) **Dictyonema cristatum** It is possible that the **D. rusticum** provisionally identified (B, 1950, p. 67) is from here but it also resembles **D.** sp. recorded here from bed 29. Ruedemann, 1947, records this form from Green Point. **Dictyonema flabelliforme** s.l. **Anisograptus matanensis** (B, 1950,p.67) **Anisograptus matanensis** var. **tetragraptoides** **Staurograptus dichotomus** var. **apertus** at 5.0 m **Aletograptus hyberboreus** cf. **Aletograptus hyperboreus** cf. **Aletograptus** (much like **A. hyperboreus**, except for second order, flexous stipes) ?**Aletograptus** sp. nov. **Staurograptus dichotomus** cf. **Triograptus** (probably a new genus)		

Unit	Description	Thickness (m) Unit	Total from base
	R., 1947, p. 59, records **D. bulmani** B, 1950, p. 67 records a possible **Triograptus canadensis**		
25	SHALE AND RIBBON LIME MUDSTONE - 2/3 green shale; a 0.3 m thick conglomerate lens occurs at 0.9 m, 95% clasts (90% equant) (average 1 cm, largest 50 cm), green argillaceous and dolomite matrix, 10% quartz, chert at top.	4.0	171.2
	<u>Trilobites</u>: (RAF) in conglomerate **Symphysurina** cf. **brevis** pygidium of **S. brevis** type		
	<u>Graptolites</u>: (RAF) **Dictyonema** sp. (siculate)		
24	SHALE AND SILTSTONE - grey-green shale (40%) and parallel to cross-laminated calcareous and dolomitic siltstone.	2.2	167.2
23	SHALE AND RIBBON LIMESTONE - lime mudstone, often wrinkled with thin lenses of grainstone with traces of quartz, interbedded with 10% green shales.	3.5	165.0
	<u>Graptolites</u>: Dendroid fragments		
	Martin Point Member		
22	SHALE - green and black, lenses of lime mudstone, graptolite proximal ends.	1.5	161.5
	<u>Graptolites</u>: Dendroid fragments		
21	SHALE AND RIBBON LIMESTONE - olive green shale (2/3) and wrinkled ribbon limestone (1/3).	2.0	160.0
20	SHALE - green, with a 2 cm thick bed of lime mudstone at 0.7 m and several lenses of mudstone just above 0.7 m.	1.6	158.0
19	CONGLOMERATE - 90% clasts, 3/4 tabular (average 5 cm, largest 20 cm), green dolomite mudstone matrix, irregular upper surface.	1.2	156.4
	<u>Trilobites</u>: (RAF) **Symphysurina cleora** **Tatonaspis** sp.		
	<u>Brachiopods</u>: (RAF) ?**Nanorthis hamburgensis**		
18	SHALE - grey-green and black with 10 cm thick beds of wrinkled, folded, cracked and overthrust lime mudstone beds at 0, 1.0, 1.8, 3.5, 4.0, 4.7 and 7.7 m.	7.7	155.2
	<u>Graptolites</u>: Indeterminate fragments		
17	SHALE - 90% grey-green and black; siltstone partings, cross to parallel laminations, most common near the base, sparce ribbon limestone, wrinkled and nodular; numerous graptoloid fragments.	21.1	147.5
16	SHALE AND RIBBON LIMESTONE - 80% green shale with slightly calcareous silty partings evenly bedded with lime mudstones that are often nodular and occasionally wrinkled.	14.2	126.4
15	SHALE - green with ribbon lime mudstone bands regularly spaced about every 20 to 30 cm.	3.5	112.2
14	SHALE - green, occasional 5 cm thick calcareous siltstone partings.	3.4	108.7
13	SHALE - green and interbedded with parallel to cross-laminated, brown-weathering siltstone.	2.8	105.3
12	CONGLOMERATE - 90% tabular clasts (average 10 cm, largest 25 cm) in a finely crystalline matrix.	0.1	102.5
11	SHALE, SILTSTONE AND LIMESTONE -	13.0	102.4
	(c) shale, green and black, with a conglomerate lens similar to (b) at base.	4.0	
	(b) shale (40%), green and black, ribbon limestone (60%) and one conglomerate at 1.5 m with tabular clasts and a grainstone matrix with 10% quartz.	5.0	

Unit	Description	Thickness (m) Unit	Total from base
	(a) shale, green and black, brown siltstone partings, a few bands of ribbon mudstone.	4.0	
10	SHALE - dark green and light green with slightly calcareous siltstone partings.	3.0	89.4
9	SHALE - green and black; 10% wrinkled and nodular lime mudstone.	3.0	86.4
8	SHALE AND LIME MUDSTONE - 2/3 green shale in layers ca. 1.0 m thick and silty lime mudstones in layers 0.1 m thick which are occasionally nodular.	2.0	83.4
7	SHALES AND RIBBON LIMESTONE - 85% green shales and 15% layers of lime mudstone up to 10 cm thick.	1.4	81.4
6	SHALES - aqua green with green siltstone partings.	1.0	80.0
5	SHALE AND SILTSTONE - dark green shales and brown-weathering dolomitic siltstones which are cross-laminated and rippled and vary from 3 to 10 cm thick; top siltstone layer has 5-10 cm cap of calcite spar.	6.0	79.0
4	SHALE - dark green.	0.7	73.0
3	SHALE, SILTSTONE AND RIBBON LIMESTONE -	10.0	72.3
	(c) same as unit (a), also siltstone.	4.5	
	(b) siltstone, brown-weathering, calcareous, cross-laminated, minor shale.	1.5	
	(a) shale, green to black; ribbon limestone parallel to cross-laminated; conglomerate lenses similar to unit 2.	4.0	
2	CONGLOMERATE - 2/3 clasts, tabular clasts of ribbon mudstone and grainstone (average 10 cm, largest 20 cm), grey-green silty mudstone matrix.	0.3	62.3
1	SHALE AND INTERBEDS OF RIBBON LIMESTONE -	62.0	62.0
	(g) ribbon limestone and shale, green-grey.	2.0	
	(f) shale, green-grey.	1.0	
	(e) ribbon limestone - beds 2 to 4 cm thick, silty mudstones and grainstones, partly nodular, parallel to cross-laminated and rippled, beef calcite, shale brown-weathering and green grey, lenses of conglomerate at 2.5 m ca. 20 cm thick and characterized by clasts of cross-laminated silty and sandy limestone, graptoloid fragments - this bed is also the first one to outcrop at the southern end of the shoreline cliff.	5.0	
	(d) shale - green-grey and black with 20% interbeds of rippled and cross-laminated silty limestone in beds 0.2 to 2.0 cm thick.	8.0	
	(c) shale - grey to green-grey and occasionally black in the upper 8 m.	32.0	
	(b) shale - grey, interbedded 20%, laminated to cross-laminated ribbon lime grainstone in beds ca. 10 cm thick, wrinkled.	2.0	
	(a) shale - grey fissile and laminated; the basal beds appear sheared.	12.0	

Begin section at lowest tide, seaward of small boat harbour. Beds are overturned.

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