GEOLOGICAL SURVEY OF CANADA
BULLETIN 430

PRE-CARBONIFEROUS GEOLOGY OF THE NORTHERN PART OF THE ARCTIC ISLANDS

HAZEN FOLD BELT AND ADJACENT PARTS OF CENTRAL ELLESMERE FOLD BELT, ELLESMERE ISLAND

H.P. Trettin

1994

Natural Resources Canada
Ressources naturelles Canada

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Paleontological Appendix 3

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1994

Available in Canada through
authorized bookstore agents and other bookstores

or by mail from

Canada Communication Group - Publishing
Ottawa, Canada K1A 0S9

and from

Geological Survey of Canada offices:

601 Booth Street
Ottawa, Canada K1A 0E8

3303-33rd Street N.W.,
Calgary, Alberta T2L 2A7

A deposit copy of this publication is also available for reference
in public libraries across Canada

Cat. No. M42-430E
ISBN 0-660-14439-5

Price subject to change without notice

Cover Description

Lower Cambrian Grant Land Formation north of head of Tanquary Fiord, Hazen Fold Belt; relief about 750 m.

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Manuscript submitted: 91.06.12
Approved for publication: 91.06.24

PREFACE

Northern Ellesmere and Axel Heiberg islands contain unique exposures of pre-Carboniferous rocks representing the North American continental shelf, a far-travelled continental fragment in the north, and an intervening deep water basin with volcanic rocks in its northern parts. A large area in northeasternmost Ellesmere Island has been selected as the site of a National Park because of its scenic, environmental, and geological interest. The remainder of the region has economic potential, apparent from showings of copper, zinc, and lead minerals.

Initial explorations were made from 1875 onward and systematic mapping by the Geological Survey of Canada was begun in 1953. However, because of the remoteness of the area and its rugged topography and complex geological history, a coherent stratigraphic-structural framework has been established only recently. This bulletin provides a systematic account of all aspects of the pre-Carboniferous geology of northern Ellesmere and Axel Heiberg islands, along with geological maps. It provides a basis for mineral exploration, more detailed geological studies, and broader compilations.

Elkanah A. Babcock
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PRÉFACE

Dans le nord des îles d'Ellesmere et Axel Heiberg, on trouve des affleurements uniques de roches précarbonifères qui représentent la plate-forme continentale de l'Amérique du Nord, un fragment continental allochtone au nord et, entre les deux, un bassin d'eau profonde qui contient des roches volcaniques au nord. On a choisi d'établir un vaste parc national dans l'extrême nord-est de l'île d'Ellesmere en raison de la beauté du paysage et de l'importance environnementale et géologique du site. Le reste de la région présente un potentiel économique que révèlent des venues de cuivre, de zinc et de plomb.

Les premières explorations de la région remontent à 1875; la Commission géologique du Canada y a commencé des travaux de cartographie systématique en 1953. Cependant, comme la région est éloignée, que sa topographie est accidentée et que sa géologie est complexe, ce n'est que récemment que l'on a pu établir un cadre stratigraphique-structural cohérent. Le présent bulletin décrit tous les aspects de la géologie précarbonifère de la partie nord des îles d'Ellesmere et Axel Heiberg et fournit des cartes géologiques. Il constitue une base d'informations utiles pour l'exploration minérale, les études géologiques plus détaillées et les compilations plus poussées.

Elkanah A. Babcock
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Abstract

The weakly metamorphosed sedimentary rocks of the Hazen and Central Ellesmere fold belts, Ellesmere Island, represent in the southeast a shelf succession, and in the northwest a deep water succession. The boundary between them migrated southeastward in late Early Cambrian and Early Silurian times.

The deep water succession comprises: 1) resedimented carbonates (Nesmith beds, Lower Cambrian, >0.2 km); 2) continent-derived sandstone, mudrock and minor conglomerate (Grant Land Formation, Lower Cambrian, >1.5 km); 3) resedimented carbonates, mudrock, and radiolarian chert (Hazen Formation, Lower Cambrian to Lower Silurian, >0.63-0.24 km); and 4) externally derived flyschoid sandstone and mudrock (Danish River Formation, Lower Silurian to Lower Devonian, 2.8 km).

The shelf succession comprises a basal sandstone-mudrock sequence (Ellesmere Group, Lower Cambrian, >1 km), and an overlying, carbonate-dominated sequence (Scoresby Bay Formation; oolitic limestone unit; Cass Fjord, Cape Clay, Ninnis Glacier, Eleanor River, Bay Fiord, Bulleys Lump, Thumb Mountain, Irene Bay, and Allen Bay formations; Lower Cambrian to Lower Silurian, 3.8 km). Growth of a shallow marine rim at the shelf margin in Early to Middle Ordovician time (Bulleys Lump Formation) explains the development of an extensive intrashelf basin, with evaporites in the centre (Baumann Fiord and Bay Fiord formations) and subtidal carbonates farther northwest (Ninnis Glacier to Bay Fiord formations).

Rapid thermal subsidence of the entire region, combined with rapid sedimentation on the shelf and slow deposition in the basin, enhanced shelf-basin relief from Middle Cambrian to Early Silurian time. As a result, an unstable, gently sloping margin developed into an erosional escarpment that may have attained a height of about 1.5 km and an average slope of roughly 40° by middle Llandovery time. A submarine slope unconformity developed when the basin was filled, in the late Llandovery, with turbidites that subsequently overstepped the previous shelf margin.

The strata were deformed mainly in mid-Paleozoic time, with some additional faulting and warping in the early Tertiary. The Hazen Fold Belt is composed mostly of deep water sediments but has Lower Cambrian clastic shelf sediments in its southeasternmost part. Three layers of complex minor folds are separated by two layers of major folds, controlled by massive units of Lower Cambrian sandstone and Ordovician chert. The adjacent northwestern part of the Central Ellesmere Fold Belt consists of Lower Cambrian to Silurian shelf carbonates and Silurian-Lower Devonian deep water sediments. Large, concentric folds are controlled by the Lower Cambrian to Lower Silurian shelf carbonates.

A sphalerite-galena showing in dolostone of the shelf rim, and a chalcopyrite showing in chert of the deep water basin attest to the economic mineral potential of the region.

Résumé

Sur l'île d'Ellesmere, les roches sédimentaires faiblement métamorphisées des zones de plissement de Hazen et du centre d'Ellesmere représentent d'une part, une succession épicontinentale (ou de plate-forme continentale) au sud-est, et d'autre part, une succession d'eau profonde au nord-ouest. La limite entre ces deux entités s'est déplacée vers le sud-est à la fin du Cambrien précoce et au Silurien précoce.

La succession d'eau profonde contient des roches carbonatées resédimentées (lits de Nesmith, Cambrien inférieur, >0,2 km); du grès, du mudstone et un peu de conglomérat, tous d'origine continentale (Formation de Grant Land, Cambrien inférieur, >1,5 km); des roches carbonatées resédimentées, du mudstone et de la radiolarite (Formation de Hazen, Cambrien inférieur-Silurien inférieur, >0,63–0,24 km); ainsi que du grès et du mudstone flyschoïdes, de provenance externe (Formation de Danish River, Silurien inférieur-Dévonien inférieur, 2,8 km).

La succession épicontinentale se compose quant à elle d'une séquence basale de grès–mudstone (Groupe d'Ellesmere, Cambrien inférieur, >1 km), sous-jacente à une séquence principalement carbonatée (Formation de Scoresby Bay; unité de calcaire oolitique; formations de Cass Fjord, de Cape Clay, de Ninnis Glacier, d'Eleanor River, de Bay Fiord, de Bulleys Lump, de Thumb Mountain, d'Irene Bay et d'Allen Bay; Cambrien inférieur-Silurien inférieur, 3,8 km). Au cours de l'Ordovicien précoce à moyen, la croissance d'une bordure épicontinentale sur le rebord de la plate-forme continentale (Formation de Bulleys Lump) explique la formation d'un vaste bassin à l'intérieur de la plate-forme continentale; cette dépression contient des évaporites au centre (formations de Baumann Fiord et de Bay Fiord) et des roches carbonatées infratidales plus loin au nord-ouest (de la Formation de Ninnis Glacier jusqu'à la Formation de Bay Fiord).

La subsidence thermique rapide de l'ensemble de la région, alliée à la sédimentation rapide sur la plate-forme continentale et à la sédimentation lente dans le bassin, a rehaussé le relief entre la plate-forme continentale et le bassin sur la période allant du Cambrien moyen au Silurien précoce. Par conséquent, une marge instable peu inclinée s'est transformée en un escarpement d'érosion dont la hauteur a pu atteindre environ 1,5 km et la pente moyenne, à peu près 40°, dès le Llandovérien moyen. Une discordance de talus sous-marin s'est dessinée au Llandovérien tardif, lorsque le bassin a été comblé de turbidites; celles-ci ont par la suite formé un dépôt transgressif discordant sur l'ancien rebord de la plate-forme continentale.

Les strates ont été déformées principalement au Paléozoïque moyen; il y a également eu formation de failles et gauchissement au Tertiaire précoce. La zone de plissement de Hazen se compose essentiellement de roches sédimentaires d'eau profonde, mais l'extrême sud-est de la zone contient aussi des clastites épicontinentales du Cambrien inférieur. Trois couches à plis mésoscopiques complexes sont séparées par deux couches à plis de grande échelle, formés dans des unités massives de grès du Cambrien inférieur et de chert de l'Ordovicien. La partie nord-ouest contigu à la zone de plissement du centre d'Ellesmere se compose de roches carbonatées épicontinentales du Cambrien inférieur au Silurien et de roches sédimentaires d'eau profonde du Silurien au Dévonien inférieur. Les grands plis concentriques ont déformé les roches carbonatées épicontinentales du Cambrien inférieur au Silurien inférieur.

Un indice de sphalérite–galène dans la dolomie du rebord de la plate-forme continentale et un autre de chalcopyrite dans le chert du bassin d'eau profonde témoignent du potentiel minéral économique de la région.

Summary

This report describes the geology of the entire Hazen Fold Belt and of an adjacent part of the Central Ellesmere Fold Belt on southwestern Judge Daly Promontory, northern Ellesmere Island, with emphasis on stratigraphy and basin development. The region is underlain by a shelf succession in the southeast and by a deep water succession in the northwest, separated by a facies boundary that migrated southeastward in Early Cambrian and Early Silurian times.

The studied part of the Cambrian to Lower Silurian shelf succession comprises about 5.4 km of carbonate sediments and continent-derived siliciclastic sediments, divisible into fourteen major units that can be placed into five sequences or genetic assemblages, separated by disconformities or changes in shelf architecture, as follows.

1. The exposed part of the Ellesmere Group, late Early Cambrian in age, includes the Ritter Bay Formation, 183 m of sandstone and minor mudrock; the Rawlings Bay Formation, 548 m of of sandstone and mudrock; and the Kane Basin Formation, 271 m of mudrock with minor sandstone and rare limestone. Most strata were deposited in deeper subtidal shelf environments, with delta front deposits in the middle part of the Rawlings Bay Formation. Phosphate-cemented intraformational conglomerates probably indicate transgression-related diastems within the Ritter Bay Formation and at the base of the Kane Basin Formation. Chlorite pellets pseudomorphous after glauconite are common in the mudrocks.

2. The Scoresby Bay Formation, probably latest Early to early Middle Cambrian in age, overlies the Kane Basin Formation with a disconformable contact. It consists of 952 m of dolostone and limestone of peritidal to shallow subtidal aspect, with evaporite solution breccias in the lower 145 m. It is conformably overlain by the oolitic limestone unit (new informal unit) of assumed early Middle Cambrian age, composed of 273 m of oolitic and peloidal limestone, deposited in an agitated shallow marine setting.

3. The disconformably overlying Cass Fjord Formation, latest Middle Cambrian to earliest Ordovician (early Tremadoc) in age, is made up of 727 m of limestone, dolostone, varicoloured mudrock, quartzose sandstone, and minor intraformational conglomerate. Deposited mainly in intertidal and shallow subtidal settings, the formation reflects numerous fluctations of sea level and an overall increase in water depth with time. The northwesternmost exposures contain some deep subtidal strata. The conformably overlying Cape Clay Formation, Early Ordovician (early Tremadoc) in age, comprises 319 m of bioturbated limestone (mainly peloidal grainstone) of shallow subtidal aspect, and minor amounts of dolostone and sandstone. It is conformably overlain by the lower Ninnis Glacier Formation, a transitional carbonate unit, some 100 m thick and of middle Tremadoc age, composed of laminated and massive limestone and dolostone.

4. The conformably overlying Early to early Middle Ordovician (middle Tremadoc to latest Llandeilo) formations represent a shelf margin carbonate buildup in the northwest (Bulleys Lump Formation), and an intrashelf basin on the southeast (upper Ninnis Glacier Formation and Eleanor River and Bay Fiord formations). The Bulleys Lump Formation consists of 1.6 km of massive, laminated, and crosslaminated limestone, and minor amounts of dolostone, siltstone and sandstone. Packstones or wackestones composed of microbial(?) peloids, and intraclastic grainstones, both with common fenestral structures, indicate shallow subtidal to intratidal settings. The upper Ninnis Glacier Formation (about 200 m), Eleanor River Formation (191 m), and Bay Fiord Formation (400 m) are made up of alternating units of: 1) flat-laminated limestone or dolostone and minor siltstone of deep subtidal aspect, and 2) bioturbated massive limestone or dolostone of shallow subtidal aspect. The first rock type predominates in the Ninnis Glacier and Bay Fiord formations, and the second in the Eleanor River Formation. Thinly laminated dolostones evidently formed as a result of early diagenetic replacement in a superhaline basin that had gypsum and halite in its central parts (southwest of the study area).

5. The conformably overlying Thumb Mountain Formation (275–404 m; Middle to Late Ordovician, Caradoc to early Ashgill), Irene Bay Formation (117–198 m; Late Ordovician, Ashgill), and Allen Bay Formation (250–318 m; Late Ordovician to Early Silurian, Ashgill to early or middle Llandovery) are composed of bioturbated skeletal lime wackestone, deposited in shallow subtidal environments.

The deep water succession comprises more than 5 km of strata, divisible into four major units that are mostly conformable, although local diastems probably occur at the base and top of the third unit (Hazen Formation).

The Nesmith beds, (new informal unit) consist of more than 200 m of resedimented carbonates, ranging in size grade from lime mudstone to pebble conglomerate; their base is concealed. The unit probably is mid-Early Cambrian in age and was derived from the Franklinian shelf on the southeast.

The Grant Land Formation comprises more than 1.5 km of continent-derived quartzose and feldspathic sandstone, varicoloured mudrock, and minor pebble conglomerate. The formation is late Early Cambrian in age and correlative with the Ellesmere Group. Sandy sequences studied in detail represent submarine canyon or channel deposits. Shelf-derived carbonate fragments occur in the lowermost part, and chlorite pseudomorphous after glauconite in the middle and upper parts.

The Hazen Formation, latest Early Cambrian to Early Silurian (early late Llandovery) in age, includes resedimented carbonates, mudrock, radiolarian and secondary chert, and minor sandstone. It is divisible into a lower carbonate-dominated member and an upper chert-dominated member, separated by a diachronous contact that becomes older to the northwest. The formation thickness decreases from >632 m in the southeast to 241 m in the northwest. The carbonates range in size grade from large, allochthonous blocks and boulder conglomerate to lime mudstone, and decrease in size grade and abundance from southeast to northwest. Although all carbonate sediments are ultimately of shelf origin, many conglomerates originated by sliding in the slope environment. The inferred depositional environments extend from outermost shelf to basin plain.

The Danish River Formation (new name; previously included in Imina Formation) contains 2.8 km of mixed siliciclastic and calcareous-dolomitic sandstone and mudrock, largely turbidites, with minor siliciclastic and carbonate conglomerate. It ranges in age from Early Silurian (early late Llandovery) to late Early Devonian (Emsian), but the upper contact is highly diachronous, being earliest Devonian (early Lochkovian) at the type section at Caledonian Bay, Cañon Fiord. The sediments were derived mainly from external orogenic sources with minor contributions from the Franklinian Shelf. In the Hazen Plateau region, more than 2000 paleocurrent determinations indicate southeastward transverse flow, merging with strike-parallel southwestward flow in the southeastern part of the basin.

Exposures on southwestern Judge Daly Promontory permit reconstruction of the development of the shelf–basin transition from Middle Cambrian to Early Silurian time. Rapid subsidence of the entire region, combined with rapid sedimentation on the shelf and slow sedimentation in the basin, progressively enhanced the shelf–basin relief from Middle Cambrian to Early Silurian time. As a result, a gently sloping margin developed into an erosional escarpment. A structural cross-section indicates a relief of about 1.5 km and an average slope of around 40° in the middle Llandovery (provided that the carbonate strata were horizontal at that time). A submarine slope unconformity developed when the basin was filled with upper Llandovery turbidites of the Danish River Formation, which subsequently overstepped the original shelf margin. Similar relations have been observed at Navarana Fjord, North Greenland, where the strata are undeformed.

The Cambrian to Devonian rocks were affected by a southeastward-progressing deformation that cannot be dated precisely in this region, but must have occurred prior to late Early Carboniferous (Viséan) time (Ellesmerian Orogeny). The Hazen Fold Belt is composed mainly of deep water sediments, but has Lower Cambrian shelf sediments of the Ellesmere Group in its southeastern part. Three layers of complex minor folds, commonly of chevron type, are separated by two layers of major folds, controlled by massive sandstones of the Grant Land Formation, and by the chert member of the Hazen Formation, respectively. The northwestern part of the Central Ellesmere Fold Belt consists of Lower Cambrian to Lower Silurian shelf sediments and Lower Silurian to Lower Devonian deep water sediments. It is characterized by large concentric folds that are controlled by the Lower Cambrian to Lower Silurian shelf carbonates.

The regional metamorphism in both belts is incomplete. The clay fraction has generally been metamorphosed to white mica and chlorite, and fine grained mudrock has been metamorphosed to slate, but detrital biotite and K-feldspar (incompatible with the lower greenschist facies) are preserved in the coarse silt and sand fractions. Ordovician conodonts have Conodont Alteration Index values of 4.5 to (predominantly) 5.

The region has not been prospected thoroughly, but mineral potential is indicated by: 1) a sphalerite-galena deposit in dolostone of the shelf margin (probably Bulleys Lump Formation) on northeastern Judge Daly Promontory (beyond the study area); and 2) a chalcopyrite showing in chert of the Hazen Formation north of Hare Fiord. Moreover, the Hazen Formation is comparable in lithology and mode of origin to the Road River Formation of the northern Cordillera (Selwyn Basin), which contains large base metal deposits.

Sommaire

Le présent rapport décrit la géologie de l'ensemble de la zone de plissement de Hazen et d'une région contiguë de la zone de plissement du centre d'Ellesmere (partie sud-ouest du promontoire Judge Daly, dans le nord de l'île d'Ellesmere); il met l'accent sur la stratigraphie et l'évolution du bassin. Dans la région, on observe une succession épicontinentale au sud-est et une succession d'eau profonde au nord-ouest, que sépare une limite de faciès qui s'est déplacée vers le sud-est au Cambrien précoce et au Silurien précoce.

La partie à l'étude de la succession épicontinentale du Cambrien au Silurien inférieur comporte environ 5,4 km de roches sédimentaires soit carbonatées, soit silicoclastiques d'origine continentale; ces matériaux se subdivisent en quatorze unités majeures qui appartiennent à cinq séquences ou assemblages génétiques, que délimitent des discordances ou des changements dans l'architecture de la plate-forme continentale :

1. La partie affleurante du Groupe d'Ellesmere remonte à la fin du Cambrien précoce; elle comprend la Formation de Ritter Bay (183 m de grès avec un peu de mudstone), la Formation de Rawlings Bay (548 m de grès et de mudstone) et la Formation de Kane Basin (271 m de mudstone avec un peu de grès et de rares calcaires). La plupart des strates se sont accumulées dans des milieux épicontinentaux et infratidaux de plus grande profondeur; il existe des dépôts de front de delta dans la partie centrale de la Formation de Rawlings Bay. La présence de conglomérats intraformationnels à ciment phosphatique indique vraisemblablement l'existence des lacunes de transgression au sein de la Formation de Ritter Bay et à la base de la Formation de Kane Basin. De la glauconite pseudomorphosée en pellets de chlorite se rencontre fréquemment dans les mudstones.

2. La Formation de Scoresby Bay s'échelonne de la toute fin du Cambrien précoce au début du Cambrien moyen (incertain); elle repose en discordance sur la Formation de Kane Basin. Elle se compose de 952 m de dolomie et de calcaire de milieu péritidal à infratidal peu profond, avec des brèches de dissolution d'évaporites dans les 145 m inférieurs. Elle est en concordance sous l'unité de calcaire oolitique (nouvelle unité informelle), qui remonte vraisemblablement au début du Cambrien moyen et qui se compose de 273 m de calcaire oolitique et pelletoïdal de milieu épicontinental agité.

3. La Formation de Cass Fjord, qui repose en discordance sur l'unité précédente, s'échelonne de la toute fin du Cambrien moyen à l'Ordovicien initial (Trémadocien précoce); elle se compose de 727 m de calcaire, de dolomie, de mudstone multicolore et de grès quartzeux, avec un peu de conglomérat intraformationnel. Elle s'est accumulée principalement dans des milieux infratidaux peu profonds et intertidaux; elle reflète les nombreuses fluctuations du niveau marin et un approfondissement global de l'eau dans le temps. Les affleurements à l'extrême nord-ouest contiennent quelques strates de milieu infratidal profond. La formation sus-jacente de Cape Clay est en contact concordant et date de l'Ordovicien précoce (Trémadocien précoce); elle comprend 319 m de calcaire bioturbé (principalement du grainstone pelletoïdal) de milieu infratidal peu profond, avec un peu de dolomie et de grès. Elle s'observe en concordance sous la partie inférieure de la Formation de Ninnis Glacier, une unité carbonatée intermédiaire qui a quelque 100 m d'épaisseur, qui date du Trémadocien moyen et qui se compose de dolomie et de calcaire laminés et massifs.

4. Les formations sus-jacentes sont en contact concordant et s'échelonnent de l'Ordovicien précoce au début de l'Ordovicien moyen (Trémadocien moyen-Llandeilien terminal); elles représentent un monticule carbonaté de rebord de plate-forme continentale au nord-ouest (Formation de Bulleys Lump) et un bassin à l'intérieur d'une plate-forme continentale au sud-est (partie supérieure de la Formation de Ninnis Glacier et formations d'Eleanor River et de Bay Fiord). La Formation de Bulleys Lump se compose de 1,6 km de calcaires massifs, laminés et à laminations obliques, avec un peu de dolomie, de siltstone et de grès. Des packstones ou wackestones composés de pelletoïdes microbiens(?) et des grainstones intraclastiques, tous avec de fréquentes

structures fenestrées, témoignent de milieux infratidaux peu profonds ou intertidaux. La partie supérieure de la Formation de Ninnis Glacier (environ 200 m), la Formation d'Eleanor River (191 m) et la Formation de Bay Fiord (400 m) se composent d'unités en alternance (1) de calcaire ou de dolomie à laminations horizontales, avec un peu de siltstone de milieu infratidal profond, et (2) de dolomie ou de calcaire massifs et bioturbés de milieu infratidal peu profond. La première lithologie prédomine dans les formations de Ninnis Glacier et de Bay Fiord, tandis que la deuxième est plus abondante dans la Formation d'Eleanor River. Les dolomies finement laminées dérivent manifestement d'un remplacement lors de la diagenèse précoce, qui s'est produit dans un bassin hypersalin contenant du gypse et de la halite dans sa partie centrale (au sud-ouest de la région à l'étude).

5. Les formations sus-jacentes sont en contact concordant et se composent de wackestone bioturbé à bioclastes, déposé dans des milieux infratidaux peu profonds; il s'agit des formations de Thumb Mountain (275–404 m; Ordovicien moyen–Ordovicien tardif, Caradocien–Ashgillien précoce), d'Irene Bay (117–198 m; Ordovicien tardif, Ashgillien) et d'Allen Bay (250–318 m; Ordovicien tardif-Silurien précoce; Ashgillien–Llandovérien précoce ou moyen).

La succession d'eau profonde comporte plus de 5 km de strates, qui se subdivisent en quatre unités majeures principalement concordantes; il se peut cependant que des lacunes locales soient présentes à la base et au sommet de la troisième unité (Formation de Hazen).

Les lits de Nesmith (nouvelle unité informelle) se composent de plus de 200 m de roches carbonatées resédimentées, dont la granulométrie varie de celle des mudstones calcaires à celle des conglomérats à cailloux; la base de ces strates est masquée. L'unité remonte vraisemblablement au milieu du Cambrien précoce et dérive de la plate-forme continentale franklinienne au sud-est.

La Formation de Grant Land comprend plus de 1,5 km de grès feldspathique et quartzeux, de mudstone multicolore et de conglomérat à cailloux (quantités mineures), tous d'origine continentale. Elle remonte à la fin du Cambrien précoce et peut être mise en corrélation avec le Groupe d'Ellesmere. Les séquences sableuses examinées en détail sont considérées comme des dépôts de canyon ou de chenal sous-marin. Des fragments carbonatés dérivés de la plate-forme continentale s'observent dans la partie inférieure de la formation, tandis que dans ses parties centrale et supérieure, on note la présence de glauconite pseudomorphosée en chlorite.

La Formation de Hazen, qui s'échelonne de la toute fin du Cambrien précoce au Silurien précoce (début du Llandovérien tardif), comprend des roches carbonatées resédimentées, du mudstone, de la radiolarite, du chert secondaire et des quantités mineures de grès. Elle peut se subdiviser en un membre inférieur à prédominance carbonatée et en un membre supérieur à prédominance cherteuse, que sépare un contact diachrone dont l'âge s'accroît vers le nord-ouest. L'épaisseur de la formation passe de >632 m au sud-est à 241 m au nord-ouest. La granulométrie et l'abondance des roches carbonatées diminuent du sud-est vers le nord-ouest; de conglomérats à grands blocs allochtones et à blocs, on passe à des mudstones calcaires. Bien qu'en fin de compte, toutes les roches sédimentaires carbonatées proviennent de la plate-forme continentale, bon nombre des conglomérats se sont formés après avoir glissé sur le talus continental. Les milieux sédimentaires déduits vont de la partie la plus externe de la plate-forme continentale à la plaine du bassin.

La Formation de Danish River (nouveau nom; anciennement comprise dans la Formation d'Imina) contient 2,8 km de grès et de mudstone silicoclastiques et calcaro-dolomitiques mélangés (en grande partie des turbidites), avec un peu de conglomérat silicoclastique et carbonaté. Elle s'échelonne du Silurien précoce (début du Llandovérien tardif) à la fin du Dévonien précoce (Emsien); le contact supérieur est toutefois fortement diachrone et se situe au Dévonien initial (Lochkovien précoce), à l'emplacement du stratotype observé dans la baie Caledonian (fjord Cañon). Les sédiments dérivent principalement de sources orogéniques externes, des quantités mineures provenant cependant de la plate-forme continentale franklinienne. Dans la région du plateau de Hazen, plus de 2 000 déterminations de paléocourants indiquent un écoulement transversal vers le sud-est, qui fusionne avec un écoulement longitudinal vers le sud-ouest dans la partie sud-est du bassin.

Les affleurements qui se rencontrent dans le sud-ouest du promontoire Judge Daly ont permis de reconstituer comment s'est formé la transition entre la plate-forme continentale et le bassin sur la période allant du Cambrien moyen jusqu'au Silurien précoce. La subsidence rapide de l'ensemble de la région, alliée à la sédimentation rapide sur la plate-forme continentale et à la sédimentation lente dans le bassin, a progressivement rehaussé le relief entre la plate-forme continentale et le bassin sur la période allant du Cambrien moyen au Silurien précoce. Par conséquent, une marge peu inclinée s'est transformée en un escarpement d'érosion. Une coupe transversale de la structure indique un relief d'environ 1,5 km et une pente moyenne d'environ 40° au Llandovérien moyen (dans la mesure où les strates carbonatées étaient horizontales à cette époque). Une discordance de talus sous-marin s'est formée au Llandovérien supérieur, lorsque le bassin a été comblé des turbidites de la Formation de Danish River; celles-ci ont fini par former un dépôt transgressif discordant sur le rebord d'origine de la plate-forme continentale. Des liens semblables ont été identifiés au fjord Navarana (Groenland septentrional), où les strates sont intactes.

Une phase de déformation, qui s'est déplacée vers le sud-est, a touché les roches du Cambrien au Dévonien. Il est impossible de la dater avec précision dans la région, mais elle a dû se produire avant la fin du Carbonifère précoce (Viséen) (orogenèse ellesmérienne). La zone de plissement de Hazen se compose principalement de roches sédimentaires d'eau profonde; dans sa partie sud-est cependant, elle présente des roches sédimentaires épicontinentales du Cambrien inférieur faisant partie du Groupe d'Ellesmere. Trois couches à plis mésoscopiques complexes, fréquemment du type en chevrons, sont séparées par deux couches de plis de grande échelle, formés respectivement dans les grès massifs de la Formation de Grant Land et le membre cherteux de la Formation de Hazen. La partie nord-ouest de la zone de plissement du centre d'Ellesmere comprend des roches sédimentaires épicontinentales du Cambrien inférieur au Silurien inférieur et des roches sédimentaires d'eau profonde du Silurien inférieur au Dévonien inférieur. Elle se caractérise par la présence de grands plis concentriques qui ont déformé les roches carbonatées épicontinentales du Cambrien inférieur au Silurien inférieur.

Le métamorphisme régional survenu dans les deux zones est incomplet. En général, la fraction argileuse a été métamorphisée en mica blanc et en chlorite, tandis que le mudstone à grain fin est devenu schiste ardoisier; par contre, les fractions de silt grossier et de sable contiennent de la biotite et du feldspath potassique détritiques, ce qui est incompatible avec le faciès des schistes verts inférieur. Les conodontes ordoviciens ont des indices d'altération de 4,5 à 5, le dernier chiffre étant prédominant.

La région n'a pas été explorée en détail, mais son potentiel minéral est défini par la présence (1) d'un gisement de sphalérite-galène dans la dolomie du rebord de la plate-forme continentale (probablement la Formation de Bulleys Lump), qui s'observe dans la partie nord-est du promontoire Judge Daly (au-delà des limites de la région à l'étude); et (2) d'un indice de chalcopyrite dans du chert de la Formation de Hazen, au nord du fjord Hare. En outre, la lithologie et l'origine de la Formation de Hazen se comparent à celles de la Formation de Road River, dans le nord de la Cordillère (bassin de Selwyn), qui contient de vastes gisements de métaux communs.

Frontispiece. *Judge Daly Promontory, view to northeast. In the foreground is part of the key area shown in the geological map, Figure 1. Four major stratigraphic-structural belts are apparent, from left to right: 1) an area covered mainly by the carbonate member of the Hazen Formation (* $ЄO_{H1}$ *) with outcrops of the Kane Basin (* $Є_{EK}$ *) and Rawlings Bay (* $Є_{ERA}$ *) formations in the cores of two anticlines; 2) a belt of shelf carbonate and clastic units of Cambrian to Early Silurian age (* $ЄO_{CF}$ *-* OS_A *: Cass Fjord to Allen Bay formations); 3) the Danish River Formation (* SD_{DR} *); and 4) another belt of shelf carbonate and clastic formations (* OS_A *-* $Є_{ERI}$ *: Allen Bay to Ritter Bay formations). The stratigraphy of the shelf succession on the northwestern limb of the Ninnis Glacier Syncline (section EB3) differs significantly from that on the southeastern limb (section EB4). (Part of oblique aerial photograph NAPL T-401-L-132.)*

CHAPTER 1

INTRODUCTION

This is the first of three parts of a comprehensive report on the pre-Carboniferous geology of northern Ellesmere Island and Axel Heiberg Island. It deals with the southeastern, exclusively sedimentary region of northern Ellesmere Island, with emphasis on stratigraphy and basin development. Part 2 (in preparation, 1992) will discuss the remainder of northern Ellesmere Island and northern Axel Heiberg Island, which contain volcanic and plutonic rocks. Geological maps of the entire region will be provided in Part 3 (in preparation, 1992).

LOCATION AND ACCESSIBILITY OF THE PROJECT AREA

The project area is situated in the northern part of Ellesmere Island, the largest of the Queen Elizabeth Islands in the Canadian Arctic Archipelago (Figs. 2, 3). The nearest airline terminal is at Resolute Bay, Cornwallis Island, where smaller aircraft can be chartered. The nearest open settlements are Eureka, a weather station on west-central Ellesmere Island, and the summer headquarters of the Ellesmere Island National Park Reserve at the head of Tanquary Fiord. Alert, a weather station and base of the Canadian Armed Forces on the northeastern tip of the island, can be visited with special permission only.

GEOLOGICAL INVESTIGATIONS

The history of geological investigations in the project area may be divided into four phases, based on the methods of travel and scientific emphasis.

During the first phase, from 1875 to 1940, far-ranging journeys were made on foot or with dogs and sledges in the course of multidisciplinary expeditions concerned with geographic, biological, geophysical, glaciological or ethnological aspects in addition to geology. The geological work was done mainly by Europeans. This phase has been chronicled by Christie (1964, p. 1-4; Christie and Dawes, 1991), and only contributions to lower Paleozoic geology will be mentioned here.

In 1875 and 1876 parts of northeastern Ellesmere Island and Greenland were explored by a British naval expedition led by Sir George Nares. Members of the expedition, notably the naturalist H.W. Feilden, collected rocks and fossils from the region between Lady Franklin Bay and Cape Columbia. The geological results were published by Feilden and de Rance (1878).

The Danish geologist, J.C. Troelsen, a member of the Danish Thule and Ellesmere Land Expedition led by Van Hauen, sledged around central Ellesmere Island in May, 1940. He traversed the southern Hazen Plateau between Antoine tte Bay and Beatrix Bay, and then proceeded along Archer Fiord to Cape Baird, the northeastern extremity of Judge Daly Promontory (Troelsen, 1950). In 1952, he explored an area around Caledonian Bay, Cañon Fiord, which he reached from Eureka on skis, pulling his own pulka as he had lost his dogs to disease (Troelsen, 1952).

During the second phase, 1953 to 1958, systematic reconnaissance work by officers of the Geological Survey was begun, but work still was done on foot or with dogs and sledges. R.G. Blackadar, the first scientist of the Geological Survey of Canada to visit northern Ellesmere Island, reconnoitered the region between Robeson Channel, Lake Hazen, and Cape Columbia in 1953 (Blackadar, 1954).

Blackadar's reconaissance work was continued in 1957 and 1958 by R.L. Christie, who investigated large parts of the project area from a base camp at Lake Hazen. Both Blackadar and Christie were members of expeditions led by G. Hattersley-Smith, a glaciologist of the Canadian Defence Research Board. The information obtained during this phase was compiled by R.L. Christie (1964) who prepared the first nearly complete map of northeastern Ellesmere Island. The differentiation of strata of early Paleozoic, late Paleozoic, Mesozoic, and Tertiary ages was perhaps the most important result of this work. The lower Paleozoic rocks were assigned to three major units, named Cape Rawson Group, Archer Fiord Terrane, and Daly River Terrane, but the precise ages and mutual relations of these units remained uncertain.

During the third phase, from 1961 to 1973, stratigraphic and structural studies were made mainly on foot from widely spaced fly camps, set out by small airplanes or small helicopters with piston engines. Emphasis was on construction of a stratigraphic framework and on obtaining some ground control for reconnaissance maps at the 1:250 000 scale, prepared mainly by interpretation of aerial photographs. Major operations, ranging far beyond the present project area, were based at Eureka in 1961 and 1962, at Alert in 1965, and at Lake Hazen in 1966 and 1967.

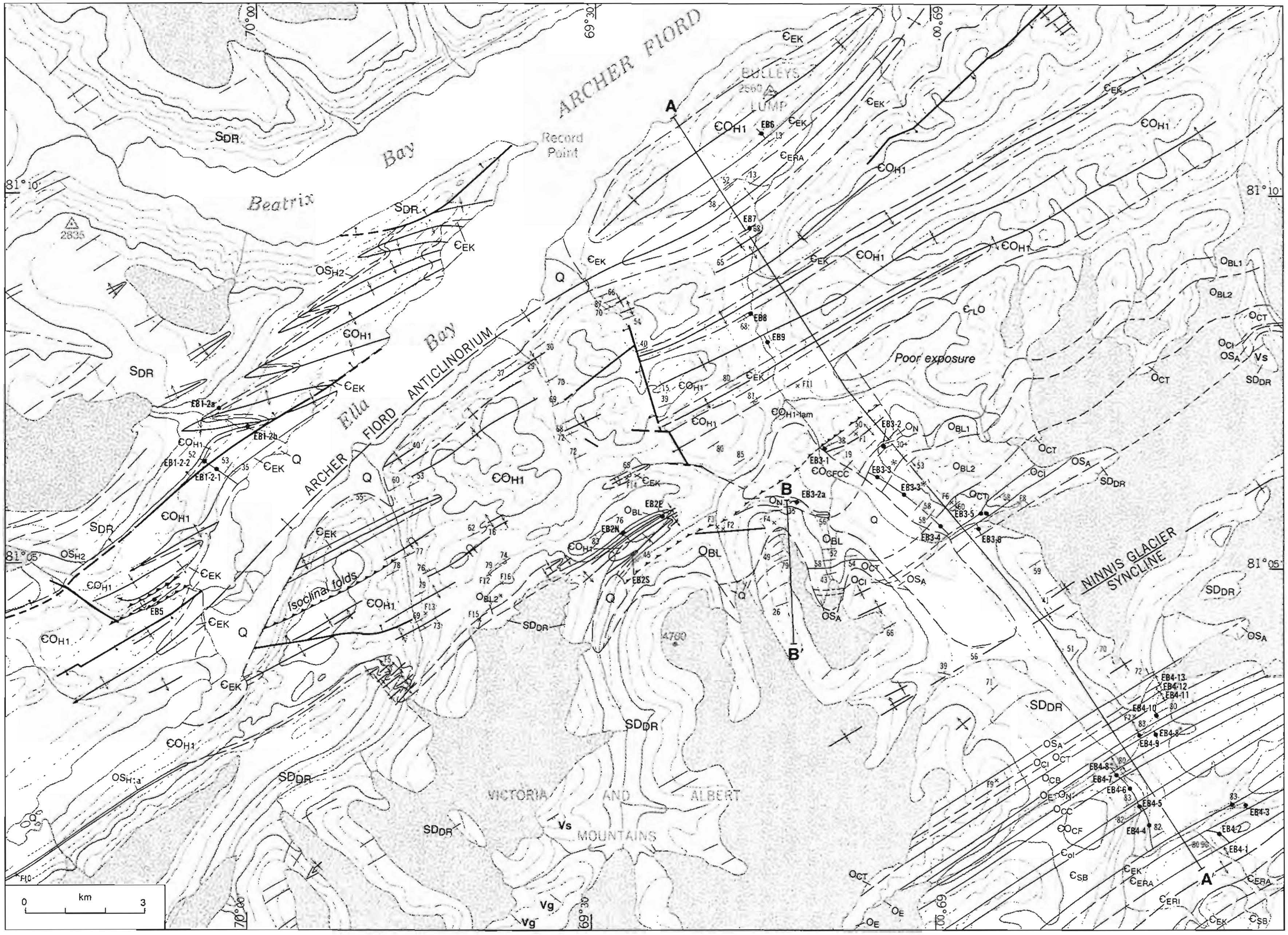


Figure 1. Geological map of Ella Bay area with structural cross-section and locations of stratigraphic sections and fossil collections.

LEGEND

QUATERNARY

Q	*Unconsolidated sediments*
	Glacier

DEEP WATER SUCCESSION

SILURIAN, SILURIAN AND LOWER DEVONIAN

SD_{DR} / S_{DR}	*DANISH RIVER FORMATION*

LOWER CAMBRIAN TO LOWER SILURIAN

OS_{H2}	*HAZEN FORMATION* ($€O_{H1}$-OS_{H2}) *Chert member:* (Upper Ordovician and Lower Silurian)
OS_{H1A}	*Carbonate member: upper limestone unit* (Upper Ordovician? and Lower Silurian)
$€O_{H1}$	*Carbonate member: undifferentiated* (Lower Cambrian to Upper Ordovician) $€O_{H1\text{-}lam}$: *laminated facies (conglomerate/breccia absent)*

SHELF MARGIN CARBONATE BUILDUP

LOWER AND MIDDLE ORDOVICIAN

O_{BL}	*BULLEYS LUMP FORMATION* (O_{BL2}-O_{BL1}) O_{BL2}: *Member B* O_{BL2}*: *may include basal Thumb Mountain Formation (submarine slide?)* O_{BL1}: *Member A*

UNDIFFERENTIATED

CAMBRIAN AND ORDOVICIAN

$€\text{-}_LO$	*CASS FJORD, CAPE CLAY, NINNIS GLACIER AND HAZEN FORMATIONS*

SHELF SUCCESSION

UPPER ORDOVICIAN AND LOWER SILURIAN

OS_A	*ALLEN BAY FORMATION*

ORDOVICIAN

CORNWALLIS GROUP (O_{CB}-O_{CI})

O_{CI}	*IRENE BAY FORMATION*
O_{CT}	*THUMB MOUNTAIN FORMATION*
O_{CB}	*BAY FIORD FORMATION*
O_E	*ELEANOR RIVER FORMATION*
O_N	*NINNIS GLACIER FORMATION*

MIDDLE CAMBRIAN TO LOWER ORDOVICIAN

O_{CC}	*CAPE CLAY FORMATION*	$€O_{CFCC}$ *Undifferentiated*
$€O_{CF}$	*CASS FJORD FORMATION*	

LOWER AND MIDDLE CAMBRIAN

$€_{ol}$	*Oolitic limestone unit*
$€_{SB}$	*SCORESBY BAY FORMATION*

ELLESMERE GROUP ($€_{ERI}$-$€_{EK}$)

$€_{EK}$	*KANE BASIN FORMATION*
$€_{ERA}$	*RAWLINGS BAY FORMATION*
$€_{ERI}$	*RITTER BAY FORMATION*

Geological boundary (defined, approximate, projected through ice or overburden)

Bedding (strike and dip direction; tops known, unknown, photogrammetric dip determination) 39 72

Bedding (general trend; tops known, unknown, dip direction unknown) Vg Vs

Drag-fold (arrow indicates plunge) 15

Fault, unspecified (defined)

Normal fault (defined, approximate)

Thrust fault (defined, approximate, assumed or projected through overburden; teeth indicate upthrust side)

Anticline, syncline (arrow indicates plunge)

Anticline, syncline (overturned)

Fossil locality 15

Stratigraphic section, photogrammetric section (indicates type section)* EB3-3*

Structural cross-section A —— A′

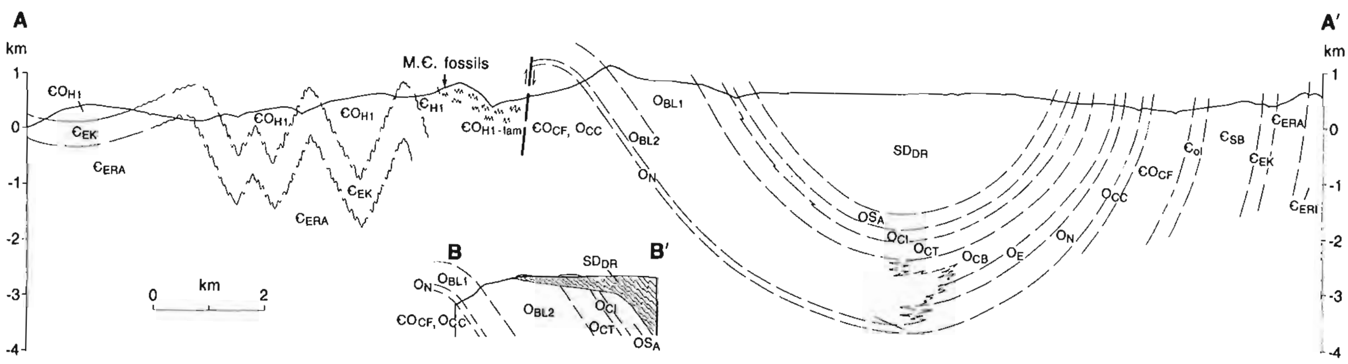


Figure 1. (cont'd.)

The stratigraphic framework for the Central Ellesmere Fold Belt was established by J.W. Kerr in 1961 and 1962. Relevant for the project area are his studies on southwestern Judge Daly Promontory (Kerr, 1967a, b, 1968, 1973a), where he recognized two formations of assumed Late Proterozoic age, and eleven formations of Early Cambrian to Late Ordovician ages.

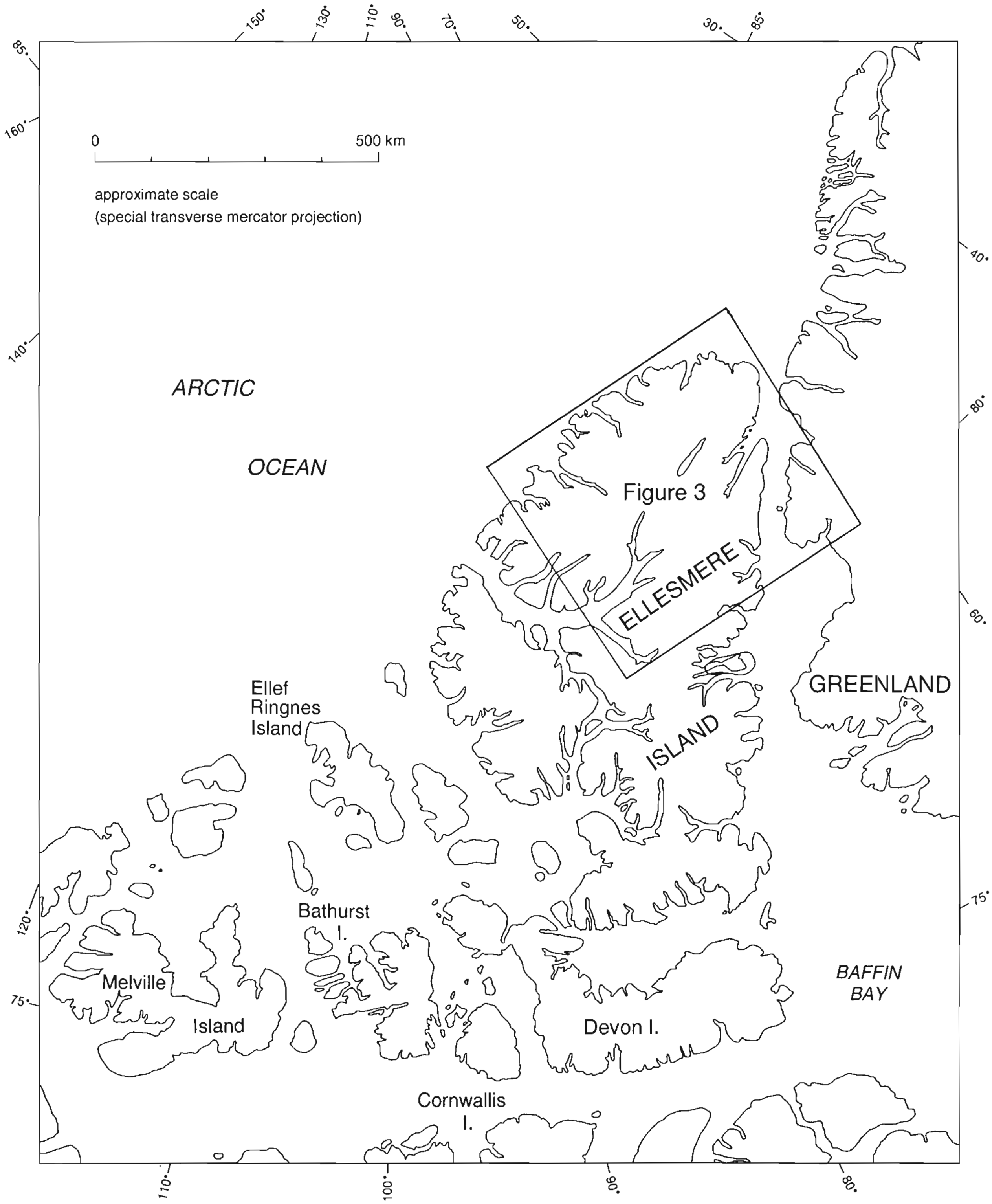


Figure 2. Queen Elizabeth Islands showing location of Figure 3.

In 1966, B.S. Norford measured an additional stratigraphic section on Judge Daly Promontory, which yielded important fossil collections (Norford, 1966).

In 1973, R.L. Christie (1974) carried out more fieldwork on Judge Daly Promontory, extending Kerr's mapping and applying his stratigraphic nomenclature.

During the same season, a field party of J.C. Sproule and Associates, Ltd., led by U. Mayr, investigated the geology of east-central Ellesmere Island (including some areas not covered by Kerr) for the Great Plains Development Company of Canada, Ltd. The resulting report (J.C. Sproule and Associates, Ltd., 1974), originally confidential, has been accessible to the public for several years. It contains a wealth of field observations, photogeological interpretation, and photogrammetric data. From an economic point of view, the most important result was the discovery of a lead-zinc showing on northeastern Judge Daly Promontory. This showing was trenched and further investigated by a field party of the Great Plains Development Company in 1974 (McClaren and Habbishaw, 1974; Gibbins et al., 1977). An extensive geochemical prospecting program was disappointing.

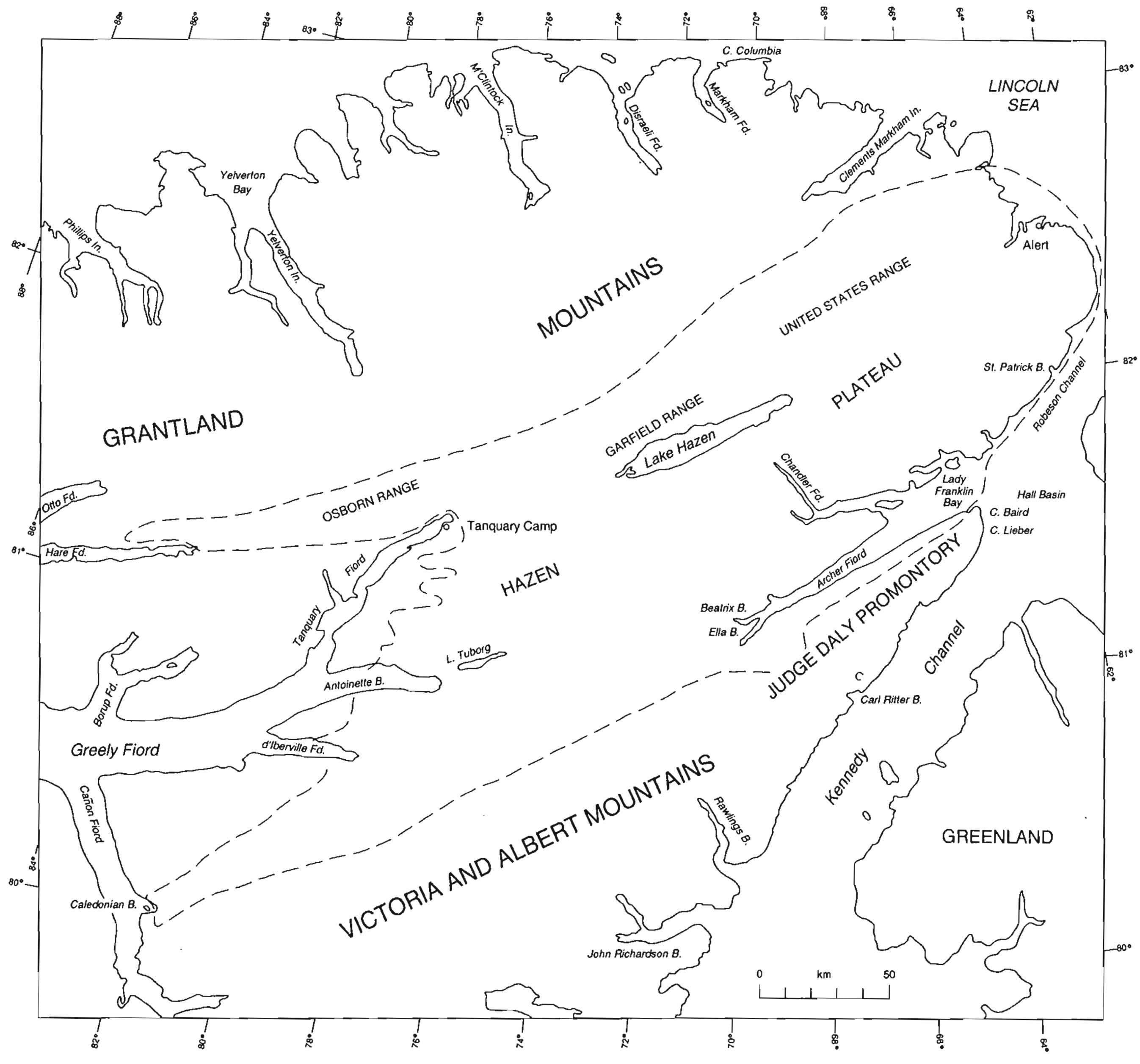


Figure 3. Geographic setting of study area (dashed outline). For location of geographic setting, see Figure 2.

I investigated the region now known as the Hazen Fold Belt in 1962, 1965, 1966, and 1967. The strata in this belt were assigned to three formations of Cambrian to Silurian age (Trettin, 1971). Additional studies of deep water sediments in the Central Ellesmere Fold Belt were made in the Cañon Fiord and Trold Fiord regions in 1970, 1972, and 1973 (Trettin, 1978, 1979).

The fourth phase, from 1975 to 1990, was part of a continuing program to complete the initial investigation of all of northern Ellesmere and Axel Heiberg islands. Most of the work still was done from fly camps, but helicopter support was more effective because of the use of machines with turbine engines from 1977 onward. The base camp was at the head of Tanquary Fiord for most of the field seasons, but was located at Lake Hazen in June, 1977. I carried out stratigraphic studies and mapping during parts of the 1975, 1977, 1979, 1980, 1982, and 1984 seasons. D.G.F. Long studied Lower Cambrian formations of the Central Ellesmere Fold Belt on southeastern Judge Daly Promontory in 1982, and his work (Long, 1989a, b and *in* Trettin et al., 1991) is briefly summarized below. Detailed structural studies were made during the 1988 field season in selected areas of the Hazen Fold Belt by E. Klaper (1990) and L. Maurel (1989), and some additional mapping was done by D.W. Esson at Ella Bay in 1990.

This work has resulted in significant changes in the stratigraphic framework and in substantial improvements of the geological maps.[1]

The work outlined here marginally overlaps with studies of Upper Ordovician to Lower Devonian formations of the Franklinian Shelf made independently by T.A. de Freitas (1991) in 1987–1989. Most relevant for this report are his investigations of the Cape Phillips Formation on the southeastern coast of Judge Daly Promontory at Cape Lieber and Carl Ritter Bay, and of a Silurian shelf margin carbonate mud mount at Cañon Fiord. This work was done in 1988 with the aid of skidoos and minimal aircraft support.

ACKNOWLEDGMENTS

The stratigraphy presented here is based largely on fossil identifications by G.S. Nowlan, B.S. Norford, and W.H. Fritz. Identifications by C.R. Barnes, T.A. de Freitas, H.J. Hofmann, G.A. Cooper, G.M. Narbonne, D.E. Jackson, J. Pojeta, Jr., J. Riva, R. Thorsteinsson, and R.V. Tipnis also are gratefully acknowledged. Significant field contributions were made by A.K. Higgins and J.N. Soper, who recognized the Nesmith beds as a separate unit, correlative with the Paradisfjeld Group of North Greenland, and by M.P. Cecile, who found age-diagnostic trace fossils in the Grant Land Formation. I also thank Doug Esson for careful mapping and stratigraphic section work in 1990, and Greg Stewart for able assistance with the 1984 fieldwork. M. Labonté and D.W. Morrow gave advice on the computer treatment of statistical problems. For critical reading of the manuscript and numerous helpful suggestions I am indebted to T.A. de Freitas and M.P. Cecile. I thank J. Korthenschyl and J.M. Monro for drafting and editing, respectively.

[1]Preliminary versions of geological maps (scale 1:125 000) covering the Hazen Fold Belt (and adjacent other elements) have been released in the following Open Files of the Geological Survey of Canada:
- Lady Franklin Bay map area, O.F. 2136 (Trettin and Mayr, 1990)
- Tanquary Fiord map area, O.F. 2135 (Mayr and Trettin, 1990a)
- Clements Markham Inlet and Robeson Channel map areas, O.F. 2138 (Mayr and Trettin, 1990b)
- Parts of Greely Fiord East, Greely Fiord West, and Cañon Fiord map areas, O.F. 836 (Trettin, 1982) (out of date with respect to formational nomenclature and age assignments, but the basic geology is valid in conjunction with the present report)
- Otto Fiord map area, O.F. 757 (Trettin and Mayr, 1981) (out of date, revised version in preparation)

Final versions of these maps, as mentioned, will be presented in Part 3 of this series.

CHAPTER 2

STRATIGRAPHIC-STRUCTURAL FRAMEWORK

REGIONAL FRAMEWORK

Five first-order tectonic provinces are recognized in the Arctic Islands — from southeast to northwest, the Canadian Shield, Arctic Platform, Franklinian mobile belt (formerly Franklinian Geosyncline), Sverdrup Basin, and Arctic Continental Terrace Wedge (Fig. 4; cf. Trettin, 1989, 1991a).

The Canadian Shield consists of Archean and Lower Proterozoic crystalline basement rocks and of unconformably overlying sedimentary and volcanic successions, ranging in age from late Early to latest Proterozoic (Frisch and Trettin, 1991). Seismic reflection data suggest that the Proterozoic supracrustal deposits are 10 to 12 km thick in the subsurface of Melville Island (about 1000 km southwest of the project area), and that they contain several unconformities (Kanasewich and Berkes, 1988). This thickness is not excessive, considering that it represents a longer time span than the Phanerozoic record. In the Thule Basin of southeastern Ellesmere Island and adjacent Greenland, only about 4.5 km of strata of late Middle and Late Proterozoic age are preserved (Dawes, 1976; Dawes et al., 1982; Frisch and Christie, 1982; Dawes and Vidal, 1985; Jackson, 1986), but the Proterozoic supracrustal succession probably is thicker and more complete farther northwest, beneath the Central Ellesmere Fold Belt.

The Arctic Platform is characterized by relatively undisturbed Phanerozoic successions that unconformably overlie the Canadian Shield.

The Franklinian mobile belt comprises strata of latest Proterozoic to Late Devonian age affected by a series of deformations that culminated in the extensive Ellesmerian Orogeny during the latest Devonian and Early Carboniferous. The Early Cambrian to Early Devonian strata were deposited in a southeastern Shelf Province and a northwestern Deep Water Basin, separated by a boundary that receded cratonward in several steps from late Early Cambrian to Early Silurian time. The Deep Water Basin is divisible into a southeastern sedimentary subprovince that can be traced from northeastern Greenland to Prince Patrick Island, and a northwestern sedimentary and volcanic subprovince, exposed only in northern Ellesmere and Axel Heiberg islands. The Shelf Province is overlain by a middle and Upper Devonian foreland basin, containing a thick succession of shallow water marine and nonmarine clastic sediments. Nonmarine clastic sediments of Middle and/or Late Devonian age in the Yelverton Pass region (Tanquary Fiord map area) appear to be erosional remnants of a separate intermontane basin that overlies parts of the sedimentary and volcanic subprovince of the Deep Water Basin (Maurel, 1989; Mayr, 1992).

In the Arctic Islands, the Upper Silurian-Devonian orogenic system has been divided into nine fold belts that differ in structural trend, structural style, and/or aspects of their geological history. In central and northern Ellesmere Island (Fig. 5) there are three fold belts and one composite terrane. The Central Ellesmere Fold Belt corresponds essentially to the Shelf Province, the Hazen Fold Belt to the sedimentary subprovince of the Deep Water Basin, and the Clements Markham Fold Belt to the sedimentary-volcanic subprovince. In northernmost Ellesmere Island, the Clements Markham Fold Belt is bordered by Pearya, a composite terrane that differs from the Franklinian mobile belt with respect to basement age and Ordovician tectonic history, but has affinities with the Appalachian-Caledonian belt (Trettin, 1987b). Time and mode of accretion of Pearya are problematic and will be discussed in Part 2 of this Bulletin (in preparation, 1992).

Sverdrup Basin strata lie with angular unconformity on the bevelled structures of the Ellesmerian Orogen. The basin is about 1300 km long, up to 400 km wide, and contains up to 3 km of upper Paleozoic strata and up to 9 km of Mesozoic strata (Davies and Nassichuk, 1991; Embry, 1991). Basin development was terminated by the Eurekan Orogeny of latest Cretaceous to Paleogene (latest Eocene or earliest Oligocene) age, which produced syntectonic clastic sediments assigned to the Eureka Sound Group.

The Arctic Continental Terrace Wedge is confined to the northwestern margin of the Arctic Archipelago, where it is exposed from Meighen Island to Banks Island. The wedge consists of a southeastward tapering succession of clastic sediments that probably ranges in age from Late Cretaceous to Holocene offshore but is restricted to the Neogene on land.

STRATIGRAPHIC FRAMEWORK OF THE PROJECT AREA

The project area, along with the environs of Caledonian Bay, Cañon Fiord (Trettin, 1979), and the

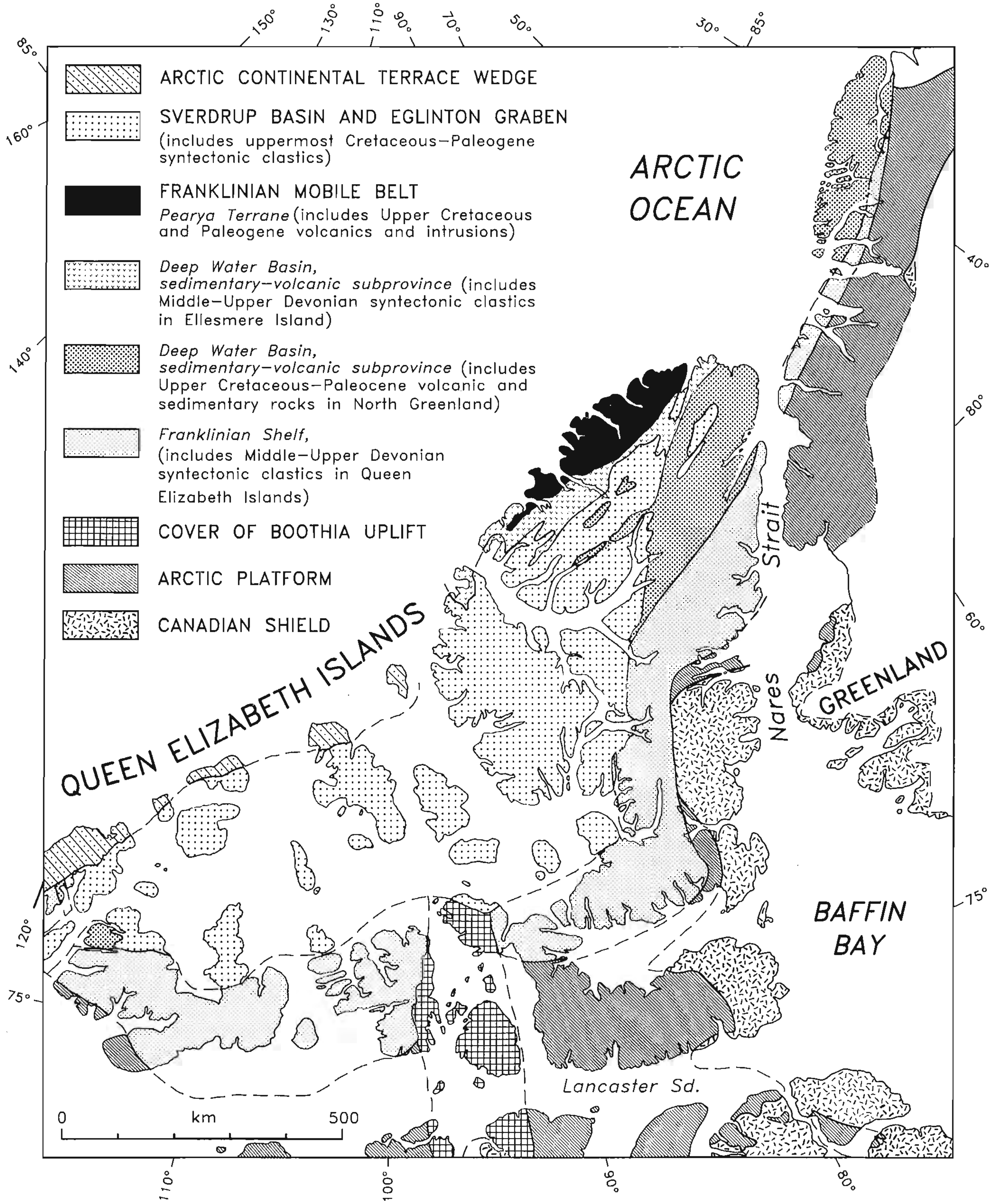


Figure 4. Major stratigraphic-structural provinces of Queen Elizabeth Islands and North Greenland. (Partly adapted from Harrison, 1991, Figs. 26, 108.) For locality names, see Figure 2.

Carl Ritter Bay Anticline of southwestern Judge Daly Promontory (Kerr, 1967a, 1968; Long 1989a, b) contains the most important exposures of the Franklinian Deep Water Basin and of the outer part of the Franklinian Shelf in the Arctic Islands. Moreover, exposures southeast of Ella Bay permit reconstruction of the Ordovician shelf-basin transition, the only area in the Arctic Islands where this is possible (Fig. 1). The nomenclature and regional correlation of the units recognized in the project area are shown in Figure 6, and a stratigraphic cross-section of the shelf margin at Ella Bay is shown in Figure 7.

Briefly, the shelf succession in this region ranges in age from Early Cambrian to Early Silurian. Southeast of Ella Bay (Ella Bay 3 and Ella Bay 4 sections), it comprises the following major units:

1. Craton-derived clastic sediments of the Ellesmere Group (Lower Cambrian).

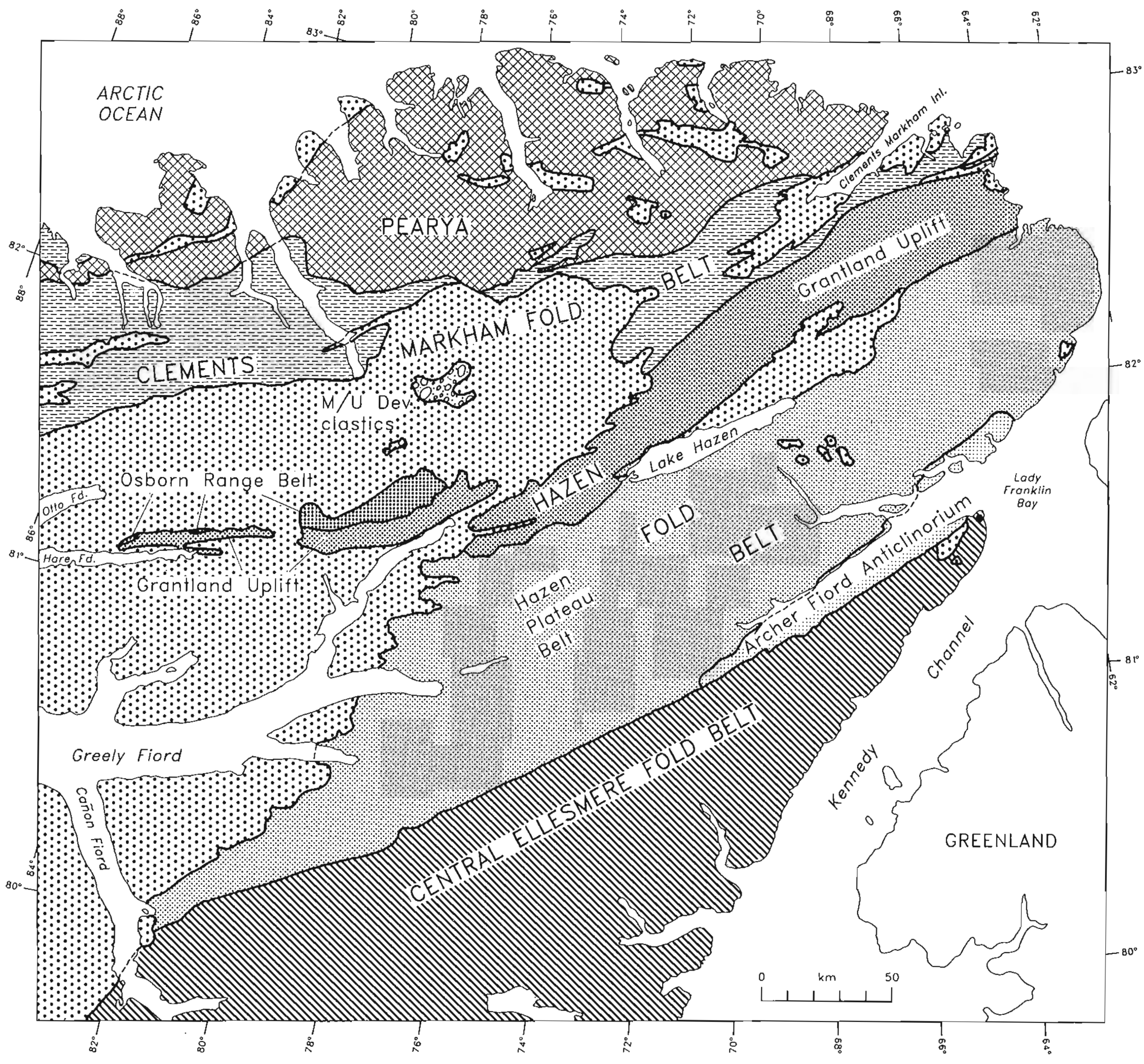


Figure 5. Pre-Carboniferous stratigraphic-structural elements of northern Ellesmere Island. Areas with dotted pattern are underlain by Carboniferous to Tertiary rocks. Contacts have been extrapolated through ice cover. For additional locality names, see Figure 3. Greenland geology not shown.

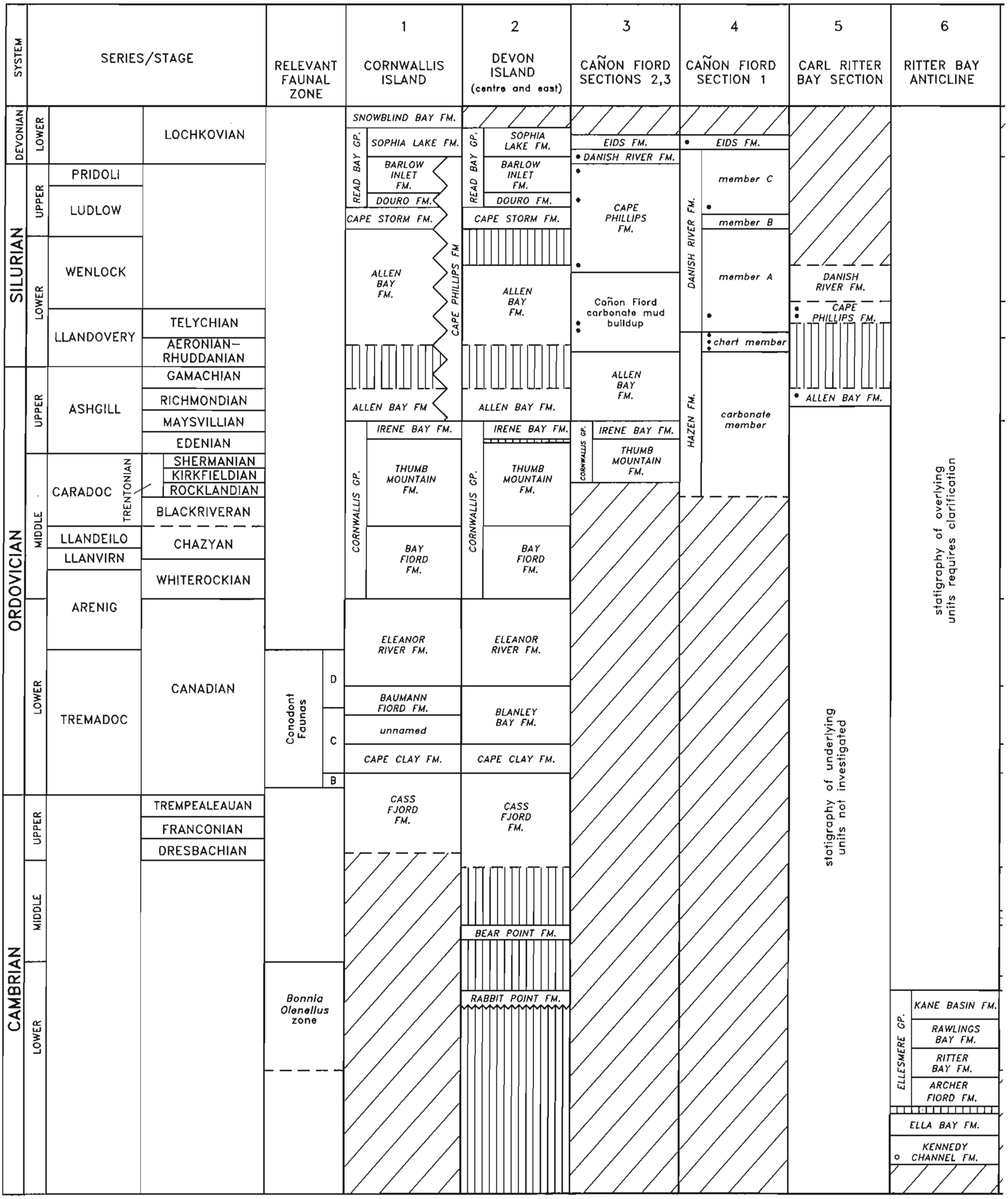


Figure 6. a) Correlation chart. b and c) Index maps showing correlation chart area localities and legend.

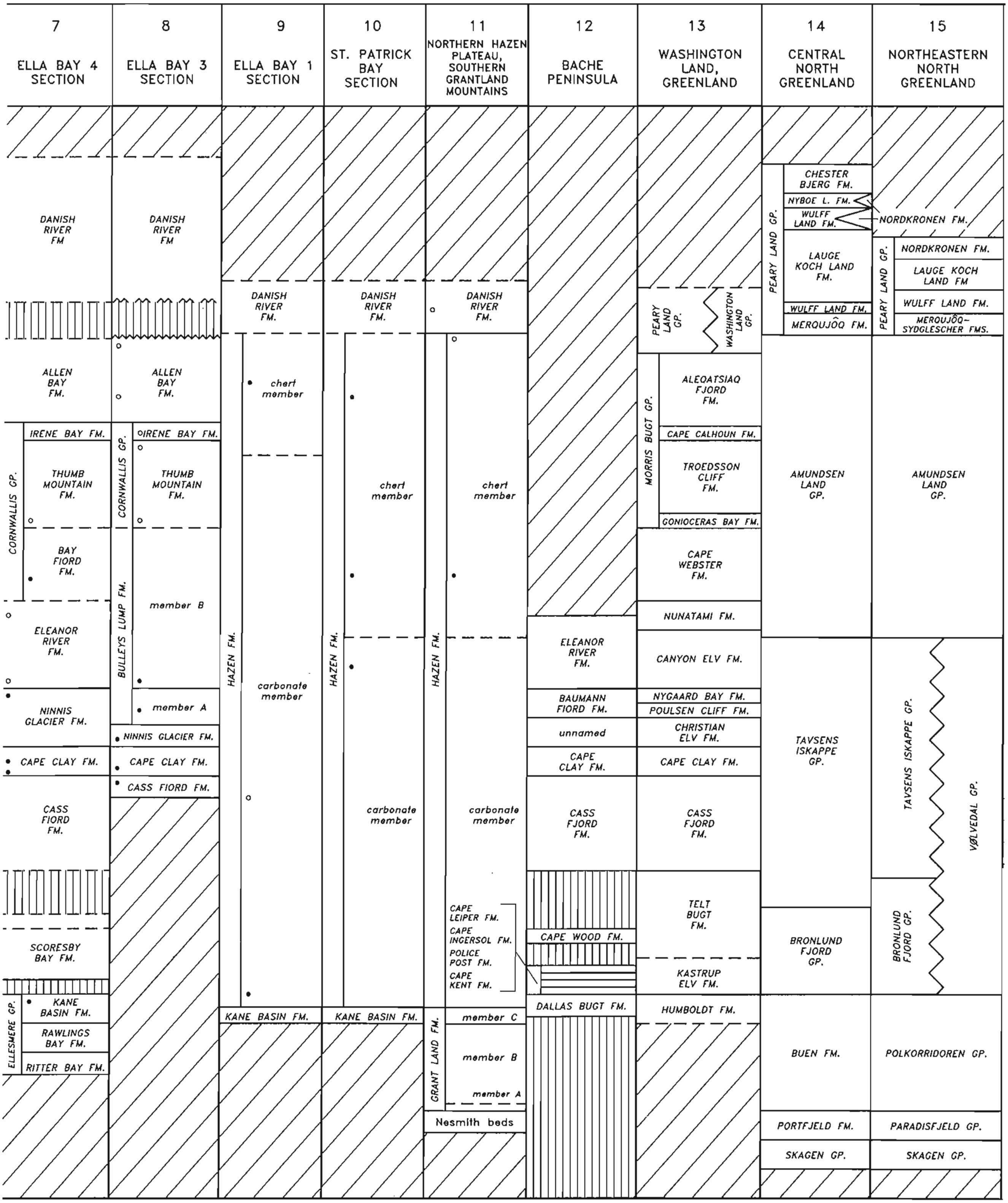
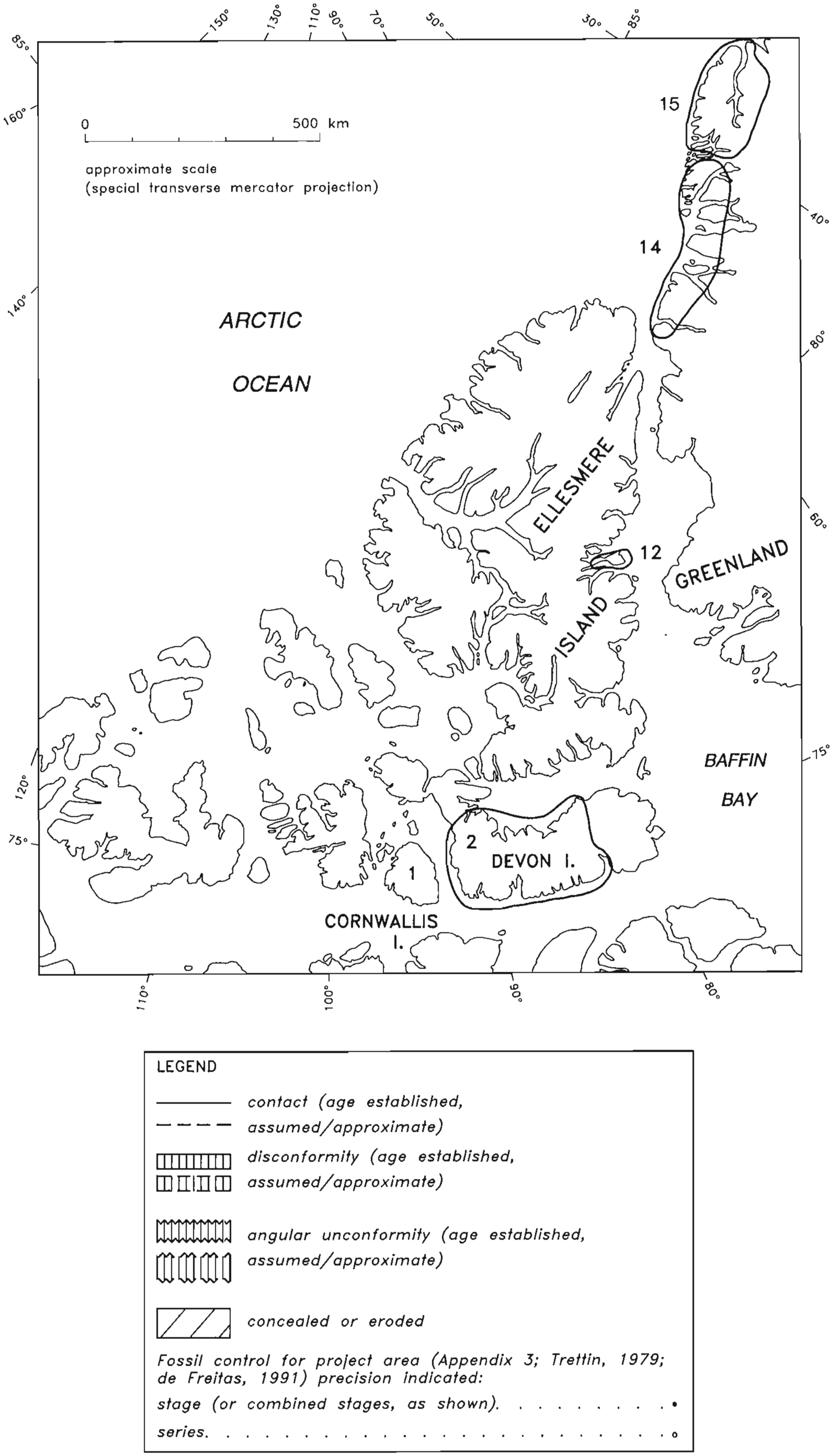
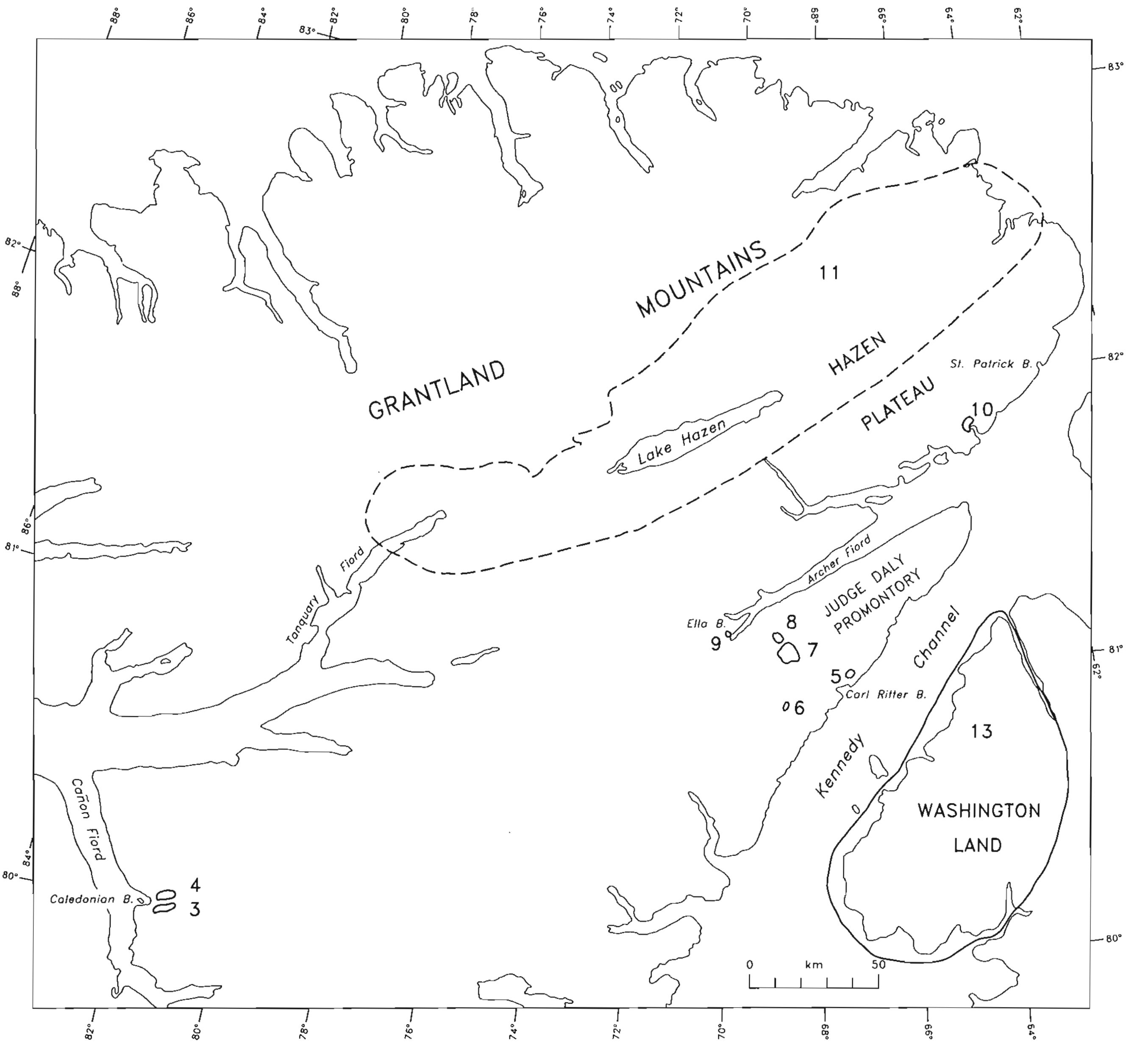


Figure 6a. (cont'd.)



0 500 km
approximate scale
(special transverse mercator projection)
ARCTIC
OCEAN
ELLESMERE
ISLAND
GREENLAND
BAFFIN
BAY
DEVON I.
CORNWALLIS
I.
15
14
12
2
1
150°
130°
110°
90°
70°
50°
30°
85°
160°
140°
120°
75°
40°
80°
60°
75°
110°
100°
90°
80°
LEGEND
contact (age established,
assumed/approximate)
disconformity (age established,
assumed/approximate)
angular unconformity (age established,
assumed/approximate)
concealed or eroded
Fossil control for project area (Appendix 3; Trettin, 1979; de Freitas, 1991) precision indicated:
stage (or combined stages, as shown). . . . . •
series. . . . . ∘

Figure 6b.



Sources

1: Thorsteinsson and Kerr, 1986; Thorsteinsson, 1980; Thorsteinsson and Mayr, 1987; Mayr *in* Trettin, 1991c.
2: Thorsteinsson and Mayr, 1987; Mayr *in* Trettin, 1991c.
3-4: Kerr, 1968; Trettin, 1979; T.A. de Freitas, 1991.
5: de Freitas, 1991; this report.
6: Kerr, 1967a; Long, 1989a, 1989b.
7-11: This report.
12: Christie, 1967; Peel and Christie, 1982; Peel et al., 1982; Mayr *in* Trettin, 1991c.
13-15: Peel and Sønderholm *in* Trettin, 1991c; Higgins et al., 1991.

Figure 6c.

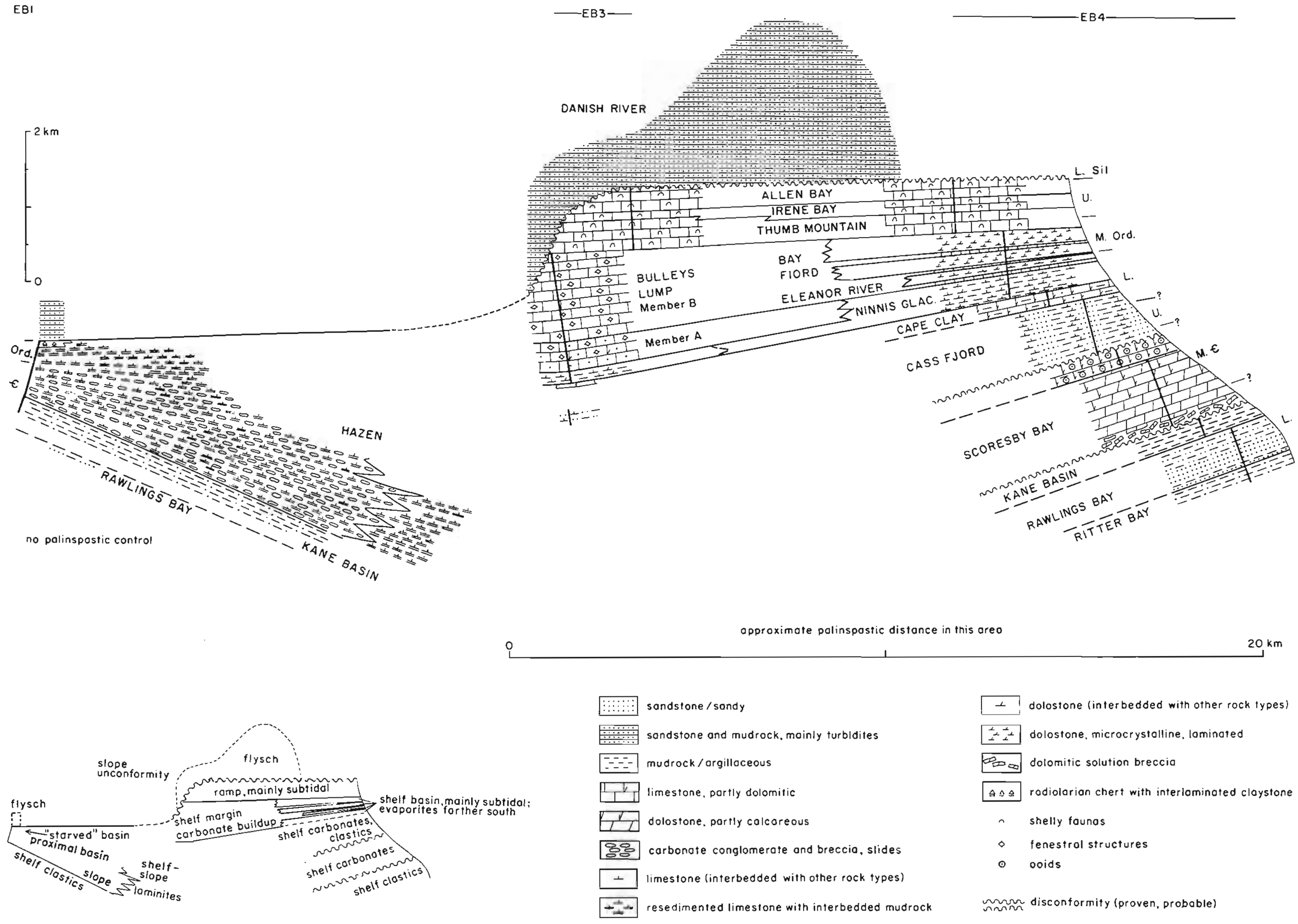


Figure 7. *Restored stratigraphic cross-section, Ella Bay area. Areas with insufficient control are left blank. For location of sections, see Figure 1.*

2. Carbonates and mixed carbonate and clastic sediments assigned to the Scoresby Bay Formation, oolitic limestone unit, and the Cass Fjord and Cape Clay formations, and to the lower part of the Ninnis Glacier Formation (transitional to major unit 4, below) (uppermost Lower Cambrian to lowermost Ordovician).

3. A shelf-margin carbonate buildup, the Bulleys Lump Formation (Lower to lower Middle Ordovician).

4. Carbonates and minor mudrocks of an intrashelf basin, comprising the upper part of the Ninnis Glacier Formation and the Eleanor River and Bay Fiord formations (Lower to lower Middle Ordovician, correlative with unit 3).

5. Carbonates (deposited on a very gently inclined ramp), assigned to the Thumb Mountain, Irene Bay, and Allen Bay formations (Middle Ordovician to Lower Silurian, middle Llandovery).

In the central and northern parts of the Hazen Fold Belt, the deep water succession comprises four major units:

1. Resedimented carbonates assigned to the Nesmith beds (mid-Lower Cambrian).

2. Rapidly deposited, craton-derived clastic rocks of the Grant Land Formation (upper Lower Cambrian).

3. A condensed succession of resedimented carbonates, mudrock, radiolarian chert, and minor sandstone assigned to the Hazen Formation (uppermost Lower Cambrian to Lower Silurian, upper Llandovery).

4. Rapidly deposited, synorogenic clastic rocks (flysch) of the Danish River Formation (Early Silurian, upper Llandovery to earliest Devonian).

The shelf-basin boundary receded southeastward during several episodes, and consequently the boundary between the shelf and deep water successions is diachronous in the southeastern part of the study area. Thus, in the southeastern Hazen Fold Belt, the Hazen Formation lies on the Ellesmere Group (Kane Basin Formation), rather than on member C of the Grant Land Formation. At Carl Ritter Bay and Cañon Fiord, the shelf carbonates are overlain diachronously by a deep water succession comprising:

1. Resedimented carbonates, mudrock and chert of the Cape Phillips Formation (Silurian; Llandovery at Carl Ritter Bay, Wenlock to Pridoli at Cañon Fiord).

2. Flysch of the Danish River Formation (Silurian, Wenlock, at Carl Ritter Bay; upper Llandovery to lowermost Devonian at Cañon Fiord).

However, southeast of Ella Bay (Ella Bay 3 and Ella Bay 4 sections), the flysch lies disconformably on the carbonates.

STRUCTURE OF THE PROJECT AREA

The project area comprises all of the Hazen Fold Belt and an adjacent part of the Central Ellesmere Fold Belt (Fig. 5) and has undergone deformation in mid-Paleozoic [Ellesmerian Orogeny and older(?) events] and early Tertiary time (Eurekan Orogeny).

MID-PALEOZOIC DEFORMATION

Age

The mid-Paleozoic deformation is represented by an angular unconformity between Devonian or older and Carboniferous or younger strata. The youngest preserved beds beneath this unconformity are Silurian in the northwestern and central parts of the Hazen Fold Belt, and earliest Devonian in the southwesternmost parts of the Hazen Fold Belt and in adjacent parts of the Central Ellesmere Fold Belt. The precise age of deformation(s) of the Hazen Fold Belt, within this broad interval, is uncertain; this complex, unresolved problem cannot be discussed without taking into consideration the stratigraphic and structural relations with regions to the southeast and northwest.

The Central Ellesmere Fold Belt — like the Parry Islands Fold Belt — clearly was folded and faulted in latest Devonian–Early Carboniferous time (Ellesmerian Orogeny *sensu stricto*) and this event must have affected the Hazen Fold Belt. The structural history of the Clements Markham Fold Belt is less certain. Indirect evidence suggests two phases of deformation: tight folding and faulting, sometime within the late Ludlow–Frasnian interval; and faulting (perhaps with open folding) during the Ellesmerian Orogeny. The main question is the precise age of the earlier event and its effect on the Hazen Fold Belt.

Boundaries of the mid-Paleozoic fold belts

The project area comprises all of the Hazen Fold Belt and an adjacent part of the Central Ellesmere Fold Belt on southwestern Judge Daly Promontory. On Judge Daly Promontory, the boundary between these two belts is equated with the relatively stable position of the shelf margin from latest Early Cambrian to middle Llandovery time. Where exposed, it is a steeply dipping thrust fault. At Caledonian Bay, where it is concealed, it is equated with the approximate northwestern limit of a carbonate buildup at the original shelf margin that persisted until late Early Silurian (early Wenlock) time (T.A. de Freitas, 1991).

The boundary between the Hazen and Clements Markham fold belts is exposed only in the Clements Markham Inlet map area (Mayr and Trettin, 1990b) where it coincides with the Porter Bay Fault, the southeasternmost element of the Feilden Fault Zone (Okulitch and Trettin, 1991). This fault zone must have been active during the Eurekan Orogeny because it affects strata of the Sverdrup Basin. Its braided appearance, and thrust-fault characteristics at a bend northeast of Piper Pass suggest dextral strike slip, but there are no transverse markers that can be used to establish offset. It is possible that the Porter Bay Fault dates back to the Late Silurian–Devonian movements and that it had a different sense of displacement then, but this hypothesis is even more difficult to test. Elsewhere, the boundary between the Hazen and Clements Markham fold belts is covered by younger strata or glaciers.

Subdivisions of the Hazen Fold Belt

In the Hazen Fold Belt, four subdivisions are recognized that differ mainly with respect to level of exposure, but also with respect to Lower Cambrian stratigraphy (Fig. 5; for locality names, see Figure 3) or Eurekan deformation.

1. The Osborn Range Belt, exposed north of Hare Fiord and in the Osborn Range, is underlain by Cambrian to Silurian strata of the Grant Land, Hazen, and Danish River formations. The belt was affected by folding and faulting during the mid-Paleozoic deformation and by faulting (reverse and normal) during the Eurekan Orogeny. The absence of the Osborn Range Belt in the northeastern part of the project area may be due to truncation by the Porter Bay Fault.

2. The Grantland Uplift, extending from northwest of Alert to north of Hare Fiord, is underlain by Lower Cambrian strata, mainly of the Grant Land Formation and to a lesser extent of the Nesmith beds. Between Henrietta Nesmith Glacier and the Lincoln Sea, the Nesmith beds underlie three narrow, elongate areas. The structure of the Nesmith beds in these areas is mostly concealed, but outward vergence of the adjacent Grant Land strata suggests fan-shaped anticlinoria.

   In the Grantland Uplift, the basal strata of the Sverdrup Basin lie on the Grant Land Formation, indicating that the Hazen and Danish River formations were removed by uplift and erosion prior to Sverdrup Basin sedimentation. The belt was elevated again during the Eurekan Orogeny by movements on the Lake Hazen Fault Zone, the main faults of which form the southeastern limit of this subdivision of the Hazen Fold Belt.

3. The Hazen Plateau Belt is dominated by Silurian strata of the Danish River Formation (Fig. 8) with anticlines in the Hazen Formation along its northwestern, northeastern, and southeastern margins (the last included in the Archer Fiord Anticlinorium). This configuration indicates a broad, southwestward-plunging synclinorium. The belt is unconformably overlain by slightly deformed upper Paleozoic sediments along its southwestern margin and by flat-lying Paleogene strata in the central part, indicating that it formed a stable block during the Eurekan Orogeny.

4. Archer Fiord Anticlinorium contains outcrops of Lower Cambrian shelf sediments (Rawlings Bay and Kane Basin formations) and of Cambrian to Lower Silurian deep water sediments (Hazen and Danish River formations). The nose of this southwestward-plunging structure is exposed southwest of Ella Bay, and the northwestern and southeastern flanks are exposed on the northwestern and southeastern sides of Archer Fiord and at Lady Franklin Bay. Second-order folds, showing mirror-image, en echelon arrangement, occur on either side of the nose of the anticlinorium at Ella Bay (Figs. 1, 9, 135). They are comparable in style to the folds of the Hazen Plateau Belt and indicate that the Archer Fiord Anticlinorium is a mid-Paleozoic feature. However, the faults separating the latter from the Central Ellesmere Fold Belt probably are early Tertiary in age — similar structures affect an outlier of the Eureka Sound Formation on northeastern Judge Daly Promontory (cf. Mayr and de Vries, 1982).

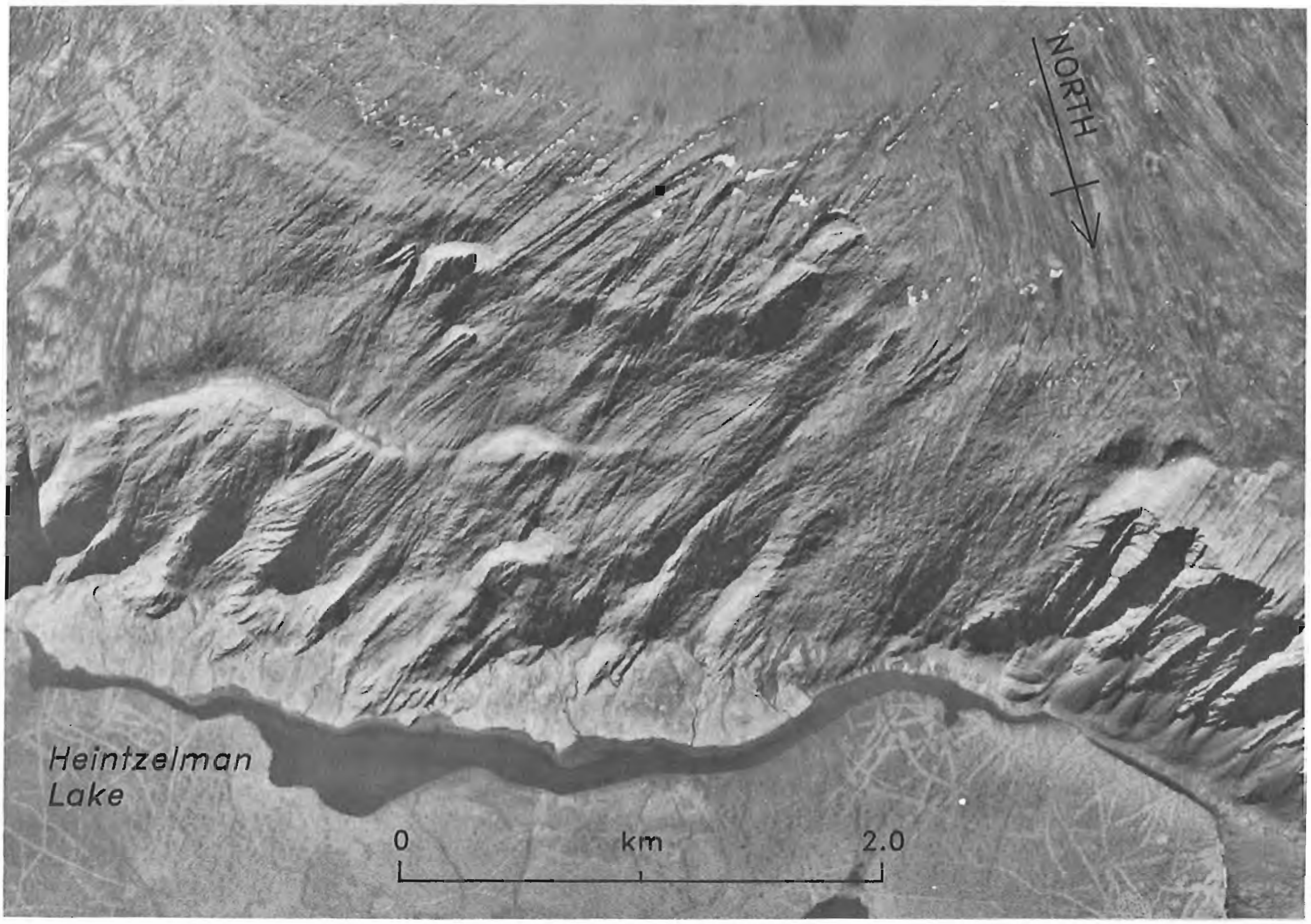


Figure 8. Vertical aerial photograph, showing complex, chevron-type folds in the Danish River Formation; Hazen Plateau Belt of the Hazen Fold Belt, Lady Franklin Bay map area (unit 5 of Table 1); relief about 600 m (part of aerial photograph NAPL A16609-44).

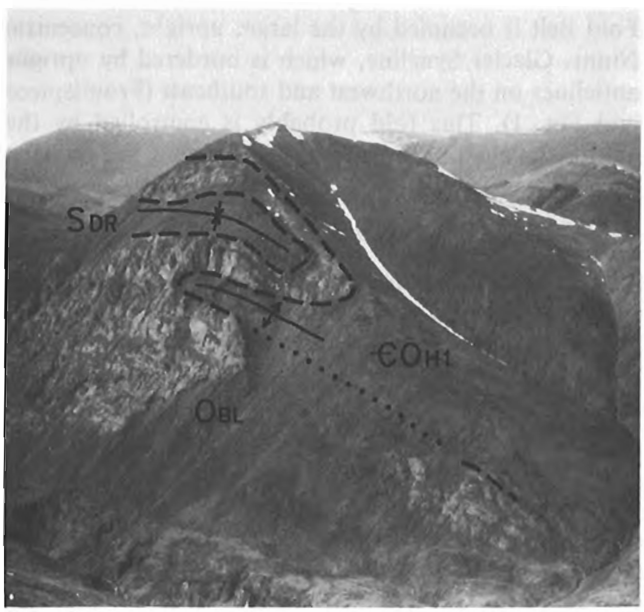


Figure 9. Second-order, en echelon folds on southeastern flank of Archer Fiord Anticlinorium (looking northwest), involving the carbonate member of the Hazen Formation ($ЄO_{Hl}$), and Bulleys Lump (O_{BL}), and Danish River (S_{DR}) formations. ISPG photo. 2256-37.

Structural style of the Hazen Fold Belt

Folding was disharmonious; two layers with mappable major folds, controlled by competent units, alternating with three layers of complex minor folds, formed in incompetent units (Table 1).

1. The Nesmith beds and the lowermost part of the Grant Land Formation (member A), which contain relatively high proportions of slate, are involved in exceedingly complex, minor folds and faults (Figs. 10c, 142).

2. Major anticlines and synclines (Fig. 10b), traceable on airphotos for distances up to 5 km, or monoclinal thrust sheets (Fig. 143) where massive sandstone units (ten or tens of metres thick) are present in member B of the Grant Land Formation.

3. The carbonate member of the Hazen Formation, where it consists of thinly interstratified carbonates and slates, forms a second layer of minor structures, that can be chaotic (Figs. 10a, 11). However, mappable minor folds occur where massive carbonate units are present (Figs. 1, 91, 135).

4. The most extensive folds, up to 18 km long, are supported by the chert member of the Hazen Formation (Figs. 10a, 138) or by the entire formation, where carbonates and mudrocks have been chertified. Surface exposures are mostly anticlines.

5. Strata of the Danish River Formation directly above the chert member of the Hazen Formation conform with the major folds supported by that unit (Fig. 10a). Higher in the section, however, complex, minor chevron folds prevail that rarely are mappable (Fig. 8).

TABLE 1

Hazen Fold Belt, stratigraphic-structural units

Mappable major folds	Minor folds
4. Hazen Fm., chert mbr.	5. Danish River Fm.
2. Grant Land Fm., mbr. B (or parts)	3. Hazen Fm., carbonate mbr.*; Grant Land Fm., mbr. C
	1. Grant Land Fm., mbr. A Nesmith beds

*The carbonate member forms major folds where it contains thick carbonate units or where it has been replaced by chert.

Recent studies by Klaper (1990) have provided additional information on the style and mechanism of folding, which can be summarized as follows. The folding was accomplished by flexural slip and folds approach chevron style. Bedding-cleavage intersection lineations are parallel to associated minor fold axes. Folded multilayers display cleavage fans suggesting synchroneity of fold and cleavage formation. The amount of shortening, deduced from line length measurements, is about 50 per cent at St. Patrick Bay, and 50 to 60 per cent near the head of Tanquary Fiord.

Structure of the Central Ellesmere Fold Belt southeast of Ella Bay

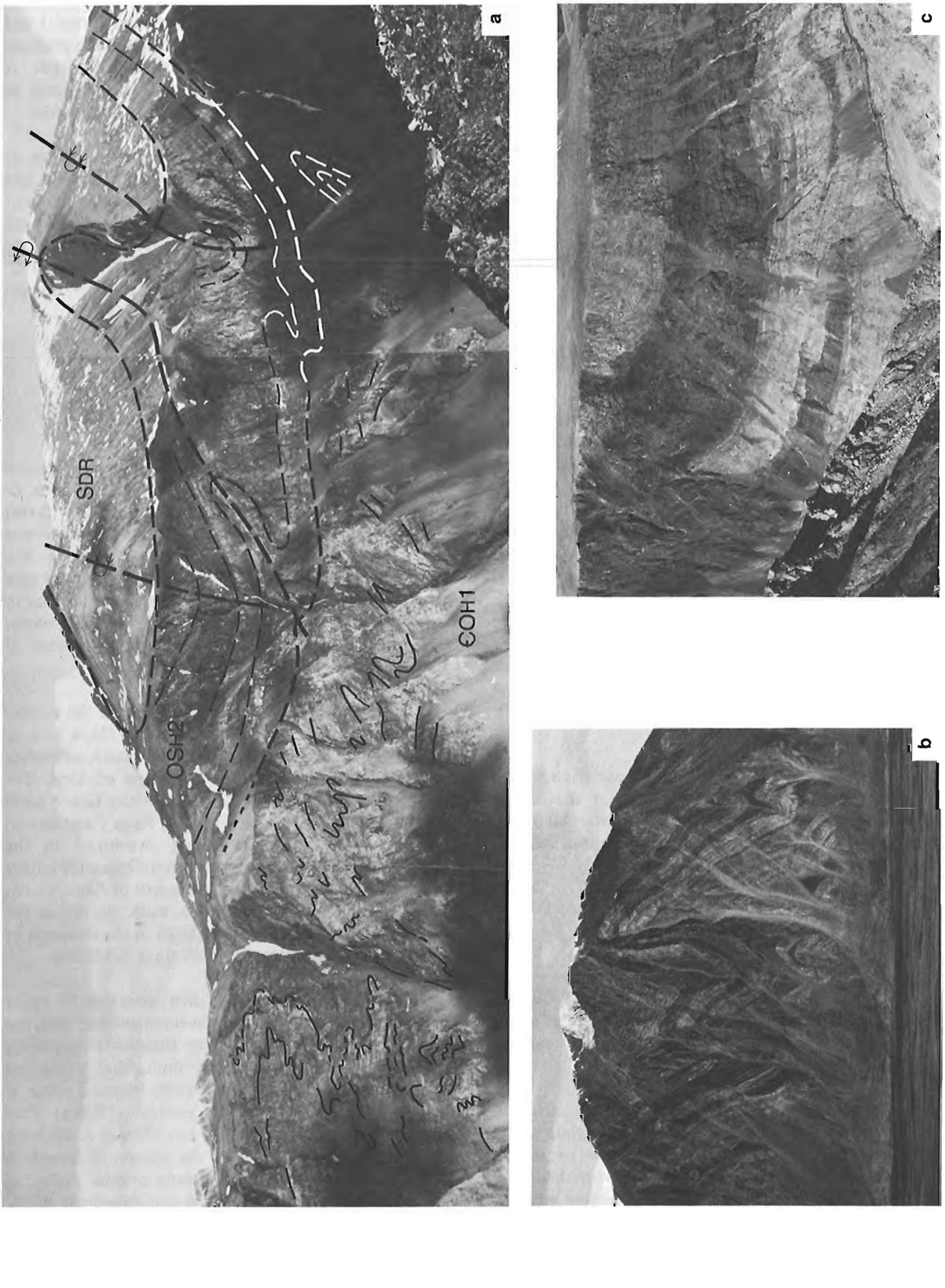
Most of the area assigned to the Central Ellesmere Fold Belt is occupied by the large, upright, concentric Ninnis Glacier Syncline, which is bordered by upright anticlines on the northwest and southeast (Frontispiece and Fig. 1). This fold probably is controlled by the competent shelf carbonate succession, 3.8 km thick at

Figure 10. *Vertical variations in structural style in the Hazen Fold Belt, Tanquary Fiord map area.*

a) Structures at forks of Macdonald River, 14 km east-southeast of the head of the Tanquary Fiord, looking east. The carbonate member of the Hazen Formation ($\mathcal{C}O_{H1}$) displays chaotic folds and faults (unit 3 of Table 1). Major, in part overturned, folds are formed by the competent chert member (OS_{H2}, unit 4 of Table 1), which controls structures in the overlying Danish River Formation (S_{DR}). Relief about 700 m.

b) Chevron-type folds in member B of the Grant Land Formation (unit 2, Table 1) north of the head of the Tanquary Fiord; Grantland Uplift. Major folds are held up by units of massive sandstone. The dark bands are purple mudrocks (see colour photograph on cover).

c) Overturned to recumbent anticline formed in uppermost strata of the Grant Land Formation (light grey) and of the basal Hazen Formation (dark grey) (unit 3, Table 1); about 12 km northwest of the head of Tanquary Fiord; Osborn Range Belt.



a
SDR
OSH2
ЄOH1
b
c

Figure 11. Parasitic folds in the carbonate member of the Hazen Formation southeast of Ella Bay (cf. Fig. 1). ISPG photo. 3629-1.

the Ella Bay 4 section, comprising the Scoresby Bay to Allen Bay formations. The underlying Ellesmere Group, about 1.5 km of alternating sandstone and mudrock units, conforms with this syncline and has not developed a structural style of its own. This suggests that the structure of the Ellesmere Group, in turn, was influenced by the underlying Lower Cambrian Ella Bay Formation, another thick carbonate unit exposed in the core of the nearest anticline on the southeast (Kerr, 1967a; Long, 1989b), but concealed in the study area.

The structure of the Danish River Formation, which overlies the Allen Bay in the centre of the Ninnis Glacier Syncline, is poorly exposed. Airphoto interpretation and limited ground observations indicate tight and complex minor folds.

Metamorphic grade of the Hazen and Central Ellesmere fold belts

Strata of the Hazen Fold Belt and the Central Ellesmere Fold Belt southeast of Ella Bay are at about the same grade of metamorphism, which can be summarized as follows:

1. Clay minerals have recrystallized to white mica and chlorite, commonly of fine silt grade. The recrystallized phyllosilicates show preferred orientations at varying angles with bedding, imparting slaty cleavages to most fine grained mudrocks and argillaceous limestones and cherts.

2. The sand and coarse silt fractions of the major detrital units (Ellesmere Group and Grant Land and Danish River formations) have not attained the greenschist facies; detrital K-feldspar is preserved in all three units, and detrital biotite in the Grant Land and Danish River formations.

3. Most conodont collections from the Ordovician to Lower Silurian shelf carbonate succession and from the Hazen Formation have a Colour Alteration Index of 5, although values of 4.5 were measured locally. CAI values of 4 and 5 indicate temperatures of 190 to 300° and 300 to 480°C, respectively, according to experiments by Epstein et al. (1977) and Rejebian et al. (1987).

EUREKAN OROGENY

In the study area, the Eurekan Orogeny occurred during the early Tertiary (middle to late Eocene or earliest Oligocene). It was characterized by thrust faulting and associated open folding in some areas and was accompanied or followed by normal faulting. The effects of the Eurekan Orogeny can be recognized with confidence only in those areas where Carboniferous to lower Tertiary strata are preserved (Mayr and Trettin, 1990a, b; Trettin and Mayr, 1990; final versions of these maps are to be published later).

The most important Eurekan feature in the project area is the Lake Hazen Fault Zone (Fig. 12), a zone of southeast-directed, en echelon thrust faults, extending from north of Hare Fiord to northwest of Alert. The main thrust in any given area places the Grant Land Formation on strata ranging in age from Cambrian to Cretaceous. A major syncline, developed in the footwall of such a thrust, preserves an extensive outlier of the Sverdrup Basin in the area north of Lake Hazen. A broad anticline, about 9 km wide, occurs in the hanging wall of another main thrust in the area east of the head of Tanquary Fiord (Viking Anticline).

It is widely accepted now that inversion of faults plays a major role in basin development and orogeny (e.g., Ziegler, 1987). Thus many Eurekan thrust faults probably are inverted normal faults that originated during the Late Carboniferous–Early Permian phase of rifting, which initiated the Sverdrup Basin. This interpretation is fitting for the Lake Hazen Fault Zone because of its position near the margin of Sverdrup Basin. Some of the late Paleozoic normal faults, in turn, may have originated as mid-Paleozoic thrust faults.

Of key importance for the dating of the Eurekan Orogeny in the study area is a conglomerate of probable Middle Eocene age (Boulder Hills Formation of Miall, 1986 or Buchanan Lake Formation of Ricketts, 1986), located southeast of the main thrusts. Produced by early movements of the Lake Hazen Fault Zone, it was overthrust from the northwest during later movements.

Southeast of the Lake Hazen Fault Zone, the Tertiary deformation appears to have been weak or absent. Along the southwestern margin of the Hazen Fold Belt, southeast of middle and lower Tanquary Fiord, the Hazen and Danish River formations are unconformably overlain by Carboniferous and younger strata that form a very gentle, west-northwest-dipping monocline, disrupted only by minor normal faults and shallow folds. Farther northeast, in the central part of the Hazen Plateau, the Danish River Formation is unconformably overlain by flat-lying erosional remnants of the Eureka Sound Group. The plateau evidently represents a peneplain that developed after the Ellesmerian Orogeny and was exhumed repeatedly.

Tertiary movements, mainly thrust faulting and local strike slip faulting, have affected most of the

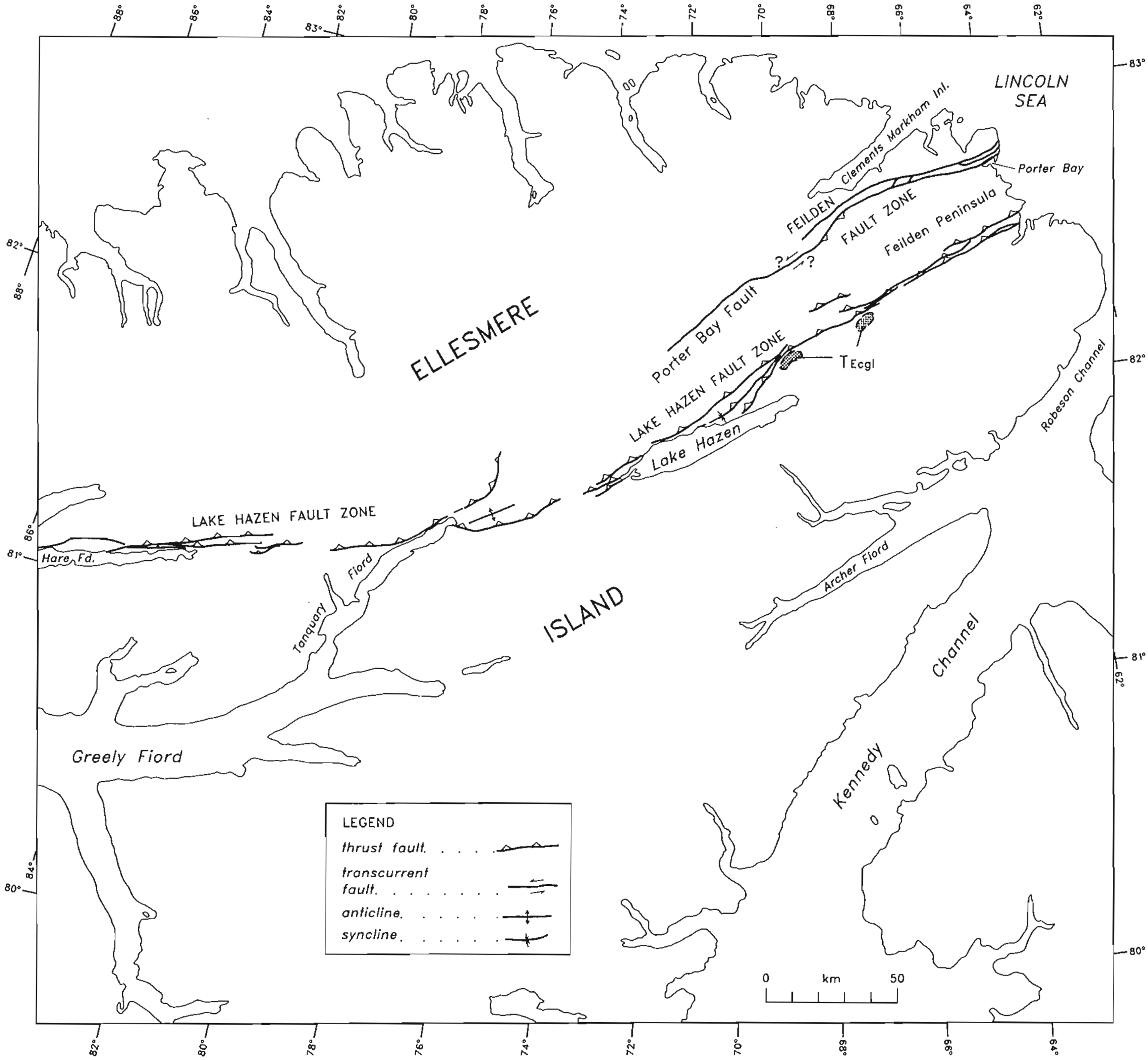


Figure 12. Major Tertiary fault zones of the project area and outcrop area of syntectonic conglomerate (TE_{cgl}).

Central Ellesmere Fold Belt and probably also the southeastern part of the Hazen Fold Belt. The steeply dipping thrust fault separating the Hazen and Central Ellesmere fold belts southeast of Ella Bay, for example, may be a Eurekan structure.

GEOMORPHIC EXPRESSION OF STRUCTURAL ELEMENTS

The project area forms part of three major subdivisions of the Axel Heiberg–Ellesmere region of the Arctic Islands (Bostock, 1970; Dawes and Christie, 1991; Figs. 3, 5).

1. The Osborn Range Belt and the Grantland Uplift of the Hazen Fold Belt together form the southeastern part of the Grantland Mountains, which extend from the position of the main thrusts of the Lake Hazen Fault Zone to the north coast of Ellesmere Island. The southern Grantland Mountains include the Osborn, Garfield, and United States ranges, and other unnamed ranges. This region is characterized by southwest- to west-trending ridges formed mainly in member B of the Grant Land Formation. The ridges rise to elevations of more than 1800 m and support fairly extensive ice caps, drained by rivers that flow southeastward or southward into Lake Hazen, Lady Franklin Bay, Archer Fiord, Tanquary Fiord, or Hare Fiord, or northeastward into Clements Markham Inlet (Fig. 3).

2. The Hazen Plateau Belt and Archer Fiord Anticlinorium form part of the Eureka Upland and its most important subdivision, the Hazen Plateau. The latter is a peneplain of mid-Paleozoic age that was stripped of its cover both before and after Paleogene sedimentation. Subsequently, perhaps in middle or late Tertiary time, it was elevated and incised by rivers. The higher parts of the plateau commonly are 800 to 900 m in altitude but rise to nearly 1400 m northwest of Ella Bay. The largest river valleys were straightened and deepened by glaciers during the earlier part of the Pleistocene. Later in the Quaternary, these valleys were invaded by the sea to form fiords such as Archer, Greely, and Tanquary (cf. Fortier and Morley, 1956; Trettin, 1989, 1991a; Hodgson, 1991). Tongues of the major ice caps in the Grantland Mountains and Victoria and Albert Mountains extend into this region, and small, isolated ice caps are present locally, especially near Archer and Tanquary fiords.

3. The Central Ellesmere Fold Belt coincides largely with the Victoria and Albert Mountains, characterized by strike-parallel, northeast-trending ridges and valleys. The ridges are carved in resistant lower Paleozoic carbonate and clastic formations, such as the Cambro-Ordovician Cass Fjord, and attain altitudes of about 1400 m in the project area. A broad cross-valley extends from southeast of Ella Bay to Carl Ritter Bay at Kennedy Channel. Numerous ice caps of varying size drain into Archer Fiord and Kennedy Channel.

CHAPTER 3

STRATIGRAPHY OF THE SHELF SUCCESSION

LITHOLOGICAL NOMENCLATURE AND ANALYTICAL METHODS

CLASSIFICATION OF CLASTIC SEDIMENTS

The nomenclature for the clastic sediments is based entirely on size grade according to the Wentworth scale. Sand-grade sediments are simply referred to as sandstones and for further information the reader is referred to the analytical data and textural descriptions. The purpose of more specific names (e.g., orthoquartzite, arkose, arenite, wacke) is to convey information that is significant for the provenance, compositional maturity, or mode of transport of the sediments. However, in the study area, application of such names would be misleading because of the complex depositional and diagenetic history of the rocks. For example, many sandstones of the Lower Cambrian Ellesmere Group and Grant Land Formation may have been arkoses or feldspathic arenites originally that have developed into quartz arenites or quartz wackes (nomenclature of Williams, Turner, and Gilbert, 1955) by dissolution or alteration of feldspar.

Sediments containing more than 50 per cent of grains that are finer than 62 μm are referred to as mudrocks (Ingram, 1953). Although coarse siltstones are readily recognizable, differentiation of the finer grained sediments into siltstones and claystones is difficult because most clay-size (≤4 μm) phyllosilicates have recrystallized to silt grade. The term shale, commonly applied to fissile claystones and siltstones, is not used here because fissility is a diagenetic textural feature (of complex origin and limited significance) that should not enter a rock classification based on size grade (Ingram, 1953; Picard, 1971; Weaver, 1980, etc.).

The colours of both clastic and carbonate sediments are described in terms of the standard rock colour chart of the Geological Society of America (Goddard et al., 1963).

CLASSIFICATION OF CARBONATE ROCKS

Limestones are classified mainly according to Dunham (1962) with some modifications. The nomenclature for carbonate crystal size has been adopted from Leighton and Pendexter (1962) and Drummond (1963) and used in previous reports by the writer (e.g., Trettin, 1979). It differs from commonly used terminology introduced by Folk (1959).

2-1 mm	very coarse crystalline
1-0.5 mm	coarse crystalline
0.5-0.25 mm	medium crystalline
0.25-0.12 mm	fine crystalline
0.12-0.06 mm	very fine crystalline
0.06-0.004 mm	microcrystalline
0.06-0.03 mm	coarse microcrystalline
0.03-0.04 mm	fine microcrystalline
<0.004 mm	cryptocrystalline

A common, but enigmatic rock type, called *peloidal packstone/wackestone* throughout this report, requires an explanation. The term peloid is widely used for round or elliptical, structureless cryptocrystalline grains of various undetermined origins (adapted from Flügel 1982, p. 121, 124). The peloids discussed here are mostly of silt to very fine or fine sand grade and surrounded by clear calcite that usually is confined to the 4 to 20 μm range but can be as coarse as 60 μm. In well preserved specimens the peloids are commonly seen to be surrounded by a layer of radiating, fine microcrystalline calcite. In such specimens the peloids and their microcrystalline rims either are closely packed or, less commonly, separated by lime mud matrix so that the terms packstone or wackestone are applicable. However, many specimens are recrystallized to such a degree that peloids and original cement or matrix cannot be distinguished from neomorphic microcrystalline calcite. In the past the peloids often were interpreted as fecal pellets, and the rocks were called pelsparites or pelmicrites, according to the nomenclature of Folk (1959). More recent evidence suggests that many are algal precipitates (e.g., Chafetz, 1986).

ANALYTICAL METHODS AND PRESENTATION OF DATA

The composition of the sediments has been established mainly by a combination of whole-rock X-ray diffraction analysis and thin section inspection or point count analysis, and the results are tabulated in Appendix 2. In the text, mineral compositions cited represent uncorrected X-ray diffraction data, unless otherwise stated.

The procedures followed are explained in the introduction to Appendix 2, but a few remarks are appropriate here. The percentages quoted express the relative height of the principal peak for each mineral as a percentage of the total height of the principal peaks of all minerals listed. The peak heights are controlled mainly by the relative abundances of the minerals, but also by a factor inherent in each mineral and by their crystallinity.

It is impossible to convert these semiquantitative data into quantitative data without additional chemical analyses. However, approximate corrections can be applied to selected mineral ratios expressing:

1. The proportion of feldspar in the combined feldspar + quartz fraction.

2. The proportion of plagioclase in the total feldspar fraction.

3. The proportion of dolomite in the combined dolomite and calcite fraction.

These corrections are discussed in the introduction to Appendix 2 (p. 213-214). The ratios also are useful for purposes of lithological comparison or correlation.

CONCEALED PRECAMBRIAN TO LOWER CAMBRIAN UNITS

As mentioned in the Introduction (Regional framework), the lower Paleozoic shelf succession of central Ellesmere Island is probably underlain at depth by the crystalline basement and supracrustal successions of the Canadian Shield that include the upper Middle to Upper Proterozoic Thule Group of southeastern Ellesmere Island. In addition, younger and older Proterozoic units, not preserved in that area, may also be present. In the absence of deep exploration wells and of seismic information, the thickness and age range of these successions is unknown.

The two oldest formations of the Central Ellesmere Fold Belt, the Kennedy Channel and Ella Bay (Kerr, 1967a), are exposed about 15 km southeast of the project area and undoubtedly underlie the succession described in this chapter. The brief summary below is based on studies by Long (1989a, b).

The Kennedy Channel Formation, established by Kerr (1967a), has a maximum exposed thickness of 1223 m at the type section, the Ritter Bay Anticline of southwestern Judge Daly Promontory (Fig. 13, Section 3); its base is concealed. It is composed of quartzose sandstone, mudrock, and limestone, representing four major phases of progradation of shallow marine facies into deeper water environments. The occurrence of the trace fossil *Skolithos* near the base of the exposures indicates that the formation is Phanerozoic in age. Trilobite fragments in the lowest carbonate unit are of an unspecified post-Tommotian

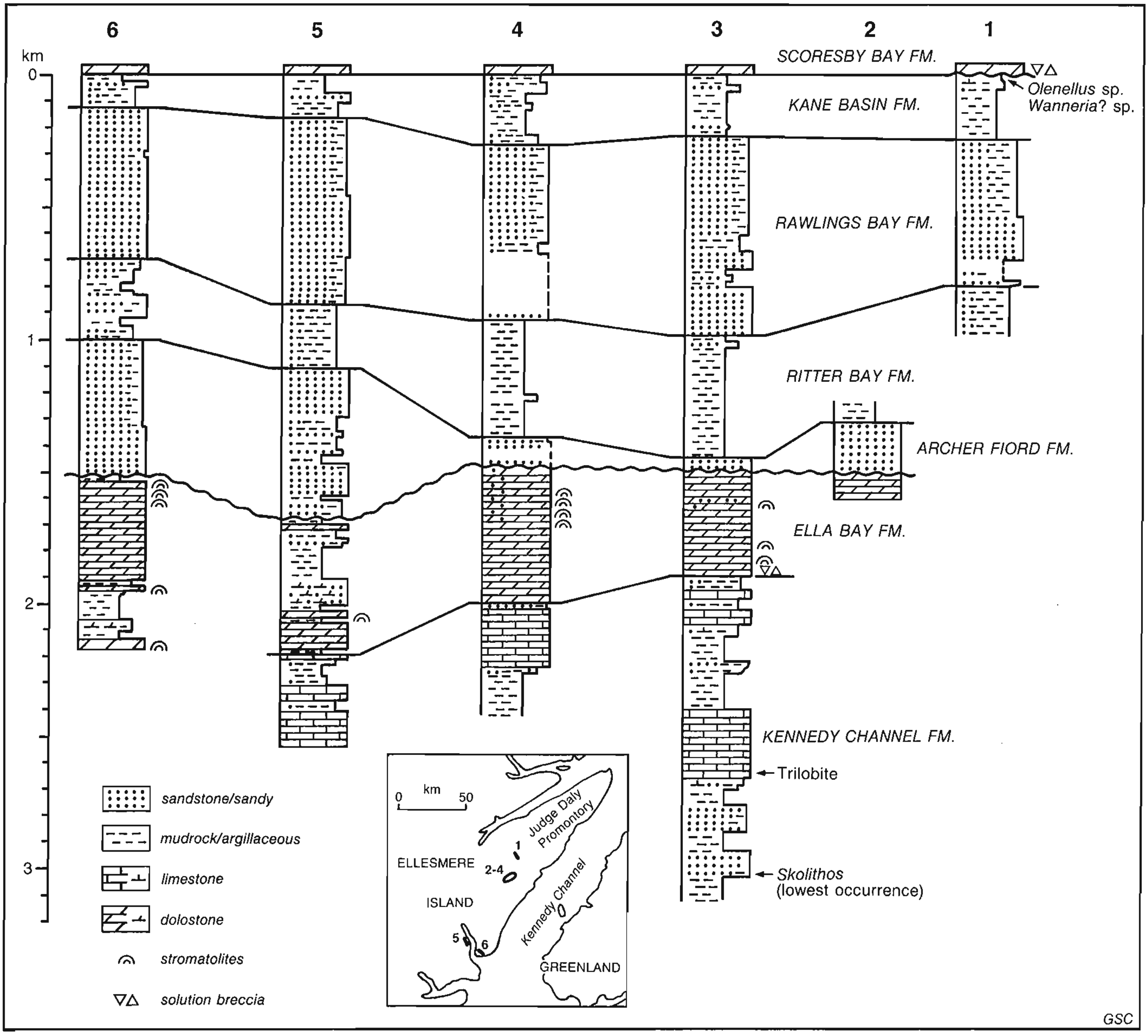


Figure 13. Stratigraphic sections of Lower Cambrian formations in east-central Ellesmere Island. (From Trettin et al., 1991.) Sections 2 to 6 are based on work by G.D.F. Long; section 1 is equivalent to Ella Bay 4-1, 4-2, and 4-3 sections of this report.

age. (The Tommotian, the oldest Stage of the Early Cambrian, is characterized by shelly faunas devoid of trilobites). Combined with Early Cambrian trilobites from the Ellesmere Group (see below), these fossils indicate a largely post-Tommotian Early Cambrian age for the Kennedy Channel Formation.

The Ella Bay Formation (Kerr, 1967a) overlies the Kennedy Channel with conformable contact and, like the latter, has its type section at the Ritter Bay Anticline of southwestern Judge Daly Promontory (Fig. 13, Section 3). Its upper contact, with the Archer Fiord Formation of the Ellesmere Group, is discussed below. It consists mainly of dolostone with variable proportions of mudrock and quartz sandstone and locally includes stromatolitic bioherms. Sections measured by Long (1989b) range in thickness from 399 to 590 m. Fossil collections from the Kennedy Channel Formation and Ellesmere Group imply that the formation is Early Cambrian in age.

ELLESMERE GROUP

The term, Ellesmere Group, was introduced by Kerr (1967a) for a "sequence of complexly related clastic formations of Early Cambrian age", comprising four new formations of east-central Ellesmere Island, named for Archer Fiord, Ritter Bay, Rawlings Bay, and Kane Basin. The group is underlain and overlain by carbonates assigned to the Ella Bay and Scoresby Bay formations, respectively. Kerr assumed that the lower contact of the Ellesmere Group is disconformable everywhere, but Long (1989b) concluded that it is unconformable at some localities and disconformable at others. The Archer Fiord and Rawlings Bay formations consist mainly of sandstone and the Ritter Bay and Kane Basin formations mainly of mudrock. The Archer Fiord Formation and the lower part of the Ritter Bay Formation are concealed in the study area. Fossil collections from the Kennedy Channel, Kane Basin, and Scoresby Bay formations indicate that the entire group has a post-Tommotian Early Cambrian age (see below, Age and correlation).

Kerr also included in the Ellesmere Group the Rensselaer Bay Formation of Bache Peninsula, erected by Troelsen (1950). However, Peel et al. (1982) established that the latter included clastic sediments of late Middle Proterozoic age in addition to unconformably overlying Lower Cambrian sandstone. They restricted the Rensselaer Bay Formation to the Proterozoic strata and re-assigned the Lower Cambrian strata to the Dallas Bugt Formation. The latter has its type area in Greenland and does not form part of the Ellesmere Group.

ARCHER FIORD FORMATION
(concealed in study area)

The Archer Fiord Formation has its type section at the Ritter Bay Anticline on southwestern Judge Daly Promontory (Kerr, 1967a; Fig. 13, Section 3) where it lies stratigraphically between the Ella Bay and Ritter Bay formations. According to Long (1989b), the lower contact is an "erosional discontinuity" in most areas, but a conformable contact at least in two areas. The upper contact is gradational and conformable (Kerr, 1967a; Long *in* Trettin et al., 1991). The unit ranges in thickness from 45 to 184 m and is divisible into two members (Long *in* Trettin et al., 1991). The lower member consists of very coarse to fine, quartzose and dolomitic sandstone, locally with pebble conglomerate at the base. The strata show ripple and trough crosslamination and contain abundant ooids and oncoids. The upper member consists of fine to very coarse, quartzose and feldspathic sandstone, showing ripple marks and some planar and trough crosslamination. Both units are of shallow marine origin. The basal oolitic and oncolitic member has not been recognized south of the type area.

RITTER BAY FORMATION
(partly concealed in study area)

The Ritter Bay Formation, introduced by Kerr (1967a) for argillaceous sediments of the Ellesmere Group lying between sandy strata of Archer Fiord and Rawlings Bay formations, has its type section at the Ritter Bay Anticline on southwestern Judge Daly Promontory (Fig. 13, Section 3).

Distribution, thickness, and contact relations

The Ritter Bay Formation is exposed in several areas of northeastern central Ellesmere Island (Sections 1-6 of Fig. 13), but wedges out southeast of Radmore Harbour (the inlet between Sections 5 and 6 of Figure 13). Southeast of the project area, sections measured by Long (*in* Trettin et al., 1991) range in thickness from 275 to 586 m. The formation is incompletely exposed in the southeastern part of the project area where its relatively undisturbed upper part is 183 m thick according to a photogrammetric determination. The contacts with the underlying Archer Fiord Formation (Kerr, 1967a) and overlying Rawlings Bay Formation, are both gradational and conformable. (For a description of the upper contact, see Rawlings Bay Formation.)

Lithology

A bed of quartzose sandstone, about 1.5 m thick, with rip-up pebbles up to 3 cm in diameter, occurs at the base of the exposed section (Figs. 14, 15). The sandstone is medium to coarse grained and consists of moderately sorted, rounded quartz grains with undulose extinction. The pebbles represent: 1) fine grained, well sorted sandstone, composed of rounded quartz with phosphatic cement; 2) phosphatic mudrock; and 3) ordinary mudrock.

The remainder of the formation is composed of three, thinly interstratified rock types: mudrock, sandy mudrock, and very fine grained, variably argillaceous sandstone. Some strata show a thin, flat lamination; others are massive and bioturbated. The mudrocks are medium grey and weather greyish and greenish; the sandstones are medium light grey or medium grey and weather greyish.

Three specimens of mudrock, analyzed by X-ray diffraction (XRD) and thin section inspection, have the following average mineral composition[1]: quartz, 59 per cent; chlorite, 18 per cent; mica, 12 per cent; feldspar, 9 per cent (plagioclase, 8%; K-feldspar, 1%); siderite 2 per cent; calcite, trace (Appendix 2, Table 1). Five specimens of argillaceous sandstone interlaminated with sandy mudrock have similar compositions, except that chlorite (9%) and mica (6%)

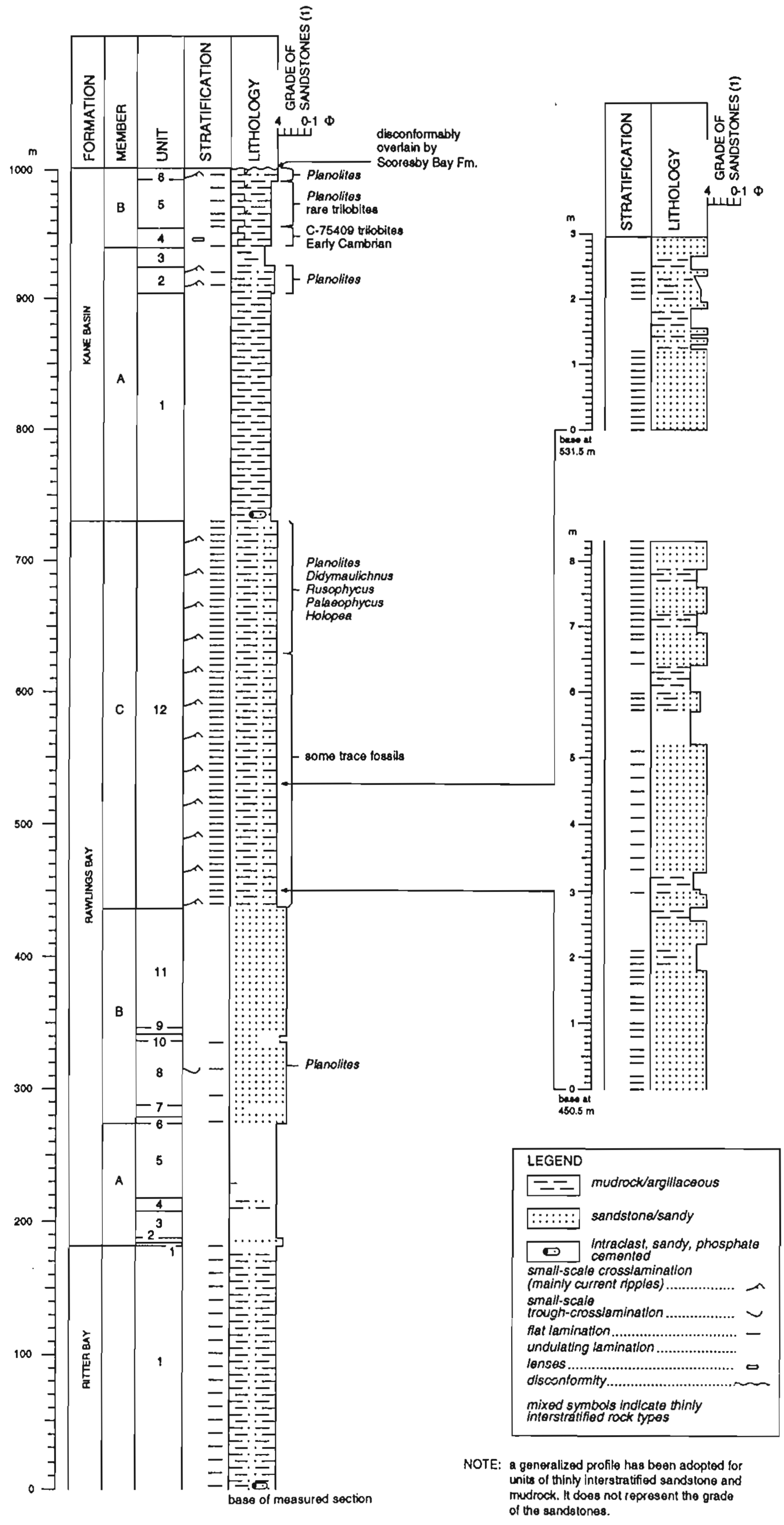


Figure 14. Columnar diagram of the Ellesmere Group at Ella Bay 4 section; for description of units, see Appendix 3, sections 4-1 to 4-3. The Kane Basin Formation is overlain by the Scoresby Bay Formation.

[1]Unless stated otherwise, the mineral compositions quoted represent uncorrected, semiquantitative data obtained by whole-rock X-ray diffraction analysis, combined with thin section petrography. Possible correction factors are discussed in the introduction to this chapter and to Appendix 2.

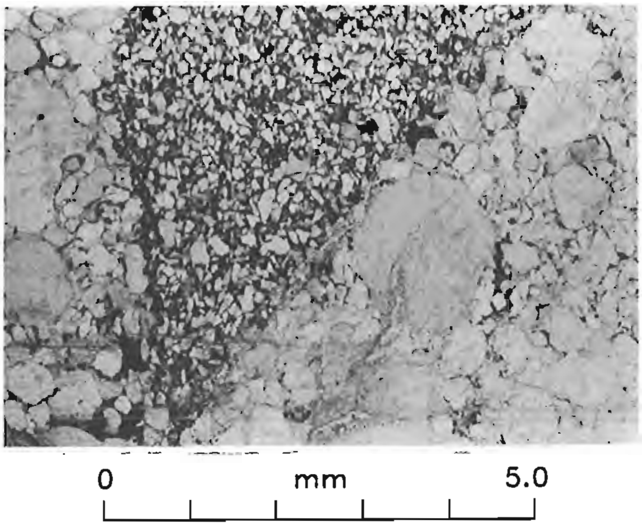


Figure 15. Photomicrograph (ordinary light) of pebble (rip-up clast) of phosphate-cemented (phosphate is dark), fine grained sandstone. The pebble occurs in poorly sorted, coarse and very coarse grained, quartzose sandstone; Ritter Bay Formation, base of Ella Bay 4-1 section. ISPG photo. 2032-86.

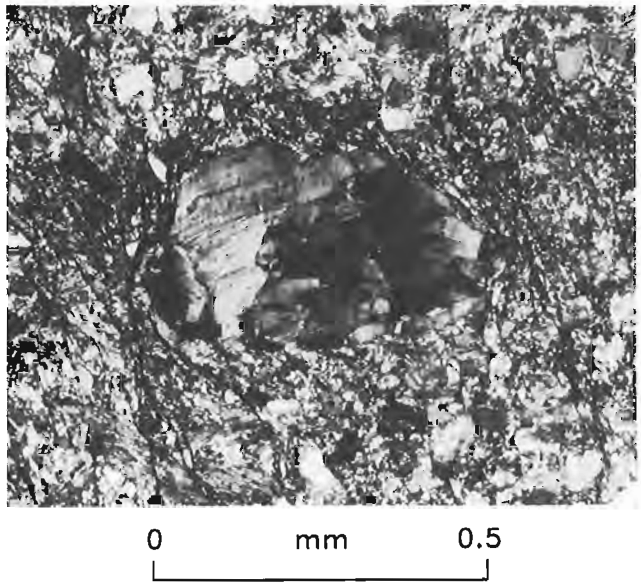


Figure 16. Photomicrograph (ordinary light) of ellipsoidal grain of chlorite and minor muscovite (white lines), pseudomorphous after morphological glauconite, in mudrock of the Ritter Bay Formation, west of Ella Bay 4-1 section, showing spaced cleavage. ISPG photo. 2032-26.

are less abundant, and quartz is more abundant (74%; Appendix 2, Table 2). As discussed below (Mode of origin of the Ellesmere Group), the phyllosilicates are of mixed, detrital, and metamorphic origins.

Most samples of mudrock examined in thin section contain ovoid grains of sand grade that are composed mainly of flaky chlorite with some interlayered white mica (Fig. 16). They probably represent altered (cf. Dapples, 1979, p. 109) "morphological glauconite" (term of Triplehorn, 1964), also known as "glaucony" (term of Odin and Matter, 1981).

Siderite replaces all other minerals and occurs in clusters of euhedral, commonly very fine to very coarse crystals. The mineral is partly altered to limonite.

A closely spaced, anastomosing slaty cleavage (nomenclature of Borradaile et al., 1982) is well developed in the fine grained mudrocks (Fig. 16).

RAWLINGS BAY FORMATION

The name, Rawlings Bay Formation, was introduced by Kerr (1967a) for predominantly sandy sediments lying between the argillaceous Ritter Bay and Kane Basin formations. The type section is at the Ritter Bay Anticline of southwestern Judge Daly Promontory (Fig. 13, Section 3).

Distribution, thickness, and contact relations

The Rawlings Bay Formation is exposed mainly in the southeasternmost part of the study area, where it is 548 m thick at the Ella Bay 4-2 section. Its contact with the Ritter Bay Formation is covered, but probably conformable. The contact has been placed at the base of the lowest resistant sandstone unit above a thick succession of recessive argillaceous and sandy strata (cf. Kerr, 1967a, Plate V). The contact with the Kane Basin Formation probably is a submarine disconformity (diastem; see below, Kane Basin Formation).

In addition, two small outcrop areas of the Rawlings Bay Formation occur: in anticlinal structures on the southeastern coast of Archer Fiord, southeast of Bulleys Lump; and about 40 km southwest of Cape Baird, at the northeastern extremity of Judge Daly Promontory. Only the uppermost part of the formation is exposed in these areas.

Lithology

Ella Bay 4-2 section

At the Ella Bay 4-2 section, the formation is divisible into three members, informally referred to as members A, B, and C.

Member A (92.5 m)

A unit, about 6 m thick, of poorly bedded quartzose sandstone, very fine to fine grained and well sorted, occurs at the base of the member. The remainder of the member is recessive and mostly covered by talus from other units. Some rubble in the middle part, however, may represent bedrock weathered in place. A typical specimen consists of very fine and fine grained sand of quartz and minor feldspar in a matrix of slaty mudrock, with morphological glauconite altered to chlorite and white mica.

Member B (163 m)

This is the most resistant part of the entire Ellesmere Group in this area. It is well exposed and consists largely or entirely of sandstone, although a recessive covered interval, 61.5 to 67 m above the base of the unit, may be partly underlain by mudrock.

The average grain size of most sandstone samples is fine, but some medium grained laminae are present. The maximum grain size ranges from fine to very coarse and commonly is coarse or very coarse.

Most beds are massive, with parting surfaces spaced 0.2 to 1 m; flat lamination, undulating lamination, and small-scale crosslamination are less common. Undulations have amplitudes of a few centimetres and half-wavelengths of 30 to 40 cm. Concave foresets, 10 to 20 cm in height, occur about 40 m above the base of the member. Bedding-parallel burrow casts (*Planolites*) were seen 42 m above the base of the section.

Figure 17. *Interbedded sandstone and mudrock in the Rawlings Bay Formation, member B. Note sharp basal contact of sandstone beds near top of hammer handle. Above this and to the left, some flat lamination. ISPG photo. 2256-30.*

Member C (292.5 m, photogrammetric determination)

This member is composed of two lithofacies.

The first is a quartzose, mostly fine grained, sandstone. Maximum grain size ranges up to very coarse, but coarse and very coarse grains are less common than in member B, and sorting is better. Units range in thickness from a few centimetres to about two metres and commonly are 10 to 50 cm thick (Fig. 17). The strata show a vague to distinct, flat lamination and commonly have abrupt lower contacts; ripple marks are rare.

The second lithofacies comprises interstratified mudrock, sandy mudrock, and very fine grained argillaceous sandstone, showing flat or slightly undulating flat lamination and some graded bedding. Mudrock with shrinkage cracks was seen in talus only. Fine grained mudrock has a slaty cleavage. Also present are minor amounts of intraformational conglomerate. A typical specimen (from 235 m above the base of the member) consists of clasts of mudrock, up to 5 cm long, in a sandy matrix.

Bedding-parallel trace fossils occur throughout the unit and are most abundant in the upper 100 m. *Planolites* is abundant; less common are *Didymaulichnus*, *Rusophycus*, *Palaeophycus*?, and *Halopoa*? (Hoffmann, Appendix 3A, C-7540 to C-75493) (Fig. 18).

Mineral composition and diagenetic features of sandstone

The sandstones of the three members are similar and can be discussed together (Appendix 2, Tables 3-6).

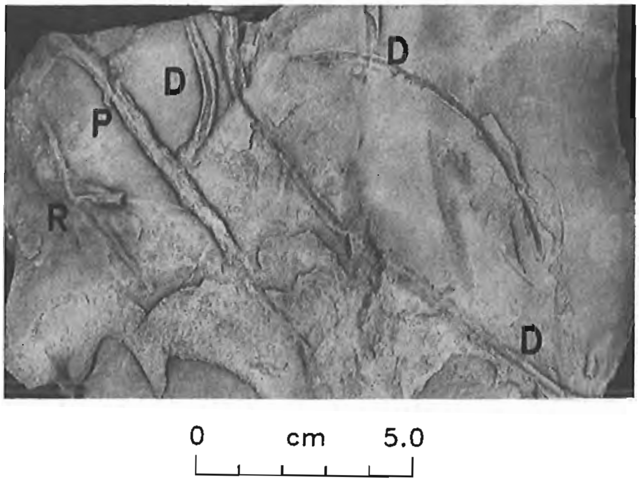


Figure 18. Trace fossils ***Didymaulichnus*** *(D),* ***Rusophycus*** *(R), and* ***Planolites*** *(P) from the Rawlings Bay Formation, member C, Ella Bay 4-2 section, 61 m to 112 m below top of formation. ISPG photo. 1563-7; spec. C-75490.*

Sandstone (mostly fine grained and in some cases medium grained) consists mainly of quartz with small amounts of feldspar, less mica, and trace amounts of chlorite in some rocks, not counting the secondary minerals discussed below. Heavy mineral separations have not been made, but tourmaline and zircon are present in most thin sections, and apatite was identified by scanning electron microscope in one thin section.

The quartz consists mostly of single crystals with straight, or less commonly, undulose extinction. Composite or semicomposite aggregates are restricted to the coarsest size grades.

Feldspar comprises 4 to 10 per cent of the combined quartz-feldspar fraction according to point count analyses (Appendix 2, Table 3). The feldspar is clear or variably altered. X-ray diffraction analyses indicate that plagioclase generally is dominant over K-feldspar, but that the latter predominates in some units, for example in a suite of samples from member B.

Detrital white mica, which comprises up to 1 per cent of the sandstones analyzed by point count, occurs as scattered flakes that are several times as long as the diameters of associated quartz and feldspar (Fig. 19).

A nondetrital argillaceous matrix, probably derived by alteration of feldspar (Fig. 20; see below, Diagenesis and metamorphism), makes up 9 to 20 per cent of the rock volume (Appendix 2, Table 3).

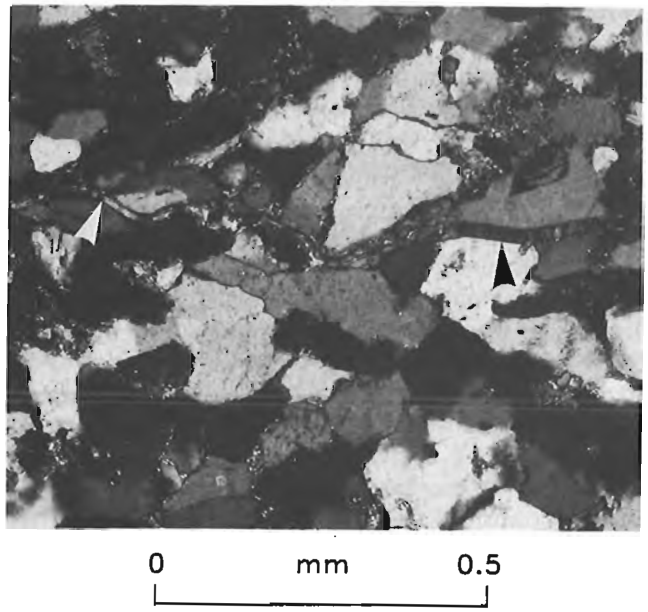


Figure 19. Photomicrograph (cross-polarized light) showing long flake of sedimentary muscovite (arrows) in quartz sandstone that has undergone compaction and pressure solution; Rawlings Bay Formation, member B, west of Ella Bay 4-2 section. ISPG photo. 2032-32.

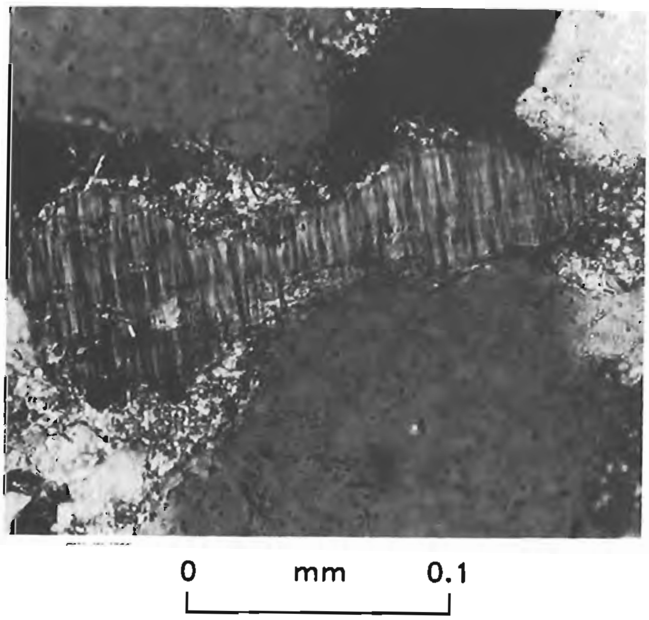


Figure 20. Photomicrograph (cross-polarized light) of sandstone from the Rawlings Bay Formation, member B, west of Ella Bay 4-2 section. A grain of microcline, showing the effects of considerable pressure solution, is separated from adjacent quartz by an argillaceous matrix that probably was produced by feldspar alteration. ISPG photo. 2032-28.

Coast of Archer Fiord

The uppermost strata of the formation, exposed in the core of an anticline southeast of Bulleys Lump, consist mainly of sandstone with lesser amounts of thinly interstratified mudrock.

The sandstones are either fine grained or transitional from very fine to fine grained. Most samples are bimodal, containing a relatively small population of medium or medium to coarse grains that are markedly larger than the predominant population. Beds are 5 to 40 cm thick and flat-laminated, crosslaminated, or structureless. Lower and upper contacts commonly are sharp, and load casts, flame structures and groove casts occur at the bases of some beds. The grooves indicate transport in a strike-parallel direction (the sense of movement has not been established).

Fine grained sandstones consist mostly of quartz with about 1 to 4 per cent of combined plagioclase and K-feldspar, and 2 to 5 per cent of combined mica and chlorite in individual analyses (Appendix 2, Table 7). Some specimens also have a few per cent of carbonate — calcite, dolomite, and/or siderite. These minerals are concentrated in small nodules and replace silicates. Rocks with red-brown spots contain sideritic nodules that have been altered to limonite.

Very fine grained, argillaceous sandstones have higher concentrations of chlorite and mica, which amount to 10 to 15 per cent in XRD analyses.

The mudrocks are slaty, variably sandy, and contain grains of chlorite and minor white mica that are pseudomorphous after morphological glauconite.

In an anticline near the coast of Archer Fiord, 41 km southwest of Cape Baird (the northeastern extremity of Judge Daly Promontory), the uppermost few metres of the formation consist of sandstone beds that are 5 to 20 cm thick and separated by argillaceous laminae. The sandstones are very fine to fine grained (maximum size is medium sand grade) and well sorted. They consist mostly of quartz with small amounts of feldspar, mica, and chlorite, and locally contain siderite that is partly altered to limonite. In addition to white mica, trace amounts of biotite are present in one specimen.

KANE BASIN FORMATION

The Kane Basin Formation, introduced by Kerr (1967a), consists of predominantly argillaceous strata lying between the Rawlings Bay and Scoresby Bay formations. Its type section is at the Ritter Bay Anticline of southwestern Judge Daly Promontory (Fig. 13, Section 3).

Distribution, thickness, and contact relations

The Kane Basin Formation is exposed in three main areas: the southeastern extremity of the study area; a broad belt on the southeast side of Archer Fiord, extending from Cape Baird to northwest of Ella Bay; and an area on the northwest side of Archer Fiord, in the vicinity of St. Patrick Bay (for locality names see Figure 3).

The formation is 270.5 m thick at the Ella Bay 4-3 section, and somewhat thicker at Bulleys Lump according to a structural cross-section. It has a minimum thickness of 211 m at the Ella Bay 1-1 section, where its lower part is concealed.

The Kane Basin Formation overlies the Rawlings Bay both at the Ella Bay 4-3 section and south of Archer Fiord. The local occurrence of phosphate-cemented intraformational pebble conglomerate at the base of the formation (see below) suggests a submarine disconformity (diastem).

In the southeastern part of the project area, the Kane Basin Formation is overlain by the Scoresby Bay Formation with a disconformable contact, and farther northwest by the Hazen Formation with a gradational, conformable contact (see below, Scoresby Bay Formation and Hazen Formation).

Lithology

Southeastern part of the project area

At the Ella Bay 4-3 section, the Kane Basin Formation is divisible into two distinct units, informally referred to as members A and B.

Member A (208.5 m at Ella Bay 4-3 section)

This member consists mostly of medium grey to medium dark grey mudrock that is recessive and represented by rubble. Stratification is mostly obscured by bioturbation and slaty cleavage, but a flat and undulating lamination is recognizable here and there.

Six samples of mudrock from the lower 15 m, mostly coarse grained and sandy, have an average composition of: quartz, 58 per cent; chlorite, 22 per cent; mica-illite, 14 per cent; feldspar (mainly plagioclase), 6 per cent (XRD analyses; Appendix 2, Table 8). Part of the chlorite and associated white mica occur as ovoid grains interpreted as altered morphological glauconite. The rest has recrystallized to flakes, ten to several tens of micrometres long, that occur in several preferred orientations.

A bed of sandstone, about 0.5 m thick, occurs locally in the lowermost part of the formation. It consists of poorly sorted, bimodal grains of quartz with rip-up pebbles, up to 7 mm long, of phosphate-cemented sandstone (Fig. 21). A typical sample is composed of: quartz, 82 per cent; apatite, 6 per cent; chlorite, 6 per cent; mica-illite, 3 per cent; and plagioclase, 2 per cent (XRD analysis).

In the upper part of the member (174–195 m), there is a unit of coarse, quartzose and feldspathic mudrock (siltstone), interbedded with a smaller proportion (20% or less) of finer grained mudrock, which is richer in mica and chlorite. The quartzose beds are 2 to 50 cm thick and show some flat lamination and small-scale crosslamination. A typical specimen contains: quartz, 75 per cent; feldspar, 18 per cent (plagioclase, 14%, K-feldspar, 4%), calcite, 3 per cent; mica, 2 per cent; chlorite, 2 per cent (XRD determination; Appendix 2, Table 9). The unit has relatively large trace fossils, including *Rusophycus*? and common *Planolites*.

Member B (62 m)

This member is divisible into three units. The lowest unit, 16.5 m thick, is composed of medium grey, highly calcareous mudrock, commonly forming lenses, with abundant trilobite fragments (Fig. 22) and interbedded medium grey to medium dark grey, slightly calcareous mudrock. Typical specimens of the two rock types contain 33 per cent and 11 per cent, respectively, of calcite according to uncorrected XRD determinations (Tables 10 and 11 of Appendix 2 give average compositions for two different intervals).

The middle unit, 36.5 m thick, consists of similar, but less calcareous mudrocks, analyzed specimens containing 21 per cent and 2 per cent of calcite, respectively, and small amounts of dolomite (Appendix 2, Table 11). Calcite content and bed thickness decrease stratigraphically upward.

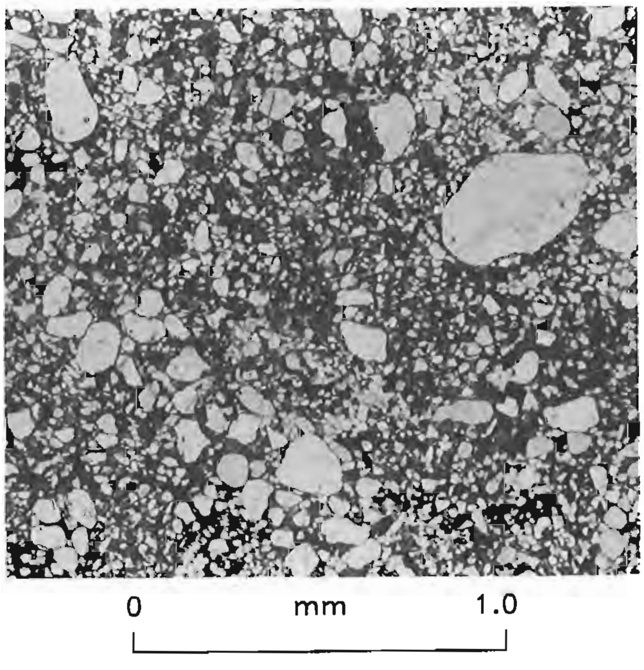


Figure 21. Photomicrograph (ordinary light) of sandstone at the base of the Kane Basin Formation, Ella Bay 4-3 section. Poorly sorted, very fine to very coarse grained, rounded quartz (light) is cemented by phosphate (dark) and carbonate (light). ISPG photo. 2032-92.

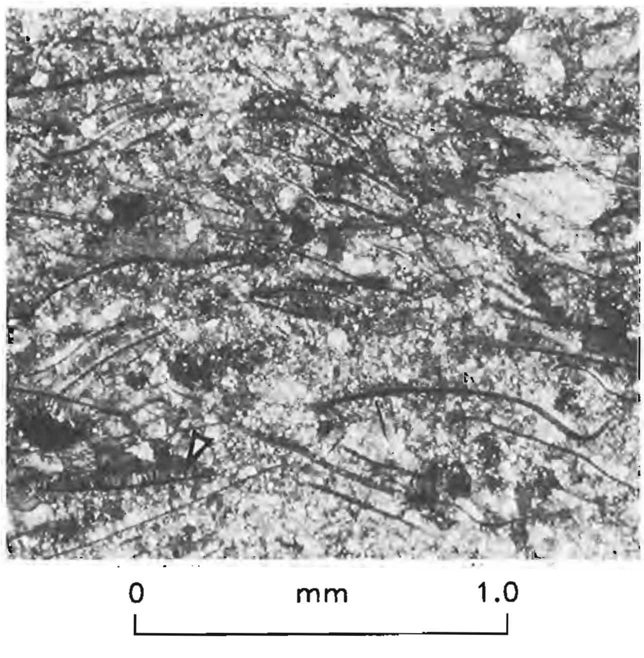


Figure 22. Photomicrograph (ordinary light) of calcareous mudrock with abundant trilobite fragments; secondary calcite crystals (arrow) normal to surfaces; Kane Basin Formation, member B, at Ella Bay 4-3 section, 209.5 m. ISPG photo. 2032-104.

The uppermost unit, 9 m thick, is composed of interbedded coarse, sandy siltstone and very fine grained, argillaceous sandstone, both rock types being calcareous and slightly dolomitic. Sandstone beds are 1 to 15 cm thick and show flat lamination and small-scale crosslamination. Bedding-parallel burrow casts (*Planolites*) are common. Mudrock and sandstone are composed mainly of quartz with roughly 10 per cent feldspar and variable proportions of calcite (up to 20%), dolomite (up to 17%) and siderite (up to 6%; Appendix 2, Tables 12, 13). The plagioclase content of the feldspar fraction decreases from 77 per cent in the lower part to 17 per cent in the upper part.

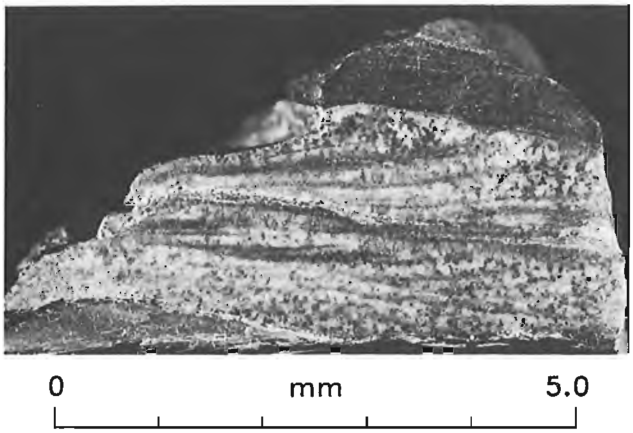


Figure 23. Primary structures in specimen from Kane Basin Formation, member A, Ella Bay 1-1 section, 79 m. The lower part of the sample consists of crosslaminated sandstone that is very fine grained, quartzose, and silty (light grey); and minor mudrock that is partly sandy and glauconitic (dark grey). Both rock types show spotty dolomite replacement. The crosslamination is truncated by an erosion surface covered with dark grey mudrock. ISPG photo. 2203-3.

Archer Fiord region

Strata of the Kane Basin Formation exposed around Archer Fiord are similar to member A at the Ella Bay 4-3 section; sediments similar to member B have not been recognized. This may indicate that member B at the Ella Bay 4-3 section is a local facies, but two other features suggest that strata equivalent to member B in this area have been included in the Hazen Formation: the presence of *Olenellus* sp. in the lowermost Hazen Formation (see below), and the fact that the lower Hazen Formation shows a similar decline in the plagioclase content of the feldspar fraction as observed in member B at the Ella Bay 4-3 section (see above).

In this area, the formation consists mostly of mudrock with small amounts of sandstone that is generally very fine grained and argillaceous, but locally very fine to fine grained (e.g., east of Discovery Harbour). The rocks are light to predominantly medium light grey and weather greenish grey. Greyish red-purple weathering slate, similar to that in the upper part of the Grant Land Formation, has only been seen in an anticline at St. Patrick Bay. Exposures at the head of Ella Bay show small-scale crosslamination and some erosion surfaces overlain by mudrock (Fig. 23). X-ray diffraction analyses of samples from Bulleys Lump and from the Ella Bay 1-1 section are comparable to analyses of samples from the Ella Bay 4-3 section (Appendix 2, Tables 14-16). Chlorite and minor white mica, pseudomorphous after morphological glauconite, are common in these strata also (Fig. 24). The trace fossil *Teichichnus* sp. was found in an isolated outcrop southeast of Ella Bay (Fig. 25).

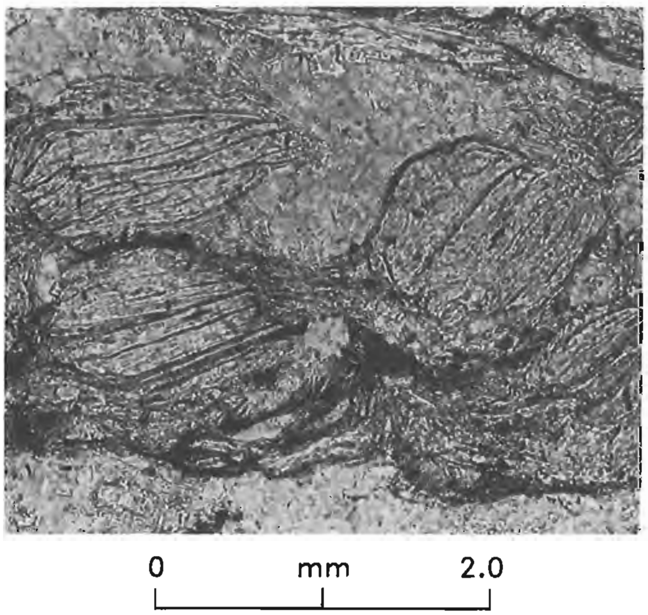


Figure 24. Photomicrograph (ordinary light) of pellets of chlorite and minor interlaminated muscovite, pseudomorphous after morphological glauconite, in coarse grained, sandy siltstone; Kane Basin Formation, Ella Bay 1-1 section, 79 m; same specimen as shown in Figure 23. ISPG photo. 2260-146.

DIAGENESIS AND METAMORPHISM

The most important diagenetic changes apparent in the Ellesmere Group are:

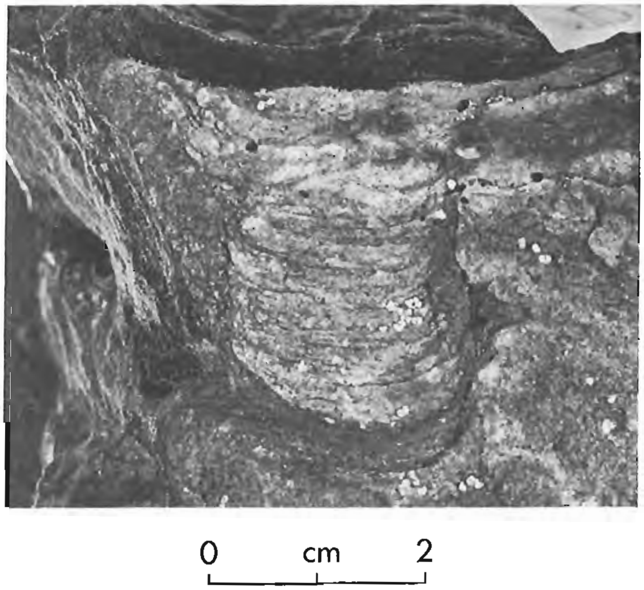


*Figure 25. Trace fossil **Teichichnus** in mudrock and quartzose siltstone of the Kane Basin Formation; locality F14, Figure 1. ISPG photo. 3598-1.*

1. Partial replacement of silicates by carbonate minerals (calcite, dolomite, siderite). The siderite is largely altered to limonite.

2. Pressure solution of quartz and feldspar and sericitization of feldspar. Many grains of quartz and feldspar are tightly appressed or penetrate each other. Feldspar grains that have undergone pressure solution (or a high degree of alteration by intrastratal fluids) are surrounded by an argillaceous matrix that was probably derived from them (Fig. 20).

3. Recrystallization of glauconite(?) to chlorite and minor white mica, preserving the pelletal shape of morphological glauconite.

The only metamorphic feature observed is the slaty cleavage of the fine grained mudrocks. It is due to recrystallization of clay minerals to white mica and chlorite, mainly of fine silt grade, and probably occurred during the Ellesmerian Orogeny. However, it must have been preceded by a series of diagenetic changes during deep burial (Kisch, 1983).

The phyllosilicates in the coarse silt and sand fractions appear to be of mixed origin. Sheared layers with metamorphic white mica and chlorite are fairly common, but do not constitute a well defined cleavage. Most of the white mica occurs as isolated flakes, considerably larger than associated quartz, that appear to be of detrital origin. This material commonly is subparallel to bedding and does not show preferred orientations when inclined to bedding. The coarse siltstones and sandstones thus do not have a metamorphic texture. Moreover, the survival of detrital K-feldspar indicates that these fractions are below the greenschist facies (cf. Kisch, 1983, 1987; Frey, 1987).

MODE OF ORIGIN

Provenance

Derivation of the Ellesmere Group from the continental interior is apparent from the restriction of major shaly units, such as the Ritter Bay Formation, to the northwestern part of its distributional area. The sources of the Ellesmere Group probably included quartzo-feldspathic crystalline terranes as well as Proterozoic sedimentary rocks. These sources evidently supplied quartz, feldspar, and phyllosilicates.

Depositional environments and processes

The strata of the Ellesmere Group as a whole can be assigned to five lithofacies that probably were deposited under somewhat different conditions.

1. *Glauconitic mudrock and associated, subordinate, very fine grained, argillaceous sandstone.* This lithofacies is common in the Ritter Bay and Kane Basin formations and probably also in the poorly exposed member A of the Rawlings Bay Formation. The rocks are medium to dark grey or greenish grey, (except for a few reddish strata in the Kane Basin Formation at St. Patrick Bay). The stratification commonly is obscure, but some flat lamination and small-scale crosslamination are preserved. Internal erosion surfaces, overlain by mudrock, are apparent in strata of the Kane Basin Formation at the Ella Bay 1-1 section (Fig. 23). Such features could be taken as evidence of intertidal deposition, but other evidence of intertidal conditions (cf. Terwindt, 1988) is lacking. An alternative explanation would be current erosion followed by slack-water mud deposition, both taking place in the submerged state.

   The most diagnostic feature of this lithofacies is the common occurrence of pellets of chlorite and minor white mica, interpreted as recrystallized morphological glauconite. In recent settings, morphological glauconite occurs mainly in continental shelf environments of low to intermediate latitudes, at water depths broadly between 60 and 550 m and most commonly between 150 and 300 m (Odin and Fullagar, 1988). The process of glauconitization requires access of sea water to the sediment; that is, a pause in sedimentation that may be due to rapid transgression or to winnowing by currents.

Deposition in middle to outer shelf environments also is indicated by the trace fossil *Teichichnus* from the Kane Basin Formation (Fig. 25; Frey and Seilacher, 1980).

2. *Sandstone, medium to coarse grained, with phosphate-cemented pebbles.* Two beds of poorly sorted, medium and coarse grained sandstone with pebbles of similar, but phosphate-cemented, sandstone occur, one within the Ritter Bay Formation (base of the Ella Bay 4-1 section) and the other at the base of the Kane Basin Formation (base of the Ella Bay 4-3 section). This unusual rock type probably was produced by three events: 1) submarine erosion, resulting in a poorly sorted, unusually coarse lag deposit of quartz sand; 2) partial cementation by phosphate; and 3) disintegration and redeposition by currents. Processes (1) and (2) probably took place on bathymetric highs in outer shelf settings, adjacent to an area of upwelling, during a pause in sedimentation caused by a transgression (cf. Riggs, 1984; Cook and Shergold, 1984).

3. *Calcareous mudrock with trilobite fragments.* This rock type is restricted to member B of the Kane Basin Formation. The highly disaggregated state of the skeletal material suggests redeposition by storm-generated currents, presumably in a subtidal shelf environment.

4. *Sandstone, predominantly massive, with some lamination, including flat, undulating, and crosslamination* (Rawlings Bay Formation, member B). This relatively thick unit has few diagnostic characteristics. An absence of features suggestive of nonmarine conditions, and association with units of shelf origin suggest a delta front environment (the principal site of sandstone accumulation in clastic sequences), but an offshore bar environment cannot be excluded.

5. *Interstratified sandstone and mudrock.* These rock types characterize member C of the Rawlings Bay Formation. This unit is difficult to interpret and requires more detailed study. The presence of bedding-parallel trace fossils and absence of vertical burrows militate against upper shoreface environments, and the lack of well developed crosslamination against intertidal settings. The stratigraphic position between probable delta front deposits (member B of the Rawlings Bay Formation) and subtidal shelf deposits (lower Kane Basin Formation) suggests a position seaward of the delta front. Such an environment ("delta platform") has been assigned to laminated sandstone interbedded with mudrock in the Cretaceous–Tertiary Difunta Group of Texas by McBride and others (1975, p. 504). These authors suggest that the laminated sandstones are turbidites, deposited by sediment-charged floods emerging from tributaries. Although convincing evidence of deposition by turbidity currents was not seen at the Ella Bay 4-2 section, erosional sole marks are present southeast of Bulleys Lump.

Depositional cycles

Bounded by disconformities at the base (Long, 1989b) and at the top (see below, Scoresby Bay Formation), the Ellesmere Group can be regarded as a second-order sequence within the Sauk Sequence or as a third-order sequence within the Sauk I Subsequence of Sloss (1988). It is far thicker than the third-order transgressive–regressive cycles in the Mesozoic succession of the Arctic Islands (Embry, 1991), but rates of subsidence and net deposition were exceptionally high in the Early Cambrian (see below, Fig. 123).

In the study area, the Rawlings Bay Formation seems to represent a regressive–transgressive half-cycle, the turning point of which lies at the base of member C. In the absence of biostratigraphic control, it is impossible to determine whether this half-cycle is regional or local in extent; that is, due to widespread changes in relative sea level or to local factors such as lateral shifts of distributaries in a delta.

By contrast, the transition from mixed coarse and fine deposition to fine clastic deposition at the Rawlings Bay/Kane Basin contact seems to be a regional phenomenon that probably was due to a rapid marine transgression. This transgression may also account for the local occurrence of lag deposits (relatively coarse sandstone and phosphate-cemented pebbles) at the base of the Kane Basin Formation. It probably was followed by a regression, possibly manifested by the slight coarsening in the upper part of the Kane Basin Formation at the Ella Bay 4-3 section, and also indicated by the disconformity at the top of the Kane Basin Formation at the Ella Bay 4-3 section.

Age and correlation

So far, diagnostic fossils have been found only in the Kane Basin Formation. Most important is a collection from the upper part of the Ella Bay 4-3 section (208.5–225.0 m), which includes the trilobites *Olenellus* sp., *Yukonites* sp., and *Wanneria*? sp., along with the undiagnostic brachiopod *Obolella* (Fritz, Appendix 3A, C-75409). All three trilobites belong to the *Bonnia-Olenellus* Zone, and *Wanneria*? sp. may indicate the middle part of that Zone. A trilobite, found in talus about 98.5 m below the top of the Kane Basin Formation at the Ella Bay 1-1 section, was identified as *Elliptocephala*? sp. (Fritz, Appendix 3A, C-74520). It may represent either the *Bonnia-Olenellus* Zone or the preceding *Nevadella* Zone, but the regional stratigraphic relations mentioned below support the first alternative. The underlying older parts of the Ellesmere Group have not been dated directly, but must be substantially younger than Tommotian because of the occurrence of a trilobite fragment in the lower part of the Kennedy Channel Formation (see above).

Lower Cambrian clastic sediments of nearshore or shelf origin are widespread in North Greenland (Buen, Humboldt, and Dallas Bugt formations) and central and southern Ellesmere Island (Dallas Bugt Formation) and also occur on Devon Island (Rabbit Point Formation). Olenellids of late Early Cambrian age have been found at various localities in these units (Peel and Christie, 1982; Thorsteinsson and Mayr, 1987) and the upper part of the Ellesmere Group clearly is correlative with them. The lower part of the Ellesmere Group may be older than most of these occurrences, except for exposures of the Buen Formation in North Greenland that are close to the margin of the Franklinian Shelf.

SCORESBY BAY FORMATION

The name, Scoresby Bay Formation, was given by Kerr (1967a) to a predominantly dolomitic carbonate unit lying stratigraphically between the Kane Basin and Parrish Glacier formations. The type section, where the formation is 564 m thick, is northwest of Scoresby Bay. Southern exposures have been restudied by Brunton and Long (Brunton, 1986; Brunton and Long, 1989). In the study area, the formation, as mapped by Kerr (1967a, Plate V), can readily be distinguished on aerial photographs. In contrast to the type section, it here includes substantial amounts of limestone in its upper part.

Distribution, thickness, and contact relations

Outcrops of the Scoresby Bay Formation are limited to the southeasternmost part of the project area. At the Ella Bay 4-4 section, the formation is 952 m thick and lies between the Kane Basin Formation below it and the "oolitic limestone unit" above. The contact with the Kane Basin Formation is abrupt, and the top of the Kane Basin Formation is brecciated and cemented by dolomite. This boundary is interpreted as a disconformity, mainly because of the abrupt change from pure siliciclastic sediments of outer shelf aspect to pure carbonate sediments of peritidal aspect (see Mode of origin). The contact with the "oolitic limestone unit" appears to be conformable.

Lithology

At the Ella Bay 4-4 section, the Scoresby Bay Formation is divisible into three members, informally referred to as members A, B, and C (Fig. 26).

Member A (145 m)

This member consists of three rock types: chaotic dolostone breccia, stratified dolostone breccia, and unbrecciated laminated dolostone. Chaotic breccia is dominant in the lower part (0–27.5 m and 52.0–53.2 m); stratified breccia occurs intermittently from 27.5 m to the top of the member; and laminated dolostone occurs from 27.5 m to the top, becoming dominant from 63.5 m upward.

The fragments in the breccias range from pebble to boulder grade, the largest (maximum diameter 17 cm) occurring in the basal strata. The fragments are composed of very fine to medium crystalline, cloudy dolomite and are cemented by somewhat coarser, clear dolomite. In the chaotic breccias ("rubble floatbreccia" of Morrow, 1982) the fragments have random orientations and bedding is not apparent (Fig. 27). In the stratified breccias ("floatbreccia mosaic" and "packbreccia mosaic" of Morrow, 1982) they are partly parallel with bedding (Fig. 28) and stratigraphic continuity is apparent in places. The laminated dolostone is medium grey and phanerocrystalline. Lamination is mainly flat and less commonly undulating; small-scale crosslamination is rare.

Member B (458 m)

Member B consists mainly of dolostone with small amounts (perhaps 10%) of limestone. The dolostone varies in tone from medium grey to predominantly

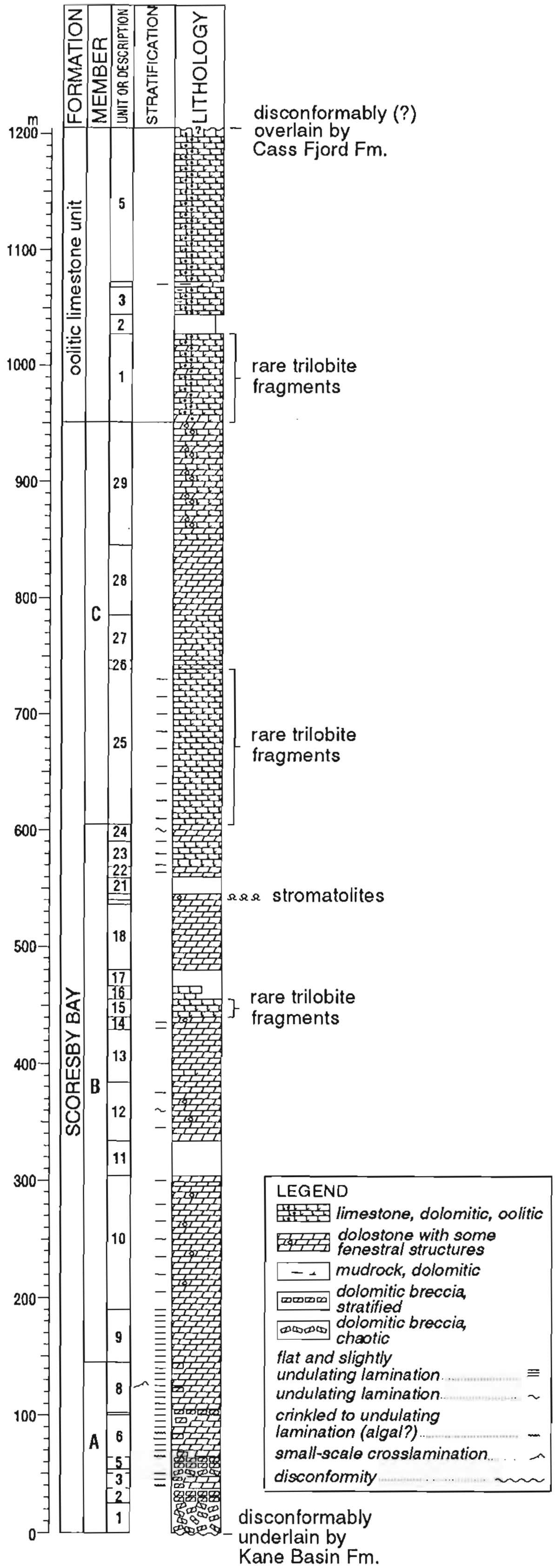


Figure 26. Columnar diagram of the Scoresby Bay Formation and oolitic limestone unit at Ella Bay; for description of units, see Appendix 1, Ella Bay 4-4 and 4-5 sections.

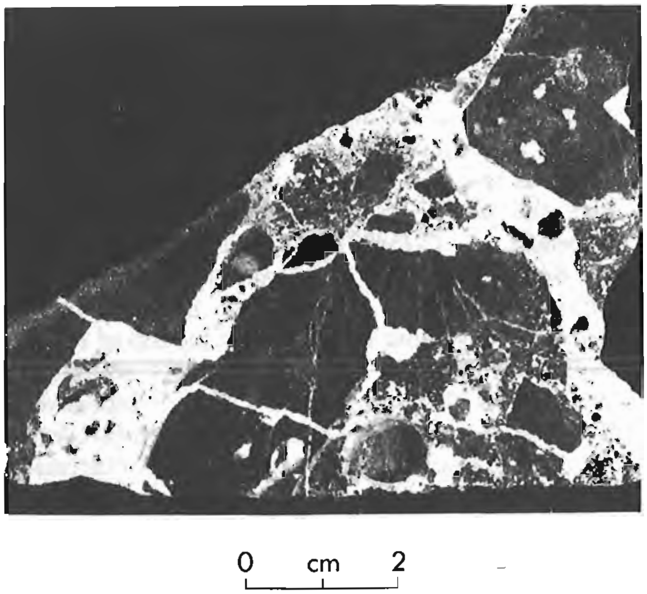


Figure 27. Chaotic dolomitic breccia, 7 m above the base of the Scoresby Bay Formation, member A, Ella Bay 4-4 section. Irregularly shaped fragments of medium dark grey dolostone are cemented by clear dolomite. ISPG photo. 2031-4.

medium dark grey, and in crystal size mainly from microcrystalline to fine or medium crystalline. Some strata are massive, others show flat or undulating lamination; still others are brecciated and crisscrossed by veinlets of dolomite (''crackle packbreccia'' of Morrow, 1982). Relict fenestrae, some relict bioturbation and intraclasts are present. The trace fossil *Palaeophycus tabularis* Hall (Narbonne, Appendix 3A, C-96913) occurs in the lower part of the subdivision. A bed with columnar stromatolites, about 30 cm high (Figs. 29a, b), occurs in the upper part of the subdivision (536.9–541.7 m); it is 5 m thick.

Limestone is present mainly in two units, 441 to 466.5 m and 568 to 590.5 m above the base of the formation. The rocks are medium dark grey, cryptocrystalline to very fine crystalline lime mudstones. They contain rare trilobite fragments and are replaced, to varying extents, by dolomite euhedra, disseminated or concentrated in burrows (Fig. 30).

Member C (349 m)

The member is composed of roughly two-thirds limestone and one-third dolostone. The limestones are medium dark grey. The most common rocks are interpreted as recrystallized peloidal packstones, mainly of silt to fine sand grade (about 0.02–0.2 mm). The peloids, dark brown and cryptocrystalline to very fine microcrystalline, are surrounded by clearer and coarser calcite, mostly in the 4 to 20 μm range, formed by recrystallization and/or precipitation (see above, in the section on Lithological nomenclature and analytical methods, peloidal packstone/wackestone). Also present are lime wackestones containing similar peloids along with larger peloids, coated grains, and skeletal fragments (mainly recrystallized trilobite fragments). Fenestral structures are rare. Like the limestones of member B, they are replaced to varying extents by dolomite that is disseminated or concentrated in burrows.

The dolostone is medium light grey to (predominantly) medium dark grey, mainly microcrystalline to medium crystalline, and massive.

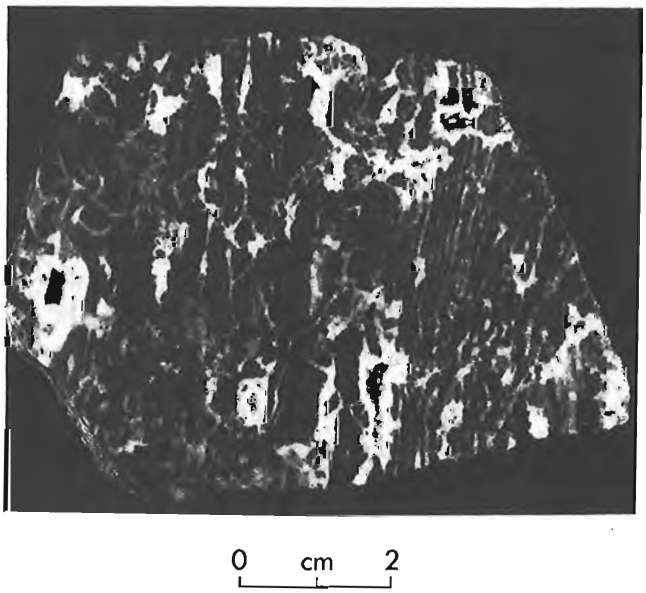


Figure 28. Stratified dolomitic breccia in Scoresby Bay Formation, member A, Ella Bay 4-4 section, 99 m. Fragments show flat or crinkled algal(?) lamination. ISPG photo. 2031-5.

Mode of origin

The stratiform character of many member A breccias suggests solution of thin evaporite beds by groundwater. Undulating and crinkled laminae in the

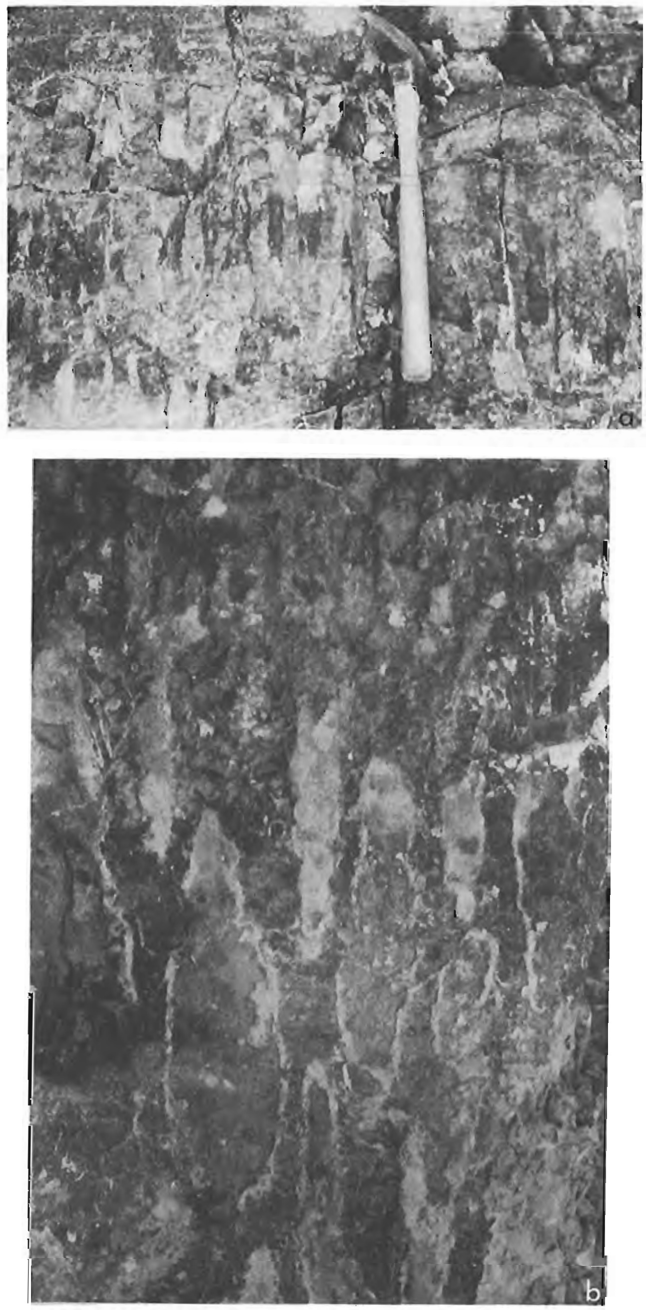


Figure 29. Dolomitized stromatolites in Scoresby Bay Formation, member B, Ella Bay 4-4 section, about 540 m. Lateral linkage vaguely apparent in (a). Hammer handle (30 cm) for scale. ISPG photos. 2256-63, 2256-64.

0 cm 3

Figure 30. Deeply weathered limestone (peloidal packstone/wackestone) of the Scoresby Bay Formation, member B, about 380 m above base of formation, Ella Bay 4-4 section, showing three-dimensional network of burrows with dolomitic fill; note conspicuous cylindrical burrow in centre of specimen. ISPG photo. 2031-2.

stratified dolostones may represent microbial mats of high intertidal origin, and evaporites could have been deposited in such settings. Removal of limestone; that is, karst development, inferred for breccias of the Scoresby Bay Formation in other areas (Brunton, 1986), appears less likely here.

The presence of fenestrae in many dolostone beds of members B and C may indicate intertidal to shallow subtidal conditions, although fenestral structures are not restricted to such settings. The internal structure of the stromatolites has been obscured by dolomitization, but it appears that they were laterally linked, with not more than a few centimetres of relief on individual laminae. If so, these features indicate high intertidal settings.

Age and correlation

No diagnostic fossils have been found in the Scoresby Bay Formation in this area. The only diagnostic fossils reported from the entire formation are trilobites from northwest of Irene Bay, central Ellesmere Island, that were assigned by J.W. Cowie to the "upper *Olenellus* sub-zone of the Lower Cambrian" (Kerr, 1967a, p. 33). At that locality the formation is 259 m thick and the fossils occurred 107 m above its base.

Kerr assumed that the Scoresby Bay Formation was limited entirely to the Early Cambrian and correlated it with the combined Cape Leiper, Cape Ingersoll, Police Post, and Cape Kent formations of Bache Peninsula. However, a comparable dolomitic unit in Washington Land, northeast Greenland, the Kastrup Elv Formation, contains trilobites of both Early Cambrian and early Middle Cambrian ages (Peel and Christie, 1982). It is probable, therefore, that the Scoresby Bay Formation extends into the early Middle Cambrian.

Palmer (1981) inferred a widespread disconformity between the Lower and Middle Cambrian Series of eastern North America from the fact that strata with trilobites of the *Bonnia-Olenellus* Zone are commonly directly overlain by Middle Cambrian beds with trilobites of the *Glossopleura* or *Bathyuriscus-Elrathina* zones, the lower two trilobite zones of the Middle Cambrian being absent. This disconformity has been recognized on Devon Island, where it separates the Rabbit Point and Bear Point formations (Kurtz et al., 1952; Thorsteinsson and Mayr, 1987). The stratigraphic sections of Bache Peninsula and northeastern Greenland, presented by Peel and Christie (1982, Fig. 4), show the *Glossopleura* Zone a short distance above olenellids, but do not indicate a disconformity between them. If such a disconformity is present in the project area, it probably occurs within the Scoresby Bay Formation and is represented by one of the numerous brecciated layers in members B or C.

OOLITIC LIMESTONE UNIT (informal new unit)

The provisional name, "oolitic limestone unit", is here given to strata that constitute the lower of two units distinguished by Kerr (1967a) in the Parrish Glacier Formation, a term not used in this report (Fig. 31; see below). The oolitic limestone unit is readily mappable in the field and recognizable on airphotos by its relatively dark tone.

Distribution, thickness, and contact relations

Outcrops are limited to a narrow belt on the southeastern limb of the Ninnis Glacier Syncline. The unit is 272.5 m thick at the Ella Bay 4-5 section, where it overlies the Scoresby Bay Formation with conformable, gradational contact. The contact with the Cass Fjord Formation is abrupt and is interpreted as disconformable.

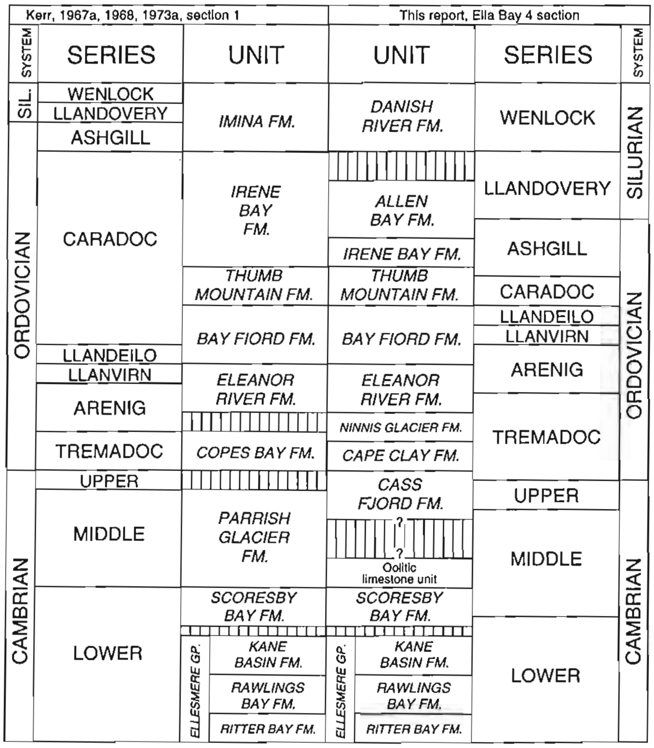


Figure 31. *Formational nomenclature and age assignments for Ella Bay 4 section, according to Kerr (1967a) and this report.*

Lithology

The unit consists mainly of dolomitic limestone with lesser amounts of dolostone and small amounts of siltstone.

The limestone is medium dark grey and generally massive, with some parting surfaces. Most specimens examined in thin section are grainstones; a lesser number are recrystallized peloidal packstones or wackestones of silt to fine sand grade, or lime mudstones. The grainstones are composed of peloids, variably micritized ooids (Fig. 32), and rare skeletal material — identifiable fragments are trilobite appendages. The peloids of the grainstones seem to represent both intraclasts of lime mudstone and completely micritized ooids. Microcrystalline to coarse crystalline dolomite is concentrated in stringers, tubes, or irregular blobs, some of which may represent burrows, and also occurs as single crystals. The dolomite contents of four typical specimens range from 8 to 33 per cent (Appendix 2, Table 17).

In the middle part of the unit, there is a recessive interval of silty limestone, overlain by about 2.5 m of calcareous and dolomitic siltstone. The strata show flat and undulating lamination with some bioturbation and bedding-parallel burrow casts (*Planolites*). A typical specimen of siltstone is composed mainly of quartz (40%) and carbonates (dolomite 19%, calcite 18%) with lesser amounts of feldspar (K-feldspar 14%, plagioclase 2%), and small amounts of white mica (4%) and chlorite (2%).

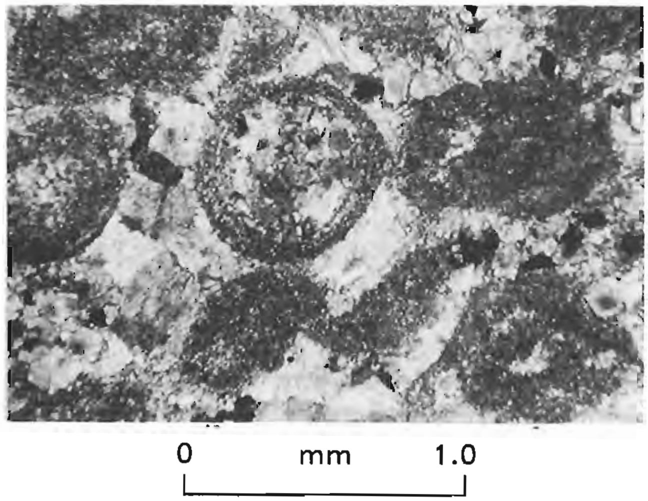


Figure 32. *Photomicrograph (cross-polarized light) of ooid (partly micritized) and peloids in grainstone of oolitic limestone unit, lowermost strata. Cement and core of ooid consist of calcite and euhedral dolomite. ISPG photo. 2032-12.*

Mode of origin

The presence of abundant grainstone with ooids and peloids indicates a shallow, high energy, marine environment.

Age and correlation

No fossils have been found in the oolitic unit, but regional lithological relations suggest that it is correlative with the upper part of the Cape Wood Formation of Bache Peninsula and Inglefield Land, and with the upper part of the combined Telt Bugt-Kastrup Elv formations of Washington Land. This correlation is based on its stratigraphic position in the upper part of a thick carbonate sequence that is overlain by the mixed clastic and carbonate sediments of the Cass Fjord Formation, without regard for the oolitic texture of the rocks, which probably is a local facies development. These carbonate units, as mentioned, have yielded trilobites of the early Middle Cambrian *Glossopleura* Zone (cf. Peel and Christie, 1982, Fig. 4). If so, the oolitic limestone unit is also correlative with lower parts of the Parrish Glacier Formation at the type section at Copes Bay, where trilobites of the same zone have been found (Thorsteinsson, 1963; Kerr, 1967a; Fritz, pers. comm., 1981).

CASS FJORD FORMATION

The Cass Fjord Formation has its type area in Washington Land, northwestern Greenland (Poulsen, 1927; Koch, 1929a, b). There, it lies stratigraphically between the Telt Bugt and Cape Clay formations, is 470 m thick, and ranges in age from late Middle Cambrian to earliest Ordovician. At its type section it consists of limestone, commonly with silty laminae, intraformational conglomerate, dolostone, and minor siltstone, shale, sandstone, and local anhydrite (Henriksen and Peel, 1976). Channels, ripple marks, "sun cracks", and burrows of different kinds are common, and some red and yellow weathering shales and dolostones form markers.

In the Arctic Islands, the formation has been mapped on Bache Peninsula (Troelsen, 1950; Christie, 1967), southern Ellesmere Island (Mayr and Okulitch, 1984), and Devon Island (Thorsteinsson and Mayr, 1987). In this region the formation ranges in thickness from 170 to 488 m and is divisible into four widely recognized members. The most characteristic rock type is flat-pebble conglomerate, locally amounting to 11 per cent of the section, composed of mixed lime mud and siliciclastic silt. Beds and mounds of stromatolitic boundstone form extensive markers. Other conspicuous rock types are rhythmites composed of peloidal calcisiltite and marl; gypsum; herringbone-crossbedded quartz sandstone; and massive, faintly banded to variegated dolosiltite. These deposits represent a complex mosaic of shallow subtidal to predominantly peritidal environments (Packard, *in* Trettin et al., 1991).

Correlative deposits in central Ellesmere Island (Kerr, 1967a), and in the subsurface of Cornwallis Island (Mayr, 1978), were previously all assigned to parts of the Parrish Glacier and Copes Bay formations. However, the stratigraphic nomenclature of northwestern Greenland has recently been introduced in Cornwallis Island also (Thorsteinsson and Mayr, 1987, Fig. 37), and the Parrish Glacier Formation and the lower part of the Copes Bay have been reassigned to the Cass Fjord. According to the new stratigraphic breakdown, the Cass Fjord Formation comprises 1440 m of lime mudstone, shale, siltstone, and minor sandstone and intraformational conglomerate in the Panarctic Deminex Cornwallis Central Dome K-40 well. A trilobite of probable early Late Cambrian (Dresbachian) age, found near the bottom of the well (Mayr, 1978), suggests that the formation is almost completely represented in this well.

In central Ellesmere Island (including the study area), serious stratigraphic problems have arisen with respect to the Parrish Glacier and Copes Bay formations. For example, trilobites of the early Middle Cambrian *Glossopleura* Zone occur within widespread pure carbonate units such as the Castrup Elv, Telt Bugt, and Cape Wood formations of Greenland, the Cape Wood Formation of Bache Peninsula, and the Bear Point Formation of Devon Island (cf. Peel and Christie, 1982; Thorsteinsson and Mayr, 1987), all of which are correlative with the unfossiliferous interval comprising the upper Scoresby Bay Formation and the oolitic limestone unit. These carbonate units, as mentioned, lie stratigraphically between Lower Cambrian siliciclastic sediments (Dallas Bugt, Humboldt, and Rabbit Point formations) and the mixed carbonate and siliciclastic sediments of latest Middle Cambrian to earliest Ordovician age that are now assigned mostly to the Cass Fjord Formation. However, at its type section at Copes Bay, the Parrish Glacier Formation includes limestones with trilobites of the same zone (Thorsteinsson, 1963; Fritz pers. comm., 1981), which implies that the type section includes strata assigned elsewhere to the Cape Wood or Scoresby Bay formations. This discrepancy could be explained by diachronous facies changes, but there is no evidence that the contact between the carbonate units (Cape Wood Formation etc.) and the mixed carbonate and clastic units (Cass Fjord Formation, etc.) is diachronous; on the contrary, it appears that the base of the mixed carbonate and silicilastic units is no older than latest Middle Cambrian, and that it is separated from the underlying carbonate units by a hiatus (Thorsteinsson and Mayr, 1987, Table 2). Problems concerning the Copes Bay Formation are discussed below (see the section on the Cape Clay Formation).

In order to eliminate these problems and to provide a simpler regional picture, the Cass Fjord Formation has been extended into the study area, where it can readily be equated with the upper part of the Parrish Glacier Formation, as mapped and described by Kerr (1967a) (Fig. 31). Both units are mixed carbonate and clastic assemblages of relatively shallow marine origin, lying stratigraphically between two carbonate units: the Cape Clay Formation above, and the Cape Wood Formation or the oolitic limestone unit below (Figs. 6, 31). In both cases the upper contact is conformable and the lower contact probably disconformable. Moreover, the uppermost part of the (here abandoned)

Parrish Glacier Formation has yielded conodonts of earliest Ordovician age that are coeval with conodonts from the uppermost Cass Fjord Formation (see below).

On the other hand, the lithology of the Cass Fjord Formation in this area (and on Cornwallis Island) is somewhat different from the lithology of equivalent strata in the outcrop belt extending from Greenland through Bache Peninsula to southeastern Ellesmere Island and Devon Island. For example, intraformational conglomerate is less abundant and stromatolitic reefs and evaporites are absent. These differences indicate that the strata in this area (and on Cornwallis Island) represent a facies deposited farther offshore, in somewhat deeper water environments.

In summary, it is justified and convenient to use the name Cass Fjord Formation for the strata assigned tothe upper Parrish Glacier Formation by Kerr (1967a, Section 1, Unit 13) in this area.

Distribution, thickness, and contact relations

The Cass Fjord Formation is completely exposed on the southeastern limb of the Ninnis Glacier Syncline at the Ella Bay 4-6 section, where it is 727 m thick (Figs. 33, 34). Its lower contact, with the oolitic limestone unit, is abrupt and probably disconformable; its upper contact, with the Cape Clay Formation, is gradational and conformable.

Upper parts of the formation are exposed on the northwestern limb of the same syncline, but the contact with the Cape Clay Formation is covered there. An incomplete section (Ella Bay 3-1), bounded by overburden and a fault, includes 188 m of strata (Fig. 33c).

Lithology

The Cass Fjord Formation consists of limestone, dolostone, mudrock (mainly siltstone), quartz sandstone, and minor intraformational conglomerate, showing a considerable variety of primary structures and colours. The Ella Bay 4-6 section provides a complete record of the formation in a setting some distance from the shelf margin, whereas the Ella Bay 3-1 section provides a more limited record of a different development of the upper part of the formation in a setting close to the Cambrian–Ordovician shelf margin.

The rock types of the Cass Fjord Formation can be assigned to six lithofacies, summarized in Table 2. The vertical distribution of these lithofacies (Table 3) permits division of the formation into two members, informally referred to as members A and B. Briefly, member A (536.5 m) is dominated by thinly interstratified carbonate and siliciclastic sediments, whereas member B (190.5 m) is dominated by nonlaminated carbonates (Fig. 33b).

The Cass Fjord Formation differs from all other units in its variegated weathering colours, especially its redbeds. At the Ella Bay 4-6 section, red or pink strata occur between 121 and 605 m above the base of the formation, mainly in member A. They are concentrated in five intervals, up to 23 m thick, and comprise 6 per cent of the column, but the redbeds themselves probably make up no more than 2 to 3 per cent of the entire formation.

The sediments of the Cass Fjord Formation are assigned to six lithofacies, summarized in Table 2. The proportion of these lithofacies in members A and B at the Ella Bay 4-6 and 3-2 sections is listed in Table 3.

Analytical results. One hundred and eighteen samples were studied in thin section and by X-ray diffraction. Although the samples are mostly from the few intervals measured in detail, they may nevertheless give a fairly representative picture of the lithological and mineralogical composition of the formation as a whole (Appendix 2, Table 23).

About 60 per cent of the samples represent a single rock type; the remainder are composed of two or three interlaminated rock types. There are significant differences between the samples representing one rock type only and those representing two or more rock types. Limestone makes up the bulk of the single rock type category (66%), followed by dolostone (17%), sandstone (11%), and siltstone (6%). In the multiple rock type category, dolostone (32%) and siltstone (26%) are most common, followed by limestone (21%), sandstone (7%), and minor intraformational conglomerate (6%). The most common combinations are siltstone + dolostone (29%) and limestone + dolostone (19%).

Overall, carbonate rocks make up 70 per cent of the samples (limestone 47%, dolostone 23%), and clastic sediments the remaining 30 per cent. The latter consist of nearly equal proportions of siltstone (14%) and sandstone (13%), with small amounts of intraformational conglomerate (3%).

The mixing of carbonate and siliciclastic components, apparent from these lithological data, also is evident in the X-ray diffraction data. Most

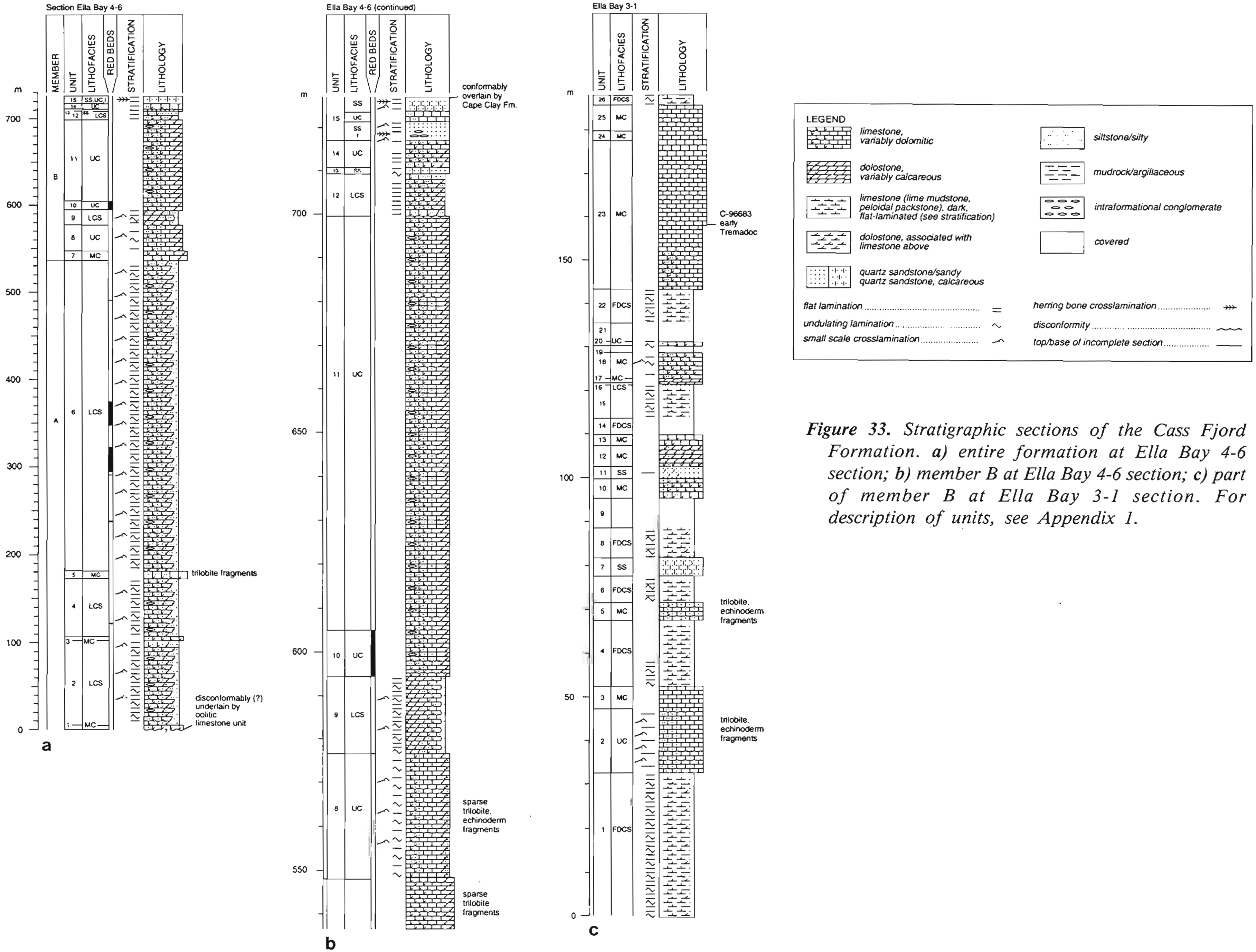


Figure 33. *Stratigraphic sections of the Cass Fjord Formation.* ***a)*** *entire formation at Ella Bay 4-6 section;* ***b)*** *member B at Ella Bay 4-6 section;* ***c)*** *part of member B at Ella Bay 3-1 section. For description of units, see Appendix 1.*

carbonate rocks contain varying proportions of quartz and feldspar, and all sandstones and siltstones contain varying proportions of calcite and/or dolomite. The variability of the compositions is apparent from wide ranges and large standard deviations (Appendix 2, Tables 18–22).

The average limestone from the Ella Bay 4-6 section contains: calcite, 66 per cent; quartz, 15 per cent; dolomite, 14 per cent; and feldspar, 5 per cent (mainly K-feldspar; Appendix 2, Table 18); a few samples also have minor amounts of white mica and chlorite. However, quartz ranges up to 37 per cent; dolomite up to 35 per cent; and K-feldspar up to 13 per cent. Samples from the Ella Bay 3-1 section are comparable to those from the Ella Bay 4-6 section (Appendix 2, Table 19).

The dolostones analyzed contain even larger amounts of impurities. These samples average: dolomite, 56 per cent; quartz, 23 per cent; calcite, 16 per cent; and feldspar, 5 per cent; with small amounts of mica and chlorite in some samples (Appendix 2, Table 20).

The siltstones contain relatively large proportions of carbonate minerals (dolomite 20%, calcite 9%) and feldspar (K-feldspar 10%, plagioclase 1%), in addition to the predominant quartz (59%; Appendix 2, Table 21).

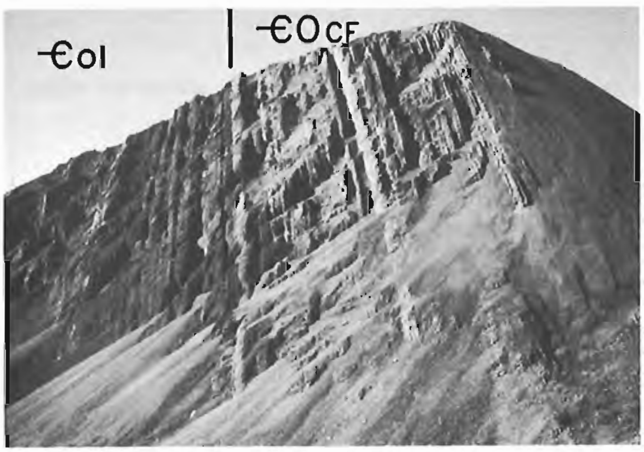


Figure 34. The oolitic limestone unit ($Ꞓ_{ol}$) and member A of the Cass Fjord Formation ($ꞒO_{CF}$) at Ella Bay 4 section, looking southwest. Abrupt contact probably is disconformable. ISPG photo. 2256-57.

By contrast, the sandstones have smaller carbonate (15%) and feldspar (3%) contents and a correspondingly larger quartz content (83%; Appendix 2, Table 22).

Organic metamorphism

A conodont collection from the upper part of the formation at the Ella Bay 3-1 section has a Colour Alteration Index of 4 (Nowlan, Appendix 3B, C-96683; but note that the overlying Cape Clay to Allen Bay formations have an index of 5).

Mode of origin

The Cass Fjord Formation differs from other units of the Lower Cambrian to Lower Silurian shelf carbonate succession by its relatively high siliciclastic sand and silt content, derived from the continental interior. It is a predominantly shallow marine unit, but inferred water depths range from intertidal to below wave base.

The presence of herringbone crosslamination and intraformational conglomerate indicates that at least some strata of the *sandstone facies* are intertidal in origin.

The *laminated carbonate-siliciclastic facies* also has some features suggestive of intertidal deposition, such as intraformational conglomerates, small scours, minor unconformities, and colours of red and orange, although none of these are conclusively diagnostic. (Intraformational conglomerates, for example, occur as storm deposits in subtidal environments, but storm deposits have not been recognized in this facies.) On the other hand, the associated limestones are shallow subtidal in aspect. Thus, this lithofacies probably encompasses intertidal and shallow subtidal settings.

Massive, bioturbated limestones of the *massive and undifferentiated carbonate facies* are considered to be mainly of shallow subtidal origin, with the possible exception of certain grainstones and some pink weathering strata.

A deeper subtidal environment is inferred for the *flat-laminated dark carbonate-siliciclastic facies*. The dark colour indicates a poorly oxygenated environment. The flat lamination may indicate sedimentation from turbid layers generated by storms in shallower shelf areas. The fact that this lithofacies is restricted to the northwesternmost part of the distributional area of the formation, close to the laminite facies of the Hazen Formation, supports this inference.

TABLE 2

Cass Fjord Formation, characteristics of lithofacies

Massive carbonate facies (MC)	
Rock types:	**Limestone,** variably dolomitic, silty, sandy, and associated **minor dolostone,** calcareous, silty, sandy **Limestone**: lime mudstone, peloidal packstone/wackestone, peloidal and skeletal wackestone with microscopic fragments of trilobites and echinoderms **Dolostone**: mainly microcrystalline
Colour:	Limestones are mainly medium to medium dark grey, but are light grey in the lower 105 m Lithofacies weathers in hues of grey and orange, depending on dolomite content, but greyish red-purple from 594.5 to 605.0 m
Stratification:	Massive as a result of bioturbation
Distribution:	Subordinate in member A, common in member B
Undifferentiated carbonate rocks (UC)	
Rock types:	**Limestone,** variably dolomitic, **minor dolostone,** calcareous, both variably silty, sandy **Limestone**: lime mudstone, peloidal packstone/wackestone, recrystallized limestones, etc. **Dolostone**: mainly microcrystalline (includes thick units examined only cursorily)
Colour:	Limestones are medium light grey to medium dark grey; weather in hues of grey and orange, depending on dolomite content
Stratification:	Some flat or undulating lamination; some crosslamination (including troughs 15 cm long, 10 cm deep at EB3-1, unit 2); partly massive owing to bioturbation
Distribution:	Abundant in member B at Ella Bay 4-6 section; minor component of section EB3-1
Laminated carbonate-siliciclastic facies (LCS) (Figs. 35, 37, 38)	
Rock types:	Mainly impure **limestone** (peloidal packstone/wackestone, grainstone) and **dolostone** (mostly microcrystalline); lesser amounts of calcareous-dolomitic **siltstone** (coarse grained) and **sandstone** (very fine grained); minor intraformational conglomerate with clasts of all four rock types
Colour:	Light grey to medium light grey; weathering in hues of orange (mainly pale yellowish orange or greyish orange, less commonly orange-pink), rarely red (moderate red, dusky red, greyish red-purple); greenish strata are associated with some redbeds
Stratification:	Mainly flat lamination; also undulating lamination, small-scale crosslamination (including trough crossbedding), convolute lamination, soft-sediment injection structures, shrinkage cracks, minor unconformities Also included are massive carbonate beds, <3.5 m thick in member A
Distribution:	Predominant in member A, subordinate in member B
Flat-laminated dark carbonate-siliclastic facies (FDCS)	
Rock types:	Mainly **limestone; minor dolostone, mudrock,** and **sandstone** **Limestone:** lime mudstone, peloidal packstone/wackestone; variably dolomitic, silty, sandy **Dolostone**: microcrystalline, calcareous, silty, sandy **Sandstone:** very fine grained, silty, calcareous, dolomitic
Colour:	Mainly medium dark grey
Stratification:	Flat and undulating lamination, rare microscopic crosslamination; solution zones common (marked by undulating, pinching and swelling concentrations of siliciclastic material and carbonaceous matter)
Distribution:	Common in upper part of formation at the Ella Bay 3-1 section; absent from the Ella Bay 4-6 section
Sandstone facies (SS) (Fig. 36)	
Rock types:	**Sandstone**, minor **limestone,** intraformational **conglomerate** **Sandstone**: quartzose, calcareous and/or dolomitic, very fine or fine grained, generally very well sorted; quartz grains are rounded
Colour:	Very light grey to medium grey
Stratification:	Flat lamination, undulating lamination, crosslamination (including herringbone crossbedding); also indistinct flat beds, 5 to 10 cm thick
Distribution:	Minor component of member B
Intraformational conglomerate facies (I)	
Rock type:	Clasts composed of sandstone or limestone, disk-shaped
Colour:	Medium light grey
Stratification:	Clasts partly parallel with bedding, partly inclined
Distribution:	Recorded separately only as one thin unit in member B at the Ella Bay 4-6 section (717.2-717.6 m), but occurs as minor component of other lithofacies

TABLE 3

Cass Fjord Formation, relative abundance of lithofacies by section and member

Lithofacies	Stratigraphic section and member EB4-6 mbr. A	EB4-6 mbr. B	EB3-1 mbr. B
MC	3.3%	6.1%	38.0%
UC	-	74.6	12.7
LCS	96.7	14.6	0.3
FDCS	-	-	45.7
SS	-	4.5	3.1
I	-	0.4	-

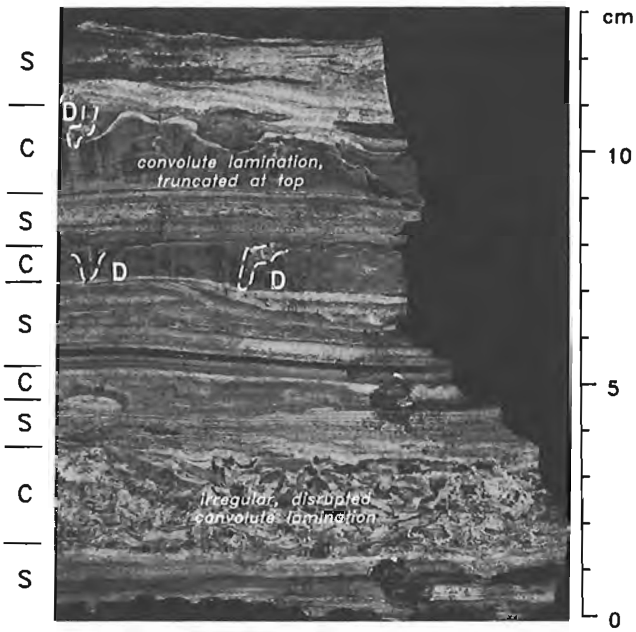


Figure 35. Typical sediments and primary structures of the Cass Fjord Formation, member A, laminated carbonate-siliciclastic facies (LCS) at the Ella Bay 4-6 section. All sediments consist of varying proportions of siliciclastic and carbonate materials and are coloured orange, brown, or pink. C: composed mainly of dolomite and lime mud; note convolute lamination in lowermost and uppermost layers, the latter truncated by erosion surface; S: composed mainly of siliciclastic silt and very fine grained sand; note flat lamination and small-scale cross-lamination; D: dykelets of siliciclastic silt and very fine grained sand. ISPG photo. 2031-3.

Figure 36. Fine grained quartzose sandstone (lithofacies SS) showing flat lamination and opposing directions of small-scale cross-lamination; Cass Fjord Formation, Ella Bay 4-6 section, unit 15, 718 m. ISPG photo. 2256-59.

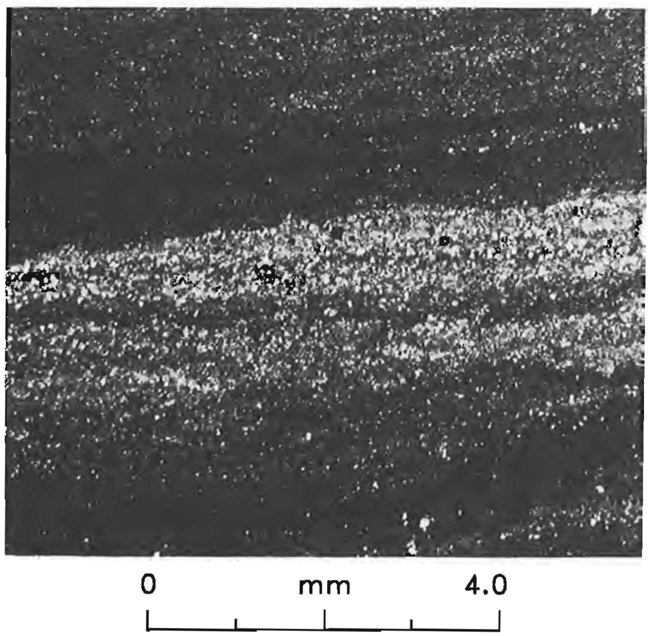


Figure 37. Photomicrograph (ordinary light) of laminated carbonate-siliciclastic lithofacies (LCS) in the upper Cass Fjord Formation at Ella Bay 3-1 section. Dark components are lime mud and peloids; light components are dolomite, and siliciclastic silt and very fine grained sand. Note predominantly flat lamination with small-scale crosslamination at low angles. ISPG photo. 2032-111.

The Ella Bay 4-6 section, with relatively shallow water deposits in member A and at the top of member B, and somewhat deeper water deposits in the main part of member B, represents a transgressive-regressive cycle with numerous superimposed cycles of higher frequency.

The Ella Bay 3-1 section represents no less than six cycles, indicated by alternations of the *flat-laminated dark carbonate-clastic facies* with a variety of shallower facies.

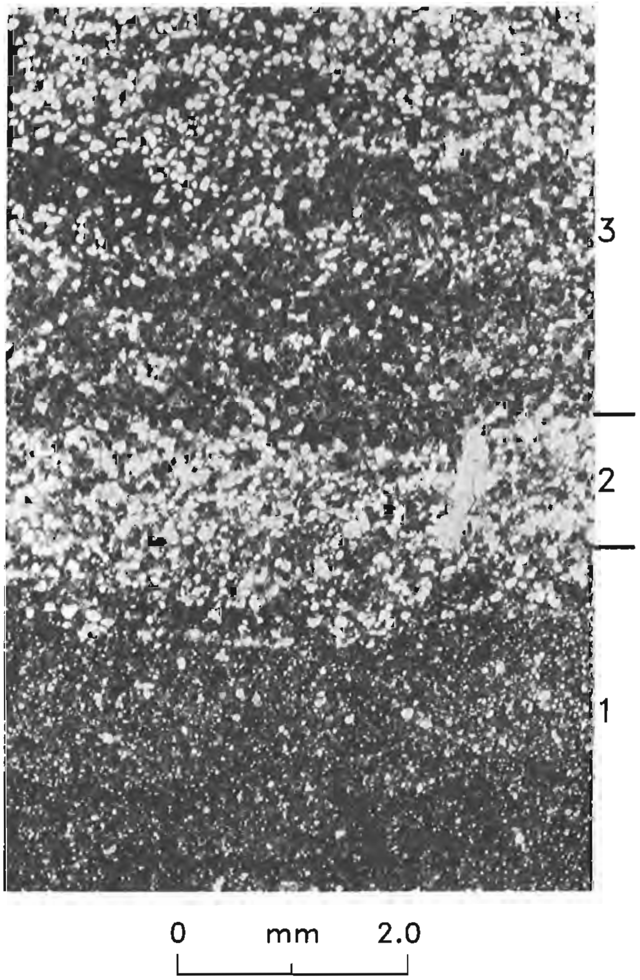


Figure 38. Photomicrograph (ordinary light) of laminated carbonate-siliciclastic lithofacies (LCS) in the upper Cass Fjord Formation at Ella Bay 3-1 section. Layer 1: dolostone, microcrystalline, highly calcareous; Layer 2: sandstone, very fine grained, rich in lime mud and peloids; Layer 3: peloidal packstone, silty and very fine grained sandy. ISPG photo. 2032-61.

Age and correlation

At the type section in Washington Land, the Cass Fjord Formation ranges in age from latest Middle Cambrian to earliest Ordovician [early Tremadoc; lower part of Fauna C or *L. bransoni* conodont interval of Ethington and Clark (1981)]. This range is well established by trilobites from the Cambrian part of the unit (Palmer and Peel, 1981) and by conodonts from the Ordovician part.

The only fossils obtained on Judge Daly Promontory are conodonts from the Ella Bay 3-1 section, assigned to Fauna B of early Tremadoc age (Nowlan, Appendix 3B, C-96683). The section clearly is in the upper part of the formation, but its stratigraphic position has not been determined precisely. However, collections from the overlying Cape Clay Formation (see below) indicate that the top of the Cass Fjord is no younger than early Tremadoc. The base of the formation is assumed to be latest Middle Cambrian in age, as in northwest Greenland.

CAPE CLAY FORMATION

The Cape Clay Formation was established in Washington Land, northwestern Greenland, where it overlies the Cass Fjord (Poulsen, 1927; Koch, 1929a). In the type area it is Early Ordovician (Tremadoc) in age and consists of about 50 m of yellowish brown weathering, mottled, indistinctly bedded limestone that contains small, reef-like structures (Henriksen and Peel, 1976).

Like the Cass Fjord Formation, the Cape Clay has been mapped on Bache Peninsula (Christie, 1967), southern Ellesmere Island (Mayr and Okulitch, 1984), and Devon Island (Thorsteinsson and Mayr, 1987). It now also is recognized in the subsurface of Cornwallis Island, where it comprises strata originally included in the middle part of the Copes Bay Formation (Mayr, 1978; Thorsteinsson and Mayr, 1987).

In the project area the Cape Clay Formation is equated with the lower part of the Copes Bay Formation as mapped by Kerr (1967a, Plate V; Fig. 31). The reassignment of these strata to the Cape Clay Formation is based on their stratigraphic position, lithology, and conodont fauna. The upper part of the Copes Bay Formation is reassigned to a new unit, the Ninnis Glacier Formation (see below), which is partly correlative with Kerr's (1968) Baumann Fiord Formation.

Distribution, thickness, and contact relations

The Cape Clay Formation is exposed on both limbs of the Ninnis Glacier Syncline, but exposure is poor on the northwestern limb. The formation is 220 m thick at the Ella Bay 4-7 section, where it lies between the Cass Fjord and Ninnis Glacier formations. Both contacts are conformable.

Lithology

The Cape Clay Formation can be assigned to two lithofacies, similar to those of the Cass Fjord (Table 4).

Organic metamorphism

Two conodont collections from the Ella Bay 4-8 section have Colour Alteration Index values of 5+ and 5, respectively (Nowlan, Appendix 3B, C-75430 and C-75432).

Mode of origin

The predominant sediment type — massive, bioturbated grainstone — suggests a shallow subtidal environment, periodically affected by waves or currents.

Age and correlation

At its type section in Washington Land, the Cape Clay Formation is restricted to a short interval within the Early Ordovician, middle Tremadoc (middle of Fauna C or *L. bransoni* conodont interval; J. Peel and P. Smith, pers. comm., 1987).

Three conodont collections from Judge Daly Promontory are relevant (Nowlan, Appendix 3B). The oldest (C-75430), from strata 0 to 1 m above the base of the formation at the Ella Bay 4-7 section, contains elements comparable to Faunas B and C.

The second collection (C-54915), obtained from beds of uncertain stratigraphic position on the northwestern limb of the Ninnis Glacier Syncline, is suggestive of Fauna C.

The third collection (C-75432), from beds 88 to 91 m above the base of the formation at the Ella Bay 4-7 section, contains several species characteristic of Fauna C although one species ranges into a younger fauna.

TABLE 4

Cape Clay Formation, characteristics of lithofacies

Massive limestone facies (ML)	
Rock types:	**Limestone**, variably dolomitic and silty; mainly grainstone, peloidal, with rare skeletal fragments (trilobites, minor echinoderms, gastropods?, algae?); minor **lime mudstone** Average composition: calcite 76 per cent; dolomite 17 per cent; quartz 4 per cent; and K-feldspar 2 per cent with or without very small amounts of plagioclase, mica and chlorite (XRD analyses; Appendix 2, Table 24)
Colour:	Medium light to medium dark grey, mainly medium grey
Stratification:	Massive as a result of bioturbation; dolomite concentrated in burrows
Distribution:	Dominant throughout the formation (96.6%) except for middle part (see below)
Laminated sandstone-dolostone facies (LSSD)	
Rock types:	Mainly **sandstone**, very fine grained, silty, calcareous, dolomitic (e.g., quartz 39%, calcite 32%, dolomite 19%, and K-feldspar 10%); minor **dolostone**, microcrystalline to fine crystalline, silty, sandy, calcareous (e.g., dolomite 80%, calcite 17%, quartz 2%, K-feldspar 1%)
Colour:	Light grey and medium grey
Stratification:	Flat and undulating lamination
Distribution:	Confined to 129.4-136.9 m (3.4%)

In summary, the most diagnostic collections are assigned to Fauna C of early to middle Tremadoc age and permit correlation with the type section in Greenland. This correlation is strengthened by conodonts from the underlying Cass Fjord Formation and from the overlying Ninnis Glacier Formation.

NINNIS GLACIER FORMATION (new formation)

The name, Ninnis Glacier Formation, is here introduced for a unit of relatively recessive carbonate strata with minor siltstone and sandstone that lies conformably between the Cape Clay and Eleanor River formations on the southeastern limb of the Ninnis Glacier Syncline, and between the Cape Clay and Bulleys Lump formations on the northwestern limb. The southeastern and northwestern exposures differ slightly in age range, lithology, and inferred depositional environment (Figs. 39, 40).

The strata on the southeastern limb of the syncline were included in the upper part of the Copes Bay Formation by Kerr (1968) (Fig. 31). In most of central Ellesmere Island, the Copes Bay Formation is separated from the Eleanor River Formation by evaporites and carbonates assigned to the Baumann Fiord Formation. Because of the absence of evaporites below the Eleanor River at the Ella Bay 4 section, Kerr inferred a disconformity between that formation and the Copes Bay (which does not contain diagnostic macrofossils in this area). However, subsequent conodont identifications have shown that in this area the lower part of the Copes Bay Formation is equivalent to the Cape Clay Formation (see above, Cape Clay Formation) and the upper part to the Baumann Fiord Formation of central Ellesmere Island (Kerr, 1968), and to the slightly older Christian Elv Formation of northwestern Greenland (Henriksen and Peel, 1976; Fortey and Peel, 1989; see below, Age and correlation).

At the Ella Bay 4 section, therefore, the Eleanor River and Cape Clay formations are separated by a carbonate unit that lacks evaporites and is correlative with the combined Baumann Fiord and Christian Elv formations. It fringes the Baumann Fiord evaporite basin on the northwest and is the counterpart of the Blanley Bay Formation of Devon Island (Thorsteinsson and Mayr, 1987), which fringes the same basin on the southeast. The unit merits formational rank because of its significance in the regional stratigraphic framework.

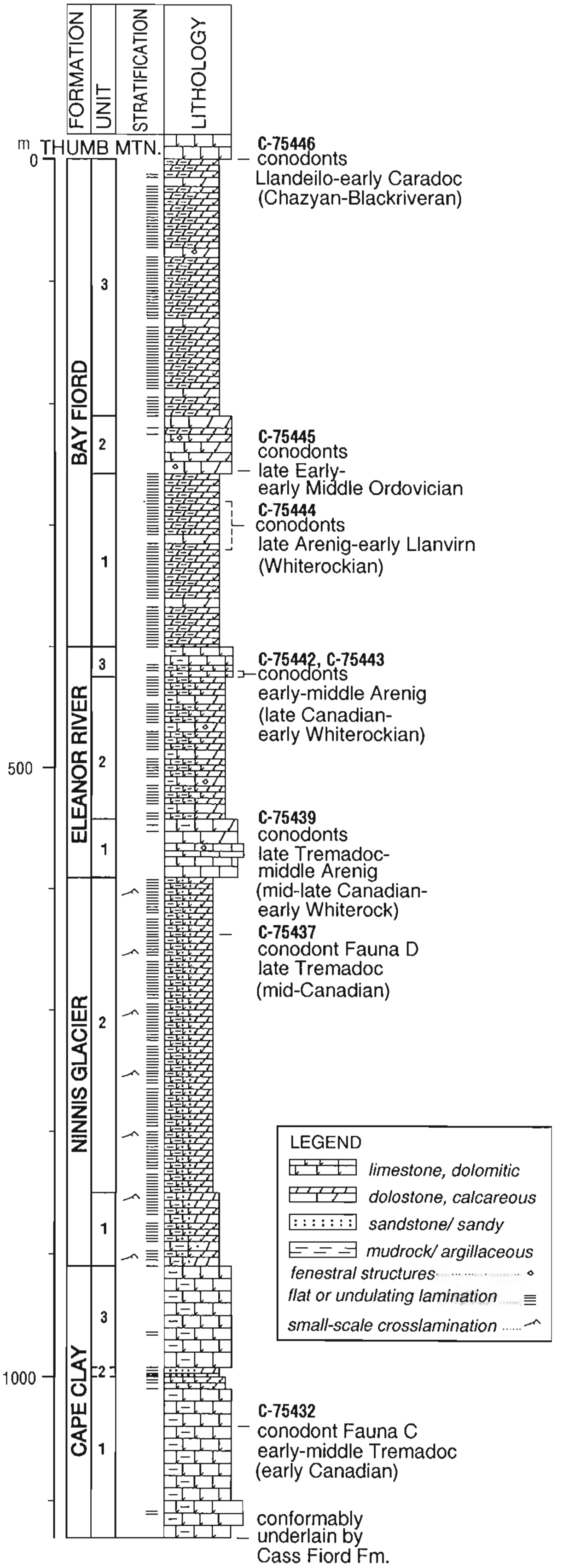


Figure 39. Generalized stratigraphy, Cape Clay, Ninnis Glacier, Eleanor River, and Bay Fiord formations at Ella Bay 4 section. For description of units, see Appendix 1, sections Ella Bay 4-7 to 4-10.

Figure 40. Ninnis Glacier Formation (dark grey) lying on the Cape Clay Formation (light grey) near Ella Bay 3 section, looking northeast. ISPG photo. 2256-41.

As mentioned, the top of the formation is diachronous, becoming older to the northwest. Thus, on the northwestern flank of the Ninnis Glacier Syncline, the Ninnis Glacier Formation is correlative with the Christian Elv Formation only, the overlying member A of the Bulleys Lump Formation being correlative with the Baumann Fiord (see below under Age and correlation, and Bulleys Lump Formation).

Distribution, thickness, and contact relations

The Ninnis Glacier Formation, as mentioned, underlies two narrow belts, on the southeastern and northwestern limbs of the Ninnis Glacier Syncline. The formation is 319 m thick in the southeastern belt at the Ella Bay 4-8 section, and 108 m in the northwestern belt at the Ella Bay 3-2 section, where it has a more restricted age range. Both lower and upper contacts are gradational and conformable.

Lithology

Ella Bay 4-8 section

Only the lower 59 m of the Ninnis Glacier Formation are well exposed. These strata have been measured and analyzed in some detail and the results are listed below in Table 5.

Slightly less than two thirds (62.5%) of the detailed interval consist of strata showing flat and undulating lamination with rare small-scale crosslamination (Fig. 41). The laminites are composed mainly of dolostone with lesser amounts of limestone, and minor amounts of sandstone and siltstone. All rock types are impure, the carbonate rocks containing varying proportions of silt and sand, and the siltstones and sandstones varying proportions of calcite and

TABLE 5

Ninnis Glacier Formation, Ella Bay 4-8 section, unit 1, rock types and their abundance

Stratification	Rock types	N	Units Thickness (m)	% of section
Massive, bioturbated	limestone	9	0.15-4.0	16.1
Massive, bioturbated	dolostone	5	0.3-2.5	9.8
				(25.9)
Sparse or indistinct lamination	limestone	2	0.9-1.9	4.7
Sparse or indistinct lamination	dolostone	2	0.4-0.8	2.0
Sparse or indistinct lamination	ls. + dol.	2	1.4-1.5	4.9
				(11.6)
Flat and undulating lamination	limestone	2	0.5-1.2	2.9
Flat and undulating lamination	dolostone	7	0.6-2.0	16.9
Flat and undulating lamination	ls. + dol.	7	0.5-4.6	26.7
Flat and undulating lamination	ls. + ss.	1	0.3	0.5
Flat and undulating lamination	dol. + ss.	1	2.3	3.9
Flat and undulating lamination	dol. + ss. + siltst.	1	5.1	8.6
Flat and undulating lamination	ls. + dol. + ss.	1	0.6	1.0
Flat and crosslamination	ls. + siltst.	1	1.2	2.0
				(62.5)

( ) = Total per cent of the section

dolomite. The dolostones are predominantly microcrystalline. The limestones are lime mudstones and peloidal packstones/wackestones (for an explanation of the term see above under Lithological nomenclature and analytical methods). The lamination is caused by vertical variations in the concentration of carbonaceous matter, siliciclastic impurities, crystal size of the dolomite, or dolomite-calcite ratio (Fig. 42),

Figure 41. Small-scale crosslamination in highly calcareous and silty dolostone of the Ninnis Glacier Formation at Ella Bay 4-7 section. The upper set of crosslaminae represents a longitudinal section of a small trough. ISPG photo. 2249-2.

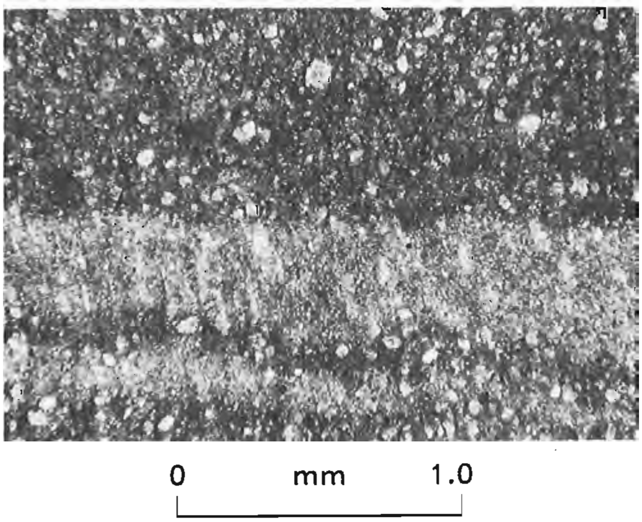


Figure 42. Photomicrograph (cross-polarized light) of flat lamination in dolomitic lime mudstone of the Ninnis Glacier Formation, Ella Bay 4-7 section. Dark layers are richer in submicroscopic carbonaceous matter and microcrystalline euhedral dolomite (light spots). Incipient cleavage at high angles to lamination. ISPG photo. 2260-112.

and also by bedding-parallel solution zones, marked by pinching and swelling concentrations of siliciclastic grains and carbonaceous matter. Most sandstones are very fine to fine grained, but very fine and coarse grained, bimodal sandstones also are present.

About one quarter (25.9%) of the detailed interval consists of massive, bioturbated limestone and subordinate microcrystalline dolostone. A deeply weathered specimen shows a three-dimensional network of dolomitized burrows (Fig. 43). These carbonates contain lesser proportions of siliciclastic impurities than the laminites. Most limestones are lime mudstones or peloidal grainstones/wackestones with rare skeletal fragments derived from trilobites. In addition there are at least two units (2.3% of section) of sand to granule grade intraclastic packstone, the fragments of which consist mainly of lime mudstone and peloidal packstone/wackestone with some coated grains, echinoderm fragments, and quartz. The quartz ranges in size from silt to coarse sand grade and the medium and coarse grains are well rounded.

The remainder of the interval (11.6%) is composed of limestone (lime mudstone and peloidal packstone/wackestone) and dolostone showing sparse or indistinct, flat or undulating lamination.

The rest of the Ninnis Glacier Formation, represented mainly by rubble, appears to be similar to the lower 59 m. Thicker intervals of recessive dolostone, limestone, and minor sandstone, showing flat lamination and rare, small-scale crosslamination, are interrupted by ledges, one to a few decimetres thick, of massive limestone and dolostone.

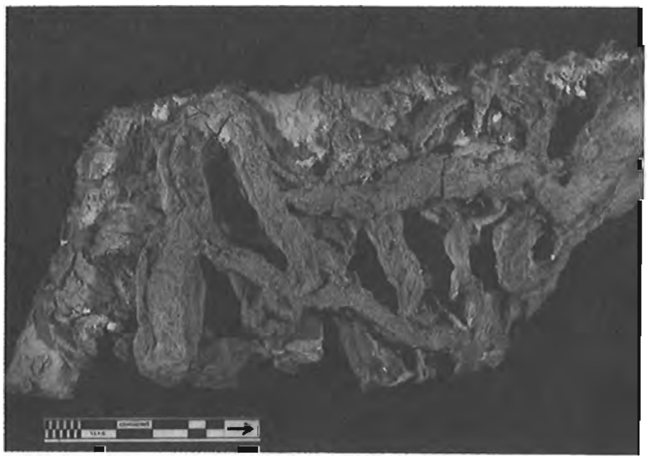


Figure 43. Dolomitized burrows (weathered out) in the Ninnis Glacier Formation, Ella Bay 4-7 section. ISPG photo. 2249-3.

The average limestone composition at Section 4-8 (regardless of stratification type) is: calcite, 71 per cent; quartz, 11 per cent; and K-feldspar, 4 per cent; with trace amounts of plagioclase, mica, and chlorite (Appendix 2, Table 25). The average dolostone composition is: dolomite, 65 per cent; calcite, 17 per cent; quartz, 14 per cent; and K-feldspar, 4 per cent; with trace amounts of plagioclase (Appendix 2, Table 26). Both limestone and dolostone are mainly medium light grey or medium grey and, less commonly, medium dark grey.

Ella Bay 3-2a section

This partial section, comprising 60 m of strata, consists mainly of laminated limestone and minor dolostone that are medium dark grey (87.4% of section; unit thickness 0.7–12.5 m). Flat and undulating lamination are predominant whereas small-scale crosslamination is rare. Bedding-parallel burrow casts are fairly common. The limestone, classified as lime mudstone or peloidal grainstone/wackestone, contains variable proportions of mostly microcrystalline dolomite and siliciclastic silt and sand, the latter mainly very fine grained. Common solution zones are enriched in dolomite and siliciclastic material. A sample of rather impure limestone contains: calcite, 34 per cent; quartz, 32 per cent; dolomite, 27 per cent; K-feldspar, 5 per cent; and white mica, 2 per cent (XRD analysis). The dolostone is predominantly microcrystalline and variably calcareous, silty and sandy.

These rocks are comparable to the laminated strata at Section 4-8, but differ from them by their darker colour, predominance of limestone over dolostone, and apparent absence of sandstone, at least within the short interval studied.

The remainder of the section consists of one bed each of packstone and intraformational conglomerate (Fig. 44). The packstone bed, 80 cm thick, is composed mostly of intraclasts of lime mudstone and peloidal packstone/wackestone with lesser amounts of skeletal material, derived mainly from trilobites and echinoderms. The carbonate intraclasts are mostly of sand grade, but range up to 5 mm in length. The bed is massive and medium grey and comparable to the packstone at the Ella Bay 4-8 section.

The intraformational conglomerate, 6.2 m thick and medium grey, is composed of fragments of lime mudstone, peloidal packstone/wackestone, and skeletal lime wackestone — all silty to medium grained sandy — in a matrix of silty and sandy lime mud. The internal structure of the unit is obscured by solution zones and partial dolomitization. Two samples, analyzed by X-ray diffraction, average: calcite, 66 per cent; dolomite, 19 per cent; quartz, 12.5 per cent; K-feldspar, 2 per cent; and plagioclase, 0.5 per cent (Appendix 2, Table 27).

Organic metamorphism

Two conodont collections from the Ella Bay 4-8 section have a Colour Alteration Index of 5 (Nowlan, Appendix 3B, C-75436, C-75437).

Mode of origin

The bioturbated lime mudstones and peloidal packstones/wackestones at the Ella Bay 4-8 section probably were deposited in shallow subtidal shelf environments.

The flat-laminated strata, which make up the bulk of the unit, were laid down in somewhat deeper water subtidal settings[1]. Moreover, the northwestward increase in organic carbon content (indicated by darker colours) suggests increasing water depth in that direction. Vertical variations in the calcite/dolomite ratio of individual laminae imply that the dolomite is

Figure 44. Intraformational conglomerate overlying laminated limestone, Ninnis Glacier Formation, Ella Bay 3-2a section. ISPG photo. 1878-63.

[1]Inferences about water depth are relative to tidal range and wave base and not to bathymetry. It is likely that tidal range was smaller and wave base shallower during those intervals when a restricted intra-shelf basin existed (upper Ninnis Glacier Formation southeast of Ninnis Glacier Syncline). Also, higher salinity during such conditions would result in less bioturbation and increased preservation of organic carbonaceous matter. These remarks also apply to the laminites of the Eleanor River and Bay Fiord formations.

of penecontemporaneous origin. The carbonate mud probably originated on adjacent shelves and was transported by storm-generated turbulent suspensions (nepheloid layers).

In contrast, the much coarser sediments of packstones and intraformational conglomerate must have been carried into this environment by more powerful currents, possibly storm induced.

Regional relations (see below, Bulleys Lump Formation) indicate that the upper part of the unit at the Ella Bay 4-8 section was deposited in a large, evaporitic intrashelf basin, rimmed by a carbonate buildup (Bulleys Lump Formation).

Age and correlation

Collection C-75437, from the southeastern limb of the Ninnis Glacier Syncline has been assigned to Fauna D of late Tremadoc age (Nowlan, Appendix 3B). In this area the formation is approximately correlative with the following units: 1) the combined Christian Elv, Poulsen Cliffs and Nygard Bay formations of northwestern Greenland (Peel and Christie, 1982; Fortey and Peel, 1982; Peel, *in* Trettin, 1991c, column 76); 2) map unit 6 of Christie (1967), and the Baumann Fiord Formation (Kerr, 1968) of the Bache Peninsula region, central Ellesmere Island; and 3) the Blanley Bay Formation of Devon Island (Thorsteinsson and Mayr, 1987).

A slightly shorter age range is inferred for the strata on the northwestern limb of the syncline, which are overlain by beds of the Bulleys Lump Formation containing conodonts transitional between Faunas C and D. In that area, conodonts of Fauna C have been obtained from the Ninnis Glacier Formation (Nowlan, Appendix 3B, C-96682).

Ordovician strata at Daly River (Section DR, Fig. 1) were assigned by Norford (1966) to two major units, informally referred to as Formations A and B. The lower five units (152 m) of Formation A are here tentatively assigned to the Ninnis Glacier Formation, although the contact with the Eleanor River Formation may lie within Unit 5.

ELEANOR RIVER FORMATION

The name, Eleanor River Formation, was introduced by Thorsteinsson (1958) for a limestone unit on Cornwallis Island that was overlain by the Cornwallis Formation (later raised to group rank); the base of the formation was not known to be exposed at that time. Kerr (1968) established that in most of central Ellesmere Island the Eleanor River Formation is underlain by a carbonate-evaporite unit that he named the Baumann Fiord Formation. This formation was later also recognized on Cornwallis Island (Thorsteinsson and Kerr, 1968).

Distribution, thickness, and contact relations

The Eleanor River Formation is exposed in a narrow belt on the southeastern limb of the Ninnis Glacier Syncline; correlative strata on the northwestern limb are included in the lower part of member B of the Bulleys Lump Formation. It lies conformably between the Ninnis Glacier Formation and the Bay Fiord Formation. At the Ella Bay 4-9 section, the Eleanor River Formation is 191 m thick.

Lithology

The Eleanor River Formation is characterized by massive carbonates (lithofacies MC), metres or tens of metres thick, but also includes small proportions of flat-laminated carbonates and minor siltstone (lithofacies FC). At the Ella Bay 4-9 section, the formation is divisible into three units. The resistant lower (0–49 m) and upper (165–191 m) units consist largely of massive carbonates, the relatively recessive middle unit is composed of alternating massive and laminated carbonates.

The *massive carbonate facies (MC)* is made up mainly of limestone, dolomitic limestone and related variably calcareous dolostone. In the lower resistant unit, the lower 30 m of strata consist entirely of limestone, and the overlying 17.5 m of limestone with an upward-increasing proportion of dolostone. The massive character is due to bioturbation, and the dolomite, mainly microcrystalline to very fine crystalline, but also fine crystalline in size grade, appears to be concentrated in burrows. Some massive carbonate strata (e.g., at 28 m and 111-120 m), show fenestrae (Fig. 45). X-ray diffraction analyses show that siliclastic impurities are scarce or absent. The rock colour varies from medium light grey to predominantly medium grey or medium dark grey.

The spectrum of limestone types comprises, in order of abundance, peloidal packstone/wackestone (for explanation of term see above, Lithological nomenclature and analytical methods) with some intraclasts and micritized skeletal grains, lime mudstone, skeletal and peloidal wackestone, and very minor amounts of stromatolitic limestone. Identifiable skeletal material was derived from ostracodes, trilobites, echinoderms, and gastropods.

A bed of stromatolitic limestone, 39 m above the base of the formation, is composed of laminated peloidal grainstone/wackestone and minor calcareous dolostone, forming small domes, 4.5 cm in diameter and 1 cm high in a typical specimen. According to an XRD analysis it contains: calcite, 55 per cent; dolomite (microcrystalline to very fine crystalline), 44 per cent; and quartz, 1 per cent.

The *flat-laminated carbonate facies (FC)* comprises dolostone, limestone, and very small amounts of related calcareous and dolomitic siltstone showing flat or undulating lamination. The rocks consist of variable proportions of the following components: lime mud, peloids, microcrystalline to very fine crystalline dolomite, quartz and minor feldspar of silt to very fine sand grade, and very small amounts of carbonaceous matter. The lamination is due to vertical variations in the concentration of these components or in the crystal size of the dolomite (Fig. 46). In addition, some rocks contain very minor amounts of ostracode and trilobite(?) fragments. Laminated dolostones and limestones contain up to 25 per cent quartz, up to 7 per cent K-feldspar, up to 4 per cent mica, and up to 2 per cent plagioclase, but the last two minerals are sporadic in distribution (Appendix 2, Tables 28, 29). Interlaminated dolostone and dolomitic siltstone average: dolomite, 58 per cent; quartz, 24 per cent; calcite, 10 per cent; and K-feldspar, 9 per cent (Appendix 2, Table 30).

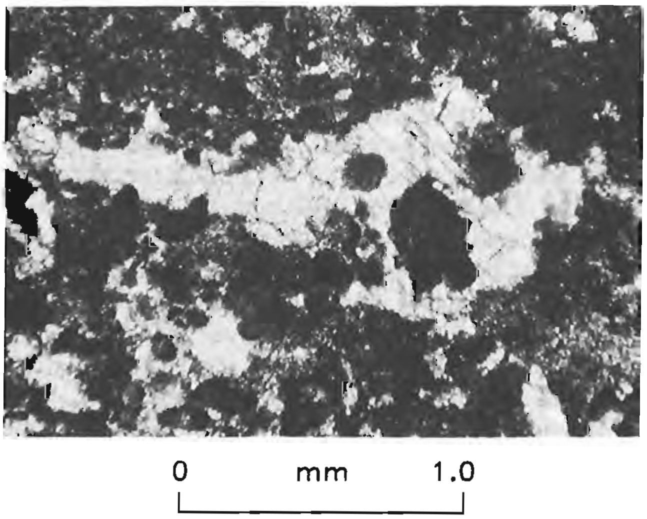


Figure 45. *Photomicrograph (ordinary light) of fenestral structure in peloidal packstone/wackestone of the Eleanor River Formation, massive carbonate facies, Ella Bay 4-9 section. Fenestrae are filled with blocky calcite (spar). ISPG photo. 2260-14.*

Organic metamorphism

Four conodont collections from the Ella Bay 4-9 section have Colour Alteration Index values of 5 or 5+ (Nowlan, Appendix 3B, C-75438, C-75439, C-75442, C-75443).

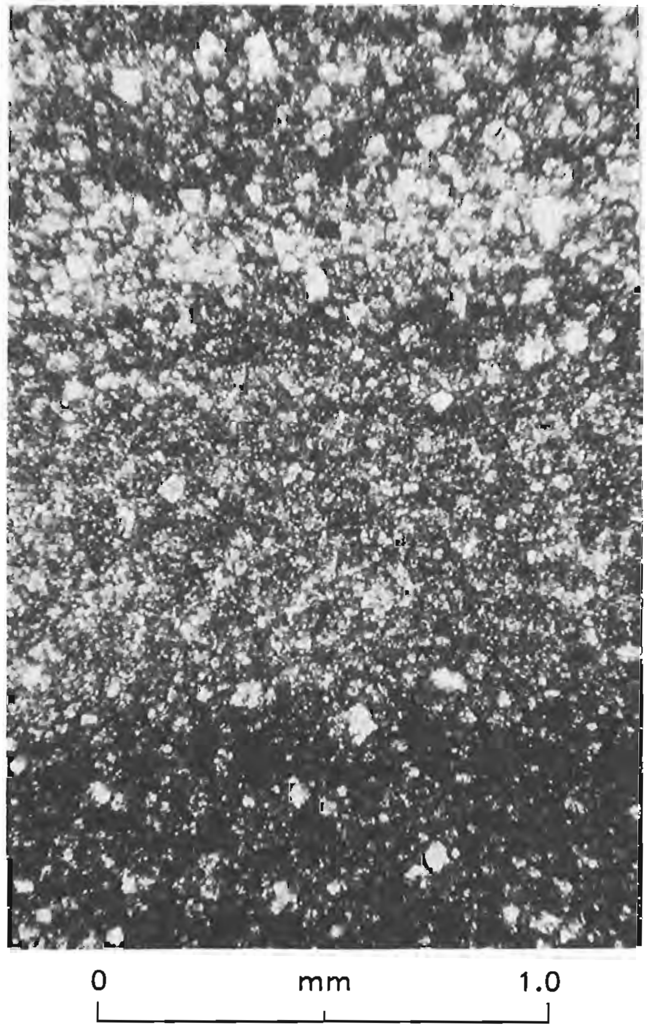


Figure 46. *Photomicrograph (ordinary light) of lamination in impure dolostone of the Eleanor River Formation, Ella Bay 4-9 section. Lamination is due to vertical variation in concentration of carbonaceous matter, siliciclastic silt and very fine grained sand, calcite/dolomite ratio, and crystal size of dolomite (rhombs). ISPG photo. 2260-8.*

Mode of origin

Inferences about the origin of the Ninnis Glacier Formation (see above) are applicable also to the Eleanor River Formation. The massive carbonate facies (except for the stromatolitic limestone) was deposited in shallow subtidal environments and the flat-laminated carbonate facies in deeper subtidal environments (below wave base) that formed part of a large intrashelf basin, barred on the northwest by the Bulleys Lump Formation. The dolomite in the laminated facies probably formed by penecontemporaneous replacement. (See footnote, p. 59.)

Age and correlation

Regional relations (Thorsteinsson and Mayr, 1987) indicate that the Eleanor River Formation is correlative with the combined Nygard Bay, Canyon Elv, and Nunatami formations of Washington Land. The last three formations together range in age from late Tremadoc (middle of Fauna D) to middle Arenig (middle of Fauna 1) (P. Smith, pers. comm., 1987).

In the study area, collection C-75439, from beds 21 to 24 m above the base of the formation, is typical of Fauna D, but some elements range into Fauna E (Nowlan, Appendix 3B). Collections C-75442 and C-75443 combined, 166.5 to 170 m above the base of the formation, are indicative of Fauna E (early Arenig). Within the area studied, the Eleanor River Formation, as mentioned, is correlative with the lower part of member B of the Bulleys Lump Formation.

Units 6 to 10 (233 m) of Norford's (1966) Judge Daly River section are tentatively assigned to the Eleanor River Formation. These strata yielded a trilobite questionably identified as *Bathyurus* sp., which also occurs in the Eleanor River Formation of central Ellesmere Island (Kerr, 1968), as well as the longer ranging gastropod *Maclurites* sp.

BAY FIORD FORMATION (CORNWALLIS GROUP)

The Bay Fiord Formation, a recessive unit lying conformably between the more resistant Eleanor River and Thumb Mountain formations, was established by Kerr (1967b, 1968) with a type section northeast of Irene Bay in central Ellesmere Island. The formation, widely distributed from east-central Ellesmere Island to central Melville Island, consists of thinly interstratified dolostone, limestone, and mudrock, with evaporites in the centre of its distributional area. Kerr recognized that the Bay Fiord Formation was identical with the lower part of the Cornwallis Formation, established by Thorsteinsson (1958) on the north tip of Cornwallis Island and subsequently extended to Ellesmere Island (Thorsteinsson, 1963). Kerr also recognized that the middle and upper parts of the Cornwallis Formation corresponded to two distinct and widely distributed formations, named by him the Thumb Mountain and Irene Bay formations (Kerr, 1967b, 1968). Accordingly, he redefined the Cornwallis Formation as a group consisting of the three formations mentioned. The Cornwallis Group, although retained for historical reasons, is not a natural entity: considering both lithology and regional setting, the Bay Fiord Formation is closely related to the Eleanor River and Baumann Fiord formations, and the Thumb Mountain and Irene Bay formations are related to the Allen Bay Formation.

Distribution, thickness, and contact relations

The formation underlies a narrow belt on the southeastern limb of the Ninnis Glacier Syncline. Photogrammetry indicates a thickness of about 400 m at the Ella Bay 4-10 section. It lies between the Eleanor River and Thumb Mountain formations, and both contacts appear to be conformable, although the upper contact is sharp.

Lithology

The Bay Fiord Formation is divisible into three major units, and its rocks can be assigned to two lithofacies: a massive carbonate facies (MC) and a flat-laminated dolostone facies (FLD). The thicknesses of the lower and upper units have been measured by photogrammetry, resulting in some uncertainty; the thickness of the middle unit has been measured on the ground. The lower unit, 142.5 m thick and recessive, consists mostly of flat-laminated dolostone (FLD) with a few interbedded massive carbonate beds (MC) that are generally a few decimetres to about 1.5 m thick, but are up to 6 m thick in the lower part of the unit. The middle, relatively resistant unit, 47.5 m thick, consists mainly of the massive carbonate facies (MC) with minor proportions of the flat-laminated dolostone facies (FLD). The upper unit, 210 m thick and recessive, is dominated by flat-laminated dolostone (FLD), but contains a significant proportion of massive carbonates (MC) in the upper part.

The *massive carbonate facies (MC)* comprises nonlaminated limestone and dolostone units no less than a few decimetres thick. Rare fenestrae are the only sedimentary structures recorded.

The limestones vary in colour from medium light grey to medium dark grey and are predominantly medium grey. Most are lime mudstone or peloidal packstone/wackestone, but minor amounts of wackestone and grainstone also are present. The framework of the wackestones and grainstones consists of skeletal fragments, peloids, coated grains, and intraclasts. Identifiable skeletal materials are fragments of ostracodes, gastropods, trilobites(?), and pelecypods. The rocks contain variable amounts of dolomite, mainly microcrystalline to very fine crystalline (9 and 31 per cent in two analyzed specimens; Appendix 2, Table 31) and a few per cent or less of quartz and minor feldspar.

The dolostones are medium dark grey to predominantly medium light grey. They are microcrystalline to very fine crystalline and in part calcareous. Some specimens contain lime mud and peloids, others dolomitized ghosts of intraclasts.

The *flat-laminated dolostone facies (FLD)* consists mainly of dolostone with very minor amounts of dolomitic siltstone and shows flat or undulating lamination with rare crosslamination on a millimetre scale. Most rocks are medium dark grey or medium grey. The dolomite is mainly microcrystalline, commonly in the 4 to 20 μm range, but has an overall range from cryptocrystalline to medium crystalline. Twelve specimens analyzed by X-ray diffraction have an average composition of: dolomite, 82 per cent; calcite, 8 per cent; quartz, 7 per cent; and feldspar, 2 per cent; with trace amounts of mica and chlorite (Appendix 2, Table 32). The calcite occurs as lime mud and in pellets. The lamination reflects vertical variations in the concentration of carbonaceous matter and siliciclastic impurities and in the crystal size of the dolomite (Figs. 47, 48).

Organic metamorphism

Two conodont collections from the Ella Bay 4-10 section have a Colour Alteration Index of 5 (Nowlan, Appendix 3B, C-75444 and C-75445).

Mode of origin

The laminites of the Bay Fiord Formation originated in essentially the same kind of setting as those of the Eleanor River Formation, and of the upper part of the Ninnis Glacier Formation at the Ella Bay 4-8 section: a large intrashelf basin, restricted on the northwest by the Bulleys Lump Formation. They differ, however, by having a higher dolomite/calcite ratio. This may be due to a higher salinity in the basin as the dolomite is largely or entirely of penecontemporaneous origin. In addition, the Bay Fiord Formation differs from the Eleanor River by containing a smaller poportion of shallow subtidal strata — a phenomenon observed throughout the Arctic Islands and indicative of a slightly higher stand of sea level than during deposition of the Eleanor River Formation. (See footnote, p. 59.)

Age and correlation

The Bay Fiord Formation is correlative with the Cape Webster Formation of Washington Land (Thorsteinsson and Mayr, 1987), and the latter ranges in age from late Arenig to early Caradoc (earliest to latest Whiterockian, including the Chazyan; Fauna 1 to *P. sweeti* Zone).

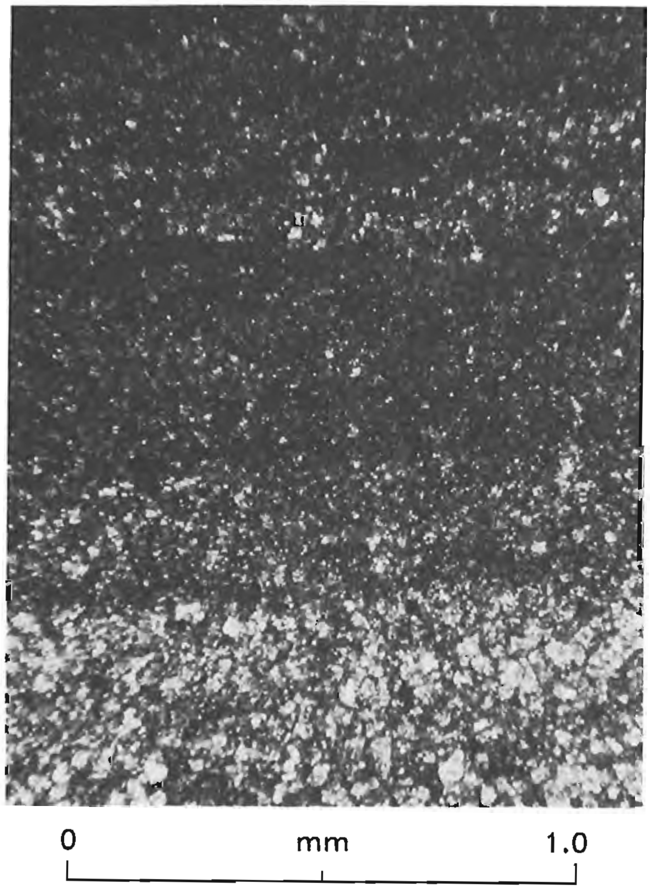


Figure 47. Photomicrograph (ordinary light) of flat lamination in dolostone of the Bay Fiord Formation, Ella Bay 4-10 section. Lamination is caused by vertical variations in the content of carbonaceous matter and in the crystal size of the dolomite. ISPG photo. 2260-10.

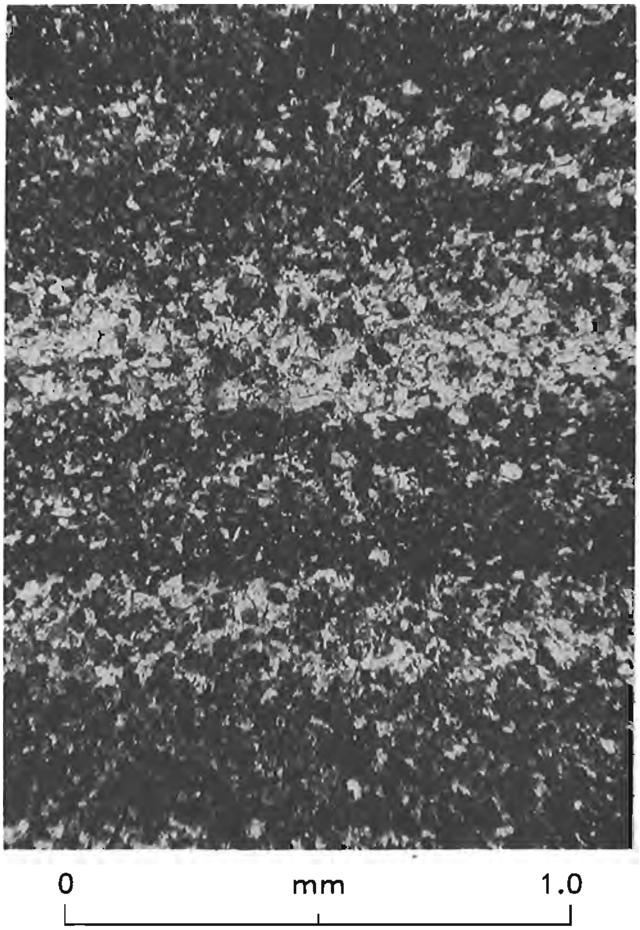


Figure 48. Photomicrograph (ordinary light) of interlaminated, coarse grained, dolomitic siltstone (light) and dolostone of the Bay Fiord Formation, Ella Bay 4-10 section. ISPG photo. 2260-2.

The only diagnostic conodont obtained on Judge Daly Promontory, occurring in the lower part of the formation, is Whiterockian in age (Nowlan, Appendix 3B, C-75444).

Units 11 to 17 (428 m) of Norford's (1966) Judge Daly River section, forming the upper part of his Formation A, are here tentatively assigned to the Bay Fiord Formation. No diagnostic fossils were found in these strata.

BULLEYS LUMP FORMATION (new formation)

The name, Bulleys Lump Formation, is here given to a unit of carbonate and minor siliciclastic sediments lying between the Ninnis Glacier and Thumb Mountain formations on the northwestern margin of the Franklinian Shelf. The type section is on the northwestern limb of the Ninnis Glacier Syncline (Ella Bay 3-3 section; Fig. 49). The formation is correlative with a succession on the southeastern limb of the Ninnis Glacier Syncline that comprises the upper part of the Ninnis Glacier Formation and the Eleanor River and Baumann Fiord formations, but differs from these units in lithology and inferred depositional environment.

Distribution, thickness, and contact relations

The formation is exposed in two southwest-trending belts on the southeast side of Ella Bay and upper Archer Fiord — a relatively broad eastern belt, representing the entire formation and containing the type section, and a narrow western belt representing uppermost parts only. At the type section the formation is about 1.6 km thick, based on photogrammetry, and lies conformably between the Ninnis Glacier and Thumb Mountain formations. Farther southwest in the eastern belt, the Bulleys Lump Formation is overlain by the Danish River Formation with a diachronous contact, interpreted as a submarine unconformity (see below, Stratigraphic Synthesis). The western belt is a westward thinning wedge, lying between the Hazen and Danish River formations (Figs. 1, 9), and the lower contact is possibly faulted (see below).

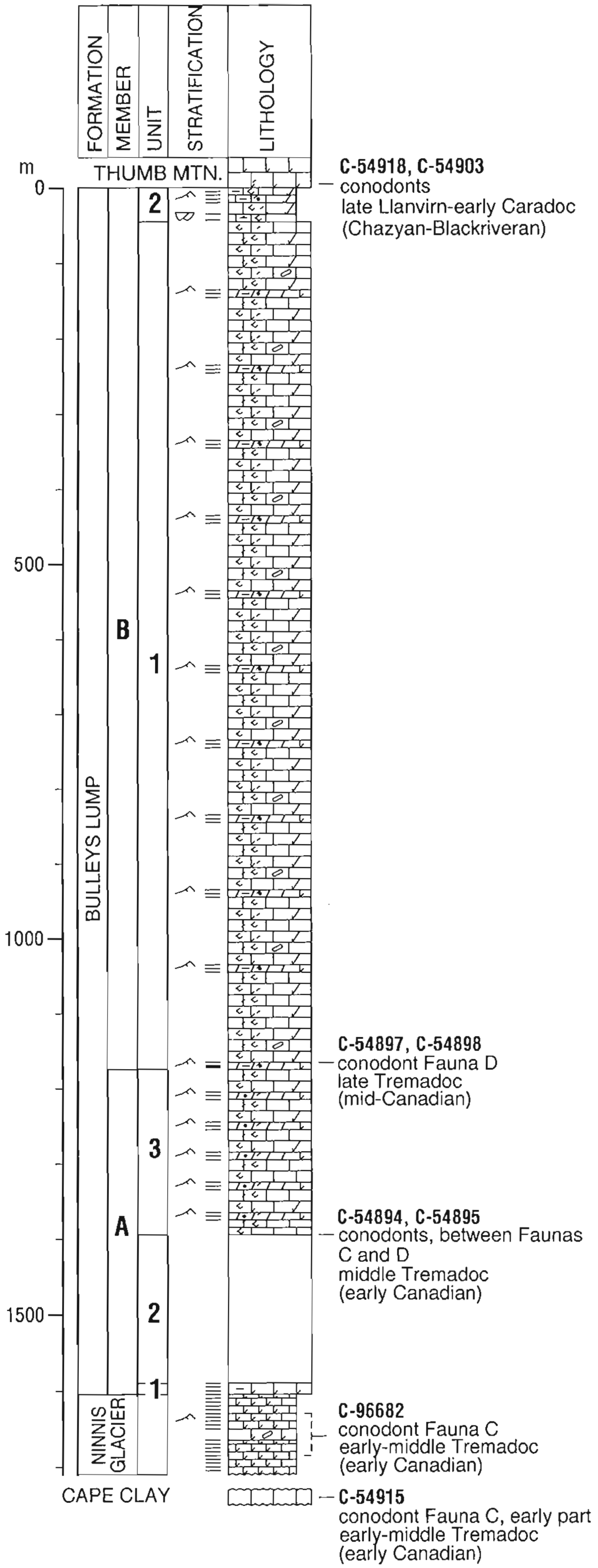
Lithology

At the type section, the formation is divisible into two members, informally referred to as members A and B.

Member A

Member A is about 440 m thick at the type section based on a photogrammetric determination.

The lower 17 m consist of variably dolomitic, silty and very fine grained sandy, medium grey limestone with an undulating lamination produced by stylolites and solution zones (characterized by pinching and swelling concentrations of noncalcareous materials). Bioclastic material in lime mudstones and wackestones was derived mainly from trilobites, dasycladacean algae, and echinoderms. Predominantly microcrystalline dolomite is concentrated in solution zones and burrows. Seven samples, analyzed by X-ray diffraction (Appendix 2, Table 33), have an average composition of: calcite, 66 per cent; dolomite, 17 per cent; quartz, 14 per cent; and K-feldspar, 3 per cent; with less than 1 per cent of plagioclase.



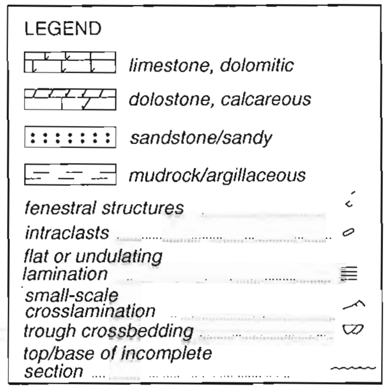


Figure 49. Generalized stratigraphy of the Ninnis Glacier and Bulleys Lump formations, Ella Bay 3 section.

This unit is overlain by 192 m of rubble and talus of limestone and dolostone.

The upper 217 m are divisible into a massive carbonate facies (MC) and a flat-laminated and crosslaminated carbonate facies (FXC). The following summary description of the two facies is based on statistical evaluation of five, very short, incomplete sections with a total thickness of 34 m, that have been measured bed by bed. According to these sections, the massive lithofacies (MC) makes up about two thirds of the unit, the remainder consisting of the flat-laminated and crosslaminated lithofacies (FXC).

The *massive carbonate facies (MC)* occurs in units that range in thickness from 0.3 to 7.3 m and average 1.6 m. It consists mostly of limestone with minor amounts of intraformational conglomerate and dolostone. Most rocks either are massive or have parting surfaces, spaced 0.2 to 1 m, but some strata show a vague, crinkled lamination.

The limestones, mainly medium grey, but varying from medium light grey to medium dark grey, are divisible into three types: 1) peloidal grainstone, commonly intraclastic (Fig. 50) with some skeletal fragments (predominant); 2) peloidal packstone/wackestone (common); and 3) lime mudstone (rare). The peloids of the packstone/wackestone are mainly of silt to fine sand grade and more uniform in size and shape than those of the grainstone. They are separated by relatively clear calcite crystals, about 20 to 40 μm in diameter, which are smaller and less abundant than the calcite crystals (spar) of the grainstones. It is difficult to estimate how much of this material is cement and how much is recrystallized sediment, but the vagueness of the boundaries between peloids and sparry calcite suggests that recrystallization was pervasive. Fenestral structures (Fig. 51), commonly irregular, but also tubular, occur in some pelletal packstones and lime mudstones. They are similar to those in member B but less abundant.

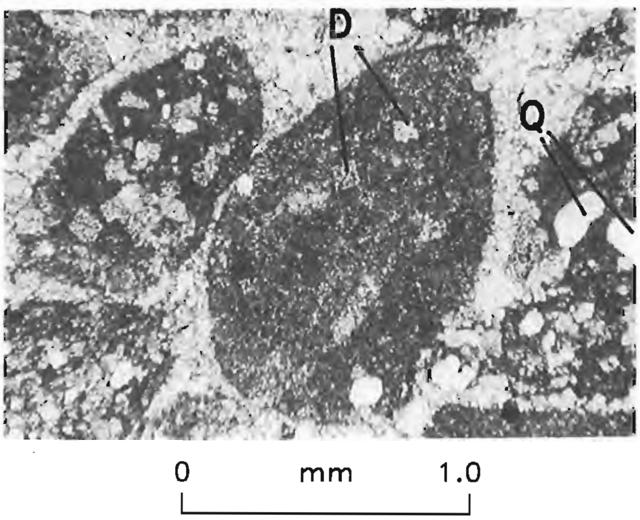


Figure 50. Photomicrograph (ordinary light) of intraclastic grainstone within pebble conglomerate of the Bulleys Lump Formation, member A. Coated grains of lime mudstone (with vaguely peloidal structure) contain turbid euhedral dolomite (D) and rounded quartz (Q). Cement is clear calcite. ISPG photo. 2260-31.

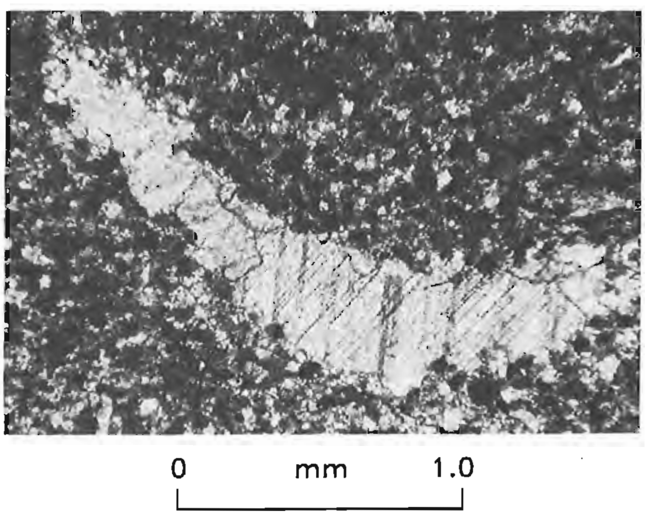


Figure 51. Photomicrograph (ordinary light) of peloidal packstone with fenestral structure in the Bulleys Lump Formation, member A. Relatively light areas between dark peloids are microcrystalline calcite and euhedral dolomite. ISPG photo. 2260-50.

Most limestones contain minor amounts of dolomite and siliciclastic material. The dolomite occurs as scattered rhombohedra, microcrystalline to very fine crystalline in size grade. Seven X-ray diffraction analyses indicate an average dolomite content of 4 per cent (Appendix 2, Table 34). The siliciclastic material is of silt to medium sand grade and consists of quartz (mean content 2%) with trace amounts of feldspar and phyllosilicates. Fenestral structures are fairly common, being present in 7 out of 18 specimens. Most structures are irregular, but some are laminar or tubular (terminology of Grover and Read, 1978). Bioturbation also is fairly common.

The flat-pebble conglomerates are similar to the intraclastic peloidal grainstones, but contain pebbles up to 2.5 cm in diameter. The latter consist mainly of limestone and dolostone with lesser amounts of calcareous sandstone (for composition see Appendix 2, Table 35). Units composed of interbedded flat-pebble conglomerate and intraclastic grainstone are up to 1.5 m thick.

The *flat-laminated and crosslaminated carbonate facies (FXC)* forms units that range in thickness from 0.35 to 1.45 m and average 0.85 m. This facies is composed mainly of dolostone, which makes up about nine tenths of the samples, and of small amounts of pure or sandy lime mudstone. Stratification is characterized by well developed flat or undulating lamination and small-scale crosslamination (Fig. 52).

The dolostone varies from light to medium dark grey, but is mainly medium light grey. The rock is microcrystalline to very fine crystalline, rarely fine crystalline. Siliciclastic material is of silt to very fine sand grade with small proportions of fine grained sand. Eight analyzed specimens contain on average 15 per cent quartz and 1 per cent each of plagioclase and K-feldspar, with trace amounts of white mica and chlorite (Appendix 2, Table 36). Calcite averages 11 per cent and makes up 14 per cent of the total carbonate fraction.

The lamination is caused by vertical variations in the concentration of carbonaceous or siliciclastic impurities or in the crystal size of the dolomite. A small proportion of the laminae show graded bedding and have erosional bases.

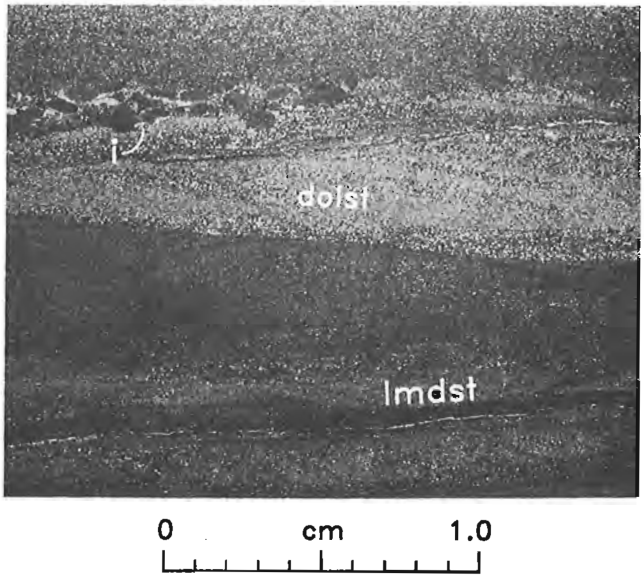


Figure 52. Photomicrograph (ordinary light) of dolostone (dolst) and lime mudstone (lmdst), showing flat lamination and low-angle crosslamination with one layer of lime mudstone intraclasts (i); Bulleys Lump Formation, member A. ISPG photo. 2260-165.

Member B at type section

Member B, 1177 m thick at the type section based on photogrammetry, is composed of the same two lithofacies as the upper unit of member A, but in a different proportion. It is divisible into two major units of unequal thickness.

The *lower unit* is 1133 m thick based on photogrammetry. Extrapolation from six partial sections (total thickness 557 m) indicates that the massive carbonate facies (MC) constitutes nine tenths of this unit and the flat-laminated and crosslaminated lithofacies (FXC) about one tenth.

In the partial sections studied, the massive carbonate facies (MC) occurs in units that range in thickness from 0.2 m to 45 m (mean 11 m, standard deviation 14 m). It is composed mostly of limestone with probably no more than 10 per cent dolostone. The limestone commonly is massive, with or without interbeds of dolostone, and has parting surfaces, spaced from a few centimetres to about 20 cm.

About two thirds of the samples are peloidal packstone/wackestone (Fig. 53); the remainder are peloidal grainstone (Fig. 54), lime mudstone, or calcareous intraformational conglomerate. Coated grains and skeletal fragments are more common in these rocks than in member A. The skeletal material was derived mainly from ostracodes and trilobites and to a lesser extent from gastropods, echinoderms, and dasycladacean algae (Fig. 55).

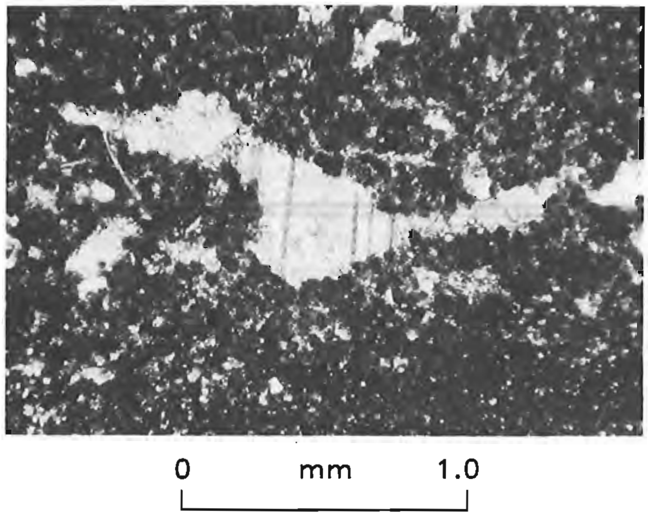


Figure 53. Photomicrograph (ordinary light) of peloidal packstone with fenestral structures in the Bulleys Lump Formation, member B. Relatively light areas between dark peloids are microcrystalline calcite and dolomite and rare quartz silt. ISPG photo. 2260-38.

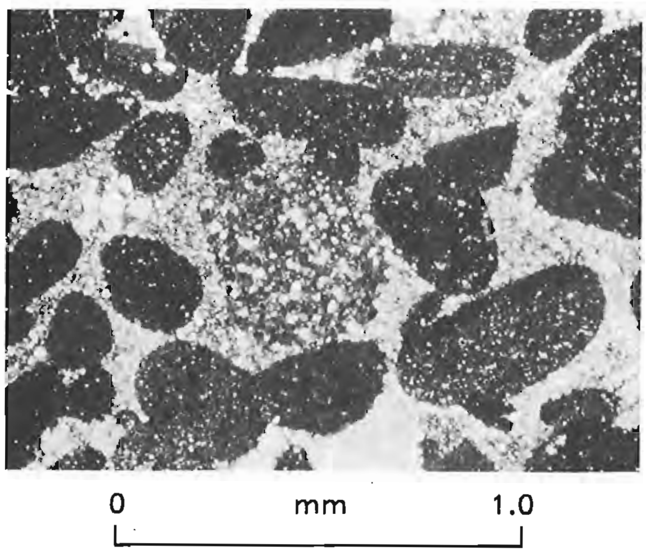


Figure 54. Photomicrograph (ordinary light) of grainstone in the Bulleys Lump Formation (probably the lower part of member B). Grains consist of lime mudstone; peloidal packstone, in part silty and very fine grained sandy; and fine to medium grained sandstone. ISPG photo. 2032-75.

Dolomite occurs as scattered rhombohedra, mostly microcrystalline to very fine crystalline, rarely fine or medium crystalline, that constitute, on average, about 5 per cent of the rock (Appendix 2, Table 37).

Siliciclastic impurities also are sparse, averaging about 5 per cent in the diffractograms. They are of silt and very fine sand grade and consist mostly of quartz, with or without small amounts of K-feldspar, plagioclase, white mica, and chlorite.

Fenestral structures were seen in about three quarters of the samples. Most are irregular (Figs. 53, 56), some are laminar, and a few are tubular. Most fenestral structures have sharp boundaries and contain relatively large and clear calcite cystals or generations of crystals, that appear to be void fillings.

Units composed of the flat-laminated and cross-laminated carbonate facies (FXC) are 0.2 to 9.1 m thick (mean 1.5 m, standard deviation 1.9 m) and consist mostly of dolostone (four fifths of the samples), lesser amounts of limestone (peloidal packstone/wackestone, peloidal grainstone, and lime mudstone) and very small amounts of mudrock and very fine grained sandstone that is calcareous and dolomitic. The crosslamination generally is of very small scale, but troughs up to 40 cm long and 20 cm deep were seen.

The content of siliciclastic impurities in the dolostones and limestones (mean values are 12% and 10%, respectively; Appendix 2, Tables 39, 40) is slightly larger than in the massive facies (5% and 5%, Appendix 2, Tables 37, 38), but size grade (silt and very fine grained sand) and composition (mainly quartz, minor K-feldspar, very small amounts of plagioclase, white mica, and chlorite) are comparable. The calcite content of the dolostones averages 17 per cent and the dolomite content of the limestones, 6 per cent.

Fenestral structures are present in some limestones of this facies, and the laminar type is more common than in the massive facies. Relics of fenestral structures are also apparent in some dolostones. Fossil fragments, mainly ostracodes, are rare and are restricted to the limestones.

The *upper unit* was recognized only at the Ella Bay 4-3 section and probably is a facies of small areal extent. It is 44 m thick and contains 58 per cent strata that are predominantly flat-laminated and to a lesser extent crosslaminated (Lithofacies FLC), and 27 per cent nonlaminated strata (lithofacies MC); the remaining 15 per cent of the section is covered.

The flat-laminated and crosslaminated lithofacies (FXC) in this unit — in contrast to other parts of the formation — has a relatively large limestone content (64%). The balance consists of dolostone (26%; Appendix 2, Table 41), mudrock (7%), and very small amounts of sandstone. Dolomitic sets of strata (mean thickness 0.9 m) and argillaceous sets (0.9 m) are thinner than calcareous sets (2.7 m).

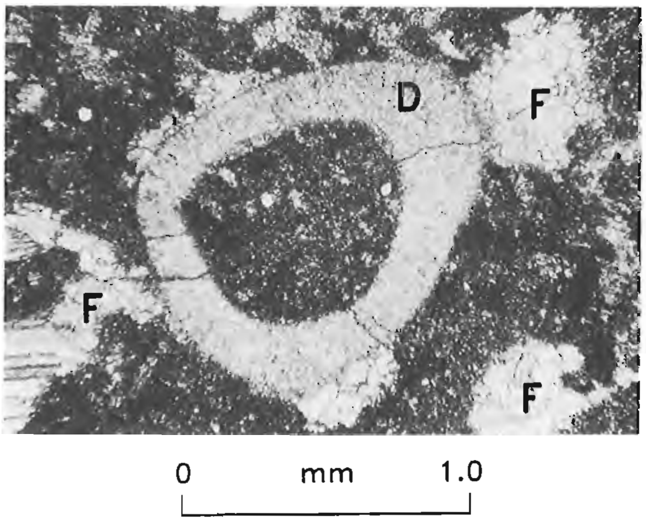


Figure 55. *Photomicrograph (ordinary light) of dasycladacean alga (D) in peloidal packstone with fenestral structure (F); Bulleys Lump Formation, member B. ISPG photo. 2260-35.*

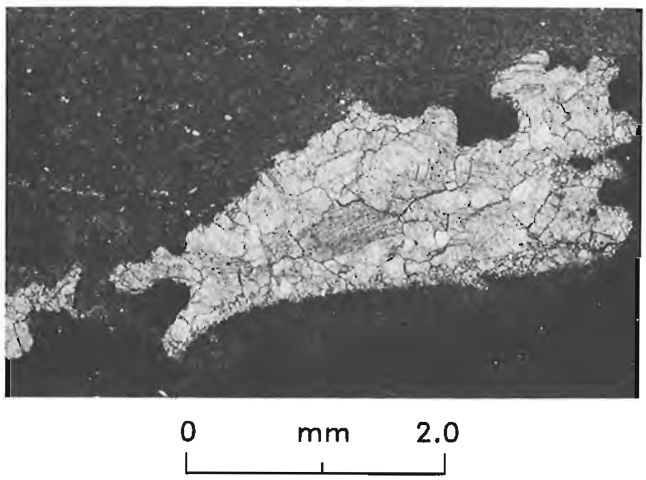


Figure 56. *Photomicrograph (ordinary light) of fenestral structures in silty lime mudstone of the Bulleys Lump Formation, member B. ISPG photo. 2260-167.*

The massive carbonate facies (MC) comprises two units of limestone (0.8 and 5.3 m thick) and one unit of dolostone (0.7 m).

The limestones of both lithofacies are classified as peloidal packstone/wackestone, peloidal grainstone, and lime mudstone. Rare fossil fragments represent ostracodes and echinoderms(?). Fenestral structures and recrystallized calcite are common. Seven analyzed specimens of limestone contain only about 2 per cent of siliciclastic material and no detectable dolomite (Appendix 2, Table 43), but one specimen of silty limestone contained 14 per cent of silicilastic material (Appendix 2, Table 42).

The mudrocks are coarse grained, in part sandy, and highly dolomitic.

Western outcrop belt

At the Ella Bay 2-North section, the belt appears to contain roughly 100 m of strata representing the uppermost part of member B (see below, Age and correlation). The thickness, difficult to determine because of the massive character of the rocks, appears to increase to the south. The unit thins southwest of the Ella Bay 2-North section and pinches out southeast of the head of Ella Bay. In contrast to the eastern outcrop belt, the strata here are tightly folded and sheared.

At the Ella Bay 2-North section, member B consists mostly of medium dark grey, rather pure limestone that is difficult to classify texturally because of recrystallization. However, the rocks contain recognizable intraclasts, coated grains, and fragments of gastropods, bryozoans, echinoderms, ostracodes, trilobites, and algae. Bryozoan boundstone(?) with some isopachaous bladed calcite cement of marine origin is present in the uppermost part of the formation at the Ella Bay 2-East section (Fig. 57). This section also contains silty limestone and medium dark grey, calcareous and dolomitic mudrock reminiscent of the Hazen and Ninnis Glacier formations (Appendix 2, Tables 43–45). Aggregates of radiating fibrous calcite, a few centimetres in diameter, were observed in the mudrock in one stratum.

Organic metamorphism

Three conodont collections from the northwestern outcrop belt have a Colour Alteration Index of 4.5 (Nowlan, Appendix 3B, C-74617, C-94383; Nowlan and Tipnis, Appendix 3B, C-74618). One collection from the northwestern outcrop belt and four from the southeastern outcrop belt have a Colour Alteration Index of 5 (Nowlan, Appendix 3B, C-54894, C-54895, C-54897, C-54898, C-54921).

Mode of origin

Massive carbonate facies

The most common and characteristic rock type of the massive carbonate facies is a peloidal packstone/wackestone that contains plentiful fenestral structures. The origin of this rock type is problematic. Peloidal packstone/wackestone is abundant throughout the Cambrian to Silurian carbonate succession in the area southwest of Ella Bay. Fenestral structures also occur in the Scoresby Bay Formation and lower Thumb

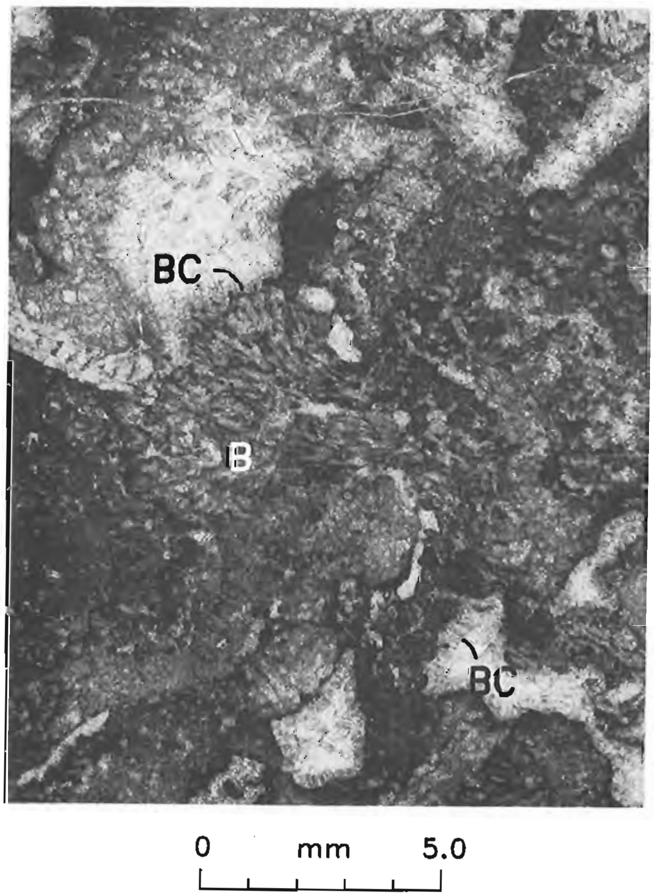


Figure 57. Photomicrograph (ordinary light) of bryozoan (B) boundstone(?) with cavities, lined with isopachous, bladed calcite (BC) of marine origin and filled with equant, clear calcite; Bulleys Lump Formation, member B, Ella Bay 2-East section, 31.2 m. ISPG photo. 2032-110.

Mountain Formation, but are less common in these formations than in the Bulleys Lump. In the past, relatively small peloids of uniform size and shape were commonly interpreted as fecal pellets (e.g., Folk, 1959). Studies of both Recent and ancient sediments showed that fenestral (or bird's-eye structures) occur "preferentially in intertidal and supratidal environments" (Flügel, 1982). There they are formed by a variety of processes — drying and shrinking, burrowing, or as original open spaces within algal mats (Shinn, 1968; Grover and Read, 1978; Flügel, 1982).

However, in recent years it has become apparent that peloids are formed by bacteria, not only in nonmarine settings (Chafetz and Folk, 1984), but also in marine environments (Chafetz, 1986). Moreover, it now is increasingly accepted that microbial precipitation has played an important role in the genesis of stromatolitic and thrombolitic reefs and mud-mounds (Kennard and James, 1986; Burne and Moore, 1987) and that microbial peloids commonly are associated with these structures (Tsien, 1985; Sun and Wright, 1989; Reid and Browne, 1991). Calcite-filled voids of different types occur in stromatolites and thrombolites.

In the Arctic Islands these concepts were first applied by T.A. de Freitas (1991) to Silurian mud-mounds at Cañon Fiord and Trold Fiord. The mounds are composed mainly of peloidal micrites with common fenestral structures, but include a variety of other rock types. The occurrence of the fenestral peloidal micrites within shallowing-upward sequences, above pentamerid rudstones and below tabular stromatoporid boundstones, suggests deposition in subtidal settings between storm and fairweather wave base.

Application of the same interpretation to the peloidal packstone/wackestone of the Bulleys Lump Formation is attractive because the Bulleys Lump Formation formed in a setting similar to that of the (younger) mud-mound at Cañon Fiord (see below). The origin and environmental significance of the fenestral structures remains uncertain, but can perhaps be resolved by detailed studies of the cement in them. Available, rather indirect evidence suggests that they were cemented by calcite at shallow depth (Fig. 58).

The common occurrence of grainstone, especially of intraclastic grainstone and associated flat-pebble conglomerate, indicates that part of this lithofacies was deposited in high energy settings where lime mud was winnowed by currents and/or waves.

Flat-laminated and crosslaminated carbonate facies

Current and/or wave activity in intertidal or shallow subtidal settings is indicated by the trough cross-lamination. On the other hand, some strata showing flat lamination and undulating lamination may represent stromatolites of high intertidal or supratidal origin, and laminar fenestrae associated with such strata may be original voids or may have formed by the decay of microbial mats. The fact that dolostone is predominant in this facies, but rare in the massive lithofacies, supports the view that this lithofacies is of a shallower, peritidal origin. Penecontemporaneous dolomitization is known to occur on modern tidal flats (Shinn et al., 1969; Shinn, 1982).

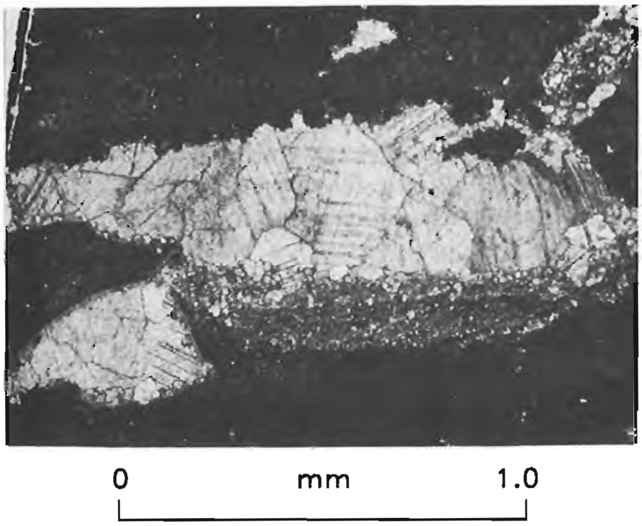


Figure 58. Photomicrograph (ordinary light) showing calcite cement in voids formed by trilobite fragment and fenestral structure in peloidal packstone/wackestone of the Thumb Mountain Formation, Ella Bay 3-4 section, 15 m. (Peloidal structure is indistinct on the photograph.) Preservation of the concave shape of the trilobite fragment is attributed to filling of the void below it with calcite (or possibly strong cementation of the enclosing pelletal packstone/grainstone) at very shallow depth. Formation of the fenestral structure was preceded by cementation of the peloidal packstone/wackestone and was followed by: 1) deposition of (now recrystallized) geopetal sediment, and 2) void filling by calcite, probably also at shallow depth. ISPG photo. 2032-76.

Conodont evidence

Conodont collections from all other units of the shelf succession, and most from the Bulleys Lump Formation, are characteristic of the North American Midcontinent Province. It is noteworthy that elements of the North Atlantic Faunal Province occur in three samples — alone in one (C-74738) and mixed with Midcontinent Province elements in three others (C-94383, C-74618, and 194904). The "North Atlantic" elements indicate the proximity of cool, normal marine waters in outer shelf or deeper settings — rather than a location in the North Atlantic region (Nowlan, Appendix 3B).

Synthesis

The Bulleys Lump Formation probably was deposited in intertidal to shallow subtidal environments and reflects frequent changes of relative sea level. It differs from correlative units to the southeast (Ninnis Glacier, Eleanor River, and Bay Fiord formations) and to the northwest (parts of Hazen Formation, see below) in the absence of medium to dark grey laminated strata deposited below the photic zone. The Bulleys Lump Formation thus represents a carbonate buildup (or mud-mound) on the northwestern margin of the Franklinian Shelf, bordered by the Deep Water Basin on the northwest and by an extensive intrashelf basin on the southeast (see Chapter 5, Stratigraphic synthesis). The hypothesis that the abundant peloidal packstone/wackestones are of microbial origin, as they are in the Silurian mud-mound at Cañon Fiord (T.A. de Freitas, 1991) provides an attractive explanation for the ultimate origin of the carbonates in this setting and also for the early consolidation of its northwestern slope (see Chapter 5, Stratigraphic synthesis).

Age and correlation

Type section

The underlying Ninnis Glacier Formation, as mentioned, has yielded conodonts of Fauna C, of early to middle Tremadoc age. Conodonts from strata 212 to 215 m above the base of member A are transitional between Faunas C and D and hence middle Tremadoc in age (Nowlan, Appendix 3B, C-54894 and C-54895). They include new taxa, also present in the Baumann Fiord Formation.

Conodonts from strata 13 to 14 m above the base of member B probably represent Fauna D of late Tremadoc age (Nowlan, Appendix 3B, C-54897 and C-54898). Overlying strata of the lowermost Thumb Mountain Formation (see below) have yielded conodonts of undifferentiated Chazyan or Blackriverian age and regional relations suggest that they are slightly above the Chazyan-Blackriverian (Llandeilo-Caradoc) boundary.

Undivided Bulleys Lump Formation southwest of type section

On the hill southwest of the type section (vicinity of cross-section B-B′, Fig. 1), the formation has not been subdivided because of insufficient control. Conodont-bearing samples were collected at three localities and the structural setting indicates that collection C-74749 from locality F2 is the oldest. It represents conodont Fauna D of late Tremadoc age (Barnes, Appendix B), which occurs in the Baumann Fiord Formation and lower Eleanor River Formation. Collections C-74750 and C-74751 fall into the same broad interval (Barnes, Appendix 3B), although the structural setting suggests that they are slightly younger. A collection from locality F4 (C-74738), higher in the section, has yielded a middle Arenig to middle Llanvirn age (Barnes, Appendix 3B).

Western outcrop belt

A collection from the lower two metres of the preserved part of the formation south of the Ella Bay 2-South section, is of Whiterockian, possibly late Whiterockian age (Nowlan, Appendix 3B, C-94383). A late Whiterockian (Llanvirn) age was also obtained for a collection of unspecified stratigraphic position from locality F15 (Fig. 1), some 4 km to the west-southwest of the Ella Bay 2-South section (C-194904). Two collections were made from the upper 20 m at the Ella Bay 2-East section. The lower one (C-74617) is probably Llandeilo in age, although it may be slightly older or younger. The upper one probably is mixed as it contains elements of late Llanvirn-Llandeilo age, as well as a new subspecies of probable early Caradoc age that has been reported from the lower Thumb Mountain Formation (C-74618, Nowlan, Appendix 3B).

A collection from locality F5 (Fig. 1) farther southwest, is of unspecified Arenig to Caradoc age (Nowlan, Appendix 3B, C-54921).

Summary

Member A is probably limited to the middle Tremadoc and is approximately correlative with the Baumann Fiord Formation and also with upper parts of the Ninnis Glacier Formation at the Ella Bay 4-8 section. Member B extends from late Tremadoc approximately to the Llandeilo–Caradoc boundary and is correlative with the combined Eleanor River and Bay Fiord formations. The occurrence of early Caradoc conodonts, reported so far only from the lower Thumb Mountain Formation, at the top of the Ella Bay 2 section in the western outcrop belt, poses a problem. It is possible that the western outcrop belt includes equivalents of the lower Thumb Mountain Formation; the contact between the two formations would be difficult to recognize in these recrystallized rocks. Alternatively, the age range of the conodonts may extend into the late Llandeilo.

THUMB MOUNTAIN FORMATION (CORNWALLIS GROUP)

The name, Thumb Mountain Formation, was given by Kerr (1967b, 1968) to a bluff-forming unit of limestone that lies stratigraphically between the more recessive Bay Fiord and Irene Bay formations. It is the second of three formations included in the Cornwallis Group. The type section is northeast of the head of Irene Bay in central Ellesmere Island.

Distribution, thickness, and contact relations

The Thumb Mountain Formation underlies two narrow belts on the northwestern and southeastern flanks of the Ninnis Glacier Syncline. Photogrammetric determinations indicate a thickness of 404 m on the western flank (Ella Bay 3-4 section) and of perhaps 275 m on the southeastern flank, where the contact with the Irene Bay Formation is concealed (Ella Bay 4-11 section).

Lithology

The Thumb Mountain Formation was studied only at the Ella Bay 3-4 section. There, it consists almost entirely of limestone with very minor amounts of dolostone in the lower part (e.g., at 36.5–36.8 m and at 64–65 m). The limestone is generally massive and varies from light grey to medium dark grey. Most rocks are nearly pure, containing on the average only about 2 per cent of quartz with trace amounts of mica and dolomite (Appendix 2, Table 46), but a few are silty and sandy, containing as much as 28 per cent siliciclastic material; mainly quartz with some feldspar, mica, and chlorite (Table 47).

The limestones are classified as lime mudstone, peloidal packstone/grainstone, and skeletal lime wackestone. Some peloidal packstone/grainstone bedscontain skeletal material, and are in part transitional to lime wackestone and grainstone. The skeletal material was derived mainly from echinoderms, to a lesser extent from trilobites, ostracodes, molluscs (including gastropods) and algae (including dasycladaceans), and to only a minor extent from bryozoans and brachiopods.

The stratigraphic distribution of these rock types is as follows. Samples from the lower 135 m consist mainly of peloidal packstone/grainstone and lime mudstone with smaller amounts of skeletal lime wackestone. In the remainder of the section, peloidal packstone/grainstone with skeletal content is predominant (about 2/3 of samples), with subordinate skeletal lime wackestone (1/7) and minor amounts of peloidal packstone/grainstone and lime mudstone without skeletal fragments.

It appears that fenestral structures of irregular type are fairly common in the lower 130 m (Fig. 58) and sporadic in the middle and upper parts of the formation. However, a fair number of the samples are recrystallized and veined, and in these rocks sparry calcite formed by replacement is difficult to distinguish from sparry calcite in fenestral structures.

Organic metamorphism

Nine conodont collections from the Ella Bay 3-4 and 4-11 sections, or their vicinity, all have a Colour Alteration Index of 5 (Nowlan, Appendix 3B, C-54903, C-54907, C-54908, C-54916, C-54917, C-54918, C-75446, C-75447, C-75451).

Mode of origin

The massive limestones of this formation are generally subtidal in aspect. A gradual increase in water depth probably is indicated by the upward increase in skeletal content and upward decrease in the abundance of fenestral structures.

Age and correlation

The Thumb Mountain Formation has been correlated with the Gonioceras Bay and Troedsson Cliff formations of Washington Land on the basis of stratigraphic setting, lithology, and fossils (Thorsteinsson and Mayr, 1987), and the last two formations (combined) have been dated as early Caradoc (Blackriverian) to early Ashgill (Edenian), using conodonts. Fossils from Judge Daly Promontory are compatible with that assignment, but do not prove it.

Conodonts from the basal strata of the formation at, or near, the Ella Bay 3-4 and 4-11 sections, have been assigned to the early Middle Ordovician, Chazyan or Blackriverian (late Llanvirn to early Caradoc) (Nowlan, Appendix 3B, C-54916, C-54917, C-54918, C-54903). Conodonts from the uppermost 1.5 m are of Middle to Late (probably Middle) Ordovician (Caradoc) age (Nowlan, Appendix 3B, C-54908).

Formation B at the Daly River section (Norford, 1966) probably represents the lower 183 m of the Thumb Mountain Formation. Fossils from the base of the formation, which included the genera *Foerstephyllum* and *Ceraurus* were assigned a Wildernessian to possibly Maysvillian age range. Fossils from the upper part, which included the genera *Ceraurus, Receptaculites, Grewingkia, Catenipora, Calapoecia, Labyrinthites, Paratetradium,* and *Rhabdotetradium* were considered to be Edenian or Maysvillian in age.

IRENE BAY FORMATION (CORNWALLIS GROUP)

The Irene Bay Formation, erected by Kerr (1967b, 1968), is a relatively thin and recessive, greenish weathering unit, composed of thin bedded limestone and minor shale with an abundant and varied "Arctic Ordovician fauna". The formation lies stratigraphically between the resistant Thumb Mountain and Allen Bay formations. It is the upper of three formations making up the Cornwallis Group, and its type section is northeast of Irene Bay in central Ellesmere Island.

The name is here applied to a unit within the Middle Ordovician to Lower Silurian limestone succession that is relatively recessive and rich in shelly fossils. However, in contrast to more typical developments, the formation in this area weathers dark grey (Figs. 119, 120) rather than green, and lacks shale.

Distribution, thickness, and contact relations

Like the Thumb Mountain and Allen Bay formations, the Irene Bay underlies two narrow belts on the southeastern and northwestern limbs of the Ninnis Glacier Syncline, respectively. On the northwestern limb, at the Ella Bay 3-5 section, the Irene Bay Formation is well exposed, 117 m thick, and has conformable contacts with the Thumb Mountain and Allen Bay formations. Photogrammetry indicates a thickness of perhaps 198 m for exposures on the southeastern limb of the syncline, at the Ella Bay 4-12 section, where the contacts are covered.

Lithology

At the Ella Bay 3-5 section, the formation consists of medium dark grey limestone. Relatively recessive units alternate with more resistant units, but there are no marked lithological differences between them. All samples collected are pure limestones, containing only small amounts of quartz silt or sand and very minor amounts of dolomite (Appendix 2, Table 48). The dark colour is due to submicroscopic carbonaceous impurities. The rocks are classified mainly as skeletal lime wackestone, in part transitional to lime mudstone and packstone (both with skeletal content). The skeletal material was derived mainly from echinoderms, trilobites, algae (including dasycladaceans), ostracodes, and molluscs (including gastropods), and to a lesser extent from brachiopods. The most abundant macrofossils are chain corals, but solitary corals and receptaculitids also are present.

Organic metamorphism

Three conodont collections from the Ella Bay 3-5 and 4-12 sections have a Colour Alteration Index of 5 (Nowlan, Appendix 3B, C-54909, C-75448, C-75449).

Mode of origin

The medium dark grey colour of the limestones, their rich and varied fossil content, and their texture (lime wackestone and mudstone) indicate deposition below storm wave-base, but within the photic zone of a relatively deep shelf.

Age and correlation

The Irene Bay Formation is identical in lithology and stratigraphic setting with the Cape Calhoun Formation of Washington Land, and the latter has been placed into the early to middle Ashgill (upper Edenian–lower Maysvillian *O. velucuspis* Zone). Conodonts from the study area (Nowlan,

Appendix 3B, C-75448 and C-75449) are compatible with that assignment.

Two closely related shelly faunas are distinguished in the upper Middle Ordovician and Upper Ordovician succession of the Arctic Islands and adjacent parts of the continental interior. The older one, commonly referred to as the Red River Fauna, is characteristic of the Red River Formation of Manitoba (Nelson, 1963), the Bad Cache Rapids Group of the Hudson Bay Lowlands (Nelson, 1964) and Melville Peninsula (Bolton, 1977), and upper parts of the Thumb Mountain Formation of Ellesmere Island (Kerr, 1968). The younger one, known as the *Bighornia-Thaerodonta* Fauna, (e.g., Barnes et al., 1981), occurs in the Stony Mountain Formation of Manitoba (Nelson, 1963), the Churchill River Group of the Hudson Bay Lowlands (Nelson, 1964), and other formations. The two faunas have many fossils in common, but differ with respect to some genera or species. The coral *Bighornia* is restricted to the *Bighornia-Thaerodonta* Fauna and the longer ranging coral *Palaeofavosites* makes its first appearance in it.

Kerr (1968, p. 53-55) collected index fossils of the *Bighornia-Thaerodonta* Fauna [*Streptelasma* cf. *S. trilobatum*, *Palaeofavosites* sp., and *Troedssonites conspiratus* (see Bolton, 1965, p. 25)] from the Irene Bay Formation at two localities in central Ellesmere Island. Collections from other localities lack index fossils that could be used to discriminate between the Red River and *Bighornia-Thaerodonta* faunas.

On Judge Daly Promontory, *Palaeofavosites* is absent in a collection from the same beds that yielded conodonts of Edenian-Maysvillian age (Norford, Appendix 3A, C-75450; Nowlan, Appendix 3B, C-75448, C-75449), but is present in a collection from another locality (Norford, Appendix 3A, C-54934). This may imply that the Irene Bay Formation — here as in other parts of the Arctic Islands — contains elements of both faunas and straddles the age boundary between them. If the Irene Bay Formation indeed is late Edenian-early Maysvillian in age, then the boundary between the Red River and *Bighornia-Thaerodonta* faunas probably lies within that span.

ALLEN BAY FORMATION

A resistant, predominantly dolomitic carbonate unit on Cornwallis Island, lying stratigraphically between the original Cornwallis and Read Bay formations, was named the Allen Bay Formation by Thorsteinsson (1958). Kerr (1975) restricted the Allen Bay Formation to strata overlying the Irene Bay Formation and underlying the Cape Storm, a new formation that comprised uppermost parts of the original Allen Bay Formation and lowermost parts of the original Read Bay Formation. On Ellesmere Island, the Allen Bay Formation includes significant proportions of limestone in addition to dolostone (Mayr, 1974; McGill, 1974; Kerr, 1976). Only the lower part of the formation is present in the area studied; strata correlative with the upper part are clastic sediments of deep water origin (Danish River Formation).

Distribution, thickness, and contact relations

The Allen Bay Formation is exposed on the northwestern and southeastern limbs of the Ninnis Glacier Syncline. On the northwestern limb, at the Ella Bay 3-6 section, it is 318 m thick and overlies the Irene Bay Formation with conformable contact. Photogrammetry suggests a thickness of about 250 m on the southeastern limb (Ella Bay 4-13 section) where the contact with the Irene Bay Formation is concealed. The contact with the overlying Danish River Formation is represented by rubble only. It appears to be abrupt and probably represents a minor submarine disconformity (see Chapter 5, Stratigraphic synthesis).

Lithology

At the Ella Bay 3-6 section, the formation consists of uniform, mostly massive, resistant limestone. Six analyzed samples (Appendix 2, Table 49) contain only a few per cent of quartz and one per cent or less of dolomite. However, a specimen from locality F9 (Fig. 1) on the southeastern limb of the Ninnis Glacier Syncline, contains 9 per cent quartz and 7 per cent dolomite in addition to the predominant calcite. Most rocks are classified as peloidal packstone/grainstone with skeletal content; skeletal and peloidal grainstone; or skeletal wackestone (Fig. 59). The skeletal material was derived mainly from echinoderms, trilobites, algae (mainly dasycladaceans) and gastropods, and to a lesser extent from corals, pelecypods, and brachiopods. Corals are the most common macrofossils whereas cephalopods are rare. Colonial tetracorals are especially common in the upper 20 m of the Ella Bay 3-6 section. One specimen (Fig. 60), shows the chain coral *Catenipora* sp. (Norford, Appendix 3A, C-96088) together with *Wetheredella*, a problematic genus, perhaps a porostromate cyanophyte, and micrite of probable microbial origin, which encrusts the chain coral and in places has a stromatolitic structure (T.A. de Freitas, Appendix 3A, C-96088). Cavities are filled with drusy calcite. This specimen may represent coralline-algal boundstone, but more detailed work is required to establish whether or not small bioherms are present at this level.

Organic metamorphism

Four conodont collections from the Ella Bay 3-6 and 4-13 sections (or their vicinity) and two from a nunatak southeast of d'Iberville Fiord all have a Colour Alteration Index of 5 (Nowlan, Appendix 3B, C-54910, C-54911, C-54913, C-54914, C-75463, C-75464). In contrast, two collections from the top of the formation at Ritter Bay have an index of 4 (Nowlan, Appendix 3B, C-94389, C-94390), indicating a southeastward decrease in organic metamorphism.

Mode of origin

The Allen Bay Formation is petrographically similar to the Irene Bay Formation and, like the latter, was mostly deposited in a low-energy, subtidal shelf environment.

Age and correlation

On Judge Daly Promontory, southeast of Ella Bay, most of the Allen Bay Formation is Late Ordovician in age and within the range of the *Bighornia-Thaerodonta* Fauna. This is apparent from: 1) the age of the underlying Irene Bay Formation (see above); 2) the occurrence of conodonts of Late Ordovician age from 84 to 85 m and of Middle or Late Ordovician age from 301.5 to 313.5 m above the base of the formation at the Ella Bay 3-6 section (Nowlan, Appendix 3B, C-54910, C-54911); 3) the occurrence of Richmondian conodonts in the upper part of the formation near the Ella Bay 3-6 section (Nowlan, Appendix 3B, C-54914); and 4) the occurrence of *Bighornia* sp. in the upper part of the formation (Norford, Appendix 3A, C-75273).

However, conodonts from strata 1.5 m below the top of the formation at the Ella Bay 3-6 section (Nowlan, Appendix 3B, C-54913) are early or middle Llandovery in age. The apparent absence of conodonts of latest Ordovician (Gamachian) age, and possibly also of early Llandovery age, may indicate the presence of a hiatus, but no lithological evidence of a disconformity was seen.

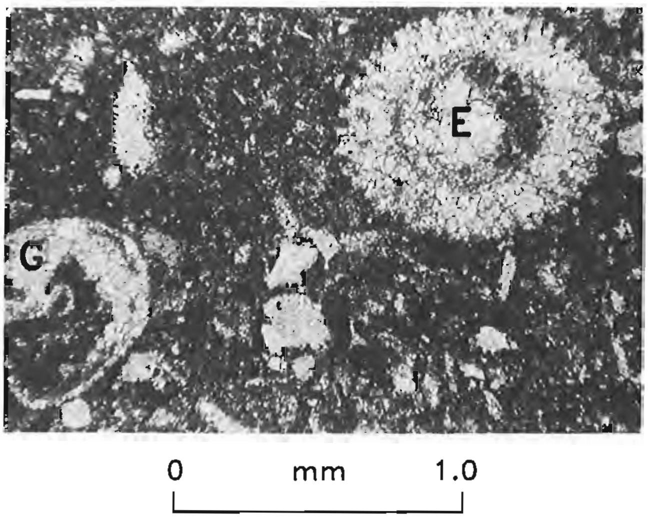


Figure 59. Photomicrograph (ordinary light) of skeletal lime wackestone in the lower part of the Allen Bay Formation at Ella Bay 3-6 section. G, gastropod; E, echinoderm columnal. ISPG photo. 2260-125.

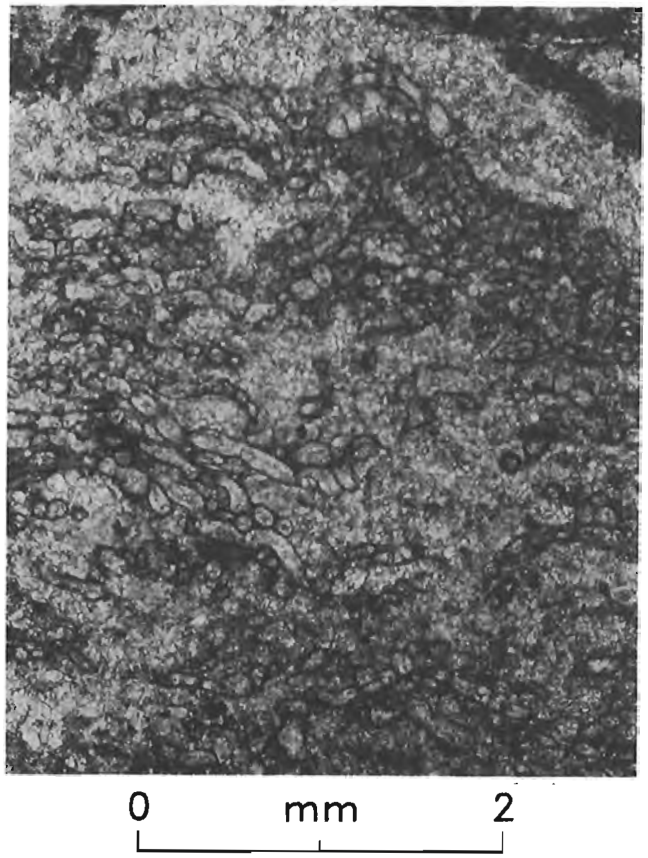


Figure 60. Photomicrograph (ordinary light) showing ***Wetheredella*** *sp. in the Allen Bay Formation, Ella Bay 3-6 section, 316.5 m. ISPG photo. 3728-24 by T.A. de Freitas.*

At the Ritter Bay section, where the Allen Bay Formation is overlain by the Cape Phillips, the uppermost strata (2 m) of the Allen Bay Formation have yielded conodonts of Richmondian (late Ashgill) age (Nowlan, Appendix 3B, C-94389 and C-94390).

Conodonts of Late Ordovician age have also been obtained southeast of the head of d'Iberville Fiord (C-75464), but the age of the top of the formation has not been determined there.

CHAPTER 4

STRATIGRAPHY OF THE DEEP WATER SUCCESSION

INTRODUCTION

The exposed part of the deep water succession in the Hazen Fold Belt ranges in age from Early Cambrian to earliest Devonian (early Lochkovian). Here, as in the Central Ellesmere Fold Belt, the underlying succession is unknown. However, it is reasonable to assume that the crystalline basement and supracrustal sedimentary succession, recognizable in seismic reflection profiles of the subsurface of the Franklinian Shelf on Melville Island (Kanasewich and Berkes, 1988; Harrison, 1991) continues to the northwest for some distance (cf. Sobczak et al., 1986).

Stratigraphic studies, new fossil collections, and correlation with North Greenland (Friderichsen et al., 1982; Surlyk and Hurst, 1984; Higgins et al., 1991) have led to substantial revisions of the framework established for the Hazen Fold Belt in the 1960s (Trettin, 1971). Four major units of formational rank, named Nesmith beds, Grant Land Formation, Hazen Formation, and Danish River Formation, are now recognized. The Nesmith beds include strata in the northwestern Hazen Fold Belt that had been erroneously assigned to the Hazen Formation. The age ranges of the Grant Land and Hazen formations have been revised substantially. Danish River Formation is a new name for flysch previously assigned to the Imina Formation; the latter now is restricted to the Clements Markham Fold Belt.

In the Central Ellesmere Fold Belt, the deep water succession oversteps the Ordovician shelf margin and lies on Silurian carbonates with a highly diachronous contact. There it ranges in age up to late Early Devonian (Emsian), and comprises the Cape Phillips and Danish River formations. At Cañon Fiord, the Danish River Formation is overlain by strata of the Eids Formation that are of transitional, deep to shallow marine aspect. Brief comments on the deep water sediments in that area and at Trold Fiord are based on earlier reports (Trettin, 1978, 1979).

NESMITH BEDS (informal new unit)

The informal name, Nesmith beds, is here given to a unit of resedimented limestone and siliciclastic sediments that underlies the Grant Land Formation. The unit is very complex structurally and is generally poorly exposed. It is of formational rank, but not defined as a formation because it lacks a suitable type section and its base is concealed. The best exposures are on the southwest side of middle and lower Henrietta Nesmith Glacier (Section HNG) and north of Rollrock Lake (Section RL, Fig. 142). The inference that the Nesmith beds underlie the Grant Land Formation is based on fining directions in Bouma sequences, both in the Nesmith beds and in the Grant Land Formation, combined with the fact that the exposures of the Grant Land Formation in these areas are thick. Moreover, no carbonate strata have been discovered anywhere within the Grant Land Formation.

Distribution, thickness, and contact relations

Outcrops are limited to the northwestern Hazen Fold Belt (Fig. 61). The thickness of the exposed Nesmith beds has not been determined. The contact with the Grant Land Formation, placed at the top of the uppermost limestone, is gradational and conformable.

Lithology

The Nesmith beds consist of resedimented carbonates ranging in grade from lime mudstone to pebble conglomerate, and of variably calcareous siliciclastic sediments, ranging in grade from mudrock to fine pebble conglomerate. Seven very short sections at Henrietta Nesmith Glacier were measured bed by bed, and a few typical sequences are portrayed in Figures 62 and 63. Observations about the constituent rock types are summarized in Table 6.

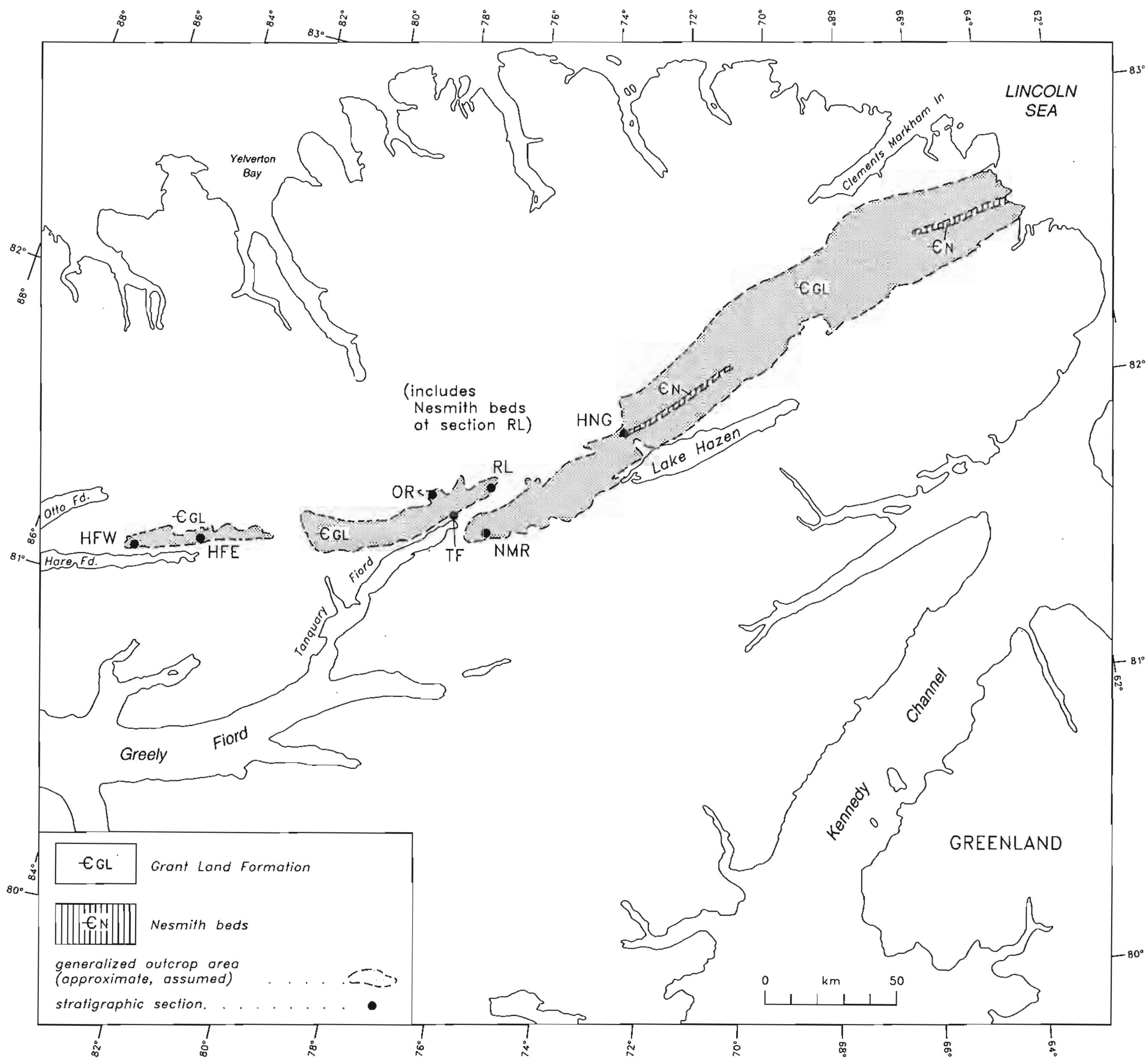


Figure 61. Distribution of the Nesmith beds and Grant Land Formation in northeastern Ellesmere Island and section localities (from east to west: HNG = Henrietta Nesmith Glacier; RL = Rollrock Lake; NMR = north of Macdonald River; TF = Tanquary Fiord; OR = Osborn Range; HFE = Hare Fiord East; HFW = Hare Fiord West.

Mineral compositions established by semi-quantitative X-ray diffraction analyses are listed in Appendix 2, and some are also shown in Figure 62. Impure lime mudstone and calcarenite (Appendix 2, Tables 50, 56) contain on the average about one-third siliciclastic silt and sand, mainly quartz, with a few per cent each of feldspar (mainly plagioclase), mica, and chlorite. Relatively pure types contain about 5 per cent quartz (Appendix 2, Tables 51, 57). Calcareous sandstones contain 23 to 42 per cent calcite (Appendix 2, Tables 52, 58). Feldspar, ranging from trace amounts to 9 per cent, is mainly or entirely plagioclase (albite). Mica and chlorite average a few per cent each. Some rocks contain ooids (Fig. 64). Mudrocks are divisible into highly calcareous types, containing up to 50 per cent calcite (Appendix 2, Tables 54, 55), and noncalcareous types (Appendix 2, Table 53). In most rock types, dolomite is scarce or absent, but makes up as much as 6 per cent of calcareous mudrocks (Appendix 2, Table 55) and 14 per cent of argillaceous and sandy lime mudstones (Appendix 2, Table 56).

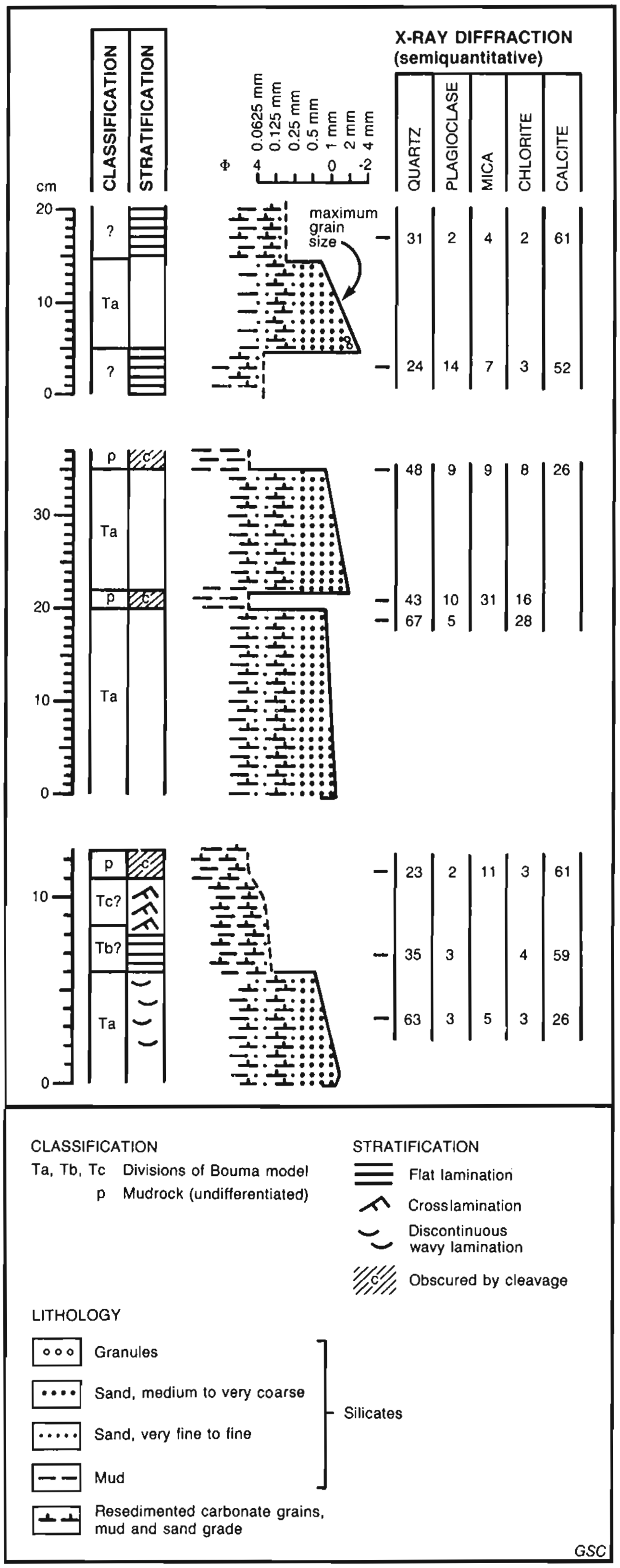


Figure 62. Stratigraphy of typical turbidites of the Nesmith beds at Henrietta Nesmith Glacier.

Calcareous pebble conglomerate has been observed at two localities only. A 25 cm thick bed at Patterson River contains pebbles up to 7 mm in diameter, and a bed northwest of Henrietta Nesmith Glacier has pebbles up to 1.3 cm in diameter. In both occurrences, the pebbles are disc shaped and bounded by solution surfaces. They are composed of lime mudstone, in part silty and sandy, of peloidal packstone/wackestone (for explanation of this term see above, Lithological nomenclature and analytical methods), and oolitic and oncolitic grainstone (Fig. 65).

Figure 63. Photograph of the upper interval shown in Figure 62 (head of hammer at base of section). Graded calcareous sandstone lies between flat-laminated silty and sandy limestones. Scale in centimetres marked on hammer handle. ISPG photo. 1878-71.

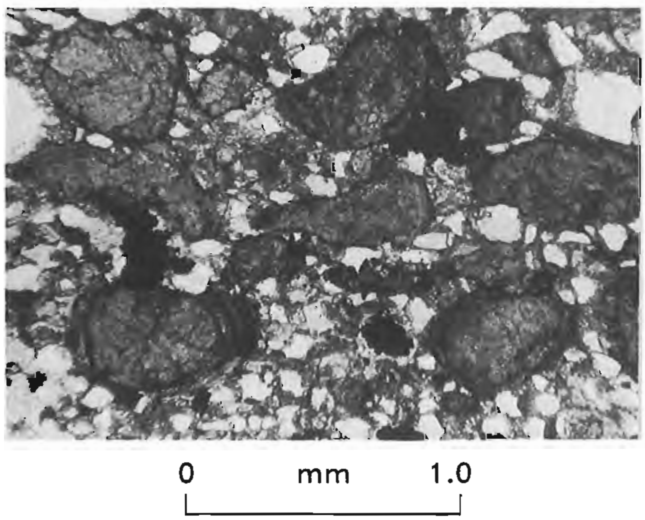


Figure 64. Photomicrograph (ordinary light) of calcareous sandstone with ooids; Nesmith beds, Patterson River area. ISPG photo. 2260-128.

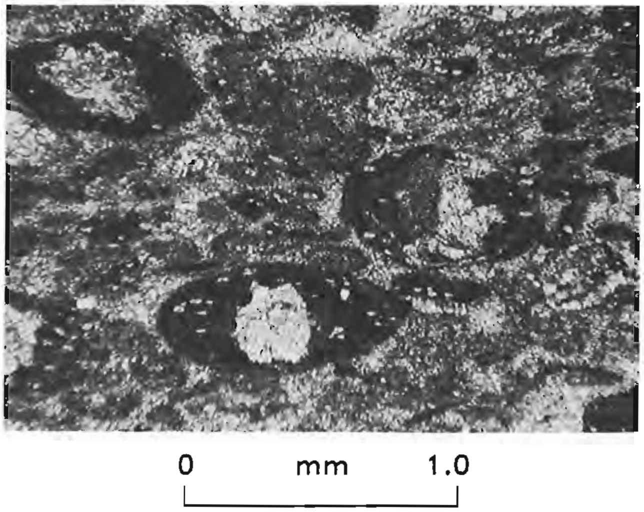


Figure 65. Photomicrograph (ordinary light) of (part of) a pebble of grainstone with flattened oncoids; Nesmith beds, Patterson River area. Oncoid in lower part of photograph (centre) has large calcite crystals in the centre and contains small amounts of quartz silt (light specks). ISPG photo. 2260-25.

TABLE 6

Nesmith beds, Henrietta Nesmith Glacier section, characteristics of rock types

1. **Calcarenite**, quartz-sandy, "coarse", graded

   Number of examples: 2

   Bed thickness: 61.5-72 cm

   Maximum grain size at base: granules up to 3.4 mm

   Maximum grain size at top: fine or coarse grained sand

   Stratification: massive

   Setting and classification: abrupt lower contacts; one example, abruptly overlain by mudrock, represents a Ta turbidite (consisting of an A-division only)

2. **Sandstone**, calcareous, "coarse", graded

   Number of examples: 4

   Bed thickness: 6-20 cm

   Grain size: bimodal; the coarser population ranges from medium grained sand to granule grade and consists mainly of quartz; it decreases upward in grain size and abundance. The finer population ranges in grade from coarse silt to medium grained sand and consists mainly of calcite and quartz with minor feldspar, mica, and chlorite. Maximum grain size at base, mostly very coarse grained sand with granules (2.9 mm) in one case; maximum grain size at top, coarse grained sand (very dilute)

   Stratification: graded bedding; no internal stratification

   Setting and classification: overlies finer grained units with abrupt contacts; forms A divisions of possible Ta, Tab and Ta-c turbidites

3. **Siltstone**, coarse grained, and **sandstone**, very fine grained, calcareous

   Number of examples: 3

   Bed thickness: 5-16.5 cm

   Grain size: coarse silt to very fine sand; vague graded bedding in one case

   Stratification: flat lamination with some wavy and crosslamination

   Setting and classification: the graded example may be a Tbc turbidite or part of a Ta-c turbidite

4. **Lime mudstone**, nearly pure

   Number of examples: 1

   Bed thickness: 90 cm

   Grain size of siliciclastic material: coarse silt to very fine grained sand

   Structure: massive

5. **Lime mudstone**, argillaceous

   Number of examples: 8

   Bed thickness: 1.5-5 cm

   Stratification: some flat lamination; stratification partly obscured by cleavage

Metamorphism

Fine grained mudrocks display a continuous slaty cleavage, caused by recrystallization of clay minerals to silt-grade white mica and chlorite, but the other rock types do not have a metamorphic texture.

Mode of origin

The common occurrence of graded, resedimented carbonate sediments indicates deposition below the shelf edge. The sediments probably were derived from nearly contemporaneous shelf carbonates of the Ella Bay Formation (see Age and correlation). The presence of pebble conglomerate shows that the source area was not remote.

Age and correlation

No microfossils were recovered from seven limestone samples from the Henrietta Nesmith Glacier and Patterson River areas, nor were skeletal fragments seen in any of the numerous thin sections examined.

Regional relations strongly suggest that the Nesmith beds are correlative with the Paradisfjeld Group of northeasternmost Greenland (Friderichsen et al., 1982; Higgins et al., 1991). The Paradisfjeld Group is at least 1 km thick and consists mainly of resedimented carbonates, ranging in grade from lime mudstone through calcarenite and conglomerate to very large olistoliths. The unit is overlain by the Polkorridoren Group (Friderichsen et al., 1982), which is similar to the Grant Land Formation and correlative with it. Sponge spicules (of *Chancelloria* sp.; Peel and Higgins, 1980) and inarticulate brachiopods of Phanerozoic age occur in the upper part of the Paradisfjeld Group. Lithological relations demonstrate that it is the deep water equivalent of the Lower Cambrian Portfjeld Formation and of the correlative Ella Bay Formation of Ellesmere Island.

GRANT LAND FORMATION

The name, Grant Land Formation, derived from the Grant Land Mountains (now spelled Grantland Mountains), was introduced by Trettin (1971) for a thick succession of fine to coarse grained, multicoloured (grey, green and purple) clastic sediments underlying the Hazen Formation. Minor amounts of limestone were included in the original definition, but subsequent work has shown that the few exposures seen were part of the Nesmith beds and not of the Grant Land Formation. The formation is structurally complex, and no complete section is known. The type section north of central Hare Fiord (HFW, Hare Fiord West) represents only a small portion in the middle part of the entire formation. It was established at a time when the formation was known from reconnaissance mapping only. In this report, incomplete reference sections north of eastern Hare Fiord East (HFE), Tanquary Fiord (TF), and Rollrock Lake (RL) are combined to establish a composite section for the entire formation.

Distribution, thickness, and contact relations

The Grant Land Formation is extensively exposed in the Hazen and Northern Heiberg fold belts, and similar rocks also occur in the western part of the Clements Markham Fold Belt (Fig. 61). The exposures in the Hazen Fold Belt extend for about 370 km, from central Hare Fiord to the coast of Lincoln Sea (Fig. 61).

The thickest stratigraphic section known, situated north of eastern Hare Fiord [Hare Fiord East (HFE); Figs. 61, 143], comprises about 1.3 km of strata. However, the section is bounded at the base by a thrust fault, and member A and an unknown part of member B are missing, so the total thickness of the formation probably is no less than 1.5 km. A minimum thickness of 2 km was estimated for the correlative Polkorridoren Group of northeasternmost Greenland (Friderichsen et al., 1982).

The contact with the Nesmith beds is gradational and conformable. It is placed where impure carbonates give way to calcareous siliciclastic sediments. The contact with the Hazen Formation is structurally conformable but abrupt (see Hazen Formation). It may represent a submarine disconformity, but there is no evidence of an intervening episode of emergence.

Lithology

Macroscopic aspects

The Grant Land Formation is composed of slightly metamorphosed sandstone and mudrock with small amounts of granule to pebble conglomerate and of intraformational conglomerate. The formation has been metamorphosed mainly in the subgreenschist facies, but locally in the greenschist facies — the sandstones to quartzite, and the mudrocks to slate, phyllite, or schist. Most rocks are medium grey to medium dark grey, but purple and greenish mudrocks are common in the middle and upper parts of the formation.

Stratigraphic studies were restricted to the southwestern part of the main outcrop area of the formation, extending from north of central Hare Fiord to Henrietta Nesmith Glacier. In this area three members, informally referred to as members A, B, and C, are recognized. Briefly, member A is composed of sandstone and mudrock and differs from member B mainly by the presence of calcareous detritus and abundant Bouma sequences. Member B is composed of sandstone and mudrock with minor amounts of pebble conglomerate and intraformational conglomerate. Instead of Bouma sequences, thick units of massive sandstone are characteristic. Member C consists mainly of mudrock with an upward-diminishing proportion of fine grained sandstone.

Members A and C are thin and their stratigraphic positions at the base or top of the formation are apparent from their positions above the Nesmith beds or below the Hazen Formation, respectively. Member B comprises the bulk of the formation.

Member A

A complete, but partly covered section north of Rollrock Lake (Rollrock Lake section, RL in Fig. 61) is 123 m thick. It consists mainly of sandstone and minor mudrock, which is richly calcareous in the lower part (A_1) but rarely so in the upper part (A_2). Bouma sequences are abundant. Member A_1 is exceptionally well exposed at the southwestern margin of lower Henrietta Nesmith Glacier where some short sections were studied in detail (Section HNG). A total of 14 turbidites, ranging in thickness from 4 to 156 cm, are separated by units of slaty mudrock, 5 to 57 cm thick (Table 7). Four different types of turbidites are present, all beginning with A-divisions. In addition, there are units of nongraded, flat-laminated sandstone of uncertain origin. Variations in grain size and mineral composition of turbidites from member A_1 and from the base of member A_2 are portrayed in Figures 66 and 67, respectively; detrital compositions are discussed below (under Microscopic aspects).

Member B

Member B, more than 1.3 km thick, makes up the bulk of the formation. It consists mainly of sandstone, lesser amounts of varicoloured mudrock, and small amounts of pebble conglomerate. The unit is rather monotonous, but shows a slight overall decrease in average size grade. At the Hare Fiord East section (HFE), for example, conglomerate is limited to the lower part of the exposures (49–356 m) and mudrock and fine grained sandstone are most abundant in the upper few hundred metres. At the same section, reddish mudrocks are absent from the lower 485 m (Appendix 1; the section is not represented graphically).

The member can be described in terms of two, alternating, major lithofacies that are dominated by sandstone (lithofacies S) and mudrock (lithofacies P, for pelite). The following statistical statements about these lithofacies are based on five short, detailed sections within the lower part of the Hare Fiord East section (Fig. 68; stratigraphic position from Fig. 143), and on the Tanquary Fiord section (Fig. 68). The latter is 236 m thick and divisible into 153 units of description. The field observations have been supplemented by inspection of numerous thin sections.

At the Tanquary Fiord section, units composed of lithofacies S range in thickness from 19.5 to greater than 66.9 m, and units composed of lithofacies P, from 2.6 to 27.5 m. These sandstone- or mudrock-dominated units seem to be extensive and to maintain a rather constant thickness within given exposures (<3 km); nowhere were they seen to wedge out or to interfinger with each other. The contacts are mostly flat, although small troughs, no more than about 1 m deep, occur locally at the base of lithofacies S. Markers within these units, such as beds of purple mudrock or resistant beds of sandstone or conglomerate, also appear to be extensive.

Lithofacies S. The lithological composition of this lithofacies is summarized in Table 8. It consists mostly of sandstone (91%), which is predominantly medium

TABLE 7

Grant Land Formation, member A_1 at Henrietta Nesmith Glacier section, statistical summary of detailed sections

Classification	Number of units	Thickness (cm)	Fraction of total thickness
Ta	7	10-56	28%
Tab	3	4-52	8%
Ta-c	3	32-156	36%
Ta-d	1	62	8%
mudrock	9	0.2-18	7%
sandstone, flat-laminated	5	5-57	13%

and coarse grained (62%), and to a lesser extent very fine and fine grained (29%). The remainder is composed of mudrock (5%) and conglomerate (4%).

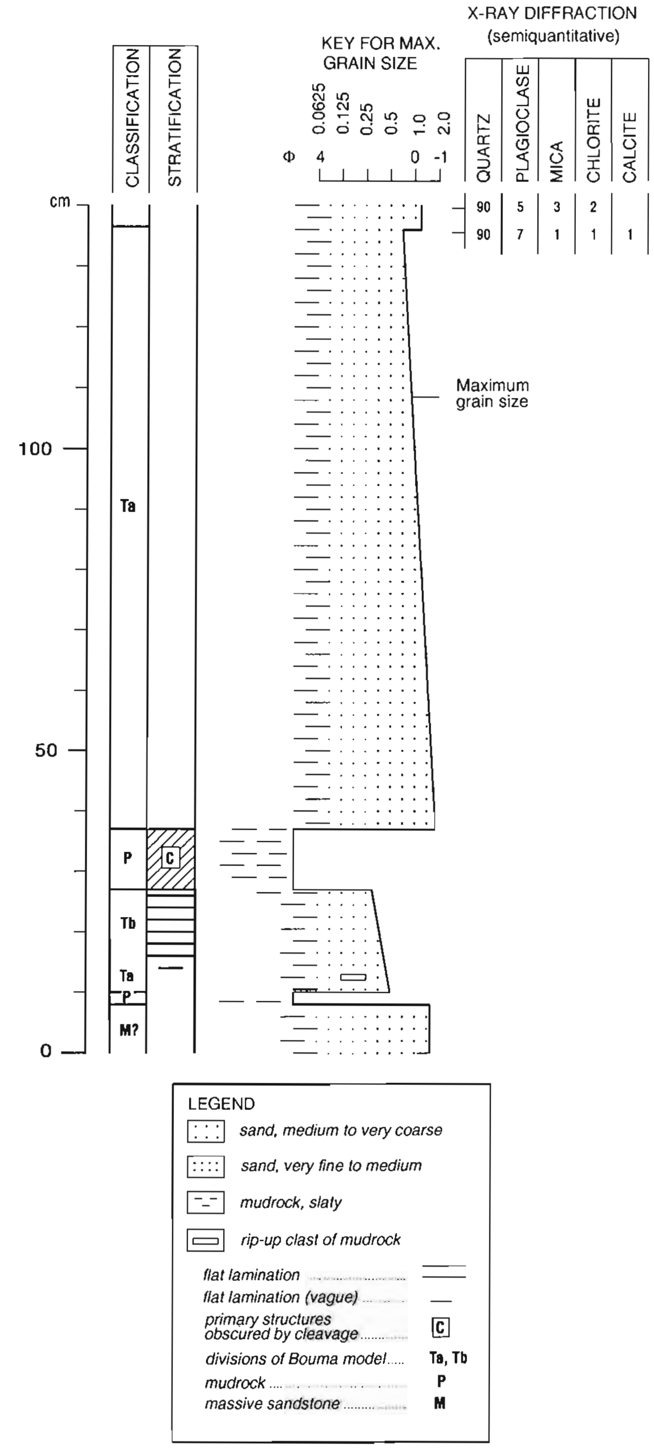


Figure 66. Turbidites in member A_1 of the Grant Land Formation at Rollrock Lake section (RL of Fig. 61) — vertical variations in grain size and mineral composition (based on uncorrected XRD data).

The sandstones have been subdivided on the bases of stratification, presence or absence of rip-up clasts of mudrock, and grain size, into various subfacies (shown in Table 8 and Figure 68). Structureless units more than 0.6 m thick are most common (45%; Fig. 69). They reach thicknesses of up to nearly 7 m and generally average 1.8 to 1.9 m. Next in importance are strata showing flat lamination and small-scale crosslamination (24%; Fig. 70), structureless units less than 0.6 m thick (13%; Fig. 69), trough-crossbedded strata (6%), and flat-laminated strata (3%). The trough-crossbedded units range in thickness from about 0.1 to 1 m. The troughs measured were 0.05 to 1 m deep and 0.4 to 4 m long in longitudinal or oblique cross-sections (Fig. 71). One was filled with rip-up clasts (Fig. 72). Some sandstone beds have load casts at their bases (Fig. 73).

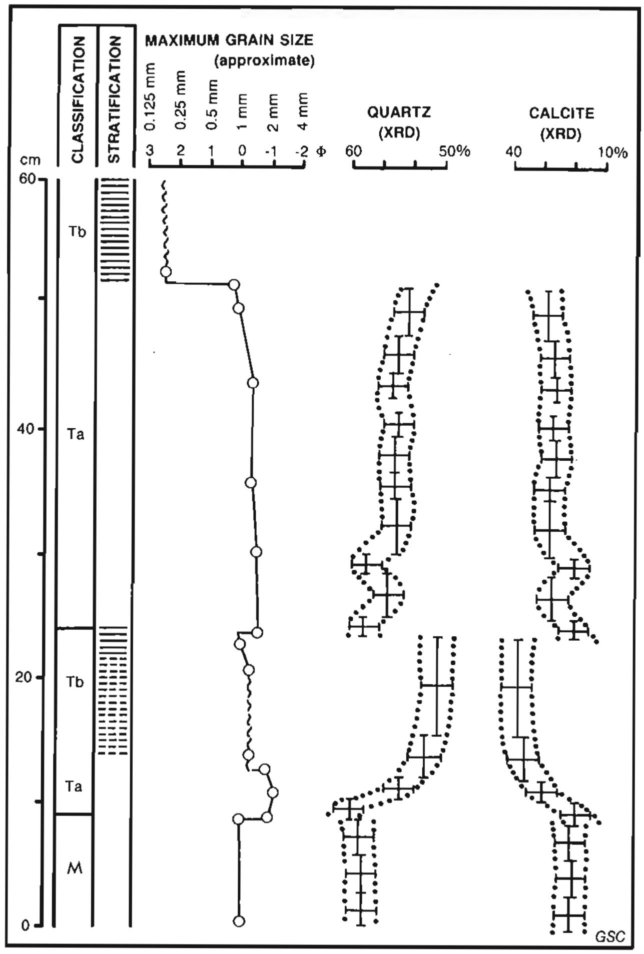


Figure 67. Turbidites at the base of member A_2 of the Grant Land Formation at the Rollrock Lake section (RL of Fig. 61) — vertical variations in grain size and some mineral compositions (based on uncorrected XRD data).

TABLE 8

Grant Land Formation, member B at Tanquary Fiord and Hare Fiord East sections, characteristics of rock types of lithofacies S

Symbol	Rock Types	Stratification	Grade of sand	SECTION TF: Number of units	SECTION TF: Thickness (mm) X̄	SECTION TF: Thickness (mm) Range	SECTION TF: % of Total Thickness, lithofacies S	SECTION TF: % of Total Thickness, lithofacies S (group)	SECTION HFE: Number of units	SECTION HFE: Thickness (mm) X̄	SECTION HFE: Thickness (mm) Range
p	mudrock; minor sandstone	flat and undulating lamination, crosslamination	vf+f	15	0.4	0.10-2.50	4.7	4.7	3	0.4	0.20-0.65
sx	sandstone; minor mudrock	flat lamination, (small-scale) crosslamination	vf+f	16	1.4	0.15-4.35	16.1		5	0.9	0.20-3.00
			m+cs	9	1.7	0.20-3.30	7.6	24.1			
sxi	sandstone; minor mudrock with rip-up clasts		vf+f	1	0.5		0.4		2	0.7	0.40-0.90
st	sandstone; minor mudrock	trough crossbedding	m+cs	11	0.8	0.10-1.00	6.4	6.4	2	1.1	1.0-1.1
sfl	sandstone; minor mudrock	flat lamination	vf+f	5	0.5	0.10-1.40	1.9		9	0.7	0.07-2.80
			m+cs	3	0.4	0.20-0.70	0.9	2.8	2	0.1	0.10-0.10
sfli	sandstone; minor mudrock with rip-up clasts		vf+f						1	0.6	
			m+cs						2	1.2	0.95-1.50
sf	sandstone	flat bedded and structureless units <0.6 m thick	vf+f	7	0.9	0.06-2.00	4.6		1	0.15	
			m+cs	11	1.0	0.06-5.70	8.2	13.3	2	0.5	0.50-0.35
sfi	sandstone with rip-up clasts		vf+f						2	0.1	0.10-0.15
			m+cs	2	0.3	0.15-0.50	0.5				
sm	sandstone	structureless units >0.6m thick	vf+f	3	1.9	1.30-3.00	4.1		15	2.4	0.75-5.10
			m+cs	20	1.9	0.60-6.70	26.7				
smi	sandstone with rip-up clasts and rare mudrock lenses		vf+f	3	0.9	0.80-1.00	2.0	44.5	11	2.9	0.60-9.20
			m+cs	9	1.8	0.70-5.20	11.7				
cg	granule and pebble conglomerate	structureless		3	0.5	0.10-1.00	1.0		1	0.5	
cgi	granule and pebble conglomerate with rip-up clasts			5	0.9	0.15-2.80	3.3		4	2.4	1.50-3.30
cgt	granule and pebble conglomerate	trough crossbedding						4.4	1	0.1	
cgti	granule and pebble conglomerate with rip-up clasts			1	0.2		0.1				
	mudrock (mainly)							4.7			
	sandstone (mainly)		vf+f				29.1				
			m+cs				62.0	91.1			
	conglomerate (mainly)							4.4			

Total thickness of lithofacies S at section TF: 140.13 m

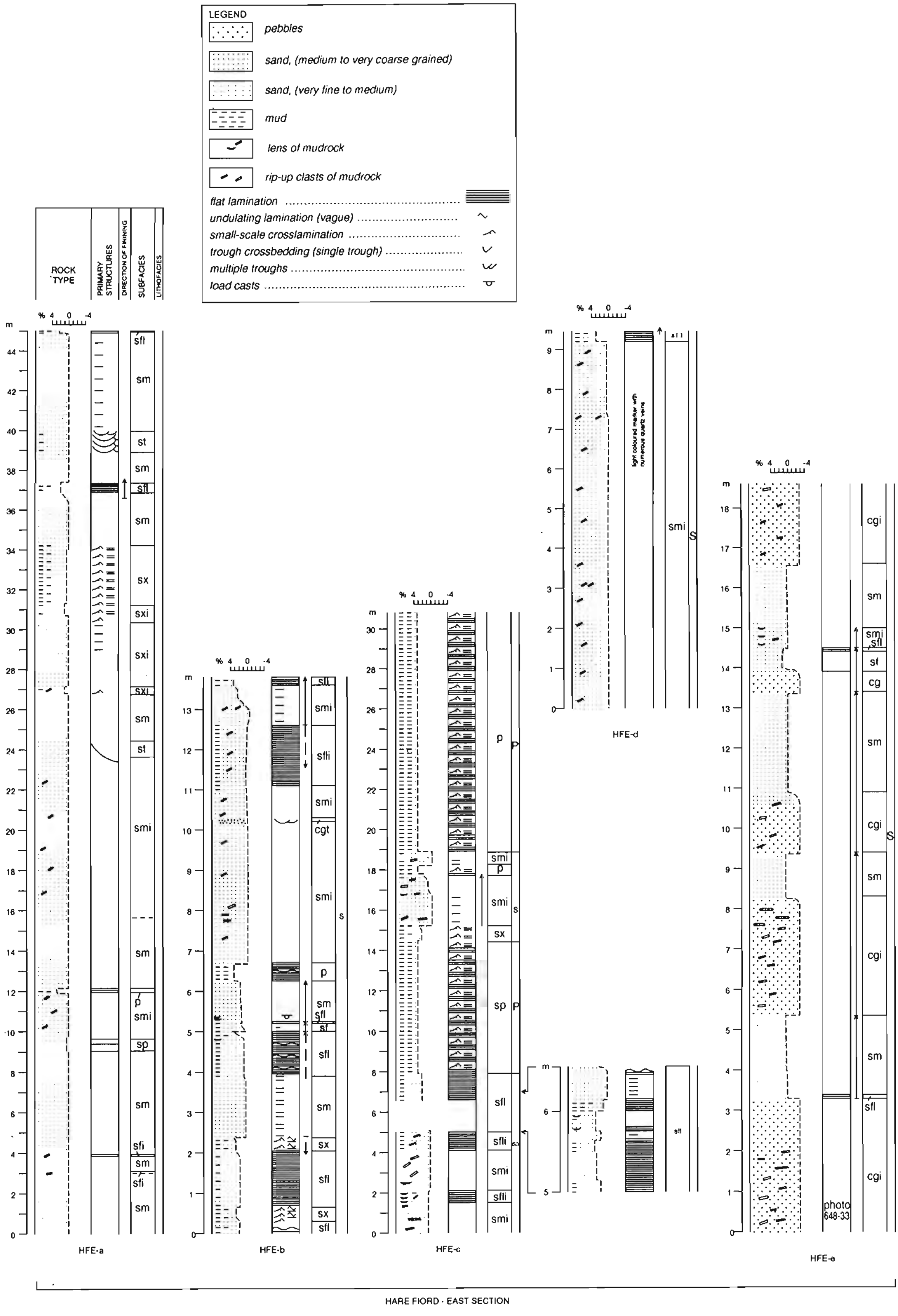


Figure 68. Grant Land Formation, member B; columnar logs of representative short sections.

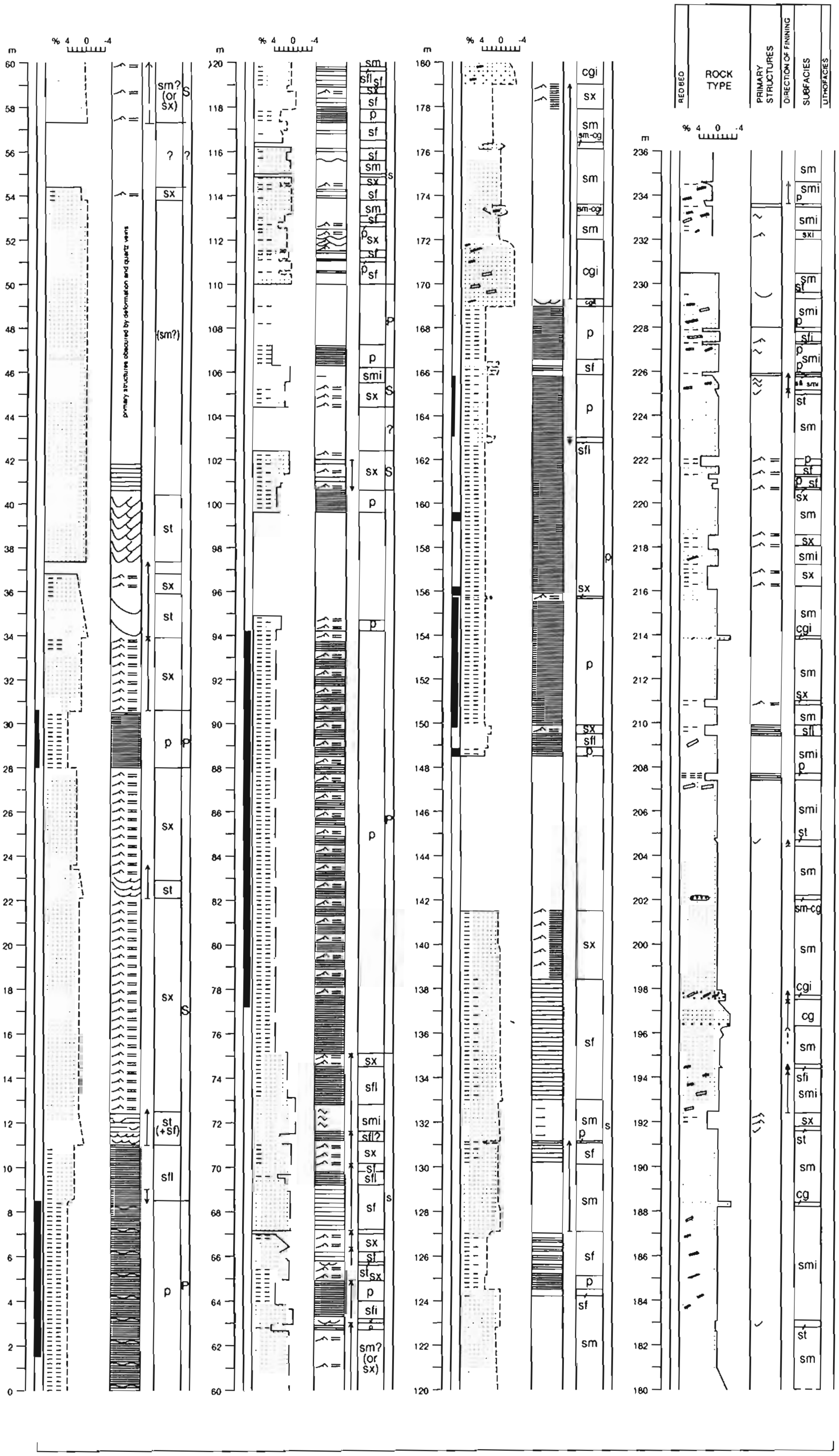


Figure 68. (cont'd.).

Rip-up clasts of mudrock occur in nearly all sandstone types and are most common in the thick, structureless units (Figs. 69, 74). They are medium dark grey and vary in length from a few millimetres to several decimetres. Some layers of aligned, closely spaced rip-up clasts give the impression of having been disintegrated almost *in situ.*

Figure 69. *Structureless sandstone alternating with slaty mudrock in member B of the Grant Land Formation near the Tanquary Fiord section. Stratigraphic upward direction is right-to-left. Measuring staff (1.5 m) points to rip-up clast shown in Figure 74. ISPG photo. 1360-5.*

Figure 70. *Thin beds of sandstone (2-5 cm), interbedded with thin layers of mudrock (0.5-2 cm) in member B of the Grant Land Formation at Hare Fiord East-1 section, unit 50 (see Appendix 1). Stratification is mainly horizontal, although some small-scale crosslamination (not apparent on photograph) also occurs. ISPG photo. 3588-2.*

Figure 71. *Trough crossbedded sandstone in member B of the Grant Land Formation near the Tanquary Fiord section; 1.5 m staff for scale. ISPG photo. 1360-33.*

Figure 72. *Trough-shaped scour filled with rip-up clasts of mudrock, in member B of the Grant Land Formation near the Tanquary Fiord section.* ***a)*** *Cross-section;* ***b)*** *Longitudinal section. ISPG photos. 1360-15, 1360-16.*

Medium and coarse grained sand is most abundant in trough-crossbedded and structureless units, and very fine and fine grained sand in flat-laminated and crosslaminated units.

Conglomerates are of granule to fine pebble grade, the maximum observed clast size being 2 cm. Most beds are structureless, but a few show shallow troughs, 8 to 30 cm deep. Most conglomerates have rip-up clasts of mudrock (Fig. 75). Conglomeratic units range in thickness from 0.1 to 2.8 m and average less than 1 m. Most extend laterally for tens of metres or more, but some form lenses that are only a few metres wide.

Figure 73. Load casts in sandstone of the Grant Land Formation, member B, at Hare Fiord East-1 section, unit 44. Beds dip gently to the left. ISPG photo. 3588-1.

Figure 74. Rip-up clasts of mudrock (dark) of different sizes in structureless sandstone of member B of the Grant Land Formation near the Tanquary Fiord section (see Fig. 69). ISPG photo. 1360-2.

Fining-upward sequences make up 28 per cent of lithofacies S (Table 9). Overall, 24 different types of such sequences, consisting of one to four rock types, can be distinguished. The sequences range in thickness from 0.15 to 10 m, and most begin with massive sandstone, conglomerate (Fig. 76) or trough-crossbedded sandstone. Only a few of the 24 types of sequences have a possible relation with the Bouma model.

Coarsening-upward sequences, on the other hand, are insignificant, as they constitute only 1.5 per cent of lithofacies S. They are restricted to flat-laminated and crosslaminated units.

Lithofacies P. This lithofacies consists mainly of multicoloured mudrock. Overall, medium dark grey to light grey or light greenish grey colours prevail, but greyish red-purple ("maroon") is common in the middle and upper parts of the member. At the Tanquary Fiord section, these reddish mudrocks, which alternate with greenish grey mudrocks of similar grain size and composition, make up 56 per cent of the lithofacies (Figs. 68, 77). Primary structures have to some degree been obscured by cleavage development, but it seems that flat lamination and slightly undulating lamination are more common than small-scale crosslamination.

Figure 75. Rip-up clasts in pebble conglomerate of the Grant Land Formation, member B at the Hare Fiord East section; hammer handle is perpendicular to bedding. ISPG photo. 648-33.

Small amounts of very fine grained sandstone are interlaminated with the mudrocks. Discrete sandy units range in thickness up to 65 cm. They comprise very fine and fine grained sandstones that show flat lamination and crosslamination, and beds of medium grained sandstone that are about 20 to 30 cm thick.

Member C

Member C, as mentioned, consists mainly of mudrock with an upward-diminishing proportion of fine grained sandstone. This is apparent at localities where the Grant Land Formation is overlain by the

TABLE 9

Grant Land Formation, member B at Tanquary Fiord and Hare Fiord East sections, characteristics of fining-upward and coarsening-upward sequences

		SECTION NTF				SECTION HFE	
Bouma Equivalent	**Sequence**	**Number of units**	**Thickness (m)**	**% of Total thickness lithofacies**		**Number of units**	**Thickness (m)**
Tc	sx	1	3.3	2.35	3.33		
	sx-p	2	0.8, 0.57	0.98			
Tb	sfl					1	0.2
	sfl-sm					1	2.1
	st	1	0.3	0.21	5.32		
	st-sf-sx	1	0.8	0.57			
	st-sx	1	1.55, 2.9	3.18			
	st-sfl-p	1	1.9	1.36			
Tab	sf				4.22	1	0.25
	sf-(st + sf)-sx	1	1.5	1.07			
	sf-sfl	1	2.55	1.82			
	sf-sx-sfl	1	1.71	1.22			
	sfi	1	0.15	0.11			
	sm-sf-p	1	4.07	2.90	8.15		
	sm-sfl					1	1.0
	smi	2	1.0, 2.0	2.14		2	1.0, 1.0
	smi-sm					1	2.1
	smi-sm	1	3.55	2.53			
	smi-sfl-sx	1	0.8	0.57			
	smi-sfi-p						
	smi-p					1	2.5
Tab	cg-sf-sfl				7.28	1	1.1
	cgi	1	0.2	0.14			
	cgi-sm					2	4.0, 4.0
	cgi-sm(sm + cgi)-sm-(sm + cgi)-sm-sx	1	10.0	7.13			
	Total	19	39.65		28.3		

Coarsening-upward sequences

sx	1	1.3	0.93	0.93	1	1.0
sfl	2	0.5, 0.35	0.60	0.60	1	2.1
sfli						
Total	3	2.15		1.53		

Hazen Formation (e.g., Hare Fiord East section, Fig. 143, and Osborne Range section, Fig. 87). The lower part of this member (C_1) consists of very fine and fine grained sandstone with a larger proportion of mudrock than is present in member B. A short, detailed section (Fig. 78), measured north of Macdonald River (Macdonald River 1 section; Fig. 140), probably is stratigraphically high in this part of the member. It comprises a thin, predominantly sandy unit that is both underlain and overlain by thicker mudrock units.

The lower part of the section consists of three beds of very fine grained sandstone, 8 to 10 cm thick, which show flat lamination and small-scale crosslamination. They are separated by beds of mudrock, 5 to 8 cm thick, which contain some very thin lenses of sandstone. This lower unit is followed by a bed of very fine grained sandstone, 3 m thick, that is massive except for some indistinct flat lamination and parting surfaces, spaced 5 to 20 cm. This sandstone is reminiscent of the massive sandstones in member B, but differs from them in good sorting and the absence of mudrock rip-up clasts.

Figure 79 represents the upper part of member C_2 as exposed in the Osborne Range (also Fig. 87). The section, as measured, is 65 m thick, but may include unrecognized structural repetitions. It consists almost entirely of mudrock, with only two beds of very fine grained sandstone, 10 to 15 cm thick, in the lower part. The lower and middle parts of the section are characterized by alternating greenish grey and red-purple mudrock units, 0.1 to 8.5 m thick. In the upper 14.6 m, the colour changes from greenish grey at the base to medium light grey at the top. These strata contain numerous, very thin, dark grey patches, irregular in shape, that probably are trace fossils, but cannot be identified any further. The same kind of markings were seen in member C_2 north of Macdonald River, 24 km to the southeast.

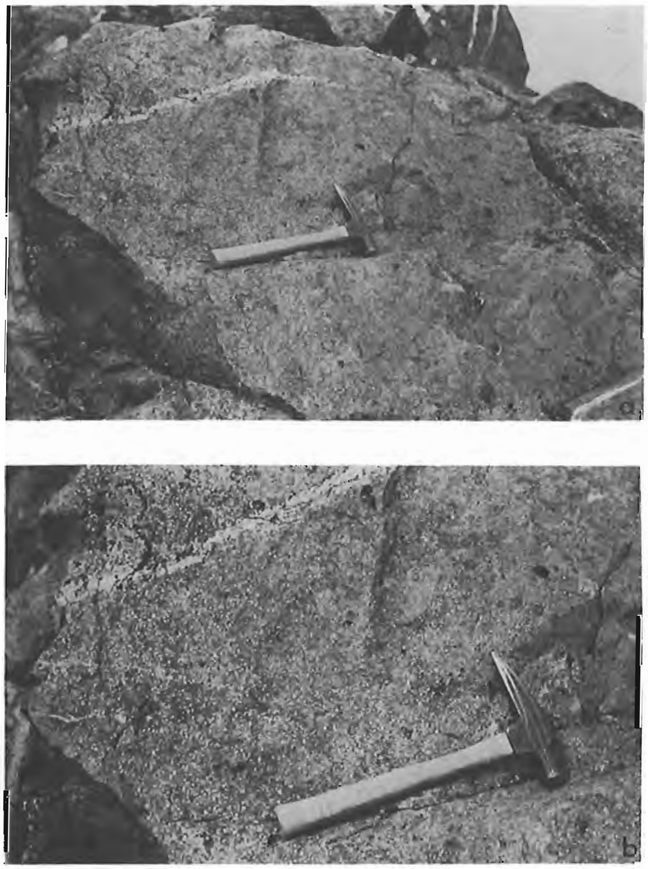
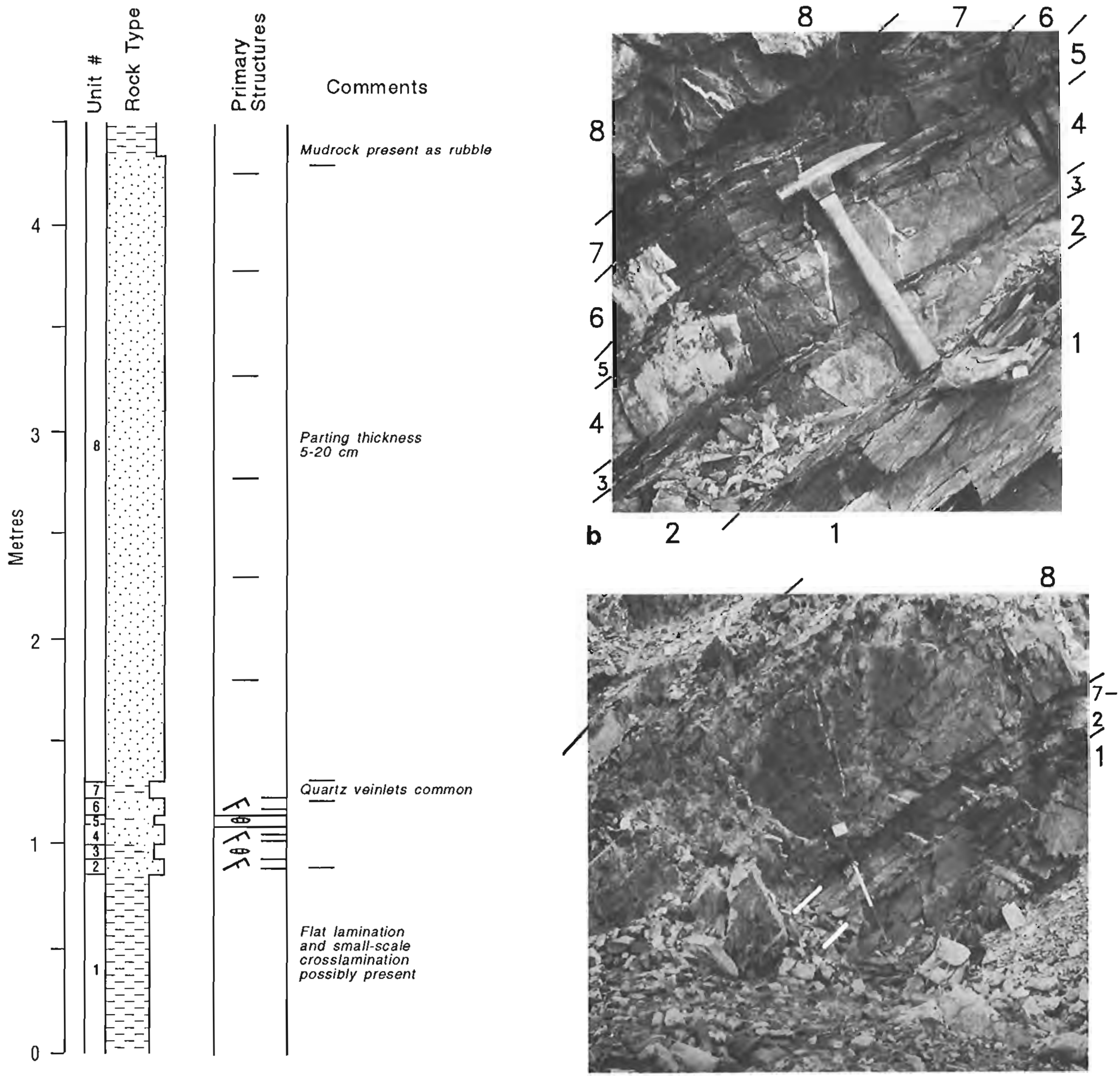


Figure 76. *Pebble conglomerate, fining upward to structureless sandstone, in member B of the Grant Land Formation, near Tanquary Fiord (stratigraphic upward direction is left to right). **a)** Entire bed, recessive mudrock units above and below show bedding; **b)** Close-up of basal part, showing graded bedding. ISPG photos. 648-52, 648-51.*

Figure 77. *Mudrock, greyish purple-red (dark) and light greenish grey (light); Grant Land Formation, member B, section Hare Fiord East-1, unit 83. ISPG photo. 3588-3.*



LEGEND

ROCK TYPE

sandstone mainly very fine grained, medium to light grey

mudrock, slaty, mostly fine grained; greenish grey; primary structures generally obscured

PRIMARY STRUCTURES

flat lamination and small-scale crosslamination, both indistinct

flat lamination and small-scale crosslamination, both indistinct

mostly massive; some indistinct flat lamination

a

Figure 78. *Grant Land Formation, member C_1 at the Macdonald River-1 section.* ***a)*** *Columnar log;* ***b)*** *Upper part of the Macdonald River-1 section. ISPG photo. 1360-33;* ***c)*** *Macdonald River-1 section, unit numbers as in Figure 78a, looking northeast. ISPG photo. 1360-34.*

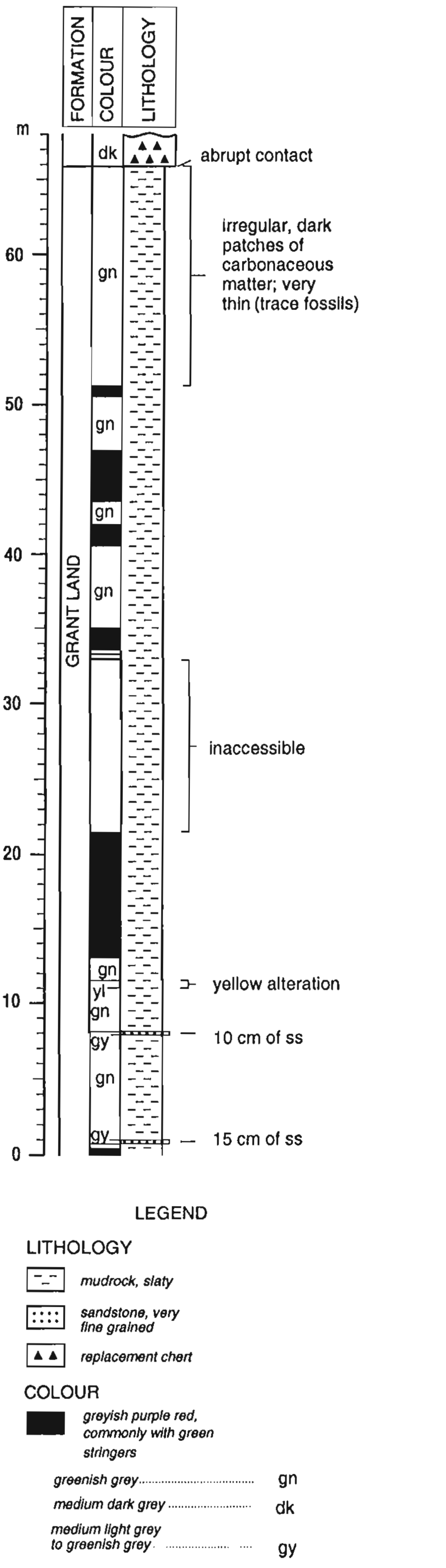


Figure 79. *Grant Land Formation; columnar log of member C_2 at the Osborn Range section.*

Microscopic aspects

Detrital composition

The main detrital components are quartz, feldspar, white mica, and chlorite, with significant proportions of resedimented carbonates in the lowermost part of the formation and with trace amounts of heavy minerals, chiefly tourmaline and zircon. The proportions of these minerals vary with clast size and stratigraphic position. The results of combined point count and X-ray diffraction analyses on selected specimens from member B are listed in Table 10. X-ray diffraction analyses are reported in Appendix 2, Tables 59 to 74, and further summarized in Table 11. Unless otherwise stated, the quantitative statements below are based on the semiquantitative X-ray diffraction data.

Resedimented carbonate detritus. This material is restricted to member A_1, where sandstones contain up to 42 per cent of this material; the largest set of data averages 26 per cent. The material consists mainly of recrystallized limestone clasts, but includes individual ooids (Fig. 80).

Quartz and feldspar. Quartz is the main constituent of all rock types. The means of groups of non-calcareous sandstone samples range from 73 to 90 per

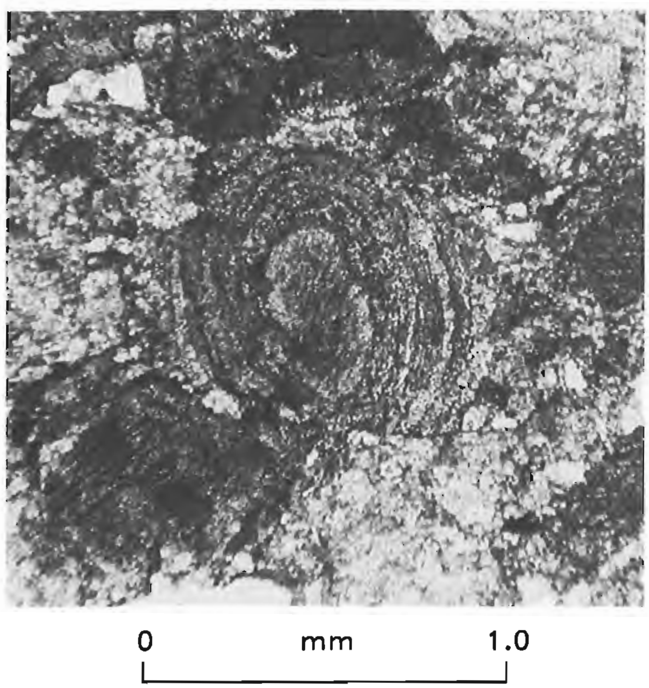


Figure 80. *Photomicrograph (ordinary light) of micritized ooid, bounded by solution contacts, in highly calcareous sandstone of the Grant Land Formation, member A_1, at the Rollrock Lake section. ISPG photo. 2260-55.*

cent, and the means of groups of noncalcareous mudrock samples from 56 to 68 per cent. Single crystals prevail, but semi-composite vein quartz and composite quartz are common in the coarser sand grades and in the granule and pebble grades. Single crystals commonly show undulose extinction.

Feldspar also is common, but its abundance varies considerably with rock type and stratigraphic position. This is most clearly apparent from variations in the ratio:

(feldspar)/(feldspar + quartz) x 100,

as inferred from X-ray diffraction peak heights. Comparison with point count analyses of stained thin sections indicates that this value has to be doubled to obtain the true value (Table 10). This relation, also observed in granitic rocks, is due to the different molecular structures of the two minerals. Briefly, feldspar is far more abundant in member B than in members A and C; and its abundance is inversely proportional to grain size, that is; greater in mudrocks than in sandstones, and greater in very fine or fine grained sandstones than in coarse grained sandstones.

TABLE 10

Grant Land Formation, member B at Tanquary Fiord and Hare Fiord East sections, combined point count and X-ray diffraction analyses of medium and coarse grained sandstones

		HFE and TF combined[1]			
		N	Range %	$\bar{X}$ %	σ %
POINT COUNT[2]	Quartz	30	40-89	61	11
	K-feldspar[3]	30	0-11	4	4
	Plagioclase[3]	30	7-33	17	6
	Muscovite	30	tr-1	tr	
	Biotite	30	0-1	tr	
	Chlorite	30	0-1	tr	
	Carbonates	30	0-9	0.5	2
	"Matrix"[4]	30	8-35	17	8
	Fsp/Fsp + Qtz	30	4-40	26	9
	Plag/Plag + K-Fsp	30	54-100	82	17
X-RAY DIFFRACTION	Quartz	29	65-94	85	6
	K-Feldspar	29	0-5	1	1
	Plagioclase	29	4-20	10	4
	Mica/Illite	29	0-8	2	2
	Chlorite	29	0-6	2	1
	Calcite	29	0-3	tr	
	Dolomite	29	0-0	0	
	Fsp/Fsp + Qtz corrected[5]	29	5-24	11	5
	Plag/Plag + K-Fsp[6]	29	62-100	92	11

[1]20 specimens from Hare Fiord East, 10 from Tanquary Fiord sections.
[2]400-500 points per section.
[3]Plagioclase stained with cobaltinitrite.
[4]"Matrix" comprises all those materials, largely of silt grade, that were not clearly identifiable.
[5]Correction factor (x2) based on point counts.
[6]Uncorrected data; point counts suggest correction factor x0.95.

The X-ray diffraction analyses indicate that the feldspar consists mainly of plagioclase (largely or entirely albite), with or without generally smaller proportions of K-feldspar (largely or entirely microcline). Point counts of stained thin sections (Table 10) indicate a correction factor of 0.95 for the ratio:

(plagioclase)/(plagioclase + K-feldspar) x 100.

This ratio has only been recorded for samples containing no less than 5 per cent of total feldspar, and therefore the database is small.

The uncorrected values for this ratio range from 40 to 100 per cent. Means of grouped data range from 56 to 100 per cent, but 13 out of 14 groups have means higher than 74 per cent, and 12 have group means higher than 81 per cent (Table 11). The relations with grain size and stratigraphic position are less persistent than they were for the feldspar/quartz relation. The available limited data suggest that the ratio declines upward in the section, and, within given units, with grain size (being lower in mudrocks than in coarse sandstones), but with some variation. The lowest values were obtained from mudrocks of member C_2.

Point count analyses of 30 stained thin sections of medium or coarse grained sandstone from member B (at Tanquary Fiord and Hare Fiord East sections) indicate average contents of 17 per cent plagioclase and 4 per cent K-feldspar (Table 10). This excludes minor amounts of intensely altered, unidentifiable feldspar, counted as "matrix".

Both plagioclase and K-feldspar usually are twinned. The common occurrence of chessboard twinning in the albite suggests that much of it has formed by replacement of K-feldspar (Smith, 1974, p. 286-290).

Mica and chlorite. As might be expected, the percentages of these two mineral groups (combined) vary inversely with grain size (Table 11). The means of grouped data average as follows: coarse sandstones and conglomerates, trace amounts to 4 per cent; fine

TABLE 11

Grant Land Formation, compilation of relevant X-ray diffraction data, based on tables of Appendix 2

			Feldspar/Feldspar + Quartz %				Plagioclase/Plagioclase + K-feldspar %				Mica				Chlorite			
Table	Rock Types	Member	N	Range	$\bar{X}$	σ	N	Range	$\bar{X}$	σ	N	Range	$\bar{X}$	σ	N	Range	$\bar{X}$	σ
59	sandstone, bimodal	A_1	18	1-8	5.6	2.7	6	86-100	92.3		18	0-3	0.9	1.0	18	0-0		
60	sandstone, bimodal	A_1	3	2-10	5.3		1		100		3	0-0			3	0-1	0.3	
61	sandstone, bimodal	A_1?	2	2-8	5.0						2	0-3	1.5		2	2-3	2.5	
62	sandstone, bimodal	A_2	2	5-7	6.0		2	100-100	100		2	1-3	2.0		2	1-2	1.5	
63	mudrock, sandy	A_1	1		12		1		100		1		6		1		0	
64	mudrock	A_1	2	10-14	12.0		2	67-83	75.0		2	22-26	24.0		2	12-13	12.5	
65	granule and pebble conglomerate	B	4	10-15	11.8		4	68-100	81.8		4	0-2	1.3		4	0-2	1.3	
66	sandstone, medium and coarse	B	29	5-24	11.1	4.7	29	62-100	92.2	10.8	29	0-8	1.8	1.9	29	0-6	1.8	1.4
67	sandstone, medium and coarse	B	20	2-18	10.6	4.5	20	58-100	80.7	13.2	20	0-13	2.4	2.7	20	0-3	1.3	1.1
68	sandstone, very fine to medium	B	12	7-33	17.4	8.0	12	71-100	93.3	8.5	12	1-3	5.7	3.3	12	1-12	5.2	3.1
69	sandstone, very fine to medium	B	7	8-16	13.0		7	59-100	85.0		7	3-13	6.4		7	2-10	5.1	
70	mudrock	B	14	5-28	13.9	6.4	13	70-94	86.8	7.8	14	5-39	17.0	8.0	14	0-21	11.6	5.3
71	mudrock	B	9	6-41	20.1		9	82-94	86.8		9	5-37	17.8		9	10-28	17.0	
72	sandstone, very fine	C_1	10	0-8	1.9	2.2	1		100		10	2-6	3.2	1.5	10	0-9	3.4	3.2
73	mudrock	C_1	2	4-6	5.0						2	5-10	7.5		2	21-30	25.5	
74	mudrock	C_2	9	5-10	7.2		5	40-81	56.3		9	7-15	10.4		9	3-30	16.4	

sandstones and coarse, sandy mudrocks, 6 to 12 per cent; and mudrocks, 27 to 37 per cent. Through most of the column, the two mineral groups are present in roughly equal proportions. However, mudrocks from member C have persistently higher proportions of chlorite.

Thin sections indicate that overall, white mica is more abundant than biotite, but trace amounts to a few per cent of biotite are present in most rocks. The detrital origin of most of the mica is evident from flakes that are several times longer than the diameter of associated quartz; such flakes are considered to be hydrodynamically equivalent to the quartz grains. The chlorite is similar in habit and evidently represents replaced biotite. However, a small proportion of the white mica and chlorite occur as diagenetic matrix.

Some mudrocks contain sand-size, rounded aggregates of chlorite and minor white mica that can be interpreted as replaced morphological glauconite (Fig. 81). Such aggregates are present in member B, but are more abundant in member C. The preponderance of chlorite in the mudrocks of member C may be related to the relative abundance of these pellets.

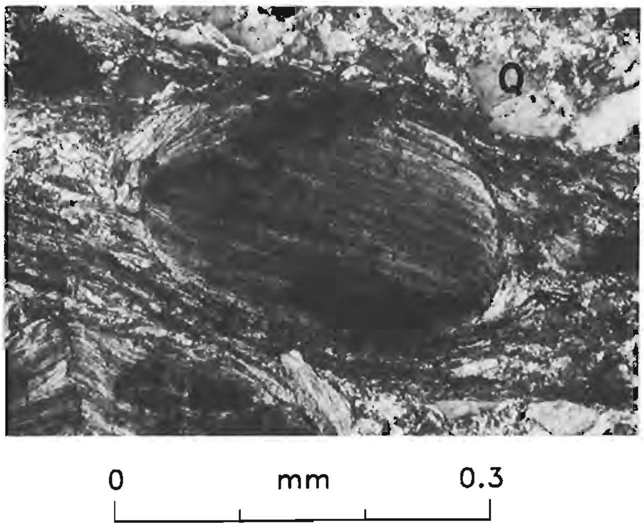


Figure 81. Photomicrograph (cross-polarized light) of a pellet of chlorite, pseudomorphous after morphological glauconite, in sandy mudrock of the Grant Land Formation, member C_1 at the Macdonald River-1 section. Q, quartz. ISPG photo. 2032-36.

Textural features of sandstones

Compositional sorting. Pronounced compositional sorting is apparent in the graded A-divisions of member A_1. They are similar to the A-divisions in the Nesmith beds in that they are bimodal sandstones. One population ranges in grade from medium grained sand to granules and consists mostly of quartz. The other population, ranging in grade from silt to medium sand, includes most of the calcite, feldspar, mica, and chlorite, and the rest of the quartz. Within individual graded beds (A-divisions), the first population diminishes upward both in grade and abundance, so that the quartz content decreases and the detrital calcite content increases (Fig. 66). By contrast, bases and tops of graded beds in the lowermost part of member A_2 have similar mineral compositions (Fig. 67).

Size sorting. The statistical parameters of the grain size distribution of quartz and feldspar in 12 specimens of very fine to coarse grained sandstones are listed and discussed in Trettin, 1971 (p. 25, 126). They were based on the measurement of 100 grain diameters per thin section. The standard deviations, ranging from 0.56 to 1.44 phi units[1] indicate moderately poor to poor sorting. The phi-skewness is mainly positive, although four specimens have small negative values.

No statistical grain size analyses were made on the samples from the Hare Fiord East and Tanquary Fiord sections. However, the relation between the estimated average grain size and the measured maximum grain size in thin sections is indicated in the columnar logs of Figure 68. Many samples show a considerable spread between these two parameters (usually between 1.5 and 3 phi units), again indicating relatively poor sorting in various rock types.

In contrast to member B, the sandstones of member C_2 do not contain coarse fractions and are well sorted.

Rounding and pressure solution. Quartz and feldspar appear to have been rounded originally, but have been modified to a large extent by pressure solution (see below), and are now mostly subrounded or subangular (Fig. 82).

Diagenetic matrix. The framework grains are embedded in a matrix of intergrown quartz, white mica, and chlorite, that probably is mainly diagenetic

[1]The phi scale, commonly used in sedimentology, is a logarithmic transformation of the Wentworth grade scale, based on the negative logarithm to the base 2 of the particle diameter (in mm). 1/16 mm = 4 phi, 1/8 mm = 3 phi, 1/4 mm = 2 phi, 1/2 mm = 1 phi, 1 mm = 0 phi, 2 mm = -1 phi, 4 mm = -2 phi.

in origin because it appears to replace detrital quartz and feldspar.

Diagenesis and metamorphism

The most important diagenetic changes, apparent in thin section, are:

1. Partial replacement of silicates by carbonate minerals.

2. Partial solution of feldspar, which probably has generated the diagnetic matrix described above.

3. Pressure solution, which has transformed rounded grains of quartz and feldspar into predominantly subrounded or angular grains.

4. In some specimens, the formation of aligned, elongate aggregates ("beards") of diagenetic quartz, white mica and chlorite, that are probably located in strain shadows (Fig. 83).

In most of the area, incipient metamorphism is restricted to the fine grained mudrocks. Any clay minerals that may have been present originally have recrystallized to white mica and chlorite of silt grade. Most of this material shows preferred orientations, which impart slaty cleavages to the rocks, but the characteristic pellet shape of morphological glauconite has survived.

On the other hand, the preservation of minor amounts of detrital biotite and K-feldspar in many sandstones indicates that these rocks have not attained the greenschist facies of regional metamorphism in most of the area. However, sandstones at the north end of Piper Pass, near the Porter Bay Fault, have a schistose texture (Trettin, 1971, Fig. 17). Some coarse siltstones and silty sandstones rich in mica show an incipient crenulation cleavage defined by alignment of microscopic folds in the mica. This is probably not a metamorphic feature as the mica flakes appear to be of detrital origin.

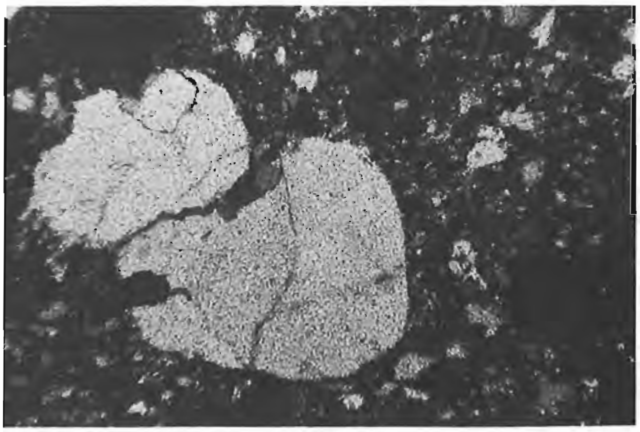


Figure 82. Photomicrograph (cross-polarized light) of rounded quartz showing pressure solution; Grant Land Formation, member A at the Macdonald River-1 section. ISPG photo. 2260-62.

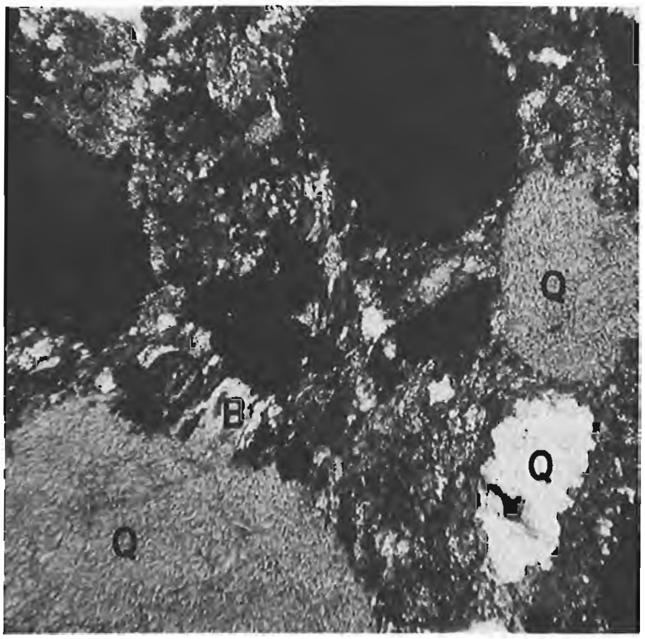


Figure 83. Photomicrograph (cross-polarized light) of calcareous sandstone of the Grant Land Formation, member A_1 at the Henrietta Nesmith Glacier section. Q, quartz (note jagged grain boundaries, due to solution); C, detrital carbonate grain; B, "beard" — diagenetic growths mainly of quartz with minor muscovite, chlorite, and calcite in the strain shadow. ISPG photo. 2260-52.

Mode of origin

Sediment sources

Siliciclastic material. Metamorphic–plutonic terranes must have been the ultimate source of the detrital quartz, feldspar, mica, and chlorite, and sediments rich in feldspar and biotite were probably derived directly from such sources. Mature quartz sandstones with low feldspar content either were derived from recycled Proterozoic–Lower Cambrian sediments or, if they were first-cycle deposits, were subjected to feldspar destruction in high-energy nearshore environments or within the Grant Land Formation during deep burial.

Two potential sources of this material have to be considered — the crystalline basement of Pearya, and the Canadian Shield. In the absence of relevant sedimentological information (e.g., paleocurrent determinations, isopach maps, or maps showing clast size variations within well defined subunits) an attempt was made to resolve this question by U-Pb age determinations on detrital zircon (Trettin et al., 1987). The zircon was separated from a sample of coarse to very coarse grained, feldspar-rich sandstone (collected at the Tanquary Fiord section) that appeared to have been derived directly from metamorphic-plutonic sources.

The zircons were colourless to red and subhedral to rounded, the diversity in shape reflecting variable abrasion during sedimentary transport. This rather diverse population was divided into four fractions, using colour and shape criteria. The U-Pb results on these fractions are very discordant, probably indicating diversity of age in the source terrane. The apparent ages of the four fractions range from 2.2 to 2.4 Ga, but the true age may be as old as 2.5 Ga if Pb loss had occurred prior to deposition. These results seem to rule out derivation from Pearya, which should have yielded zircons about 1 Ga in age, and suggest derivation from the northern Canadian Shield[1].

Carbonate fragments. The presence of ooids indicates that at least some carbonate clasts were derived from an adjacent shelf, perhaps a shallow shelf margin where high-energy conditions existed. Strata of the uppermost Ella Bay Formation are the most likely source of this material. The upward disappearance of carbonate clasts coincides with the transition from carbonate to siliciclastic deposition on the Franklinian Shelf in Early Cambrian time (Ella Bay Formation to Ellesmere Group).

Mechanisms and environments of deposition

Member A

The common occurrence of turbidites beginning with member A of the Bouma model suggests deposition in a relatively proximal submarine fan environment, perhaps lobes of the outer fan (Facies Association C of Mutti and Ricci Luchi, 1975).

Member B

The modes of transportation and environments of deposition of this member are problematic.

Lithofacies S. The structureless sandstones and associated conglomerates evidently were deposited by currents that were capable of eroding and transporting large fragments of mudrock. The massive nature of the strata, combined with relatively poor sorting, suggest subaqueous, turbulent debris flows although they lack an abundant muddy matrix of primary origin. The associated laminated sediments were deposited by tractive currents of uncertain origin.

Apart from some lenticular conglomerates that filled shallow scours, a few metres wide, no field evidence of channelling has been seen. Thus, if lithofacies S represents channel fills, the channels must have been flat bottomed and wider than the outcrops examined.

Lithofacies P. As mentioned, the primary structures of the pelitic units have been obscured to some degree by cleavage. Flat lamination and ripple marks are common. Repetitive graded bedding has not been noted; if present, it must be subtle.

If conventional models of sedimentation on submarine fans are applied, lithofacies P must represent levee and overbank deposits, perhaps of an inner fan environment dominated by channel complexes (cf. Mutti and Ricci Luchi, 1975; Mutti, 1979; Hiscott and Middleton, 1979; Hiscott, 1980). If so, they should be "distal" Bouma sequences, involving divisions C, D, and E, and they should pass laterally into sandy and conglomeratic deposits, but this does not seem to be the case.

A possible alternative interpretation is given by the concept of "inefficient" transport (Mutti, 1979; Link and Nilsen, 1980; Nilsen, 1980; Homewood and

[1]Recently, $^{207}Pb/^{206}Pb$ age determinations have been made on single zircon crystals from the same sample analyzed by Trettin et al. (1987). Concordant or nearly concordant analyses indicate crystallization in the Early Proterozoic (1750, 1827, 1841, 1853, and 1950 Ma) and Archean (2688 and 2710 Ma; V. McNicoll, pers. comm., March 1992).

Caron, 1982). According to this concept, lithofacies S was deposited by gravity flows that did not develop into turbidity currents because of a scarcity of mud. Such flows may have originated in canyons that tapped sand-rich, nearshore environments. Lithofacies P would have been deposited by unrelated mechanisms; for example, by low-density turbidity currents or nepheloid layers, generated by storms in muddy offshore environments or by contour currents. The alternation of the two modes of deposition might have been due to fluctuations in sea level or to changes in supply caused by other mechanisms (e.g., lateral shifts of distributaries).

The alternation of greyish red-purple mudrocks with greenish grey mudrocks evidently indicates frequent changes from oxidizing to reducing conditions on the seafloor or in the shallow subsurface. Although most redbeds in the geological record seem to have formed in shallow marine and nonmarine environments, a smaller proportion, occurring in flysch successions of Cambrian to Tertiary age (e.g., Lajoie and Chagnon, 1973; Faupl and Sauer, 1978), must have formed in deeper water environments. In present deep-sea environments, brown or red clays are common where accumulation rates are very slow (Kennet, 1982, p. 426–427). Thus the red-purple mudrocks in the Grant Land Formation cannot be used as indicators of water depth.

Member C

The only indicators of deep water conditions are the rare massive sandstones in member C_1, which probably were deposited by sandy debris flows or high-density turbidity currents, like those in member B. The fining-upward trend in this unit probably is supply related because it also is apparent in the uppermost part of the Ellesmere Group (Kane Basin Formation). The trend probably was caused by a marine transgression on the Franklinian Shelf (see Ellesmere Group, Mode of origin).

Trace fossils, age, and correlation

Trace fossils are rare and limited to mudrocks in the uppermost part of the formation (upper part of member B and possibly member C). *Oldhamia* has been found northwest and east of the head of Tanquary Fiord (Hofmann, Appendix 3, C-194462, C-194463), and the undiagnostic *Planolites* east of the head of Tanquary Fiord (Hofmann, Appendix 3, C-194464) and at the top of of the Hare Fiord East 1 (HFE-1) section. *Oldhamia* is of Early Cambrian age. In the Yukon it occurs in Lower Cambrian sediments that are comparable in stratigraphic position, lithology, and inferred depositional environment to the upper Grant Land Formation (Hofmann and Cecile, 1981; Cecile, 1988; Lane and Cecile, 1989). It also has been reported from adjacent northeastern Alaska (Churkin and Brabb, 1965).

Regional lithological features suggest that the bulk of the Grant Land Formation is correlative with the Ellesmere Group because of the following relations:

1. The Ellesmere Group and Grant Land Formation constitute the only major siliciclastic units within the entire Cambrian and Ordovician successions of the Central Ellesmere and Hazen fold belts.

2. Both the Ellesmere Group and Grant Land Formation are underlain by carbonate units (Ella Bay Formation and Nesmith beds).

3. The uppermost parts of the two units, the Kane Basin Formation and member C_2 of of the Grant Land Formation, are similar macroscopically and microscopically. Both, for example, contain chlorite/white mica pellets reminiscent of morphological glauconite, and diagenetic carbonate minerals.

4. Within the Hazen Fold Belt, both of these uppermost units are overlain by the Hazen Formation.

The fact that the lowermost part of the Grant Land Formation (member A_1) contains carbonate material, probably derived from the Ella Bay Formation, suggests that these strata are correlative with the hiatus between the Ella Bay and Archer Fiord formations and possibly also with the uppermost part of the Ella Bay Formation.

The proposed correlation is strengthened by comparison with northeasternmost Greenland (Friderichsen et al., 1982). The Nesmith beds, as mentioned, are comparable to the Paradisfjeld Formation, and the Grant Land Formation is comparable to the Polkorridoren Group, which has been placed in the Early Cambrian (Fig. 6). The latter is correlative with the fossiliferous Buen Formation, equivalent to the Ellesmere Group.

HAZEN FORMATION

A succession of "chert, shale, siltstone and limestone with minor amounts of breccia and dolomite", lying stratigraphically between the Grant Land and Imina formations, was named Hazen

Formation by Trettin (1971). Fossils from the middle and upper parts of the type section at St. Patrick Bay, Robeson Channel [Figs. 84, 85 (loc. SPB), 139] suggested an early to late Middle Ordovician age range. The lower part of the formation in that area is incompletely exposed and unfossiliferous.

Subsequent studies have led to the following major revisions:

1. The lower part of the formation was found to be well exposed at Ella Bay and a reference section representing almost the entire formation [Ella Bay 1 section (EB1), Figs. 1, 85, 135] was established there.

2. Fossil collections indicate an age range from late Early Cambrian to Early Silurian for the Hazen Formation.

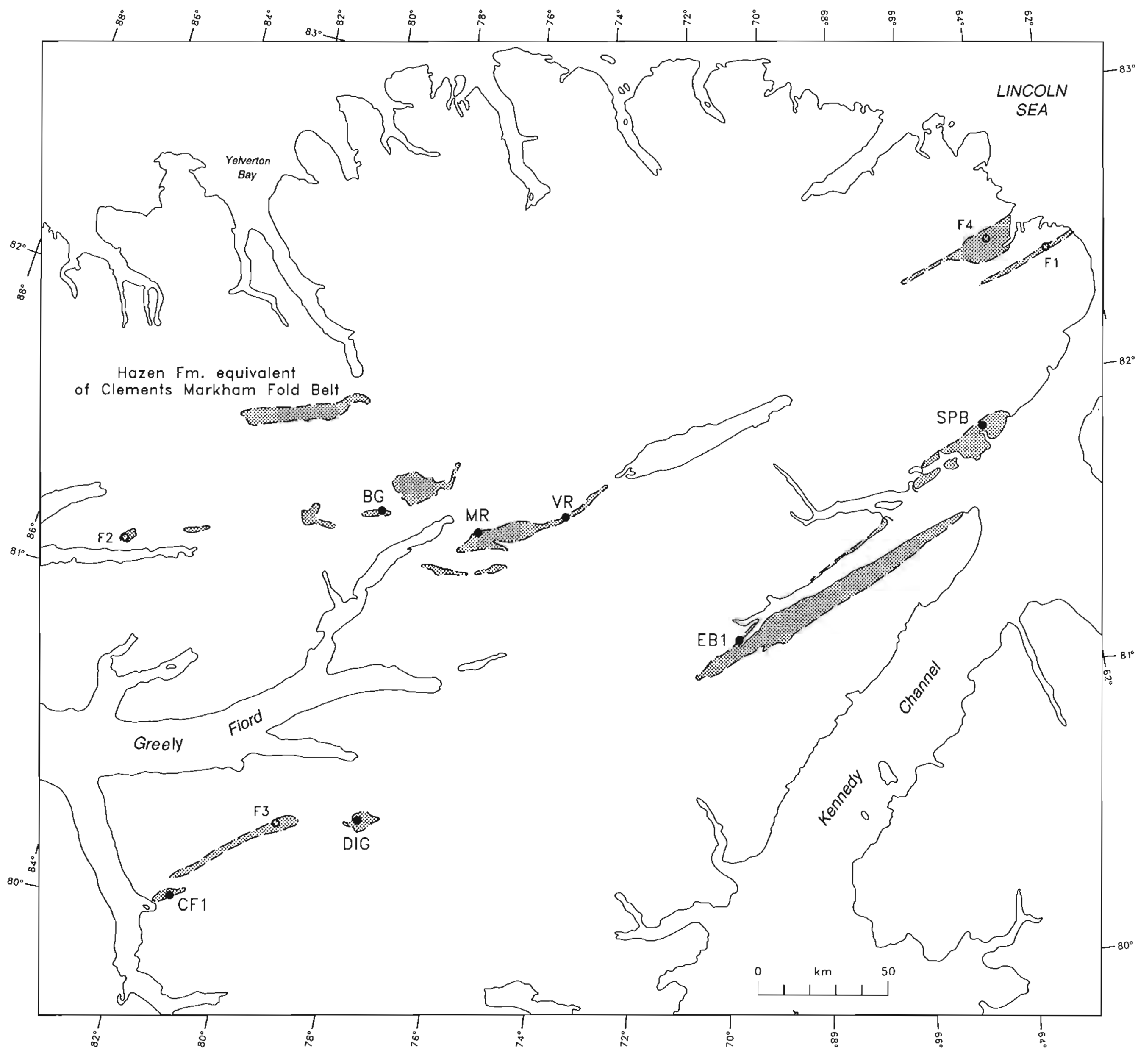


Figure 84. Distribution of the Hazen Formation in the project area and location of stratigraphic sections and of some fossil localities (F1-F4). Along line of stratigraphic cross-section (Fig. 85): CF1, Cañon Fiord 1 (section 1 of Trettin, 1979); DIG, d'Iberville Glacier; EB1, Ella Bay 1; SPB, St. Patrick Bay; VR, Very River; MR, Macdonald River; BG, Bent Glacier. For stratigraphic sections and fossil localities in the Ella Bay area, see Figure 1.

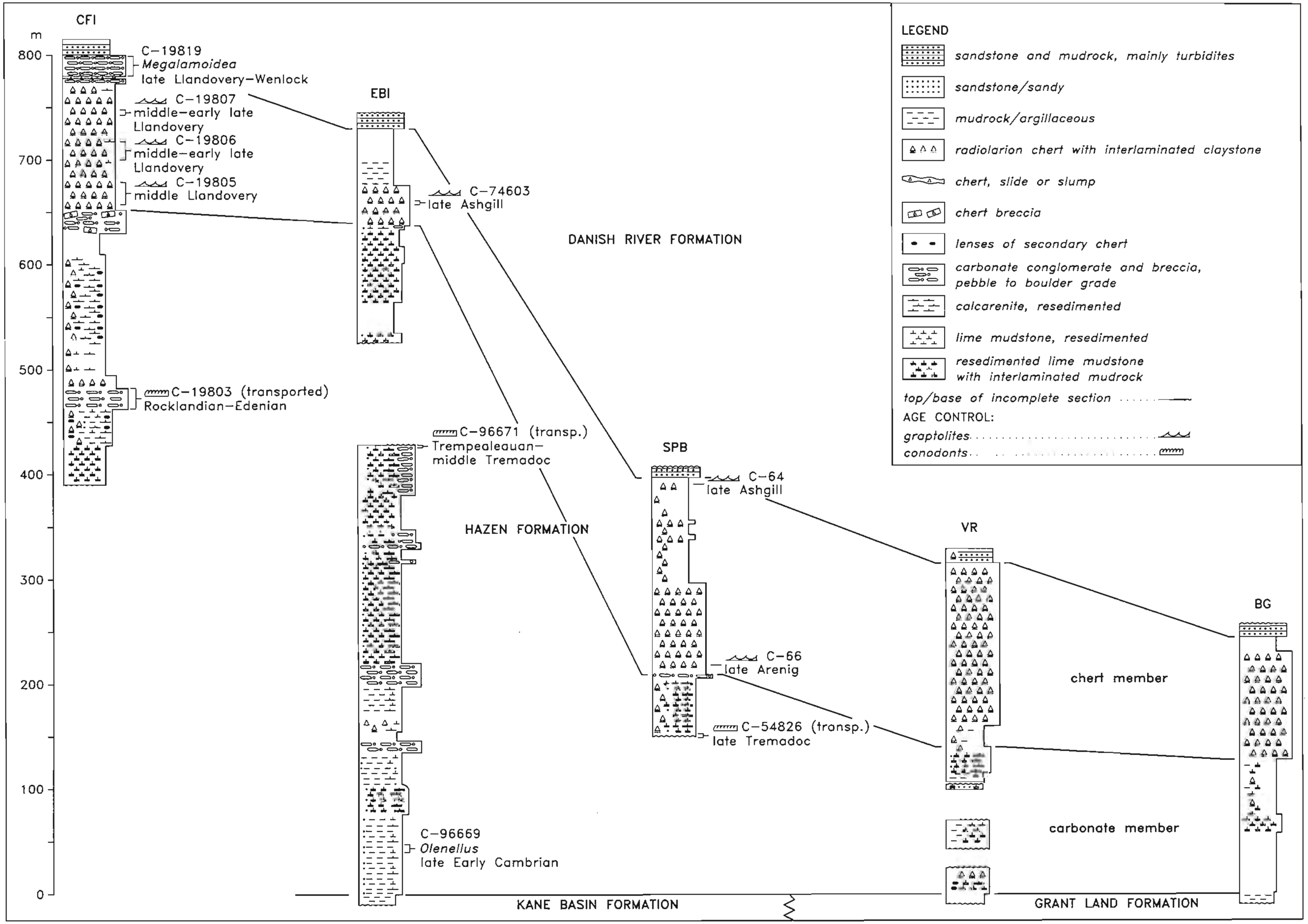


Figure 85. *Hazen Formation; columnar presentation of stratigraphic sections. For name and location of sections, see Figure 84.*

3. The strata underlying the Hazen Formation in the vicinity of Archer Fiord are now assigned to the Kane Basin Formation, and the strata overlying the Hazen Formation in the entire Hazen Fold Belt (except for the transition to the Central Ellesmere Fold Belt southeast of Ella Bay) are now assigned to the Danish River Formation.

Distribution, thickness, and contact relations

Within the Hazen Fold Belt, major belts of scattered outcrop areas occur north and northeast of Caledonian Bay, Cañon Fiord; around Archer Fiord and Ella Bay; on the northeastern Hazen Plateau; and between Lake Hazen and the area north of central Hare Fiord (Fig. 84). Equivalents of the Hazen Formation also occur in the Clements Markham and Northern Heiberg fold belts.

Measured thicknesses range from more than 632 m north of Ella Bay (Ella Bay 1 section) to about 241 m at Bent Glacier (Bent Glacier section). The formation probably increases in thickness between the Ella Bay 1 section and the facies boundary with carbonate units of the Franklinian Shelf. No complete sections are exposed in that area, but the increase is apparent from comparison of the upper part of the Ella Bay 1 section with the Cañon Fiord 1 section (CF1), which is incomplete (Fig. 85), and also from thickness variations in the lowermost part of the formation at Ella Bay (Fig. 90, below).

At Ella Bay, the contact with the Kane Basin Formation is conformable and gradational and placed at the base of the lowest bed of resedimented carbonates. It coincides approximately with a change in tone from medium grey to medium dark grey that is mappable in the field and also apparent on aerial photographs (Fig. 86).

The contact with the Grant Land Formation is abrupt and problematic. In the Osborn Range, northwest of the head of Tanquary Fiord, the mudrock

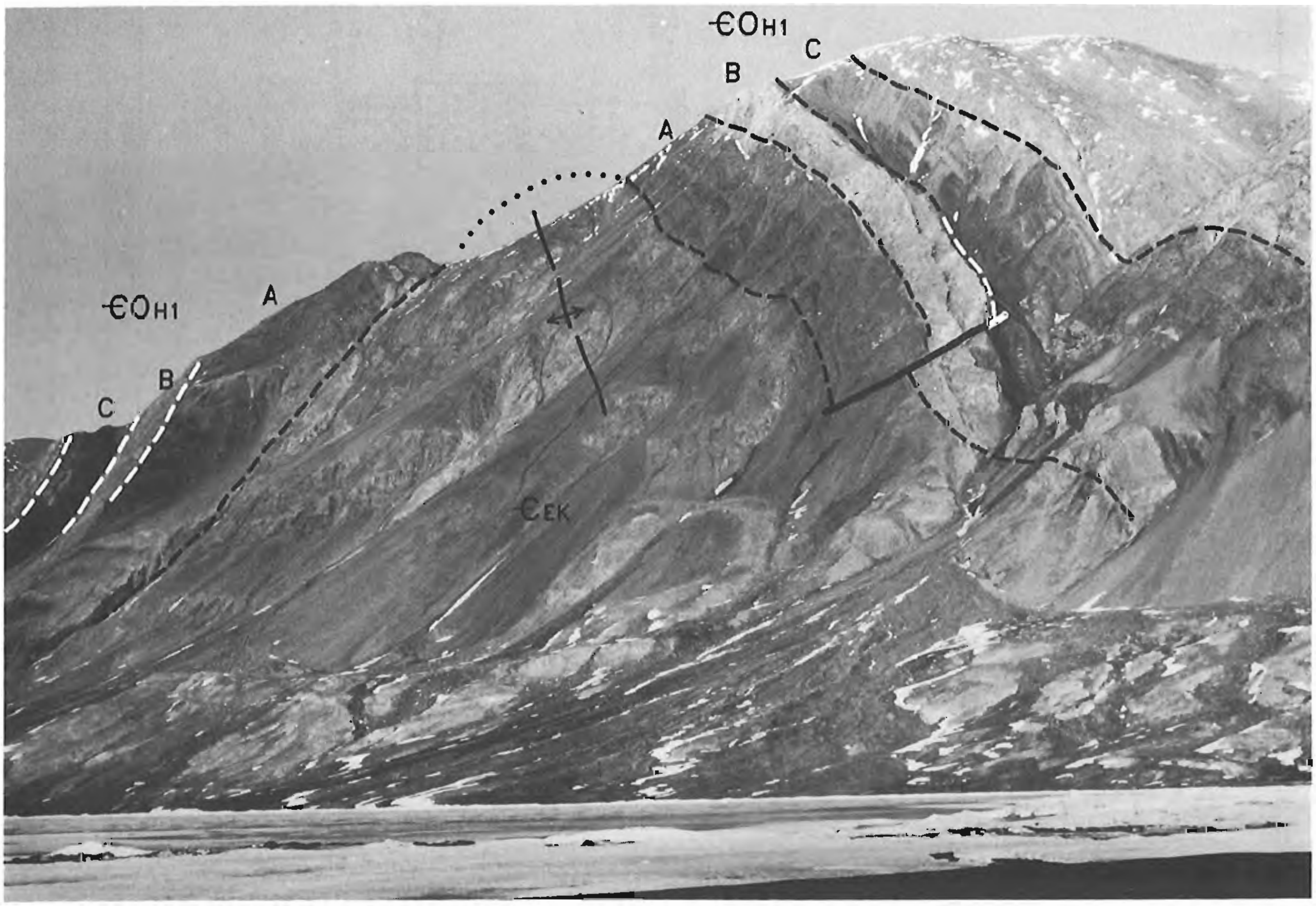


Figure 86. The Kane Basin Formation and lower Hazen Formation in an anticline southeast of the head of Ella Bay, view east. $Є_{EK}$*, Kane Basin Formation;* $ЄO_{H1}$*, Hazen Formation, carbonate member; A, B, C, subdivisions of lowermost Hazen Formation. ISPG photo. 978-39.*

and carbonates of the lower Hazen Formation have been replaced by dark grey chert, which has a sharp contact with medium light grey mudrock of the Grant Land Formation (Fig. 87). A similar abrupt contact between mudrock and chert is seen north of central Hare Fiord [Hare Fiord East section (HFE), Fig. 61]. At Very River (Section VR), basal lime mudstone of the Hazen Formation lies with sharp contact on medium grey mudrock of the Grant Land Formation (Fig. 88), but mudrocks interbedded with carbonates in the lowermost part of the formation are closely similar to mudrocks in the uppermost Grant Land Formation. The contact is similar at Macdonald River, except that the mudrock of the Grant Land Formation there is greenish grey. The abruptness of this contact may indicate a submarine disconformity, but there is no evidence of emergence and erosion; both underlying and overlying sediments are of deep water aspect.

The contact with the Danish River Formation is structurally conformable and stratigraphically gradational in some areas; in other areas it is abrupt, but without evidence of emergence (see below, Danish River Formation). The contact with the Bulleys Lump Formation, which may be faulted, is discussed below (Stratigraphic synthesis, Ella Bay Escarpment).

Lithology

The Hazen Formation consists of resedimented carbonates, mudrock, and chert (radiolarian and secondary), with minor amounts of calcareous and dolomitic sandstone. The predominance of carbonates in the lower part of the formation and of radiolarian chert in the upper part permits division into two members, informally referred to as the carbonate and chert members (Fig. 88). However, in some areas this division has been obscured by pervasive chertification of the carbonate member.

Figure 87. Contact between the Hazen Formation (dark grey, above) and Grant Land Formation (light and dark, below) in the Osborn Range (section OR of Figure 61), looking northeast. The Hazen Formation (dark grey) is here replaced by chert. The banded appearance of the Grant Land Formation is due to the alternation of purple-red and grey or greenish beds. ISPG photo. 1584-1.

Carbonate member

Measured thicknesses range from more than 540 m at the Ella Bay 1 section to about 127 m at Bent Glacier.

The member consists mainly of impure, resedimented carbonates, ranging in grade from lime mudstone through calcarenite and conglomerate to large allochthonous blocks; calcareous mudrock and minor sandstone; and minor amounts of radiolarian chert.

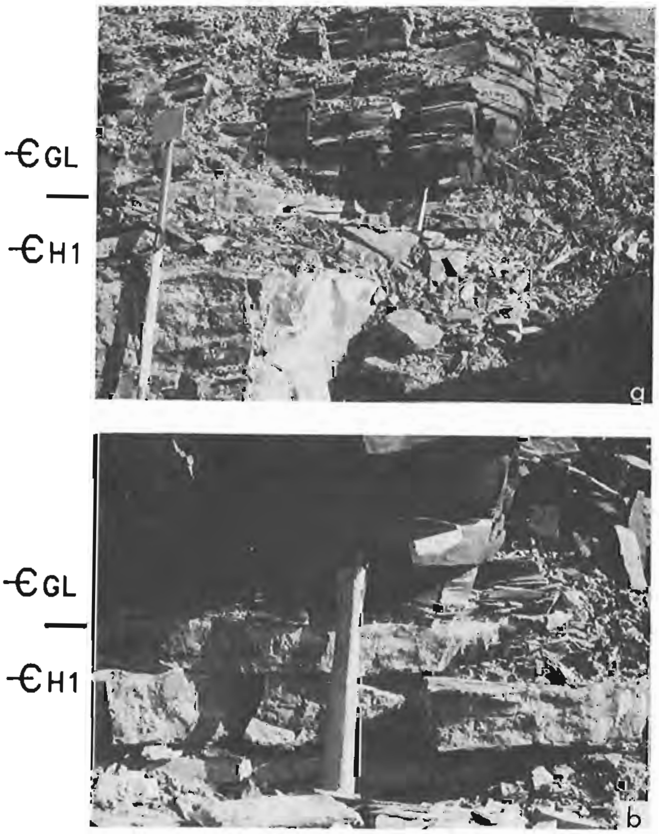


***Figure 88.** a) Overturned contact between dark grey mudrock of the Grant Land Formation ($Є_{GL}$) and limestone and interbedded mudrock of the Hazen Formation ($Є_{H1}$) in a recumbent anticline near Very River; **b)** close-up view of (a). ISPG photos. 648-44, 648-37.*

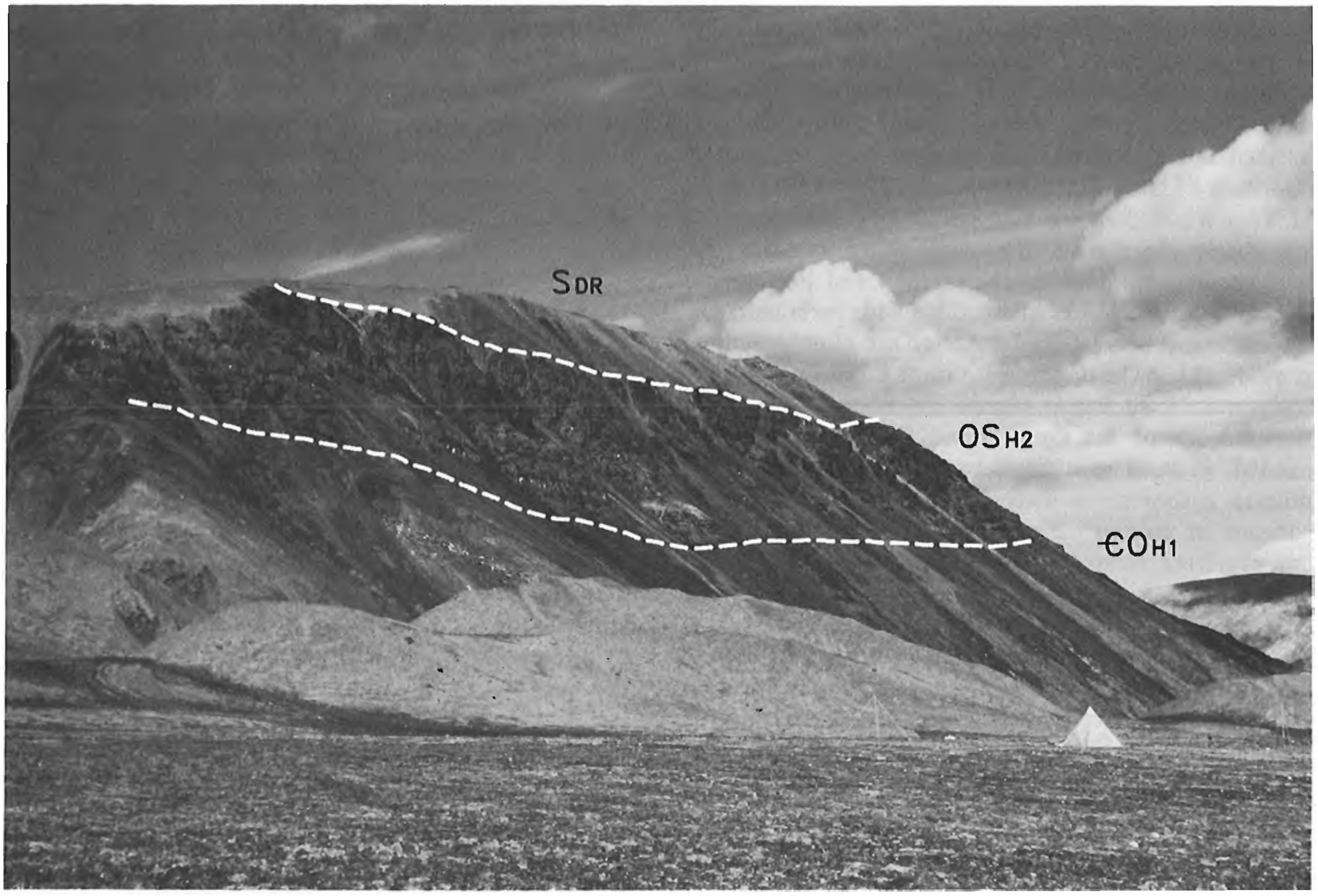


Figure 89. Carbonate member ($ЄO_{H1}$) and chert member (OS_{H2}) of the Hazen Formation, overlain by the Danish River Formation (S_{DR}) at Very River section, looking northeast. ISPG photo. 648-38.

Four subdivisons (A to D) are recognized in the lower part of the formation at Ella Bay (Ella Bay 1 and Ella Bay 5 to 9 sections). The succession at the Ella Bay 1 section can be summarized as follows:

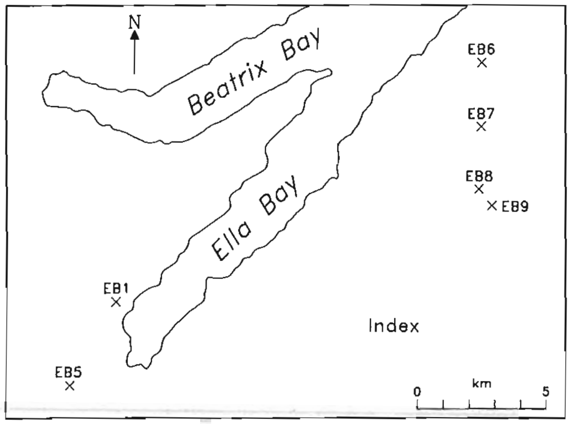
(overlying strata: mudrock, lime mudstone, calcarenite, etc.)

Subdivision D (21.3 m)	carbonate conglomerate, granule to cobble grade; relatively light grey from a distance, resistant
Subdivision C (51.7 m)	C_2: (30.25 m) mudrock, minor lime mudstone, calcarenite; medium grey, recessive
	C_1: (21.45 m) mainly radiolarian chert, dark grey; minor mudrock, lime mudstone, calcarenite; recessive, lower 10 m covered
Subdivision B (11.5 m)	carbonate conglomerate, granule to cobble grade; relatively light grey from a distance, resistant
Subdivision A (133.5 m)	interbedded mudrock, lime mudstone, calcarenite, and sandstone; medium to medium dark grey, recessive

Variations in thickness of these four subdivisions are listed in Figure 90. At the Ella Bay 9 section (EB9), subdivision B includes a 31.5 m thick allochthonous block in addition to the typical conglomerate. The lateral extent of the four subdivisions beyond the area investigated is unknown. It is known, however, that across strike they terminate about 1 km southeast of the Ella Bay 9 section (EB9). Farther southeast, conglomerate and chert are absent and the exposures consist entirely of fine grained calcareous and siliclastic sediments referred to as the laminated facies of the carbonate member (map-unit $ЄO_{H1\text{-}lam}$ of Fig. 1 and Fig. 96, below).

A relatively resistant subdivision, mappable in the field (Fig. 91; also Trettin, 1971, Fig. 48) and from airphotos (Fig. 140), forms the lowermost part of the carbonate member in a belt extending from east of the head of Tanquary Fiord northeastward to Wood River (west of Alert). This subdivision is conspicuous

SUBDIVISION		SECTION EB5	EB1	EB6	EB7	EB8	EB9
D			21.3	20.25	30.0	37.5	28.0
C	c		30.25				40.0
C		—	51.7	19.5	31.0	—	66.5
C	c	43.2	21.45				26.5
B	slide	0	0	0	0		31.5
B		26.0	11.5	9.0	13.0	5.0	43.5
B	conglo-merate	26.0	11.5	9.0	13.0	5.0	12.0
A		163.5	133.5	70.0	98±		119.0



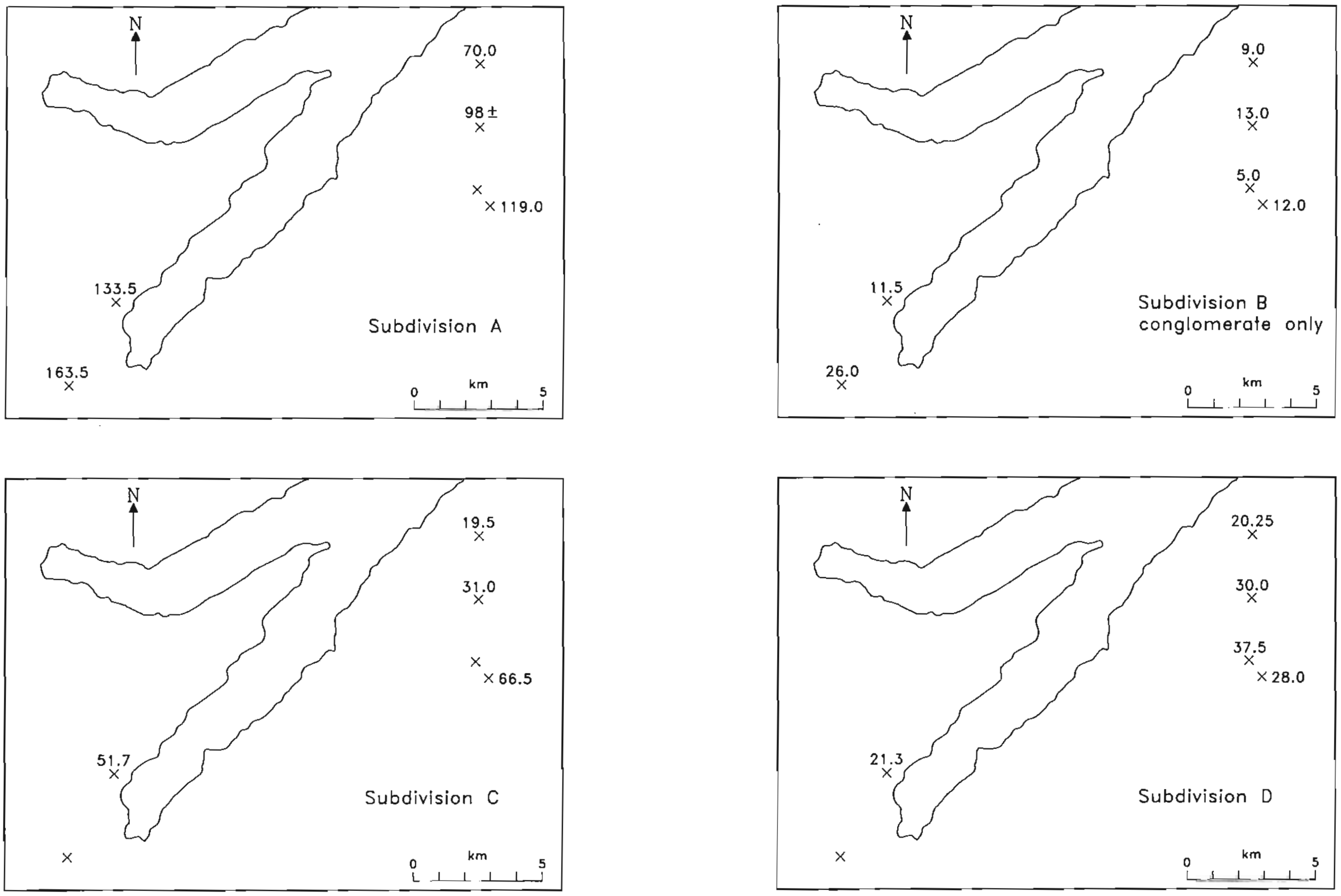


Figure 90. Hazen Formation; thickness (in metres) of subdivisions A to D of the carbonate member.

because its limestone beds are thicker (up to 50 cm) and more abundant than in the rest of the carbonate member (Fig. 92). It is 19 m thick at Macdonald River, and 12 m thick at Very River.

Chert member

Measured thicknesses range from zero to perhaps 218 m (Fig. 93). The member is thickest on the Hazen Plateau (St. Patrick Bay to Macdonald River) and thins both to the southeast and northwest. The southeastward thinning is due to a decrease in age span as the base becomes younger; the northwestward thinning (at the Bent Glacier section) is due to a thinning of the entire formation.

In most areas the member consists largely of thin bedded radiolarian chert and interlaminated mudrock, with or without small amounts of lime mudstone and calcarenite. However, at Caledonian Bay (Section CB1) a limestone boulder conglomerate, 27 m thick, occurs at the top of the member and formation. It was previously treated as a separate informal member (Trettin, 1979), but is here included in the chert member because of its limited areal extent.

Description of rock types

Mudrock is one of the most abundant constituents of the carbonate member and a lesser, but important, constituent of the chert member. It occurs in units ranging in thickness from a few tens of micrometres to

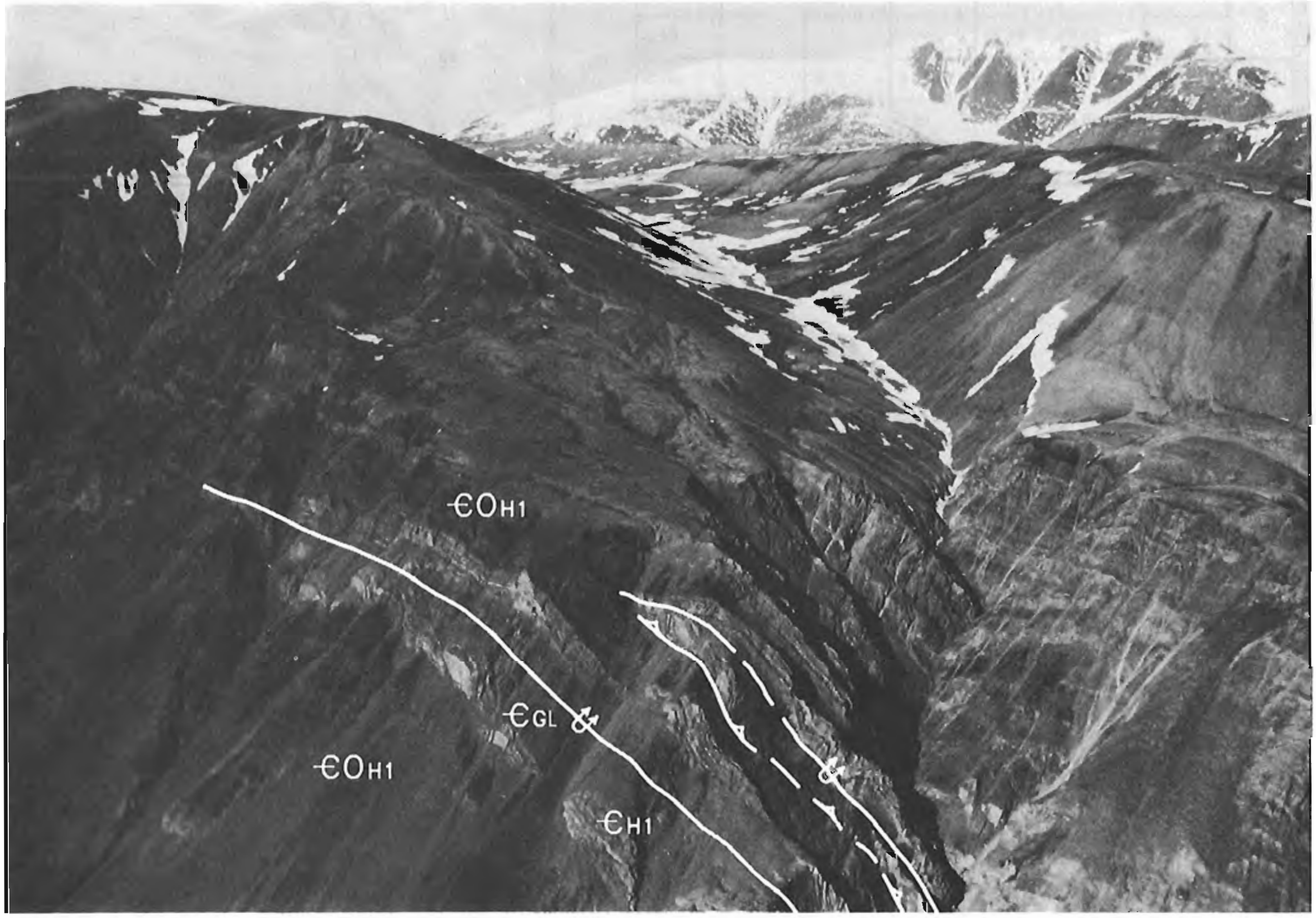


Figure 91. *Overturned anticlines and a minor thrust fault marked by the lower, resistant carbonate unit of the carbonate member of the Hazen Formation north of Macdonald River (Є$_{H1}$), looking northwest. This unit is overlain by darker, recessive strata of the carbonate member (ЄO$_{H1}$). The uppermost part of the Grant Land Formation (Є$_{GL}$) is exposed in the core of the two anticlines. ISPG photo. 648-47.*

Figure 92. *Limestone (resistant strata) with interbedded mudrock (thin recessive strata) in the lower, resistant carbonate unit of the carbonate member of the Hazen Formation near Very River. ISPG photo. 648-41.*

several metres, but usually is thinly interstratified with lime mudstone and minor sandstone and calcarenite (Figs. 94-96). A thin, flat lamination, caused by vertical variations in grain size, mineral composition and/or concentration of carbonaceous matter, is the predominant primary structure. In some sections, for example at Ella Bay (Ella Bay 1 section), this lamination has to some extent been disturbed by burrowing organisms. Some laminae have sharp bases and show an upward decrease in grain size (Fig. 97). Small-scale crosslamination has been observed mainly in mudrocks that are interlaminated with sandstone, calcarenite, and lime mudstone. Microscopic crosslamination at low angles is apparent in mudrocks at d'Iberville Glacier (see Appendix 1) that form small lenses in lime mudstone.

Most mudrocks are medium dark grey, but some strata near the base of the formation are medium grey. Seen in thin section, the average grain size varies from very fine to very coarse silt grade, but coarse siltstones commonly include very fine grained sand. Clay-size particles seem to have recrystallized to silt grade. The composition of 36 samples analyzed by XRD is summarized in Appendix 2, Tables 75 to 79. The average composition is: quartz, 55 per cent; carbonates, 24 per cent; feldspar, 18 per cent; chlorite, 6 per cent; and mica, 5 per cent. The carbonate

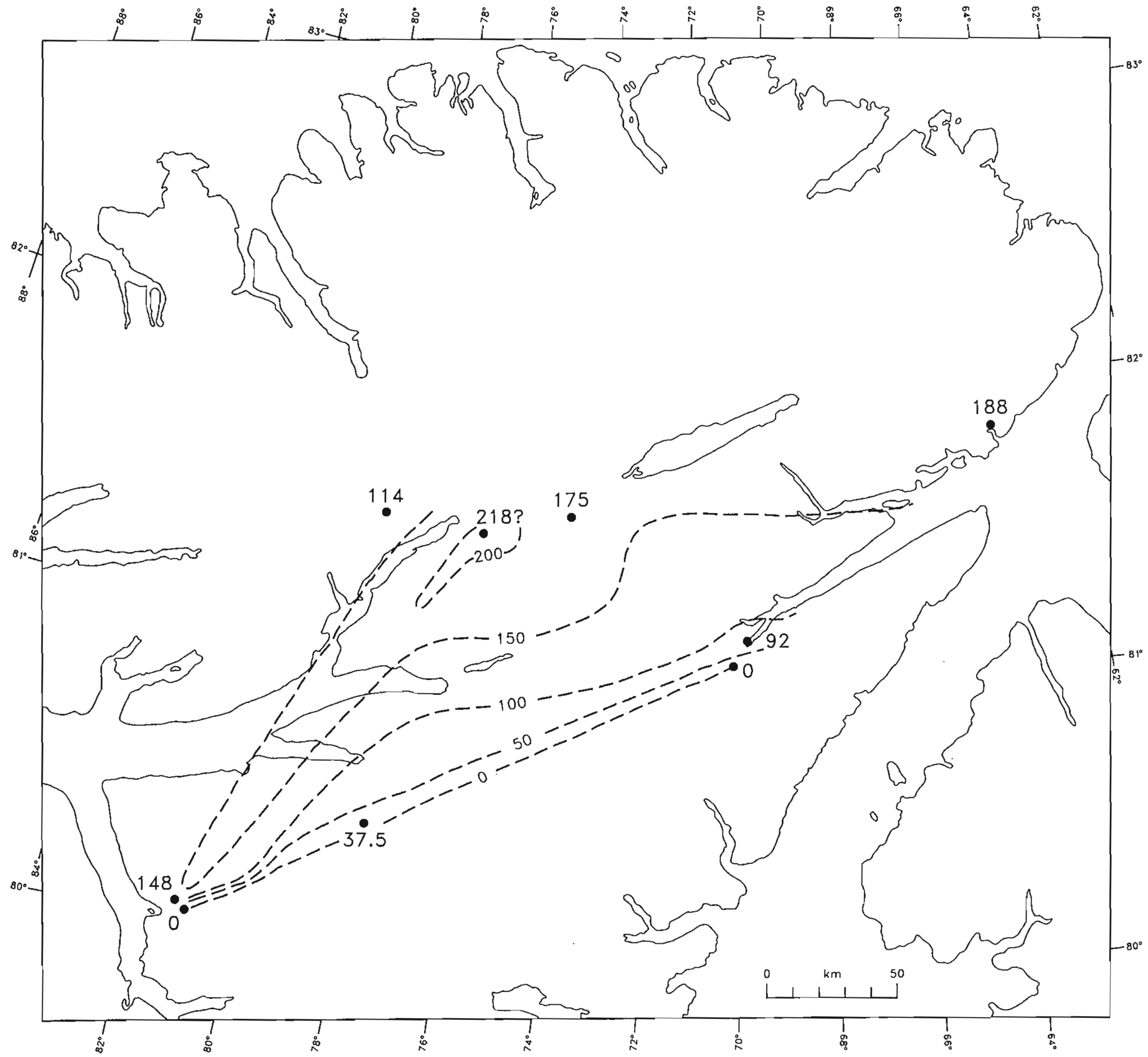


Figure 93. Hazen Formation; thickness (in metres) of the chert member.

Figure 94. Thinly interstratified, calcareous, argillaceous, and sandy sediments of the carbonate member of the Hazen Formation, showing predominantly flat lamination; Ella Bay 1 section, 259 m. ISPG photo. 978-45.

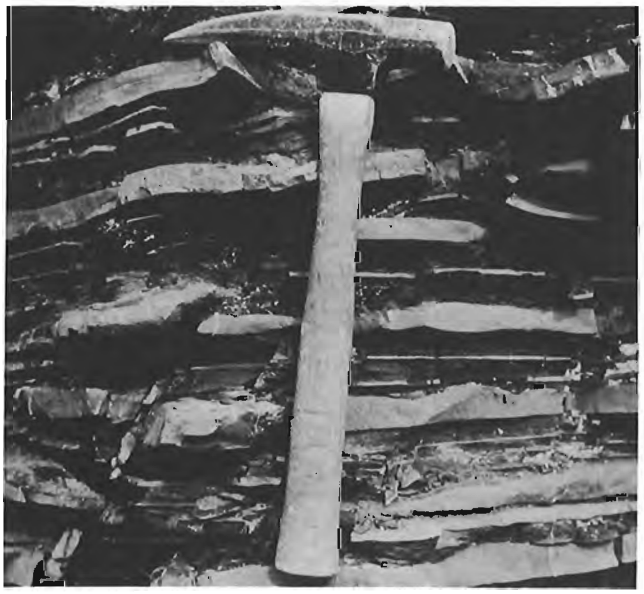


Figure 95. Thinly interstratified limestone (resistant) and mudrock (recessive) in the lower part of the carbonate member of the Hazen Formation at Very River. ISPG photo. 648-39.

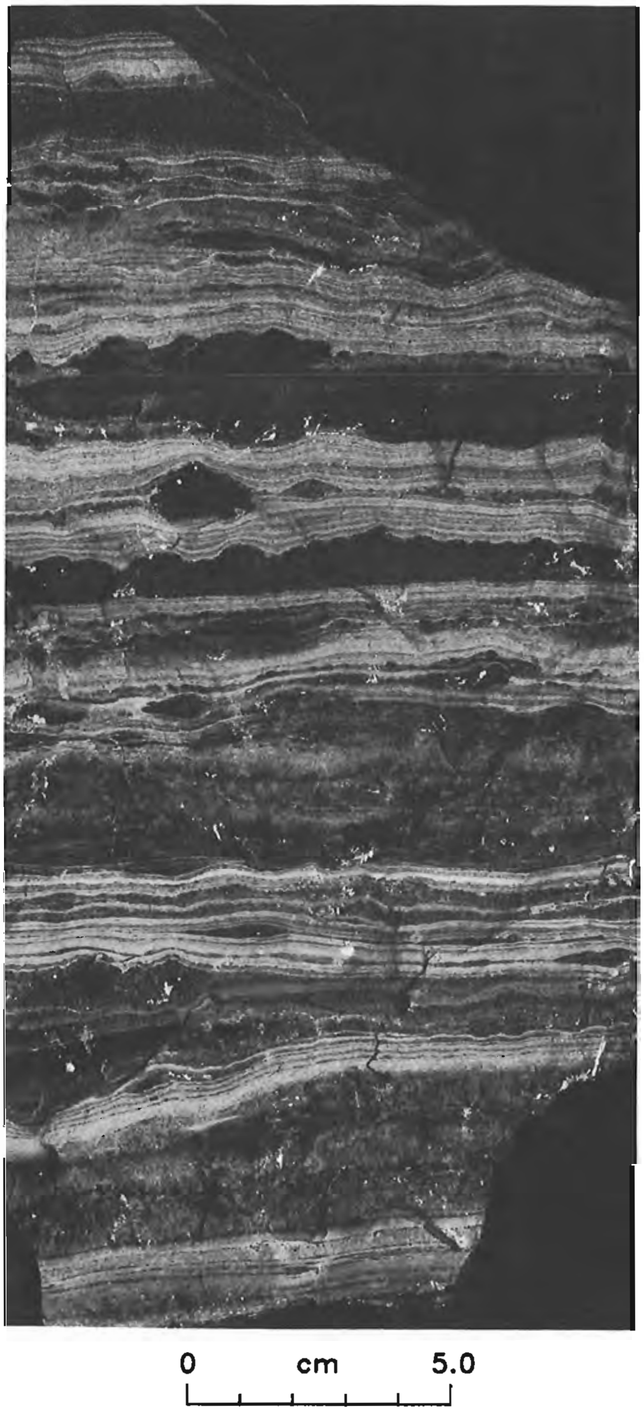


Figure 96. Typical strata of the southeasternmost facies of the Hazen Formation, near the facies boundary with shelf carbonates. Dark grey layers are composed mainly of lime mud, light grey layers of mixtures of siliciclastic silt and very fine grained sand, microcrystalline dolomite, and lime mud. The undulations in the laminae are diagenetic. ISPG photo. 1563-3.

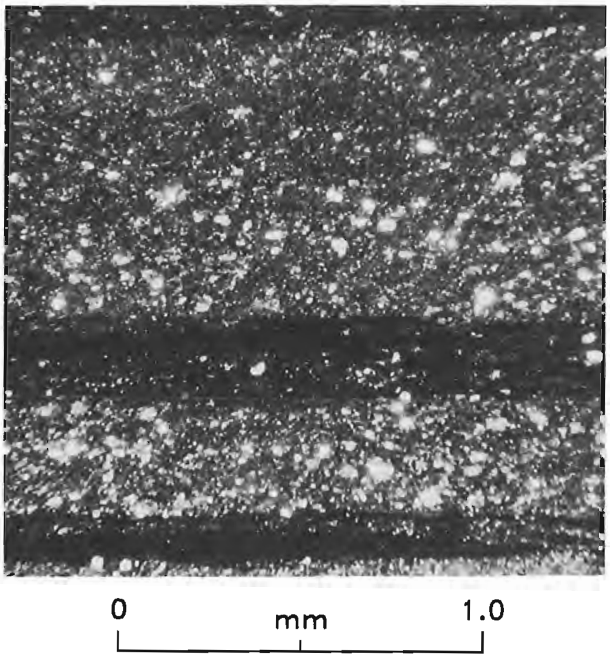


Figure 97. Photomicrograph (cross-polarized light), showing flat lamination and graded bedding (arrow) in mudrock of the carbonate member of the Hazen Formation at Ella Bay 1 section, 186 m. Dark streaks are rich in carbonaceous matter. ISPG photo. 2032-17.

fraction consists mainly of calcite, but some specimens are dolomitic. The feldspar fraction is dominated by K-feldspar, except for the lower 48 m of the Ella Bay 1 section where plagioclase prevails. Ellipsoidal aggregates of chlorite (with or without minor white mica) of silt to fine sand grade, interpreted as altered morphological glauconite, were noted in the lower part of the formation at Ella Bay and Very River.

A total of 16 specimens, 14 from Ella Bay, and one each from d'Iberville Glacier and Very River, were analyzed for organic carbon with the following results:

Range: 0.144–1.016%
Mean: 0.441%
Standard deviation: 0.305%

Sandstone, mostly medium grey, is a minor component of the carbonate member. It generally occurs in units less than 10 cm thick that are interstratified with mudrock or carbonate sediments. Flat, undulating, and small-scale crosslamination are the characteristic primary structures. Sandstone concretions up to 40 cm thick occur in the Very River section. Four sandstones, analyzed by X-ray diffraction (Appendix 2, Table 80), are composed mainly of quartz (mean 52%) and calcite (30%) with lesser proportions of feldspar (11%, mainly K-feldspar) and dolomite (6%).

In samples from Ella Bay, both modal and maximum grain size are very fine and the sorting is very good; in samples from Very River and Macdonald River, the modal grain size is very fine or fine, the maximum grain size ranges up to medium, and the sorting is accordingly poorer. Four samples from these two sections, analyzed by XRD, have an average composition of: quartz, 52 per cent; carbonates, 36 per cent (calcite, 30%; dolomite 6%); feldspar, 11 per cent (K-feldspar, 8%; plagioclase, 3%); and mica, 1 per cent.

Lime mudstone is the most abundant rock type of the carbonate member and occurs in very minor amounts in the chert member. Strata range in thickness from tens of micrometres to about 50 cm. Thin, flat lamination is the most common primary structure, but small-scale crosslamination and undulating lamination also occur (Fig. 98; also Trettin, 1971, Fig. 23). Normal and reverse graded bedding is seen in lime mudstones that are closely associated with graded calcarenite (Fig. 99a, b).

The carbonate fraction, which makes up about three quarters or more of the rock volume (Appendix 2, Tables 81-84), consists largely of calcite with minor dolomite. Texturally, it comprises lime mud, silt-size aggregates of lime mud, and microcrystalline calcite, evidently formed by recrystallization of aggregates because an originally polycrystalline texture is commonly visible under cross-polarized light in the extinction position.

Siliciclastic impurities consist mainly of quartz (3–35%), with generally no more than a few per cent of feldspar, mica, and chlorite.

The organic carbon content of the lime mudstones is smaller than that of the mudrocks. A total of 16 samples, mainly from the Ella Bay 1 and d'Iberville Glacier sections, yielded the following results:

Range: 0.076–0.748%
Mean: 0.212%
Standard deviation: 0.159%

Calcarenite occurs in minor amounts in the carbonate member and in very small amounts in the chert member. Strata range in thickness from a few millimetres to about 35 cm. Flat lamination is the predominant primary structure, and small-scale crosslamination is comparatively rare. The grain size ranges from very fine to very coarse sand grade, and granules or pebbles may also be present. In some calcarenites, the grains are in solution contact, in others they are embedded in a matrix of lime mud. Normal graded bedding was noted in a few strata, 0.5 to 35 cm thick, and normal and reverse graded bedding in some laminated calcarenites (Fig. 99). X-ray diffraction analyses indicate 52 to 90 per cent of calcite and 0 to 5 per cent of dolomite (Appendix 2, Tables 85, 86). The most common type of carbonate clasts are grains of lime mudstone and single crystals that probably represent recrystallized lime mudstone clasts. Less common are fossil fragments, derived mainly from trilobites, echinoderms, ostracodes and brachiopods, and coated grains.

The silicate fraction consists mainly of quartz (6–33%), with minor K-feldspar (1–8%) and chlorite (0–5%), and trace amounts of mica.

Figure 98. *Flat lamination and small-scale cross-lamination in lime mudstone of the Hazen Formation near Wood River. ISPG photo. 978-56.*

Carbonate conglomerate is restricted to the southeastern part of the distributional area of the formation (but is absent from those southeasternmost parts underlain by the laminated facies). Stratigraphically it occurs mainly in the carbonate member and also at the top of the chert member at Caledonian

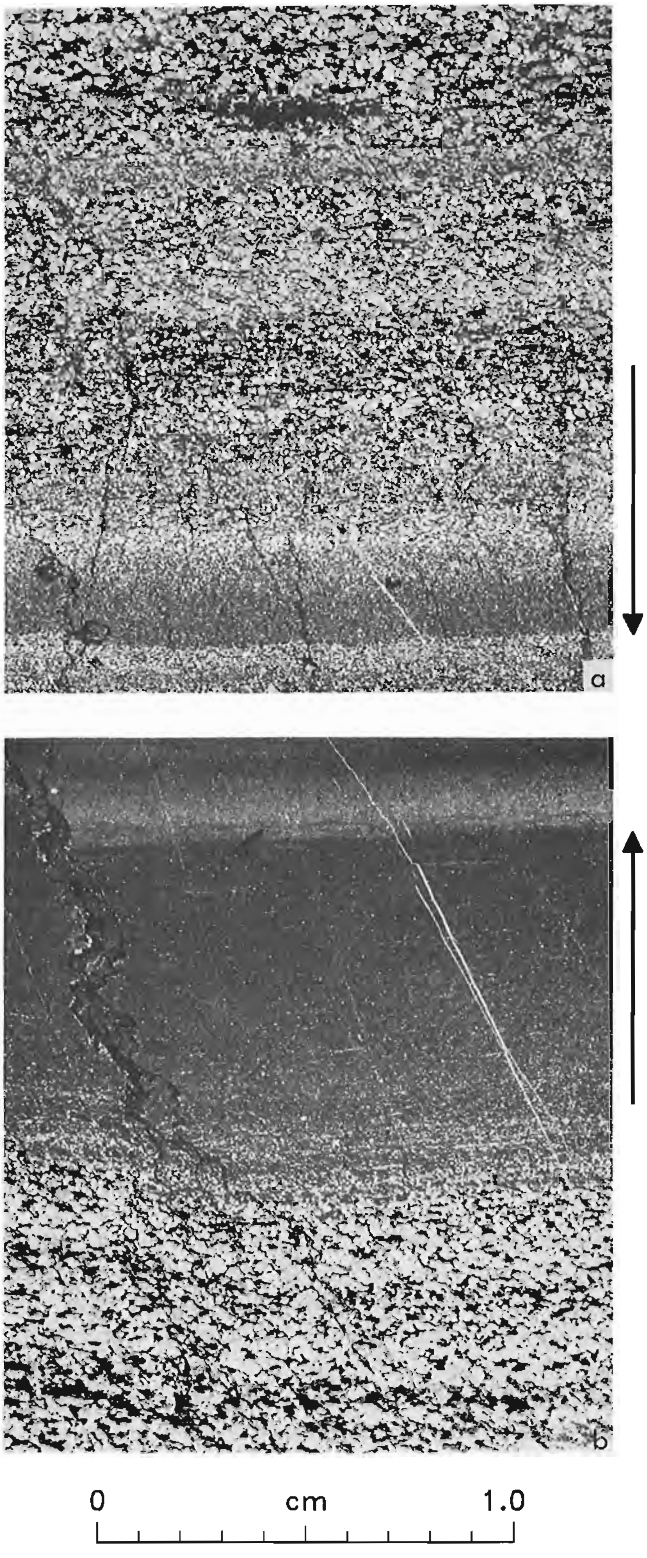


TABLE 12

Hazen Formation, statistics of carbonate conglomerates

SECTION	CF1	DIG	EB1	SPB
Section thickness	407.2 m	332.0 m	631.5 m	247.5 m
Total thickness of conglomerate	67.0	6.8	59.65	2.4 m
Percentage of section thickness	16.5%	2.0%	9.4%	1.0%
Number of conglomerate units	3	3	22	1
Unit thickness, $\bar{X}$	22.3	2.3	2.7	2.4
Unit thickness, range	18.3-27.4 m	0.6-3.3 m	0.35-21.3 m	
Observed max. clast diameter	90 cm	20 cm	100 cm	30 cm
Shelf-derived fossils	present	absent	absent	absent

Bay. Measured unit thicknesses range from 0.35 to 27.4 m (Table 12). The boulder conglomerate at Caledonian Bay has a minimum strike length of 14.5 km. The conglomeratic subdivisions C and D of the carbonate member in the Ella Bay area have been traced along strike for 18 km and across strike for about 5 km (palinspastic distance perhaps 10 km), but their full lengths and widths are unknown.

Most conglomerate beds are massive, although a few contain thin units of laminated limestone. The clasts range from granule to boulder grade and generally are poorly sorted. Clasts may be tabular with rounded to rather angular margins, ellipsoidal, spheroidal, or irregular (Figs. 100–104; see also Trettin, 1971, Fig. 26 and Trettin, 1979, Figs. 25–28). Fragments up to 4 m long by 15 cm thick were observed at the Ella Bay 9 section (EB9); that is, close to the southeastern limit of the conglomerate facies. Some clasts are parallel to bedding, but most are inclined. They commonly are supported by a matrix of fine grained carbonate and siliciclastic detritus (Fig. 104), but in places show clast-support with solution surfaces at the contacts. Pore space is filled with calcite and locally with chalcedony.

*Figure 99. Photomicrographs (ordinary light) of a flat-laminated and graded calcarenite-lime mudstone bed in the Hazen Formation at Ella Bay 1 section, 258.5 m. **a)** Upper part of specimen, showing reverse graded bedding; **b)** lower part of same specimen, showing normal graded bedding. Arrows show direction of fining. The bed is 5.2 cm thick and the two photographs are not continuous. ISPG photos. 2260-156, 2260-157.*

Most clasts consist of medium dark grey lime mudstone and minor chert and mudrock, similar to adjacent strata of the Hazen Formation, and some appear to be almost *in situ*. However, clasts of fossiliferous lime mudstone, wackestone and grainstone, and individual fossils occur in the conglomerates at Caledonian Bay.

A large *allochthonous block*, composed of dolostone and of sandstone reminiscent of the Cass Fiord Formation occurs within the upper part of subdivision B at the Ella Bay 9 section. It is 31.5 m thick, has a minimum strike length of 20 m, and is strongly brecciated.

***Figure 100.** Carbonate conglomerate/breccia in subdivision D of the carbonate member of the Hazen Formation, Ella Bay 1 section. Tightly packed, tabular, mostly subhorizontal clasts (seen in cross-section) are poorly rounded. ISPG photo. 2256-26.*

Figure 101. Carbonate conglomerate in subdivision D of the carbonate member of the Hazen Formation (seen in cross-section), Ella Bay 1 section. Note dark, elongate clast in lower part of photo. ISPG photo. 978-59.

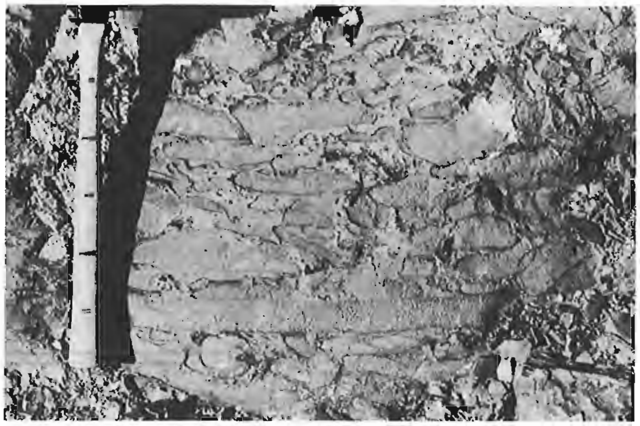


Figure 102. Carbonate conglomerate in the carbonate member of the Hazen Formation at Ella Bay 1 section, 327 to 333 m. Clasts (seen in cross-section) are horizontal and tabular with rounded edges. ISPG photo. 978-46.

Figure 103. Carbonate conglomerate in the upper part of the carbonate member of the Hazen Formation at Ella Bay 1 section. Photograph of bedding plane shows irregular plan view of clasts; 1.5 m staff for scale. ISPG photo. 978-42.

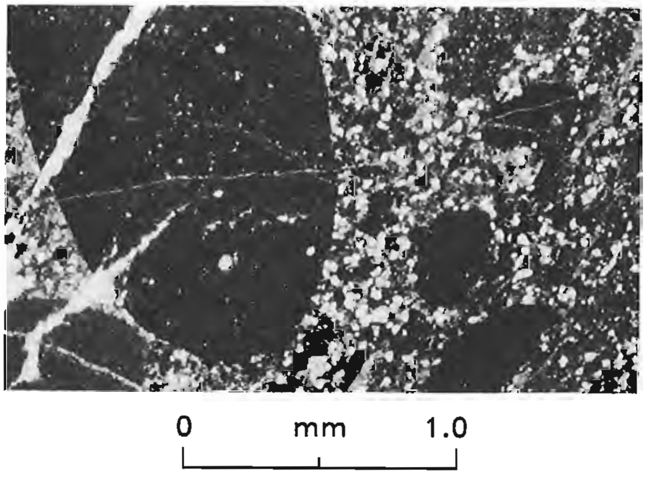


Figure 104. Photomicrograph (ordinary light) of a carbonate conglomerate in the carbonate member of the Hazen Formation at Ella Bay 1 section, 314.7 m. Coarse sand grains, granules, and pebbles of limestone (lime mudstone and peloidal packstone/wackestone, but peloids are very faint at this scale) are embedded in a matrix of lime mud and quartz (silt to very fine grained sand grades). ISPG photo. 2032-95.

Other large blocks, of unknown stratigraphic position, are present southeast of Ella Bay. One block of limestone, about 20 m long, wide, and thick, has yielded conodonts of probable Arenig age (Nowlan, Appendix 3B, C-194905), indicating derivation from member B of the Bulleys Lump Formation. The rock is massive but intensely fractured and cut by the same cleavage developed in the surrounding mudrock.

Radiolarian chert is predominant in the chert member and subordinate in the carbonate member (e.g., subdivision C_1). It forms laminae or beds that are 0.5 to 20 cm (mostly 1 to 10 cm) thick (Fig. 105), and are separated by laminae or very thin beds of mudrock. Most strata are medium dark grey, but medium grey to greenish grey and medium light grey strata also occur.

In thin section, many specimens show a thin, flat lamination, caused by vertical variations in the concentration of carbonaceous matter, carbonate minerals, or radiolarian tests (Fig. 106; also Trettin, 1979, Fig. 29). Some layers rich in radiolarian skeletons have sharp contacts.

Radiolarian tests are abundant, but usually poorly preserved. In thin section they appear as relatively clear nodules, a few to a few tens of micrometres in diameter. The nodules are spherical or ellipsoidal in shape, depending on the amount of stretching that has occurred during folding and faulting. Tests represented by an outer rim of chert and an interior filled with quartz or chalcedony seem to have undergone dissolution and backfilling. Detailed structures are rarely preserved (Fig. 107), but at least one specimen from Caledonian Bay was identifiable at the generic level (*Flustrella* sp.; J.H. Wall *in* Trettin, 1979, Fig. 30).

X-ray diffraction analyses indicate that the cherts consist almost entirely of quartz (mean 98%; Appendix 2, Table 87) with only a few per cent of combined feldspar, mica, and chlorite. In addition, small amounts of secondary calcite and dolomite occur in some specimens.

Alteration and metamorphism

Chertification. Partial replacement of carbonate rocks by small lenses of chert or chalcedony is common throughout the Hazen Fold Belt. The entire carbonate

Figure 105. The chert member of the Hazen Formation near Wood River, west of Alert, view to northeast. Thin bedded radiolarian chert (resistant) and thinly interstratified recessive mudrock show minor folds and faults; axial planes and cleavage dip northwest (1.5 m staff for scale). ISPG photo. 978-54.

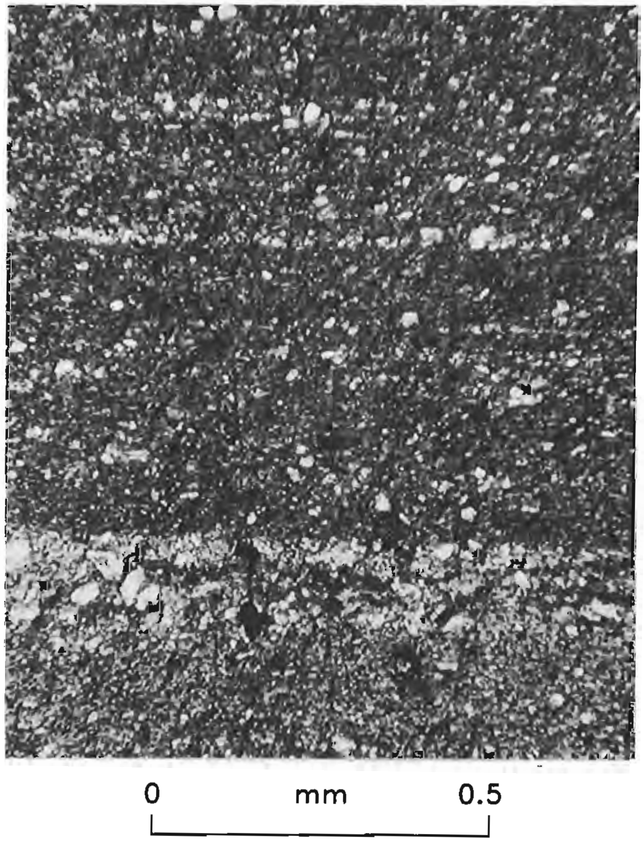


Figure 106. Photomicrograph (ordinary light) of impure radiolarian chert in the chert member of the Hazen Formation at Macdonald River 3 section. Thin, flat lamination is defined by variations in submicroscopic carbonaceous matter and concentration and size of quartz grains. ISPG photo. 2260-133.

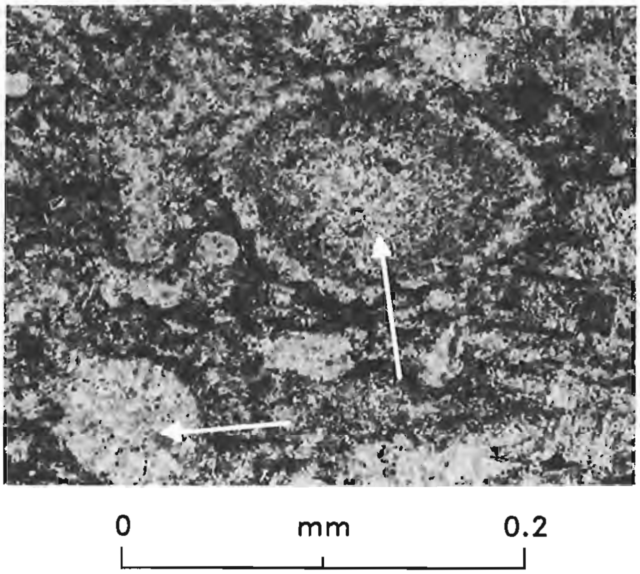


Figure 107. Photomicrograph (ordinary light) of poorly preserved radiolarian tests (arrows) in the chert member of the Hazen Formation at Ella Bay 1 section. ISPG photo. 2032-1.

member is replaced by chert in several areas, for example southwest of St. Patrick Bay, in the Osborn Range (Fig. 87), and north of eastern Hare Fiord. The silica probably was derived from the associated radiolarian chert, and the small-scale replacement probably occurred during early diagenesis (cf. Maliva and Siever, 1989), but the large-scale chertification could have occurred later, during deeper burial or subsequent deformation.

Slaty cleavage. Many mudrocks and argillaceous cherts have a slaty cleavage, caused by recrystallization of clay minerals to white mica and chlorite of fine silt grade.

Organic metamorphism. Five conodont collections from St. Patrick Bay, from the Ella Bay 1-2 section, and from southwest of Ella Bay, all have a Colour Alteration Index of 5 (Tipnis in Appendix 3B, C-54826; Nowlan in Appendix 3B, C-54922, C-54923, C-96671, C-96684).

Mode of origin

The *Olenellus*-bearing beds (Fig. 108) in the lowermost part of the formation (see below, Age and correlation) must be of shelf origin, because they contain crawling tracks of trilobites (*Cruziana* sp., Fig. 26), and the overlying strata of subdivison A of the carbonate member probably are of transitional shelf to slope origin. On the other hand, the Middle and Upper Cambrian trilobites from southeast of Ella Bay are suggestive of deeper water environments (Fritz, Appendix 3, C-171536, C-171537); moreover, they have no crawling traces associated with them and may be resedimented.

The following inferences pertain only to sediments above subdivision A.

The *carbonate allochthonous blocks and conglomerates* are crucial for the undertanding of the depositional site and provenance of the Hazen Formation (cf. Cook and Mullins, 1983). Intercalated between marine sediments, they must have have been transported by gravity-driven mass movements and deposited in deep water settings below shelf edge. The fact that they are confined to a narrow belt on the southeastern margin of the distributional area of the formation shows that they were derived from the southeast. The allochthonous block of Cass Fjord strata at the Ella Bay 9 section and some fossiliferous conglomerates at Cañon Fiord 1 section obviously came from the Franklinian Shelf. The majority of the conglomerates, however, were derived from slope sediments of the Hazen Formation itself, indicating early cementation of these strata (cf. McIlraith and James, 1978).

These conglomerates evidently represent a spectrum of depositional settings and processes. Sliding on gently inclined slopes is indicated by conglomerates or breccias composed of tabular, bedding-parallel clasts that appear to be almost *in situ*; they are predominant in the lower part of the formation at Ella Bay (Ella Bay 1 and 5 to 9 sections). Steeper slope gradients, greater distances of transport, and deposition in proximal

***Figure 108. Olenellus** sp. from the carbonate member of the Hazen Formation at Ella Bay 1 section, 38 to 46 m (C-74640, GSC type no. 56649). ISPG photo. 1206-1 by W.H. Fritz.*

basin environments by subaqueous debris flows are indicated by conglomerates with ellipsoidal boulders; these are common at Caledonian Bay (Trettin, 1979, Figs. 26, 27).

The *calcarenites and related calcareous sandstones* are interpreted as classical turbidites because of their association with carbonate conglomerates (at Caledonian Bay and Ella Bay). Graded bedding, however, seems to be less common than in siliciclastic turbidites, and fully developed Bouma sequences have not been recorded.

The *lime mudstones and calcareous mudrocks* are interpreted as deep water deposits because of their lack of an autochthonous shelf fauna, the presence of graptolites, and their association with radiolarian chert beds and carbonate conglomerates. The predominantly flat lamination and the moderately high organic carbon content both confirm deposition below wave base. Most strata probably were deposited by dilute turbidity currents (or nepheloid layers) generated by storms on the adjacent shelves, but some may be distal turbidites related to submarine slides.

The thin bedded or laminated *primary chert* is evidently of radiolarian origin even though detailed skeletal structures are rarely preserved. Sharp-based laminae rich in radiolarian tests may have been redeposited by currents, but graded bedding, indicative of turbidity currents, has not been seen. The regular alternation of chert and mudrock, characteristic of many ancient deep-sea deposits (e.g., the Cache Creek Group of the Cordillera), may reflect cycles in the productivity of radiolarians, perhaps on the scale of tens of thousands of years (cf. Jenkyns and Winterer, 1982).

Regional facies relations and accumulation rates are discussed below (Stratigraphic synthesis).

Age and correlation

Base of formation

The age of the base of the Hazen Formation has been determined only in the vicinity of Ella Bay. *Ollenellus* sp. occurs approximately 38 to 46 m above the base of the formation (cf. Fritz, Appendix 3A) at the Ella Bay 1 section (EB1) and, as mentioned, associated crawling tracks indicate that the fossil is not resedimented, but that arthropods lived in these strata (Figs. 108, 109). The strata of the Kane Basin Formation underlying the Hazen Formation at this locality contained trilobites either of the *Bonnia-Olenellus* Zone or of the preceding *Nevadella* Zone (Fritz, Appendix 3A). However, all other collections from the Kane Basin Formation are in the *Bonnia-Olenellus* Zone, so the second alternative can probably be discounted. Thus the base of the Hazen Formation almost certainly is of late Early Cambrian age.

As mentioned before, it is possible that the lowermost part of the Hazen Formation is correlative with the uppermost part of the Kane Basin Formation southeast of Ella Bay, representing a facies equivalent that originated in somewhat deeper water. The two units have in common the trilobite occurrences mentioned and relatively high plagioclase/K-feldspar ratios that decrease upsection. In the rest of the Hazen Formation, K-feldspar is dominant over plagioclase.

Top of formation

The most precise, and youngest, age for the top of the Hazen Formation has been obtained at the Cañon Fiord 1 section (CF1) (Fig. 85). There, macrofossils of unspecified late Llandovery or Wenlock age occur in a carbonate conglomerate, 27 m thick, at the top of the formation. A Wenlock age can be ruled out because graptolites of latest Llandovery age were found in the overlying Danish River Formation. Chert and mudrock beneath the carbonate conglomerate yielded graptolites of middle or early late Llandovery age, including *Monograptus* sp. aff. *M. delicatulus* Elles and Wood (Norford *in* Trettin, 1979, Appendix 3).

Southwest of the head of Ella Bay (Fig. 1, loc. F10), where the chert member is absent owing to a facies change, a carbonate conglomerate underlying the Danish River Formation yielded a mixed assemblage of

***Figure 109.** Trilobite track (Cruziana) in the carbonate member of the Hazen Formation at Ella Bay 1 section, 38 to 46 m. ISPG photo. 979-1.*

conodonts of Late Ordovician and middle Llandovery age (Nowlan, Appendix 3B, C-96684).

Graptolites of unspecified early or middle Llandovery age occur in the uppermost few metres of the formation at Wood River, west of Alert (locality F4, Fig. 84; Norford, Appendix 3A, C-74700).

Graptolites of the Late Ordovician *Dicellograptus complanatus ornatus* Zone were found 70 to 72 m below the top of the formation north of Ella Bay (C-74603), 0 to 30 m below it northwest of d'Iberville Glacier (51962; loc. F3 of Fig. 84), and only 7 m below it at St. Patrick Bay (C-64).

Regional relations suggest that the base of the overlying Danish River Formation is probably early late Llandovery everywhere, and that condensed intervals or hiatuses exist at the top of the Hazen Formation at those localities where middle Llandovery or older fossils occur close to the top of the Hazen Formation (see below, Danish River Formation, Age and correlation).

Contact between the carbonate and chert members

This contact is highly diachronous, becoming younger toward the shelf margin. At St. Patrick Bay, its age is bracketted by conodonts of late Tremadoc age (Tipnes, Appendix 3B, C-54826) and by graptolites of latest Arenig age (Norford, Appendix 3A, C-66). Graptolites of latest Arenig age also were found in the chert member at Mount Pullen (C-65; loc. F1, Fig. 84).

North of Ella Bay, the base of the chert member lies not far below Upper Ordovician graptolites, but, as discussed below (Danish River Formation, Age and correlation), the uppermost part of the chert member there probably is condensed or truncated by a submarine disconformity.

At Caledonian Bay, the contact between the two members lies directly below strata containing middle Llandovery graptolites (see Norford, *in* Trettin, 1979, Appendix 3, p. 80).

Laminated facies of the carbonate member

Trilobites of probable early Middle Cambrian age (*Ogygopsis* sp., *Glossopleura*? sp.) were found at one locality (Fritz, Appendix 3A, C-96669). The full age range of the facies is unknown.

CAPE PHILLIPS FORMATION

A sedimentary succession on Cornwallis Island, Late Ordovician to Early Devonian in age and consisting of calcareous shale, argillaceous limestone, limestone, calcareous siltstone, chert, and dolostone, was named the Cape Phillips Formation by Thorsteinsson (1958; Thorsteinsson and Kerr, 1968). In the type area, the Cape Phillips Formation lies stratigraphically between the Irene Bay and Sophia Lake formations and is correlative with the combined Allen Bay, Cape Storm, Douro, and Barlow Inlet formations (Late Ordovician to latest Silurian, Thorsteinsson, 1988). In contrast to the shelf carbonate formations with their shelly faunas, the Cape Phillips has a diverse graptolite fauna.

In central Ellesmere Island, the Cape Phillips Formation forms a narrow facies belt along the northwestern margin of the Franklinian Shelf. There, it lies on a basal tongue of the Allen Bay Formation, on the Irene Bay Formation, or on different parts of the Upper Ordovician–Silurian carbonate succession (Allen Bay or Douro formations or their equivalents), and it is overlain by the Danish River, Eids, or Devon Island formations (Mayr, 1974; Kerr, 1976; Trettin, 1978, 1979; T.A. de Freitas, 1991).

In the areas studied previously by the writer (Trettin, 1978, 1979), the Cape Phillips Formation consists of resedimented carbonates and mudrock with lesser amounts of radiolarian chert and very fine grained sandstone. The carbonates range in size grade from lime mudstone, through calcarenite and conglomerate, to large allochthonous blocks, and also include microcrystalline dolostones. The Cape Phillips Formation is comparable to the Hazen, but differs from it in stratigraphic setting and age and by its smaller proportion of chert. Like the latter, it originated in slope and basinal settings, but probably at shallower depths.

Carl Ritter Bay Section

Lithology

In the course of the present investigation, the Cape Phillips Formation was examined only in two small areas, about 3 to 5 km north of Carl Ritter Bay (generalized location RB, Fig. 110). At locality RB1 it lies stratigraphically between the Allen Bay and Danish River formations and is 87 m thick. It is poorly exposed and characterized by recessive slopes, covered with talus of medium to dark grey rocks. Three units are distinguished.

Unit 1 (0–32.5 m) forms sporadic outcrops of lime mudstone and skeletal limestone, in part cherty, and chert.

A typical specimen of lime mudstone shows a discontinuous lamination with microscopic undulations. Organic carbon is concentrated in lumps that are about 10 to 45 μm in diameter. Thin sections reveal round aggregates of radiating calcite, commonly with a thin dark rim, that are about 40 to 120 μm in diameter. XRD analysis indicates: calcite, 88 per cent; mica, 2 per cent; and dolomite, 2 per cent.

The skeletal limestones contain fragments of trilobites, ostracodes, and sponges. Their texture is difficult to determine because of pervasive chert replacement.

The chert is medium dark grey and of both radiolarian and replacement origin.

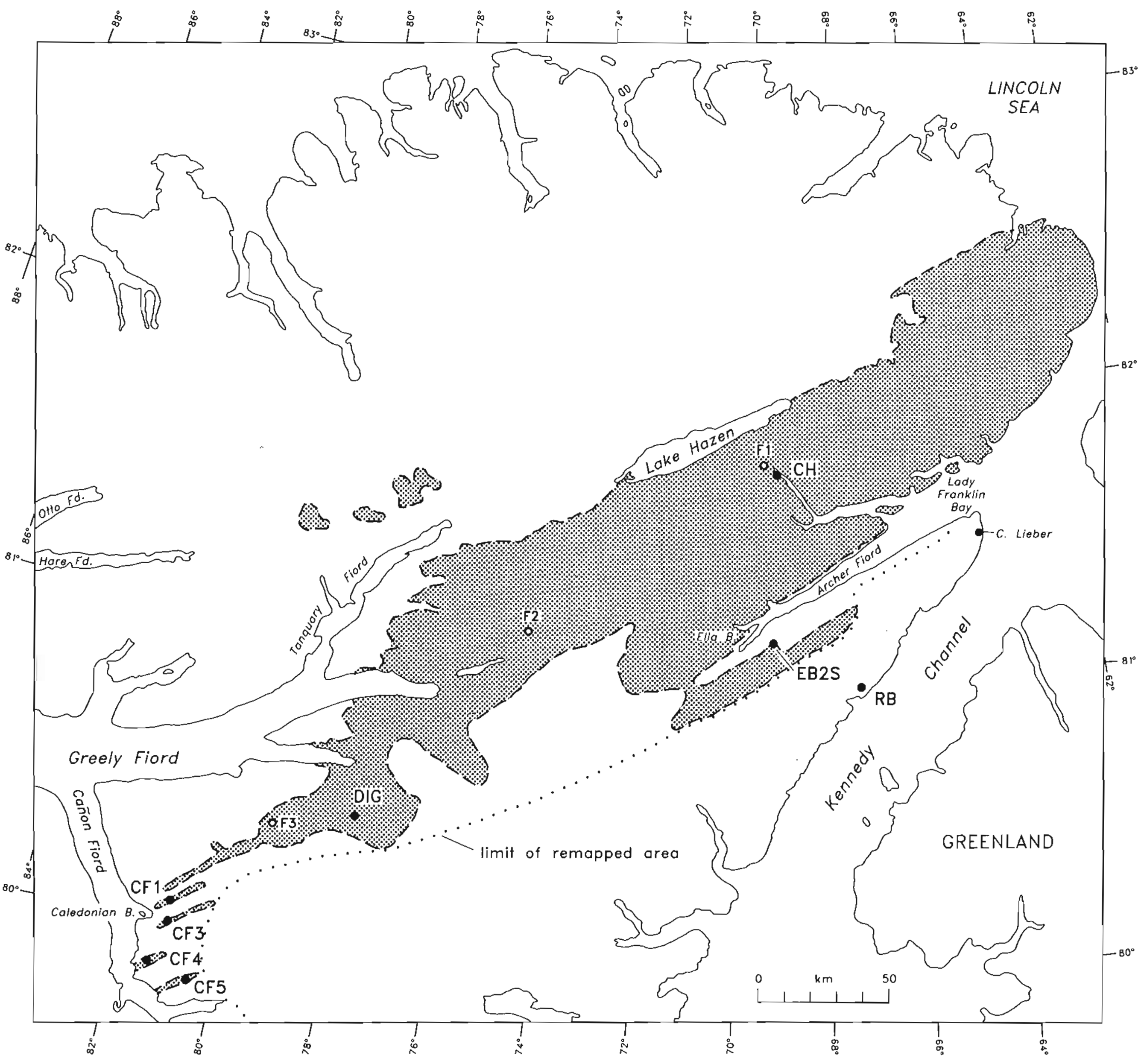


Figure 110. Section localities of the Danish River and Cape Phillips formations and generalized outcrop area of the Danish River Formation. CH, Chandler Fiord; CF1, CF3, CF4, CF5, Cañon Fiord, sections 1, 3, 4, and 5 of Trettin, 1979; DIG, d'Iberville Glacier; EB2S, Ella Bay 2-South; RB, Carl Ritter Bay; F1 to F3, fossil localities of the Danish River Formation.

Unit 2 (32.5–64.0 m, 31.5 m) is covered.

Unit 3 (64.0–87.0 m, 23 m) consists of fine to coarse, in part sandy mudrocks that are flat laminated, fissile, and medium to dark grey. XRD analysis of three specimens indicates an average composition of: quartz, 71 per cent; dolomite and calcite, 12 per cent; mica, 6 per cent; plagioclase, 4 per cent; K-feldspar, 3 per cent; and chlorite, 3 per cent.

Age

Fossil identifications made for the present project can be summarized as follows.

1. Strata 1 to 2 m below the top of the Allen Bay Formation have yielded conodonts of Late Ordovician (Richmondian) age (Fauna 12; Nowlan, Appendix 3B, loc. C-94390).

2. An outcrop about 25 to 30 m above the base of the Cape Phillips Formation has yielded *Monograptus* sp. ex gr. *M. spiralis* (Geinitz) of late Llandovery (Telchyan) age and *Monograptus* sp. ex gr. *M. priodon* (Bronn) (Norford, Appendix 3A; C-97226, C-97227) of unspecified late Llandovery–Wenlock age. In addition, *Stomatograpus grandis grandis* (Suess) of late Llandovery age was collected from talus less than 27 m above the base of the formation (C-97225). Other talus collections, of uncertain stratigraphic height (C-97375), include *Cyrtograptus* sp. and *Monoclimacis* ex aff. *M. vomerinus* (Nicholson) of unspecified latest Llandovery (*sakmaricus* Zone of Melchin, 1989) to late (but not latest) Wenlock age (cf. Lenz and Melchin, 1989).

3. *Monograptus* sp. ex gr. *M. priodon* (Bronn) of unspecified late Llandovery or Wenlock age, without any other graptolites, was found 28.5 m below the top of the formation at locality RB2 (C-97228).

4. In spite of intensive searches by several persons, no graptolites were found in unit 3. Thus, it is unlikely that the talus specimens of *Cyrtograptus* sp. and *Monoclimacis* ex aff. *M. vomerinus* came from the upper 23 m of the formation.

Exposures of the Cape Phillips Formation on Judge Daly Promontory were also studied by T.A. de Freitas in 1988 (1991) and the following results of his work are relevant in the present context.

At Carl Ritter Bay, the graptolites *Diplograptus tscherskyi tscherskyi* and *Pristiograptus* spp. occur just above the base of the Cape Phillips Formation in strata of unit 1. These graptolites are assigned to the undifferentiated *cyphus* to *convolutus* zones of early middle Llandovery (Aeronian) age (de Freitas, 1991, Figure 7b, Section 29, and p. 409).

At Cape Lieber, about 76 km to the northeast (CL, Fig. 110), the Cape Phillips Formation also lies stratigraphically between the Allen Bay and Danish River formations. At this locality a graptolite collection from the upper 5 m of the Cape Phillips Formation includes: *Monograptus griestoniensis spp., M. griestoniensis minuta, M. priodon, M.? speciosus, Pristiograptus dubius, Monoclimacis linnarsoni, M. vomerinus vomerinus,* and *M. vomerinus* spp., representing the undifferentiated *griestoniensis-sakmaricus* zones of latest Llandovery (Telychian) age (de Freitas, 1991, Fig. 7b, Section 23, 24, and p. 409).

In summary, the Allen Bay and Cape Phillips formations are separated by a hiatus encompassing the latest Ordovician and all of early Llandovery (Rhuddanian) time, and the contact between the Cape Phillips and Danish River formations probably lies within the latest Llandovery.

DANISH RIVER FORMATION (new formation)

The name, Imina group [*sic*], was given by Christie (1957) to clastic sediments exposed on the northwestern coast of Ellesmere Island between Cape Bourne and Phillips Inlet (within the Clements Markham Fold Belt of this report). The group was described (Christie, 1957, p. 17) as "a uniform series of sub-greywacke, greywacke, and argillaceous greywacke beds. The beds are blue-grey to black, fine to medium grained, and limy. Graded bedding occurs". Christie recognized that the rocks are unconformably overlain by strata of Late Carboniferous age and tentatively placed them in the upper part of the pre-Upper Carboniferous succession of northern Ellesmere Island. The unit was erected before the introduction of the Code of Stratigraphic Nomenclature (in 1961), and the term, group, was used in the earlier sense of a reconnaissance unit. It was named for a person (an Eskimo dog-team driver), rather than a locality, a type section was not indicated, and the lower contact was not defined.

Follow-up work in northwestern Ellesmere Island showed that Christie's Imina "group" is a distinct and extensive unit, but not divisible; it therefore was redefined as a formation (Trettin, 1961). To provide a geographic reference, an inlet in the centre of Christie's type area later was named Imina Inlet.

Further exploration (Trettin, 1971, 1978, 1979; Trettin et al., 1979, etc.) provided the following additional information:

1. Clastic sediments with similar composition and primary structures are widely distributed in all of northern Ellesmere Island, and also occur in parts of central Ellesmere Island.

2. The sediments are restricted in age to the Early Silurian (middle? and late Llandovery) in the Clements Markham Fold Belt (including the type area) where locally they are conformably overlain by the Lands Lokk Formation. Representative stratigraphic sections, however, are not exposed in this region because of the complex structure and deeply weathered state of the unit, which occurs mostly as felsenmeer.

3. In the southeastern part of the Hazen Fold Belt, the same kind of sediments range in age from Early Silurian (late Llandovery) to earliest Devonian, and a complete, representative section is exposed in the vicinity of Danish River at Caledonian Bay, Cañon Fiord. Farther southeast, in the Central Ellesmere Fold Belt, the age of the sediments is restricted to the Early Devonian.

Because of the lithological similarity of all these rocks with those in the type area, the name, Imina Formation, was applied to all exposures until recently. However, the term is now abandoned because of the restricted age range and poor exposure in the type area. Instead, all these sediments are now assigned to the Danish River Formation, which has its type section at Danish River, Caledonian Bay, Cañon Fiord (Section 1 of Trettin, 1979, referred to as Section CF1 in this report). The term has been used in recent regional summaries (Trettin, 1989; Trettin et al., 1991), but is formally introduced here.

The Danish River Formation, as here defined, comprises a thick succession of calcareous and dolomitic sandstone, mudrock, and minor conglomerate — all of deep water origin — that overlie the Hazen Formation in the Hazen Fold Belt, and the Cape Phillips or Allen Bay formations in the Central Ellesmere Fold Belt. Within these belts, the formation is diachronous, with an overall age range from Early Silurian (Llandovery) to Early Devonian (Emsian), but Devonian strata seem to be preserved only in the Central Ellesmere Fold Belt and immediately adjacent parts of the Hazen Fold Belt.

The name, Imina Formation has been retained by (Trettin and others, 1991) for the exposures in the Clements Markham Fold Belt.

Distribution, thickness, and contact relations

The Danish River Formation, is widely exposed in the central and southeastern parts of the Hazen Fold Belt, but also occurs in its northwestern part (Fig. 110; Hazen Plateau and Osborn Range belts of Fig. 3). In the Central Ellesmere Fold Belt, scattered outcrop areas occur southeast of Ella Bay (Fig. 1) and at Cañon and Trold fiords. Exposures in east-central Ellesmere Island, between northeasternmost Judge Daly Promontory and Richardson Bay (J.C. Sproule and Associates, Ltd., 1974; Christie, 1974; Hurst and Kerr, 1982) were previously included mainly in the Eids Formation (Kerr, 1973a, b, c). Apart from the vicinity of the Carl Ritter Bay section (loc. RB, Fig. 110), the Danish River Formation was not examined by the writer in this region and further work is required to differentiate it from the Eids Formation.

The formation is 2736 to 2795 m thick in the vicinity of the type section where it ranges in age from early late Llandovery to earliest Devonian (early Lochkovian; Fig. 111). Farther south, where it is restricted to the earliest Devonian, it decreases from 620 m at Section CF2 to 251 m at Section CF4 (Trettin, 1979). At Trold Fiord, where the top is missing, the formation has a minimum thickness of 173 m (Trettin, 1978; this area is not included in Fig. 110).

The Danish River Formation overlies the Hazen Formation in the Hazen Fold Belt and the Cape Phillips Formation in most of the Central Ellesmere Fold Belt. The contact with the Hazen Formation is mostly abrupt, but is gradational at Very River and locally at Macdonald River where chert is interstratified with sandstone in the lowermost part of the Danish River Formation. As mentioned, (Hazen Formation, Age and correlation) it is possible that the Danish River and Hazen formations are separated by a submarine disconformity (diastem) in some areas, but there is no evidence of emergence and subaerial erosion.

The contact with the Cape Phillips Formation also is abrupt at some localities and gradational at others. In the latter case it is placed where sandstone becomes predominant in the section.

Southeast of Ella Bay, the Danish River Formation overlaps, from northwest to southeast, the Bulleys Lump, Thumb Mountain, Irene Bay, and Allen Bay formations. This contact, illustrated and further discussed below (Stratigraphic synthesis, Ella Bay Escarpment), is interpreted as a submarine disconformity, caused by lateral onlap against a submarine escarpment.

The upper contact of the Danish River Formation is exposed only on the east side of Cañon Fiord (Sections CF2 and CF4, Figs. 110 and 111, corresponding to Sections 2 and 4 of Trettin, 1979). There, the Danish River Formation is overlain by medium light grey, laminated siltstone, assigned to the Eids Formation by Kerr (1976) and *in* Thorsteinsson (1972). The contact is gradational and placed where siltstone begins to form more than 90 per cent of the section.

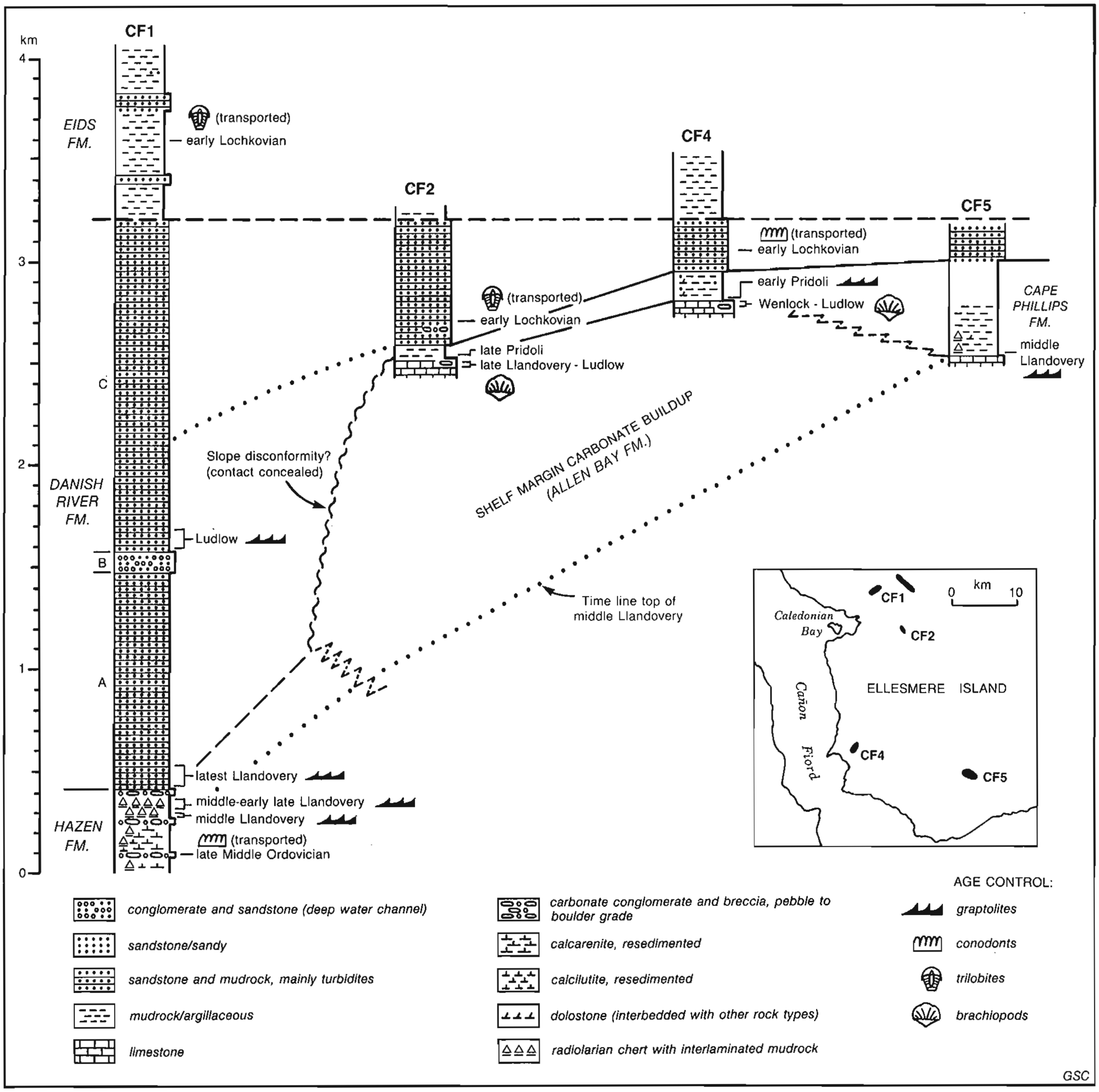


Figure 111. *Stratigraphy of the Danish River Formation at Cañon Fiord. (Adapted from Trettin, 1979.) Section CF1 is the type section of the Danish River Formation. The top of the carbonate buildup has recently been dated (using conodonts) as late early Wenlock (***patula*** Zone; T.T. Uyeno, in T.A. de Freitas, 1991, Appendix 2, C-104724) at section CF2.*

Lithology

The Danish River Formation consists largely of interstratified sandstone and mudrock showing flysch-type primary structures, with small amounts of fragmental carbonate rocks, mostly of conglomerate grade. In addition, a mappable unit of siliciclastic conglomerate occurs north of Danish River, which permits subdivision of the formation into three members in this area, as follows:

Member C (1637 m)	Sandstone and mudrock with minor amounts of calcarenite and calcareous conglomerate and breccia (as in member A)
Member B (42-101)	Pebble to cobble conglomerate, sandstone, and minor amounts of mudrock
Member A (1057 m)	Sandstone and mudrock with minor amounts of calcarenite and limestone breccia

Member B (earlier referred to as the Caledonian Bay Conglomerate Member) has been recognized only north of Caledonian Bay, and thus the formation has remained undivided outside the type area. However, in some areas, strata coeval with members A or C can be distinguished by means of fossils.

Sandstone and mudrock

Stratification

Analysis of stratification requires not only detailed, bed-by-bed field measurements, but also thin section work because the vertical grain size variations are subtle. During previous projects, one representative short section was measured in this manner on the Hazen Plateau (Trettin, 1971, p. 58–64), twenty were measured at Cañon Fiord (Trettin, 1979, Figs. 36, 37, 41–44, 50), and two at Trold Fiord (Trettin 1978, Fig. 9). Four additional short sections were studied during the present project at Chandler Fiord, d'Iberville Glacier, and Ella Bay (Figs. 112–114). The following general remarks are applicable to all 27 sections, but, unless stated otherwise, the statistical statements refer to the last four sections only.

1. *Bouma sequences*. The complete sequence (Bouma, 1962) comprises four divisions (A to D) characterized by grain size variations and primary structures. In the study area, A-divisions (designated Ta, in accordance with general practice) consist of fine to predominantly very fine grained sandstones that are structureless or show a vague, discontinuous, slightly undulating lamination. Graded bedding, if discernible at all, is subtle. Sole marks (flute casts, grooves and ridges, tool marks, etc.) are common. In the present examples (Figs. 112–114) thicknesses range from 8 to 37 cm.

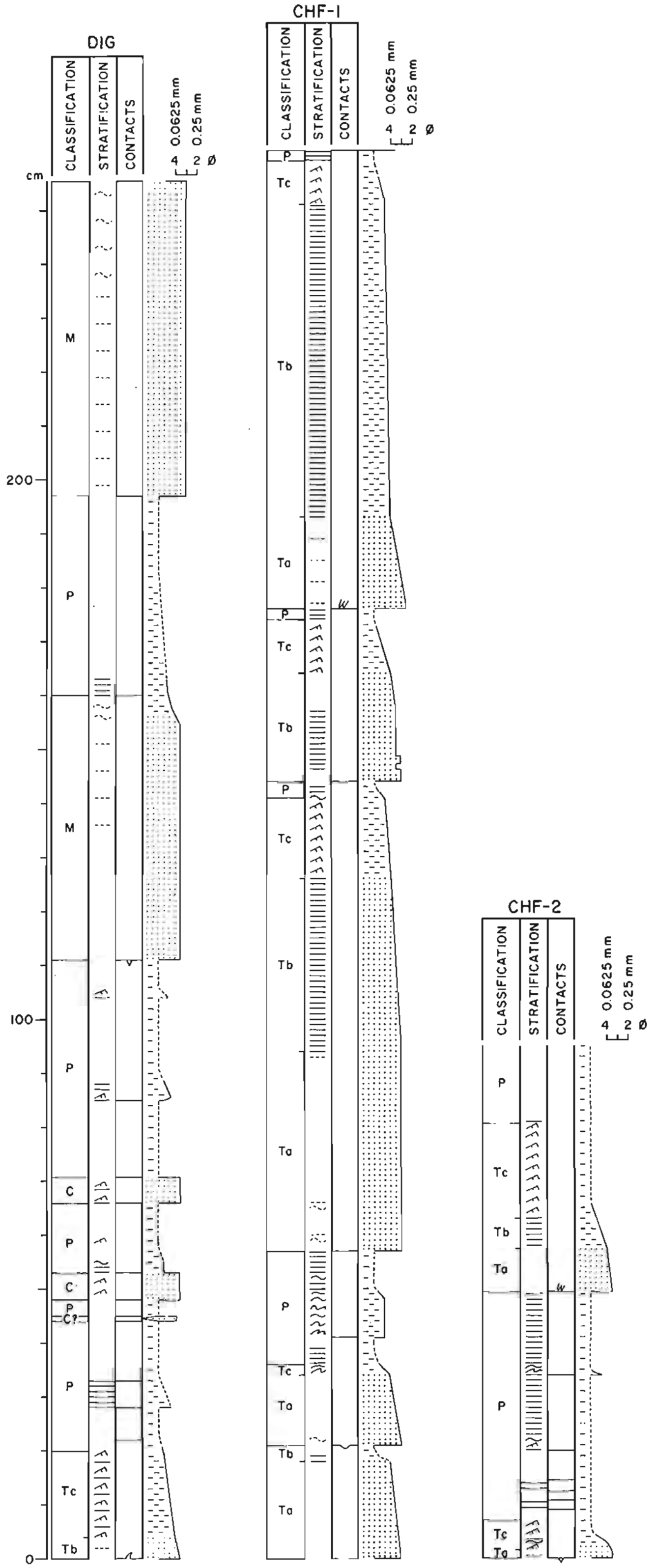
   B-divisions (Tb) are composed of mudrocks and/or very fine grained sandstones that show a flat lamination due to subtle changes in grain size. Thicknesses of 1.5 to 58 cm have been recorded.

   C-divisions (Tc) comprise coarse and fine grained mudrocks characterized by small-scale cross-lamination (commonly climbing ripples) and/or convolute lamination, both with or without undulating lamination (Trettin, 1971, Fig. 32; 1979, Figs. 42A, 43, 48, 49). They are 1 to 18 cm thick.

   D-divisions (Td) consist of flat-laminated, fine grained mudrocks that are difficult to distinguish from overlying mudrocks of unrelated origin. They have therefore been included in the "undifferentiated mudrocks (P)", discussed below.

   The sections studied contain the following normal Bouma sequences — Ta-d (3), Tb-d (2), and Tab (1), but also the anomalous sequence Tac (2).

2. *Massive sandstones (M)*. These units are similar to A-divisions, but differ from them by the absence of overlying B-divisions. The lower contact is abrupt. Sole marks may be present, but seem to be less common than in normal A-divisions. The units are fine to predominantly very fine grained, and graded bedding is limited to the uppermost few centimetres or millimetres. Vertical profiles of grain size, based on thin section study of four massive beds on the Hazen Plateau (Trettin, 1971, Fig. 31) show slight fluctuations in a narrow range between 3 and 4 phi units (0.125–0.0625 mm) in the lower and middle parts of the beds, and a subtle decrease in the upper part. Some massive sandstones contain rip-up clasts of mudrock. A massive bed at d'Iberville Glacier, 2.5 m thick, for example, contained fragments up to 60 cm long and up to 20 cm thick in an interval 0.3 to 1.0 m above the base of the bed, and fragments up to 10 cm long in the middle and upper parts of the bed. The massive sandstones are usually overlain by mudrock, which commonly shows flat lamination, and, less frequently, undulating lamination, ripple marks, and convolute lamination (Fig. 114a). In the present sections, the



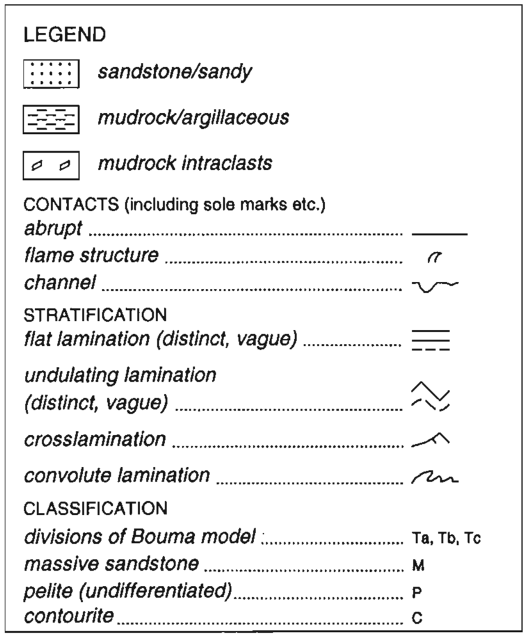


Figure 112. Danish River Formation, detailed short sections at Chandler Fiord (CHF1, CHF2) and d'Iberville Glacier (DIG). Sections are underlain by mudrock of the same formation; their stratigraphic positions within the formation are unknown.

massive beds range in thickness from 49 cm to 9.2 m, the thickest known unit occurring in the lowermost part of the formation at the Ella Bay 2-South section (Figs. 113, 114). It is possible that the unit is amalgamated but internal contacts were not recognized. Note that similar sandstones occur in correlative strata of the Merkujôq Formation of North Greenland (Hurst and Surlyk, 1982, Figs. 39, 41).

3. *Sandstones not related to Bouma sequences.* Three sandstones in the d'Iberville Glacier section, 1 to 5 cm thick and very fine grained, differ markedly both from the Bouma sequences and from the massive sandstones. They have abrupt contacts with underlying and overlying mudrocks and show crosslamination, with or without flat lamination and without graded bedding. They are labelled C(?) because they may represent contourites. Two beds are 4 to 5 cm thick, and one is 0.1 to 1 cm thick. Certain sandstones near Chandler Fiord, interbedded with slaty mudrocks, have sharp upper and lower contacts and an internal flat lamination (Fig. 115).

4. *Undifferentiated mudrocks (P)* include fine grained sediments that cannot be assigned to Bouma sequences with confidence. The

stratification commonly is obscured by slaty cleavage (Fig. 115), especially in rocks that are relatively rich in mica and chlorite. Where discernible, flat lamination is predominant, small-scale crosslamination fairly common, and convolute lamination rare.

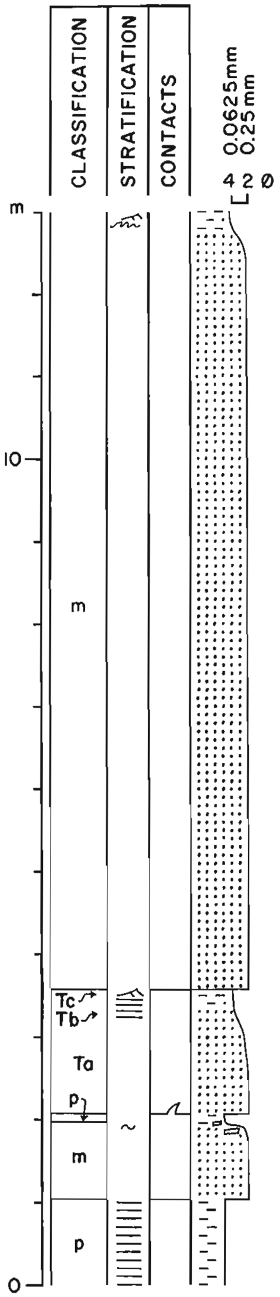


Figure 113. Columnar log of short interval within the lower Danish River Formation at Ella Bay 2-South section. Section is underlain by mudrock of the same formation; for legend see Figure 112.

Figure 114. Photographs of Ella Bay 2-South section. ***a)*** Top of massive sandstone unit, overlain by siltstone showing convolute lamination (arrow); bedding is perpendicular to photograph; ***b)*** massive sandstone unit, looking north; ***c)*** base of section; massive unit begins 1 m above base of staff, 1.5 m long. ISPG photos. 1878-59, 60, 62.

Some flat-laminated mudrocks contiguous with Ta-c or Tbc sequences probably represent D-divisions, but have not been labelled so because they could not be separated from overlying unrelated mudrocks. Some flat-laminated and crosslaminated units with abrupt basal contacts may represent Tcd or Td turbidites, respectively.

Detrital composition of sandstones

The sandstones of members A and C of the Danish River Formation are relatively uniform in composition. It is meaningful, therefore, to establish an average composition, based on combined point count (29) and XRD (77) analyses. The point count analyses (Table 13) are more reliable in general, but have several limitations. For example, untwinned feldspar is difficult to distinguish from quartz without etching and staining and appears to have been underestimated during earlier studies, and plagioclase cannot always be distinguished from K-feldspar. Therefore the point count results for quartz and feldspar have been combined and then subdivided on the basis of corrected XRD ratios for (feldspar)/(feldspar + quartz) and for (plagioclase)/(plagioclase + K-feldspar) (Table 13). Likewise, the undifferentiated carbonate fraction has been apportioned to calcite and dolomite on the basis of the corrected ratio for (dolomite)/(dolomite + calcite).

Figure 115. *Interbedded mudrock (recessive) and sandstone (resistant) near the Chandler Fiord section. Sandstone beds have flat lamination and sharp upper and lower contacts, mudrock has slaty cleavage oblique to bedding. ISPG photo. 978-26.*

For the composition of the sandstones of member B, the reader is referred to the right side of Tables 13 and 14. Briefly, silicate minerals and rock fragments make up about three quarters of the rock volume and carbonate materials one quarter. The silicate fraction consists chiefly of quartz with subordinate feldspar and minor phyllosilicates, phyllite, and chert; volcanic materials are rare.

Quartz (54%) occurs mainly as single crystals that commonly show undulose extinction, and in some instances include flakes of white mica or chlorite. Composite or semicomposite grains of vein quartz, recrystallized chert, and metamorphic rocks are rare, as is normal for fine grained sandstones.

Feldspar (13%) comprises variable proportions of plagioclase (largely or entirely albite) and K-feldspar (largely or entirely microcline). K-feldspar is predominant in the lowermost part of the formation, sampled at the Ella Bay 2-South and Ella Bay 3 sections (P/P + Kf = 21.5%) and also in member B (34.0%), but plagioclase is predominant in the rest of the formation.

The phyllosilicates (2.5%) comprise white mica, variably chloritized biotite, and chlorite.

The phyllite (3%) consists of white mica and quartz, with or without chlorite.

Small amounts of chert, averaging less than one per cent, occur in every thin section.

About 1 per cent of volcanic rock fragments was recorded in samples from member B; elsewhere volcanic rock fragments are absent, or present only in trace amounts.

Carbonate grains (calcite, 17%; dolomite, 8%) consist mainly of fragments of lime mudstone and of single crystals of calcite or dolomite that commonly have formed by recrystallization of lime mudstone (polycrystalline texture apparent in extinction position). Fossil fragments, mostly from echinoderms or ostracodes, are rare and confined to localities near the southeastern margin of the Deep Water Basin.

Grain size, sorting, and rounding of the sand fraction

Statistical data on grain size distributions in sandstone samples from the Hazen Plateau and Cañon Fiord are reported in Trettin, 1971 (p. 60-63) and 1979 (Figs. 40, 48), respectively. They are based on measurement of 100 grains of quartz, chert or feldspar

TABLE 13

Danish River Formation, point count analyses of sandstones. (From Trettin, 1978, p. 15, and Trettin, 1979, Appendix 2.) Values in brackets have been calculated from X-ray diffraction ratios in Table 14.

Member/equivalent	A			C			A+C			B	
Section	CF1	CF1	CF2	CF4	CF5	TF	Section means			CF1	
N	3	3	9	5	4	3	Range	$\bar{X}$		2	
Quartz + feldspar	54.0	80.4	68.0	65.9	66.6	65.6	54.0-80.4	66.8		81.7	
(quartz)								(53.7)		(68.9)	
(K-feldspar)								(4.2)	{ 13.1	(8.7)	{ 12.8
(plagioclase)								(8.9)		(4.1)	
Chert	1.3	1.0	0.7	0.6	0.5	tr	tr-1.3	0.7		tr	
Muscovite	1.0	3.7	1.9	2.2	1.8	2.3	1.0-3.7	2.2		1.5	
Biotite	tr	2.0	1.1	0.6	tr	3.0	tr-3.0	1.1		1.0	
Chlorite	1.0	2.0	1.3	1.0	1.0	1.0	1.0-2.0	1.2		tr	
Phyllite	1.03	1.0	2.3	1.4	4.0	1.3	1.0-10.3	3.4		2.0	
Volcanics	tr	0	tr	0	0	0	0-tr	tr		1.0	
Carbonates	32.3	9.8	24.6	28.3	26.0	26.8	9-32.3	24.6		12.8	
(calcite)								(16.9)		(6.3)	
(dolomite)								(7.7)		(6.5)	

per sampled area (an entire thin section or part of a thin section) in a total of 38 sampled areas. In all instances, the mean grain size lies between 3 and 4 phi units; that is, in the range of very fine grained sandstones (0.125–0.0625 mm). The standard deviations range from 0.62 to 1.25 phi units, with averages of 0.92 and 0.82 for two suites from the Hazen Plateau and 0.76 for two samples from Cañon Fiord. The sieve equivalents (Friedman, 1958) for the same data are 0.8, 0.72, 0.68 and 0.68 phi units and the rocks are "moderately" to predominantly "moderately well" sorted according to the terminology of Friedman (1962).

Most quartz grains are subangular to angular, but subrounded to rounded grains also are present. At least some of the angularity appears to be due to diagenetic corrosion. Chert, feldspar, and rock fragments are subangular to angular.

Paleocurrent directions of sandstones

Sole markings, generally at the bases of graded or massive sandstone beds and rarely at the bases of conglomerates, were studied to determine the directions of sediment gravity flow. Flute marks (Fig. 116) (common) and chevron marks (rare) provided both sense and direction of flow; grooves and ridges (common) and tool marks (rare), directions only (cf. Dzulynski and Walton, 1965).

The orientation of these features was measured as pitch; that is, as the angle they form with a horizontal line (strike) marked on steeply dipping bedding planes of folded strata (Fig. 117). The pitches were then converted to azimuths by theoretical rotation of the beds into their original horizontal positions, which involves: 1) elimination of the plunge of the folds by rotation about the pole of the axial plane, and 2) flattening of the limbs by rotation about the now horizontal fold axes. The geometrical procedures are explained in Trettin, 1971 (p. 67, 68).

The strikes of beds and axial planes were determined on aerial photographs. The pitches of the fold axes were inferred from direct measurements of plunge wherever possible, for example, by sighting down the crests of anticlines. Where this was not possible, the pitches of the fold axes were inferred from the difference between the average pitches of about 50 paleocurrent indicators measured on opposing fold limbs, assuming uniform paleocurrent flow.

A total of 2619 determinations, made at 30 stations, are divisible, by age and location, into four groups (Fig. 118, A to D).

TABLE 14

Danish River Formation, X-ray diffraction analyses of sandstones. (From Appendix 3, Tables 88, 90, 92, 94; Trettin, 1978, p. 15; and Trettin, 1979, Appendix 2.)

Member or equivalent	A					C				A+C			B	
Section, area	Hazen Plateau	CHF	EB2S, EB3	DIG	CF1	CF1	CF2	CF5	TF	Section or area means			CF1	
N	11	7	7	8	6	10	4	5	19	Range	$\bar{X}$	corrected values	2 $\bar{X}$	corrected values
Quartz	49.4	54.4	59.6	54.9	55.5	64.8	45.5	66.4	53.6	45.5-64.8	56.0		80.0	
K-feldspar	0.8	0.6	4.1	0.8	3.0	2.5	1.3	0.6	3.5	0.6-4.1	2.1		5.5	
Plagioclase	4.8	6.4	1.4	3.4	3.7	4.9	3.3	3.8	6.9	1.4-6.9	4.3		3.0	
Mica	7.5	3.4	2.1	2.3	3.5	5.5	3.3	3.6	4.4	2.1-7.5	4.0		2.0	
Chlorite	8.9	5.6	2.1	2.3	3.7	5.2	2.8	5.6	5.5	2.1-8.9	4.6		1.5	
Calcite	20.2	21.0	20.1	24.9	20.2	11.5	40.0	15.2	19.4	11.5-40.0	21.4		5.0	
Dolomite	8.7	8.6	10.9	11.6	10.5	5.6	4.0	4.8	6.7	4.0-11.6	7.9		3.0	
F/F+Q	10.1	11.1	8.6	6.6	10.8	10.0	8.5	6.8	16.1	6.6-16.1	9.8	19.6[1]	9.5	19.0[1]
P/P+K-f	85.0	95.6	21.5	88.0	50.5	68.4	86.3	84.3	67.9	21.5-95.6	71.9	68.3[2]	34.0	32.3[2]
D/D+C	28.9	29.6	31.0	32.5	30.7	17.1	44.0	20.0	26.1	17.1-32.5	28.9	31.2[3]	48.5	50.8[3]

Correction constants:
1 x2 (from point count and XRD data from Grant Land Formation sandstones
2 x0.95 (from point count and XRD data from Grant Land Formation sandstones
3 +2.3% from Royse et al., 1971

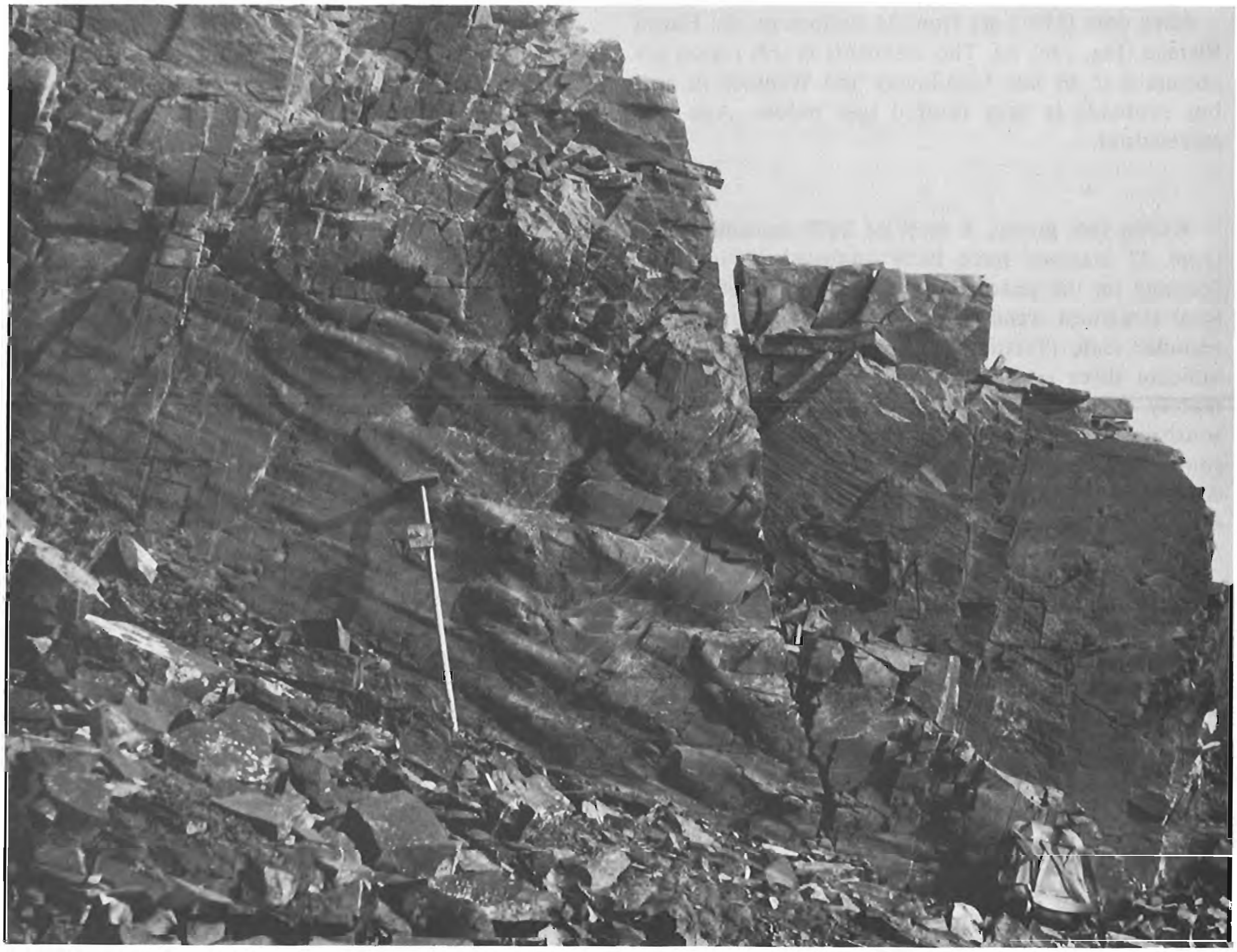


Figure 116. Giant flute casts in member C of the Danish River Formation at Caledonian Bay; 1.2 m staff for scale. Beds on the right also show furrows and ridges. ISPG photo. PRA-003-6.

Figure 117. Tightly folded, steeply dipping strata of the Danish River Formation in central part of the Hazen Fold Belt, north of the head of Antoinette Bay. Such exposures are best suited for paleocurrent studies. ISPG photo. 648-7.

Most data (2191) are from 23 stations on the Hazen Plateau (Fig. 118, A). The sediments in this region are presumed to be late Llandovery and Wenlock in age, but evidence is very limited (see below, Age and correlation).

Within this group, a total of 2079 determinations from 22 stations have been analyzed statistically, focusing on the relations between flow direction and local structural trend, which is slightly arcuate on a regional scale (Trettin, 1971, p. 69-76). Histograms indicate three overlapping populations — approximately parallel to the structural trend, to the southwest; normal to the structural trend, to the southeast; and intermediate. The most important statistical parameters of the three populations can be summarized as follows.

Population	% of data	Vector mean (relative to strike SW)	σ
Longitudinal (to WSW)	67.6	4°	36°
Transverse (to SE)	30.0	-83°	38°
Intermediate (to SW)	2.4	-47°	44°

The longitudinal and transverse populations were compared with circular normal distributions having the same vector mean, vector strength, and number of observations, using the chi square test. The fit was poor in both cases, but statistically acceptable for the longitudinal population.

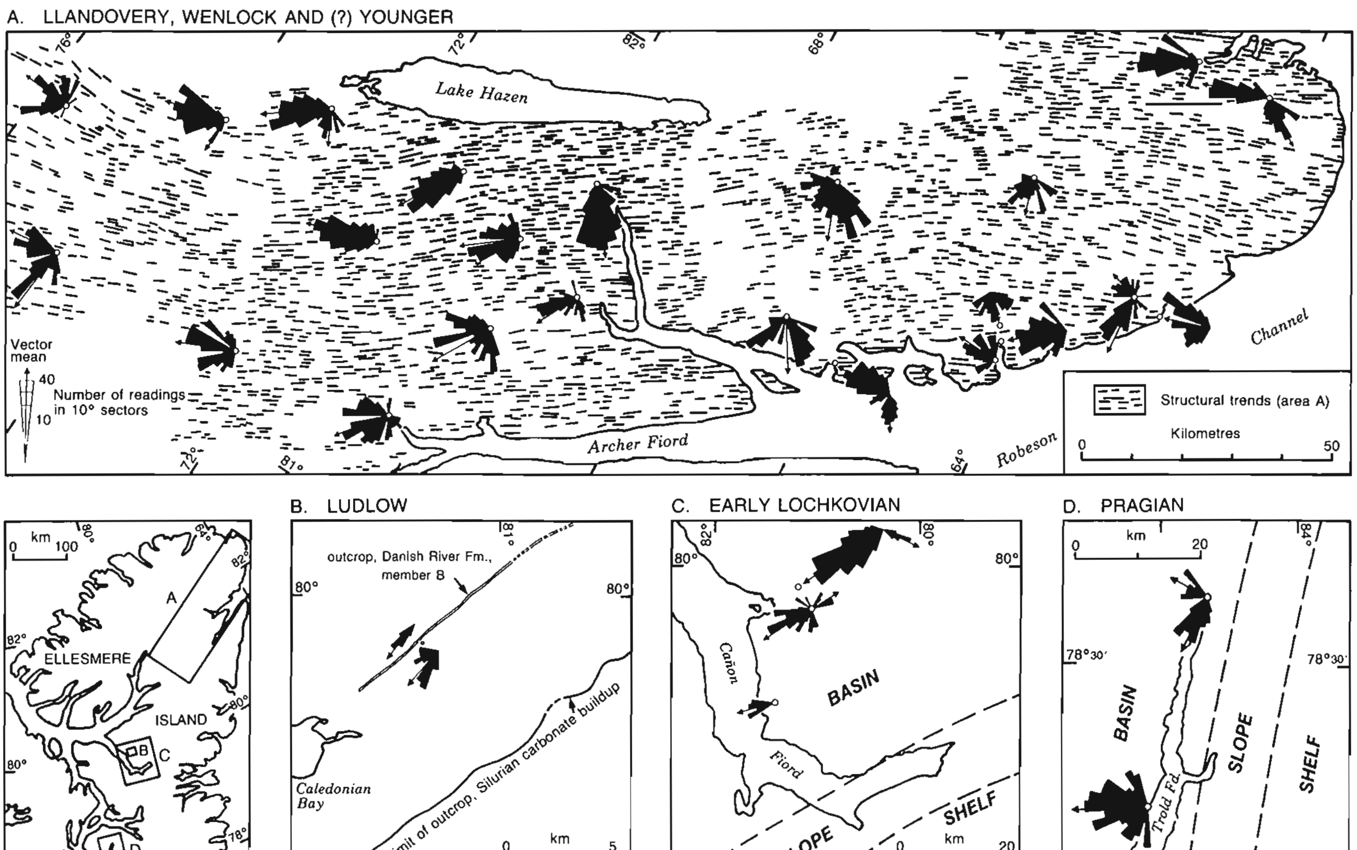


Figure 118. Paleocurrent directions in the Danish River Formation. Arrows indicate vector means.

At Cañon Fiord the structural trend (outlined by member B and the shelf/slope boundary) is southwest, and the age of the paleocurrent indicators is Ludlow and early Lochkovian. Current indicators are oriented mainly longitudinal to the southwest, with the exception of two minor sets that are directed northeast and southeast, respectively (Fig. 118, B and C, based on Trettin, 1979, p. 46, 62, 64).

At Trold Fiord the structural trend (outlined by the shelf/slope boundary) is south-southwest and the strata studied are Pragian and possibly Lochkovian in age. Flow was mainly transverse in westerly directions and only to a minor extent longitudinal to the southwest (Fig. 118, D; based on Trettin, 1978, p. 17, 18, 82, 83).

Composition and microscopic textural features of mudrocks

The average compositions of 70 samples of mudrock are listed in Table 15. The average values are similar to the XRD data for the sandstones, except that mica and chlorite are more abundant (15% combined vs. 9% combined) and quartz is correspondingly less abundant (51% vs. 56%).

Material of clay grade appears to be scarce or absent, perhaps as a result of recrystallization.

Siliciclastic conglomerate

The only terrigenous conglomerate known is member B at Caledonian Bay. Exposed along strike for 13 km, it is 42 to 101 m thick. The member consists mainly of conglomerate with lesser amounts of interbedded sandstone and mudrock. The conglomerate is largely of pebble grade, but includes cobbles and boulders up to 60 cm in diameter, as well as rip-up clasts of mudrock, and slumped blocks of mudrock and sandstone derived from the Danish River Formation. The pebbles, cobbles, and boulders are embedded in a sandy matrix, similar to the interbedded sandstones. In these conglomerates, most of the clasts support each other, but some are supported by the matrix. Sorting is poor where cobbles and boulders are present, and moderate where they are absent. Graded bedding is rare. Conglomerate beds range in thickness from 9 cm to 5.6 m and are massive, as are the interbedded sandstones. Both occur as lenses 1 to 10 m in length. Some beds have sole marks such as grooves and ridges, and crude, triangular flute casts.

TABLE 15

Danish River Formation, X-ray diffraction analyses of mudrocks. (From Appendix 3, Tables 89, 91, 93, 95; Trettin, 1978, p. 15; and Trettin, 1979, Appendix 2.)

Member or equivalent	A					C						
Section, area	Hazen Plateau	CHF	EB2S	DIG	CF1	CF1	CF2	CF5	TF	Range	$\bar{X}$	corrected values
N	7	25	5	9	2	3	7	7	5			
Quartz	42.7	41.6	44.8	50.0	50.0	61.7	50.6	57.0	56.8	41.6-61.7	50.6	
K-feldspar	1.0	1.0	4.6	0.7	2.5	2.0	1.1	0.6	3.6	0.6-4.6	1.9	
Plagioclase	6.9	4.5	1.2	3.6	3.0	6.0	5.4	4.6	7.0	1.2-7.0	4.7	
Mica	9.7	12.2	6.2	5.4	4.0	11.7	8.0	4.3	6.8	4.0-12.2	7.6	
Chlorite	7.4	14.1	6.0	4.2	4.0	11.0	5.3	5.6	6.2	4.0-14.1	7.1	
Dolomite	9.1	7.5	14.8	16.7	13.5	5.7	8.7	7.1	7.2	5.7-16.7	10.0	
F/F+Q	15.1	11.5	12.0	7.7	9.5	12.3	11.3	8.6	16.2	7.7-16.2	11.6	23.2[1]
P/P+K-f	89.6	82.2	23.0	75.7	52.5	75.3	86.1	89.3	69.4	23.0-89.6	71.5	67.9[2]
D/D+C	28.6	34.4	40.4	46.8	36.5	66.3	36.1	25.4	37.2	25.4-66.3	39.1	41.4[3]

Correction constants:
[1] x2
[2] x0.95
[3] +2.3%

Most pebbles and cobbles are composed of chert; a lesser number of quartzite, in part arkosic; and a few of variably metamorphosed limestone. The chert clasts are mostly massive and unfossiliferous, but a few are laminated and contain poorly preserved radiolarians.

The associated sandstones (Tables 13, 14) differ from those of members A and C by having larger contents of quartz (65%) and feldspar (15%), and smaller contents of carbonate (13%). Also, the plagioclase content of the feldspar fraction (32% corrected) is smaller than in the upper part of member A and in member C.

Carbonate conglomerate

Carbonate conglomerates are common in the Cañon Fiord and Trold Fiord areas (Trettin, 1978, 1979). They consist of granules, pebbles, and cobbles of shelf limestone or fossil fragments in a matrix of massive sandstone.

Metamorphism

The fine grained mudrocks have a slaty cleavage, caused by the recrystallization, in preferred orientations, of clay minerals to white mica and chlorite of fine silt grade. The preservation of detrital biotite and K-feldspar in coarse mudrocks and sandstones shows that these rocks have not attained the greenschist facies.

Mode of origin

This section interprets the provenance, mode of transport, and environment of deposition of the three main sediment groups described above. However, the provenance of the siliciclastic sediments cannot be discussed adequately without taking into consideration the depositional and structural history of Pearya Terrane and Clements Markham Fold Belt, to be discussed in a second report on northern Ellesmere Island (Trettin, work in progress); the remarks on this subject, therefore, are generalized and provisional.

Sandstone and mudrock

Sandstone and mudrock, as mentioned, make up the bulk of the formation and siliciclastic material constitutes about three quarters of the rock volume. The detrital mineral suite — quartz, albite, microcline, white mica, chlorite, and rare biotite — is compatible with derivation from a variety of low-grade metamorphic or altered rock types such as phyllite, low-grade schist, and spilite, although microcline does not survive in the greenschist facies. However, as mentioned, silt-grade white mica and chlorite in slaty mudrock probably have recrystallized from clay minerals (see below, Metamorphism). If the source terrane included igneous and metamorphic rocks with highly unstable minerals such as hornblende, pyroxene, and plagioclase other than albite, this material must have been destroyed during erosion, transport, or diagenesis. Nevertheless, the preservation of detrital biotite and of fragments of phyllite indicates a fair degree of compositional immaturity. The absence of volcanic rock fragments, volcanic quartz (with its characteristic euhedral form and embayments), and high percentages of plagioclase and chlorite, indicate that contemporaneous volcanism did not contribute significantly to this formation — in contrast to other Silurian deep water units in northwestern Ellesmere and northern Axel Heiberg islands (cf. Trettin, 1969, 1987a). Radiolarian chert fragments also are rare, but this may be related, to some degree, to grain size rather than to provenance; in the Lands Lokk Formation of the Clements Markham Fold Belt, for example, which is coarser grained, chert content decreases with decreasing grain size (unpublished data).

The carbonate grains, which constitute the remaining one quarter of the rock volume, probably were derived from carbonate strata interbedded with the siliciclastic source rocks, because they are of the same grain size as the siliclastic grains and mixed with them thoroughly and uniformly. The inferred terrigenous origin of the carbonate fraction implies arid conditions in the source area and rapid erosion.

The fine grain size of the sandstones indicates that the sources of sandstone and mudrock were remote. The paleocurrent directions suggest three different source regions active at different times, or together.

1. One major source, inferred from the transverse, southeastward paleocurrent directions on the Hazen Plateau (Fig. 118, inset A), must have lain to the northwest of that region. The transverse flows evidently were deflected into strike-parallel northeast-southwest directions in the distal southeastern part of the Deep Water Basin.

2. In North Greenland, only longitudinal southwestward indicators have been observed, suggesting that the sediments were derived exclusively from the Caledonides on the northeast.

It should be noted, however, that the determinations were mostly in the distal part of the basin, which is aligned with the region of longitudinal flow in Ellesmere Island (see below, Fig. 132). Thus an additional northwesterly source cannot be ruled out.

3. East-west paleocurrent directions obtained at two localities near Trold Fiord (Fig. 118, D) point to a cratonic source east of central Ellesmere Island, which also may have produced clastic sediments of late Lochkovian–early Pragian age in the area south of Cañon Fiord (Red Canyon River Formation; Trettin, 1978). Alternatively, these transverse indicators may represent reflection of currents on the basin margin (cf. Kneller et al., 1991). This mechanism may also explain anomalous southwest-northeast directions recorded close to the basin margin in lower Lochkovian strata at Caledonian Bay (Fig. 118, C).

The sandstone and mudrock were deposited mainly by turbidity currents and deposited in basin floor and distal submarine fan environments; the present information is insufficient to distinguish these two settings.

Siliciclastic conglomerate

In contrast to the sandstones and mudrocks, the conglomeratic member B of the Danish River Formation (Ludlow) must have come from a relatively proximal source. The abundant chert was derived from radiolarian chert of deep water origin. The associated quartzite, arkosic quartzite, and carbonate rocks, on the other hand, represent a weakly metamorphosed miogeoclinal suite, comparable to Proterozoic to Lower Ordovician strata of the Pearya Terrane (succession II of Trettin, 1987b). Derivation from the cratonic interior of North America can be ruled out because of facies relations — the Ludlow deposits of the Franklinian Shelf consist of carbonate strata.

The primary structures and very limited distribution indicate deposition by subaqueous debris flows and associated tractive currents in a submarine canyon or channel.

Carbonate conglomerate

Discrete carbonate bodies are confined to the southeastern margin of the Deep Water Basin. Distribution and fossil content indicate derivation from contemporaneous marine strata of the adjacent Franklinian Shelf. The sediments were transported by subaqueous debris flows and turbidity currents and deposited on the basin floor where they became mixed with much finer grained siliciclastic detritus of different provenance.

Age and correlation

Age of base of formation

Hazen Fold Belt

As mentioned above (Hazen Formation, Age and correlation), the upper part of the Hazen Formation has yielded:

1. Macrofossils of late Llandovery or Wenlock age, from 0 to 27 m, and graptolites of late Llandovery age, from 53 to 101 m below the Danish River Formation at Cañon Fiord, Section CF1 (Norford, *in* Trettin, 1979, p. 80).

2. Conodonts of middle Llandovery age, directly beneath the Danish River Formation southeast of Ella Bay (Fig. 84, loc. F2).

3. Graptolites of early or middle Llandovery age, from a few metres below the Danish River Formation at Wood River (Fig. 84, loc. F1).

4. Graptolites of Late Ordovician age, 7 m below the Danish River Formation at St. Patrick Bay (Fig. 84, loc. SPB).

The oldest fossil collection from the Danish River Formation itself, made at Cañon Fiord, Caledonian Bay, Section CF1, includes *Cyrtograptus canadensis* Jackson and Etherington (synonymous with *C. sakmaricus*) and *Stomatograptus* sp. cf. *S. grandis* (Suess) (Norford, *in* Trettin, 1979, p. 82), which belong to the youngest graptolite subzone of the Llandovery.

The available evidence thus indicates that the base of the formation is late Llandovery at the type section (CF1). The fossil collections from the uppermost Hazen Formation permit slightly older ages (latest Ordovician to middle Llandovery) at the other localities mentioned, if condensed intervals or submarine disconformities (diastems) are absent below the Danish River Formation. However, relations with North Greenland indicate that this assumption is not justified.

Central Ellesmere Fold Belt

The base of the formation is highly diachronous within the Central Ellesmere Fold Belt, as evident from fossil collections from the following three areas.

1. Southeast of Ella Bay, at the Ella Bay 3 section, the Danish River Formation overlies strata of the Allen Bay Formation with a seemingly abrupt contact that probably is disconformable. The uppermost strata of the Allen Bay Formation have yielded conodonts of early to to middle Llandovery age (Nowlan, in Appendix 3B, C-54913); the Danish River Formation is barren.

2. On the southeastern coast of Judge Daly Promontory, the Danish River Formation lies on the Cape Phillips. At Cape Lieber, graptolites of the undivided *griestoniensis-sakmaricus* zones of late Llandovery (Telchyan) age occur in the upper 5 m of the Cape Phillips Formation; the Danish River Formation is barren (T.A. de Freitas, 1991, Fig. 7b, Sections 23, 24).

3. East of Cañon Fiord, at the Cañon Fiord 2 section (CF2), the graptolite *Monograptus* sp. cf. *M. uniformis parangustidens* Jackson and Lenz of late Pridoli age (Norford, *in* Trettin, 1979, p. 80) occurs in the Cape Phillips Formation, 43 m below the base of the Danish River Formation, and the (transported) trilobite *Warburgella* sp. cf. *W. rugulosa canadensis* Ormiston of probable earliest Lochkovian age (Ormiston, *in* Trettin, 1979, p. 82) 123 m above the base of the Danish River Formation. At the Cañon Fiord 4 section (CF4), the transported conodonts *Icriodus woschmidti* Ziegler and *Ozarkodina remscheidensis remscheidensis* Ziegler of earliest Lochkovian age were found, in limestone clasts, 99.7 m above the base of the formation (Uyeno, *in* Trettin, 1979, p. 83). Combined, these collections indicate that the base of the formation is close to the Silurian-Devonian boundary and probably earliest Lochkovian in age in this area.

Age of top of formation

The top of the formation has been dated only at Caledonian Bay, at the type section (CF1), where the Danish River Formation is overlain by the Eids Formation. The trilobite *Warburgella* n. sp. aff. *W. rugulosa* (Alth) (Ormiston, *in* Trettin, 1979, p. 84) of probable early Lochkovian age (cf. Trettin, 1978, p. 6, 7) was found 353 m above the Danish River/Eids contact. Combined with evidence of a Lochkovian age for the Danish River Formation at the adjacent Cañon Fiord 2 section, this indicates that the top of the Danish River Formation lies within the early Lochkovian in this area.

However, at the head of Trold Fiord, the conodont *Polygnathus dehiscens lenzi* Klapper of early Zlichovian age occurs in the upper part of the exposures (Uyeno, *in* Trettin, 1978, p. 110). The top of the formation is not preserved in that area, owing to truncation by the mid-Paleozoic unconformity, but the conodonts indicate that it cannot be be older than early Emsian.

Age of member B

Monograptus sp. cf. *M. bohemicus* (Barrande) of Ludlow age occurs approximately 60 m above member B at the type section (CF1). The graptolite is too poorly preserved to determine its subspecies, and hence its position within the Ludlow. Member B therefore is Ludlow or Wenlock in age — probably Ludlow because the graptolites are stratigraphically close to member B and deposition was rapid.

Age of strata preserved in the Hazen Plateau region

The graptolite *Monograptus* aff. *M. priodon* (Bronn) of late Llandovery to Wenlock age was found at three localities (F1, F2, and F3 in Fig. 110) in the Hazen Plateau region (Appendix 3A). The apparent absence of younger fossils and of strata comparable to member B suggest that the Late Silurian and Early Devonian parts of the formation (equivalents of members B and C) have been eroded in that region. However, this conclusion is rather tentative, because of the reconnaissance nature of the present work and the scarcity of fossils.

Correlation with flysch units in North Greenland

In North Greenland, the Llandovery to Late Silurian parts of the Danish River Formation are correlative with the siliciclastic portion of the Peary Land Group; that is, the combined Sydgletscher, Merkujôq, Lauge Koch Land, Nordkronen, and Nyboe Land formations (cf. Hurst and Surlyk, 1982; Larsen and Escher, 1987). Compositionally, members A and C are comparable to the Merkujôq, Lauge Koch Land, and Nyboe Land formations. Member B has features in common with the Hendrik Member of the Nordkronen Formation, placed in the early Ludlow by Larsen and Escher (1987).

The Sydgletscher and Merkujôq formations were deposited north of the limit of the Ordovician–early Llandovery shelf edge; the Lauge Koch Land Formation overstepped that edge in latest Llandovery–Wenlock time. The onset of flysch sedimentation was early late Llandovery in western and central North Greenland where graptolites of that age occur both in the lowermost Merkujôq Formation and in an underlying chert unit that is comparable to the chert member of the Hazen Formation (Higgins and Soper, 1985). At Sydgletscher, Johannes V. Jensen Land, middle to early late Llandovery graptolites (belonging to the *atavus* to *cyphus* zones) were found in chert and mudrock of the Amundsen Land Formation, 60 m below the Sydgletscher Formation (Friderichsen et al., 1982). Graptolites of latest Ordovician age have been found just below the Amundsen Land Group/Merkujôq Formation contact in Amundsen Land (Friderichsen et al., 1982).

Implications of the onset of flysch sedimentation in the Hazen Fold Belt

The fact that flysch sedimentation began in late Llandovery time both at Cañon Fiord and in different parts of North Greenland suggests that the base of the flysch (Danish River, Merkujôq, and Sydgletscher formations) is nearly synchronous throughout the Hazen and North Greenland fold belts, within the limits of biostratigraphic resolution.[1] The localities at which slightly older fossils occur not far below the base of the flysch have an erratic distribution that does not support the notion of systematic diachronism related to progradation. The underlying strata — radiolarian chert and minor mudrock — were deposited very slowly in a deep basin (*see* below, Stratigraphic synthesis, discussion of accumulation rates; and Fig. 123). In such settings, condensed intervals or hiatuses due to minimal deposition or erosion by bottom currents are common.

CHAPTER 5

STRATIGRAPHIC SYNTHESIS

ELLA BAY ESCARPMENT: ORDOVICIAN EROSIONAL SHELF MARGIN WITH SUBMARINE SLOPE UNCONFORMITY

NATURE OF THE BASAL CONTACT OF THE DANISH RIVER FORMATION SOUTH OF BULLEYS LUMP

Crucial for the interpretation of the Ordovician shelf margin is the basal contact of the Danish River Formation in the area south and southeast of Bulleys Lump. This area is delineated by structural cross-section B-B′ and by the Ella Bay 4-3 section (Fig. 1) and excludes the western outcrop belt of the Bulleys Lump Formation, discussed below. At the location shown in cross-section B-B′, the Danish River Formation lies on strata of the Bulleys Lump Formation that have a middle Arenig–middle Llanvirn conodont age and are equivalent to middle parts of member B at the type section. Following this contact to the southeast and east, within a few kilometres, the Danish River Formation progressively overlaps the upper Bulleys Lump Formation and the entire Thumb Mountain, Irene Bay, and Allen Bay formations (Figs. 119, 120). The Danish River Formation remains on top of the Allen Bay in the rest of the area, except for the southeastern coast of Judge Daly Promontory (e.g., Carl Ritter Bay), where it lies on the Cape Phillips Formation. As the base of the Danish River Formation is no older than late Llandovery, this implies a southeastward-diminishing age gap between the Danish River Formation and the underlying carbonate units (Fig. 119). Analysis of this contact suggests that it is either a fault (and in this case more likely a reverse than a normal fault), or some kind of an unconformity. I shall briefly discuss a few alternatives and then focus on the most probable explanation.

Interpretation of the contact as a thrust fault

In many orogenic belts (for example in the Appalachians; Williams and Hatcher, 1983), deep water sediments of oceanic origin have been thrust over shelf successions, and geologists unfamiliar with the stratigraphy and structure of the Franklinian Shelf may be inclined to speculate that this was the case at Ella Bay. Such a thrust fault would place younger on older strata. It would cut upsection to the top of the Allen Bay Formation and then become bedding-parallel and involved in the Ninnis Glacier Syncline, implying that the thrust faulting preceded the regional folding.

[1]If the lowest graptolite collection from Caledonian Bay dates the base of the formation, then the base of the formation ascends in age from early late Llandovery in Northwest Greenland to latest Llandovery at Caledonian Bay, concomitantly with southwestward progradation.

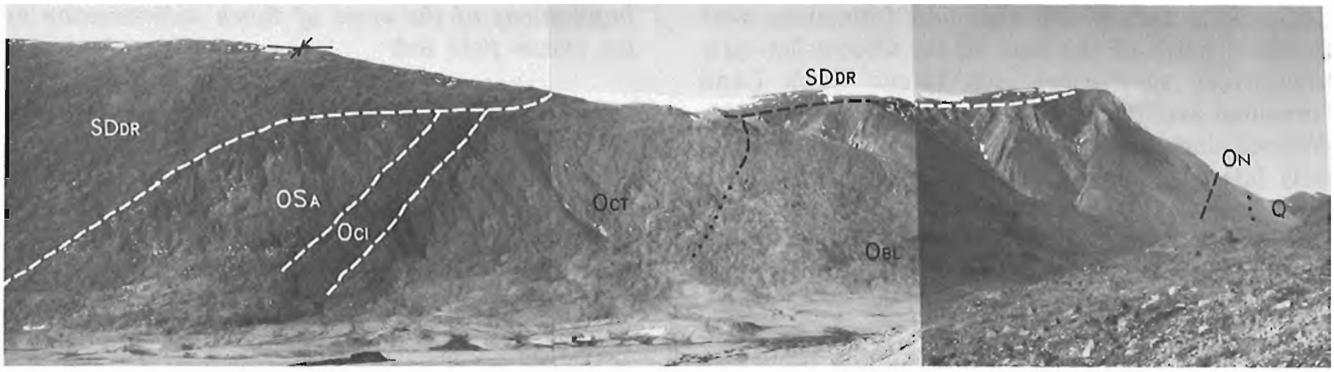


Figure 119. Relation of the Danish River Formation with underlying units southeast of Ella Bay. Composite photograph, looking southwest. On the right Quaternary cover (Q) and the Ninnis Glacier Formation (O_N). The Danish River Formation (SD_{DR}) overlaps part of the Bulleys Lump Formation (O_{BL}), and all of the Thumb Mountain (O_{CT}), Irene Bay (O_{CI}), and Allen Bay (OS_A) formations. ISPG photos. 2256, 2242-2244.

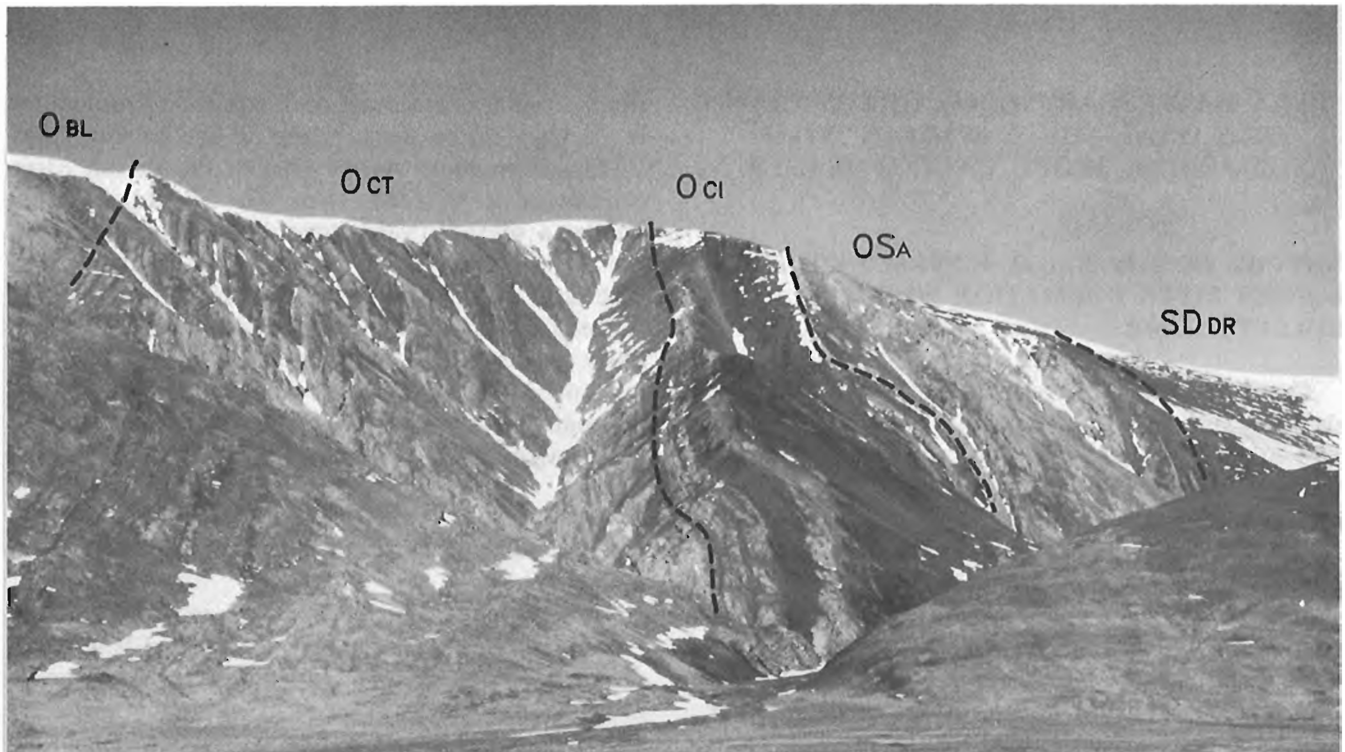


Figure 120. Opposite side of the same valley shown in Figure 119, looking northeast. Here the Danish River Formation lies on the Allen Bay Formation; for legend, see Figure 119. ISPG photo. 1360-26.

However, thrusts placing younger on older strata are unknown in the Central Ellesmere and North Greenland fold belts. On the other hand, stratigraphic observations and numerous fossil collections have shown clearly that the Silurian-Lower Devonian flysch encroached on the shelf depositionally rather than structurally, both in the Arctic Islands (Trettin, 1978, 1979; Trettin et al., 1991) and in North Greenland (Hurst and Surlyk, 1982; Surlyk and Hurst, 1984; Higgins et al., 1991).

Interpretation of the contact as a structurally modified submarine unconformity

An unconformity may be either subaerial or submarine. In this case, a subaerial unconformity can probably be ruled out because the contact is overlain by deep water sediments without any (exposed) record of intervening emergence. A submarine unconformity, on the other hand, is compatible with the regional setting: the transition zone from shelf to Deep Water Basin. The absence of the Hazen Formation can readily be explained by the existence of a steep margin during much of Ordovician time, followed by submarine onlap in the Silurian when the basin was rapidly filled with flysch sediments (see below, discussion of accumulation rates; also Schlager and Camber, 1986; Schlager, 1989).

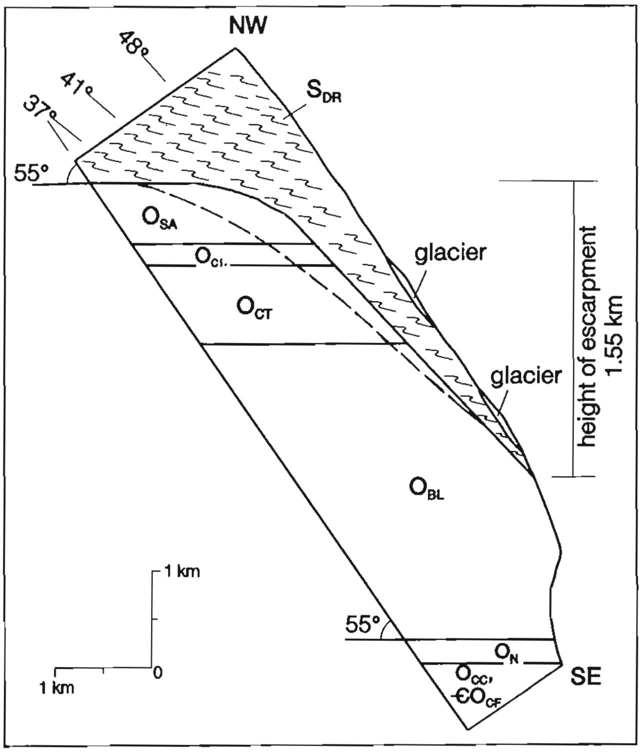


Figure 121. Structural cross-section, subparallel to Figure 119, rotated to restore carbonates to horizontal position (mirror-image of cross-section B-B' in Fig. 1). Dashed line indicates alternative interpretation for basal contact of Danish River Formation; for legend, see Figure 119. Occ: Cape Clay Formation; ЄOCF: Cass Fjord Formation.

According to this hypothesis, the flysch was not deposited **on** the escarpment but laterally **against it.** The stratigraphic-structural configuration resulting from such an onlap (see below, Fig. 122) has two characteristics:

1. Flysch and carbonates have the same bedding attitude.

2. The bedding attitude of flysch and carbonates forms an angle with the unconformity that is equal to the inclination of the bypass margin.

The bedding attitude of the carbonates clearly forms steep angles with the basal contact of the flysch; that is, with the inferred unconformity; only in the upper Allen Bay Formation does this angle decrease to zero (Figs. 119-121).

The attitude of the flysch, on the other hand, is difficult to determine because of intense frost shattering — the Danish River Formation occurs mostly as felsenmeer (bedrock weathered in place). Limited airphoto evidence and field observations indicate variable relations. At some localities (for example on the north end of the ridge shown in cross-section B-B') the bedding of the flysch seems to abut the basal contact in a manner suggesting onlap (seen on aerial photographs only, not in Fig. 119). At another locality (Fig. 119, above the Irene Bay Formation) the lowermost flysch beds are about parallel to the unconformity, but higher beds form a shallow syncline (apparent on aerial photographs, Figure 136). Such structures are entirely unrelated to the structure of the underlying carbonates.

The inconsistent angular relation between the flysch beds and the basal contact of the flysch can be explained by the hypothesis that the unconformity functioned as a décollement during the Ellesmerian Orogeny, which separated minor folds in the flysch from large structures in the carbonates. In some areas, however, the incompetent flysch strata seem to have been forced into parallelism with the unconformity. This implies that the attitudes of the flysch beds (in contrast to the attitudes of the carbonates) cannot be used for the reconstruction of the slope angle (see below).

HEIGHT AND INCLINATION OF THE SHELF MARGIN

If the basal contact of the Danish River Formation is essentially a submarine slope unconformity, then structural cross-sections should provide some information about the height and inclination of that slope, provided that the carbonate succession was horizontal during flysch sedimentation.

Assuming horizonal bedding of the carbonates prior to Ellesmerian deformation, cross-section B-B′ indicates a height of roughly 1.5 km (Fig. 122a, b; the precise value in this reconstruction is 1.55 km). This relief clearly was attained before the onset of flysch sedimentation, as the youngest shelf carbonates are older than the oldest flysch: in contrast to Navarana Fjord, north Greenland (see below), no further upbuilding of the carbonate shelf occurred during flysch sedimentation in this particular area. The inclination is more difficult to establish because of uncertainty about the subsurface configuration. Exposures in the large valley east of the position represented by the cross-section (Fig. 1), as mentioned, indicate that it is steep in the lower and middle parts of the slope and flattens in the upper part (Figs. 119, 121). The closest estimate for the inclination in the lower and middle parts of the slope is 48°. When averaged for the entire slope, the inclination appears to be 37 to 41°.

However, if the carbonates had been tilted southeastward along listric faults, both inclination and height of the escarpment would have been lower, and this possibility cannot be excluded (Fig. 122c). Note that this reconstruction produces a carbonate ridge, comparable perhaps to that seen in Figure 132 (late Llandovery). If the carbonates had been tilted northwestward, as seems to be the case at Navarana Fjord (Surlyk and Ineson, 1987a; see below), inclination and slope would have been higher. To evaluate whether or not the reconstructions made at Ella Bay are realistic, I shall first consider observations made at other localities along the Ordovician-Silurian shelf margin, in North Greenland and Ellesmere Island, and then some possible modern analogues.

DATA FROM OTHER LOCALITIES ALONG THE ORDOVICIAN-SILURIAN SHELF MARGIN

Inclination of slope. An Ordovician–Silurian escarpment, comparable to the Ella Bay Escarpment, is exceptionally well exposed on the west side of Navarana Fjord, North Greenland (Surlyk and Hurst, 1984; Surlyk and Ineson, 1987a). In contrast to Ella Bay, the strata defining the escarpment are not folded

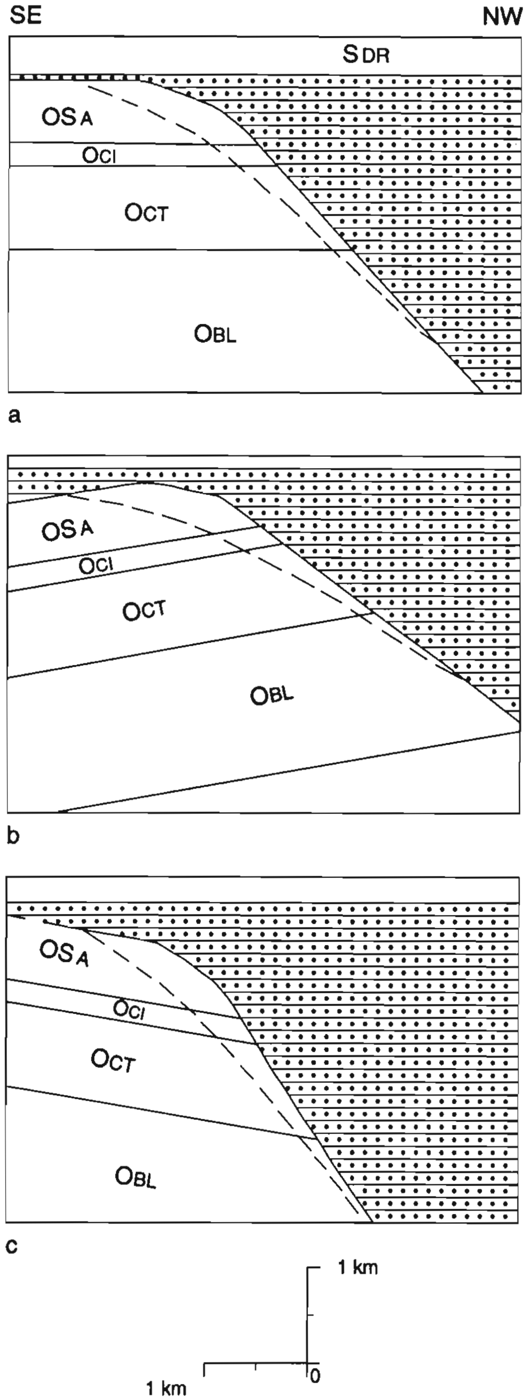


Figure 122. *Restored cross-sections based on Figure 121 with folds in the Danish River Formation eliminated. Dashed line indicates alternative interpretation for the basal contact of the Danish River Formation, as before.* ***a)*** *shelf carbonates horizontal;* ***b)*** *shelf carbonates tilted cratonward, as would be the case in down-to-the-basin listric normal faulting;* ***c)*** *shelf carbonates tilted basinward, as at Navarana Fjord. For legend, see Figure 119, for further geological interpretation, see Figure 132.*

but dip gently north. Along the scarp, upper Llandovery turbidites of the Merqujôq Formation abut 800 m of shelf carbonates. The lower 100 m are Late Ordovician, and the overlying 700 m Early Silurian (Llandovery) in age. As the scarp is approached, the northward dip of the shelf carbonates increases to about 20° and intraformational conglomerates and breccias appear. However, the fragments of these conglomerates do not seem to have been transported; that is, they do not represent clinoforms. The upper 300 to 400 m of the escarpment is concave and inclined about 30°; the lower 400 to 500 m is inclined about 45°. Regionally, both turbidites and platform margin are overlapped by a thin, graptolitic mudrock unit of latest Llandovery age (Thors Fjord Member of the Wulff Land Formation), in turn overlain by a Wenlock siliciclastic turbidite unit (Lauge Koch Land Formation). However, in this area, the Lauge Koch Land Formation and Thors Fjord Member have been eroded over the platform margin. Directly beneath the Thors Fjord Member, a tongue of carbonate conglomerate (Navarana Fjord Member of the Merqujôq Formation; Surlyk and Ineson, 1987b) extends from the platform margin into the siliciclastic turbidites of the Merkujôq Formation.

Height of escarpment based on the thickness of flysch units. At Navarana Fjord, as mentioned above, the escarpment clearly is more than 800 m in height, and the upper 700 m of strata are Early Silurian in age.

The thickness of the Merkujôq Formation provides a very rough estimate for the total height of the escarpment as it would appear in a stratigraphic cross-section depicting its status at the end of Llandovery time; that is, after the filling of the adjacent basin. No measurements are available for this area, but interpolation of data from northern Nyboe Land (2.8 km; Escher and Larsen, 1987) and western Peary Land (1 km; Hurst and Surlyk, 1982) suggests a thickness of roughly 2 km (Surlyk and Ineson, 1987a). Correction for compaction would raise this value, and correction for possible growth faulting would lower it, but the displacement caused by growth faulting is unknown.

To calculate the bathymetric height of the escarpment at the beginning of the Silurian, Surlyk and Ineson subtracted the thickness of the Silurian part of the carbonate escarpment (700 m) from the estimated total thickness of Merkujôk Formation (2 km), neglecting a few tens of metres of lower and middle Llandovery "shale", and obtained an estimate of 1.3 km. The escarpment still must have grown in height until the onset of flysch sedimentation in the early late Llandovery, but the thickness of the lower and middle Llandovery part of the carbonate succession is unknown. Thus a few hundred(?) metres have to be added to the 1.3 km estimate before making a comparison with the Ella Bay Escarpment.

The same type of estimate can be applied at Caledonian Bay, where the escarpment itself is concealed. At the type section (Section CF1 in Fig. 111) the Danish River Formation has a total thickness of 2.7 to 2.8 km and ranges in age from early late Llandovery to earliest Devonian (early Lochkovian). At the adjacent Section CF2, it is only 620 m thick and is restricted in age to the early Lochkovian, being underlain by a carbonate buildup with a condensed Cape Phillips Formation on top. Thus, that part of the Danish River Formation abutting shelf carbonates and Cape Phillips Formation is about 2.1 to 2.2 km thick, if the thickness of the Lower Devonian portion remains constant, or somewhat smaller, say 2 km, if the Lower Devonian portion thickens to the northwest.

Judging from brachiopod collections, the late Llandovery to early Wenlock part of the adjacent carbonate buildup is no less than 460 m and possibly as much as 810 m thick (T.A. de Freitas, 1991, his Fig. 33; and pers. comm., 1991). The overlying condensed Cape Phillips Formation (early Wenlock to latest Silurian according to T.A. de Freitas, 1991) is 64 m thick (Trettin, 1979), giving a total thickness of 520 to 870 m. Subtraction of these values from the thickness of the coeval flysch (2.0–2.2 km) gives an estimated bathymetric height of 1680 to 1130 m or 1.4 ± 0.3 km, again neglecting compaction and possible growth faulting.

MODERN ANALOGUES AND ORIGIN OF THE ESCARPMENT

For the purpose of the present discussion, two types of platform margins can be distinguished (cf. Schlager and Camber, 1986, Fig. 4). In the first type, flat-lying carbonate strata pass into clinoforms, analogous to the foresets of Gilbert-type deltas. Analysis of 20 ancient and modern examples by Kenter (1990) showed that maximum slope angles depend on sediment fabric: (lime) mudstones maintaining slopes up to 5°, wackestones and floatstones up to 15°, and conglomerates and breccias up to 45°. The relief of the slopes analyzed by Kenter varied from 100 m to 1 km but was mostly less than 600 m.

In the second type of margin, flat-lying platform strata terminate against sea water, and clinoforms are absent. These platform margins can be several kilometres in height and can have slope inclinations up to 90° or overhanging (Cook and Mullins, 1983), although steep slopes are exceptional. A well studied example of a steep slope is the lower part of the Florida Escarpment, from about 1750 m to its base at 2500 to 3400 m. There, steep to vertical limestone cliffs, alternating with gently sloping terraces, have average slopes of about 45°, with slope angles of some 50° along two profiles (Paull et al., 1990, Fig. 2). Although parts of these two profiles are concave, their overall configuration is slightly convex. Slopes of 35 to 42° without terraces were encountered in intercanyon areas at depths of 2000 to 2600 m (Twichell et al., 1991). Samples from the cliff face represent lagoonal or low-energy intertidal deposits. The absence of rocks characteristic of high-energy environments suggests that part of the platform margin has been lost to submarine erosion.

Another example is the Bahama Escarpment, the lower part of which slopes 30 to 40° off Cat Island (Freeman-Lynde and Ryan, 1985, Fig. 2). In that area, truncated facies relations indicate an escarpment retreat of 5 km since Early Cretaceous time. Again, collapse along joints appears to have been an important process, and large-scale sliding has occurred locally. Weakening of the strata by burrowing, chemical corrosion below the calcite compensation depth, and removal of sediments at the base of the slope by longitudinal abyssal currents may also have contributed to the erosion of the Bahama Escarpment (*op. cit.*). In addition, slope-normal turbidity currents are powerful agents of erosion on escarpments in general (Schlager and Camber, 1986).

Inclined beds with some intraformational conglomerate have been observed at Navanara Fjord, but their inclination (20°) is much smaller than the slope of the escarpment (30-45°), indicating that the formation of the escarpment is due to erosion (Surlyk and Ineson, 1987a). At Ella Bay, clinoforms have not been recognized; if present, they are less steeply inclined than the contact with the Danish River Formation (Fig. 119). Thus the Ella Bay Escarpment must be an erosional feature, similar in origin to the Navarana Fjord, Florida, and Bahamas escarpments.

Little is known about the timing and mechanisms of erosion. However, the following observations, inconclusive as yet, suggest that the western outcrop belt of the Bulleys Lump Formation may be a listric fault slice that slid on the Hazen Formation just before the beginning of flysch sedimentation:

1. The contact between the Bulleys Lump and Hazen formations is abrupt wherever observed in outcrop or rubble.
2. Along the line of cross-section B-B′ and in the panoramic view, Figure 119, the age of the carbonate strata beneath the Danish River Formation increases steadily from Late Ordovician (Ashgill) in the southeast to middle Llanvirn–middle Arenig in the northwest (loc. F4, Fig. 1, see Appendix 3B). If the western outcrop belt were contiguous with the eastern outcrop belt, the top of the formation should be no younger than middle Llanvirn in the former. However, conodont identifications show that it is Llandeilo or early Caradoc at the Ella Bay 2-East section and that it may include strata of the Thumb Mountain Formation.
3. The western outcrop belt is aligned with and close to a resedimented, conglomeratic carbonate unit of Late Ordovician–Llandovery age (map unit OS_{H1a} of Figure 1) forming the top of the Hazen Formation in the area southwest of the head of Ella Bay. This configuration is difficult to explain if the Bulleys Lump Formation is assumed to be autochthonous. Unfortunately, exposure is very poor in this critical area.

If this belt is allochthonous, the fact that the Bulleys Lump Formation remained coherent whereas the source rocks of map unit OS_{H1a} were disintegrated must be explained. The answer may lie in the time span between original sedimentation and redeposition: about 30 million years for the Bulleys Lump Formation and no more than a few million years for the sources of map unit OS_{H1a}, dated as Late Ordovician and middle Llandovery on the basis of conodonts (Nowlan, Appendix 3B, C-96684).

If the western belt of the Bulleys Lump Formation indeed is a slide transported on a listric normal fault, then the strata should have been rotated during movement and should differ in attitude from the Hazen and Danish River formations. Unfortunately, the attitude of the Bulleys Lump strata is difficult to establish because of their massive and recrystallized nature, and the Danish River strata have been disintegrated at the surface by frost action.

If the western outcrop belt is not a fault slice, it must represent a tongue of the upper part of the formation that thins out to the northwest. More detailed work is required to resolve this problem.

The origin and development of the escarpment are further discussed below in the context of the regional depositional and tectonic history (Fig. 133).

DEPOSITIONAL HISTORY AND TECTONIC INTERPRETATION

The history of the Deep Water Basin within the Hazen Fold Belt comprises four major phases of deposition represented by: 1) the Nesmith beds (middle Early Cambrian), 2) the Grant Land Formation (late Early Cambrian), 3) the Hazen Formation (latest Early Cambrian to Early Silurian, Llandovery), and 4) the Danish River Formation (late Llandovery to Early Devonian). These phases provide a convenient organizational scheme for the following discussion. The record of the Shelf Province corresponds closely to that of the Deep Water Basin during phases 1 and 2, but becomes more complex from latest Early Cambrian time onward and requires further differentiation.

For each of the four major intervals a summary of the regional facies relations will be followed by discussions of accumulation rates and tectonic conditions. The accumulation rates (Fig. 123, Table 16) will be expressed in terms of highly compacted sediments, ignoring the possibility that they were less compacted at the end of the intervals considered. The calculated accumulation rates are therefore somewhat smaller than depositional rates established for uncompacted modern sediments. Absolute ages are taken from Harland et al. (1989); note that the time scale for the Cambrian is poorly controlled and controversial (Cowie and Harland, 1989). Inferred variations in water depth and salinity are shown in Figure 124.

The following discussion and lithofacies maps are restricted to the Hazen and Central Ellesmere fold belts and their equivalents in Greenland. Possible relations with the Clements Markham Fold Belt and Pearya Terrane will be discussed in the second report on northern Ellesmere Island (Trettin, work in progress).

MIDDLE EARLY CAMBRIAN (PHASE 1)

Facies relations

This is the oldest interval with a stratigraphic record both on the shelf and in the basin (Fig. 125), and was characterized by carbonate sedimentation in both regions (Trettin, 1989, Plate 9A; Trettin et al., 1991, Fig. 8B.27). The shelf deposits, assigned to the Ella Bay Formation, are 762 m thick and are preserved or exposed only in east-central Ellesmere Island (Ella Bay Formation) and North Greenland (Portfjeld Formation; cf. Higgins et al., 1991). In Ellesmere Island they are up to 762 m thick and consist mainly of dolostone, including stromatolitic reefs, with minor proportions of mudrock and sandstone (Long, 1989b).

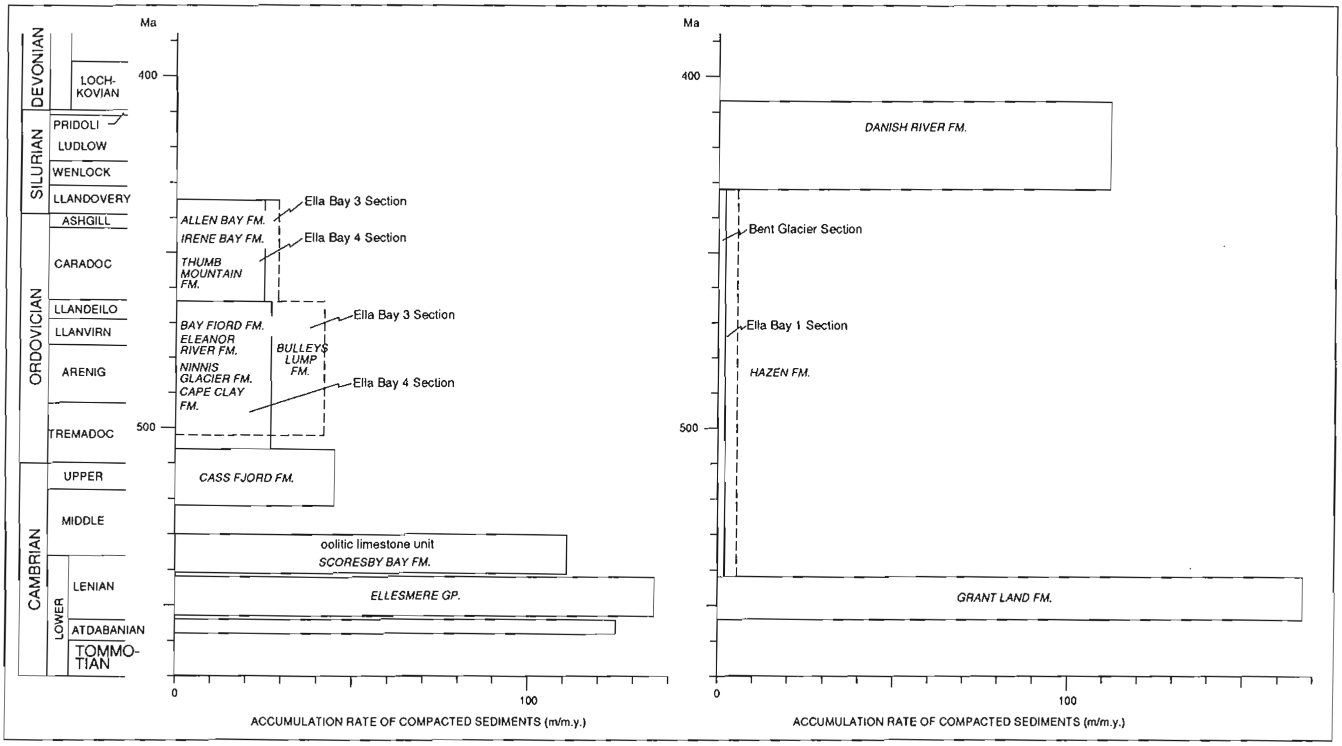


Figure 123. Accumulation rates of Cambrian to Lower Devonian formations; absolute time scale of Harland et al. (1989).

TABLE 16

Accumulation rates of compacted sediments, based on time scale of Harland et al. (1989). Note that control is poor for the Cambrian and that the accumulation rate would be markedly higher if an age of 530-540 Ma were accepted for the base of the Cambrian

Units	Stratigraphic age	Radiometric age (Ma)	Thickness (m)	Accumulation rate (m/m.y.)
Shelf, section Ella Bay 3				
Allen Bay +Irene Bay +Thumb Mountain	middle Llandovery to early Caradoc	435-464 (29)	839	29
Bulleys Lump	early Caradoc to middle Tremado	464-502 (38)	1603	42
Shelf, section Ella Bay 4				
Allen Bay +Irene Bay +Thumb Mountain	middle Llandovery to early Caradoc	435-464 (29)	723	25
Bay Fiord +Eleanor River +Ninnis Glacier +Cape Clay	early Caradoc to early Tremadoc	464-506 (42)	1130	27
Cass Fjord	early Tremadoc to late Middle Cambrian	506-522 (16)	727	45
Oolitic limestone +Scoresby Bay	early Middle Cambrian to lastest Early Cambrian	530-541 (11)	1224.5	111
Shelf, Judge Daly Anticline section (Long)				
Ellesmere Group	late Early Cambrian	542-553 (11)	1500	136
Ella Bay	mid-Early Cambrian	554-558 (4)	500	125
Deep Water Basin, section Caledonian Bay 1				
Danish River	early late Llandovery to earliest Lochkovian	407-432 (25)	2795	112
Deep Water Basin, section Ella Bay 1				
Hazen	late Middle Llandovery to latest Early Cambrian	432-542 (110)	631.5+	5.7+
Deep Water Basin, Bent Glacier section				
Hazen	late Middle Llandovery to latest Early Cambrian	432-542 (110)	218	2
Deep Water Basin, Hare Fiord and Rollrock Glacier sections, combined				
Grant Land	late Early Cambrian	542-554 (12)	2000±	167±

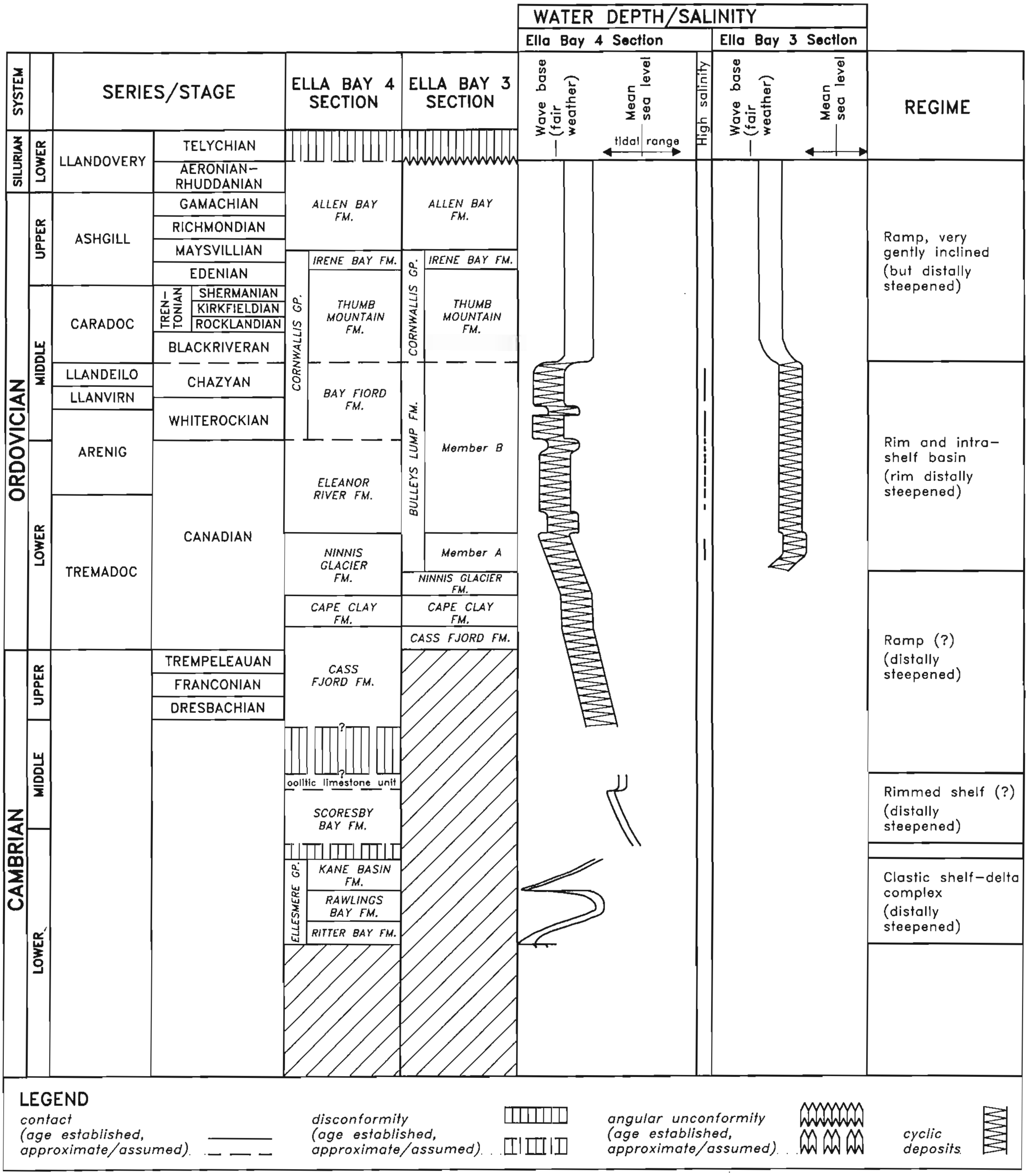


Figure 124. Interpreted water depth and salinity of Cambrian to Lower Silurian shelf succession. Inferences about depth, based on textural features, colour, and fauna are relative to wave base and tidal range, not to absolute water depth. Note that tidal range probably was smaller and wave base shallower at section 3 during restricted intervals in late Tremadoc to Llandeilo time.

The basinal sediments, assigned to the Nesmith beds in Ellesmere Island and to the Paradisfjeld Formation in northeastern Greenland (Friderichsen et al., 1982; Higgins et al., 1991), are composed largely of resedimented carbonates, ranging in grade from lime mudstone to conglomerate, and of lesser proportions of mudrock and calcareous sandstone. The Nesmith beds are poorly exposed, and the thickness of the unit is unknown. The better exposed Paradisfjeld Group has a minimum thickness of 1 km.

The outcrops of the Ella Bay Formation and the Nesmith beds are about 125 km apart and therefore the location of the shelf margin during this phase is poorly constrained. Comparison with phase 2 in Ellesmere Island and with phases 1 and 2 in Greenland suggests that it lies beneath the Hazen Plateau.

Accumulation rate

The accumulation rate during this interval is difficult to establish because of uncertainty about the biostratigraphic age range of the Ella Bay Formation and the length of the Early Cambrian. Assuming that the Ella Bay Formation spans about half of the Atdabanian Age and that the latter lasted 6 million years (m.y.), the accumulation rate for the Ella Bay Formation was 125 m/m.y.. The value would be considerably higher if the base of the Early Cambrian were as young as 530 to 540 Ma, as is proposed by some authors (cf. Morris, 1988; Cowie and Harland, 1989).

Tectonic conditions

As mentioned above (Chapter 2, Regional framework), the Franklinian mobile belt probably was initiated by a rift event in Late Proterozoic time (ca. 750 Ma), but the latest Proterozoic to earliest Cambrian record is concealed. If the rift/drift transition indeed occurred during late Early Cambrian time (see below), then the Ella Bay Formation and its equivalents were deposited during a late rift stage (Long, 1989b).

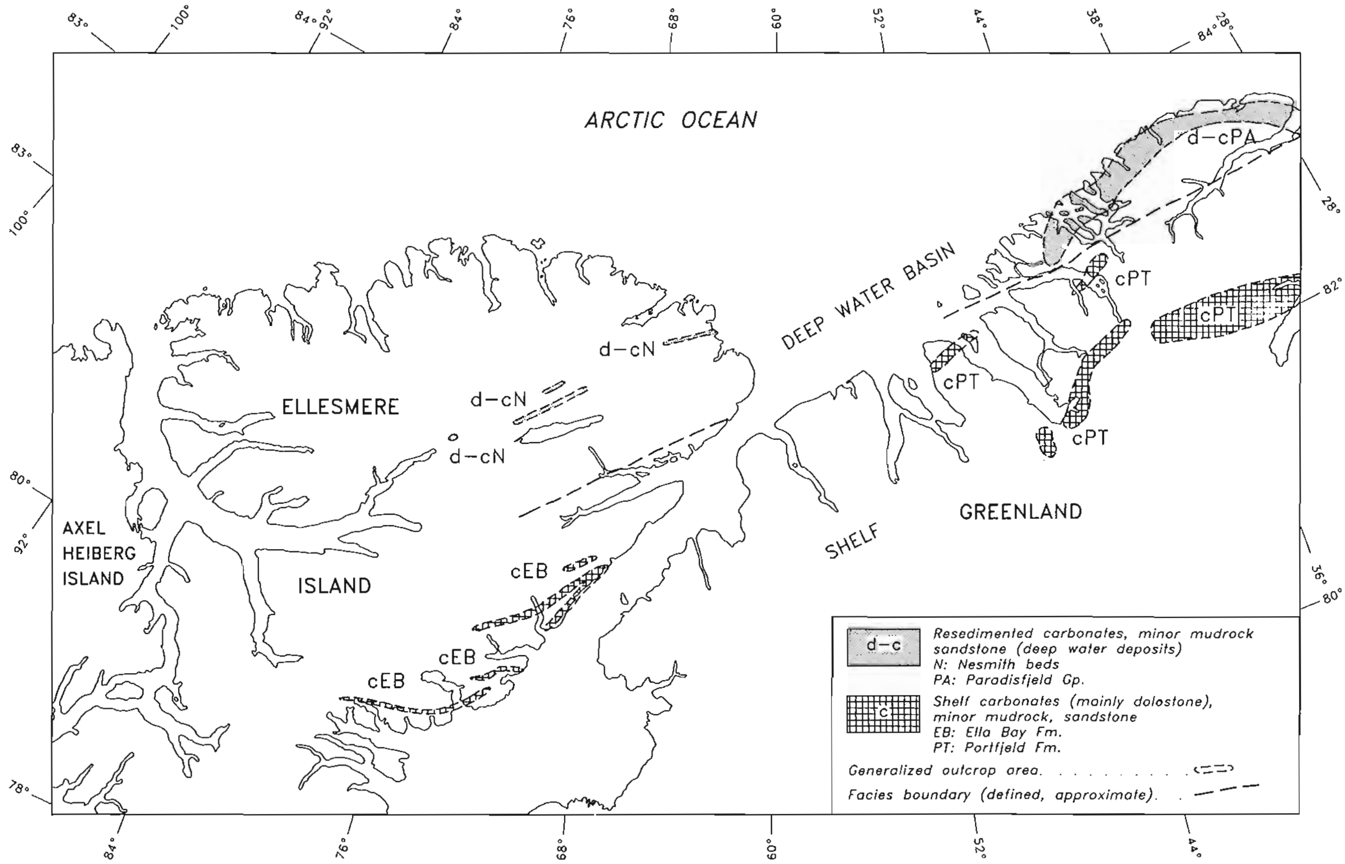


Figure 125. Facies relations, mid-Early Cambrian.

LATE EARLY CAMBRIAN (PHASE 2)

Facies relations

The second phase was characterized by rapid clastic deposition both on the shelf and in the basin (Fig. 126). The sediments, mainly sandstone and mudrock with minor pebble conglomerate, were derived from crystalline terranes and Proterozoic strata of the continental interior.

Regionally, the shelf sediments form a southeastward tapering wedge, scattered outcrops of which extend from the project area to Devon Island (Trettin, 1989, Plate 9B; Trettin et al., 1991, Fig. 8B.28). In east-central Ellesmere Island, this wedge lies disconformably on the Ella Bay Formation; farther south it lies on Proterozoic sediments or crystalline basement rocks with unconformable or nonconformable contacts. Those parts of the wedge in east-central Ellesmere have been assigned to the Ellesmere Group, consisting of the Archer Fiord Formation (sandstone, minor mudrock), Ritter Bay Formation (mudrock, minor sandstone), Rawlings Bay Formation (sandstone and mudrock), and Kane Basin Formation (mainly mudrock). Complete sections of the Ellesmere Group south of the project area range in thickness from 1.5 to about 1.7 km (Fig. 14). The fact that thick mudrock units of subtidal aspect are restricted to the northwestern part of the wedge shows that the wedge was deposited on a slightly inclined ramp.

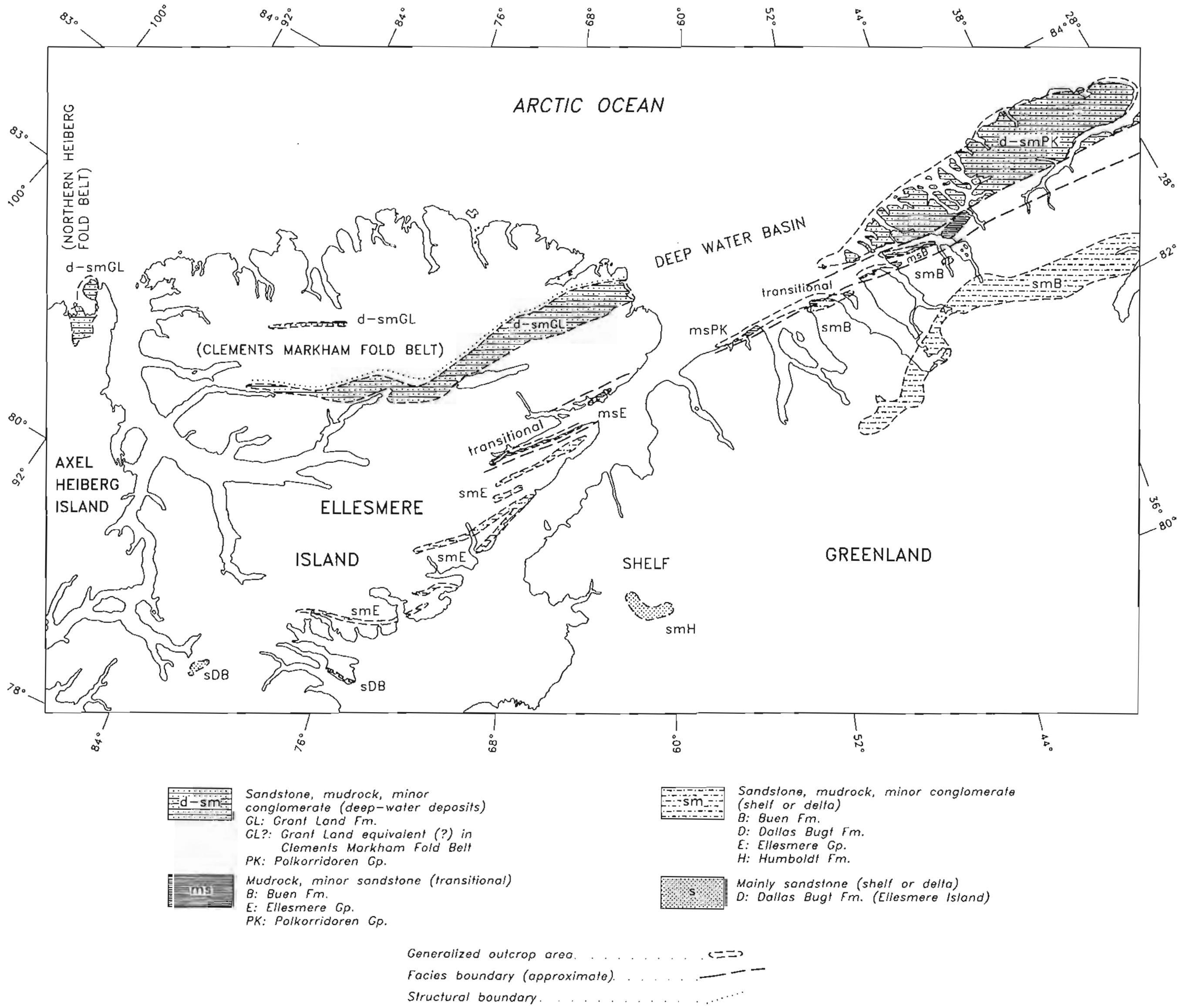


Figure 126. Facies relations, late Early Cambrian.

In the project area, the exposed part of the Ellesmere Group (upper Ritter Bay, Rawlings Bay, and Kane Basin formations) is about 1.5 km thick. The inferred depositional environments range from delta front to outer shelf. Bounded by disconformities at base and top, the Ellesmere Group forms a major sequence. Internal transgressive-regressive cycles are more difficult to recognize because of the apparent lack of subaerial disconformities. However, minor phosphatic-pebble conglomerates within the upper part of the Ritter Bay Formation and at the base of the Kane Basin Formation probably are lag deposits that mark submarine disconformities (diastems) related to marine transgressions.

The upper Lower Cambrian clastic sediments of the Deep Water Basin are assigned to the Grant Land Formation, which comprises more than 1.5 km of sandstone, mudrock, and minor pebble conglomerate. The lower 60 m or so contain detrital carbonate grains in addition to the predominant siliciclastic material. This material may have been deposited while the Ella Bay Formation was exposed; that is, during the hiatus that separates the Ella Bay and Archer Fiord formations. The remainder of the formation probably is correlative with the Ellesmere Group.

Within the area studied (Henrietta Nesmith Glacier to north of central Hare Fiord) only the lower 120 m or so of the Grant Land Formation (member A) has abundant Bouma sequences, indicative of deposition by turbidity currents on submarine fans. The bulk of the formation (member B) is characterized by the alternation of predominantly sandy units (including minor pebble conglomerate and mudrock), commonly tens of metres in thickness, with pelitic units, which are several or tens of metres in thickness. Classical turbidites of Bouma type have neither been recognized in the pelitic units nor in the sandy and conglomeratic units, although fining-upward sequences are common in the latter. The mechanisms of transportation and environments of deposition (within the deep water realm) of these strata are problematic; alternative interpretations are discussed above (Stratigraphy of the Deep Water Succession, Grant Land Formation, Mode of origin).

The uppermost part of the formation (member C) consists mainly of mudrock with minor occurrences of fine grained sandstone that disappear toward the top of the formation. The stratigraphic position and fine grain size of member C suggest correlation with the Kane Basin Formation. The common occurrence of chloritized morphological glauconite in both units supports this correlation.

Accumulation rates

The biostratigraphic time span and absolute duration of this interval also are uncertain. Assuming that it comprised much but not all of the Lenian[1] Age (11 m.y. of a total of 18 m.y.), the accumulation rate of the Ellesmere Group would be 136 m/m.y. and the accumulation rate of the Grant Land Formation (considered to be perhaps 2 km thick) would be somewhat faster, 167 m/m.y. Again, both rates would be considerably faster if a younger radiometric age were assumed for the base of the Cambrian.

Tectonic conditions

An uplift of the continental interior occurred at the beginning of this interval, producing a disconformity and supplying large volumes of sediments, not only to the Arctic but also to the eastern Cordillera (e.g., Gog Group of the Rocky Mountains). Subsidence analysis of the Cordilleran miogeocline suggests that seafloor spreading in the adjacent oceanic region began some time within the Early Cambrian Epoch (Bond et al., 1985; Devlin and Bond, 1988) and the resulting "breakup unconformity" (Falvey, 1974) has been equated with the unconformity at the base of the Gog Group. A similar scenario has been inferred for the Appalachian mobile belt (Williams and Hiscott, 1987). Analogy with these regions suggests that on Ellesmere Island, the disconformity at the base of the Ellesmere Group, or perhaps the inferred diastem at the base of the Kane Basin Formation, may signal the onset of seafloor spreading in a region somewhere northwest of the Hazen Fold Belt.

LATEST EARLY CAMBRIAN TO EARLY SILURIAN, MIDDLE LLANDOVERY (PHASE 3)

Lithofacies, Franklinian Shelf

The record of the Franklinian Shelf during this phase is complex and divisible into four intervals, with some subdivisions.

[1]The Lenian is the youngest of three Ages/Stages distinguished in the Early Cambrian Epoch/Series, the other two being Tommotian and Atdabanian (cf. Harland et al., 1989).

Latest Early Cambrian to early Middle Cambrian

Carbonates of this age are exposed in central and southern Ellesmere Island, and on Devon Island (Figs. 127, 128) (Trettin et al., 1991, Fig. 8B.29). Bounded by disconformities at the base and probably also at the top, they seem to represent another major sequence. In the study area they are assigned to the Scoresby Bay Formation (952 m) and to the oolitic limestone unit (273 m). The shelf architecture during this interval is uncertain because of insufficient fossil control; however, the oolitic unit may represent shoals near the shelf margin; that is, a "rimmed shelf".

Late Middle Cambrian to earliest Ordovician

Deposits of this age, overstepping those of the preceding interval with disconformable contact, extend from the project area to Foxe Basin (Trettin et al., 1991, Fig. 8B.30). In the project area they are included in three units, which were deposited in successively deeper environments: 1) The Cass Fjord Formation — mixed carbonate and clastic sediments of peritidal and shallow subtidal aspect (727 m); 2) the Cape Clay Formation — carbonates of shallow subtidal aspect (220 m); and 3) all of the Ninnis Glacier Formation at the Ella Bay 3 section (108 m) and a corresponding

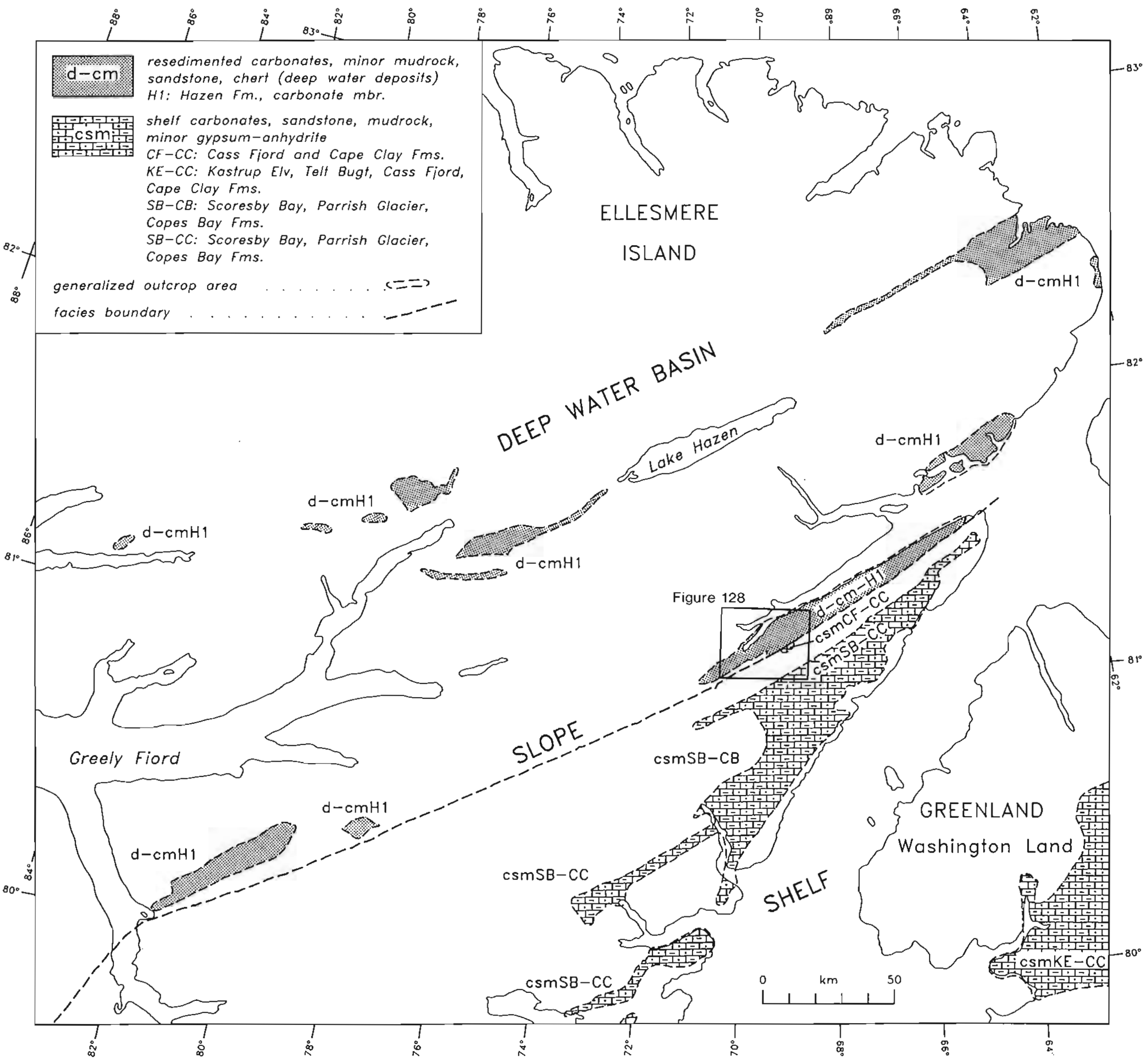


Figure 127. Facies relations, Middle Cambrian to earliest Ordovician (early Tremadoc). Inset shows location of Figure 128.

lower part of the Ninnis Glacier Formation at the Ella Bay 4 section. The Cass Fjord is a highly diagnostic formation, now widely recognized in Ellesmere and Devon islands and also in the subsurface of Cornwallis Island (cf. Thorsteinsson and Mayr, 1987). However, peritidal features are less conspicuous in this formation in the project area than in southern Ellesmere Island and Devon Island; for example, flat-pebble conglomerates are less common, and evaporites and stromatolites are absent. Likewise, the Ninnis Glacier Formation was deposited in deeper water than the correlative Christian Elv Formation of northwestern Greenland and southern Ellesmere Island. These facies changes indicate deposition on a slightly inclined ramp of large dimensions.

Early Ordovician (late Tremadoc) to late Middle Ordovician (Llandeilo)

Strata of this age are widespread in the Arctic Islands and can be traced from central Ellesmere Island to Melville Island and Foxe Basin. Facies maps (Figs. 129, 130) (Trettin, 1989, Plate 9D; Trettin et al., 1991, Figs. 8B.31, 8B.32) depict a large intrashelf basin that received evaporites during two time intervals, represented by the Baumann Fiord Formation (middle Tremadoc) and the Bay Fiord Formation (late Arenig to Llandeilo). These evaporitic units are separated by normal shelf carbonates of the Eleanor River Formation.

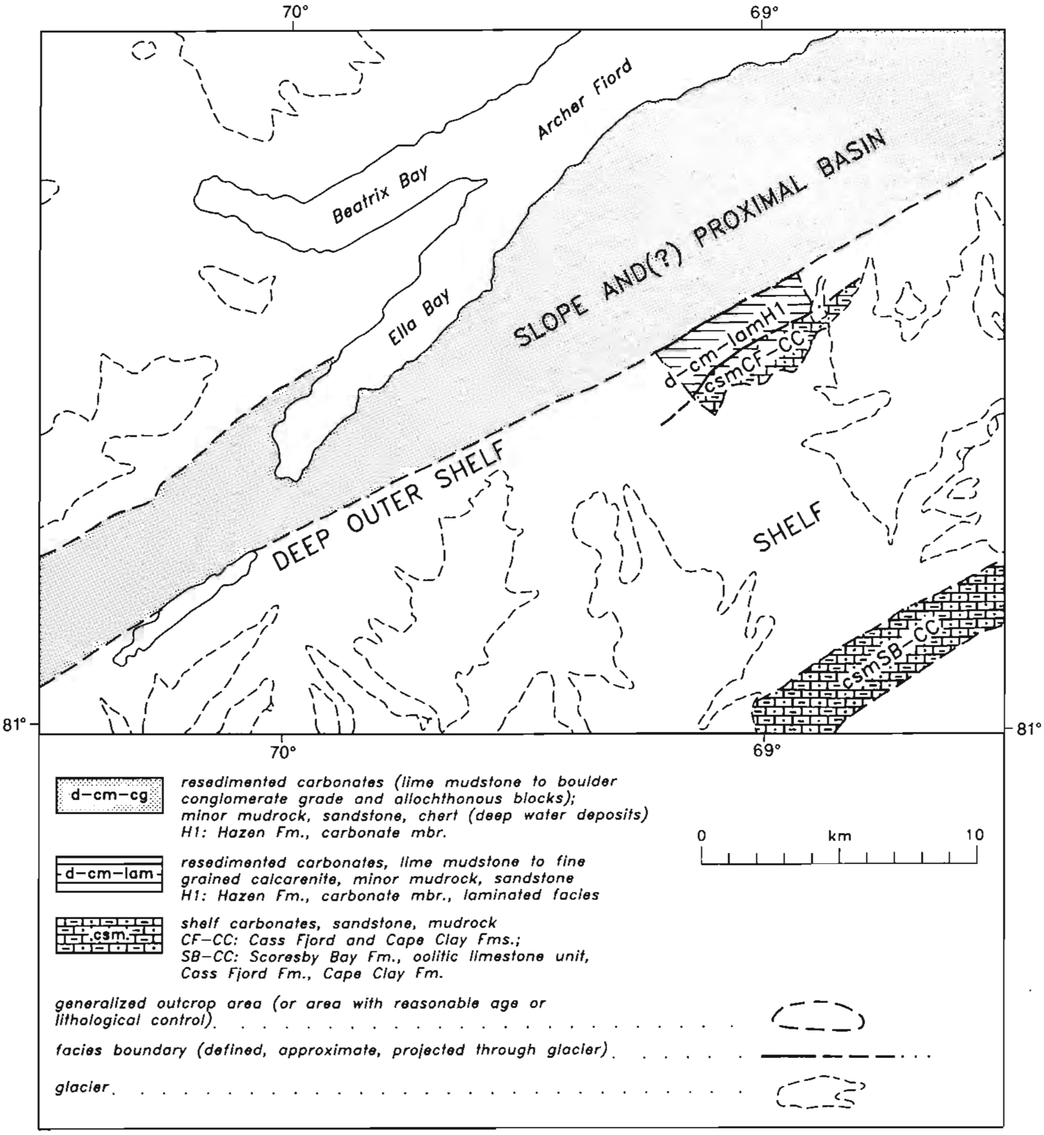


Figure 128. Facies relations, latest Early Cambrian to earliest Ordovician (early Tremadoc), Ella Bay area.

Control is best for the time of Bay Fiord deposition, when the intrashelf basin comprised the following three facies: 1) a central, halite-bearing facies, also including gypsum-anhydrite and carbonates; 2) a surrounding facies consisting of gypsum-anhydrite and carbonates; and 3) a northwestern facies belt composed mainly of deeper water subtidal carbonates and mudrock with local evaporites. The intrashelf basin was bordered on the south, southeast, and northeast (in Greenland) by carbonate units deposited in shallower waters.

The project area is important for the interpretation of the regional picture because it contains significant outcrops of the northwestern carbonate facies (3), and the only known outcrops of the shelf rim; subcrops of the rim have been penetrated by wells on northwestern Melville Island.

The rim facies is assigned to the Bulleys Lump Formation, consisting of 1559 m of carbonates and minor clastic rocks. A largely peritidal origin is inferred from abundant fenestral structures and common grainstones and flat-pebble conglomerates. The unit forms a narrow outcrop belt on the northwestern limb of the Ninnis Glacier Syncline. It was bordered by a steep margin on the northwest (see

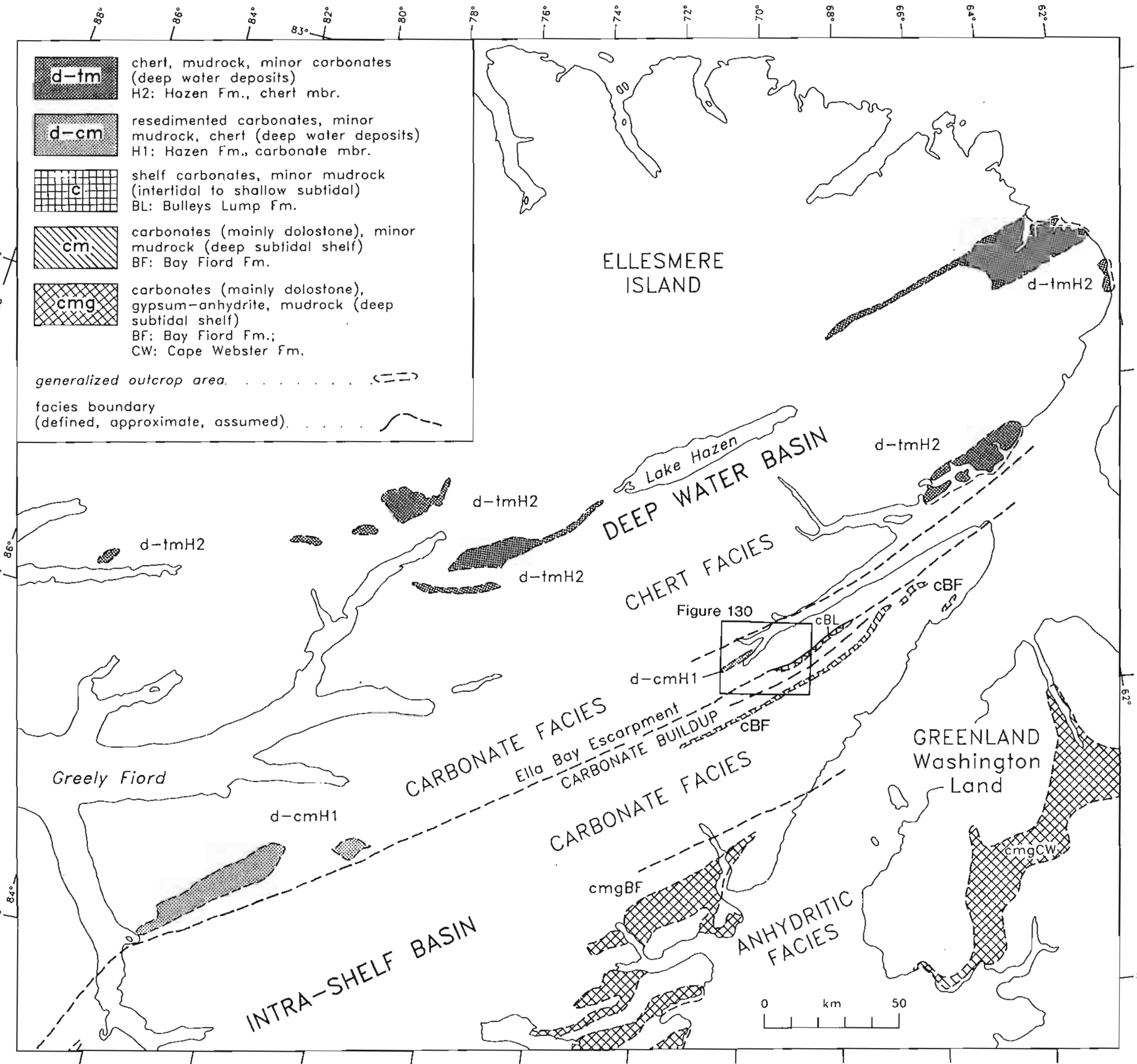


Figure 129. Facies relations, late Early Ordovician (late Arenig). Inset shows area of Figure 130.

below) and is separated from sediments of the intrashelf basin on the southeast by a concealed facies change. Conodont collections show that the Bulleys Lump Formation is correlative with the combined Baumann Fiord, Eleanor River, and Bay Fiord formations in their respective type areas.

The strata of the intrashelf basin, exposed on the southeastern limb of the Ninnis Glacier Syncline and studied at the Ella Bay 4 section, are assigned to the upper part of the Ninnis Glacier Formation (ca. 200 m), the Eleanor River Formation (191 m), and the Bay Fiord Formation (400 m). All three units contain laminated carbonates of deeper water subtidal aspect and nonlaminated carbonates of shallow subtidal aspect, but laminites are more common in the Ninnis Glacier and Bay Fiord formations than in the Eleanor River Formation.[1] The shallow subtidal nonlaminated carbonates can be interpreted as tongues of the shelf margin carbonate buildup, but are not included in the Bulleys Lump Formation (Fig. 7). The laminites of the Bay Fiord Formation consist of microcrystalline dolostone, those of the Ninnis Glacier Formation of dolostone and limestone (lime mudstone and pelletal packstone). Deposition in subtidal settings below wave base is apparent from the prevalent flat lamination (although some microscopic undulation and cross-lamination also are present), and from the preservation

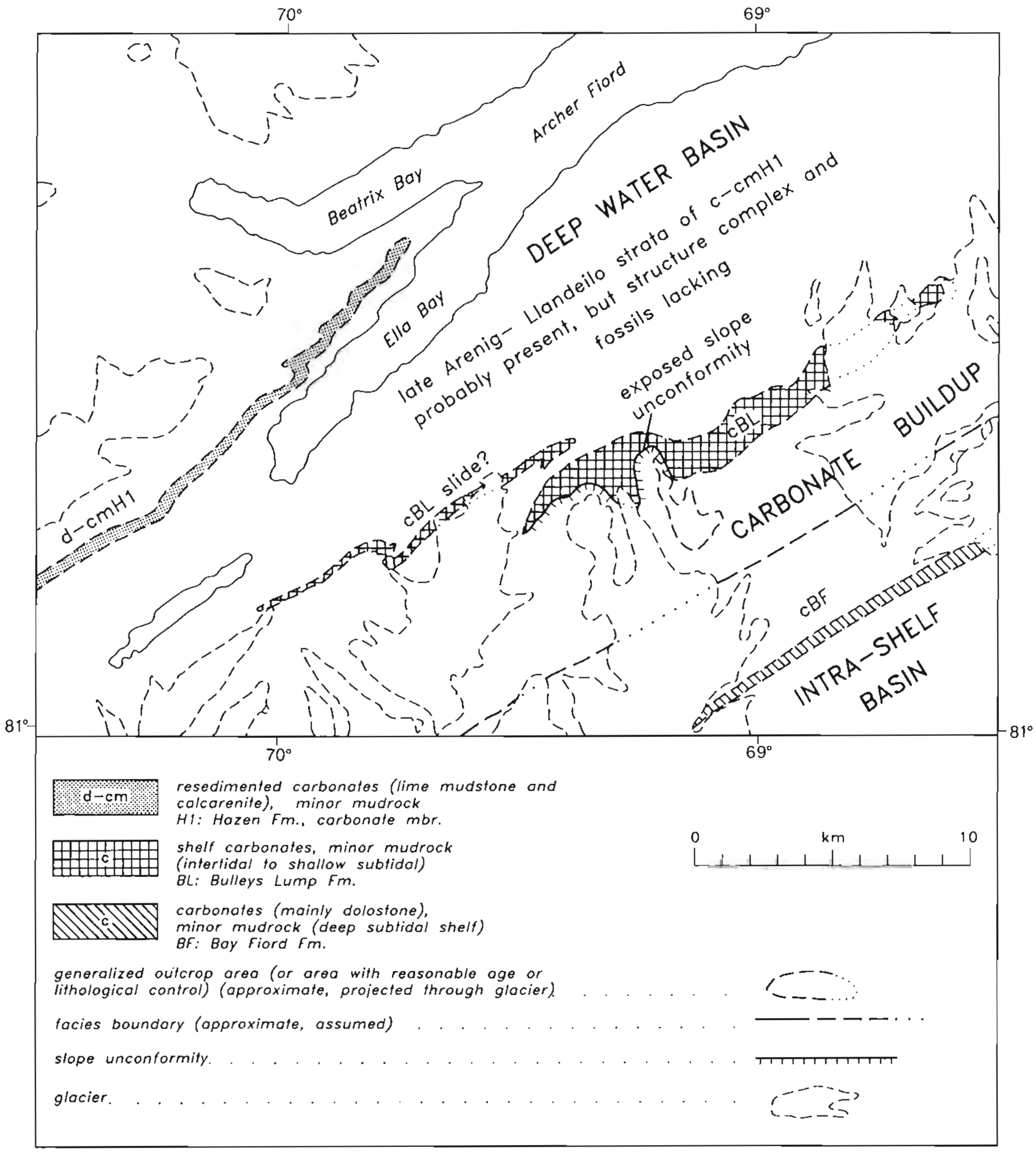


Figure 130. Facies relations, Early to Middle Ordovician (late Arenig–Landeilo), Ella Bay area.

[1]Inferences about water depth are relative to tidal range and wave base and not to bathymetry. It is likely that tidal range was smaller and wave base shallower during those intervals when a restricted intra-shelf basin existed (upper Ninnis Glacier Formation southeast of Ninnis Glacier Syncline). Also, higher salinity during such conditions would result in less bioturbation and increased preservation of organic carbonaceous matter. These remarks also apply to the laminites of the Eleanor River and Bay Fiord formations.

of appreciable amounts of (submicroscopic) carbonaceous matter. The carbonate particles probably were deposited from turbulent suspensions generated by storms on adjacent shelves. The fact that individual laminae commonly differ in their calcite/dolomite ratios suggests penecontemporaneous dolomitization in a restricted basin with fluctuating salinities (cf. Behrens and Land, 1972). Thus, the dolostones of the northwestern, marginal facies are probably genetically related to the evaporites in the basin centre.

Late Middle Ordovician (Caradoc) to Early Silurian (middle Llandovery)

This time-rock interval is characterized by extensive, rather uniform carbonates of predominantly shallow subtidal aspect (Trettin, 1989, Plate 9E; Trettin et al., 1991, Fig. 8B.33). In the project area, as in most of the Arctic Archipelago, these strata are assigned to the Thumb Mountain (404 m), Irene Bay (117 m), and Allen Bay (318 m) formations. All three consist of relatively pure limestones (lime mudstone, pelletal packstone, wackestone). Bioturbation and the presence of a rich and diverse invertebrate fauna indicate shallow water subtidal environments. The Irene Bay Formation differs from the underlying and overlying units only in its more recessive weathering profile, darker tone, and higher fossil content.

There is no evidence of either rim development or a marked seaward inclination of the shelf during this interval, although the Irene Bay Formation probably was deposited in somewhat deeper water than farther southeast. It appears that a very gently inclined shelf (ramp) was bordered by a steep slope (see above, Ella Bay Escarpment, and below).

Stratigraphic data from many areas indicate an extensive transgression — probably the most widespread transgression in the entire Phanerozoic history of the continent — in late Middle to Late Ordovician time (Bally, 1989, Plate 10C). It was followed by a brief regression in the latest Ordovician and early Llandovery, and a second extensive transgression in the middle Llandovery (Johnson, 1987). The regression, marked by a widespread but subtle disconformity, is generally attributed to a glaciation in the Sahara (e.g., Barnes, 1986; Vaslet, 1991). The apparent absence of early Llandovery fossils from the uppermost Allen Bay Formation is the only evidence of these events seen in the study area, and a detailed restudy of the critical interval is required.

Deep Water Basin and slope

The latest Early Cambrian to middle Llandovery sediments of the Deep Water Basin are assigned to the Hazen Formation. In the latest Middle Cambrian, a large outer area of the shelf subsided and the shelf margin retreated to a position a few kilometres southeast of Ella Bay. This subsidence is recorded in the lowermost part of the formation (subdivision A of the carbonate member) at the Ella Bay 1-2 section. Most strata are of deep water aspect but the occurrence of *Olenellus* and *Cruziana,* 38 to 45 m above the base of the Hazen Formation, indicates that shelf conditions existed at least during one episode.

The following three facies (from southeast to northwest) are recognized in the interval extending approximately from Middle Cambrian to Early Ordovician (early Arenig) time:

1. Laminated, fine grained, calcareous and siliciclastic sediments, probably deposited in outermost shelf/upper slope settings.

2. Carbonate conglomerates and related calcarenites, fine grained laminites as in facies 1, and minor amounts of radiolarian chert. The conglomerates were derived partly from the adjacent shelf but more commonly from the slope itself and probably were deposited in lower slope or proximal basin environments. Slide blocks of shelf sediments also are present in this facies. Typical slope conglomerates in the lowermost part of the Hazen Formation (subdivisions B and D of the carbonate member) have a minimum southeast-northwest extent of 5 km (their northwestern limit is covered); that is, a palinspastic extent of probably more than 10 km. A slope 10 km wide and inclined 2° would have been about 350 m high. If the shelf edge were at a depth of only 150 m, water depth in the basin would have been about 500 m — a minimum estimate.

3. Strata as in facies 1 with minor calcarenite and radiolarian chert.

Facies 1 is not directly in contact with the coeval shelf facies but separated from it by a steeply dipping thrust fault, just south of the Ella Bay 3 section (Fig. 1). So, a part of the shelf/basin transition is concealed, but the distance of southeastward translation on the fault is unknown. The fact that laminites similar to those of the Hazen Formation also occur in the adjacent shelf units (Ninnis Glacier and Cass Fjord formations) suggests that the missing interval is narrow.

Two major changes occurred from perhaps late Arenig time onward:

1. Deposition of fourth facies, of interbedded radiolarian chert and minor mudrock, began in the northwest and slowly advanced to the southeast, but did not reach the shelf margin. It coexisted with a carbonate-dominated lithofacies farther southeast, similar to facies 2 described above.

2. The basin margin developed into a steep escarpment, sculptured by submarine erosion, which may have attained a maximum height of about 1.5 km with an average slope inclination of 37 to 41° prior to the onset of flysch sedimentation in the early late Llandovery. Carbonate conglomerates and breccias, and possibly a large listric fault slice or slide (the western outcrop belt of the Bulleys Lump Formation) were derived from this unstable edifice at that time. The upper 800 m of a similar escarpment with slope angles of 30 to 45° are exceptionally well exposed at Navarana Fjord, North Greenland (Surlyk and Ineson, 1987a).

Accumulation rates

Accumulation rates on the shelf were markedly slower than during the Early Cambrian and decreased with time, perhaps in an exponential fashion; calculated rates vary from 40 to 27 m/m.y. However, accumulation on the shelf was still much faster than in the basin, where average rates of 6 and 2 m/m.y. were obtained at proximal and distal locations, respectively (Ella Bay 1 and Bent Glacier sections).

Tectonic conditions

The shelf margin, as mentioned, was situated somewhere beneath the central Hazen Fold Belt until late Early Cambrian time; then the outer shelf subsided and the shelf margin retreated to southeast of Archer Fiord and Ella Bay. Exposure is insufficient to determine whether this was accomplished by crustal bending, normal faulting, or by a combination of normal faulting at depth and bending at higher levels. Subsequently, the shelf margin remained in a stable position a few kilometres southeast of Archer Fiord.

The exponential(?) decrease in the accumulation rate of the shelf sediments suggests subsidence due to lithospheric cooling (cf. Bond et al., 1985), combined with sedimentary loading. Thermal subsidence also must have affected the basin but sedimentary loading there was insignificant. The increase in relief between shelf margin and basin can be attributed to the marked difference in sedimentation rates in these two realms and does not require normal faulting.

The occurrence of major resedimented carbonate bodies at the top of the Hazen Formation both at Caledonian Bay (Caledonian Bay Conglomerate Member) and Ella Bay (map units OS_{H1a} and O_{BL2*}) indicates a phase of marked instability just before the onset of flysch sedimentation (late middle–early late Llandovery). It is unknown whether this instability was due to oversteepening of the slope or to tectonic causes.

EARLY SILURIAN (LATE LLANDOVERY) TO EARLY DEVONIAN (PHASE 4)

Lithofacies

The upper Llandovery to Lower Silurian sediments of the Deep Water Basin, interstratified sandstones and mudrocks with flysch-like primary structures, are assigned to the Danish River Formation, which is about 2.8 km thick at the type section at Cañon Fiord. It was deposited largely by turbidity currents, but contour currents may also have been active. Sedimentation exceeded subsidence so that the sediment gravity flows began to fill the basin, abutting laterally the Ella Bay escarpment (Figs. 131, 132).

Large outer parts of the previous carbonate shelf had been drowned during the Late Ordovician, and this process continued during the Silurian, while isolated carbonate buildups persisted for varying lengths at the original shelf margin. The drowned areas generally were encroached first by graptolitic carbonates and mudrocks of the Cape Phillips Formation and subsequently by flysch of the Danish River Formation, although southeast of Ella Bay, the flysch lies directly on the shelf carbonates. These processes were highly diachronous over short distances and resulted in different stratigraphic columns in three areas studied by the writer.

At Cañon Fiord a carbonate buildup, which persisted until early Wenlock time (T.A. de Freitas, 1991), developed along the previous margin. It became separated from the retreating shelf margin by a narrow "backreef basin" filled with graptolitic mudrock and carbonates of the Cape Phillips Formation, which also encroached on the buildup. The flysch facies (Danish River Formation) overstepped the buildup and "backreef basin" in earliest Devonian (early Lochkovian) time and was succeeded by transitional, deep water to shelf deposits of the Eids Formation, also in early Lochkovian time.

At Carl Ritter Bay, Upper Ordovician strata are overlain by a thin Cape Phillips Formation of middle to latest Llandovery age, which is succeeded by undated strata of the Danish River Formation.

In the Ninnis Glacier Syncline, southeast of the Ella Bay escarpment, the Allen Bay Formation extends in age to the middle Llandovery. It is overlain by the Danish River Formation with a concealed contact that appears to be abrupt and disconformable. The Danish River Formation has not yielded any fossils in this area. The base of the formation, where it overlaps the Allen Bay Formation, may be near the Llandovery/ Wenlock boundary, as at Navarana Fjord and Carl Ritter Bay, and the top may be earliest Devonian as at Cañon Fiord. A possible explanation for this anomalous situation is shown in Figure 132. The northwestern part of the Allen Bay Formation may have formed a submarine ridge that separated the main Deep Water Basin on the northwest from a shallower shelf basin on the southeast. The postulated ridge was too deep for carbonate production and too high for turbidite deposition.

Accumulation rates

At Caledonian Bay, about 2.8 km of (compacted) sediments accumulated during an interval of ca. 25 m.y., indicating an average accumulation rate of ca. 112 m/m.y. — vastly greater than the previous accumulation rate in the basin, and several times greater than the previous accumulation on the shelf,

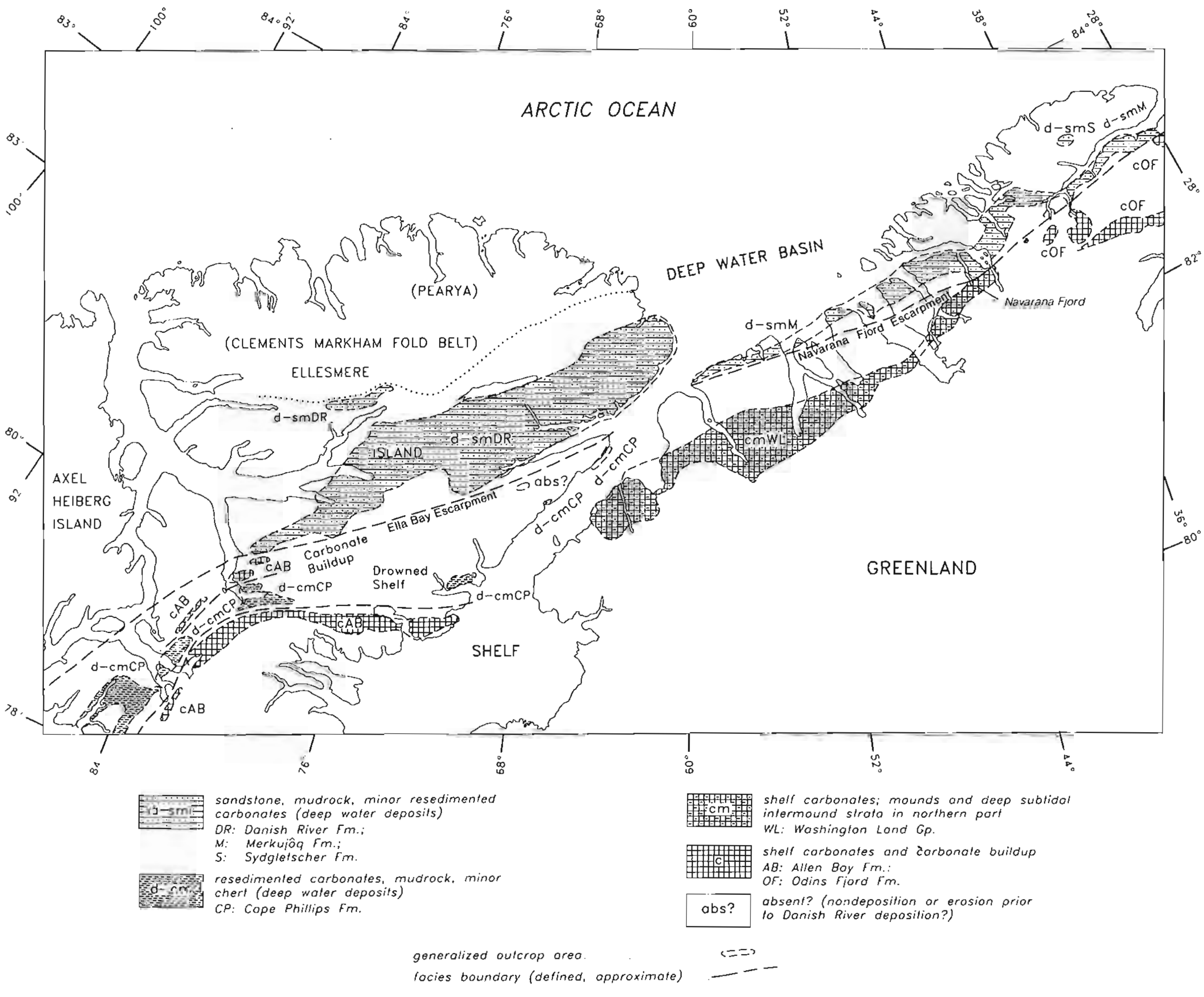


Figure 131. Facies relations, mid-Early Silurian (late Llandovery).

but smaller than the Early Cambrian accumulation rates for shelf and basin. Accumulation was probably not uniform, being most rapid during the late Llandovery, when 1.5 km of sediments were laid down, but the time scale for this interval is too poorly constrained to establish a realistic accumulation rate (cf. Harland et al., 1989).

Tectonic conditions

Thermal subsidence probably continued, but sedimentary loading must have played a larger role in basin subsidence than during the preceding interval. This loading would also have affected the adjacent basin margin if subsidence was of flexural type, but growth faulting cannot be ruled out.

The cause of the termination of carbonate sedimentation on the shelf is a major unresolved problem. Some possible mechanisms are briefly reviewed below:

1. *Drowning due to excessive thermal subsidence.* This explanation is unsatisfactory because the change in sedimentation occurred near the end of an exponentially(?) decreasing subsidence cycle.

2. *Drowning due to rapid sedimentary loading in the basin.* This explanation also is unconvincing as in many areas carbonate sedimentation ceased in Late Ordovician to middle Llandovery time, well before the onset of flysch sedimentation in the late Llandovery.

3. *Drowning due to tectonic loading.* No evidence of contemporaneous thrust faulting (e.g., internal unconformities), has been discovered within the Late Ordovician and Silurian deep water succession of the Hazen Fold Belt.

4. *Drowning due to extension.* This mechanism cannot be ruled out, but no structural evidence of Late Ordovician to middle Llandovery normal faulting has been obtained as yet.

5. *Flooding of the outer shelf with anoxic waters that killed the carbonate-generating organisms.* This explanation has been invoked for the Late Devonian and Cretaceous of Western Canada by

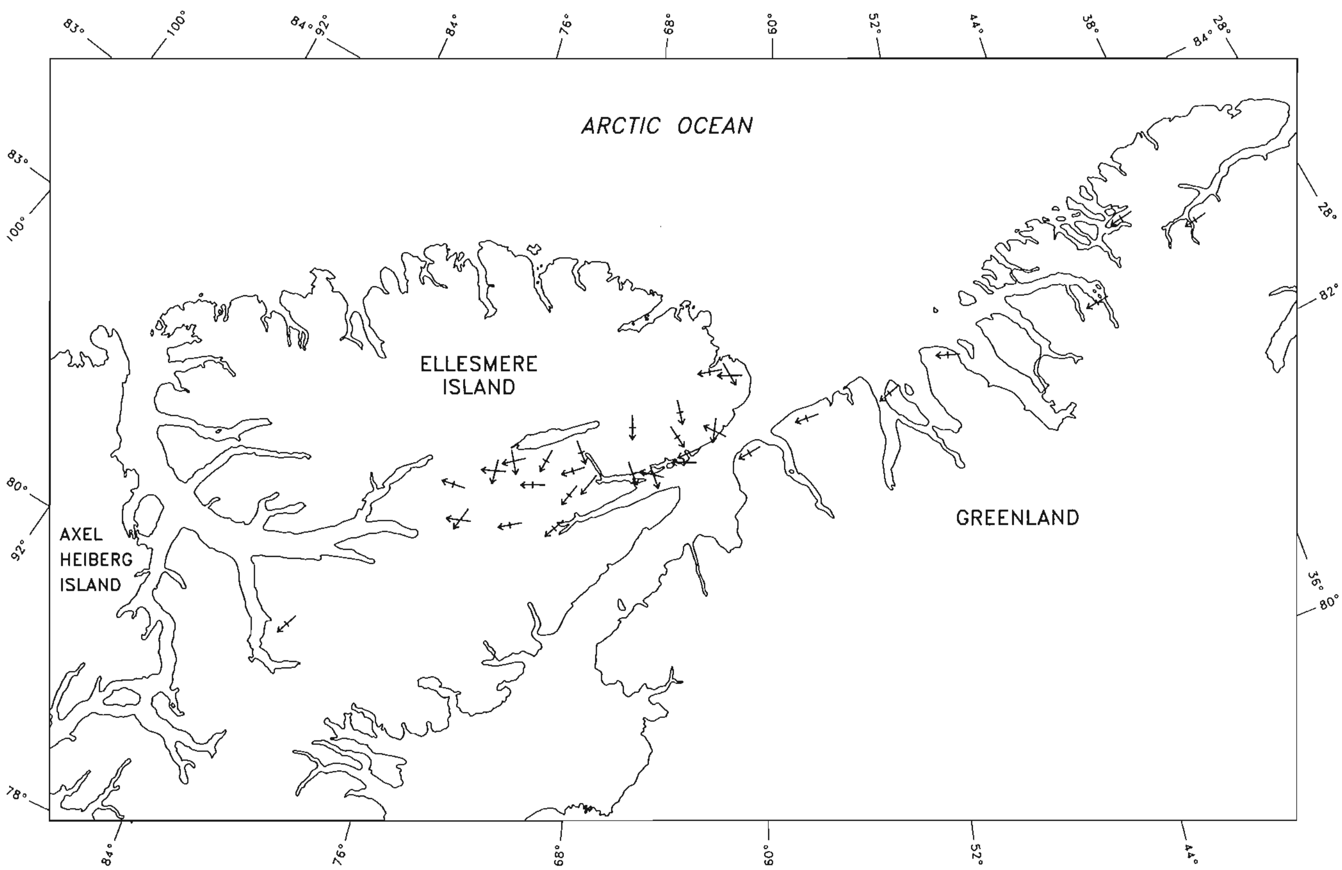


Figure 132. Mean paleocurrent directions in Silurian flysch of North Greenland (Silurian; from Hurst and Surlyk, 1982, Fig. 124) and the Hazen Fold Belt.

Geldsetzer (1989) and may be applicable here. It would require that the Ordovician Deep Water Basin was density-stratified (cf. Railsback et al., 1990), and that an oxygen-deficient layer of that ocean overlapped parts of the deep outer shelf during the extensive Late Ordovician transgression.

CHAPTER 6

ECONOMIC GEOLOGY

BASE METAL DEPOSITS

Known mineral showings, and comparisons with other regions, indicate that the following rock types are promising targets for base metal exploration:

1. *Starved-basin deposits of the Hazen Fold Belt.* The Hazen Formation is a promising potential host for stratiform lead-zinc deposits of exhalative origin, because of the following features or relations (Sangster, 1981):

   a) Its deep water origin and extremely slow rate of sedimentation, which would allow accumulation of significant deposits, even at slow rates of exhalation.

   b) The presence of coeval volcanic rocks in the adjacent Clements Markham Fold Belt (cf. Trettin et al., 1987; Trettin and Nowlan, 1990) — provided that the two belts were in contact at the time of deposition.

   c) Similarities with lower Paleozoic units in the Selwyn Basin that contain significant lead-zinc deposits (Road River Formation and equivalents).

The only known mineral showing in the Hazen Formation occurs north of central Hare Fiord (loc. F2, Fig. 84). There, patches of malachite and minor azurite can be seen on a steep cliff face of chert, and chalcopyrite is present in adjacent talus (Economic Geology Division, Geological Survey of Canada, 1980, p. 79). Malachite, of course, is a conspicuous mineral and the fact that no showings of other minerals have been found so far may be due to lack of thorough prospecting. Most outcrop areas of the Hazen Formation lie within the Ellesmere Island National Park Reserve.

2. *Shelf-margin carbonates.* A significant lead-zinc deposit occurs in dolostone on northeastern Judge Daly Promontory, 32 km southwest of Cape Baird, the northeastern extremity of the peninsula (beyond the study area). Discovered and staked in 1973 for the Great Plains Development Company of Canada, Ltd., it was trenched and further investigated in 1974 (McClaren and Habbishaw, 1974; Gibbins et al., 1977, p. 63-65). The main showing, which extends across strike for about 300 m, contains lenses and disseminated crystals of sphalerite and less abundant galena. The host rock, for which fossil-dating is not available, was assigned previously to the Copes Bay Formation, equivalent to the combined Cape Clay and Ninnis Glacier formations, and also to member A of the Bulleys Lump Formation. The description given by McClaren and Habbishaw (1975), and the location of the showing suggest that it occurs in the Bulleys Lump Formation. Because of the abundance of fenestral structures and grainstones, this formation must have had a high initial porosity, favourable for mineralization at an early stage; that is, before tight calcite cementation. The deposit lies only 3 km southeast of the faulted contact with the Hazen Formation. The proximity to the main Deep Water Basin on the northwest and to a Silurian "graptolitic shale basin" on the southeast is probably not coincidental. It remains uncertain, however, whether the lead and zinc were deposited by fluids expelled from the Hazen or Cape Phillips formations, or whether they ascended, from deep sources, through fractures or faults at the basin margins.

In either case, the entire shelf margin, and especially the Bulleys Lump Formation, are potential sites of lead-zinc deposits. This was recognized by the geologists of the Great Plains Development Company, who explored the area in 1974, but with little success. Local glaciers on Judge Daly Promontory and the huge Agassiz Ice Cap farther southwest severely limit the area that can be explored.

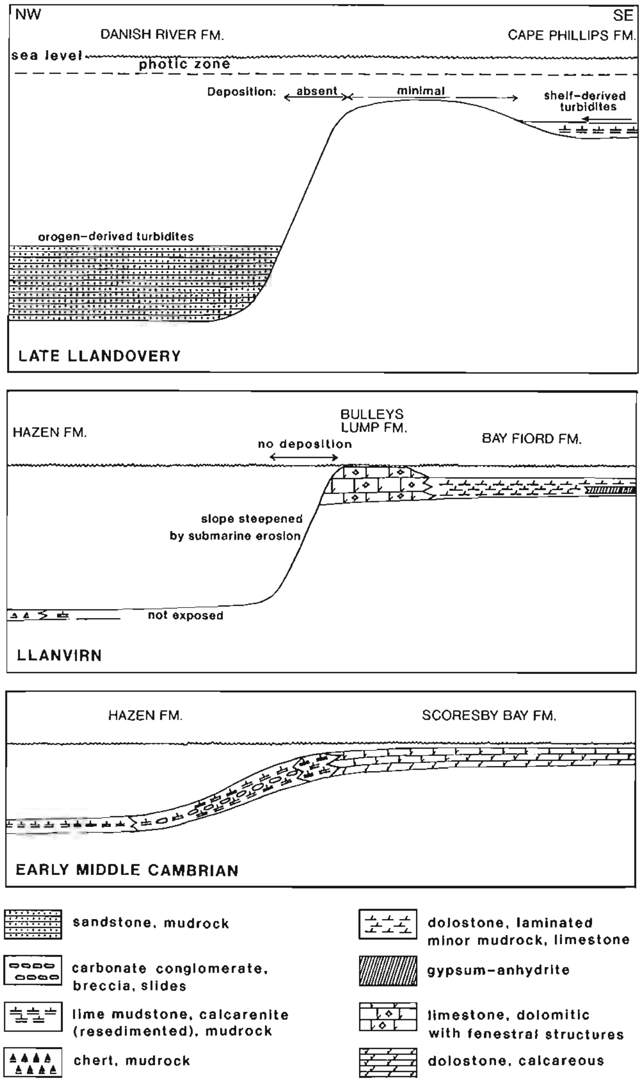


Figure 133. *Geological interpretation of the development of the shelf-basin transition (not to scale, diagrammatic).*

Early Middle Cambrian: *A new shelf margin had been established in the latest Early Cambrian, perhaps by deep-seated normal faulting. The new slope is gentle enough to retain sediments, but sliding occurs intermittently.*

Llanvirn: *Relief between basin and shelf, and slope inclination have increased, owing to rapid subsidence of the entire area combined with rapid sedimentation on the shelf and slow sedimentation in the basin. Additional slope steepening is due to submarine erosion (sliding, slumping, etc.), and the slope now is too steep to retain sediments. A carbonate buildup at the shelf margin rims an evaporitic intrashelf basin to the southeast.*

Late Llandovery: *Rapidly deposited turbidites in the deep water basin abut against the carbonate escarpment, creating a slope unconformity. Resedimented carbonates and mudrocks of graptolitic facies, deposited in an intrashelf basin, are separated from the main deep water basin by an area in which late Llandovery strata are absent, turbidites of latest Llandovery or Wenlock(?) age lying on lower or middle Llandovery shelf carbonates. In the absence of evidence of emergence, the area is here interpreted as the top of a submarine ridge that lay below the photic zone, where most carbonates are generated.*

PETROLEUM

The Hazen Fold Belt has no petroleum potential because of its intensely faulted, complex structure and high degree of organic metamorphism. However, the Hazen Formation, which is relatively rich in organic carbon, may have generated petroleum that migrated into adjacent parts of the Central Ellesmere Fold Belt prior to the deformation and metamorphism of the Hazen Fold Belt.

The small part of the Central Ellesmere Fold Belt examined southeast of Ella Bay is not a promising target for petroleum exploration. Strata as old as Early Cambrian are exposed at the surface and have been breached by erosion. Moreover, the Colour Alteration Index values — mostly 5, rarely 4.5 or 4 — indicate temperatures too high for petroleum preservation. However, southwestern parts of the fold belt that are covered by Middle and Upper Devonian strata have some potential (cf. Mayr et al., 1978; Uyeno, 1990; Embry et al., 1991).

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APPENDIX 1

STRATIGRAPHIC SECTIONS

This appendix contains descriptions of 14 stratigraphic sections (Fig. 134), and brief comments on several short sections that were studied in detail and are depicted graphically in the text of the report. Most sections were measured from the base up with measuring staffs that had clinometers attached to them. (Samples from the various localities are marked by the field numbers cited.)

ELLA BAY 1 SECTION (EB1)

Location: Lady Franklin Bay map area (120 C), northwest side of upper Ella Bay; UTM Zone 19X, 482000E, 9005200N (Figs. 134, 135).

Section EB1-1 includes the upper part of the Kane Basin Formation and Section EB1-2 the Hazen Formation. The latter consists of two parts (EB1-2-1 and EB1-2-2) that appear to be separated by a normal fault. Measured from the base up in 1977; field number 77TM1.

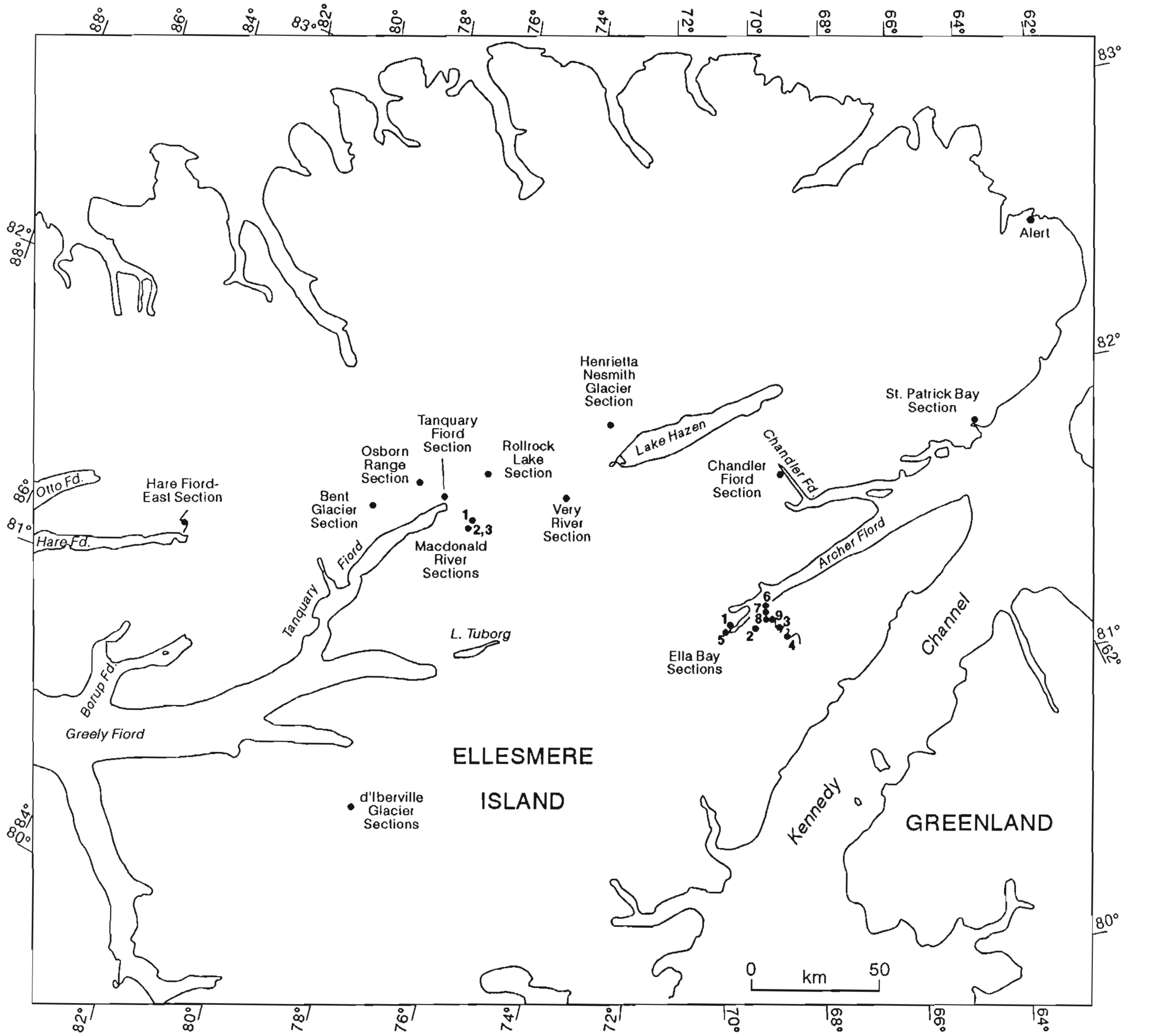

Figure 134. Index of sections listed in Appendix 1.

KANE BASIN FORMATION (Section EB1-1)

Base of section: talus slope, within Kane Basin Formation.

Unit 1, 0-211.0 m (211.0 m)
Mainly **mudrock**: light grey to predominantly medium light grey, fine to coarse grained, in part sandy, with minor amounts of thinly interstratified **sandstone**: very fine grained, argillaceous; flat lamination, small-scale crosslamination, some bioturbation; contains ellipsoidal aggregates of chlorite and minor muscovite, pseudomorphous after glauconite; some dolomite alteration.

Fossil collection C-74520, talus, probably close to source at 112.5 m: *Nevadella* Zone or *Bonnia-Olenellus* Zone, middle or late Early Cambrian (Fritz, Appendix 3A).

Conformable contact.

HAZEN FORMATION (Section EB1-2-1)

Carbonate member

Subdivision A

Unit 1, 0-133.5 m (133.5 m)
Recessive units of **mudrock**, alternating with slightly more resistant, thin units of **calcarenite**, **lime mudstone**, and **sandstone**. The last three are difficult to distinguish other than in thin section and are collectively referred to as **CSS** (for calcareous and siliciclastic sediments).

Mudrock: mainly medium dark grey but medium grey in lower 7 m or so, fine to coarse grained, in part sandy, variably calcareous and dolomitic; flat lamination partly obscured by bioturbation; slaty cleavage developed mainly in fine grained, carbonate-poor strata.

CSS: medium dark grey to medium grey; may consist of any combination of calcarenite, lime mudstone, and sandstone; flat lamination predominant with some undulating lamination and small-scale crosslamination.

Sandstone: very fine grained, argillaceous, very well sorted, calcareous; quartz and feldspar commonly subangular or angular.

Calcarenite: predominantly very fine grained but up to medium grained, sandy and argillaceous, slightly dolomitic.

Lime mudstone: comprises lime mudstone and fine to coarse grained lime mudstone, argillaceous and slightly sandy and dolomitic; carbonate aggregates (especially relatively fine ones) commonly recrystallized to single crystals.

0-75.5 m (75.5 m)
About 80% **mudrock**; **CSS**: units 0.5-8 cm, commonly 2-3 cm thick; trilobite fragments in specimens from lower 20 m.

Fossil collection C-74640 from approximately 38-46 m (outcrop about 100 m NE of section), *Bonnia-Olenellus* Zone, late Early Cambrian (Fritz, Appendix 3A); associated crawling tracks (*Cruziana*) show that trilobites are approximately in place, not redeposited.

75.5-105.0 m (29.5 m)
Mudrock: about 10-15%, rising to about 30% in upper 3 m; units 1-5 cm thick; **CSS**: units commonly 10-20 cm thick; flat lamination predominant.

105.0-133.5 m (28.5 m)
Mudrock: about 95%; trace fossils common on bedding planes; trilobite fragments abundant in specimen from 112 m; **CSS**: units about 2 cm thick; limonite common in upper 2 m.

Subdivision B

Unit 2, 133.5-145.0 m (11.5 m)
Carbonate conglomerate: massive; clasts range from granule to cobble grade; are flat, round, prismatic, or irregular, closely packed, cemented by calcite, and composed of dolostone, silty dolostone, and argillaceous and sandy lime mudstone.

Subdivision C1

Unit 3, 145.0-155.0 m (10.0 m)
Covered, recessive.

Unit 4, 155.0-166.45 m (11.45 m)
Predominantly **chert** with perhaps 8% **CSS** and minor amounts of **mudrock**. **Chert**: medium dark grey, contains poorly preserved radiolarians and some pyrite; occurs in thin beds with internal flat lamination that are separated by layers of **mudrock**. **CSS**: analyzed specimens are **lime mudstone** and **calcarenite**.

155.0-157.5 m (2.5 m)
Predominantly **chert** with minor interlaminated **mudrock**. **Chert**: beds 0.5-5 cm thick.

157.5-158.1 m (0.6 m)
CSS with 5 cm of **chert**, 40 cm above base.

158.1-165.1 m (7.0 m)
Chert.

165.1-165.45 m (0.35 m)
CSS: analyzed specimens consist of **lime mudstone** and very fine grained **calcarenite**.

165.45-166.45 (1.0 m)
Chert.

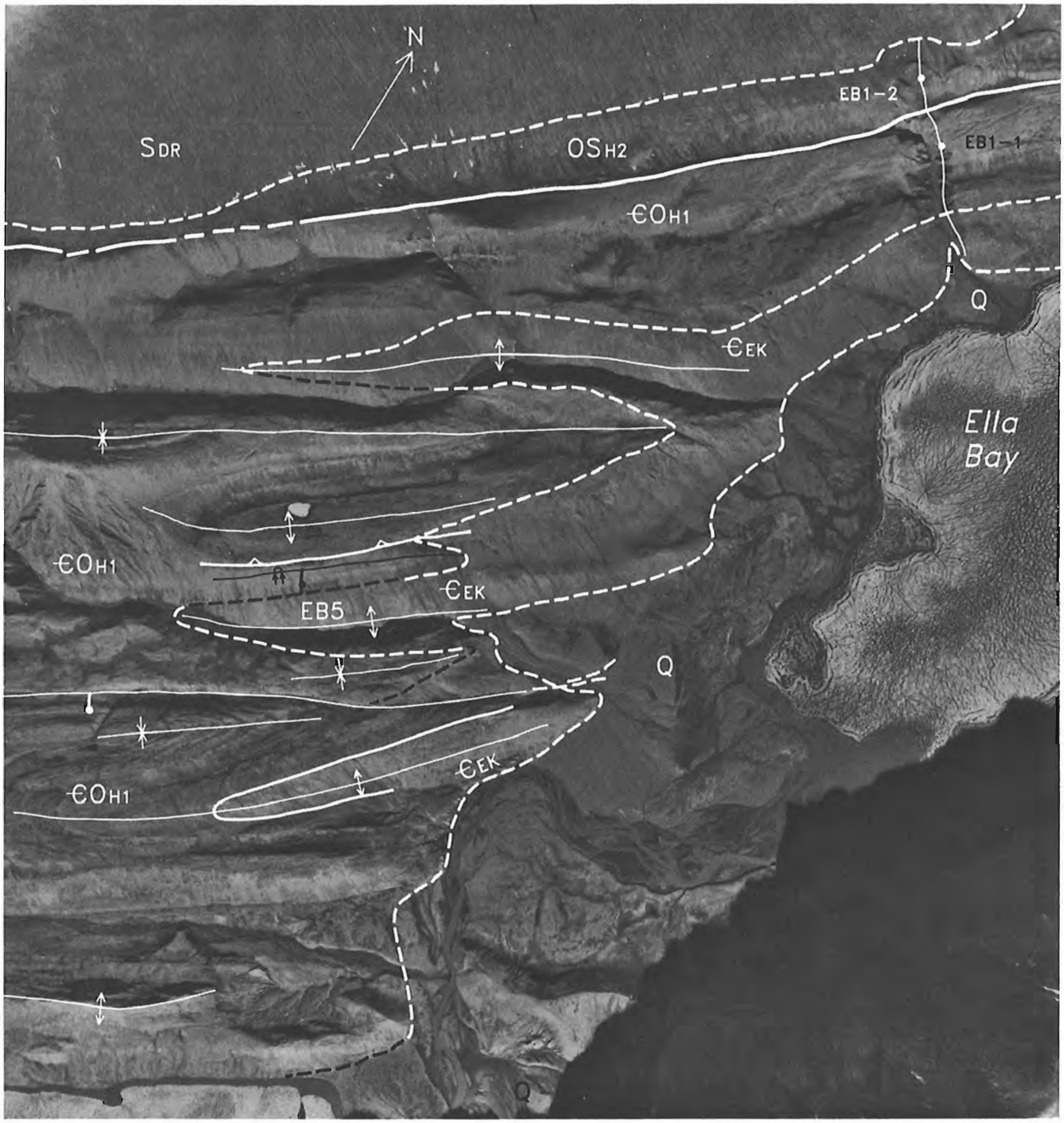

Figure 135. Vicinity of Ella Bay 1 section (EB1; reference section for Hazen Formation) and Ella Bay 5 section (EB5). Part of aerial photograph NAPL A-16609-37. For legend see Figure 1.

Subdivision C2

Unit 5, 166.45-196.7 m (30.25 m)
Predominantly **mudrock**. **CSS**: about 10%; analyzed specimens are **calcarenite** and **lime mudstone**.

166.45-166.8 m (0.35 m)
CSS: analyzed specimen is **calcarenite**, very fine to fine grained.

166.8-173.6 m (6.8 m)
Mudrock: partly rich in pyrite, with about 10% **CSS**; flat lamination.

173.6-182.7 m (9.1 m)
Mudrock: some strata rich in pyrite.

182.7-186.3 m (3.6 m)
Mudrock and **CSS** interbedded. **CSS**: beds 1-3 cm thick; analyzed specimen is **lime mudstone**, fine grained.

186.3-195.6 m (9.3 m)
Mudrock: dolomitic.

195.6-196.7 m (1.1 m)
Mudrock and **CSS**: occurring in three beds, 5-7 cm thick; analyzed specimen is **lime mudstone**, coarse grained; unit is flat-laminated, pyritic.

Subdivision D

Unit 6, 196.7-218.0 m (21.3 m)
Carbonate conglomerate: clasts commonly flat and ellipsoidal, ranging in grade from granules to boulders (observed maximum diameter 1 m); analyzed specimen contains clasts of lime mudstone, silty and sandy, dolostone silty, and mudrock, coarse grained, sandy; many fragments bounded by solution surfaces; pyrite common.

Undifferentiated subdivisions

Unit 7, 218.0-314.5 m (96.5 m)
Mudrock and **CSS** as in unit 1. **CSS**: mainly **calcarenite** and lime **mudstone**, minor sandstone; trilobite fragments in specimen from 243.2 m.

Unit 8, 314.5-317.0 m (2.5 m)
Two beds of **carbonate conglomerate**, similar to unit 6, making up 30% of unit, separated by one unit of **CSS** and **mudrock**.

314.5-315.0 m (0.5 m)
Carbonate conglomerate: fragments up to 20 cm long; specimen is composed of lime mudstone and peloidal lime wackestone in matrix of calcarenite, very fine grained, sandy, silty.

315.0-316.75 m (1.75 m)
CSS and **mudrock**.

316.75-317.0 m (0.25 m)
Carbonate pebble conglomerate.

Unit 9, 317.0-327.0 m (10.0 m)
CSS and **mudrock**. **CSS**: analyzed specimen consists of **lime mudstone**, coarse grained, sandy.

Unit 10, 327.0-333.0 m (6.0 m)
Carbonate conglomerate: pebble to boulder grade; fragments mostly flat; observed maximum diameter 50 cm.

Unit 11, 333.0-345.6 m (12.6 m)
Carbonate conglomerate (about 46%), alternating with **CSS** and **mudrock**.

333.0-336.0 m (3.0 m)
CSS and **mudrock**; unit is structurally disturbed.

336.0-338.5 m (2.5 m)
Carbonate conglomerate: clasts tabular; observed maximum diameter 35 cm.

338.5-341.0 m (2.5 m)
CSS and **mudrock**.

341.0-341.5 m (0.5 m)
Carbonate conglomerate: observed maximum diameter 20 cm.

341.5-342.2 m (0.7 m)
CSS and **mudrock**.

342.2-343.3 m (1.1 m)
Carbonate conglomerate: mainly of pebble grade but ranging up to cobble grade; observed maximum diameter 20 cm.

343.3-343.4 m (0.1 m)
CSS: wedges out laterally.

343.4-343.85 m (0.45 m)
Carbonate pebble conglomerate.

343.85-344.05 m (0.2 m)
CSS and **mudrock**.

344.05-344.55 m (0.5 m)
Carbonate pebble to cobble conglomerate: observed maximum diameter 15 cm.

344.55-344.9 m (0.35 m)
CSS and **mudrock**.

344.9-345.6 m (0.7 m)
Carbonate pebble to boulder conglomerate: clasts tabular; maximum observed diameter 30 cm.

Unit 12, 345.6-380.0 m (34.4 m)
CSS and **mudrock**. **CSS**: analyzed specimens are **lime mudstone**, flat-laminated.

Unit 13, 380.0-426.7 m (46.7 m)
Thin beds of **carbonate conglomerate** (31%), alternating with thin units of **CSS** and **mudrock**. **CSS**: analyzed specimens are mainly **lime mudstone** with minor **calcarenite**.

380.0-380.7 m (0.7 m)
Carbonate pebble to cobble conglomerate: clasts tabular; observed maximum diameter 10 cm.

380.7-381.1 m (0.4 m)
CSS and **mudrock**.

381.1-383.4 m (2.3 m)
Carbonate pebble to cobble conglomerate: maximum observed diameter 15 cm.

383.4-385.9 m (2.5 m)
CSS and **mudrock**. **CSS**: analyzed specimen is **lime mudstone**, fine grained.

385.9-388.5 m (2.6 m)
Carbonate pebble to cobble conglomerate: observed maximum diameter 25 cm; analyzed fragments are lime mudstone, sandy and silty, and sandstone, very fine grained, calcareous.

388.5-391.5 m (3.0 m)
Lower part covered; upper 0.8 m **CSS** and **mudrock**.

391.5-392.5 m (1.0 m)
Carbonate conglomerate.

392.5-393.0 m (0.5 m)
CSS: analyzed specimen is **lime mudstone**, fine grained, laminated.

393.0-394.0 m (1.0 m)
Carbonate conglomerate.

394.0-396.0 m (2.0 m)
Covered.

396.0-396.35 m (0.35 m)
Carbonate conglomerate.

396.35-403.85 m (7.5 m)
CSS and **mudrock**. **CSS**: carbonate beds 0.5-5 cm, commonly 2 cm thick; analyzed specimen is **lime mudstone**.

403.85-406.35 m (2.5 m)
Mostly covered, recessive; outcrop of **mudrock** in upper 1 m.

406.35-407.2 m (0.85 m)
Carbonate granule to boulder conglomerate: clasts tabular, observed maximum diameter 30 cm; analyzed fragments are lime mudstone, sandy, pelitic.

407.2-410.7 m (3.5 m)
Recessive, mostly covered unit; in upper part outcrop of **mudrock** with about 20% **CSS**: analyzed specimen is **calcarenite**.

410.7-412.45 m (1.75 m)
Carbonate pebble to cobble conglomerate: clasts tabular, observed maximum diameter 25 cm.

412.45-415.45 m (3.0 m)
Covered.

415.45-417.0 m (1.55 m)
Mudrock and **CSS** (about 50%): flat lamination and small-scale crosslamination.

417.0-417.7 m (0.7 m)
Carbonate pebble to cobble conglomerate: clasts tabular; observed maximum diameter 20 cm.

417.7-419.2 m (1.5 m)
Covered.

419.2-419.9 m (0.7 m)
CSS and **mudrock**.

419.9-420.5 m (0.6 m)
Carbonate pebble to cobble conglomerate: observed maximum diameter 10 cm; quartz veins and replacements.

420.5-424.2 m (3.7 m)
CSS (about 50%) and **mudrock**; beds 0.5-5 cm thick.

424.2-426.7 m (2.5 m)
Carbonate pebble to boulder conglomerate: observed maximum diameter 30 cm.

Conodont collection C-96671 from 426.5 m, latest Cambrian (Trempeleauan) to Early Ordovician (Fauna B, middle Tremadoc) (Nowlan, Appendix 3B).

Fault, cutting out an unknown thickness of strata.

(Section EB1-2-2)

Unit 14, 0-112.8 m (112.8 m)
Predominantly **CSS** with lesser amounts of **mudrock. CSS**: mainly **lime mudstone**, less **calcarenite**, small amounts of **sandstone**.

0-10.5 m (10.5 m)
Mudrock and **CSS**: beds 1-5 cm thick; analyzed specimen consists of fine to coarse grained **lime mudstone** and calcareous **sandstone**.

10.5-38.3 m (27.8 m)
Covered, recessive.

38.3-75.8 m (37.5 m)
Mudrock and **CSS**: beds commonly 1-5 cm, but up to 50 cm thick in middle of unit; analyzed specimens are flat-laminated **lime mudstone**.

75.8-92.8 m (17.0 m)
Mainly **CSS**: analyzed specimens are flat-laminated **lime mudstone**; carbonate-rich beds, 20-30 cm thick, separated by 0.5-1 cm thick beds of argillaceous **lime mudstone**.

92.8-108.3 m (15.5 m)
Predominantly **mudrock** (about 60%) with 1 cm thick beds of **CSS** (probably mainly **lime mudstone**); indistinct trace fossils on bedding planes.

108.3-112.8 m (4.5 m)
Mainly **CSS**: beds commonly 5 cm thick; flat lamination and small-scale crosslamination; **flat-pebble conglomerate** at 538.5-539.0 m; some **chert** lenses.

Chert member

Unit 15, 112.8-151.3 m (38.5 m)
Chert: medium dark grey; thinly laminated; beds 1-8 cm thick, separated by thin laminae of **mudrock**; radiolarians common, generally poorly preserved; pyrite common.

112.8-116.8 m (4.0 m)
Beds 1-2 cm thick; extensive but structurally disturbed marker.

116.8-129.8 m (13.0 m)
Beds 1-8 cm thick; rusty zones in upper 4 m.

129.8-151.3 m (21.5 m)
Beds 0.5-3 cm, commonly 1 cm thick; some graptolites.

Fossil collection C-74603 at 132.8-134.8 m, Late Ordovician, late Ashgill (Norford, Appendix 3A).

Unit 16, 151.3-172.3 m (21.0 m)
Mudrock: medium dark grey, calcareous, thinly laminated, slaty.

Unit 17, 172.3-204.8 m (32.5 m)
Covered, recessive.

Abrupt contact with the overlying Danish River Formation.

Summary of thicknesses, Ella Bay 1 section

Kane Basin Formation	>211.0 m
Hazen Formation	>631.5 m
Carbonate member	>539.5 m
Subdivision A	133.5 m
Subdivision B	11.5 m
Subdivision C	21.45 m
Subdivision D	21.3 m
Chert member	92.0 m

ELLA BAY 2 SECTION (EB2)

Location: Lady Franklin Bay map area (120 C).

Ella Bay 2-North (EB2-N) is 10.13 km south of Record Point (mouth of Ella Bay); UTM Zone 19X, 492300E, 9003400N.

Ella Bay 2-East (EB2-E) is 9.88 km south-southeast of Record Point (mouth of Ella Bay); UTM Zone 19X, 493200E, 9003800N.

Ella Bay 2-South (EB2-S) is 10.5 km south of Record Point (mouth of Ella Bay); UTM Zone 19X, 492300E, 9003000N.

This composite section consists of three partial sections. Ella Bay 2-North provides a thickness of the Bulleys Lump Formation close to its northern limit. Ella Bay 2-East contains a detailed description of the uppermost part of the same formation, and section Ella Bay 2-South an interval in the lowermost part of the Danish River Formation. Ella Bay 2-East was measured in 1977 (field number 77TM2); sections Ella Bay 2-North and Ella Bay 2-South were measured in 1982 (field numbers 82TM12 and 82TM13).

BULLEYS LUMP FORMATION (Section EB2-N)

Base of section: approximate contact with Hazen Formation (covered).

Member B

0-110±30 m (110±30 m)
Limestone: medium light grey to medium dark grey, massive, commonly medium grey; some fenestrae; gastropods at 12 m; petrographic classification impossible because of shearing and recrystallization; thin sections show skeletal fragments of gastropods, trilobites, echinoderms(?), bryozoans(?), algae, and peloids.

Top of section: approximate contact with Danish River Formation (covered, probably abrupt).

BULLEYS LUMP FORMATION (Section EB2-E)

Member B

Base of section: level in uppermost part of Bulleys Lump Formation, member B.

Unit 1, 0-4.5 m (4.5 m)
Limestone: medium light grey to medium dark grey, massive, sheared; thin section shows abundant peloids and fragments of ostracodes, echinoderms, and algae(?).

Unit 2, 4.5-9.7 m (5.2 m)
Lime mudstone with interbedded **mudrock**.

Lime mudstone: medium dark grey, quartz silty, slaty, beds 2-3 cm thick.

Mudrock: medium dark grey, highly calcareous, slightly dolomitic, beds 1-3 cm thick.

Unit 3, 9.7-16.2 m (6.5 m)
Mostly covered; some outcrops of **mudrock**: medium dark grey, slaty, highly dolomitic, slightly calcareous; two or more beds of **limestone** as before; at 13.5 m some aggregates of radiating fibrous calcite, about 3.5 cm in diameter.

Unit 4, 16.2-36.2 m (20.0 m)
Limestone: medium grey to medium dark grey, massive, mostly recrystallized; at 21 m packstone(?) composed of peloids, coated grains, algae, echinoderms, and unidentified skeletal matter; at 25.2 m bryozoan boundstone(?); at 31.2 m bryozoan boundstone(?) with calcite-filled vugs.

Conodont collection C-74617 from lower part of unit probably is Llandeilo in age; C-74618 from upper part contains elements of late Llanvirn to early Caradoc ages; it may be mixed (Tipnis and Nowlan, Appendix 3B).

Top of section: abrupt contact with Danish River Formation, represented by talus (submarine unconformity).

DANISH RIVER FORMATION (Section EB-2S)

Base of section: within the lowermost part of the Danish River Formation.

Unit 1, 0-1.045 m (1.045 m)
Mudrock: medium dark grey, fine grained; flat lamination; weak slaty cleavage forms low angle with bedding.

– abrupt contact –

Unit 2, 1.045-1.975 m (0.93 m)
Mostly **sandstone**: medium grey, massive; at base very fine to fine grained, poorly sorted (maximum grain size coarse grained); in upper 5 cm **rip-up clasts of mudrock** up to 5 cm long; sandstone fines in uppermost part and is overlain by about 4 cm of **mudrock**: coarse grained, sandy, with rip-up clasts and discontinuous, undulating lamination.

Unit 3, 1.975-2.055 m (0.08 m)
Mudrock: medium dark grey, fine grained, slaty, massive.

– abrupt contact –

Unit 4, 2.055-3.325 m (1.27 m)
Sandstone: medium grey, very fine to fine grained, massive; flame structure at base; subtle graded bedding.

Unit 5, 3.325-3.42 m (0.095 m)
Mudrock: medium dark grey, coarse grained, very fine grained sandy; vague to distinct flat lamination.

Unit 6, 3.4-3.58 m (0.16 m)
Interlaminated **mudrock** and minor **sandstone**; mainly flat lamination with small-scale crosslamination in upper 3 cm.

– abrupt contact –

Unit 7, 3.58-12.78 m (9.20 m)
Sandstone: medium grey, very fine grained, poorly sorted, massive; fining in uppermost part.

Unit 8, 12.78-13.0 m (0.22 m)
Mudrock: medium to medium dark grey, coarse grained; crosslamination and minor convolute lamination.

Top of section: talus of **sandstone** and **mudrock**.

ELLA BAY 3 SECTION (EB3)

This section comprises a short detailed section in the upper part of the Cass Fjord Formation (EB3-1), and a continuous section extending from the base of the Ninnis Glacier Formation to the top of the Allen Bay Formation (EB3-2 to EB3-6), supplemented by a detailed section of part of the Ninnis Glacier Formation at a distance from the main line of section (EB3-2a).

Location: Lady Franklin Bay map area (120 C), 11.75-15.1 km southeast of Record Point at mouth of Ella Bay; UTM Zone 19X, 498400E, 9005200N to 501500E, 9003500N. Section EB3-2a at UTM Zone 19X, 496500E, 9004250N (Fig. 136).

Total thickness of Thumb Mountain Formation and of parts of Bulleys Lump Formation based on photogrammetry; other thicknesses and partial sections measured on the ground in 1979 and 1984. Field numbers: 84TM4 (Cass Fjord Fm.); 84TM3, 84TM6 (Ninnis Glacier Formation); 84TM6, 79TM3 (Bulleys Lump Formation); 79TM3, 79TM4 (Thumb Mountain and Irene Bay formations); 79TM5 (Allen Bay Formation).

CASS FJORD FORMATION (Section EB3-1)

Base of section: base of coherent outcrop; within the uppermost part of the Cass Fjord Formation; stratigraphic height above base of formation unknown.

Unit 1, 0-32.3 m (32.3 m)
Flat-laminated dark carbonate-siliciclastic facies (FDCS) predominantly **limestone** with small amounts of interlaminated **dolostone, mudrock**, and **sandstone**; mainly medium grey and medium dark grey; flat and undulating lamination and rare microscopic crosslamination; solution zones common, enriched in quartz, feldspar, dolomite and carbonaceous matter.

Limestone: **lime mudstone, peloidal packstone/ wackestone**, variably dolomitic, silty, and sandy; sand fraction mainly very fine but up to medium grained.

Dolostone: microcrystalline, generally highly calcareous, variably silty and sandy.

Sandstone: very fine grained, silty, calcareous and dolomitic.

Unit 2, 32.3-47.5 m (15.2 m)
Undifferentiated carbonate rocks (UC)

Lime mudstone: light grey and medium grey; some skeletal grains (trilobites, echinoderms); variably silty and sandy (maximum observed grain size is coarse); vague flat bedding, minor crossbedding (troughs about 15 cm long, 5-10 cm deep).

Unit 3, 47.5-52.6 m (5.1 m)
Massive carbonate facies (MC)

Limestone: light grey, peloidal, highly recrystallized, massive.

Unit 4, 52.6-67.6 m (15.0 m)
Flat-laminated dark carbonate-siliciclastic facies (FDCS)

Unit 5, 67.6-71.6 m (4.0 m)
Massive carbonate facies (MC)

Limestone: light grey, highly recrystallized, highly sandy and transitional to **sandstone**: light grey, highly calcareous, fine grained.

Unit 6, 71.6-78.6 m (7.0 m)
Flat-laminated dark carbonate-siliciclastic facies (FDCS)

Unit 7, 78.6-81.6 m (3.0 m)
Sandstone facies (SS)

Sandstone: light grey, fine grained, very well sorted, grains rounded; calcareous and slightly dolomitic.

Unit 8, 81.6-88.3 m (6.7 m)
Flat-laminated dark carbonate-siliciclastic facies (FDCS)

Unit 9, 88.3-95.3 m (7.0 m)
Covered.

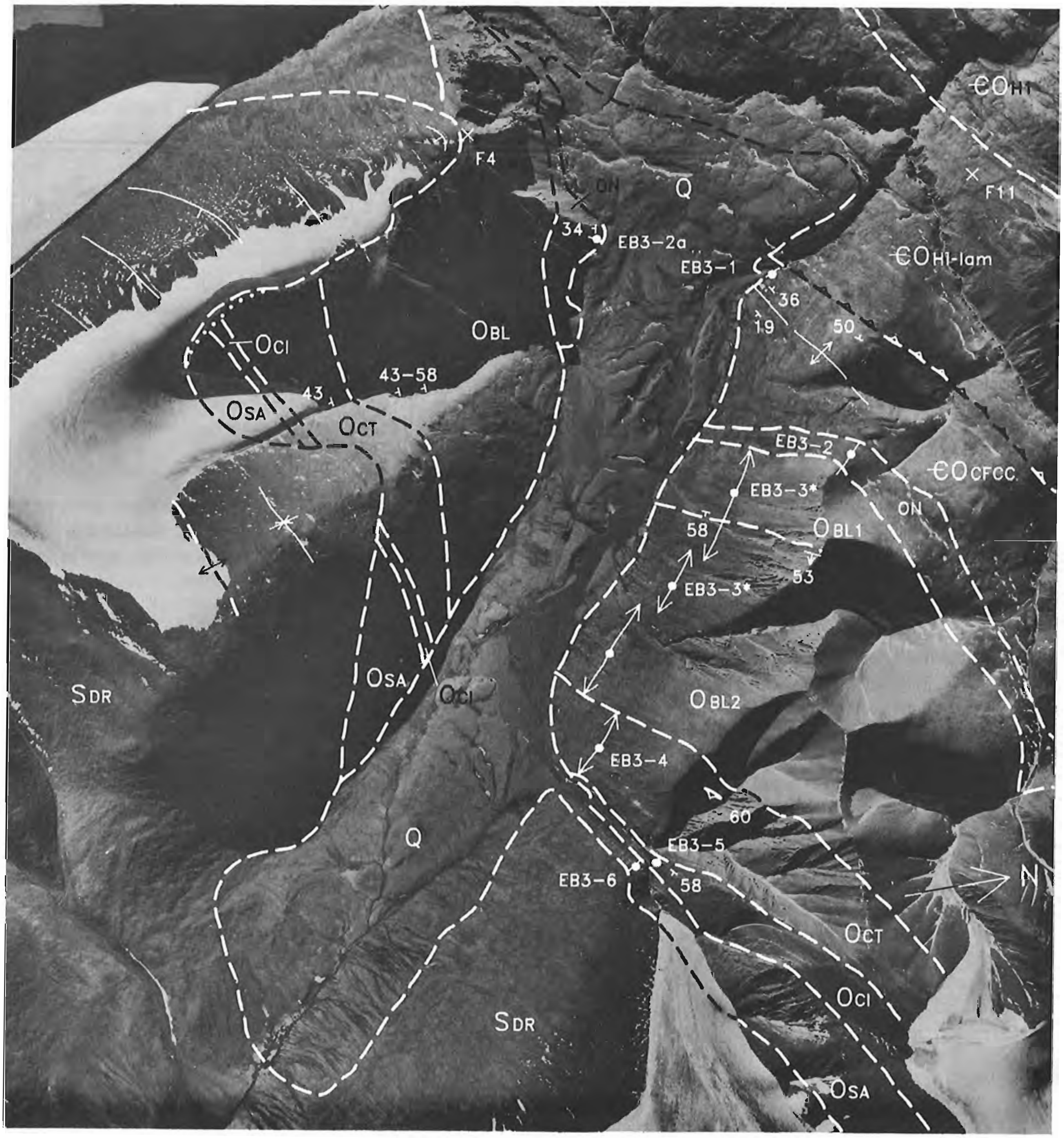

Figure 136. Vicinity of Ella Bay 3 section (EB3; type section of the Bulleys Lump Formation). Part of aerial photograph NAPL A-16611-84. For legend see Figure 1.

Unit 10, 95.3-99.8 m (4.5 m)
Massive carbonate facies (MC)

Limestone: light grey, partly recrystallized, probably lime mudstone or lime wackestone with skeletal grains (trilobites, echinoderms) and intraclasts; highly silty to medium grained sandy, highly dolomitic, probably bioturbated.

Unit 11, 99.8-102.5 m (2.7 m)
Sandstone facies (SS)

Sandstone: very light grey, quartzose, slightly dolomitic, fine grained, very well sorted, grains rounded; vague flat bedding, beds 5-10 cm thick.

Unit 12, 102.5-107.2 m (4.7 m)
Massive carbonate facies (MC)

Dolostone: medium light grey, microcrystalline and very fine crystalline, highly calcareous, slightly silty and very fine grained sandy; solution zones.

Unit 13, 107.2-109.7 m (2.5 m)
Massive carbonate facies (MC)

Limestone: light grey, peloidal, dolomitic, poorly bedded.

Unit 14, 109.7-113.7 m (4.0 m)
Covered.

Unit 15, 113.7-121.2 m (7.5 m)
Flat-laminated dark carbonate-siliciclastic facies (FDCS)

Unit 16, 121.2-121.7 m (0.5 m)
Laminated carbonate-siliciclastic facies (LCS)

Sandstone: fine grained, very well sorted, slightly calcareous; **lime mudstone**: highly dolomitic, silty and very fine grained sandy; and **dolostone**: microcrystalline, calcareous, silty and very fine grained sandy; vague flat bedding and lamination.

Unit 17, 121.7-123.2 m (1.5 m)
Massive carbonate facies (MC)

Dolostone: medium grey; predominantly microcrystalline and very fine crystalline with scattered quartz of silt to coarse grained sand grade, unsorted; vague flat bedding.

Unit 18, 123.2-128.7 m (5.5 m)
Undifferentiated carbonate rocks (UC)

Limestone: medium light grey, highly dolomitic with scattered quartz sand (up to medium grained); some flat lamination, undulating lamination and cross-lamination.

Unit 19, 128.7-130.2 m (1.5 m)
Covered.

Unit 20, 130.2-131.2 m (1.0 m)
Undifferentiated carbonate rocks (UC)

Limestone: light grey, peloidal, highly dolomitic, quartzose (silt to coarse grained sand grade); some flat and undulating lamination.

Unit 21, 131.2-135.7 m (4.5 m)
Covered.

Unit 22, 135.7-143.2 m (7.5 m)
Flat-laminated dark carbonate-siliciclastic facies (FDCS)

Increasingly argillaceous in upper 3 m.

Unit 23, 143.2-177.7 m (34.5 m)
Massive carbonate facies (MC)

Limestone: medium light grey and medium grey; partly recrystallized lime mudstone(?), containing some peloids; dolomitic and silty in lower 9 m, pure in upper part; upper 19.5 m bluff-forming.

Conodont collection C-96683 from 158.2 m: Early Ordovician, early Tremadoc (Nowlan, Appendix 3B).

Unit 24, 177.7-179.9 m (2.2 m)
Massive carbonate facies (MC)

Limestone: medium grey, sheared, includes unidentified skeletal material.

Unit 25, 179.9-185.9 m (6.0 m)
Massive carbonate facies (MC)

Limestone: medium grey, nearly pure, highly recrystallized, massive.

Unit 26, 185.9-188.0 (2.1 m)
Flat-laminated dark carbonate-siliciclastic facies (FDCS)

Top of section: level within uppermost part of Cass Fjord Formation. *Lithofacies FDCS* continues to fault contact with Hazen Formation.

NINNIS GLACIER FORMATION (Section EB3-2)

Base of section: approximate upper limit of Cape Clay Formation; contact is covered.

0-108.0 m (108.0 m)
Limestone and minor **dolostone** as described below; present mainly as rubble and talus with scattered outcrop in upper 58 m.

(Section EB3-2a)

Detailed section of part of Ninnis Glacier Formation; height of section above base of Ninnis Glacier Formation is unknown.

Unit 1, 0-4.5 m (4.5 m)
Lithofacies Cf (flat-laminated carbonate rocks):

Lime mudstone and **peloidal packstone/wackestone**: medium dark grey, variably dolomitic; dolomite predominantly microcrystalline; rich in silt; minor amounts of siliciclastic sand, predominantly very fine grained but up to fine grained or coarse grained; flat and undulating lamination with rare crosslamination; solution zones enriched in dolomite and siliciclastic material are common; minor **dolostone**: predominantly microcrystalline, variably calcareous, silty and sandy; bedding-parallel burrow casts fairly common.

Unit 2, 4.5-8.0 m (3.5 m)
Covered.

Unit 3, 8.0-10.5 m (2.5 m)
Lithofacies Cf.

Unit 4, 10.5-11.5 m (1.0 m)
Covered.

Unit 5, 11.5-12.3 m (0.8 m)
Packstone: medium grey; composed mainly of intraclasts with lesser amounts of skeletal material (mainly trilobites, minor echinoderms etc.); massive.

Conodont collection C-96682, Early Ordovician, early-middle Tremadoc (Nowlan, Appendix 3B).

Unit 6, 12.3-18.3 m (6.0 m)
Lithofacies Cf.

Unit 7, 18.3-21.3 m (3.0 m)
Covered.

Unit 8, 21.3-27.5 m (6.2 m)
Intraformational conglomerate: medium grey, fragments of lime mudstone, peloidal packstone/wackestone, and skeletal lime wackestone, all variably silty to medium grained sandy, in matrix of lime mud, silty and sandy; internal structure somewhat obscured by solution zones and partial dolomitization; fragments up to about 3 cm long in specimens; massive.

Unit 9, 27.5-39.0 m (11.5 m)
Lithofacies Cf.

Unit 10, 39.0-40.0 m (1.0 m)
Limestone: massive, parting thickness 10-30 cm.

Unit 11, 40.0-52.5 m (12.5 m)
Lithofacies Cf.

Unit 12, 52.5-53.2 m (0.7 m)
Covered.

Unit 13, 53.2-59.9 m (6.7 m)
Lithofacies Cf.

Top of section: talus slope; conformable contact.

BULLEYS LUMP FORMATION (type section) (Section EB-3)

Member A

Unit 1, 0-17.0 m (17.0 m)
Lime mudstone (with skeletal content) and **skeletal lime wackestone**: predominantly medium grey, silty and very fine grained sandy; bioclastic material derived mainly from trilobites, dasycladacean algae, and echinoderms; dolomite predominantly microcrystalline but up to fine crystalline, concentrated in solution zones and burrows; stylolites and solution zones produce an undulating lamination; parting thickness 3-30 cm.

Unit 2, 17.0-209.0 m (192.0 m)
Rubble and talus of **limestone** and **dolostone.**

Unit 3, 209.0-426.0 m (217.0 m)
About 2/3 massive carbonate facies (**MC**), 1/3 flat-laminated and crosslaminated carbonate facies (**FXC**).

> **Massive carbonate facies (MC)**: mainly **limestone**, minor **flat-pebble conglomerate, dolostone**; unit thickness in detailed partial sections is 0.3-7.3 m (mean 1.6 m).

Limestone: medium light grey; **peloidal grainstone** predominant, **peloidal packstone/wackestone** common, **lime mudstone** subordinate; fenestral structures common, skeletal fragments rare [trilobites, ostracodes(?), echinoderms(?), algae]; slightly dolomitic.

Flat-laminated and crosslaminated carbonate facies (FXC): mainly **dolostone** (about 9/10), minor **lime mudstone**, in part sandy; unit thickness 0.35-1.45 m (mean 0.85 m).

Dolostone: light to medium grey, microcrystalline to very fine, rarely fine crystalline, silty and very fine grained sandy, calcareous.

Conodont collections C-54894 from 211.65-213.15 m and C-54895 from 214.65-215.1 m, Early Ordovician, middle Tremadoc (Nowlan, Appendix 3B).

Member B

Unit 4, 426.0-1559.0 m (1133.0 m)
About 9/10 **massive carbonate facies (MC)**, 1/10 **flat-laminated and crosslaminated carbonate facies (FXC)**.

Massive carbonate facies (MC):
mainly **limestone** with 10% or less **dolostone**; mean unit thickness in detailed partial sections 11.0 m, range 0.2-45.0 m, standard deviation 14.0 m.

Limestone: mainly medium grey; mainly **peloidal packstone/wackestone** (about 2/3), minor **peloidal grainstone**, **lime mudstone**, and **flat-pebble conglomerate**; coated grains common, skeletal fragments fairly common to rare (ostracodes, trilobites; minor gastropods, echinoderms, dasycladacean algae); dolomitic, slightly silty and very fine grained sandy.

Flat-laminated and crosslaminated carbonate facies (FXC): mainly **dolostone** (about 4/5), minor **limestone**; very small amounts of **mudrock** and very fine grained **sandstone**, both calcareous and dolomitic; flat lamination and small-scale crosslamination (troughs up to 20 cm deep, 40 cm long).

Dolostone: microcrystalline to fine, rarely coarse crystalline, variably calcareous, silty and very fine grained sandy; some intraclasts and fenestrae.

Limestone: **peloidal packstone/wackestone**, **peloidal grainstone**, **lime mudstone**; variably dolomitic, silty, and very fine grained sandy.

Conodont collections C-54897 from 439.0-439.4 m, C-54898 from 439.6-439.8 m, Early Ordovician, late Tremadoc (Nowlan, Appendix 3D).

Unit 5, 1559.0-1603.0 m (44.0 m)
About 27% **lithofacies MC**, 58% **lithofacies FXC**, 15% covered.

Lithofacies MC:
two units of **limestone** (0.8 m and 5.3 m thick), one unit of **dolostone** (0.7 m).

Lithofacies FXC: 64% **limestone**, 29% **dolostone**, 7% **mudrock** and very small amounts **sandstone**. Mean thickness of limestone units 2.7 m, dolostone units 0.9 m, mudrock units 0.9 m. Trough crossbedding at 1560.2-1560.75 m; troughs up to 1.5 m long, 0.5 m deep.

Limestones of both lithofacies: **peloidal packstone/wackestone, peloidal grainstone, lime mudstone**; skeletal fragments rare; fenestrae common.

Conformable contact.

THUMB MOUNTAIN FORMATION (Section EB3-4)

0-404.0 m (404.0 m)
Limestone with very minor amounts of **dolostone** in lower part (e.g., at 36.5-36.8 m, 64.0-65.0 m).

Limestone: light grey to medium dark grey; **lime mudstone, peloidal packstone/wackestone** (with or without skeletal fragments), and **skeletal lime wackestone**; echinoderm columnals most common; ostracodes, molluscs (incl. gastropods), dasycladacean algae subordinate; bryozoans, brachiopods rare; most strata contain no more than a few per cent quartz but some have appreciable amounts of silt and very fine grained sand of quartz with minor feldspar, mica, chlorite; massive.

0-135.0 m (135.0 m)
Mainly **peloidal packstone/wackestone** without skeletal fragments, and **lime mudstone**; irregular fenestrae fairly common.

135.0-404.0 m (269) m
Peloidal packstone/wackestone with skeletal fragments predominant (2/3 of all specimens);

skeletal lime wackestone subordinate (1/7 of specimens); minor peloidal packstone/wackestone without skeletal fragments and **lime mudstone**; fenestrae sporadic.

Conodont collections C-54918, C-54903 from 0-2 m, Middle Ordovician, Chazyan or Blackriverian; C-54907, C-54908 from 401.5-404.0 m, Middle to Late Ordovician, probably Blackriverian to Shermanian (Nowlan, Appendix 3B).

Conformable contact.

IRENE BAY FORMATION (Section EB3-5)

Unit 1, 0-18.0 m (18.0 m)
Covered with talus of **limestone**, medium dark grey, as in overlying unit.

Conodont collection C-54909 from 0-8.6 m, late Middle to Late Ordovician, Caradoc-Ashgill (Nowlan, Appendix 3B).

Unit 2, 18.0-26.6 m (8.6 m)
Limestone: medium dark grey; mainly **skeletal wackestone**; intact chain corals (common) and favositids; fragments of ostracodes, echinoderms, trilobites, gastropods; poorly bedded, burrowed.

Unit 3, 26.6-47.6 m (21.0 m)
Limestone: medium dark grey, mainly **skeletal wackestone** as before; large favositid colonies at 32.1 and 32.6 m; pyrite and rusty stain at 39.6 m; massive, resistant.

Unit 4, 47.6-52.6 m (5.0 m)
Covered, recessive; talus of **limestone**.

Unit 5, 52.6-54.9 m (2.3 m)
Limestone: medium dark grey; mainly **skeletal wackestone** as before; some chain corals; poorly bedded, ledge-forming.

Unit 6, 54.9-59.9 m (5.0 m)
Covered, recessive; rubble of **limestone**, probably in place, with chain corals.

Fossil collection C-54936 (talus) at 58 m, late Caradoc (Edenian) to Silurian (Norford, Appendix 3A).

Unit 7, 59.9-65.1 m (5.2 m)
Limestone: medium dark grey; mainly **skeletal wackestone**; intact corals and *Receptaculites*, fragments of trilobites, echinoderms, algae, etc.; poorly bedded, ledge-forming.

Unit 8, 65.1-66.6 m (1.5 m)
Covered with talus of **limestone**.

Unit 9, 66.6-68.1 m (1.5 m)
Limestone: medium dark grey; mainly **skeletal wackestone**; fragments of echinoderms, gastropods(?), trilobites etc.; poorly bedded, recessive.

Unit 10, 68.1-72.6 m (4.5 m)
Limestone: medium dark grey; mainly **skeletal wackestone**; echinoderms, corals, trilobites(?), algae(?); more resistant than underlying units.

Unit 11, 72.6-94.1 m (21.5 m)
Covered with talus of **limestone** as before, medium dark grey, and limestone, dolomitic; colonial corals common.

Fossil collection C-54937 at 79 m (talus), probably late Caradoc or Ashgill.

Unit 12, 94.1-99.1 m (5.0 m)
Limestone: as before, beds about 40 cm thick, ledge-forming.

Unit 13, 99.1-117.1 m (18.0 m)
Covered with talus of **limestone** as before; colonial corals common.

Conformable contact.

ALLEN BAY FORMATION (Section EB3-6)

0-318.0 m (318.0 m)
Limestone: medium dark grey; mainly **peloidal packstone/wackestone** with skeletal content, **skeletal and peloidal wackestone**, and **skeletal wackestone**; skeletal material mainly from echinoderms, trilobites, algae (mainly dasycladaceans), and gastropods, to a lesser extent from corals, pelecypods; macrofossils consist chiefly of favositids and chain corals; generally massive but some partings at 303.0-304.0 m; resistant.

0-90.0 m (90.0 m)
Outcrop.

90.0-244.5 m (154.5 m)
Talus.

244.5-304.0 m (59.5 m)
Outcrop.

304.0-318.0 m (14.0 m)
Outcrop and talus; favositids common.

Conodont collection C-54910 from 84.0-85.0 m, Late Ordovician, Maysvillian-Richmondian (Nowlan, Appendix 3B); C-54911 from 301.5-313.5 m, Middle to Late Ordovician (Nowlan, Appendix 3B); C-54913 from 316.5 m, Early Silurian, early to middle Llandovery (Nowlan, Appendix 3B).

Macrofossil collection C-54912 from 313.5-316.5 m, late Caradoc (late Edenian) to Late Silurian (Norford, Appendix 3A).

Top of section: approximate contact with Danish River Formation (covered by talus; appears to be abrupt, probably disconformable).

Summary of thicknesses, Ella Bay 3 section

Cass Fjord Formation	>188.0 m
Ninnis Glacier Formation	108.0 m
Bulley Lump Formation	1603.0 m
Member A	426.0 m
Member B	1177.0 m
Thumb Mountain	404.0 m
Irene Bay Formation	117.1 m
Allen Bay Formation	318.0 m

ELLA BAY 4 SECTION (EB4)

Location: Lady Franklin Bay map area (120 C), 25.0 to 20.6 km southeast of Record Point at mouth of Ella Bay; UTM Zone 19X; 507500E, 8995300N to 505600E, 8999900N (Fig. 137).

Thicknesses of the Ninnis Glacier, Bay Fiord, Thumb Mountain, Irene Bay, and Allen Bay formations are based on photogrammetry; all other units (and partial sections within Ninnis Glacier Formation and Bay Fiord Formation) were measured on the ground in 1980 and 1984. Some ground measurements have been adjusted on the basis of photogrammetry.

Field numbers: 77TM327c, 77TM327d, 80TM101b, 80TM101c, 82TM230a, 82TM230b (Ritter Bay Fm.); 80TM1 (Rawlings Bay Fm.); 80TM2 (Kane Basin Formation); 80TM3 (Scoresby Bay Fm.); 80TM3F, 80TM4A (oolitic limestone); 80TM4, 84TM7 (Cass Fjord Fm.); 80TM5, 84TM7 (Cape Clay Formation); 80TM5, 80TM6, 84TM8 (Ninnis Glacier Formation); 80TM7 (Eleanor River Fm.); 80TM8, 80TM149a, 80TM149b, 80TM149c, 80TM150b (Bay Fiord Fm.); 80TM140a (Thumb Mountain Fm.); 80TM150c (Irene Bay Fm.).

RITTER BAY FORMATION (ELLESMERE GROUP) (Section EB4-1)

Base of section: structurally disturbed mudrock and sandstone within the Ritter Bay Formation; height above base of formation unknown.

Unit 1, 0-183.0 m (183.0 m)
At base of unit about 1.5 m of **sandstone**: light grey, medium grained, poorly sorted (grains range from fine to very coarse grained) with rip-up clasts: dark grey, up to 3 cm in diameter, composed of very fine grained sandstone and mudrock, both cemented by phosphate.

Remainder of unit consists of **mudrock** and interbedded **sandstone**; flat lamination common. **Mudrock**: medium dark grey, variably slaty, in part sandy; contains morphological glauconite replaced by chlorite, minor muscovite. **Sandstone**: medium grey and brown, very fine grained, argillaceous; glauconite pseudomorphs common; some rip-up clasts of mudrock.

Conformable contact.

RAWLINGS BAY FORMATION (ELLESMERE GROUP) (Section EB4-2)

Member A

Unit 1, 0-2.5 m (2.5 m)
Rubble, probably in place, of **sandstone** as in unit 2.

Unit 2, 2.5-6.0 m (3.5 m)
Sandstone: medium grey, quartzose, very fine to fine grained, poorly bedded; parting thickness 15-20 cm; ledge-forming.

Unit 3, 6.0-25.5 m (19.5 m)
Covered with talus from unit 2.

Unit 4, 25.5-39.0 m (13.5 m)
Covered with talus of **mudrock**: medium dark grey, in part sandy, and **sandstone**: medium dark grey, very fine to fine grained, argillaceous.

Unit 5, 39.0-92.5 m (53.5 m)
Slope covered with talus from member B.

Member B

Unit 6, 92.5-97.0 m (4.5 m)
Sandstone: medium grey, quartzose, fine grained, mostly massive; parting thickness 0.02-1.0 m; some

vague to distinct flat lamination marked by micaceous laminae.

Unit 7, 97.0-106.0 m (9.0 m)
Talus of **sandstone**.

Unit 8, 106.0-154.0 m (48.0 m)
Sandstone: medium grey, quartzose, mostly fine grained, rarely medium grained, mostly massive; parting thickness 0.2-1.0 m; some vague flat and undulating lamination, amplitude a few centimetres, half-wavelength 30-40 cm; some concave foresets, 10-20 cm thick (e.g., at 132.5 m); *Planolites* at 134.5 m.

Unit 9, 154.0-159.5 m (5.5 m)
Covered, recessive (gulch); some talus of **sandstone**: quartzose, fine grained.

Unit 10, 159.5-164.5 m (5.0 m)
Rubble and talus of **sandstone** as in units 6 and 8, probably nearly in place.

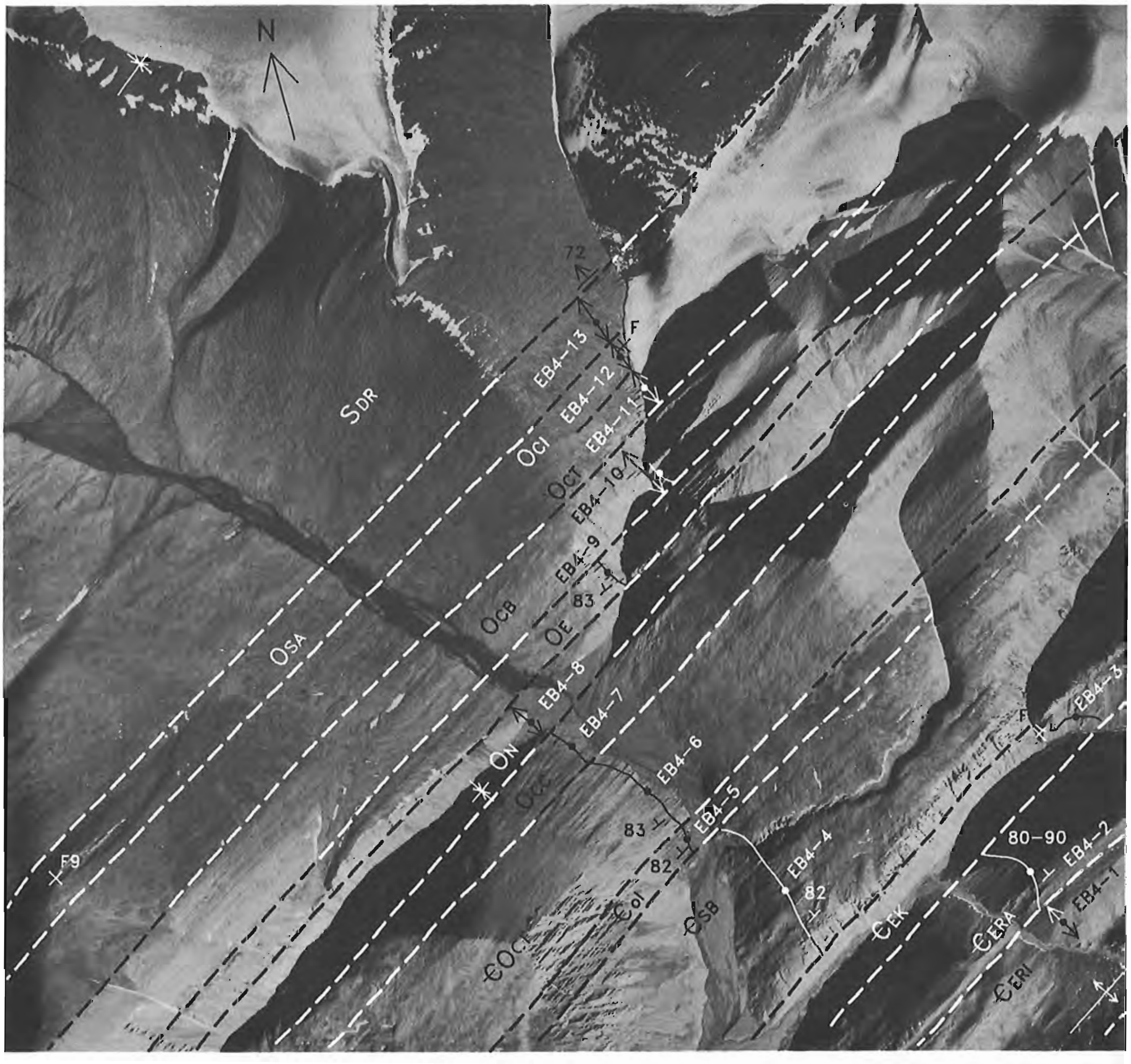

Figure 137. Vicinity of Ella Bay 4 (EB4) section. Part of aerial photograph NAPL A-16610-128. (Adapted from Kerr, 1967, Plate V.) Section EB4-8 is the type section of the Ninnis Glacier Formation. For legend see Figure 1.

Unit 11, 164.5-255.5 m (91.0 m)
Sandstone: medium grey, quartzose, fine grained (as in units 6 and 8); top of unit forms dip slope.

Member C

Unit 12, 255.5-548.0 m (292.5 m)
Mainly interbedded **sandstone** and **mudrock** (divisible into two lithofacies) with very minor amounts of **intraformational conglomerate**.

Lithofacies 1: **sandstone**: medium grey, quartzose, mainly fine grained; units 0.02-2.0 m, commonly 0.1-0.5 m thick; relatively thick units (1.8-2.0 m) less common but marked by ledges with dip slopes at the top; vague to distinct flat lamination abundant, ripple marks rare.

Lithofacies 2: **mudrock**: medium dark grey, slaty, in part sandy; rare polygonal desiccation cracks; and **sandstone**: medium dark grey, very fine grained, argillaceous; exposed units of lithofacies 2 commonly 0.03-0.5 m thick, thicker units mostly covered; flat lamination and some undulating lamination.

Intraformational conglomerate: rip-up clasts of mudrock, up to 5 cm long, in sandy matrix at 490.6 m.

Trace fossils occur throughout the unit and are most common in the upper 100 m; *Planolites* abundant, *Didymaulichnus*, *Palaeophycus(?)*, *Rusophycus*, *Cruziana*, *Halopea*(?), and cf. *Diplocraterion* relatively rare (C-75490 to C-75493; Hofmann, Appendix 3A).

Detailed interval 1, base at 267.5 m

0-2.55 m (2.55 m)
Sandstone: medium grey, quartzose, fine grained; flat lamination and some undulating lamination.

2.55-2.75 m (0.2 m)
Mudrock: medium dark grey.

2.75-2.95 m (0.2 m)
Sandstone: as before.

2.95-3.0 m (0.05 m)
Sandstone: very fine grained, argillaceous; flat lamination with some bioturbation in lowermost part.

3.0-3.3 m (0.3 m)
Mudrock: as before.

3.3-5.2 m (1.9 m)
Sandstone: medium grey, quartzose, fine grained; some flat lamination; resistant ledge.

5.2-5.7 m (0.5 m)
Covered, probably **mudrock** as before.

5.7-6.0 m (0.3 m)
Sandstone: medium grey, very fine grained, argillaceous; flat lamination.

6.0-6.4 m (0.4 m)
Mudrock: as before.

6.4-6.9 m (0.5 m)
Sandstone: as before; some flat lamination; resistant ledge.

6.9-7.2 m (0.3 m)
Mudrock: slaty, partly sandy, and **sandstone**: argillaceous as before.

7.2-7.6 m (0.4 m)
Sandstone: as before; flat lamination.

7.6-7.9 m (0.3 m)
Thinly interbedded **mudrock**: slaty, partly sandy, and **sandstone**; units 1-5 cm thick.

7.9-8.3 m (0.4 m)
Sandstone: as before; flat lamination; resistant unit with dip slope at top.

Detailed interval 2, base at 349.0 m

0-1.2 m (1.2 m)
Sandstone: medium grey, quartzose, fine grained; flat lamination; resistant ledge.

1.2-1.3 m (0.1 m)
Mudrock: medium dark grey, slaty.

1.3-1.43 m (0.13 m)
Sandstone: as before.

1.43-1.435 m (0.005 m)
Mudrock: slaty.

1.435-1.455 m (0.02 m)
Sandstone: as before.

1.455-1.485 m (0.03 m)
Mudrock: slaty.

1.485-1.965 m (0.48 m)
Sandstone: as before.

1.965-2.115 m (0.15 m)
Sandstone: very fine grained, argillaceous; flat lamination.

2.115-2.165 m (0.05 m)
Sandstone: very fine and fine grained, with interlaminated **mudrock**; flat lamination.

2.165-2.315 m (0.15 m)
Sandstone: argillaceous and **mudrock**: sandy, fining upward to mudrock.

2.315-2.455 m (0.14 m)
Sandstone: as before; flat lamination.

2.455-2.635 m (0.18 m)
Mudrock: slaty.

2.635-2.945 m (0.31 m)
Sandstone: as before.

Abrupt contact, conformable or submarine disconformity.

KANE BASIN FORMATION (ELLESMERE GROUP) (Section EB4-3)

Member A

Unit 1, 0-174.0 m (174.0 m)
Mudrock: medium grey and medium dark grey, variably slaty, fine to coarse grained, sandy near base; some glauconite pseudomorphs (chlorite, minor muscovite); carbonate alteration rare; recessive, mostly represented by rubble.

Near base 0.5 m of **sandstone**: medium grained, poorly sorted, with rip-up clasts of similar but phosphate-cemented sandstone, up to 7 mm long.

Unit 2, 174.0-195.0 m (21.0 m)
Mainly **mudrock**: medium grey and medium dark grey, coarse grained, quartzose, feldspathic, sandy (only a few percent phyllosilicates); beds 2-50 cm thick; some flat lamination and small-scale crosslamination; large trace fossils common [mainly *Planolites*, minor *Rusophycus*(?)]; ledge-forming; minor **mudrock**, variably slaty (10 units, 0.2-20 cm thick).

Unit 3, 195.0-208.5 m (13.5 m)
Mudrock: slaty, recessive.

Member B

Unit 4, 208.5-225.0 m (16.5 m)
Mudrock: medium grey, calcareous; trilobite fragments common; interbedded with mudrock, medium grey to medium dark grey, less calcareous.

Fossil collection C-75409, trilobites, late Early Cambrian (Fritz, Appendix 3A).

208.5-210.5 m (2.0 m)
Calcareous **mudrock** (estim. 10%) occurs as a few lenticular beds, about 3 cm thick.

210.5-222.5 m (12.0 m)
Calcareous **mudrock** (estim. 70%) occurs in beds or elongate lenses 10-20 cm thick.

222.5-225.0 m (2.5 m)
As preceding interval but boudins less common.

Unit 5, 225.0-261.5 m (36.5 m)
Mudrock: medium dark grey, fine and coarse grained, commonly calcareous, in part slightly dolomitic; some *Planolites*, trilobite fragments rare; beds in lower part 2-20 cm thick, calcareous; beds thinner in middle and upper parts where calcareous mudrock alternates with slightly calcareous mudrock.

Unit 6, 261.5-270.5 m (9.0 m)
Mudrock interbedded with **sandstone**.

Mudrock: medium grey and medium dark grey, coarse grained, containing very fine grained sand, calcareous and slightly dolomitic.

Sandstone: very fine grained, argillaceous, calcareous and slightly dolomitic; units 1-15 cm thick; flat lamination and small-scale crosslamination; *Planolites* common.

Disconformable contact.

SCORESBY BAY FORMATION (Section EB4-4)

Member A

Unit 1, 0-27.5 m (27.5 m)
Dolomitic breccia: medium grey, chaotic; fragments of dolostone of various sizes (observed maximum length 17 cm) and shapes, composed of dolomite, very fine to medium crystalline, cloudy, in matrix of coarser (up to coarse crystalline) and clearer dolomite.

0-6.5 m (6.5 m)
Rubble.

6.5-27.5 m (21.0 m)
Outcrop.

Unit 2, 27.5-38.5 m (11.0 m)
Dolomitic breccia: medium grey, less chaotic than below; some fragments parallel to bedding; bedding disrupted but traceable.

Unit 3, 38.5-52.0 m (13.5 m)
Dolostone: medium grey; some strata continuous, others disrupted and displaced; flat and undulating lamination; laminae differ in darkness and crystal size; numerous veinlets parallel to bedding.

Unit 4, 52.0-53.2 m (1.2 m)
Dolomitic breccia: chaotic.

Unit 5, 53.2-63.5 m (10.3 m)
Dolomitic breccia: fragments parallel to bedding.

Unit 6, 63.5-100.0 m (36.5 m)
Dolostone: medium grey; flat lamination and some crinkled, stromatolitic(?) lamination; numerous veinlets, some parallel to bedding; minor **dolomitic breccia**: fragments generally parallel to bedding.

Unit 7, 100.0-102.25 m (2.25 m)
Dolomitic breccia: fragments parallel to bedding.

Unit 8, 102.25-145.0 m (42.75 m)
Dolostone: medium grey, very fine to very coarse crystalline; flat lamination; veinlets common, mainly parallel to bedding; some small-scale crosslamination; minor **dolomitic breccia**.

Member B

Unit 9, 145.0-180.0 m (35.0 m)
Dolostone: medium grey, mostly laminated; brecciation rare.

Unit 10, 180.0-303.0 m (123.0 m)
Dolostone: mainly coarse microcrystalline to fine crystalline but up to coarse crystalline, laminated or massive; some relict fenestrae(?), coated grains(?), and burrows(?); relict *Palaeophycus tubularis* in lower few metres; some brecciation (fragments a few centimetres long or smaller); parting thickness 1.5-2 m.

180.0-267.0 m (87.0 m)
Mainly medium dark grey.

267.0-303.0 m (36.0 m)
Medium and medium light grey.

Unit 11, 303.0-334.5 m (31.5 m)
Covered, recessive.

Unit 12, 334.5-384.0 m (49.5 m)
Dolostone: medium dark grey, mainly microcrystalline to medium crystalline; relict fenestrae(?), very fine to very coarse crystalline, mainly massive with some flat and undulating lamination.

Unit 13, 384.0-429.0 m (45.0 m)
Dolostone: medium dark grey, microcrystalline to very fine crystalline, partly brecciated (fragments up to 4 cm long); numerous crisscrossing "veinlets" with clear and coarser (very fine to very coarse crystalline) dolomite; some relict fenestrae(?); minor intraformational breccia of lime mudstone: cryptocrystalline to very fine crystalline, with scattered dolomite euhedra up to coarse crystalline, in matrix of dolostone: mainly microcrystalline to fine crystalline (at 393 m).

Unit 14, 429.0-441.0 m (12.0 m)
Dolostone: medium dark grey, mainly microcrystalline to fine crystalline; relict bird's-eye textures(?); veinlets common; very vague flat lamination up to 436.5 m, upper part brecciated.

Unit 15, 441.0-455.0 m (14.0 m)
Lime mudstone: medium dark grey, cryptocrystalline to very fine microcrystalline; scattered dolomite euhedra, microcrystalline to fine crystalline; rare trilobite fragments (e.g., at 341 m); brecciated and partly bioturbated; burrows invaded by dolomite, microcrystalline to fine crystalline; also veined by dolomite.

Unit 16, 455.0-466.5 m (11.5 m)
Rubble, nearly in place, of rocks as in unit 15.

Unit 17, 466.5-478.5 m (12.0 m)
Covered.

Unit 18, 478.5-536.9 m (58.4 m)
Dolostone: partly brecciated (at 528-529 m), showing some relict bioturbation(?).

Unit 19, 536.9-541.7 m (4.8 m)
Dolostone: composed of columnar stromatolites, commonly 30 cm high, that probably are laterally linked (structural detail obscured by dolomitization).

Unit 20, 541.7-546.0 m (4.3 m)
Dolostone: relict fenestral texture(?) and bioturbation(?).

Unit 21, 546.0-559.5 m (13.5 m)
Covered.

Unit 22, 559.5-568.0 m (8.5 m)
Dolostone: cliff forming, vaguely laminated; relict bioturbation(?) and intraformational(?) brecciation.

Unit 23, 568.0-590.5 m (22.5 m)
Lime mudstone: medium dark grey, replaced to varying extent by dolomite, microcrystalline, medium dark grey and medium grey, mainly thin bedded to laminated; relict bioturbation(?) at 588-589 m.

Unit 24, 590.5-603.0 m (12.5 m)
Dolostone: medium grey, orange weathering marker, mainly fine to medium crystalline; relict intraformational(?) brecciation at base; some vague, undulating lamination.

Member C

Unit 25, 603.0-738.0 m (135.0 m)
Limestone: medium dark grey; composed mainly of peloids of silt to fine sand grade, with some larger peloids, coated grains, and rare trilobite fragments; veinlets and blobs of sparry calcite; dolomite occurs as scattered euhedra, microcrystalline to fine crystalline, and concentrated in burrows; oval to spheroidal blobs of dolomite, 1.0-1.7 cm in diameter, at 736-738 m; some vague flat lamination and brecciation.

Unit 26, 738.0-746.5 m (8.5 m)
Rubble and outcrop of **lime mudstone**: medium grey, dolomitic (dolomite is microcrystalline to coarse crystalline) with ovoid blobs of sparry calcite, up to 4 mm long; intensely sheared and crisscrossed by veinlets [*Palaeophycus tubularis*(?)].

Unit 27, 746.5-784.0 m (37.5 m)
Lime mudstone: medium dark grey, recrystallized (up to coarse microcrystalline), in part peloidal as in unit 25; rare trilobite fragments and indeterminable skeletal material; in part brecciated; partly to wholly replaced by dolomite, forming **dolostone**: light grey to medium grey, yellow brown and orange weathering, microcrystalline to medium crystalline.

Unit 28, 784.0-850.0 m (66.0 m)
Mainly **dolostone**: mainly medium light grey, pink and vuggy weathering at 792-794 m, microcrystalline to medium crystalline, mainly very fine and fine crystalline.

Unit 29, 850.0-952.0 m (102.0 m)
Interbedded **dolostone** and **limestone**.

Dolostone: medium grey to predominantly medium dark grey, microcrystalline to medium crystalline, mainly very fine and fine crystalline; some relict fenestrae(?).

Limestone: lime mudstone, recrystallized (up to coarse microcrystalline) and peloidal limestone as in unit 25; fenestrae and burrows common; partly replaced by dolomite, microcrystalline to coarse crystalline; aggregates of dolomite are ovoid [due to tectonic(?) abrasion].

Conformable contact.

OOLITIC LIMESTONE UNIT (Section EB4-5)

Unit 1, 0-92.0 m (92.0 m)
Mainly **limestone**, minor **dolostone**; generally massive, in places sheared; parting thickness 30-50 cm at 67-70 m.

Limestone: medium dark grey; mainly **grainstone**, minor **peloidal packstone/wackestone** of silt to fine sand grade and **lime mudstone**, all replaced to varying extent by dolomite, microcrystalline to coarse crystalline, occurring as scattered crystals, stringers, tubes, and blobs.

Grainstone: composed of peloids (intraclasts?), ooids (partly to entirely micritized), and rare skeletal matter (trilobites and unidentifiable material).

Dolostone: microcrystalline to coarse crystalline.

Unit 2, 92.0-108.0 m (16.0 m)
Covered interval, recessive.

Unit 3, 108.0-129.0 m (21.0 m)
Limestone: dolomitic, as in unit 1; some rocks slightly silty; parting thickness 10-30 cm.

Unit 4, 129.0-130.5 m (1.5 m)
Siltstone: medium dark grey, dark yellow-orange weathering, coarse grained, quartzose, micaceous, highly dolomitic; flat and undulating lamination; some bioturbation and vague *Planolites* (5-6 mm long in spec.).

Unit 5, 130.5-272.5 m (142.0 m)
Limestone: medium dark grey, massive, mainly peloidal, and **oolitic grainstone**; both replaced to varying extent by dolomite, fine crystalline to predominantly microcrystalline.

Abrupt, probably disconformable contact.

CASS FJORD FORMATION (Section EB4-6)

Member A

Unit 1, 0-5.5 m (5.5 m)
Massive carbonate facies (MC)

Limestone: light grey, weathering in hues of yellow, orange, and grey; peloidal, silty and very fine grained sandy; replaced to varying extent by dolomite, microcrystalline; some thin flat lamination.

Unit 2, 5.5-102.0 m (96.5 m)
Laminated carbonate-siliciclastic facies (LCS):

Thinly interstratified **carbonate rocks** (C), **siltstone** (S), quartzose **sandstone** (Q), and minor **intraformational conglomerate** (I). Fresh colour mainly light grey or medium light grey; weathering colours mainly pale yellowish orange or greyish orange, less commonly orange pink.

Stratification: mainly flat lamination, also undulating lamination, small-scale crosslamination (sets about 5-10 cm thick).

Dolostone: mostly microcrystalline, less commonly very fine crystalline, generally silty, variably calcareous.

Limestone: peloidal packstone or **grainstone**, variably dolomitic, variably silty.

Siltstone: mostly coarse grained with very fine grained sand, dolomitic, in part calcareous.

Sandstone: very fine grained, silty.

Unit 3, 102.0-105.5 m (3.5 m)
Massive carbonate facies (MC)

Lime mudstone: light grey, medium light grey weathering, rich in dolomite, microcrystalline to very fine crystalline; contains some peloids and silt and very fine grained sand; ledge-forming unit.

Unit 4, 105.5-173.0 m (67.5 m)
Laminated carbonate-siliciclastic facies (LCS)
Redbeds at 121.3 m.

Unit 5, 173.0-181.5 m (8.5 m)
Massive carbonate facies (MC)

Medium to medium dark grey; **lime mudstone** and **lime wackestone** with trilobite fragments; some strata are rich in dolomite, silt, and very fine grained sand; ledge-forming unit.

Unit 6, 181.5-536.5 m (355.0 m)
Laminated carbonate-siliciclastic facies (LCS)

Red marker units:

238.5-239.0 m (0.5m)
Dolostone and minor **siltstone**, dolomitic: moderate red to light brownish grey.

292.3-292.5 m (0.2 m)
Siltstone: red

298.5-321.5 m (23.0 m)
At base 70 cm of **sandstone**: moderate red, with interlaminated subordinate dolostone and **intraformational conglomerate**, forming extensive marker; above this, red units, 5-30 cm thick, make up an estimated 10-20% of the interval.

346-375 m (11 m)
Red and pink sets of strata, 20 cm to 2 m thick, constitute about 60% of the interval.

480.5-480.8 m (0.3 m)
Sandstone: very fine grained, silty with interlaminated **siltstone**: mainly dusky red, minor greenish grey.

Prominent carbonate units:

321.5-322.2 m (0.7 m)
Limestone: very light grey, fine microcrystalline, silty and very fine grained sandy; solution zones.

352.2-353.7 m (1.5 m)
Limestone: as before.

470.9-471.4 m (0.5 m)
Limestone: medium grey, highly dolomitic.

493.0-497.8 m (4.8 m)
About 90% **limestone**, 10% **dolostone**.

498.7-501.6 m (2.9 m)
Limestone: medium light grey, microcrystalline, silty and very fine grained sandy, probably recrystallized **peloidal packstone/wackestone**.

Detailed partial section of uppermost part:

517.5-524.95 m (7.45 m)
Dolostone: microcrystalline, coarse grained silty to very fine grained sandy, calcareous (micritic), minor **siltstone**: coarse grained, sandy, dolomitic, calcareous; flat lamination, small-scale

crosslamination, some undulating lamination and solution zones; bioturbation rare.

524.95-525.15 m (0.2 m)
Limestone, peloidal packstone/wackestone and **lime mudstone**: medium light grey, medium light grey and orange weathering; scattered microcrystalline dolomite; small amounts of silt; massive, mottled, probably bioturbated.

525.15-525.5 m (0.35 m)
Lime mudstone: medium light grey, dolomitic, silty, and **dolostone**: microcrystalline; flat and undulating lamination.

525.5-525.7 m (0.2 m)
Limestone: mottled, dolomitic, as in unit 2.

525.7-525.85 (0.15 m)
Dolostone: medium grey to medium light grey, orange-grey weathering, microcrystalline, silty and very fine grained sandy, with minor lenses of **siltstone**: coarse grained and very fine grained sandy; flat and undulating lamination.

525.85-527.45 m (1.6 m)
Lime mudstone: medium to medium light grey, light grey weathering; floating quartz sand, mainly fine (but up to medium) grained; scattered dolomite, microcrystalline; some relict undulating lamination, probably bioturbated.

527.45-530.55 m (3.1 m)
Dolostone: medium grey, greyish orange weathering; as before, with some interlaminated **sandstone**: very fine grained, highly calcareous and dolomitic, and **lime mudstone**: dolomitic, silty and sandy; some floating outsized quartz, medium and coarse grained, rounded; mainly flat lamination, some undulating and small-scale crosslamination.

530.55-531.7 m (1.15 m)
Interlaminated **lime mudstone, lime wackestone**, and **dolostone**: medium grey, medium grey and orange-grey weathering; solution zones.

Lime mudstone: dolomitic, silty, very fine grained sandy.

Lime wackestone: peloids and rare skeletal fragments; silty, very fine grained sandy, dolomitic.

Dolostone: microcrystalline, calcareous, silty, very fine grained sandy.

531.7-532.4 m (0.7 m)
Interlaminated **lime mudstone** and minor **sandstone**: medium grey, orange-grey and yellowish brown weathering; lamination mainly flat, some lenticular and crosslamination, microscopic scale; **lime mudstone**: in part highly sandy and dolomitic; **sandstone**: very fine grained, well sorted, dolomitic and calcareous.

532.4-532.5 m (0.1 m)
Dolostone: medium grey, orange-grey weathering; flat and undulating lamination; microcrystalline, calcareous, silty and very fine grained sandy; minor **lime mudstone**: dolomitic, silty and very fine grained sandy.

532.5-533.2 m (0.7 m)
Limestone: medium grey, medium light grey weathering, silty to medium grained sandy, slightly dolomitic, massive, bioturbated; specimen examined in thin section is **grainstone**: composed of intraclasts with some green algae(?) and echinoderm columnals(?).

533.2-535.3 m (2.1 m)
Interlaminated **dolostone, sandstone, lime mudstone**: medium grey, orange-grey weathering; flat lamination and small-scale crosslamination; **dolostone**: microcrystalline, highly calcareous; **sandstone**: very fine grained, well sorted, highly dolomitic and calcareous; **lime mudstone**: dolomitic.

535.3-536.5 m (1.2 m)
Mainly **dolostone**: medium grey, orange-grey and pink weathering, microcrystalline, silty to very fine grained sandy, calcareous; minor **lime mudstone**: dolomitic; flat lamination, some burrows and relict intraclasts(?).

Member B

Unit 7, 536.5-548.2 m (11.7 m)
Massive carbonate facies (MC)

Lime mudstone with sparse trilobite fragments and **peloidal packstone/wackestone**: both medium to medium dark grey, medium grey weathering, massive, bioturbated; dolomitic burrow mottling; undulating parting surfaces, spaced 5-10 cm, in upper 1 m; some irregular, wavy stringers of **dolostone**; resistant marker unit.

Unit 8, 548.2-576.5 m (28.3 m)
Undifferentiated carbonate rocks (UC)

Predominantly **limestone**, minor **dolostone**: massive and laminated.

Detailed section of lower half:.

548.2-549.5 m (1.3 m)
Lime mudstone and **peloidal packstone/ wackestone**: medium grey, medium grey and orange-grey weathering, silty to very fine grained sandy, dolomitic; flat lamination; with interlaminated **dolostone**: microcrystalline, calcareous, silty to very fine grained sandy.

549.5-551.5 m (2.0 m)
Lime mudstone: medium grey, in part peloidal, with sparse skeletal fragments [trilobites, echinoderms(?)], slightly dolomitic and silty to very fine grained sandy, massive with undulating stringers of **dolostone** in upper 1.4 m.

551.5-553.8 m (2.3 m)
Lime mudstone: medium grey, medium light grey weathering, variably silty and dolomitic (dolomite is microcrystalline); undulating lamination parallel to solution zones.

553.8-554.5 m (0.7 m)
Dolostone: medium grey, orange and pink weathering, microcrystalline, slightly silty to very fine grained sandy; flat and undulating lamination, some crosslamination.

Unit 9, 576.5-594.5 m (18.0 m)
Laminated carbonate-siliciclastic facies (LCS)

Mainly **dolostone**, minor **lime mudstone** and **siltstone**: medium light grey, orange-grey weathering; flat and undulating lamination with rare crosslamination.

Dolostone: microcrystalline, silty, calcareous; **lime mudstone**: silty; **siltstone**: sandy, calcareous and dolomitic.

Unit 10, 594.5-605.0 m (10.5 m)
Undifferentiated carbonate rocks (UC)

Limestone, **dolostone**, and calcareous and dolomitic **flat-pebble conglomerate**: about 60% of strata are greyish red-purple.

Unit 11, 605.0-699.5 m (94.5 m)
Undifferentiated carbonate rocks (UC)

Mainly **lime mudstone**: medium light grey to medium dark grey, commonly orange-grey weathering, variably silty, very fine grained sandy, and dolomitic (dolomite is microcrystalline), and related **intraformational conglomerate**; less **dolostone**: microcrystalline, variably silty, calcareous.

Unit 12, 699.5-709.3 m (9.8 m)
Laminated carbonate-siliciclastic facies (LCS)

699.5-707.3 m (7.8 m)
Interlaminated **limestone** and minor **dolostone** and **siltstone**: medium light grey; **limestone**: **peloidal packstone/wackestone** and **lime mudstone**, both dolomitic and silty.

707.3-707.7 m (0.4 m)
Peloidal packstone: medium grey, silty to medium grained sandy, slightly dolomitic, intensely bioturbated.

707.7-708.2 m (0.5 m)
Lime mudstone: medium grey, highly silty, moderately dolomitic; flat and undulating lamination; some burrows; weak slaty cleavage.

708.2-708.6 m (0.4 m)
Sandstone: light grey, mainly quartzose but including clasts of lime mudstone, dolomitic; bimodal, predominantly very fine grained and very well sorted with small amounts of medium to coarse grained sand; quartz is well rounded; massive.

708.6-709.0 m (0.4 m)
Siltstone: medium grey to medium dark grey, coarse grained, very fine grained sandy, quartzose, but including clasts of lime mudstone, dolomitic; flat and undulating lamination with some bioturbation and discrete burrows; solution zones.

709.0-709.3 m (0.3 m)
Siltstone, sandstone and **limestone**: medium grey, strongly bioturbated, massive; **siltstone**: coarse grained; **sandstone**: quartzose and calcareous, bimodal, mainly very fine grained with smaller population of medium and coarse grained grains; **limestone**: lime mudstone, dolomitic, silty and very fine grained sandy.

Unit 13, 709.3-710.9 m (1.6 m)
Sandstone facies (SS)

Sandstone: medium grey, quartzose and calcareous with peloids, slightly dolomitic, fine grained; quartz is rounded; flat and undulating lamination; sorting very good and good.

Unit 14, 710.9-717.2 m (6.3 m)
Undifferentiated carbonate rocks (UC)

710.9-714.8 m (3.9 m)
Limestone interlaminated with **dolostone**: both medium light grey and medium grey; **limestone**: **lime mudstone**, silty and very fine grained sandy, dolomitic; **dolostone**: microcrystalline and very fine crystalline, calcareous, silty and very fine grained sandy.

714.8-716.7 m (1.9 m)
Lime mudstone: medium grey to medium dark grey, fine grained silty, slightly dolomitic, massive; solution zones.

716.7-717.2 m (0.5 m)
Lime mudstone: medium light grey, highly dolomitic, with highly sandy and dolomitic stringers; quartz ranges from coarse grained silt to medium grained sand, well rounded; coated grains partly replaced by quartz; flat and undulating lamination, minor crosslamination.

Unit 15, 717.2-727.0 m (9.8 m)
Predominantly **sandstone**, minor **limestone**, **intraformational conglomerate** (several lithofacies).

717.2-717.6 m (0.4 m)
Intraformational conglomerate facies (I)
Intraformational conglomerate: medium light grey; composed of sandstone, fine grained, well sorted, quartzose, with common clasts of lime mudstone and peloids; clasts up to 6 cm long, 0.5 cm thick; partly parallel to bedding, partly inclined.

717.6-719.1 m (1.5 m)
Sandstone facies (SS)
Sandstone: medium light grey, fine grained, well sorted, quartzose; intraclastic(?) peloids; flat lamination and herringbone crosslamination (photo. 2256-59); some **intraformational conglomerate**.

719.1-721.3 m (2.2 m)
Sandstone: light grey, very fine to fine grained, slightly calcareous; flat lamination and small-scale crosslamination.

721.3-723.8 m (2.5 m)
Undifferentiated carbonate rocks (UC)
Peloidal packstone/wackestone: medium grey to medium dark grey, slightly silty, massive to vaguely laminated.

723.8-724.5 m (0.7 m)
Sandstone facies (SS)
Sandstone: medium light grey, very fine to fine grained, very well sorted, quartzose, calcareous; flat lamination and some small-scale cross-lamination; minor interlaminated **limestone**: peloidal, highly sandy.

724.5-725.2 m (0.7 m)
Sandstone: very light grey, very fine to fine grained, very well sorted; quartzose with very small proportion of calcareous clasts; quartz rounded.

725.2-727.0 m (1.8 m)
Sandstone: calcareous, as at 723.8-724.5 m; flat lamination and herringbone crosslamination.

Conformable contact.

CAPE CLAY FORMATION (Section EB4-7)

Unit 1, 0-129.4 m (129.4 m)
Mainly **limestone** with very minor amounts of **dolostone**.

Limestone: medium light to medium dark grey, mainly medium grey; mainly **peloidal packstone/wackestone**: (in part recrystallized to "grainstone") with rare skeletal fragments [mainly trilobites, minor echinoderms, gastropods(?), algae(?)], less **lime mudstone**: variably silty and dolomitic, dolomite commonly occurring in burrows; mostly massive, bioturbated; unit forms resistant ledge at 8.5-28.0 m; indistinct flat lamination at 28-29.5 m and 117.9-118.5, and 123.0-129.4 m (vague in lower part, distinct in upper part); these intervals contain laminae of **dolostone**.

Conodont collection C-75430 from 0-1 m, Early Ordovician, Tremadoc (Nowlan, Appendix 3B); C-75431 from 19-21 m, Late Cambrian to Early Ordovician (undifferentiated) (Nowlan, Appendix 3B); C-75432 from 88-91 m, Fauna C, Early Ordovician, early to middle Tremadoc (Nowlan, Appendix 3B).

Unit 2, 129.4-136.9 m (7.5 m)
Sandstone and **dolostone**, laminated.

129.4-131.6 m (2.2 m)
Sandstone: medium grey, very fine grained, silty, highly calcareous, dolomitic; flat and undulating lamination.

131.6-132.5 m (0.9 m)
Covered.

132.5-135.5 m (3.0 m)
Sandstone: light grey, very fine grained, silty, dolomitic; interlaminated with **dolostone**: fine crystalline, silty and very fine grained sandy, slightly calcareous.

135.5-136.9 m (1.4 m)
Dolostone: medium grey, microcrystalline to fine crystalline, calcareous; flat and undulating lamination.

Unit 3, 136.9-220.1 m (83.2 m)
Outcrop and rubble of **limestone** as in unit 1: **lime mudstone** and **peloidal packstone/wackestone** with rare skeletal fragments; variably dolomitic and silty, mostly massive, bioturbated with flat lamination at 164.9-166.1 m.

Conformable contact.

NINNIS GLACIER FORMATION (type section) (Section EB4-8)

Unit 1, 0-59.2 m (59.2 m)
Interbedded **limestone** and **dolostone** with very minor amounts of **sandstone** and **siltstone**: very light grey to medium dark grey, predominantly medium light grey. Roughly equal proportions of **limestone** and **dolostone** in lower part, but **dolostone** becomes predominant from 36.4 m upward. Laminated units, 0.5-8.0 m thick, alternate with bioturbated, massive units, 0.2-4.0 m thick. Flat lamination prédominant, undulating lamination common, crosslamination rare. Some undulating lamination is due to stylolites or solution zones parallel to bedding.

Limestone: mainly **lime mudstone** and **peloidal packstone/wackestone**, variably dolomitic and silty to very fine grained sandy with very rare trilobite fragments. Some peloidal packstones are partly recrystallized to "grainstone".

Dolostone: predominantly microcrystalline, variably calcareous, variably silty to very fine grained sandy.

Sandstone: mainly very fine grained, highly calcareous or dolomitic; some laminae are bimodal, containing medium to coarse grained, well rounded quartz; the latter also occurs in some **limestones** and **dolostones**.

Detailed section.

0-4.0 m (4.0 m)
Lime mudstone: medium light grey, partly or wholly recrystallized, slightly dolomitic, massive, more recessive than the Cape Clay Formation.

4.0-4.5 m (0.5 m)
Lime mudstone: medium grey, slightly dolomitic and silty; subparallel stylolites produce thin flat lamination.

4.5-7.0 m (2.5 m)
Dolostone: medium light grey, predominantly microcrystalline (but up to fine crystalline), slightly calcareous and silty, massive.

7.0-8.4 m (1.4 m)
Lime mudstone: light grey, dolomitic, and **dolostone**: predominantly microcrystalline; some vague lamination.

8.4-10.2 m (1.8 m)
Dolostone: light grey, predominantly microcrystalline, calcareous, and **lime mudstone**: light grey, dolomitic, both slightly silty; flat and undulating lamination.

10.2-11.7 m (1.5 m)
Dolostone: light grey, predominantly microcrystalline, variably calcareous, silty; flat lamination; laminae differ mainly in crystal size and possibly also in dolomite/calcite ratio.

11.7-15.3 m (3.6 m)
Interlaminated **lime mudstone**: medium light grey, dolomitic, with indistinct peloids, and **dolostone**: microcrystalline to very fine crystalline, calcareous; both silty; flat lamination; laminae differ mainly in dolomite/calcite ratio and less in silt content.

15.3 m-16.0 m (0.7 m)
Lime mudstone: light grey, dolomitic, slightly silty to very fine grained sandy; some peloids; massive.

16.0-16.6 (0.6 m)
Lime mudstone: light grey, dolomitic, and **dolostone**: predominantly microcrystalline, highly calcareous with a few stringers of **sandstone**: very fine to fine grained, highly calcareous and dolomitic; flat and undulating lamination; stylolites and solution zones parallel to lamination.

16.6-16.8 m (0.2 m)
Lime mudstone: medium light grey to medium grey, silty to very fine grained sandy, bioturbated, massive.

16.8-18.8 m (2.0 m)
Dolostone: medium light grey, microcrystalline to fine crystalline; flat lamination; laminae differ mainly in darkness (submicroscopic carbonaceous impurities); bedding-parallel stylolites.

18.8-19.6 m (0.8 m)
Dolostone: light grey, predominantly microcrystalline, silty, slightly calcareous, mostly massive with some flat lamination in lower part.

19.6-20.8 m (1.2 m)
Peloidal packstone/wackestone: medium light grey, silty, with interlaminated **siltstone**: very fine grained sandy, highly dolomitic, calcareous; flat lamination and some crosslamination.

20.8-23.8 m (3.0 m)
Dolostone: medium to medium dark grey, predominantly microcrystalline, calcareous, and **lime mudstone**: dolomitic; both slightly silty to very fine grained sandy; flat and undulating lamination; laminae differ in darkness and dolomite/calcite ratio.

23.8-24.5 m (0.7 m)
Peloidal packstone/wackestone: medium to medium dark grey, dolomitic, slightly silty, massive; solution zones.

24.5-25.5 m (1.0 m)
Lime mudstone: highly dolomitic, and **dolostone**: predominantly microcrystalline, calcareous; both medium grey, bioturbated, massive.

25.5-26.3 m (0.8 m)
Lime mudstone and **peloidal packstone/wackestone**: variably dolomitic and **dolostone**: predominantly microcrystalline, variably calcareous; both medium light grey to medium grey, silty to very fine grained sandy; flat and undulating lamination; solution zones parallel to lamination.

26.3-26.6 m (0.3 m)
Dolostone: predominantly microcrystalline, calcareous, and **lime mudstone**: dolomitic; both medium to medium light grey, slightly silty to very fine grained sandy, bioturbated, massive.

26.6-28.1 m (1.5 m)
Dolostone: microcrystalline, variably calcareous, interlaminated with **limestone** (including **lime mudstone**): variably dolomitic; both medium light grey, silty, very fine grained sandy; flat lamination.

28.1-28.5 m (0.4 m)
Dolostone: medium grey, predominantly microcrystalline, calcareous, silty to very fine grained sandy, massive.

28.5-29.7 m (1.2 m)
Peloidal packstone/wackestone and **lime mudstone**: both medium grey, dolomitic, silty; flat and undulating lamination.

29.7-29.85 m (0.15 m)
Peloidal packstone: medium to medium dark grey; composed of sand- to granule-grade intraclasts of lime mudstone with two populations of quartz: 1) silt and very fine sand, 2) medium to coarse grained sand, rounded; stylolites common; massive.

29.85-31.75 m (1.9 m)
Peloidal packstone/wackestone: medium grey, silty to very fine grained sandy, dolomitic, mostly massive with some indistinct undulating lamination.

31.75-33.65 m (1.9 m)
Dolostone: medium light grey, predominantly microcrystalline, highly calcareous, slightly silty to very fine grained sandy; very thin flat lamination in lower part; indistinct undulating lamination in upper part; laminae differ in dolomite crystal size, dolomite:calcite ratio, and darkness (submicroscopic impurities); undulating solution zones parallel to lamination.

33.65-34.85 m (1.2 m)
Lime mudstone and **intraclastic packstone**: medium light grey, sand- to granule-grade, slightly silty, with a few floating grains of quartz sand, medium to coarse grained, rounded; massive.

34.85-35.75 m (0.9 m)
Lime mudstone: medium light grey, highly silty; very vague, undulating lamination or solution zones.

35.75-36.1 m (0.35 m)
Lime mudstone and **peloidal packstone/wackestone**: medium to medium dark grey, in part recrystallized, silty, slightly dolomitic, massive.

36.1-36.4 m (0.3 m)
Peloidal packstone/wackestone: medium grey, highly sandy (very fine grained) and silty, and **sandstone**: very fine grained, highly calcareous; flat lamination and crosslamination; sets of crosslaminae 0.5-1 cm thick.

36.4-37.9 m (1.5 m)
Dolostone: microcrystalline, highly calcareous, and **lime mudstone** and **peloidal packstone/wackestone**: highly dolomitic, both silty; subparallel solution zones create indistinct undulating lamination; unit is medium light grey and medium grey.

37.9-38.5 m (0.6 m)
Dolostone: light grey to medium light grey, predominantly microcrystalline; floating quartz of silt to coarse sand grade, rounded; flat lamination.

38.5-40.8 m (2.3 m)
Dolostone and **sandstone**: medium light grey; flat lamination. **Dolostone**: predominantly microcrystalline, silty and very fine grained sandy with floating quartz up to coarse grained; **sandstone**: bimodal, predominantly very fine grained, highly dolomitic with smaller population of coarse, well rounded grains.

40.8-41.2 m (0.4 m)
Dolostone, medium light grey, predominantly very fine crystalline, with floating quartz sand, fine to very coarse grained, rounded; indistinct lamination.

41.2-43.3 m (2.1 m)
Dolostone: medium light grey, predominantly microcrystalline, slightly silty, massive.

43.3-44.2 m (0.9 m)
Dolostone: medium light grey, predominantly microcrystalline, silty; flat and undulating lamination; laminae differ in crystal size.

44.2-48.8 m (4.6 m)
Predominantly **limestone**, less **dolostone**: medium light grey to medium grey; flat and minor undulating lamination; **limestone**: **peloidal packstone/wackestone** and **lime mudstone**, variably dolomitic, silty to very fine grained sandy; **dolostone**: predominantly microcrystalline, variably calcareous, silty to very fine grained sandy.

48.8-49.3 m (0.5 m)
Dolostone and **limestone**: medium light grey, variably silty; flat and undulating lamination.

49.3-51.3 m (2.0 m)
Dolostone: medium light grey, predominantly microcrystalline, slightly calcareous; some peloids; silty to very fine grained sandy; flat lamination; stylolites parallel to lamination.

51.3-51.8 m (0.5 m)
Dolostone: massive; partly covered.

51.8-56.9 m (5.1 m)
Dolostone: medium light grey, microcrystalline to very fine crystalline, silty and very fine grained sandy; with minor **siltstone** and **sandstone** in upper part; flat and undulating lamination.

56.9-58.0 m (1.1 m)
Dolostone: medium light grey, predominantly microcrystalline, silty to very fine grained sandy, calcareous; flat and undulating lamination.

58.0-59.2 m (1.2 m)
Limestone: very light to light grey, with rare skeletal fragments (trilobites) and peloids, silty, bioturbated, massive.

Unit 2, 59.2-319.0 m (259.8 m)
Recessive unit, partly represented by rubble. Predominantly laminated **dolostone** and **limestone** as before, with very small amounts of **sandstone** as before; minor massive **dolostone** and **limestone** in thin units about 10 cm to a few tens of centimetres in thickness. Flat lamination predominant, crosslamination rare. One massive unit in lower part shows network of dolomitized burrows.

Conodont collection C-75436 from 222-223 m, Early to early Middle Ordovician (undifferentiated) (Nowlan, Appendix 3B); C-75437 from 271 m, Early Ordovician, late Tremadoc (Nowlan, Appendix 3B).

Conformable contact.

ELEANOR RIVER FORMATION (Section EB4-9)

This formation is described in terms of two lithofacies.

Massive carbonate facies (MC):
Limestone and less abundant **dolostone**: medium light grey to medium dark grey; units decimetres to metres in thickness; bioturbation common; fenestrae common in some strata.

Limestone: **peloidal packstone/wackestone**, in part transitional to **grainstone**; some fenestrae; **lime mudstone**, in part argillaceous; **wackestone**, skeletal and peloidal; skeletal material from gastropods, trilobites, and ostracodes; some fenestrae. All may contain siliciclastic silt and minor sand, very fine grained, and dolomite, microcrystalline to fine crystalline.

Dolostone: medium light grey to medium dark grey; mainly microcrystalline to very fine crystalline; may contain variable amounts of lime mud, peloids, and siliciclastic silt and very fine grained sand.

Laminated carbonate facies (LC):
Dolostone, lime mudstone, peloidal packstone/wackestone, and very small amounts of **siltstone**: coarse grained, calcareous and dolomitic; all showing flat lamination or slightly undulating lamination.

Lime mudstone and **peloidal packstone/wackestone**: commonly contain varying amounts of dolomite, microcrystalline to very fine crystalline.

Dolostone: medium grey or medium dark grey; may contain lime mud and peloids; small amounts of skeletal grains [ostracodes and trilobites(?)] in some rocks; lamination caused by vertical variations in concentration of carbonaceous and siliciclastic matter, dolomite/calcite ratio, or dolomite crystal size.

Unit 1, 0-47.5 m (47.5 m)
Lithofacies MC

0-18.0 m (18.0 m)
Limestone: relatively pure; includes some **skeletal wackestone**; massive, resistant.

18.0-30.0 m (12.0 m)
Limestone: relatively pure; includes **lime mudstone, peloidal packstone/wackestone,** and **skeletal wackestone**; fenestrae at 28 m; *Maclurites*(?) at 28-29.5 m; massive, very resistant.

30.0-47.5 m (17.5 m)
Limestone, minor **dolostone**; lower part massive, upper 2.5 m bedded; parting thickness 10-30 cm; small, dome-shaped stromatolite at 39 m; slightly silty in upper part.

Conodont collection C-75438 from 0.5-1 m, probably Early Ordovician (Nowlan, Appendix 3B); C-75439 from 21-24 m, Ordovician, late Tremadoc-middle Arenig (Nowlan, Appendix 3B).

Unit 2, 47.5-165.0 m (117.5 m)
Alternating units of **lithofacies MC** and **lithofacies LC**; **limestone** more abundant than **dolostone**; lithofacies MC in part argillaceous; some fenestrae (e.g., at 111-120 m); moderately resistant to recessive.

Unit 3, 165.0-191.0 m (26.0 m)
Mainly **lithofacies MC** (**limestone**, in part argillaceous), minor **LC** (**limestone** and **dolostone**); resistant.

Conodont collection C-75442 from 166.5-168.0 m, Ordovician, middle Tremadoc to middle Arenig (Nowlan, Appendix 3B); C-75443 from 169.0-170.0 m, Ordovician, early to mid-late Arenig (Nowlan, Appendix 3B).

Conformable contact.

BAY FIORD FORMATION (Section EB4-10)

This formation is described in terms of two lithofacies.

Massive carbonate facies (MC):
Limestone: **lime mudstone, peloidal packstone/wackestone**, very small amounts of **grainstone**: all medium light grey to medium dark grey, mainly medium grey; variable amounts of dolomite, mainly microcrystalline to very fine crystalline; small amounts of quartz and feldspar; some bioturbation; some fenestrae; **wackestone** and **grainstone**: composed of skeletal fragments [ostracodes, gastropods, trilobites(?), pelecypods], peloids, coated grains, and intraclasts.

Dolostone: medium dark grey to predominantly medium light grey; microcrystalline to very fine crystalline, in part calcareous; ghosts of peloids and fenestrae(?); small amounts of quartz and feldspar.

Flat-laminated dolostone facies (FLD):
Dolostone with small amounts of dolomitic **siltstone**: flat and undulating lamination; rare crosslamination of microscopic scale.

Dolostone: mainly medium grey and medium dark grey, also medium light grey; cryptocrystalline to medium crystalline, mainly microcrystalline (commonly 4-20 micrometres); variably calcareous (lime mud, peloids); variable amounts of quartz with minor K-feldspar, plagioclase, white mica, and chlorite of mud and very fine sand grade; lamination caused by variations in concentration of carbonaceous or siliciclastic matter or in the crystal size of dolomite.

Unit 1, 0-142.5 m (142.5 m)
Mainly **lithofacies FLD** with minor intercalations of **lithofacies MC**; basal 6 m are massive **dolostone (lithofacies C)**; other units of **lithofacies MC** are a few decimetres to about 1.5 m thick; some replacement by quartz and chalcedony.

Conodont collection C-75444 from lower part of formation (about 100 m), Middle Ordovician, Whiterockian (Nowlan, Appendix 3B).

Unit 2, 142.5-190.0 m (47.5 m)
Mainly **lithofacies MC** with minor intercalations of **FLD** in upper part; resistant.

Conodont collection C-75445 from 144.0-145.5 m, Early to early Middle Ordovician (Nowlan, Appendix 3B); C-75453 from 168.5 m, Middle Ordovician to Devonian (Nowlan, Appendix 3B).

Unit 3, 190-400.0 m (210.0 m)
Mainly **lithofacies FLD**; **lithofacies MC** is generally subordinate but becomes increasingly abundant in upper 25 m; recessive.

Conformable contact.

THUMB MOUNTAIN FORMATION (Section EB4-11)

0-275.0 m (275.0 m)
Limestone: probably mainly **lime mudstone**, minor **skeletal wackestone**, medium dark grey, resistant, poorly exposed or poorly accessible; upper contact poorly defined and thickness somewhat uncertain.

Conodont collection C-75446 from 0-2 m, Middle Ordovician, Llandeilo to early Caradoc (Chazyan to Blackriverian) (Nowlan, Appendix 3B); C-75447 from 13-15 m, Middle to Late Ordovician, Llandeilo to Ashgill (Nowlan, Appendix 3B).

Conformable contact.

IRENE BAY FORMATION (Section EB4-12)

0-198.0 M (198.0 m)
Limestone (probably mainly **lime mudstone** and **skeletal wackestone**): medium dark grey, in places richly fossiliferous (solitary and colonial corals, gastropods, *Receptaculites*, algae, echinoderms, stromatoporoids); parting thickness 0.2-1 m; less resistant than Thumb Mountain and Allen Bay formations; partly covered; contacts poorly defined and thickness somewhat uncertain.

Conodont collections C-75448 and C-75449, Late Ordovician, late Caradoc–early Ashgill (middle Edenian to middle Maysvillian; Nowlan, Appendix 3B).

Macrofossil collection C-75450, Middle or Late Ordovician, late Caradoc–early Ashgill (Edenian–Maysvillian) (Norford, Appendix 3A).

Conformable contact.

ALLEN BAY FORMATION (Section EB4-13)

0-250.0 m (250.0 m)
Limestone (including **skeletal wackestone**): medium dark grey, resistant; lower contact poorly defined and thickness somewhat uncertain.

Top of section: approximate contact with Danish River Formation (covered, probably abrupt, disconformable).

Summary of thicknesses, Ella Bay 4 section

Ritter Bay Formation	>183.0 m
Rawlings Bay Formation	548.0 m
Member A	92.5 m
Member B	163.0 m
Member C	292.5 m
Kane Basin Formation	270.5 m
Member A	208.5 m
Member B	62.0 m
Scoresby Bay Formation	952.0 m
Member A	145.0 m
Member B	458.0 m
Member C	349.0 m
Oolitic limestone unit	272.5 m
Cass Fjord Formation	727.0 m
Member A	536.5 m
Member B	190.5 m
Cape Clay Formation	220.1 m
Ninnis Glacier Formation	319.0 m
Eleanor River Formation	191.0 m
Bay Fiord Formation	400.0 m
Thumb Mountain Formation	275.0 m
Irene Bay Formation	198.0 m
Allen Bay Formation	250.0 m

ELLA BAY 5 SECTION (EB5)

Location: Lady Franklin Bay map area (120 C), about 2.2 km southwest of head of Ella Bay; UTM Zone 19X, 480400E, 9001400N (Fig. 135).

Measured in 1984, mainly to obtain thicknesses of subdivisions of carbonate member of Hazen Formation; descriptions abbreviated and generalized; field numbers 84TM1, 84TM2.

Base of section: talus; at a level within the upper Kane Basin Formation.

KANE BASIN FORMATION

0-21.0 m (21.0 m)
Mainly **mudrock**: medium grey; incipient slaty cleavage; rare concretions from 21.0 to 37.5 m; 25% concretionary beds from 37.5 m to top; concretions about 10 to 30 cm long.

Abrupt contact, probably conformable.

HAZEN FORMATION

Carbonate Member

Subdivision A

0-163.5 m (163.5 m)
Mainly **lime mudstone** and **mudrock**.

Subdivision B

163.5-189.5 m (26.0 m)
Carbonate conglomerate: mostly matrix-supported, massive, upward fining; cobbles up to 30 cm in lower part, pebbles in upper part.

Subdivision C1

189.5-232.7 m (43.2 m)
Mudrock, chert and minor **lime mudstone**.

Top of section: top of subdivision C1 (exposures continue).

ELLA BAY 6 SECTION (EB6)

Location: Lady Franklin Bay map area (120 C), southeastern slope of Bulleys Lump; UTM Zone 19X, 495700E, 9013700N.

Measured in 1984; field number 84TM10.

Base of section: conformable contact with Kane Basin Formation.

HAZEN FORMATION

Carbonate Member

Subdivision A

Unit 1, 0-58.5 m (58.5 m)
Interbedded **lime mudstone**: silty, sandy; beds 5-15 cm thick, and **mudrock**: calcareous; both medium and medium dark grey.

Unit 2, 58.5-70.0 m (11.5 m)
As unit 1 but more argillaceous; recessive weathering, partly covered.

Subdivision B

Unit 3, 70.0-79.0 m (9.0 m)
Carbonate conglomerate: clasts up to 25 cm, mostly limestone; subparallel to bedding and nearly in place or inclined up to 90°; partly matrix-supported and partly clast-supported, cemented by calcite.

Subdivision C

Unit 4, 79.0-93.5 m (14.5 m)
Scattered outcrops of **lime mudstone**: argillaceous; beds up to 8 cm thick; and **mudrock**: calcareous; both recessive.

Unit 5, 93.5-98.5 m (5.0 m)
Lime mudstone and **mudrock**: as in unit 4, contorted and mashed.

Subdivision D

Unit 6, 98.5-118.75 m (20.25 m)
Carbonate conglomerate: mostly clast-supported; at 108.5-108.75 m interbedded **mudrock** and **limestone**. **Limestone**: beds 1-3 cm thick, flat-laminated, continuous; clasts up to 30 cm in diameter,

bedding-parallel or inclined; imbrication inclined to northeast.

Undifferentiated subdivisions

Unit 7, 118.75-157.25 m (38.5 m)
Limestone: very argillaceous, dark weathering, and **mudrock**: calcareous; flat lamination; pyrite common; dark weathering, recessive unit.

Unit 8, 157.25-173.5 m (16.25 m)
Limestone: argillaceous, and **mudrock**: calcareous; unit is mainly flat-laminated as before, but more resistant and lighter coloured.

Unit 9, 173.5-181.2 m (7.7 m)
Carbonate conglomerate: clasts supported by abundant matrix; clasts ellipsoidal, rounded, commonly 10-25 cm in diameter; matrix calcareous and argillaceous.

Unit 10, 181.2-208.7 m (27.5 m)
Limestone and **mudrock**: as in unit 8 but more resistant and calcareous.

Unit 11, 208.7-250.2 m (41.5 m)
As unit 10, but more resistant.

Unit 12, 250.2-251.4 m (1.2 m)
Carbonate conglomerate: clasts almost in situ; elongate lenses up to 30 cm long.

Top of section: top of accessible part of section. Overlain by perhaps 200 m of limestone and mudrock.

Summary of thicknesses, Ella Bay 6 section

Hazen Formation
Carbonate member .... >251.4 m
Subdivision A .... 70.0 m
Subdivision B .... 9.0 m
Subdivision C .... 19.5 m
Subdivision D .... 20.25 m

ELLA BAY 7 SECTION (EB7)

Location: Lady Franklin Bay map area (120 C), 5.8 km southeast of Record Point (mouth of Ella Bay); UTM Zone 19X, 495000E, 9010600N.

Measured in 1984; field number 84TM225C.

Thickness determinations only; lithology comparable to EB6 and EB9.

HAZEN FORMATION

Carbonate Member

Subdivision A .... 98± m (partly covered)
Subdivision B .... 13 m
Subdivision C .... 31 m
Subdivision D .... 30 m

ELLA BAY 8 SECTION (EB8)

Location: Lady Franklin Bay map area (120 C), 6.9 km southeast of Record Point (mouth of Ella Bay); UTM Zone 19X, 495400E, 9009000N.

Measured in 1984; field number 84TM226e.

Thickness determinations only; lithology comparable to EB6 and EB9.

HAZEN FORMATION

Carbonate Member

Subdivision B .... 5 m
Subdivision C .... thickness not determined
Subdivision D .... 37.5 m

ELLA BAY 9 SECTION (EB9)

Location: Lady Franklin Bay map area (120 C); 7.75 km southeast of Record Point; UTM Zone 19X, 495950E, 9008200N.

Measured in 1984; field number 84TM5.

Base of section: top of Kane Basin Formation.

HAZEN FORMATION

Carbonate Member

Subdivision A

Unit 1, 0-16.5 m (16.5 m)
Lime mudstone: medium grey; in pinching and swelling

beds, a few millimetres to 5 cm thick; interbedded with **mudrock**: calcareous; flat and undulating lamination, some small-scale crosslamination, incipient slaty cleavage.

Unit 2, 16.5-33.0 m (16.5 m)
Interbedded **mudrock** and **carbonate rocks**: medium dark grey; flat lamination; some burrow casts on bedding planes; incipient slaty cleavage.

Unit 3, 33.0-39.0 m (6.0 m)
Covered.

Unit 4, 39.0-70.5 m (31.5 m)
As unit 2.

Unit 5, 70.5-75.0 m (4.5 m)
Covered or inaccessible; probably as units 2 and 4.

Unit 6, 75.0-84.0 m (9.0 m)
As unit 2 (outcrop).

Unit 7, 84.0-102.5 m (18.5 m)
Partly covered, partly inaccessible.

Unit 8, 102.5-119.0 m (16.5 m)
Outcrop of interbedded **lime mudstone** and **mudrock** (including coarse grained **siltstone**): medium dark grey; **lime mudstone:** beds up to 15 cm thick, mostly bioturbated.

Subdivision B

Unit 9, 119.0-131.0 m (12.0 m)
Carbonate conglomerate: partly clast-supported and partly matrix-supported; clasts up to 50 cm long in upper part; mostly flat with internal flat lamination.

Unit 10, 131.0-162.5 m (31.5 m)
Large **slide block** composed of **dolostone** and **sandstone**: mostly massive with some indistinct flat bedding; brecciated here in upper 5 m or so and brecciated entirely 20 m to the northeast.

Dolostone: medium light grey, fine to coarse crystalline, porous weathering, massive.

Sandstone: quartzose, slightly dolomitic, fine to medium grained, very well sorted; rounding varies from rounded to subangular.

Subdivision C1

Unit 11, 162.5-179.0 m (16.5 m)
Covered, recessive.

Unit 12, 179.0-189.0 m (10.0 m)
Lime mudstone interbedded with **mudrock** and minor **chert**: medium dark grey; dark weathering marker unit.

Lime mudstone: beds 1-25 cm thick with some internal flat lamination.

Chert: highly carbonaceous; sample is carbonaceous and slightly calcareous and contains fragments of sponge spicules.

Subdivision C2

Unit 13, 189.0-229.0 m (40.0 m)
Recessive, mostly covered; at 189-194 m and at 214.5 m outcrops of thinly interstratified argillaceous **lime mudstone** and calcareous **mudrock**; both medium grey and medium dark grey; thin flat lamination.

Subdivision D

Unit 14, 229.0-257.0 m (28.0 m)
Carbonate conglomerate: fragments up to 4 m long, 15 cm thick, but more commonly about 50 cm long; mostly inclined but partly parallel to bedding; commonly with undulating internal lamination.

Top of section: top of carbonate conglomerate (subdivision D); exposures of middle and upper parts of carbonate member continue.

Summary of thicknesses, Ella Bay 9 section

Hazen Formation	
Carbonate member	>257.0 m
Subdivision A	119.0 m
Subdivision B	43.5 m
Subdivision C	66.5 m
Subdivision D	28.0 m

D'IBERVILLE GLACIER SECTION (DIG)

Location: Greely Fiord East map area (340 A), southwest of upper part of d'Iberville Glacier; UTM Zone 18X, 447400E, 8925500N (lower part); 447400E, 8925200N (upper part) (Fig. 138).

This composite section consists of three partial sections, possibly separated by minor stratigraphic gaps. Measured in 1975; field numbers 75TM237, 75TM238.

Figure 138. Vicinity of d'Iberville Glacier section (DIG). Part of aerial photograph NAPL A-16788-35. For legend see Figure 1.

HAZEN FORMATION (Section DIG-1)

Carbonate member

Base of section: talus slope; at a level within the upper part of the member.

Unit 1, 0-3.0 m (3.0 m)
Lime mudstone: variably argillaceous, flat-laminated, with minor amounts of interlaminated **mudrock**: highly calcareous, both medium to medium dark grey.

Unit 2, 3.0-18.3 m (15.3 m)
Mudrock alternating with **carbonate conglomerate.**

Mudrock: medium dark grey, highly calcareous and slightly dolomitic, flat-laminated, slaty.

Carbonate conglomerate: medium dark grey; ellipsoidal clasts of argillaceous lime mudstone with minor interlaminated mudrock, 5-20 cm long, in abundant argillaceous matrix.

3.0-3.6 m (0.6 m)
Conglomerate.

3.6-3.9 m (0.3 m)
Mudrock.

3.9-7.2 m (3.3 m)
Conglomerate.

7.2-14.7 m (7.5 m)
Mudrock.

14.7-17.6 m (2.9 m)
Conglomerate.

17.6-18.3 m (0.7 m)
Mudrock: highly calcareous, bedding distorted in lower 20 cm.

Offset; small stratigraphic gap possible.

(Section DIG-2)

Unit 3, 0-276.2 m (276.2 m)
Lime mudstone with very minor amounts of interlaminated **mudrock** and one or more bed(s) of **calcarenite.**

Lime mudstone: medium light grey to predominantly medium dark grey, argillaceous and in part very fine grained sandy; carbonate aggregates recrystallized to single crystals; flat lamination very common; low angle crosslamination of small or microscopic scale rare; some relatively coarse grained laminae have erosional bases and normal or reverse graded bedding with indistinct injection structures at base; some strata have slaty cleavage.

Mudrock: calcareous, fine to coarse grained; occurs as thin lenses or laminae.

0-218.4 m (218.4 m)
Lime mudstone with minor **mudrock.**

218.4-218.7 m (0.3 m)
Calcarenite: composed of fragments of lime mudstone and skeletal fragments (echinoderm columnals, trilobite and/or ostracode fragments) in matrix of lime mud; poorly sorted; indistinct graded bedding with granules at base of stratum; some chert replacement.

218.7-276.2 m (57.5 m)
Lime mudstone and **mudrock**; some **chert** replacement.

Offset, small stratigraphic gap possible

(Section DIG-3)

Chert member

Unit 4, 0-37.5 m (37.5 m)
Chert: medium dark grey; beds 2-10 cm thick, separated by argillaceous partings; poorly preserved radiolarians; pyrite; some carbonate replacement; cliff-forming unit.

Abrupt contact with the overlying Danish River Formation.

Two short sections in the lower Danish River Formation, studied in detail, are shown graphically in Figure 112.

Summary of thicknesses, D'Iberville Glacier section

Hazen Formation	
Carbonate member	>276.2 m
Chert member	37.5 m

ST. PATRICK BAY SECTION (SPB)

Location: Lady Franklin Bay map area (120 C), 2.4 km north of head of St. Patrick Bay; UTM Zone 19X, 479100E, 9086700N (Fig. 139).

Measured in 1967; field number 67TM-B. (Measured in feet and converted to metres; accuracy less than indicated by decimals.) Designated type section (Trettin, 1971), but incompletely exposed.

Lower part of formation is exposed on the southwest side of St. Patrick Bay where photogrammetric determination indicates about 400 m of strata.

HAZEN FORMATION

Carbonate Member

Base of section: talus slope; at a level within the carbonate member.

Unit 1, 0-57.3 m (57.3 m)
Thinly interstratified **mudrock**, **chert**, **lime mudstone**, **calcarenite**, and minor **sandstone**.

Mudrock: medium dark grey, fine to coarse grained, variably calcareous and cherty; flat and undulating lamination.

Chert: medium dark grey and medium grey, thin flat lamination; one specimen has poorly preserved spicules; some carbonate replacement.

Lime mudstone: medium light grey to medium dark grey, fine to coarse grained, variably argillaceous, in part slightly sandy, recrystallized; flat lamination and small-scale crosslamination.

Calcarenite: medium light grey, very fine to coarse grained, silty, sandy; composed mainly of lime mudstone fragments with poorly preserved fossil fragments [echinoderms, trilobites(?)], phosphatic microfossils, and chert; flat lamination and small-scale crosslamination.

Conodont collection C-54826 from 0.5 m, Early Ordovician, late Tremadoc (Tipnis, Appendix 3B)

Unit 2, 57.3-59.74 m (2.44 m)
Breccia: composed of fragments of lime mudstone, coarse grained, sandy mudrock, and chert; fragments up to 30 cm long, flat.

Chert Member

Unit 3, 59.74-247.5 m (187.76 m)
Outcrop or talus of **chert** and interlaminated **mudrock**; very small amounts of **chert breccia** and **calcarenite**.

59.74-115.21 (55.47 m)
Chert and **mudrock**.

Fossil collection C-66 at 69.49 m, graptolites of late Early Ordovician, late Arenig age (Riva, Appendix 3A).

115.21-115.52 (0.31 m)
Calcareous breccia: composed mainly of lime mudstone with some wackestone (coated grains in matrix of recrystallized lime mud); partly replaced by chalcedony.

115.52-120.7 m (5.18 m)
Mainly **chert** and **mudrock** with a few beds of **calcarenite**, partly replaced by **chert**.

120.7-148.13 m (27.43 m)
Chert and **mudrock**.

148.13-190.20 m (42.07 m)
Covered with talus of **chert** and **mudrock**.

190.20-193.85 m (3.65 m)
Outcrop of **chert** and **mudrock**.

193.85-205.44 m (11.59 m)
Covered interval, recessive; talus of **chert** and **mudrock**.

205.44-207.87 m (2.43 m)
Outcrop of **chert** and minor **mudrock**.

Fossil collection C-67, talus, probably close to source, from 205.44-207.87 m, graptolites of unspecified Middle Ordovician to Early Silurian age (Thorsteinsson and Norford, Appendix 3A).

207.87-247.50 m (39.63 m)
Covered interval, recessive; talus of **chert** and **mudrock**.

Fossil collection C-64 from outcrop about 900 m to the south, about 6 m below top of formation, graptolites of latest Ordovician (late Ashgill) age (Riva, Appendix 3A).

Top of section: abrupt contact with Danish River Formation.

Figure 139. *Vicinity of St. Patrick Bay section (SPB). Part of aerial photograph NAPL A-16680-80. For legend see Figure 1. Є–SH: Hazen Formation.*

Summary of thicknesses, St. Patrick Bay section

Hazen Formation	>247.5 m
Carbonate member	>59.7 m
Chert member	187.8 m

VERY RIVER SECTION (VR)

Location: Tanquary Fiord map area (340 D), north side of Very River, about 23 km southwest of Lake Hazen (Fig. 89).
VR1: Zone 18X, 515100E, 9048900N
VR2, VR3: Zone 18X, 515600E, 9048250N
VR4, VR5: 515850E, 9048500N

This composite section consists of five partial sections that together extend from the base of the Hazen Formation into the lowermost Danish River Formation. Only the thicknesses of the basal resistant unit of the carbonate member and of the chert member have been determined. The bulk of the carbonate member is structurally intensely disturbed and the partial sections representing it are separated by gaps of uncertain stratigraphic thickness.

Measured in 1975; field numbers 75TM71A-75TM71E.

Base of section: abrupt contact with Grant Land Formation, medium grey, fine grained mudrock.

HAZEN FORMATION (Section VR1)

Carbonate member

Basal resistant unit

Unit 1, 0-12.0 m (12.0 m)
Limestone with thinly interstratified **mudrock**; **chert** lenses (replacement) common.

Limestone: medium light grey to medium grey; strata 6-50 cm thick; mainly **lime mudstone**, minor **calcarenite**; aggregates of lime mud recrystallized to single crystals; some flat or undulating lamination.

Mudrock: medium grey; strata 0.1-10 cm thick.

0-2.0 m (2.0 m)
Limestone: strata 6-12 cm thick; **mudrock**: strata 0.2-10 cm thick; **chert**: lenses up to 3 cm thick, 1 m long.

2.0-3.0 m (1.0 m)
Limestone beds separated by laminae of **mudrock**, **argillaceous limestone**, or **chert**; thicknesses of limestone beds, from base to top: 50 cm, 7 cm, 7 cm, 7 cm, 30 cm.

3.0-12.0 m (9.0 m)
Limestone: strata 5-10 cm thick; **mudrock**: strata 0.3-5 cm thick; a few **chert lenses**: 0.5-1 cm thick, up to 50 cm long.

Unit 2, 12.0-22.0 m (10.0 m)
Chert: medium grey and medium dark grey; strata 0.5-10 cm, commonly 2-3 cm thick with argillaceous partings; poorly preserved radiolarians.

Offset; stratigraphic gap of unknown thickness.

(Section VR2)

Unit 3, 0-30 m (30 m)
Limestone with about 50% of interstratified **mudrock**.

Limestone: medium grey; strata 0.3-20 cm, mostly <4 cm thick; flat lamination and small-scale crosslamination; analyzed specimens appear to be argillaceous and very fine grained sandy **lime mudstone**; most aggregates have recrystallized to single crystals.

Mudrock: medium dark grey, calcareous.

Unit is tightly folded (half-wavelength of some folds as small as 10 cm); thickness difficult to determine.

Offset; stratigraphic gap of unknown thickness.

(Section VR3)

Unit 4, 0-5.4 m (5.4 m)
Sandstone with lesser amounts of interbedded **mudrock** and **limestone**; minor **chert**.

Sandstone: medium grey, calcareous, dolomitic, argillaceous, very fine grained, moderately sorted; flat lamination and small-scale crosslamination; strata in lower 2 m are 2-9 cm, commonly 6 cm, thick; ellipsoidal concretions, 5-30 cm thick, in interval 2.0-3.4 m; concretions 40 cm thick in interval 3.4-5.4 m.

Mudrock: medium dark grey, in part sandy, slightly calcareous and dolomitic; strata in lower 2 m are 2-8 cm thick.

Limestone: light grey to medium grey, argillaceous and partly very fine grained sandy; analyzed specimens appear to be **lime mudstone** and **calcarenite**; aggregates recrystallized to single crystals; flat lamination and small-scale crosslamination.

Chert: dark grey; lenses, 5 cm thick, in lower 2 m.

Offset; minor stratigraphic gap possible.

(Section VR4)

Unit 5, 0-30.5 m (30.5 m)
Interbedded **mudrock** and **limestone** as before.

0-9.5 m (9.5 m)
Predominantly **mudrock**: units up to 1 m thick; **limestone**: strata 1-3 cm thick.

9.5-30.5 m (21.0 m)
Predominantly **limestone**, minor **mudrock**; proportion of mudrock rises to about 25% in upper 2 m; fragments of very small phosphatic brachiopods in one thin section.

Unit 6, 30.5-35.5 m (5.0 m)
Interbedded **chert, mudrock**, and **limestone**; limestone beds 0.2-10 cm thick; **chert** partly replaced by dolomite; relatively recessive unit.

Chert member

Unit 7, 35.5-55.0 m (19.5 m)
Covered interval, recessive; rubble of **chert** and **mudrock**.

Unit 8, 55.0-210.0 m (155.0 m)
Chert with thinly interstratified **mudrock**; highly resistant unit.

Chert: mainly pure but partly argillaceous; poorly preserved radiolarians common; thin flat lamination; beds 1-20 cm thick; pyrite common in some beds.

55.0-62.5 cm (7.5 m)
Chert: strata 1-10 cm thick, **mudrock**: strata 2-5 cm thick; pyrite common.

62.5-83.5 m (21.0 m)
Chert: beds 5-10 cm, commonly 10 cm thick.

83.5-84.5 m (1.0 m)
Predominantly **mudrock**.

84.5-123.0 m (38.5 m)
Chert: beds are 1-6 cm thick in lower 10 m or so, in upper part 2-10 cm, commonly 5-6 cm.

123.0-183.0 m (60.0 m)
Chert: beds mostly 5-10 cm thick, with some 20 cm thick beds in interval 123-135 m.

183.0-200.0 m (17.0 m)
Covered.

200.0-208.0 m (8.0 m)
Chert: beds 2-10 cm thick; **mudrock**: strata 0.3-2.0 cm thick.

Poorly preserved graptolites at 205-208 m, including biserial forms (older than middle Llandovery).

208.0-210.0 m (2.0 m)
Covered.

Conformable contact.

DANISH RIVER FORMATION (Section VR5)

Unit 1, 0-7.6 m (7.6 m)
Sandstone alternating with interlaminated **chert** and **mudrock**.

Sandstone: medium grey, calcareous and dolomitic, very fine grained, silty, moderately sorted, mostly massive with some faint flat lamination; units 1.6-2.6 m thick.

Chert: medium dark grey; beds 1-2 cm thick, separated by laminae of mudrock; poorly preserved radiolarians common.

0-1.6 m (1.6 m)
Sandstone: massive.

1.6-2.2 m (0.6 m)
Chert and **mudrock**.

2.2-4.2 m (2.0 m)
Sandstone: as before, mostly massive, with some indistinct flat lamination.

4.2-6.2 m (2.0 m)
Chert: flat lamination common.

6.2-6.8 m (0.6 m)
Sandstone: as before, massive.

6.8-7.6 m (0.8 m)
Chert: as before

Top of section: top of basal sandstone-chert unit of Danish River Formation.

Summary of thicknesses, Very River section

Hazen Formation	>262.4 m
Carbonate member	>87.9 m
Basal resistant unit	12.0 m
Chert member	174.5 m
Danish River Formation	
Basal sandstone-chert unit	7.6 m

MACDONALD RIVER SECTION (MR)

Location: Tanquary Fiord map area (340 D)

MR1: north of Macdonald River, 15 km east of Tanquary Camp; UTM Zone 18X, 483350E, 9038600N

MR2: south of Macdonald River, 11.1 km east-southeast of Tanquary Camp; UTM Zone 18X, 479200E, 903800N

MR3: south of Macdonald River, 14.9 km east-southeast of Tanquary Camp; UTM Zone 18X, 482800E, 9036300N (Fig. 140)

This composite section comprises three partial sections that are separated by complexly deformed intervals of unknown thickness. The Macdonald River 1 section (MR1) is a detailed description of a sandy unit within member C_1 of the Grant Land Formation. It is not described here, but is depicted in Figure 78. The Macdonald River 2 section (MR2) describes the basal resistant unit of the carbonate member of the Hazen Formation, and the Macdonald River 3 section (MR3) the chert member. Section MR1 was measured in 1979, field number 79TM2; section MR2 in 1970, field number 70TM-A; section MR3 in 1975, field number 75TM18.

Base of section: base of carbonate member of Hazen Formation; contact with the Grant Land Formation (recessive mudrock) is concealed.

HAZEN FORMATION (Section MR2)

Carbonate member

Basal resistant unit

Unit 1, 0-19.44 m (19.44 m)
Interstratified **lime mudstone** and minor **calcarenite**, both with **chert** lenses, and **mudrock**.

Lime mudstone: medium grey, fine to coarse grained; aggregates of lime mud recrystallized to single crystals; slightly argillaceous; variably dolomitic; beds 1-22 cm thick; flat and undulating lamination.

Calcarenite: medium grey, very fine to very coarse grained, slightly argillaceous, variably dolomitic; beds to 20 cm thick; some flat lamination; at least one bed in upper part of unit is poorly sorted and graded; composed mainly of clasts of lime mudstone and fairly common coated grains; fossil fragments (possibly from echinoderms, trilobites) rare and poorly preserved; some phosphatic fragments.

Mudrock: medium grey to medium dark grey, fine grained, in part cherty, slightly calcareous and/or dolomitic, slaty; beds about 1-10 cm thick.

0-2.93 m (2.93 m)
Lime mudstone with interbedded **mudrock. Lime mudstone**: beds about 1-16 cm thick, average 6 cm; **mudrock**: beds 1-7 cm, average 1.5 cm.

2.93-5.15 m (2.22 m)
Lime mudstone with interbedded **mudrock. Lime mudstone**: beds about 3.5-22 cm thick, average 7 cm; **mudrock**: beds 0.3-3 cm, commonly 1 cm thick.

5.15-5.94 m (0.79 m)
Lime mudstone with interbedded **mudrock. Lime mudstone**: beds about 2-6 cm thick; **mudrock** comprises about one third of unit.

5.94-7.28 m (1.34 m)
Mainly **mudrock**; at top of unit three beds of **lime mudstone**: about 2 cm thick, with interstratified **mudrock**.

7.28-11.43 m (4.15 m)
Mainly **lime mudstone** with **chert** lenses and interbedded **mudrock. Lime mudstone**: beds 3-17 cm thick, average thickness about 12 cm.

11.43-11.95 m (0.52 m)
Lime mudstone with **chert** lenses and interbedded **mudrock. Lime mudstone**: beds 2-8 cm thick; **mudrock**: beds 0.5-10 cm thick.

11.95-12.92 m (0.97 m)
Lime mudstone.

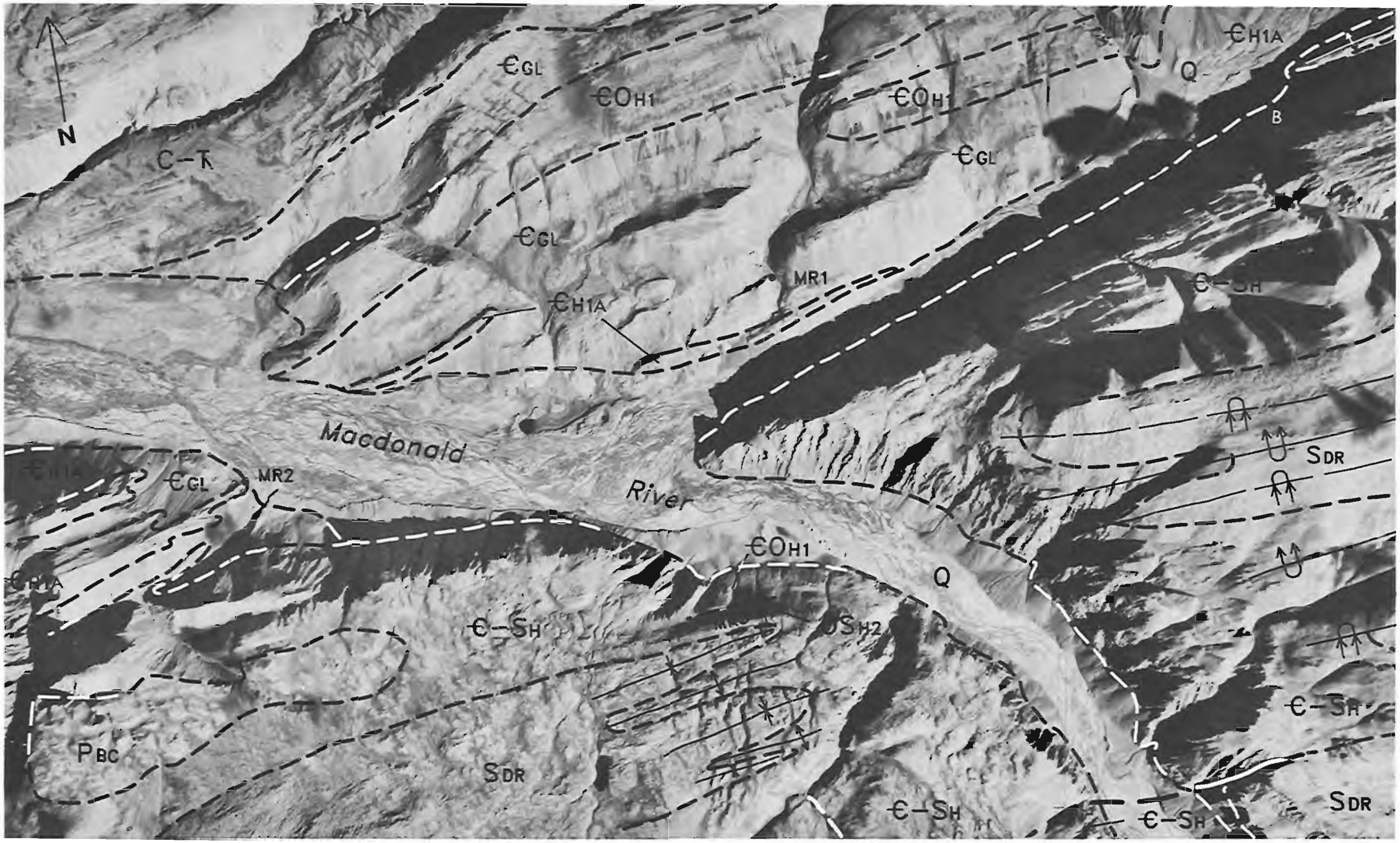

Figure 140. *Vicinity of Macdonald River section (MR). Part of aerial photograph NAPL A-161694-143. For legend see Figure 1. C–Ŧ : Carboniferous to Triassic formations; PBC: Belcher Channel Formation; €GL: Grant Land Formation; PBC: Belcher Channel Formation; €–SH: Hazen Formation.*

12.92-17.10 m (4.18 m)
Lime mudstone with minor amounts of very fine grained **calcarenite**, both with **chert** lenses and interbedded **mudrock**; thickness and proportion of limestone beds increase upsection; limestone beds 1-7 cm thick in lower part of unit, 6-13 cm in middle part, and 8-18 cm in upper part. **Mudrock**: beds 0.2-7 cm in lower half, 0.2-2 cm in upper half of unit.

17.10-18.23 m (1.13 m)
Calcarenite.

18.23-19.44 m (1.21 m)
Calcarenite and **lime mudstone**(?) with **chert** lenses and interstratified **mudrock. Limestone**: beds 1-20 cm thick; at least one bed, 20 cm thick, is crudely graded.

3.2-3.4 m (0.2 m)
Calcarenite: medium grey, fine grained, recrystallized; probably original grainstone composed of clasts of lime mudstone, coated grains, and fossil fragments (ostracodes and/or trilobites); argillaceous and sandy; indistinct flat lamination.

3.4-3.9 m (0.5 m)
Partly covered, some showings of **chert.**

3.9-4.25 (0.35 m)
Calcarenite: silty, sandy; graded, coarse grained with granules at base, fine grained at top; clasts of lime mudstone, coated grains, microfossils (ostracodes?); original texture obscured by recrystallization; chert and phosphate replacement.

Carbonate member

Unit 2, 19.44-21.88 m (2.44 m)
Chert: medium light grey, containing poorly preserved radiolarians and some pyrite; beds about 2-5 cm thick and separated by laminae of mudrock, about 2 mm thick.

Offset and major gap of unknown thickness.

(Section MR3)

Unit 3, 0-4.25 m (4.25 m)
Thinly interstratified **chert, mudrock, calcarenite,** and **calcareous sandstone.**

Chert: medium dark grey; beds 1-3 cm thick, with argillaceous partings and some internal lamination; poorly preserved radiolarians common.

Mudrock: medium dark grey, fine to coarse grained, variably calcareous, flat laminated.

0-1.0 m (1.0 m)
Thinly interstratified **mudrock, lime mudstone,** and **sandstone**; flat lamination and small-scale crosslamination; **sandstone** and **lime mudstone**: beds 1-3 cm thick; **lime mudstone**: argillaceous, slightly sandy; **sandstone**: calcareous, fine grained, well sorted; quartz and feldspar rounded to subrounded.

1.0-3.2 m (2.2 m)
Chert.

Chert member

Unit 4, 4.25-184.0 m (179.75 m)
Chert: as before, but beds up to 10 cm thick with interlaminated **mudrock,** and minor amounts of interstratified **limestone** as before.

4.25-26.5 m (22.25 m)
Chert: brownish, greenish, yellowish weathering; beds up to 10 cm thick; pyritic at 8.5-10.0 m and at 13.5-16.0 m.

26.5-30.5 m (4.0 m)
Partly covered, probably **chert** as before.

30.5-30.9 m (0.4 m)
Lime mudstone: medium grey and medium dark grey, argillaceous and very fine grained sandy; flat lamination and small-scale crosslamination.

30.9-34.5 m (3.6 m)
Covered, probably chert.

34.5-35.5 m (1.0 m)
Chert with interbedded **mudrock,** very thinly laminated.

35.5-43.7 m (8.2 m)
Chert with about 10% interbedded **limestone**: as before; beds 5-15 cm thick, flat lamination and small-scale crosslamination; analyzed specimen is **lime mudstone.**

43.7-51.0 m (7.3 m)
Chert as before.

51.0-54.9 m (3.9 m)
Chert: as before, with four (or more) **limestone** beds: 5-20 cm thick; flat lamination and small-scale crosslamination.

54.9-184.0 m (129.1 m)
Chert: beds 1-10 cm thick; minor amounts of interlaminated **mudrock**; **breccia** at 65.55-65.7 m, composed of chert and carbonate, contains weathered pyrite.

Unit 5, 184.0-218.0 m (34.0 m)
Covered interval, recessive; talus of Danish River Formation but probably underlain by Hazen Formation.

Overlying strata: sandstone of the Danish River Formation; contact covered.

BENT GLACIER SECTION (BG)

Location: nunatak on northeast side of upper Bent Glacier; UTM Zone 17X, 542900E, 9040250N (Fig. 141).

Measured in 1974; field number 74TM11.

Base of section: uppermost outcrop of Grant Land Formation, greenish weathering mudrock.

HAZEN FORMATION

Carbonate member

Unit 1, 0-57.7 m (57.5 m)
Covered slope, slightly more recessive than the slope underlain by the Grant Land Formation; talus of **mudrock** and **lime mudstone**: generally dark grey weathering.

Unit 2, 57.5-74.0 (16.5 m)
Lime mudstone: beds 1-8 cm thick, flat lamination and small-scale crosslamination; with interlaminated **mudrock**.

Unit 3, 74.0-127.0 m (53.0 m)
Covered slope, more recessive than unit 2; talus of **mudrock**, **lime mudstone**, and **chert**.

Diabase sill, 2.5 m thick, at top of unit (not included in section)

Chert member

Unit 4, 127.0-140.5 m (13.5 m)
Talus and scattered outcrops of **chert**: beds 1-8 cm thick with argillaceous partings.

Unit 5, 140.5-209.5 m (69.0 m)
Chert: as before; beds up to 15 cm, but mostly < 10 cm thick.

- Offset -

Unit 6, 209.5-229.0 m (19.5 m)
Chert: beds thinner than in unit 5, slope more recessive.

Unit 7, 229.0-241.0 m (12.0 m)
Recessive slope with dark grey soil, probably underlain by dark grey mudrock.

Top of section: approximate position of concealed contact with the Danish River Formation (steeper slope, covered with talus of **sandstone**).

Summary of thicknesses, Bent Glacier section

Hazen Formation	241 m
Carbonate member	127 m
Chert member	114 m

ROLLROCK LAKE SECTION (RL)

Location: Tanquary Fiord map area (340 D), slope northwest of Rollrock Lake; UTM Zone 18X, 483500E, 9057800N (Fig. 142).

Measured in 1984; field number 84TM12.

Base of section: talus slope, approximate top of Nesmith beds.

GRANT LAND FORMATION

Member A

Unit 1, 0-6.0 m (6.0 m)
Covered.

Unit 2, 6.0-7.5 m (1.5 m)
Sandstone, minor **granule conglomerate** and **mudrock**: all highly calcareous; units up to 20 cm thick, graded; resistant unit; for detailed sections see Figure 66.

Unit 3, 7.5-30.0 m (22.5 m)
Covered.

Unit 4, 30.0-67.0 m (37.0 m)
Interbedded calcareous **sandstone** and **mudrock**: Bouma sequences, mainly divisions A and B.

Unit 5, 67.0-98.5 m (31.5 m)
Mainly interbedded **sandstone** and **mudrock**: (estimate about 60% sandstone) graded bedding, with **granule conglomerate** at the base of some beds; divisions A and B of Bouma model; units become thinner and more recessive upsection.

Unit 6, 98.5-106.0 m (7.5 m)
Covered.

Unit 7, 106.0-116.0 m (10.0 m)
Sandstone and **mudrock**: as before, both slightly calcareous.

Unit 8, 116.0-123.0 m (7.0 m)
Covered.

***Figure 141.** Vicinity of Bent Glacier section (BG). Part of aerial photograph NAPL A-16693-126. For legend see Figure 1. Є-SH: Hazen Formation; ЄGL: Grant Land Formation.*

Member B

Unit 9, 123.0-125.4 m (2.4 m)
Sandstone: quartzose, slightly feldspathic, in part slightly calcareous (replacements and veinlets); massive in lower part, graded in upper part.

123.0-124.23 (1.23 m)
Sandstone: massive; bimodal. Population 1: coarse grained (maximum: very coarse grained or granules); population 2: fine or very fine to fine grained; slightly fluctuating grain sizes; rip-up flakes of mudrock at some levels (e.g., 123.58 m, 123.76 m); slight decrease in grain size at top.

124.23-124.34 (0.11 cm)
Sandstone: graded; bimodal in lower 0.1 m. Population 1: coarse grained; population 2: very fine and fine grained; proportion of population 2 decreases upsection; above this, fine grained.

Overlying stratum: **sandstone**, bimodal. Population 1: coarse to very coarse grained (abundant); population 2: fine grained.

TANQUARY FIORD SECTION (TF)

Location: Tanquary Fiord map area (340 D), 2.5 km north-northeast of the head of Tanquary Fiord; UTM Zone 18X, 470000E, 9047000N.

Measured in 1975; field number 75TM23.

This is a partial, detailed section of 236 m of strata at an unknown vertical position within member B of the Grant Land Formation. It is portrayed graphically in Figure 68.

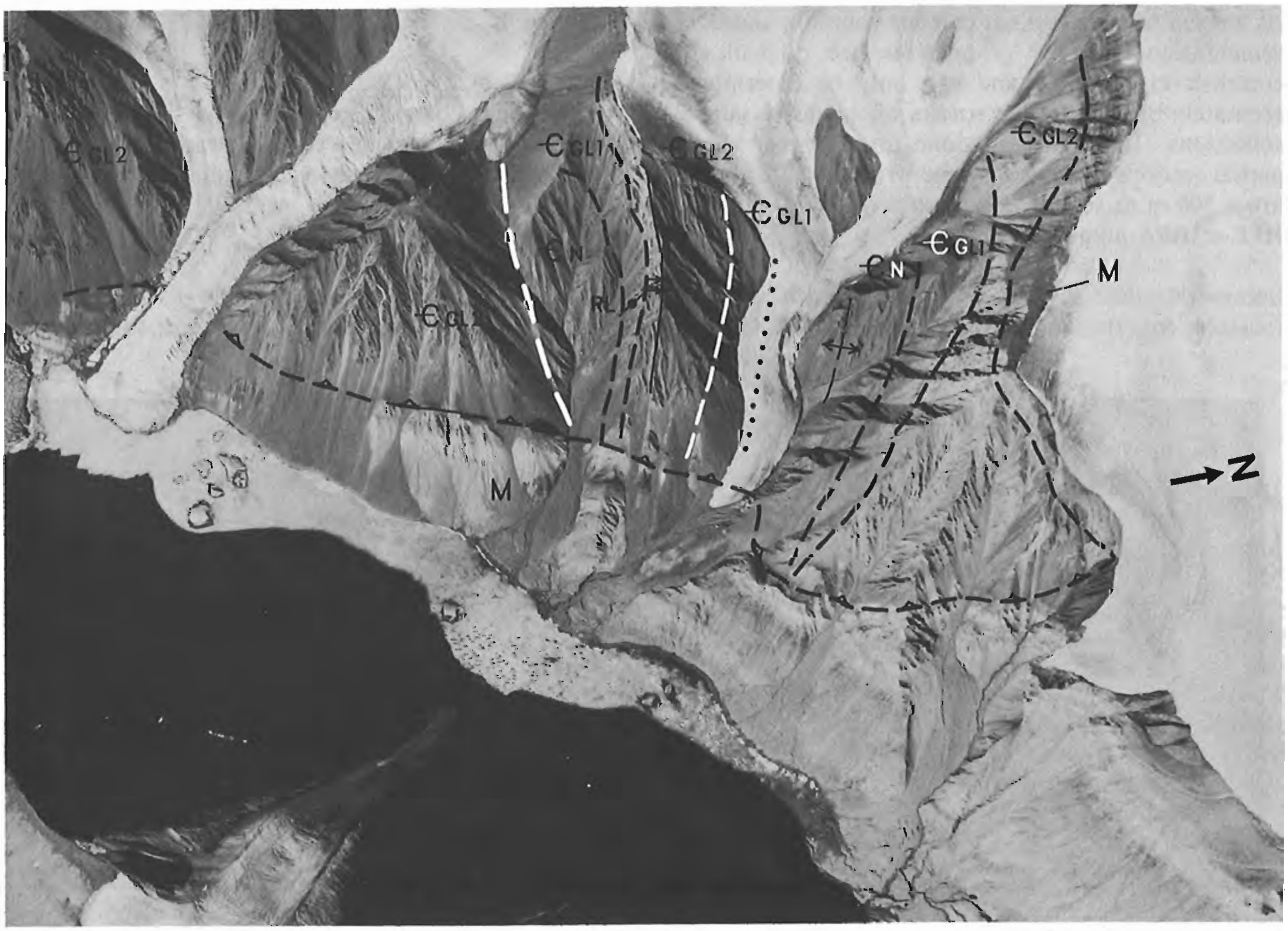

Figure 142. Vicinity of Rollrock Lake section (RL). Part of aerial photograph NAPL A-16694-138. For legend see Figure 1. ЄN: Nesmith beds; ЄGL1, ЄGL2: members A and B of Grant Land Formation; M: Mesozoic.

HARE FIORD-EAST SECTION (HFE)

Location: Otto Fiord map area (340 C), 5-6 km north of the east end of Hare Fiord; UTM Zone 17X, 478500E, 9018400N to 478200E, 902800N; upper contact at 478300E, 9021000N (Fig. 143).

A composite section, consisting of four parts, was measured by D.W. Esson in 1990. At this locality, the Grant Land Formation is bounded at the base by a thrust fault and contains a fault in the upper part. Section HFE-1 (field number 90TM-ESS-11), describing 1195 m of strata between these faults, portrays a substantial portion of member B. The strata above the upper fault are folded and represented by short partial sections only. Section HFE-2 (90TM-ESS-12) describes another 83 m of strata of member B, and section HFE-3 (90TM-ESS-13) 75 m of member C. The contact of the Grant Land Formation with the overlying Hazen Formation, covered at HFE-3, was examined at HFE-4 (90TM-ESS-14), and the latter has been combined with HFE-3.

As a result of poor sorting, pressure solution, and tight cementation, average grain sizes are difficult to establish in the field and can only be determined accurately by thin section studies on extensive sample collections. This has been done for five very short, partial sections measured by the writer in 1975, in the lower 500 m or so of the exposures (Fig 68, HFE-a to HFE-e; field numbers 75TM87a to d and f).

Because of time limitations, this approach was not feasible for the much longer section (1.35 km) measured by Esson, although some samples have been studied in thin section. In order to express the uncertainty about average grain size, the following simplified grain size nomenclature is used here:

"sandstone, fine":	very fine to medium grained, mainly very fine and fine grained
"sandstone, medium":	fine to coarse grained, mainly medium grained
"sandstone, coarse":	medium to very coarse grained, mainly coarse grained

The rocks termed mudrock are probably mainly siltstones, although minor amounts of claystone may also be present.

GRANT LAND FORMATION (Section HFE-1)

Member B

Unit 1, 0-28.0 m (28.0 m)
"**Sandstone**, coarse": greenish grey; beds 1.2-4.5 m thick, massive; includes some upward fining strata; interbedded with "sandstone, medium": dark grey; beds 30-40 cm thick.

Unit 2, 28.0-49.0 m (21.0 m)
Mainly "**sandstone**, medium": beds 0.5-2.0 m thick, mostly massive; some beds fine upward; some trough

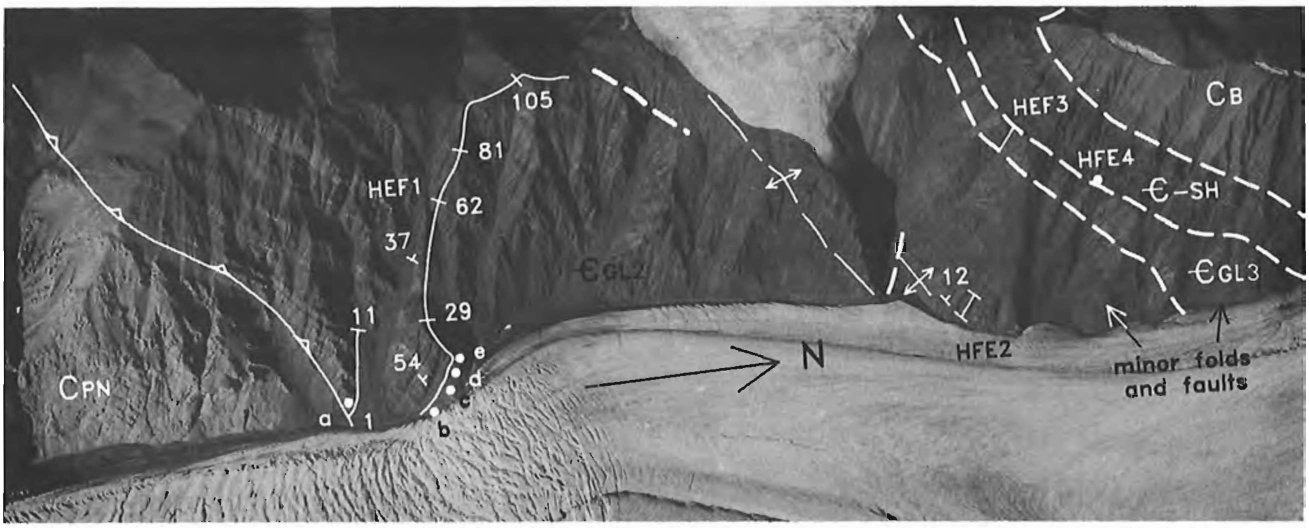

Figure 143. Vicinity of Hare Fiord East section (HFE). Part of aerial photograph NAPL A-16785-114. For legend see Figure 1. ЄGL2, ЄGL3: members B and C of Grant Land Formation; CB: Borup Fiord Formation; CPN: Nansen Formation; Є–SH: Hazen Formation.

crossbeds; some rip-up clasts of mudrock; interbedded with minor **mudrock**: dark grey, laminated; layers up to 30 cm thick; at base of unit "**sandstone**, fine"; dark grey, thin bedded, 2 m thick.

Unit 3, 49.0-58.0 m (9.0 m)
Mainly "**sandstone**, medium": beds 10-80 cm thick; ripple marks and small troughs; interbedded with **mudrock**: dark grey; layers 2-10 cm thick; two beds of **pebble conglomerate**: fining upward; rip-up clasts of mudrock, 4-38 mm long.

Unit 4, 58.0-66.5 m (8.5 m)
"**Sandstone**, coarse": massive, fining upward; rip-up clasts at base; some flat lamination.

Unit 5, 66.5-73.0 m (6.5 m)
"**Sandstone**, medium": fining upward; beds 20-110 cm thick; thinner beds have ripple marks, thicker beds are flat-laminated; irregular interbeds of **mudrock**: dark grey, laminated.

Unit 6, 73.0-84.0 m, (11.0 m)
"**Sandstone**, medium": mostly massive, but medium-bedded at top of unit.

Unit 7, 84.0-117.0 m (33.0 m)
"**Sandstone**, medium and coarse": beds 0.4-5.0 m thick; some beds fine upward.

Unit 8, 117.0-138.5 m (21.5 m)
"**Sandstone**, medium to coarse": massive; thin, discontinuous bed of **mudrock** at base. **Mudrock**: dark grey; beds 1-3 cm thick at 127.0-128.0 m.

Unit 9, 138.5-150.5 m (12.0 m)
Mainly "**sandstone**, medium to coarse": beds 10-40 cm thick; thin interbeds of **mudrock**: dark grey, and **sandstone**: argillaceous; both flat-laminated.

Unit 10, 150.5-185.5 m (35.0 m)
Mainly "**sandstone**, medium": massive; **pebble conglomerate**: fine grained; fining upward to **sandstone** at 158.0 m and 181.5 m; **mudrock**: at 171.5 m and 185.0 m; laminated; layers 40 cm thick.

Unit 11, 185.5-205.5 m (20.0 m)
"**Sandstone**, medium": thick bedded to massive, also trough crossbedded; hummocky(?) crossbed at 198.5 m.

Unit 12, 205.5-210.5 m (5.0 m)
Mainly "**sandstone**, coarse": fining upward to "**sandstone**, medium": argillaceous; interbedded **mudrock**: laminated, layers 12-14 cm thick.

Unit 13, 210.5-220.5 m (10.0 m)
Mainly "**sandstone**, coarse": massive; beds 1.7-3.0 m thick; interbedded **mudrock**: laminated, 25-30 cm thick.

Unit 14, 220.5-224.0 m (3.5 m)
"**Sandstone**, coarse": beds 50-90 cm thick; interbedded with **mudrock**: laminated, layers 20-60 cm thick.

Unit 15, 224.0-231.0 m (7.0 m)
"**Sandstone**, coarse": massive; beds 0.6-2.4 m thick; forms channel 40 m long, 1.5 m deep, at 225.5 m; interbedded with units of thinly interstratified **mudrock** and "**sandstone**, fine to medium": 15-25 cm thick.

Unit 16, 231.0-240.0 m (9.0 m)
"**Sandstone**, fine": beds mostly 3-40 cm thick, thicker beds near top of unit; ripple marks; interbedded with **mudrock**: beds 1-4 cm thick.

Unit 17, 240.0-243.5 m (3.5 m)
"**Sandstone**, coarse": fining upward, flat-laminated; interbedded with **mudrock**: layers 10-15 cm thick.

Unit 18, 243.5-257.5 m (14.0 m)
Mainly **mudrock**: medium grey, very thin bedded; ripple marks; some laminae of **mudrock**: dark grey, near base of unit; beds of "**sandstone**, coarse": 8-20 cm thick, with small troughs, near top of unit.

Unit 19, 257.5-265.0 m (7.5 m)
"**Sandstone**, medium to coarse": beds 12-90 cm thick; interbedded **mudrock**: dark grey, laminated; layers 5-15 cm thick.

Unit 20, 265.0-266.5 m (1.5 m)
Mudrock: as in unit 18; slaty cleavage.

Unit 21, 266.5-275.5 m (9.0 m)
"**Sandstone**, medium to coarse": massive; quartz veins.

Unit 22, 275.5-283.0 m (7.5 m)
"**Sandstone**, coarse": beds 0.7-1.9 m thick; interbedded with **mudrock**: dark grey, laminated; layers 7-15 cm thick.

Unit 23, 283.0-293.5 m (10.5 m)
Mainly **mudrock**: green, flat-laminated; contains lens of "**sandstone**, coarse": rich in rip-up clasts; near top of unit some interbedded "**sandstone**, medium to coarse": flat-laminated; beds 3-7 cm thick; rip-up clasts of mudrock.

Unit 24, 293.5-320.5 m (27.0 m)
"**Sandstone**, medium to coarse": beds 0.2-1.9 m thick;

some troughs, some low-angle crosslamination, some rip-up clasts; interbedded with **mudrock**: dark grey, flat-laminated; layers 0.2-1.5 cm thick.

Unit 25, 320.5-356.5 m (36.0 m)
Mainly **pebble conglomerate**: fine, fining upward, and "**sandstone**, coarse": with some laminae of **mudrock**: dark grey; at 344.5 m, trough, 40 cm deep, 1.5 m wide, filled with **pebble conglomerate**: fine; layer of **mudrock**: dark grey, flat-laminated, 50 cm thick, at 353.5 m.

Unit 26, 356.5-359.0 m (2.5 m)
Mudrock: dark grey, very thin bedded.

Unit 27, 359.0-369.0 m (10.0 m)
Mainly "**sandstone**, coarse": massive, flat-laminated in upper 2 m; grades to "**sandstone**, fine": beds 50 cm thick; interbedded with **mudrock**: dark grey; layers 15-20 cm thick in upper 2 m.

Unit 28, 369.0-384.0 m (15.0 m)
"**Sandstone**, medium to coarse": massive, beds 2-4 m thick; interbedded **mudrock**: dark grey; layers 15-20 cm thick.

Unit 29, 384.0-397.5 m (13.5 m)
As unit 28 but **sandstone** beds 0.9-1.5 m thick; exposure poor.

Unit 30, 397.5-400.5 m (3.0 m)
Covered.

Unit 31, 400.5-428.0 m (27.5 m)
Mainly **mudrock**: dark grey, laminated, pronounced cleavage; relatively coarse grained at 402.0 m (30 cm) and 423.5 m (40 cm); some carbonate replacement.

Unit 32, 428.0-431.0 m (3.0 m)
Covered.

Unit 33, 431.0-447.5 m (16.5 m)
Mudrock: dark grey, laminated; "**sandstone**, fine": flat-laminated, at 440.0 m.

Unit 34, 447.5-451.5 m (4.0 m)
Covered.

Unit 35, 451.5-462.5 m (11.0 m)
Mudrock: dark grey, laminated.

Unit 36, 462.5-467.5 m (5.0 m)
Mudrock: greenish grey.

Unit 37, 467.5-469.0 m (1.5 m)
Sandstone: dark grey, argillaceous, "medium" at base, fining upward; bedding irregular.

Unit 38, 469.0-484.5 m (15.5 m)
Mudrock: green; beds 0.3-1.0 cm thick; interbedded with "**sandstone**, fine": green, flat-laminated; beds 0.5-1.5 cm thick.

Unit 39, 484.5-489.0 m (4.5 m)
Mudrock: greyish red-purple; interbedded with "**sandstone**, fine": as in unit 38; "**sandstone**, medium": greyish red-purple, at 486.5 m.

Unit 40, 489.0-495.0 m (6.0 m)
Mudrock: green, interbedded with "**sandstone**, medium": beds 25-35 cm thick; load casts, ripple marks.

Unit 41, 495.0-519.0 m (24.0 m)
Mainly "**sandstone**, medium to coarse": beds 0.6-1.9 m thick; some rip-up clasts, some flat lamination; some laminae of **mudrock**: dark grey; load casts at base of thicker beds; units, about 25 cm thick, of interstratified "**sandstone**, medium" and **mudrock**: dark grey, at 504.0, 507.0, 512.5 m.

Unit 42, 519.0-528.5 m (9.5 m)
Mudrock: dark grey; some flat lamination; minor "**sandstone**, medium": greenish grey; beds 2-4 cm thick; unit becomes more silty toward top.

Unit 43, 528.5-535.0 m (6.5 m)
"**Sandstone**, medium to coarse": beds 20-50 cm thick; some graded bedding, load casts; interbedded with **mudrock**: dark grey, layers 4-40 cm thick.

Unit 44, 535.0-545.5 m (10.5 m)
Sandstone and **mudrock**: as in unit 41.

Unit 45, 545.5-554.0 m (8.5 m)
Mudrock: flat-laminated; minor **sandstone**: as in unit 42.

Unit 46, 554.0-563.5 m (9.5 m)
Sandstone and **mudrock**: as in unit 43; sandstone layers up to 90 cm thick.

Unit 47, 563.5-578.5 m (15.0 m)
Mudrock: flat-laminated and "**sandstone**, fine": both greenish grey, as in unit 38.

Unit 48, 578.5-598.0 m (19.5 m)
Mudrock and minor "**sandstone**, fine": as in units 38 and 39; lower 9 m mainly greyish red-purple, remainder is mixed greyish red-purple and greenish grey.

Unit 49, 598.0-601.0 m (3.0 m)
"**Sandstone**, medium to coarse": flat-laminated; beds 20-50 cm thick; some laminae of **mudrock**: dark grey.

Unit 50, 601.0-611.5 m (10.5 m)
"**Sandstone**, fine to medium": flat-laminated; some ripple marks; beds 2-5 cm thick; interbedded **mudrock**: dark grey, beds 0.5-2.0 cm thick.

Unit 51, 611.5-624.5 m (13.0 m)
Mainly **sandstone**: as in unit 41.

Unit 52, 624.5-626.0 m (1.5 m)
Covered.

Unit 53, 626.0-632.5 m (6.5 m)
Mudrock: dark greenish grey, laminated.

Unit 54, 632.5-639.0 m (6.5 m)
"**Sandstone**, medium to coarse": beds 50-80 cm thick; some laminae of **mudrock**.

Unit 55, 639.0-648.5 m (9.5 m)
Mainly **mudrock**: light greenish grey, flat-laminated; slaty cleavage; "**sandstone**, coarse": beds 40-60 cm thick, in upper part of unit.

Unit 56, 648.5-660.5 m (12.0 m)
"**Sandstone**, coarse": beds 1.0-1.5 m thick at base, 40-60 cm at top of unit; laminae of **mudrock**: dark grey, between sandstone beds.

Unit 57, 660.5-666.5 m (6.0 m)
Mudrock: greenish grey; interbedded with "**sandstone**, fine": greenish grey; some ripple marks; "**sandstone**, medium": beds 20-30 cm thick, near top of unit.

Unit 58, 666.5-672.5 m (5.5 m)
Sandstone with laminae of **mudrock** as in unit 56.

Unit 59, 672.5-677.5 m (5.5 m)
Covered; talus of **mudrock**: greenish grey, thinly stratified.

Unit 60, 677.5-682.5 m (5.0 m)
Thinly interstratified **mudrock**, and "**sandstone**, fine": both greenish grey, as in unit 38.

Unit 61, 682.5-694.0 m (11.5 m)
Mainly "**sandstone**, coarse": some beds fining upward to "medium"; bed thickness 1.5-2.0 m at base, 50-90 cm in upper part of unit; some flat lamination, some rip-up clasts of mudrock; laminae of **mudrock** between sandstone beds.

Unit 62, 694.0-699.0 m (5.5 m)
"**Sandstone**, coarse": mainly massive with some indistinct bedding planes near top.

Unit 63, 699.0-704.5 m (5.5 m)
Mudrock: greenish grey; interbedded with "**sandstone**, fine": greenish grey; beds 1.5-2.4 m thick.

Unit 64, 704.5-713.5 m (9.0 m)
Mainly "**sandstone**, medium to coarse": beds 20-50 cm thick; some beds fine upward; some flat lamination; laminae of **mudrock**: medium dark grey, between sandstone beds.

Unit 65, 713.5-717.0 m (3.5 m)
"**Sandstone**, coarse": massive.

Unit 66, 717.0-718.5 m (1.5 m)
Mudrock: greenish grey, very thinly stratified; ripple marks.

Unit 67, 718.5-732.0 m (13.5 m)
Sandstone with laminae of **mudrock**, as in unit 61.

Unit 68, 732.0-735.0 m (3.0 m)
Mudrock: greenish grey, very thinly stratified.

Unit 69, 735.0-739.5 m (4.5 m)
Sandstone with laminae of **mudrock**: as in unit 61.

Unit 70, 739.5-753.0 m (13.5 m)
Mudrock: greenish grey, beds 1-3 cm thick.

Unit 71, 753.0-764.0 m (11.0 m)
Mainly "**sandstone**, medium": beds 20-40 cm thick; interbedded with **mudrock**: greenish grey, thinly stratified (1-3 cm); layers 5-10 cm thick; poor exposure.

Unit 72, 764.0-779.0 m (15.0 m)
"**Sandstone**, coarse": massive, beds 2-5 m thick.

Unit 73, 779.0-782.0 m (3.0 m)
Covered.

Unit 74, 782.0-814.0 m (32.0 m)
"**Sandstone**, medium to coarse": beds 30-40 cm thick; some fine upward; interbedded with **mudrock**: greenish grey, laminated to very thin bedded; some layers up to 40 cm thick.

Unit 75, 814.0-817.0 m (3.0 m)
"**Sandstone**, medium": massive.

Unit 76, 817.0-820.5 m (3.5 m)
Mudrock: greenish grey, very thin bedded.

Unit 77, 820.5-856.0 m (35.5 m)
Sandstone and **mudrock**: as in unit 74.

Unit 78, 856.0-866.5 m (10.5 m)
Mainly **mudrock**: greenish grey, flat-laminated; "**sandstone**, medium" at 862.5-863.5 m.

Unit 79, 866.5-880.0 m (13.5 m)
"**Sandstone**, coarse": massive at base of unit, becoming thick to medium bedded at top of unit.

Unit 80, 880.0-889.0 m (9.0 m)
Mainly "**sandstone**, medium": beds 30-50 cm thick; with interbedded **mudrock**: mainly greenish, but orange-brown weathering at base of unit; thinly stratified (1-3 cm); layers up to 1 m thick.

Unit 81, 889.0-910.5 m (21.5 m)
Mudrock: predominantly greyish red-purple, also greyish green, flat-laminated.

Unit 82, 910.5-912.0 m (1.5 m)
"**Sandstone**, medium": structureless; beds 18-32 cm thick; interbedded with **mudrock**: greyish red-purple, flat-laminated; layers 4-15 cm thick.

Unit 83, 912.0-933.0 m (21.0 m)
"**Sandstone**, fine to medium": some ripple marks; beds mainly 0.5-10 cm thick; medium grained sandstone beds 30 cm thick at 920.5 m, 50 cm thick at 924.5 m; thinly interbedded **mudrock**: greyish red-purple.

Unit 84, 933.0-934.5 m (1.5 m)
Sandstone and **mudrock:** as in unit 82.

Unit 85, 934.5-942.5 m (8.0 m)
Mudrock: greyish red-purple and **sandstone:** as in unit 83.

Unit 86, 942.5-947.5 m (5.0 m)
Mainly **mudrock**: greenish grey, laminated; minor "**sandstone**, medium": beds 10-15 cm thick.

Unit 87, 947.5-956.0 m (8.5 m)
"**Sandstone**, fine": dark greenish grey, flat-laminated; beds 20-35 cm thick.

Unit 88, 956.0-958.5 m (2.5 m)
Covered.

Unit 89, 958.5-961.5 m (3.0 m)
Mudrock and minor **sandstone**: as in unit 86.

Unit 90, 961.5-971.5 m (10.0 m)
Mudrock: mainly greyish red-purple but greenish grey at 963.5-964.5 m; flat-laminated.

Unit 91, 971.5-974.5 m (3.0 m)
Covered, talus of **mudrock**: greenish grey, thinly stratified.

Unit 92, 974.5-1000.0 m (25.5 m)
Mudrock: greenish grey and greyish red-purple; laminated; units 2-4 m thick; exposure poor; unit may be folded.

Unit 93, 1000.0-1002.5 m (2.5 m)
"**Sandstone**, fine to medium": dark grey with angular green patches throughout; beds 40-80 cm thick with strongly undulating bedding planes; quartz veins, 2-4 cm thick, common.

Unit 94, 1002.5-1004.0 m (1.5 m)
Covered; talus of **mudrock**: dark grey, laminated.

Unit 95, 1004.0-1011.0 m (7.0 m)
Mudrock: greenish grey, very thinly stratified; layers up to 2 m thick; interbedded with "**sandstone**, fine to medium": flat-laminated; some ripple marks in upper part of unit; layers up to 80 cm thick.

Unit 96, 1011.0-1018.5 m (7.5 m)
Covered; talus of **mudrock**: greenish grey, laminated.

Unit 97, 1018.5-1023.0 m (4.5 m)
Mainly **mudrock**, dark grey, very thinly stratified; "**sandstone**, medium", 70 cm thick (similar to unit 93) at 1021.5 m.

Unit 98, 1023.0-1029.5 m (6.5 m)
"**Sandstone**, medium": light brownish grey weathering; beds 40-70 cm thick; undulating bedding planes (amplitude 40 cm) as in unit 93; resistant marker bed.

Unit 99, 1029.5-1044.0 m (14.5 m)
Mainly **mudrock**: greenish grey, laminated; a few layers of "**sandstone**, medium": thinly stratified, 10-14 cm thick, at base of unit.

Unit 100, 1044.0-1068.0 m (24.0 m)
Mudrock: greyish red-purple, laminated.

Unit 101, 1068.0-1073.5 m (5.5 m)
Mainly **mudrock**: greenish grey, laminated; two beds of "**sandstone**, medium", 15 cm thick, at base of unit.

Unit 102, 1073.5-1079.0 m (5.5 m)
Mudrock: greyish red-purple, laminated.

Unit 103, 1079.0-1086.5 m (7.5 m)
Mudrock: greenish grey, laminated; "**sandstone**, medium": beds 4-7 cm thick, at base.

Unit 104, 1086.5-1095.0 m (8.5 m)
Mudrock: greyish red-purple, laminated.

Unit 105, 1095.0-1114.5 m (19.5 m)
Mainly **mudrock**: greenish grey, laminated; minor "**sandstone**, medium": beds 20-40 cm thick, at intervals of 3-10 m.

Unit 106, 1114.5-1145.0 m (30.5 m)
Mainly "**sandstone**, medium to coarse": beds 0.4-1.0 m thick; some beds fine upward; undulating bottom surfaces; irregular bedding planes; some rip-up clasts of mudrock; interbedded **mudrock**: dark greenish grey, laminated; some layers up to 20 cm thick.

Unit 107, 1145.0-1166.5 m (21.5 m)
Mudrock: mainly greyish red-purple, but lower 4 m greenish grey; laminated; *Planolites* at 1163.5 m.

Unit 108, 1166.5-1175.5 m (9.0 m)
Mainly "**sandstone**, coarse": beds 20-35 cm thick; interbedded **mudrock**: greenish grey, laminated; layers 10-20 cm thick.

Unit 109, 1175.5-1194.5 m (19.0 m)
Mudrock: greyish red-purple, laminated.

GRANT LAND FORMATION (Section HFE-2)

Member B, (cont'd)

Unit 1, 0-9.5 m (9.5 m)
"**Sandstone**, medium": massive; rip-up clasts of mudrock; beds 8-60 cm thick; interbedded **mudrock**: dark grey, very thin bedded; ripple marks; beds 3-50 cm thick.

Unit 2, 9.5-20.5 m (11.0 m)
"**Sandstone**, fine": some flat lamination; contains thin, discontinuous beds of "**sandstone**, medium": 2-5 cm thick; ripple marks.

Unit 3, 20.5-28.0 m (7.5 m)
"**Sandstone**, medium to coarse": beds 0.5-1.7 m thick; some beds fine upward; load casts; interbedded **mudrock**: dark grey, very thin bedded.

Unit 4, 28.0-43.5 m (15.5 m)
"**Sandstone**, coarse": massive; beds up to 4.5 m thick at base of unit, 0.8-2.0 m thick at top; **mudrock**: dark grey, laminated; between sandstone beds.

Unit 5, 43.5-46.5 m (3.0 m)
Mudrock: dark grey, laminated.

Unit 6, 46.5-54.5 m (8.0 m)

"**Sandstone**, medium": massive; beds 30-85 cm thick; separated by laminae of **mudrock**: dark grey.

Unit 7, 54.5-56.0 m (1.5 m)
Mudrock: dark grey, laminated.

Unit 8, 56.0-74.0 m (18.0 m)
Mudrock: greenish grey, laminated.

Unit 9, 74.0-77.0 m (3.0 m)
"**Sandstone**, medium": beds 10-30 cm thick, separated by laminae of **siltstone**: green.

Unit 10, 77.0-83.0 m (6.0 m)
Mudrock: greenish grey, laminated.

GRANT LAND FORMATION (Sections HFE-3 and HFE-4, combined)

Member C

Unit 1, 0.0-1.0 m (1.0 m)
Mudrock: dark brown-greyish red-purple, with irregular dark greenish grey patches, 0.5-3 mm in diameter.

Unit 2, 1.0-23.0 m (22.0 m)
Mainly **mudrock**: greenish grey, laminated; some lenses of "**sandstone**, fine".

Unit 3, 23.0-30.0 m (7.0 m)
"**Sandstone**, fine": beds 3-45 cm thick; interbedded **mudrock**: laminated, ripple-marked, layers 2-10 cm thick.

Unit 4, 30.0-75.0 m (45.0 m)
Mudrock: light greenish grey and greenish brown, dark grey in upper 10 cm at HFE-4, laminated; thickness uncertain as unit may be folded.

– abrupt contact –

HAZEN FORMATION

Unit 1, 0-0.40 cm (0.4 cm)
Mudrock, chertified: dark grey, laminated.

OSBORN RANGE SECTION (OR)

Location: Tanquary Fiord map area (340 D); 14.4 km north-northwest of Tanquary Camp; north side of unnamed river; UTM Zone 18X, 462000E, 9053200N.

This section, shown graphically in Figure 79 describes member C2 of the Grant Land Formation. It is possible that the member has been thickened by thrust faults or recumbent folds, but this was not apparent in the field (Fig. 87). Measured in 1979; field number 79TM1.

HENRIETTA NESMITH GLACIER SECTION (HNG)

Location: Tanquary Fiord map area (340 D), 10.5 km northwest of Lake Hazen; UTM Zone 18X, 531500E, 9082600N.

This composite section comprises nine short sections measured in detail in tightly folded strata — 6 in the uppermost part of the Nesmith beds, and 3 in the lowermost part of the Grant Land Formation (member A_1). Statistical data for both units are listed in the text of this report, and typical intervals are portrayed graphically in Figure 62. Measured in 1982; field number 82TM15.

CHANDLER FIORD SECTIONS

Location: Lady Franklin Bay map area (120 C), southwest of upper Chandler Fiord; UTM Zone 19X, 497800E, 9069700N and 498000E, 9069500N.

Two short, detailed sections within the lower(?) part of the Danish River Formation are represented graphically in Figure 112 (see also photograph, Fig. 115). Measured in 1977; field numbers 77TM101 and 105 A.

APPENDIX 2

X-RAY DIFFRACTION AND THIN SECTION ANALYSES

This appendix presents 697 whole-rock X-ray diffraction analyses, listed and summarized statistically by stratigraphic unit, location, and rock type. The values listed for individual minerals represent the relative height of the principal peak of that mineral as a percentage of the sum of the principal peaks of all minerals identified. This value is roughly proportional to the abundance of the mineral. The peaks used are listed below with some additional comments. Values of 2Θ refer to cobalt radiation.

Quartz. Percentages are based on the 101 reflection at 31.04°. The peak represents quartz as well as chert and chalcedony.

Feldspar. Peaks near 32.5° are interpreted as the principal reflection of plagioclase and peaks near 31.9° as those of K-feldspar. Detailed analyses of specimens from central Ellesmere Island showed that most (or all) of the plagioclase is low-temperature albite and that most (or all) of the K-feldspar is low-temperature microcline (Trettin, 1978). The shape of the plagioclase peak in the present analyses supports this inference.

Mica. Peaks between 10.16° and 10.28° could be either illite or mica but thin sections show that it is largely mica — mainly white mica with minor biotite in some rocks.

Chlorite. The lattice spacings causing the principal reflections of chlorite (002) and kaolinite (001) are so close that the peaks cannot be distinguished in whole-rock diffractograms. Thin sections, however, show that in the present suites the peak at 14.4-14.6° is mainly due to chlorite.

Carbonates. The relative abundances of calcite, dolomite, and siderite are inferred from the height of the 104 reflection, which occurs approximately at 34.3°, 36.1°, and 37.4°, respectively. Some of the material listed as dolomite may in fact be ankerite, but no attempt has been made to distinguish this Fe and Mn-bearing variety.

Peak height ratios of mineral pairs are useful because they permit comparisons between formations or rock types, and because corrections can be applied to them. The following ratios are listed in all those cases where the combined percentage of the minerals is 5 or greater:

F/F + Q =
(total feldspar/quartz + total feldspar) x 100

P/P + Kf =
(plagioclase/plagioclase + K-feldspar) x 100

D/D + C =
(dolomite/dolomite + calcite) x 100

Note that these ratios have been calculated from the measured peak heights and not from the rounded off percentages listed.

In order to establish an approximate correction for F/F + Q, point count analyses on 43 etched thin sections (from the Grant Land Formation and granitoid rocks) were compared statistically with corresponding XRD values, the latter ranging from 6 to 73. The data show considerable scatter and can be treated in different ways.

1. The simplest approach is to use the ratio of the means of the point count and XRD data, which yields the correction:
   $$Y = 1.76 \times X$$
   Y indicating the "true" values, as represented by the point count data, and X the XRD values.

2. A special linear regression analysis, which assumes the Y-constant to be 0, yields:
   $$Y = 1.62 \times X$$
   (standard error of Y-estimate: 11.7).

3. A standard linear regression analysis yields:
   $$Y = (1.30 \times X) + 11.9$$
   (standard error of Y-estimate: 9.7).

   Note that this regression is applicable only to X values ranging from 6 to 73.

Grouped data indicate that the correction decreases with increasing values of X. This, combined with general considerations, suggests that a more realistic calibration line should have the following characteristics:

1. It should be a simple, convex curve.

2. It should intersect the Y-axis a short distance above 0, because small mineral concentrations (5% or less) are not detectable on X-ray diffractograms.

3. Y should approach 100 at X = 100.

So far it has not been possible to generate such a curve by strictly statistical methods because of the scatter of the data. However, a preliminary calibration curve has been constructed that lies fairly close to the linear regression in the lower and middle parts, and to available data in the upper part. The following corrections have been abstracted from this curve.

Tentative calibration for F/F + Q values

XRD	corrected
5	8
10	15
15	22
20	29
25	36
30	42
35	49
40	56
45	62
50	67
55	73
60	78
65	82
70	86
75	89
80	92
85	95
90	97
95	99

In order to establish a correction for P/P + Kf, point count analyses on 14 stained thin sections from the Grant Land Formation were used. The corresponding XRD values range from 55 to 89. The following corrections are obtained by different statistical approaches.

1. The ratio of the means of the point count data (69.6) and XRD data (73.4) provides the correction:
   $Y = 0.95 \times X.$

2. A special linear regression analysis which assumes the Y-constant to be 0 yields:
   $Y = 0.93 \times X$
   (standard error of Y-estimate: 10.8).

3. A standard linear regression yields:
   $Y = 0.66 \times X + 19.5$
   (standard error of Y-estimate: 8.71)

Royse et al. (1971) demonstrated that the weight percentage of dolomite can be obtained by adding 2.3 per cent to the ratio D/D + C, but Lumsden (1979) inferred a more complex relationship.

The symbols in the tables of this appendix have the following connotation:

N = number of samples used for statistical calculation

$\bar{X}$ = arithmetic mean

σ = standard deviation (calculated only for $N \geq 10$)

In addition to the X-ray diffraction analyses, point count analyses have been made on thin sections of sandstones. Most are listed in the text of the report but four analyses are summarized in Table 4 of this Appendix.

Table 1

Unit: Ritter Bay Fm.
Location: Ella Bay 4-1 section
Rock type: **mudrock**, in part sandy
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	3	52-64	58.7
K-feldspar	3	1-2	1.3
Plagioclase	3	6-10	8.3
Mica-illite	3	11-13	12.0
Chlorite	3	8-26	17.7
Calcite	3	0-1	0.3
Siderite	3	2-2	2.0
F/F + Q	3	11-16	14.0
P/P + Kf	3	82-86	83.3

Table 2
Unit: Ritter Bay Fm.
Location: Ella Bay 4-1 section
Rock type: **sandstone**, very fine grained, argillaceous, with interlaminated **mudrock** in some specimens
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	5	67-85	73.8
K-feldspar	5	0-2	1.0
Plagioclase	5	6-9	7.8
Mica-illite	5	4-8	6.4
Chlorite	5	4-13	9.2
Calcite	5	0-2	0.4
Siderite	5	1-2	1.6
F/F+Q	5	7-13	11.0
P/P+Kf	5	81-100	89.2

Table 3
Unit: Rawlings Bay Fm., member B
Location: Ella Bay 4-2 section
Rock type: **sandstone**, mainly fine grained, (also fine to medium grained), maximum grain sizes coarse or very coarse
Method: point count

	N	Range %	$\bar{X}$ %
Quartz	4	65-87	75.8
Feldspar	4	4-8	6.5
White mica	4	0-1	0.8
Chlorite	4	0-tr	
Carbonate	4	0-tr	
shale clasts	4	0-tr	
"matrix"	4	9-20	15.0
opaque	4	tr-6	2.0
F/F+Q	4	4-10	7.8

"Matrix": mainly intergrown white mica and quartz, may include some highly altered feldspar. Heavy minerals: tourmaline, zircon, minor epidote.

Table 4
Unit: Rawlings Bay Fm.
Location: Ella Bay 4-2 section
Rock type: **sandstone**, mainly fine grained
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %	σ %
Quartz	18	86-99	94.1	4.0
K-feldspar	18	0-5	1.3	1.9
Plagioclase	18	0-8	1.9	2.3
Mica-illite	18	0-5	1.8	1.3
Chlorite	18	0-4	0.4	1.0
Dolomite	18	0-5	0.6	1.4
Siderite	18	0-3	0.2	0.7
F/F+Q	18	0-9	3.6	2.8
P/P+Kf	5	18-100	68.0	

Table 5
Unit: Rawlings Bay Fm.
Location: southwest of Ella Bay 4-2 section
Rock type: **sandstone**, mainly fine grained
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %	σ %
Quartz	15	91-100	95.4	2.8
K-feldspar	15	0-5	2.7	1.8
Plagioclase	15	0-1	0.1	0.3
Mica-illite	15	0-2	0.6	0.8
Chlorite	15	0-2	0.3	0.6
Calcite	15	0-1	0.3	0.4
Dolomite	15	0-1	0.2	0.4
Siderite	15	0-2	0.5	0.9
F/F+Q	15	0-5	2.8	1.9
P/P+Kf	3	0	0	

Table 6
Unit: Rawlings Bay Fm., members A and C
Location: Ella Bay 4-2 section
Rock type: **sandstone**, very fine grained, argillaceous
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	2	66-81	73.5
K-feldspar	2	tr-1	0.5
Plagioclase	2	3-4	3.5
Mica-illite	2	10-15	12.5
Chlorite	2	5-14	9.5
F/F+Q	2	5-7	6.0
P/P+Kf	2	70-100	85.0

Table 7
Unit: Rawlings Bay Fm., member C, uppermost part
Location: south of Ella Bay 6 section
Rock type: **sandstone**, very fine to fine grained
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	3	86-95	89.0
K-feldspar	3	tr-1	0.7
Plagioclase	3	1-3	2.3
Mica-illite	3	1-7	3.7
Chlorite	3	1-2	1.3
Calcite	3	0-2	0.7
Dolomite	3	0-3	1.6
Siderite	3	0-2	0.7

Table 8
Unit: Kane Basin Fm., member A
Location: Ella Bay 4-3 section, 0-20 m
Rock type: **mudrock**, in part sandy
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	6	52-68	58.0
K-feldspar	6	1-2	1.7
Plagioclase	6	3-5	4.7
Mica-illite	6	9-18	13.8
Chlorite	6	15-28	22.2
F/F+Q	6	6-13	10.0
P/P+Kf	6	71-86	78.0

Table 9
Unit: Kane Basin Fm., member A
Location: Ella Bay 4-3 section, 181.5 m
Rock type: **mudrock**, coarse
Method: X-ray diffraction

	N	Range %
Quartz	1	75
K-feldspar	1	4
Plagioclase	1	14
Mica-illite	1	2
Chlorite	1	2
Calcite	1	3
F/F+Q	1	20
P/P+Kf	1	76

Table 10
Unit: Kane Basin Fm., member B
Location: Ella Bay 4-3 section, 208.5-225.0 m
Rock type: **mudrock**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	2	43-64	53.5
K-feldspar	2	3-4	3.5
Plagioclase	2	6-10	8.0
Mica-illite	2	7-15	11.0
Chlorite	2	4-11	7.5
Calcite	2	11-33	22.0
F/F+Q	2	14-22	18.0
P/P+Kf	2	59-77	68.0

Table 11
Unit: Kane Basin Fm., member B
Location: Ella Bay 4-3 section, 225.0-261.5 m
Rock type: **mudrock**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	4	49-66	57.5
K-feldspar	4	5-9	7.5
Plagioclase	4	3-6	5.0
Mica-illite	4	7-25	12.5
Chlorite	4	3-11	5.3
Calcite	4	2-21	11.3
Dolomite	4	0-3	0.6
F/F+Q	4	14-24	18.8
P/P+Kf	4	29-48	39.5

Table 12
Unit: Kane Basin Fm., member B
Location: Ella Bay 4-3 section, 264 m
Rock type: **mudrock**, coarse, in part sandy
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	2	67-72	69.5
K-feldspar	2	5-7	6.0
Plagioclase	2	2-2	2.0
Mica-illite	2	5-6	5.5
Dolomite	2	9-17	13.0
Siderite	2	2-6	4.0
F/F+Q	2	9-11	10.0
P/P+Kf	2	21-25	13.0

Table 13
Unit: Kane Basin Fm., member B
Location: Ella Bay 4-3 section, 267.7 m
Rock type: **sandstone**, very fine grained, argillaceous
Method: X-ray diffraction

	N	Range %
Quartz	1	59
K-feldspar	1	9
Plagioclase	1	2
Mica-illite	1	8
Calcite	1	20
Dolomite	1	3
F/F+Q	1	15
P/P+Kf	1	17

Table 14
Unit: Kane Basin Fm.
Location: Ella Bay 1-1 section, 73-79 m
Rock type: **sandstone**, very fine grained, argillaceous, with minor **mudrock**, coarse, sandy
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	2	77-90	83.5
K-feldspar	2	1-1	1.0
Plagioclase	2	5-6	5.5
Mica-illite	2	1-3	2.0
Chlorite	2	1-11	6.0
Calcite	2	0-2	1.0
Dolomite	2	0-2	1.0
F/F+Q	2	6-8	7.0
P/P+Kf	2	91	91.0

Table 15
Unit: Kane Basin Fm.
Location: Ella Bay 1-1 section
Rock type: **mudrock**, in part sandy
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %	σ %
Quartz	16	43-70	62.1	9.4
K-feldspar	16	1-2	1.1	0.5
Plagioclase	16	3-7	4.6	1.1
Mica-illite	16	2-14	9.3	3.3
Chlorite	16	2-42	21.9	8.7
Calcite	16	0-3	0.3	0.8
Dolomite	16	0-5	0.8	1.4
F/F+Q	16	7-10	8.6	1.2
P/P+Kf	16	71-100	81.4	8.2

Table 16
Unit: Kane Basin Fm.
Location: Ella Bay 6 section
Rock type: **mudrock**, in part sandy
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	2	66-69	67.5
K-feldspar	2	1	1.0
Plagioclase	2	6-7	6.5
Mica-illite	2	6-8	7.0
Chlorite	2	13-19	16.0
Calcite	2	0-1	0.5
Dolomite	2	0-3	1.5
F/F+Q	2	9-11	10.0
P/P+Kf	2	82-86	84.0

Table 17
Unit: oolitic limestone unit
Location: Ella Bay 4-5 section
Rock type: **limestone**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Mica-illite	4	0-2	0.5
Chlorite	4	0-tr	
Calcite	4	65-92	80.8
Dolomite	4	8-33	18.8
D/D+C	4	8-33	18.8

Table 18
Unit: Cass Fjord Fm.
Location: Ella Bay 4-6 section
Rock type: **limestone**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %	σ %
Quartz	27	0-37	15.4	11.0
K-feldspar	27	0-13	4.7	2.7
Plagioclase	27	0-1	tr	
Mica-illite	27	0-3	0.2	0.7
Chlorite	27	0-7	0.4	1.6
Calcite	27	28-95	65.9	18.5
Dolomite	27	0-35	13.9	10.1
Siderite				
F/F+Q	27	0-65	28.6	16.3
D/D+C	25	0-45	18.4	13.7

Table 19
Unit: Cass Fjord Fm.
Location: Ella Bay 3-1 section
Rock type: **limestone**
Method: X-ray diffraction

	N	Range %	X̄ %	σ %
Quartz	19	0-44	14.6	12.3
K-feldspar	19	0-13	2.4	3.1
Plagioclase	19	0-1	tr	
Calcite	19	42-100	71.9	18.0
Dolomite	19	0-36	11.1	10.9
F/F+Q	13	0-65	15.8	17.8
P/P+Kf	4	0-22	5.5	
D/D+C	19	0-43	13.9	13.2

Table 20
Unit: Cass Fjord Fm.
Location: Ella Bay 3-1 and 4-6 sections
Rock type: **dolostone**
Method: X-ray diffraction

	N	Range %	X̄ %	σ %
Quartz	12	12-34	22.5	7.9
K-feldspar	12	0-9	4.7	2.3
Plagioclase	12	0-1	0.7	0.6
Mica-illite	12	0-4	0.5	1.2
Chlorite	12	0-3	0.3	0.8
Calcite	12	7-38	15.8	11.0
Dolomite	12	47-72	55.6	9.8
F/F+Q	12	3-34	20.8	9.5
P/P+Kf	8	0-27	9.9	
D/D+C	12	55-94	78.4	13.3

Table 21
Unit: Cass Fjord Fm.
Location: Ella Bay 4-6 section
Rock type: **siltstone**
Method: X-ray diffraction

	N	Range %	X̄ %
Quartz	4	34-79	58.5
K-feldspar	4	6-18	10.0
Plagioclase	4	0-2	0.8
Mica-illite	4	0-8	2.3
Calcite	4	0-30	8.8
Dolomite	4	8-48	20.0
F/F+Q	4	7-28	17.3
P/P+Kf	4	0-17	7.8

Table 22
Unit: Cass Fjord Fm.
Location: Ella Bay 3-1 and 4-6 sections
Rock type: **sandstone**
Method: X-ray diffraction

	N	Range %	X̄ %
Quartz	8	64-96	83.1
K-feldspar	8	0-9	2.5
Plagioclase	8	0-1	0.1
Calcite	8	0-22	9.0
Dolomite	8	0-23	5.5
F/F+Q	8	0-12	3.4

Table 23
Cass Fjord Fm., statistics of combined X-ray diffraction and thin section analyses.

Samples representing		
1 rock type:	70	(59.3%)
2 rock types:	38	(32.2%)
3 rock types:	10	(8.5%)
total:	118	(100%)
Abundance in samples with 1 rock type		
limestone:	46	(65.7%)
dolostone:	12	(17.1%)
sandstone:	8	(11.4%)
siltstone:	4	(5.7%)
Abundance in samples with 2 or 3 rock types (weighted)		
dolostone:	32.4%	
siltstone:	25.7%	
limestone:	20.9%	
sandstone:	7.1%	
intrafm. congl:	6.3%	
Abundance in all samples (weighted)		
limestone	47.5%	
dolostone	23.3%	
siltstone	13.8%	
sandstone	12.8%	
intrafm. congl.	2.5%	
Combinations	N	
siltstone + dolostone	14	(29.2%)
limestone + dolostone	9	(18.8%)
sandstone + limestone	4	(8.3%)
sandstone + siltstone + dolostone	4	(8.3%)
sandstone + siltstone	3	(6.3%)
siltstone + limestone	3	(6.3%)
sandstone + dolostone + limestone	3	(6.3%)

sandstone + dolostone	2	(4.2%)
siltstone + dolostone + limestone	2	(4.2%)
limestone + dolostone (congl.)	2	(4.2%)
sandstone + limestone (congl.)	1	(2.1%)
sandstone + siltstone + limestone	1	(2.1%)

Table 24
Unit: Cape Clay Fm.
Location: Ella Bay 4-7 section
Rock type: **limestone**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %	σ %
Quartz	18	0-20	4.4	4.9
K-feldspar	18	0-10	2.2	2.7
Plagioclase	12	0-1	0.1	0.2
Chlorite	18	0-1	0.1	0.2
Calcite	18	55-99	76.2	15.7
Dolomite	18	0-44	17.2	14.1
F/F+Q	7	17-66	41.3	
P/P+Kf	3	0-11	3.7	
D/D+C	18	0-44	18.5	14.8

Table 25
Unit: Ninnis Glacier Fm.
Location: Ella Bay 4-8 section
Rock type: **limestone**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %	σ %
Quartz	20	0-33	11.1	9.0
K-feldspar	20	0-10	3.5	2.3
Plagioclase	20	0-1	0.1	0.3
Mica-illite	20	0-3	0.2	0.7
Chlorite	20	0-2	0.1	0.4
Calcite	20	40-90	70.6	18.0
Dolomite	20	0-39	14.7	13.5
F/F+Q	19	14-78	29.4	17.6
P/P+Kf	5	0-24	6.6	
D/D+C	20	0-50	17.6	16.0

Table 26
Unit: Ninnis Glacier Fm.
Location: Ella Bay 4-8 section
Rock type: **dolostone**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %	σ %
Quartz	21	5-30	14.1	5.8
K-feldspar	21	2-8	3.6	1.6
Plagioclase	21	0-1	0.2	0.4
Calcite	21	1-40	16.9	14.4
Dolomite	21	41-86	65.0	14.3
F/F+Q	21	11-35	23.6	6.3
P/P+Kf	6	0-24	10.0	
D/D+C	21	29-97	76.3	19.6

Table 27
Unit: Ninnis Glacier Fm.
Location: Ella Bay 3-2a section
Rock type: **intraformational conglomerate**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	2	11-14	12.5
K-feldspar	2	2-2	2.0
Plagioclase	2	0-1	0.5
Calcite	2	59-73	66.0
Dolomite	2	11-27	19.0
F/F+Q	2	14-21	17.5
D/D+C	2	13-32	22.5

Table 28
Unit: Eleanor River Fm.
Location: Ella Bay 4-9 section
Rock type: **dolostone**, laminated
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	3	10-25	15.7
K-feldspar	3	3-7	4.7
Plagioclase	3	0-2	0.7
Calcite	3	9-20	13.0
Dolomite	3	47-49	65.7
F/F+Q	3	19-42	27.7
P/P+Kf	1		33
D/D+C	3	71-90	83.0

Table 29
Unit: Eleanor River Fm.
Location: Ella Bay 4-9 section
Rock type: **limestone**, laminated or fissile
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	2	15-23	19.0
K-feldspar	2	0-6	3.0
Mica-illite	2	0-4	2.0
Calcite	2	71-81	76.0
F/F+Q	2	0-22	11.0
D/D+C	2	71-81	86.0

Table 30
Unit: Eleanor River Fm.
Location: Ella Bay 4-9 section
Rock type: interlaminated **dolostone** and **siltstone**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	2	12-36	24.0
K-feldspar	2	7-10	8.5
Calcite	2	9-10	9.5
Dolomite	2	45-71	58.0
F/F+Q	2	22-37	29.5
D/D+C	2	84-88	86.0

Table 31
Unit: Bay Fiord Fm.
Location: Ella Bay 4-10 section
Rock type: **limestone** (lithofacies C)
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	2	0-4	2.0
K-feldspar	2	0-3	1.5
Calcite	2	62-91	76.5
Dolomite	2	9-31	20.0
D/D+C	2	9-34	21.5

Table 32
Unit: Bay Fiord Fm.
Location: Ella Bay 4-10 section
Rock type: **dolostone** (lithofacies Cf)
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %	σ %
Quartz	12	2-25	6.8	7.5
K-feldspar	12	0-3	0.8	1.0
Plagioclase	12	0-2	0.8	0.8
Mica-illite	12	0-4	0.7	1.2
Chlorite	12	0-4	0.5	1.2
Calcite	12	0-37	8.4	9.7
Dolomite	12	61-90	82.1	9.7
F/F+Q	3	0-16	9.3	
D/D+C	12	63-100	91.2	9.6

Table 33
Unit: Bulleys Lump Fm., member A
Location: Ella Bay 3-3 section, 0-15 m
Rock type: **limestone**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	7	2-34	13.7
K-feldspar	7	2-4	3.1
Plagioclase	7	0-2	0.6
Calcite	7	49-75	65.9
Dolomite	7	11-26	16.6
F/F+Q	7	6-45	26.3
P/P+Kf	2	33-35	34.0
D/D+C	7	12-39	21.7

Table 34
Unit: Bulleys Lump Fm., member A
Location: Ella Bay 3-3 section, 209-426 m
Rock type: **limestone** (lithofacies C)
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	7	1-4	1.6
Calcite	7	75-100	94.6
Dolomite	7	0-22	3.7
D/D+C	7	0-23	3.9

Table 35
Unit: Bulleys Lump Fm., member A
Location: Ella Bay 3-3 section, 209-426 m
Rock type: **flat-pebble conglomerate** and **conglomeratic grainstone**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	3	2-7	5.0
Calcite	3	90-97	93.3
Dolomite	3	0-4	1.7
D/D+C	3	0-5	2.0

Table 36
Unit: Bulleys Lump Fm., member A
Location: Ella Bay 3-3 section, 209-426 m
Rock type: **dolostone** (lithofacies Cf)
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	8	2-30	14.9
K-feldspar	8	0-3	0.8
Plagioclase	8	0-2	0.9
Mica-illite	8	0-1	0.1
Chlorite	8	0-1	0.3
Calcite	8	1-31	10.6
Dolomite	8	38-94	72.3
D/D+C	8	55-99	86.1

Table 37
Unit: Bulleys Lump Fm., member B
Location: Ella Bay 3-3 section, 426-1559 m
Rock type: **limestone** (lithofacies C)
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %	σ %
Quartz	33	0-19	3.4	3.9
K-feldspar	33	0-11	0.8	2.3
Plagioclase	33	0-1	0.1	0.2
Mica-illite	33	0-3	0.2	0.7
Chlorite	33	0-5	0.2	0.9
Calcite	33	48-100	90.4	13.3
Dolomite	33	0-36	5.0	10.5
F/F+Q	1		4.0	
D/D+C	33	0-43	5.5	11.8

Table 38
Unit: Bulleys Lump Fm., member B
Location: Ella Bay 3-3 section, 426-1559 m
Rock type: **dolostone** (lithofacies C)
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	8	1-9	2.9
K-feldspar	8	0-1	0.8
Plagioclase	8	0-2	1.1
Mica-illite	8	0-1	0.1
Chlorite	8	0-3	0.4
Calcite	8	4-40	19.8
Dolomite	8	56-93	75.0
D/D+C	8	59-96	79.5

Table 39
Unit: Bulleys Lump Fm., member B
Location: Ella Bay 3-3 section, 426-1559 m
Rock type: **dolostone** (lithofacies fc)
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %	σ %
Quartz	17	0-27	8.8	9.3
K-feldspar	17	0-8	2.1	2.3
Plagioclase	17	0-2	0.8	0.9
Mica-illite	17	0-3	0.2	0.7
Chlorite	17	0-2	0.2	0.5
Calcite	17	4-42	17.4	10.5
Dolomite	17	48-99	70.7	13.7
F/F+Q	2	19-31	25.0	
P/P+Kf	2	0-26	13.0	
D/D+C	17	54-95	80.5	11.4

Table 40
Unit: Bulleys Lump Fm., member B
Location: Ella Bay 3-3 section, 426-1559 m
Rock type: **limestone** (lithofacies Cfc)
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	5	0-19	7.0
K-feldspar	5	0-5	1.8
Plagioclase	5	0-3	0.6
Mica-illite	5	0-2	0.4
Chlorite	5	0-1	0.2
Calcite	5	75-98	84.0
Dolomite	5	0-16	6.2
F/F+Q	3	0-40	21.3
P/P+Kf	1		33
D/D+C	5	0-16	64.0

Table 41
Unit: Bulleys Lump Fm., member B
Location: Ella Bay 3-3 section, 1559-1603 m
Rock type: **dolostone**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	3	0-8	3.7
K-feldspar	3	0-2	0.7
Plagioclase	3	0-3	1.7
Mica-illite	3	0-3	1.7
Chlorite	3	0-2	1.3
Calcite	3	15-27	25.0
Dolomite	3	61-75	66.3
D/D+C	3	63-84	73.0

Table 42
Unit: Bulleys Lump Fm., member B
Location: Ella Bay 3-3 section, 1559-1604 m
Rock type: **limestone** (lithofacies Cfc)
Method: X-ray diffraction

	N	Range %
Quartz	1	5
K-feldspar	1	5
Mica-illite	1	2
Chlorite	1	2
Calcite	1	45
Dolomite	1	42
D/D+C	1	48

Table 43
Unit: Bulleys Lump Fm., member B
Location: Ella Bay 2-East section, upper 36 m
Rock type: **limestone**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	7	1-3	1.4
K-feldspar	7	0-1	0.1
Chlorite	7	0-2	0.3
Calcite	7	96-99	98.0

Table 44
Unit: Bulleys Lump Fm., member B
Location: Ella Bay 2-East section, upper 36 m
Rock type: **limestone**, silty
Method: X-ray diffraction

	N	Range %
Quartz	1	10
K-feldspar	1	3
Mica-illite	1	1
Calcite	1	85
Dolomite	1	1
D/D+C	1	1

Table 45
Unit: Bulleys Lump Fm., member B
Location: Ella Bay 2-East section, upper 36 m
Rock type: **mudrock**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	2	39-41	40.0
K-feldspar	2	8-9	8.5
Plagioclase	2	1-2	1.5
Mica-illite	2	4-6	5.0
Chlorite	2	2-9	5.5
Calcite	2	2-40	21.0
Dolomite	2	3-34	18.5
F/F+Q	2	19-21	20.0
P/P+Kf	2	13-17	15.0
D/D+C	2	8-94	51.0

Table 46
Unit: Thumb Mountain Fm.
Location: Ella Bay 3-4 section
Rock type: **limestone**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	6	0-2	1.7
Mica-illite	6	0-1	0.2
Calcite	6	97-100	98.0
Dolomite	6	0-1	0.2
D/D+C	6	0-1	0.2

Table 47
Unit: Thumb Mountain Fm.
Location: Ella Bay 3-5 section
Rock type: **limestone**, silty, sandy
Method: X-ray diffraction

	N	Range %
Quartz	1	16
K-feldspar	1	3
Plagioclase	1	1
Mica-illite	1	5
Chlorite	1	3
Calcite	1	72

Table 48
Unit: Irene Bay Fm.
Location: Ella Bay 3-5 section
Rock type: **limestone**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	6	2-8	4.2
Calcite	6	92-98	95.7
Dolomite	6	0-1	0.2

Table 49
Unit: Allen Bay Fm.
Location: Ella Bay 3-6 section
Rock type: **limestone**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	6	2-4	2.5
Calcite	6	96-98	97.2
Dolomite	6	0-1	0.3

Table 50
Unit: Nesmith beds
Location: Henrietta Nesmith Glacier section
Rock type: **calcarenite** and **lime mudstone**, argillaceous, sandy
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %	σ %
Quartz	10	10-40	25.1	9.4
K-feldspar	10	0-1	0.1	0.3
Plagioclase	10	0-7	2.7	1.9
Mica-illite	10	0-11	2.9	3.4
Chlorite	10	0-3	1.1	1.2
Calcite	10	57-81	68.0	8.6
Dolomite	10	0-1	0.1	0.3
F/F+Q	10	0-33	12.6	11.1
P/P+Kf	1		86	
D/D+C	10	0-2	0.2	0.6

Table 51
Unit: Nesmith beds
Location: Henrietta Nesmith Glacier section
Rock type: **calcarenite** and **lime mudstone**, relatively pure
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	2	5-6	5.5
Plagioclase	2	0-2	1.0
Mica-illite	2	0-3	1.5
Calcite	2	91-93	92.0

Table 52
Unit: Nesmith beds
Location: Henrietta Nesmith Glacier section
Rock type: **sandstone**, calcareous
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	4	48-67	58.3
Plagioclase	4	3-9	5.0
Mica-illite	4	0-9	3.5
Chlorite	4	0-8	2.8
Calcite	4	26-42	30.5
F/F+Q	4	5-15	8.3
P/P+Kf	2	100	100

Table 53
Unit: Nesmith beds
Location: Henrietta Nesmith Glacier section
Rock type: **mudrock**, noncalcareous
Method: X-ray diffraction

	N	Range %
Quartz	1	43
Plagioclase	1	10
Mica-illite	1	31
Chlorite	1	16
F/F+Q	1	19
P/P+Kf	1	100

Table 54
Unit: Nesmith beds
Location: Henrietta Nesmith Glacier section
Rock type: **mudrock**, coarse, calcareous
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	3	23-45	30.7
K-feldspar	3	0-1	0.3
Plagioclase	3	1-14	6.0
Mica-illite	3	4-16	9.0
Chlorite	3	2-4	3.0
Calcite	3	47-52	50.3
F/F+Q	3	3-37	19.0
P/P+Kf	3	100	100

Table 55
Unit: Nesmith beds
Location: Patterson River
Rock type: **mudrock**, calcareous
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	3	34-54	43.7
K-feldspar	3	0-2	1.0
Plagioclase	3	4-7	5.7
Mica-illite	3	4-18	9.3
Chlorite	3	2-38	15.7
Calcite	3	1-46	22.7
Dolomite	3	0-6	2.0
F/F+Q	3	10-22	14.0
P/P+Kf	3	79-100	89.0
D/D+C	3	0-22	7.3

Table 56
Unit: Nesmith beds
Location: Patterson River
Rock type: **lime mudstone**, argillaceous, in part sandy
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	4	12-36	20.0
K-feldspar	4	0-1	0.3
Plagioclase	4	1-5	3.0
Mica-illite	4	0-4	2.5
Chlorite	4	3-7	4.5
Calcite	4	33-78	65.5
Dolomite	4	0-14	4.3
F/F+Q	4	4-20	13.5
P/P+Kf	1		89
D/D+C	4	0-29	8.0

Table 57
Unit: Nesmith beds
Location: Patterson River
Rock type: **lime mudstone**, relatively pure
Method: X-ray diffraction

	N	Range %
Quartz	1	5
Calcite	1	90
Dolomite	1	5
D/D+C	1	5

Table 58
Unit: Nesmith beds
Location: Patterson River
Rock type: **sandstone**, calcareous
Method: X-ray diffraction

	N	Range %
Quartz	1	71
K-feldspar	1	tr
Plagioclase	1	tr
Mica-illite	1	3
Chlorite	1	2
Calcite	1	23

Table 59
Unit: Grant Land Fm., member A_1
Location: Rollrock Lake section
Rock type: **sandstone**, calcareous, bimodal
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %	σ %
Quartz	18	54-80	69.2	6.7
K-feldspar	18	0-1	0.2	0.4
Plagioclase	18	1-5	3.7	1.9
Mica-illite	18	0-3	0.9	1.0
Calcite	18	19-38	25.8	5.2
F/F+Q	18	1-8	5.6	2.7
P/P+Kf	6	86-100	92.3	

Table 60
Unit: Grant Land Fm., member A_1
Location: Henrietta Nesmith Glacier section
Rock type: **sandstone**, calcareous, bimodal
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	3	69-87	77.0
Plagioclase	3	2-7	4.0
Chlorite	3	0-1	0.3
Calcite	3	11-24	18.7
F/F+Q	3	2-10	5.3
P/P+Kf	1		100

Table 61
Unit: Grant Land Fm., member A_1
Location: Patterson River
Rock type: **sandstone**, calcareous, bimodal
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	2	48-62	55.0
K-feldspar	2	0-1	0.5
Plagioclase	2	1-4	2.5
Mica-illite	2	0-3	1.5
Chlorite	2	2-3	2.5
Calcite	2	34-42	38.0
F/F+Q	2	2-8	5.0

Table 62
Unit: Grant Land Fm., member A_2
Location: Rollrock Lake section
Rock type: **sandstone**, bimodal
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	2	90	90.0
Plagioclase	2	5-7	6.0
Mica-illite	2	1-3	2.0
Chlorite	2	1-2	1.5
Calcite	2	0-1	0.5
F/F+Q	2	5-7	6.0
P/P+Kf	2	100	100

Table 63
Unit: Grant Land Fm., member A_1
Location: Rollrock Lake section
Rock type: **mudrock**, coarse, sandy, calcareous
Method: X-ray diffraction

	N	Range %
Quartz	1	62
Plagioclase	1	9
Mica-illite	1	6
Calcite	1	23
F/F+Q	1	12
P/P+Kf	1	100

Table 64
Unit: Grant Land Fm., member A_1, lower part
Location: Henrietta Nesmith Glacier section
Rock type: **mudrock**, noncalcareous
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	2	53-58	55.5
K-feldspar	2	1-2	1.5
Plagioclase	2	4-7	5.5
Mica-illite	2	22-26	24.0
Chlorite	2	12-13	12.5
F/F+Q	2	10-14	12.0
P/P+Kf	2	67-83	75.0

Table 65
Unit: Grant Land Fm., member B
Location: Tanquary Fiord section
Rock type: **granule** and **pebble conglomerate**
Method: X-ray diffraction

	N	Range %	X̄ %
Quartz	4	81-89	84.8
K-feldspar	4	0-4	2.3
Plagioclase	4	6-11	9.3
Mica-illite	4	0-2	1.3
Chlorite	4	0-2	1.3
Calcite	4	0-5	1.5
F/F+Q	4	10-15	11.8
P/P+Kf	4	68-100	81.8

Table 66
Unit: Grant Land Fm., member B
Location: Tanquary Fiord section
Rock type: **sandstone**, medium and coarse grained
Method: X-ray diffraction

	N	Range %	X̄ %	σ %
Quartz	29	65-94	85.0	6.2
K-feldspar	29	0-5	0.8	1.2
Plagioclase	29	4-20	10.1	4.0
Mica-illite	29	0-8	1.8	1.9
Chlorite	29	0-6	1.8	1.4
Calcite	29	0-3	0.4	0.8
F/F+Q	29	5-24	11.1	4.7
P/P+Kf	29	62-100	92.2	10.8

Table 67
Unit: Grant Land Fm., member B
Location: Hare Fiord East section
Rock type: **sandstone**, medium and coarse grained
Method: X-ray diffraction

	N	Range %	X̄ %	σ %
Quartz	20	69-98	86.0	6.5
K-feldspar	20	0-6	2.2	1.7
Plagioclase	20	2-13	7.9	2.9
Mica-illite	20	0-13	2.4	2.7
Chlorite	20	0-3	1.3	1.1
Calcite	20	0-1	0.2	0.4
Dolomite	20	0-2	0.2	0.5
F/F+Q	29	2-18	10.6	4.5
P/P+Kf	29	58-100	80.7	13.2

Table 68
Unit: Grant Land Fm., member B
Location: Tanquary Fiord section
Rock type: **sandstone**, very fine, fine, and fine to medium grained
Method: X-ray diffraction

	N	Range %	X̄ %	σ %
Quartz	12	62-87	72.9	8.7
K-feldspar	12	0-3	0.9	1.0
Plagioclase	12	6-28	14.5	7.5
Mica-illite	12	1-13	5.7	3.3
Chlorite	12	1-12	5.2	3.1
Calcite	12	0-7	0.8	2.0
Dolomite	12	0-tr		
F/F+Q	12	7-33	17.4	8.0
P/P+Kf	12	71-100	93.3	8.5

Table 69
Unit: Grant Land Fm., member B
Location: Hare Fiord East section
Rock type: **sandstone**, very fine, fine, and fine to medium grained
Method: X-ray diffraction

	N	Range %	X̄ %
Quartz	7	67-86	77.1
K-feldspar	7	0-5	1.6
Plagioclase	7	5-14	9.3
Mica-illite	7	3-13	6.4
Chlorite	7	2-10	5.1
Calcite	7	0-1	0.3
Dolomite	7	0-1	0.1
F/F+Q	7	8-16	13.0
P/P+Kf	7	59-100	85.0

Table 70
Unit: Grant Land Fm., member B
Location: Tanquary Fiord section
Rock type: **mudrock**
Method: X-ray diffraction

	N	Range %	X̄ %	σ %
Quartz	14	33-84	61.6	12.7
K-feldspar	14	1-3	1.1	0.5
Plagioclase	14	3-17	8.6	4.1
Mica-illite	14	5-39	17.0	8.0
Chlorite	14	0-21	11.6	5.3
Dolomite	14	0-tr		
F/F+Q	14	5-28	13.9	6.4
P/P+Kf	14	70-94	86.8	7.8

Table 71
Unit: Grant Land Fm., member B
Location: Hare Fiord East section
Rock type: **mudrock**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	9	22-74	53.3
K-feldspar	9	tr-3	1.7
Plagioclase	9	4-17	10.2
Mica-illite	9	5-37	17.8
Chlorite	9	10-28	17.0
Dolomite	9	0-tr	
F/F+Q	9	6-41	20.1
P/P+Kf	9	82-94	86.8
D/D+C			

Table 72
Unit: Grant Land Fm., member C_1
Location: Macdonald River 1 section and localities north of Macdonald River
Rock type: **sandstone**, very fine grained
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %	σ %
Quartz	10	83-95	89.4	3.4
K-feldspar	10	0-1	0.1	0.3
Plagioclase	10	0-7	1.6	2.0
Mica-illite	10	2-6	3.2	1.5
Chlorite	10	0-9	3.4	3.2
Calcite	10	0-2	0.2	0.6
Dolomite	10	0-8	2.2	2.9
F/F+Q	10	0-8	1.9	2.2
P/P+Kf	1		100	

Table 73
Unit: Grant Land Fm., member C_1
Location: Macdonald River 1 section
Rock type: **mudrock**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	2	57-92	64.5
K-feldspar	2	1-1	1.0
Plagioclase	2	1-2	1.5
Mica-illite	2	5-10	7.5
Chlorite	2	21-30	25.5
F/F+Q	2	4-6	5.0

Table 74
Unit: Grant Land Fm., member C_1
Location: Osborn Range section
Rock type: **mudrock**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	9	50-83	67.7
K-feldspar	9	1-4	2.3
Plagioclase	9	2-4	3.0
Mica-illite	9	7-15	10.4
Chlorite	9	3-30	16.4
F/F+Q	9	5-10	7.2
P/P+Kf	9	40-81	56.3

Table 75
Unit: Hazen Fm., carbonate member
Location: Ella Bay 1-2 section
Rock type: **mudrock**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %	σ %
Quartz	10	41-72	57.5	10.4
K-feldspar	10	0-5	1.2	1.3
Plagioclase	10	2-5	3.8	0.9
Mica-illite	10	6-13	9.5	2.5
Chlorite	10	6-13	9.6	2.8
Calcite	10	2-45	18.2	13.2
Dolomite	10	0-1	0.1	0.3
F/F+Q	7	7-9	8.1	
P/P+Kf	7	31-89	76.0	
D/D+C	8	0-tr		

Table 76
Unit: Hazen Fm., carbonate member
Location: Ella Bay 1-2-1 section, 101.7-593.0 m
Rock type: **mudrock**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %	σ %
Quartz	15	36-65	52.2	7.8
K-feldspar	15	3-22	12.0	5.3
Plagioclase	15	0-1	0.2	0.4
Mica-illite	15	0-6	3.3	1.9
Chlorite	15	0-13	4.6	3.1
Calcite	15	0-30	15.3	9.7
Dolomite	15	1-36	12.4	9.1
F/F+Q	14	8-28	19.7	6.4
P/P+Kf	14	0-17	1.7	4.6
D/D+C	14	9-42	46.8	29.5

Table 77
Unit: Hazen Fm., carbonate member
Location: d'Iberville Glacier section, 3-19 m
Rock type: **mudrock**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	4	38-46	41.75
K-feldspar	4	1-2	1.75
Plagioclase	4	0-2	1.0
Mica-illite	4	1-5	3.5
Chlorite	4	3-12	8.75
Calcite	4	30-45	38.0
Dolomite	4	3-8	5.25
F/F+Q	4	5-8	6.3
D/D+C	4	7-21	13.0

Table 78
Unit: Hazen Fm., carbonate member
Location: St. Patrick Bay section
Rock type: **mudrock**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	2	69-70	69.5
K-feldspar	2	7-8	7.5
Plagioclase	2	0-2	1.0
Mica-illite	2	2-3	2.5
Chlorite	2	3-4	3.5
Calcite	2	13-16	14.5
Dolomite	2		1.5
F/F+Q	2	10-11	10.5
P/P+Kf	2	0-21	10.5
D/D+C	2	7-12	9.5

Table 79
Unit: Hazen Fm., carbonate and chert members
Location: Very River section
Rock type: **mudrock**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	5	41-76	65.0
K-feldspar	5	0-10	6.6
Plagioclase	5	0-5	1.8
Mica-illite	5	0-4	2.4
Chlorite	5	0-4	2.2
Calcite	5	1-13	6.0
Dolomite	5	2-39	16.0
F/F+Q	4	0-21	11.8
P/P+Kf	3	13-28	21.3
D/D+C	5	53-80	65.2

Table 80
Unit: Hazen Fm., carbonate member
Location: Ella Bay 1-2-1 and Very River sections
Rock type: **sandstone**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	4	40-70	52.3
K-feldspar	4	4-11	8.5
Plagioclase	4	1-5	2.8
Mica-illite	4	0-2	0.5
Calcite	4	11-50	30.3
Dolomite	4	1-15	5.5
F/F+Q	4	12-23	18.0
P/P+Kf	4	11-34	24.3
D/D+C	4	2-32	16.5

Table 81
Unit: Hazen Fm., carbonate member
Location: Ella Bay 1-2 section
Rock type: **lime mudstone**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %	σ %
Quartz	15	3-33	15.7	10.6
K-feldspar	15	2-12	5.4	3.1
Plagioclase	15	0-1	0.2	0.4
Mica-illite	15	0-4	1.2	1.5
Chlorite	15	0-4	1.4	1.5
Calcite	15	45-95	67.2	20.1
Dolomite	15	0-23	8.9	7.7
F/F+Q	7	22-48	30.6	
P/P+Kf	7	0-15	5.1	
D/D+C	15	0-46	13.5	13.6

Table 82
Unit: Hazen Fm., carbonate member
Location: d'Iberville Glacier section
Rock type: **lime mudstone**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %	σ %
Quartz	13	11-35	21.5	6.1
K-feldspar	13	0-3	0.7	0.8
Plagioclase	13	0-2	0.8	0.8

	N	Range %	$\bar{X}$ %	σ %
Mica-illite	13	0-2	1.0	1.0
Chlorite	13	0-4	1.1	1.6
Calcite	13	42-75	66.2	10.1
Dolomite	13	3-24	8.7	6.0
F/F+Q	13	3-17	6.8	5.7
D/D+C	13	3-36	11.8	8.7

Table 83

Unit: Hazen Fm., carbonate member
Location: Very River and Macdonald River sections
Rock type: **lime mudstone**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	3	8-19	14.7
Plagioclase	3	0-2	0.7
Calcite	3	74-90	80.0
Dolomite	3	0-7	4.7
F/F+Q	3	0-tr	
D/D+C	3	0-9	6.0

Table 84

Unit: Hazen Fm., carbonate member
Location: St. Patrick Bay section
Rock type: **lime mudstone**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	2	8-21	14.5
K-feldspar	2		1.5
Plagioclase	2	0-tr	
Mica-illite	2	0-tr	
Chlorite	2	0-tr	
Calcite	2	77-89	83.0
Dolomite	2	tr-2	1.0
F/F+Q	2	10-13	11.5
D/D+C	2	0-2	1.0

Table 85

Unit: Hazen Fm., carbonate member
Location: Ella Bay 1-2 section
Rock type: **calcarenite**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	5	6-33	20.2
K-feldspar	5	2-8	4.2
Plagioclase	5	0-tr	
Mica-illite	5	tr-1	0.2
Chlorite	5	0-5	1.4
Calcite	5	52-90	71.4
Dolomite	5	2-5	2.6
F/F+Q	5	5-33	20.6
D/D+C	5	2-9	3.8

Table 86

Unit: Hazen Fm.
Location: St. Patrick Bay and Macdonald River 3 sections
Rock type: **calcarenite**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	2	16-20	18.0
K-feldspar	2	1-1	1.0
Calcite	2	79-82	80.5
F/F+Q	2	7-7	7.0

Table 87

Unit: Hazen Fm.
Location: Ella Bay 1-2, Macdonald River 3, and Very River sections
Rock type: **radiolarian chert**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %	σ %
Quartz	10	95-100	98.0	1.8
K-feldspar	10	0-1	0.3	0.5
Plagioclase	10	0-1	0.1	0.3
Mica-illite	10	0-2	0.6	0.8
Chlorite	10	0-3	0.4	0.9
Calcite	10	0-3	0.3	0.9
Dolomite	10	0-3	0.3	0.9

Table 88
Unit: Danish River Fm.
Location: Hazen Plateau, various localities
Rock type: **sandstone**
Method: X-ray diffraction

	N	Range %	X̄ %	σ %
Quartz	11	42-58	49.5	3.9
K-feldspar	11	0-2	0.8	0.7
Plagioclase	11	3-6	4.8	1.1
Mica-illite	11	3-13	7.5	3.0
Chlorite	11	4-13	8.9	2.9
Calcite	11	13-25	20.2	4.7
Dolomite	11	6-12	8.7	2.5
F/F+Q	11	3-13	10.1	1.8
P/P+Kf	9	66-100	85.0	
D/D+C	11	22-38	30.1	5.2

Table 89
Unit: Danish River Fm.
Location: Hazen Plateau, various localities
Rock type: **mudrock**
Method: X-ray diffraction

	N	Range %	X̄ %
Quartz	7	37-50	42.7
K-feldspar	7	0-2	1.0
Plagioclase	7	5-10	6.9
Mica-illite	7	6-17	9.7
Chlorite	7	4-9	7.4
Calcite	7	13-52	23.7
Dolomite	7	0-11	9.1
F/F+Q	7	10	15.1
P/P+Kf	7	71-100	89.6
D/D+C	7	24-46	28.6

Table 90
Unit: Danish River Fm.
Location: Chandler Fiord sections
Rock type: **sandstone**
Method: X-ray diffraction

	N	Range %	X̄ %
Quartz	7	48-58	54.4
K-feldspar	7	0-1	0.6
Plagioclase	7	5-8	6.4
Mica-illite	7	3-4	3.4
Chlorite	7	5-7	5.6
Calcite	7	17-27	21.0
Dolomite	7	6-13	8.6
F/F+Q	7	8-15	11.1
P/P+Kf	7	87-100	95.6
D/D+C	7	21-41	29.1

Table 91
Unit: Danish River Fm.
Location: Chandler Fiord sections
Rock type: **mudrock**
Method: X-ray diffraction

	N	Range %	X̄ %	σ %
Quartz	25	30-57	41.6	6.9
K-feldspar	25	0-2	1.0	0.6
Plagioclase	25	3-10	4.5	1.9
Mica-illite	25	3-27	12.2	7.9
Chlorite	25	3-27	14.1	8.0
Calcite	25	1-41	19.1	10.5
Dolomite	25	3-11	7.5	1.8
F/F+Q	25	8-18	11.5	2.9
P/P+Kf	18	65-100	82.2	11.1
D/D+C	25	12-54	34.4	18.4

Table 92
Unit: Danish River Fm.
Location: Ella Bay 2-South
Rock type: **sandstone**
Method: X-ray diffraction

	N	Range %	X̄ %
Quartz	7	43-68	59.6
K-feldspar	7	1-7	4.1
Plagioclase	7	0-3	1.4
Mica-illite	7	2-2	2.1
Chlorite	7	1-3	2.1
Calcite	7	15-27	20.1
Dolomite	7	8-15	10.9
F/F+Q	7	5-14	8.6
P/P+Kf	6	9-60	21.5
D/D+C	7	31-36	34.9

Table 93
Unit: Danish River Fm.
Location: Ella Bay 2-South section
Rock type: **mudrock**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	5	35-57	44.8
K-feldspar	5	3-7	4.6
Plagioclase	5	1-2	1.2
Mica-illite	5	4-9	6.2
Chlorite	5	4-9	6.0
Calcite	5	13-33	22.4
Dolomite	5	12-18	14.8
F/F+Q	4	9-16	12.0
P/P+Kf	4	15-38	23.0
D/D+C	5	34-55	40.4

Table 94
Unit: Danish River Fm.
Location: d'Iberville Glacier section
Rock type: **sandstone**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	8	47-66	54.9
K-feldspar	8	0-1	0.8
Plagioclase	8	3-5	3.4
Mica-illite	8	1-3	2.3
Chlorite	8	2-4	2.3
Calcite	8	15-32	24.9
Dolomite	8	9-15	11.6
F/F+Q	8	5-10	6.6
P/P+Kf	2	88	88.0
D/D+C	8	22-38	32.5

Table 95
Unit: Danish River Fm.
Location: d'Iberville Glacier section
Rock type: **mudrock**
Method: X-ray diffraction

	N	Range %	$\bar{X}$ %
Quartz	9	40-57	50.0
K-feldspar	9	0-1	0.7
Plagioclase	9	3-4	3.6
Mica-illite	9	2-15	5.4
Chlorite	9	2-8	4.2
Calcite	9	7-27	19.4
Dolomite	9	10-22	16.7
F/F+Q	9	5-12	7.7
P/P+Kf	3	72-82	75.7
D/D+C	9	35-73	46.8

APPENDIX 3

PALEONTOLOGY

A. IDENTIFICATIONS OF CAMBRIAN TO SILURIAN MACROFOSSILS AND TRACE FOSSILS

B.S. Norford, W.H. Fritz, G.A. Cooper, T.A. de Freitas, D.E. Jackson, H.J. Hofmann, G.M. Narbonne, J. Pojeta Jr., J. Riva, and R. Thorsteinsson.

RAWLINGS BAY FORMATION

GSC localities C-75487, C-75488, and C-75489. About 25 km west-southwest of Cape Leopold von Buch (south of Carl Ritter Bay); NTS 120 C; UTM Zone 19X, 501600E, 8978200N; 0-59 m above base of formation; identification by H.J. Hofmann.

Ichnofauna

Planolites sp.
Didymaulichnus sp.
cf. *Diplocraterion*

Remarks. *Planolites* is Precambrian to Recent in age and *Didymaulichnus* late Proterozoic and Paleozoic; the depositional environment probably was shallow marine.

GSC localities C-75490, C-75491, C-75492, and C-75493. Section Ella Bay 4-2; NTS 120 C, UTM Zone 19X, 507200E, 8995900N; member C, 0-212 m below top of member and formation; identification by H.J. Hofmann.

Ichnofauna

Planolites sp.
Didymaulichnus sp.
Rusophycus sp.
?*Halopoa* sp.

Remarks. *Rusophycus* is Cambrian or younger, *Halopoa* Cambrian; the depositional environment probably was shallow marine.

KANE BASIN FORMATION

GSC locality C-74520. Section Ella Bay 1-1; NTS 120 C; UTM Zone 19X, 482300E, 900500N; talus 98.5 m below top of formation; identification by W.H. Fritz.

Fauna

Elliptocephala? sp.

Remarks. *Elliptocephala* is known from the "Taconic sequence" in New York and from boulders in the Levis Formation of the St. Lawrence Lowland, Quebec. At both localities strata containing the genus belong to the *Bonnia-Olenellus* Zone. The assignment of the present specimen is questioned because of the exceptionally wide border furrow in the cephalon, and therefore the age must also be questioned, but it can be stated as probably belonging to either the *Bonnia-Olenellus* Zone or the *Nevadella* Zone.

GSC locality C-75409. Section Ella Bay 4-3; NTS 120 C; UTM Zone 19X, 507600E, 8996500N; 208.5-225.0 m above base of formation, 0-16.5 m above base of member B; same location as GSC localities 51570 and 51572 of Kerr (1967, p. 28); identification by W.H. Fritz.

Fauna

Obolella sp.
Olenellus sp.
Wanneria sp.
Yukonites sp.

Remarks. The presence of *Olenellus* and the questionable presence of *Wanneria* suggest the collection belongs to the medial part of the Lower Cambrian *Bonnia-Olenellus* Zone. Trilobites belonging to the genus *Yukonites* have previously been reported from the *Nevadella* Zone in the Mackenzie Mountains and strata of the same age in Siberia. The species of *Yukonites* in collection C-75409 is different from the known species and extends the range of the genus into younger strata.

GSC locality C-171539. Locality F14 of Figure 1; NTS 120 C; UTM Zone 19X, 492700E, 9005300N; Kane Basin Formation; collected by D.W. Esson; identification by G.M. Narbonne.

Fauna

Teichichnus sp.

Remarks. The specimen is broken on both ends and can therefore not be identified to ichnospecies level. *Teichichnus* first appears just above the base of the Cambrian and ranges throughout the Phanerozoic. Cambrian specimens occur most commonly in offshore subtidal deposits.

SCORESBY BAY FORMATION

GSC locality C-96913. Section Ella Bay 4-4; NTS 120 C; UTM Zone 19X, 505500E, 8996000N; member C, lower part; identification by G.M. Narbonne.

Ichnofauna
Paleophycus tubularis Hall

Remarks. *Palaeophycus* is non-diagnostic; it ranges in age from Late Proterozoic to Recent and occurs in environments ranging from nonmarine to deep sea.

IRENE BAY FORMATION

GSC locality C-54935. Section Ella Bay 3-5; NTS 120 C, UTM Zone 19X; 501600E, 9004000N; lower part of formation; identification by B.S. Norford.

Fauna
Catenipora sp.
Foerstephyllum sp.

Remarks. Ordovician, probably late Caradoc or Ashgill (Edenian to Richmondian).

GSC locality C-54936. Section Ella Bay 3, but offset from C-54909; about 11.7 km south-southeast of Bulleys Lump; NTS 120 C; UTM Zone 19X, 501600E, 9004000N; talus 58 m above base of formation; identification by B.S. Norford.

Fauna
Catenipora sp.

Remarks. Late Caradoc (Edenian) to Silurian.

GSC locality C-54937. Same location; talus 79 m above base of formation; identification by B.S. Norford.

Fauna
Crenulites sp.

Remarks. Ordovician, probably late Caradoc or Ashgill (Edenian to Richmondian).

GSC locality C-54934. Location as for C-54936; higher than C-54935; identification by B.S. Norford.

Fauna
Calapoecia sp.
Catenipora sp.
Crenulites sp.
Paleofavosites sp.
Palaeophyllum sp.
streptelasmid coral
algae

Remarks. Ordovician, probably Ashgill (Maysvillian or Richmondian) because of presence of *Paleofavosites*.

GSC locality C-75450. Section Ella Bay 4-12; UTM Zone 19X, 505700E, 8999500N; upper part of formation (approximately 115 m according to photogrammetry); identification by B.S. Norford.

Fauna
Calapoecia sp.
Catenipora sp.
Coccoseris astomata Flower
Crenulites akpatokensis Flower
Grewingkia sp.
?*Lobocorallium* sp.
algae
stromatoporoid
echinoderm debris

Remarks. Ordovician, late Caradoc or Ashgill, probably late Caradoc–early Ashgill (Edenian-Maysvillian; Red River correlation) and possibly coeval with third assemblage of Norford (1966, p. 11-12).

ALLEN BAY FORMATION

GSC locality C-54912. Section Ella Bay 3-6; NTS 120 C; UTM Zone 19X, 501100E, 9003500N; 313.5-316.5 m above base of formation; identification by B.S. Norford.

Fauna
?*Paleofavosites* sp.
solitary coral

Remarks. Late Edenian to Late Silurian.

GSC locality C-96088. Location as for C-54912; 316.5 m above base of formation; identification of corals by B.S. Norford and of other forms by T.A. de Freitas.

Fauna

Catenipora sp.
rugose coral indet.
Wetheredella sp.

Remarks. *Catenipora* is late Middle Ordovician to Late Silurian in age. *Wetheredella* is a problematical genus, perhaps a porostromate cyanophyte (Chuvashov and Riding, 1987), ranging in age from Ordovician to Permian. Also present is micrite of probable microbial origin, encrusting the chain coral and forming stromatolites (*sensu* Burne and Moore, 1987).

GSC locality C-75273. Locality F9, Figure 1, about 5 km southwest of section EB4-13; NTS 120 C; UTM Zone 19X, 501600E, 8997300N; identification by B.S. Norford (see Appendix 3B for condonts from same locality).

Fauna

Bighornia sp.
Catenipora sp.
echinoderm debris

Remarks. Late Ordovician, Ashgill. The presence of *Bighornia* indicates correlation with Ashgill carbonates at Daly River (on strike to the northeast) and with lower beds of the Allen Bay Formation on Devon Island (see Norford, 1966, p. 12).

GRANT LAND FORMATION

GSC locality C-194462. Osborne Range, 7 km northwest of head of Tanquary Fiord; NTS 340 D; UTM Zone 18X, 464800E, 9054700N; uppermost part of member B or lower part of member C; collected by M.P. Cecile; preliminary identification by H. Hofmann.

Fauna

Oldhamia spp.

Remarks. Early Cambrian.

GSC locality C-194463. East of head of Tanquary Fiord, northwest of Redrock Creek; NTS 340 D; UTM Zone 18X, 477700E, 9044700N; member B, upper(?) part; collected by M.P. Cecile; preliminary identification by H. Hofmann.

Fauna

Oldhamia spp.
Palaeophycus sp.

Remarks. Early Cambrian.

GSC locality C-194464. East of head of Tanquary Fiord, northwest of Redrock Creek; NTS 340 D; UTM Zone 18X, 476400E, 9044000N; member B, upper(?) part; collected by M.P. Cecile; preliminary identification by H. Hofmann.

Fauna

Planolites sp.
Didymaulichnus? sp.

HAZEN FORMATION

GSC locality C-74640. Section Ella Bay 1-2; NTS 120 C; UTM Zone 19X; 482100E, 9005250N; 100 m northeast of line of section, about 38-46 m above base of section; identification by W.H. Fritz.

Fauna

Olenellus sp.

Remarks. Late Early Cambrian, *Bonnia-Olenellus* Zone (GSC type number 56649).

GSC locality C-96669. Locality F11 of Figure 1; NTS 120 C; UTM Zone 19X, 496750E, 9007200N; laminite facies of carbonate member of Hazen Formation; identification by W.H. Fritz.

Fauna

Glossopleura? sp.
Ogygopsis sp.

Remarks. The genus *Ogygopsis* ranges from late Early Cambrian (*Bonnia-Olenellus* Zone) to the medial Middle Cambrian (*Bathyuriscus-Elrathina* Zone). The association here with one *Glossopleura*? sp. tail suggests an early Middle(?) Cambrian age (*Glossopleura* Zone). Since *Ogygopsis* commonly occurs in a slope environment, and *Glossopleura* is only known to extend a short distance basinward from the carbonate shelf, the collection may have come from an upper slope environment.

GSC locality C-171536. Locality F12 of Figure 1; NTS 120 C; UTM Zone 19X, 488800E, 9002500N; carbonate member of Hazen Formation; collected by D.W. Esson, identification by W.H. Fritz.

Fauna

inarticulate brachiopod
asaphid trilobite

Remarks. The asaphid trilobites in this collection belong to one species that resembles Upper Cambrian forms. The glabella is parallel-sided, the palpebral lobes are in a forward position and the posterior area is long (exsag.). The pygidium has at least 10 well defined axial rings and the plural furrows are also well defined. (See also remarks for C-171537, below.)

GSC locality C-171537. Locality F13 of Figure 1; NTS 120 C; UTM Zone 19X, 487200E, 9001300N; carbonate member of Hazen Formation; collected by D.W.Esson, identification by W.H. Fritz.

Fauna

olenid trilobite, cf. *Ctenopyge* sp.

Remarks. The limited material and poor preservation do not permit an exact assignment for the above two collections. However, enough features are preserved to permit a tentative placement in the Upper Cambrian. As the relative stratigraphic position or stratigraphic distance between the two collections is unknown, one tentative age assignment cannot be used to support the other. Both the lithology and the type of trilobites suggest the collections came from the outer detrital belt.

GSC locality C-54873. 9.4 km southwest of head of Tanquary Fiord, first outcrops northeast of Macdonald River; NTS 340 D; UTM Zone 18X, 580300E, 9038600N; approximately 2.5-4 m above base of lower resistant unit of carbonate member; identification by G.A. Cooper.

Fauna

poorly preserved dorsal valve of acrotretid? brachiopod

Remarks. perhaps Cambrian to Early Ordovician.

GSC locality C-54883. Same location, upper part of lower resistant unit of carbonate member; identification by J. Pojeta, Jr.

Fauna

poorly preserved cycloconchid pelecypod

Remarks. Ordovician(?) Cycloconchid pelecypods are only known from the Ordovician to date, but too little is known about Cambrian pelecypods to be certain about their lower age limit.

GSC locality C-97229. South of Bulleys Lump, Judge Daly Promontory; locality F11 of Figure 1; NTS 120 C; UTM Zone 19X, 495100E, 9010400N; lower part of carbonate member but stratigraphically above subdivision D; identification by B.S. Norford.

Fauna

inarticulate brachiopod
indeterminate trilobite
asaphid and ?nileid trilobites

Remarks. Late Cambrian to Late Ordovician. The trilobites are poorly preserved but the overall aspect suggests Early Ordovician (Tremadoc to Arenig).

GSC locality C-65. Locality F1, Figure 84; crest of Mount Pullen; NTS 120 E; UTM Zone 20X, 510300E, 9151300N; chert member; original identification by Thorsteinsson and Norford (*in* Trettin, 1971, p. 46); re-identification by D.E. Jackson (*in* Jackson, 1975).

Fauna

Isograptus cf. *I. victoriae divergens* Harris
Tetragraptus sp.

Remarks. Late Arenig, probably *Cardiograptus* Zone or *Paraglossograptus tentaculatus* Zone.

GSC locality C-66. St. Patrick Bay section; NTS 120 C; UTM Zone 20X, 479100E, 9086500N; chert member; 69.5 m above base of section, 10 m above base of member; original identification by Thorsteinsson and Norford (*in* Trettin, 1971, p. 44); re-identification by D.E. Jackson (*in* Jackson, 1975).

Fauna

Isograptus cf. *I. caduceus australis* Cooper
I. victoriae maximodivergens Harris
Glyptograptus cf. *G. austrodentatus* Harris and Keble
Skiagraptus gnomonicus (Harris and Keble)
Glossograptus c.f. *G. echinatus* Ruedemann
Glyptograptus sp.

Remarks. Very late Arenig, *Cardiograptus* Zone or *Paraglossograptus tentaculatus* Zone.

GSC locality C-67. Same location; talus, probably close to source, 205-208 m above base of section, 145-148 m above base of chert member; identification by R. Thorsteinsson and B.S. Norford (*in* Trettin, 1971, p. 46).

Fauna

?*Climacograptus* sp.
?*Diplograptus* sp.

Remarks. Middle Ordovician to Early Silurian.

GSC locality C-54999. Locality F2, Figure 84; 4.5 km northwest of Hare Fiord; NTS 340 C; UTM Zone 17X, 448800E, 9010700N; collected by J.Wm. Kerr in 1981; identification by B.S. Norford.

Fauna

?*Cryptograptus* sp.
Dicellograptus sp.
Orthograptus sp.

Remarks. Ordovician, Caradoc or Ashgill.

GSC locality C-74603. Section Ella Bay 1-2-2; NTS 120 C; UTM Zone 19X, 481450E, 9005500N; 20-22 m above base of chert member, 70-72 m below top of formation; identification by B.S. Norford.

Fauna

?*Climacograptus* sp.
Dicellograptus cf. *D. complanatus ornatus* Elles and Wood
Orthograptus sp.

Remarks. Late Ordovician, probably late Ashgill, probably Zone of *Dicellograptus complanatus ornatus*.

GSC locality 51962. Locality F3 of Figure 84 (locality 182 of Thorsteinsson and Kerr, 1972); 25.75 km south of d'Iberville Fiord; NTS 340 A; UTM Zone 17X, 528000E, 8916600N; chert member, 0-30 m below top of formation and member; collected by J. Wm. Kerr in 1962; identification by J. Riva (*in* Trettin et al., 1979).

Fauna

Euclimacograptus hastatus (T.S. Hall)
Appendispinograptus of the *longispinus* type
Paraorthograptus pacificus (Ruedemann)
Orthograptus sp.

Remarks. Latest Ordovician.

GSC locality C-64. St. Patrick Bay section, 1.8 km north-northeast of head of St. Patrick Bay (locality F2 *in* Trettin, 1971, Fig. 1); UTM Zone, 479750E, 9086100N; about 7 m below top of formation and chert member; original identification in Trettin (1971, p. 46); re-identification by J. Riva (*in* Trettin et al., 1979).

Fauna

Euclimacograptus hastatus (T.S. Hall) (1 specimen)
Appendispinograptus longispinus hvalross Ross and Berry (6 specimens)
Rectograptus cf. *R. amplexicaulis abbreviatus* Elles and Wood (rare)
Glyptograptus cf. *G. occidentalis* Ruedemann (most abundant and apparently consisting of individuals showing a great variation)

Remarks. This fauna is typical of the late Ashgill *D. complanatus ornatus* Zone of western North America and the Pacific Faunal Province. Identical species are known from the uppermost beds of the Phi Kappa Formation of Idaho, the Perkins Canyon Formation, Toquima Range, central Nevada, the uppermost "Valmy Formation" of the Tuscarora Mountains and the uppermost Agort Chert, both of northeastern Nevada. Jackson and Lenz have reported a similar fauna from the uppermost Ordovician of the Peel River, Yukon Territory. In easternmost Siberia, Sobolevskaya has described identical forms from the N and P divisions of their Ashgill Series of the Kolyma River Basin. Fauna, lithology, and preservation seem to be the same in the western U.S.A., Ellesmere Island, easternmost Siberia and also Alaska, at least for the latest Ordovician.

GSC locality C-74700. Locality F4 of Figure 84, 6.8 km west of Egerton Lake, 0.9 km southeast of Wood River; NTS 120 E; UTM Zone 20X, 488700E, 9157750N; upper few metres of chert member and formation; identification by B.S. Norford (*in* Trettin et al., 1979).

Fauna

Monograptus spp.
diplograptid

Remarks. Silurian, Llandovery, older than latest Llandovery.

GSC locality C-54053. 26.4 km east of head of Tanquary Fiord, 40.3 km southwest of Lake Hazen; NTS 340 D; UTM Zone 18X, 497600E, 9044000N; carbonate member; host rock is comparable to units 4 and 5 of Very River section; identification by B.S. Norford.

Fauna

possible corals, very poorly preserved

Remarks. If the identification is correct, probably younger than Early Ordovician.

CAPE PHILLIPS FORMATION

GSC locality C-97225. Carl Ritter Bay section; NTS 120 B; UTM Zone 19X, 529700E, 8991200N; more than 60 m below top of formation; identification by B.S. Norford.

Fauna

Monograptus spp.
M. ex gr. *M. priodon* (Bronn)
Stomatograptus grandis grandis (Suess)

Remarks. Early Silurian, latest Llandovery, *M. spiralis* or *C. sakmaricus–C. laqueous* Zone.

GSC locality C-97226. Same locality; about 60 m below top of formation; identification by B.S. Norford.

Fauna
Monograptus spp.
M. ex gr. *M. priodon* (Bronn)
M. ex gr. *M. spiralis* (Geinitz)

Remarks. Early Silurian, late Llandovery.

GSC locality C-97225. Same locality; about 58.3 m below top of formation; identification by B.S. Norford.

Fauna
Monograptus spp.
M. ex gr. *M. spiralis* (Geinitz)

Remarks. Early Silurian, late Llandovery.

GSC locality C-94375. Same locality; talus from lower part of formation; identification by B.S. Norford.

Fauna
Cyrtograptus sp.
Monograptus sp. or spp.
M. ex gr. *M. priodon* (Bronn)
Monoclimacis aff. *M. vomerinus* (Nicholson)
indeterminate brachiopod

Remarks. Silurian, latest Landovery to early Wenlock.

GSC locality C-97228. 2 km northeast of Carl Ritter Bay section; 28.5 m below top of formation; NTS 120 B; UTM Zone 19X, 529700E, 8991200N; identification by B.S. Norford.

Fauna
M. ex gr. *M. priodon* (Bronn)

Remarks. Early Silurian, late Llandovery to Wenlock.

DANISH RIVER FORMATION

GSC locality C-62. Locality F1, Figure 110; about 1.1 km southwest of Ruggles River; NTS 120 C; UTM Zone 19X, 488700E, 9075300N; identification by B.S. Norford and R. Thorsteinsson (from Trettin, 1971, p. 77).

Fauna
Monograptus aff. *M. priodon* (Bronn)

Remarks. Early Silurian, late Llandovery to Wenlock.

GSC locality C-54052. Locality F2, Figure 110; 13 km northeast of Lake Tuborg; NTS 340 D; UTM Zone 18X, 505500E, 9004300N; identification by B.S. Norford.

Fauna
Monograptus aff. *M. priodon* (Bronn)

Remarks. Early Silurian, late Llandovery to Wenlock.

GSC locality 51963. Locality F3 of Figure 110, locality 183 of Thorsteinsson and Kerr, 1972, about 25 km south of d'Iberville Fiord; collected by Kerr in 1962; identification by R. Thorsteinsson (*in* Trettin et al., 1979).

Fauna
Stomatograptus sp.
Monograptus cf. *M. priodon* (Bronn)

Remarks. Early Silurian, latest Llandovery or early Wenlock.

B. IDENTIFICATIONS OF ORDOVICIAN AND SILURIAN CONODONTS

G.S. Nowlan, C.R. Barnes, and R.V. Tipnis

CASS FJORD FORMATION

GSC locality C-96683. Section Ella Bay 3-1; NTS 120 C; UTM Zone 19X, 497250E, 9005500N; 158.2 m above base of section; identification by G.S. Nowlan.

Fauna. The sample yielded 14 specimens (CAI 4) assignable to:
Cordylodus intermedius Furnish s.f.
C. prion Lindström s.f.
C. rotundatus Pander s.f.
C. n. sp.

Remarks. This assemblage can be assigned to Fauna B of Ethington and Clark (1971); the sample is of Early Canadian (Early Ordovician; early Tremadoc) age.

CAPE CLAY FORMATION

GSC locality C-75430. Section Ella Bay 4-7; NTS 120 C; UTM Zone 19X; 504400E, 8997100N; 0-1 m above base of unit; identification by G.S. Nowlan.

Fauna. The sample yielded over 40 specimens that are black (CAI 5+) and assignable to the following taxa:

Acontiodus iowensis Furnish s.f. (3)
Coelocerodontus sp. s.f. (1)
Cordylodus intermedius Furnish s.f. (2)
C. cf. *C. prion* Lindström s.f. (3)
C. cf. *C. proavus* Müller s.f. (1)
C. n. sp. (8)
Variabiloconus bassleri (Furnish) (34)

Remarks. The fauna comprises simple cones of Lower Ordovician type but their identification at the specific level is difficult in some cases. The most abundant forms are those referred to *V. bassleri*. The other main component of the fauna is a group of elements referred to *Cordylodus*. This group is very heterogeneous in morphology and includes slender forms with very deep basal cavities (*C.* cf. *C. proavus*), broad forms with shallower basal cavities (*C. intermedius*) and crytoniodiform elements comparable to *C. prion*. The most abundant form is apparently a new species characterized by an expanded, rounded anterior margin of cusp and base.

This fauna contains elements of Fauna B (Ethington and Clark, 1971) and forms comparable to those characteristic of Fauna C (Ethington and Clark, 1971) and is thus of Early Ordovician age; a more precise age cannot be provided because of the difficulty of specific identification.

GSC locality C-75431. Same location as C-75430; 19-21 m above base of unit; identification by G.S. Nowlan.

Fauna. The sample yielded two small fragmentary simple cones referable to:

Teridontus sp. (1)
Utahconus? sp. (1)

Remarks. Both of these simple unornamented cones have basal cavities restricted to the anterior portion of the base. One is compressed posteriorly and resembles the unicostate element of a species of *Utahconus* (see Miller, 1980). The other has a rounded cross-section and can be referred to *Teridontus*, but the situation of the basal cavity apex at the anterior margin is atypical of species of that genus (see Miller, 1980). Based on this limited material the age of this sample may be Late Cambrian to Early Ordovician.

GSC locality C-75432. Same location as C-75430; 88-91 m above base of formation; identification by G.S. Nowlan.

Fauna. The sample yielded six fragmentary simple cones that are black (CAI 5).

Drepanodus cf. *D. subarcuatus* Furnish s.f. (2)
Variabiloconus bassleri (3)
New Genus n. sp. (1)

Remarks. The species listed are all characteristic of Fauna C (Ethington and Clark, 1971) although the first one ranges into younger strata. The form referred to as New Genus n. sp. is similar to elements recovered from the Baumann Fiord Formation (Nowlan, 1976, Pl. 4, figs. 20, 21) and probably represents part of an apparatus that can be ascribed to *Clavohamulus*. This sample is thus of early Canadian (Early Ordovician; early-middle Tremadoc) age.

GSC locality C-54915. Locality F1, Figure 1; limestone on south side of knoll about 8.8 km south southeast of Bulleys Lump; NTS 120 C; UTM Zone 19X; 498200E, 9005800N; identification by G.S. Nowlan.

Sample weight. 2000 g (complete breakdown).

Fauna. This sample produced a very large heavy residue that was 40% picked and yielded 110 specimens assignable to the following taxa:

Cordylodus oklahomensis Müller
C. cf. *C. proavus* Müller
Drepanodus sp.
"*Scolopodus*" cf. "*S*.quc; *gracilis* Ethington & Clark
Teridontus nakamurai (Nogami)
Variabiloconus bassleri Furnish s.f.

Remarks. This fauna is numerically dominated by specimens of *C.* cf. *C. proavus*. The form represented here differs from typical *C. proavus* in being more laterally compressed. Nowlan (1985) recovered similar forms from the Cape Clay Formation elsewhere in the Arctic Islands. The association of this form with *Vanabiloconus bassleri* is suggestive of the early part of Fauna C (Ethington and Clark, 1971) of early Canadian (early-middle Tremadoc) age. The fauna is generally similar to that recovered from the upper part of the Copes Bay Formation and the Cape Clay Formation elsewhere in the Arctic Islands (Barnes, 1974; Nowlan, 1976; 1985).

NINNIS GLACIER FORMATION

GSC locality C-75436. Section Ella Bay 4-8; NTS 120 C; UTM Zone 19X, 505500E, 8997900N; 222-223 m above base of formation; identification by G.S. Nowlan.

Fauna. The sample yielded four fragmentary, black (CAI 5) simple cones referable to the following taxa:

Drepanoistodus sp. (2)
"*Oneotodus*" sp. (1)
"*Scolopodus*" sp. (1)

Remarks. This limited fauna suggests an Early to early Middle Ordovician age. None of the elements is identifiable at the specific level, but sulcate forms of "*Scolopodus*" do not range higher than the early Middle Ordovician, thus the upper age limit. However, based on stratigraphic position the sample is presumably of Early Ordovician age.

GSC locality C-75437. Same location as C-75436; 271 m above base of formation; identification by G.S. Nowlan.

Fauna. The sample yielded over fifty black (CAI 5) simple cones assignable to the following taxa:

Drepanodus toomeyi Ethington & Clark s.f. (4)
Drepanoistodus n. sp. (7)
Glyptoconus quadraplicatus (Branson & Mehl) (28)
Scolopodus emarginatus Barnes & Tuke s.f. (3)
S. multicostatus Barnes & Tuke s.f. (7)
Ulrichodina costata? Mound s.f. (1)
Walliserodus australis Serpagli (1)

Remarks. This group of drepanodan and scolopodan taxa is typical of Fauna D (Ethington & Clark, 1971) of mid Canadian (Early Ordovician; late Tremadoc) age. *S. multicostatus* is known only from the St. George Group of western Newfoundland (Barnes & Tuke, 1970). Elements assigned to *Drepanoistodus* n. sp. are characterized by broadly flaring bases with oval cross-section. The specimen assigned to *Ulrichodina costata*? is similar to *U. abnormalis* Branson & Mehl but the lateral faces are costate. This is similar to the description of *U. costata* by Mound (1968), but his illustrations are too poor to permit confirmation of the identification.

GSC locality C-96682. Section Ella Bay 3-2a; NTS 120 C; UTM Zone 19X, 496500E, 9004250N; identification by G.S. Nowlan.

Sample weight. 1730 g.

Fauna. The sample yielded 12 poorly to moderately well preserved specimens (CAI 5) assignable to the following taxa:

Acanthodus lineatus (Furnish)
Drepanoistodus sp.
Variabiloconus bassleri (Branson & Mehl)

Remarks. This fauna can be assigned to Fauna C (Ethington & Clark 1971) of early Canadian (Early Ordovician; early-middle Tremadoc) age.

ELEANOR RIVER FORMATION

GSC locality C-75438. Section Ella Bay 4-9; NTS 120 C; UTM Zone 19X, 505200E, 8998100N; 0.5-1 m above base of formation; identification by G.S. Nowlan.

Fauna. The sample yielded five specimens of black (CAI 5) simple cones, assignable to the following taxa:

Acontiodus sp. s.f. (2)
Drepanodus sp. s.f. (2)
?"*Scolopodus*" *asymmetricus* (Barnes & Poplawski) s.f. (1)

Remarks. This sparse fauna does not provide useful biostratigraphic information. A fragment questionably assigned to "*S*". *asymmetricus* suggests an Early Ordovician age, but a younger Ordovician age cannot be ruled out, except on the basis of stratigraphic position (see below).

GSC locality C-75439. Same location; 21-24 m above base of formation; identification by G.S. Nowlan.

Fauna. The sample yielded two black (CAI 5) simple cones assignable to:

Glyptoconus quadraplicatus (Branson & Mehl) (2)

Remarks. *G. quadraplicatus* is typical of Fauna D, ranges into Fauna E (Ethington & Clark, 1971) and also occurs in strata of Whiterockian age. Thus the sample is of mid-late Canadian to Whiterockian (late Tremadoc-middle Arenig) age.

GSC locality C-75442. Same location; 166.5-168 m above base of formation; identification by G.S. Nowlan.

Fauna. The sample yielded two black to grey (CAI 5+) simple cones and some phosphatic fragments. The two specimens are assignable to:

"*Scolopodus*" *gracilis* Ethington & Clark s.f. (1)
"*S.*" sp. (1)

Remarks. "*S.*" *gracilis* ranges from Fauna D (mid to late Canadian) through into the early Whiterockian. The sample is mid Tremadoc to mid Arenig in age.

GSC locality C-75443. Same location; 169-170 m above base of formation; identification by G.S. Nowlan.

Fauna. The sample yielded two large, black to grey (CAI 5+) specimens assignable to:
Oistodus multicorrugatus Harris

Remarks. *O. multicorrugatus* ranges from late Canadian to Whiterockian in age. The sample is therefore of late Early Ordovician to early Middle Ordovician (early to mid-late Arenig) age.

BAY FIORD FORMATION

GSC locality C-75444. Section Ella Bay 4-10; NTS 120 C; UTM Zone 19X, 505750E, 8998600N; lower part of formation (about 100 m); identification by G.S. Nowlan.

Fauna. The sample yielded twelve black (CAI 5) specimens assignable to the following taxa:
Glyptoconus quadraplicatus Branson & Mehl (5)
Tricladiodus n. sp. (5)
Trigonodus sp. (2)

Remarks. The new species of *Tricladiodus* is known from the Bay Fiord Formation (Nowlan, 1976) in strata of Whiterockian age. Thus the sample is probably of early Middle Ordovician (Whiterockian) age.

GSC locality C-75445. Same location as C-75444; 144-145.5 m above base of formation; identification by G.S. Nowlan.

Fauna. The sample yielded two black (CAI 5) specimens assignable to the following taxa:
Drepanoistodus? sp. (1)
Glyptoconus quadraplicatus Branson & Mehl (1)

Remarks. This limited fauna suggests a late Early to early Middle Ordovician age based on the presence of *G. quadraplicatus* (see remarks under C-75439, Eleanor River Formation).

GSC locality C-75453. Same location as C-75444, 168.5 m above base of formation; identification by G.S. Nowlan.

Fauna. The sample yielded a single black fragment assignable to:
Panderodus sp.

Remarks. This genus is long-ranging and indicates a Middle Ordovician–Devonian age.

BULLEYS LUMP FORMATION

Type section, member A

GSC locality C-54894. Section Ella Bay 3-3; NTS 120 C; UTM Zone 19X, 498400E, 9004800N; 211.65-213.15 m above base of formation (2.65-4.15 m above base of unit 2); identification by G.S. Nowlan.

Sample weight. 1502 g (very good breakdown).

Fauna. The sample yielded 13 specimens (CAI 5) belonging to the following taxa:
Juanognathus n. sp.
Oneotodus simplex (Furnish)
"*Scolopodus*" n. sp.

Remarks. The fauna includes two new taxa known from unpublished data (Nowlan, 1976) in the Baumann Fiord Formation elsewhere in the Arctic Islands. This fauna is not described from elsewhere and in the Arctic it is post-Fauna C and pre-Fauna D of Ethington and Clark (1971). It is of early Canadian (Lower Ordovician; middle Tremadoc) age.

GSC locality C-54895. Same location as C-54894; 214.65-215.1 m above base of formation (5.65-6.1 m above base of unit 2); identification by G.S. Nowlan.

Sample weight. 1437 g (good breakdown).

Fauna. The sample yielded a single specimen (CAI 5):
Juanognathus n. sp.

Remarks. This element represents the same fauna as that remarked upon for C-54894 (see above).

Type section, member B

GSC locality C-54897. Section Ella Bay 3-3; NTS 120 C, UTM Zone 19X, 498800E, 9004700N; 439.0-439.4 m above base of formation, 13.0-13.4 m above base of member B; identification by G.S. Nowlan.

Sample weight. 1402 g (complete breakdown).

Fauna. The sample yielded 9 specimens (CAI 5) belonging to the following taxa:
Glyptoconus quadraplicatus Branson & Mehl

Oneotodus? sp.

Remarks. The fauna is indicative of Fauna D. *G. quadraplicatus* ranges from mid Canadian to early Whiterockian in age, but specimens such as those referred to *Oneotodus*? sp. are not known from strata younger than about mid-late Canadian (Late Tremadoc).

GSC locality C-54898. Same location as C-54897; 439.6-439.8 m above base of formation, 13.6-13.8 m above base of member; identification by G.S. Nowlan.

Sample weight. 1581 g (good breakdown).

Fauna. The sample yielded 50 specimens (CAI 5) belonging to the following taxa:

Drepanodus sp.
Glyptoconus quadraplicatus Branson & Mehl

Remarks. The fauna is numerically dominated by specimens of *G. quadraplicatus* and the remarks under sample C- 54897 (see above) apply in this case as well.

Undivided formation southwest of type section

GSC locality C-74749. Locality F2, Figure 1, about 11 km south of top of Bulleys Lump; NTS 120 C; UTM Zone 19X; 495000E, 9003550N; identification by C.R. Barnes.

Sample weight. 4700 g.

Fauna

Drepanodus aff. *D. subarcuatus* Furnish (1)
Paltodus spp. (3)

Remarks. The fauna indicates an Early Ordovician age, probably late Tremadoc (Fauna D of Ethington and Clark, 1971)

GSC locality C-74750. Locality F3, Figure 1; about 11 km south of top of Bulleys Lump; NTS 120 C; UTM Zone 19X; 494700E, 9003550N; identification by C.R. Barnes

Sample weight. 3420 g (insoluble residue 625 g).

Fauna

Drepanodus cf. *D. parallelus* Branson and Mehl s.f. (1)
Drepanodus cf. *D. toomeyi* Ethington and Clark s.f. (1)
Oistodus sp. s.f. (2)
Scandodus sp. s.f. (1)

Remarks. This small fauna is indicative of a late Early Ordovician age (late Tremadoc-Arenig).

GSC locality C-74751. Same locality as C-74750 but different stratum; identification by C.R. Barnes.

Sample weight. 3705 g (insoluble residue 870 g).

Fauna

Drepanodus sp. (2)
Paltodus sp. (7)
N. gen. n. sp. (1)

Remarks. This small collection has drepanodiform and paltodiform elements that are fragmentary but generally similar to those reported in samples C-74749 and C-74750 above. In addition, the specimen of N. gen. n. sp. was reported by Nowlan (1976) from the Upper Baumann Fiord and lower Eleanor River formations of the eastern Canadian Arctic Islands. The elements suggest equivalence to Faunas C and D of Ethington and Clark (1971), and thus a middle to late Tremadoc age.

GSC locality C-74738. Locality F4, Figure 1; crest of ridge 11 km south of top of Bulleys Lump; NTS 120 C, UTM Zone 19X, 496250E, 9003500N; identification by C.R. Barnes.

Sample weight. 3805 g.

Fauna

Periodon cf. *P. flabellum* (Lindström) (3)
Acontiodus sp. s.f. (1)

Remarks. All specimens are fragmentary. The specimens belonging to *Periodon* probably lie within *P. flabellum* rather than *P. aculeatus* Hadding. If so, the suggested age is middle Arenig to middle Llanvirn (cf. Serpagli, 1974, Text fig. 14). The fauna is representative of the North Atlantic Province.

Northwestern outcrop belt (member B)

GSC locality C-94383. Immediately southeast of section Ella Bay 2-South; NTS 120 C; UTM Zone 19X, 492600E, 9003000N; 0-2 m above faulted basal contact; identification by G.S. Nowlan.

Sample weight. 2335 g.

Fauna. The sample yielded eleven highly fragmentary specimens that are thermally altered to CAI 4.5. They can be assigned to the following taxa:

Drepanodus spp. s.f. (3)

Histiodella sp. (1)
Juanognathus? sp. (4)
Oistodus sp. s.f. (1)
Periodon sp. (2)

Remarks. The highly fragmentary assemblage does not permit specific identification. A single specimen assignable to *Histiodella* provides the most useful biostratigraphic information. The genus is present only in strata of early Middle Ordovician (Whiterockian; pre-Chazyan) age. The specimen is well denticulated and, although broken posteriorly, it can be assigned only to one of the younger species of the genus, possibly *H. holodentata*. The sample is thus of Whiterockian (possibly late Whiterockian, but pre-Chazyan) age. Specimens of *Periodon* represent the North Atlantic Faunal Province, suggesting proximity of cool, normal marine waters.

GSC locality C-74617. Section Ella Bay 2-East; NTS 120 C; UTM Zone 19X, 493200E, 9003800N; 0-20 m below top of formation, lower part of unit; original identification by R.V. Tipnis; re-identification of part of fauna by G.S. Nowlan; specimens illustrated by Tipnis were not available to Nowlan.

Fauna. The sample contains nine identifiable specimens (CAI 4.5) referable to:
?*Belodina* sp.
Belodina monitorensis Ethington & Schumacher
Panderodus gracilis (Branson & Mehl)
Panderodus aff. *P. breviusculus* Barnes
Protopanderodus sp.

In addition Tipnis (1978) illustrated a specimen referable to "*Belodina*" *monitorensis monitorensis* Ethington & Schumacher.

Remarks. The majority of the specimens are either too poorly preserved to permit specific identification or belong to long-ranging species. *Belodina monitorensis* was first reported from the Copenhagen Formation of central Nevada (Ethington & Schumacher, 1969). It has subsequently been reported from the Womble Shale of Arkansas by Repetski and Ethington (1977) associated with the zonal indicator *Pygodus anserinus* (Llandeilo/late Chazyan age). The sample is of Middle Ordovician age, probably Llandeilo, based on the limited distribution of *B. monitorensis*, but it could be slightly younger or older.

GSC locality C-74618. Same location as C-74617, upper part of same unit; identification by R.V. Tipnis and G.S. Nowlan, as above.

Fauna. The sample includes seven identifiable specimens, and Tipnis (1978) illustrated fifteen specimens, from the same sample. Tipnis (1978) reported the following taxa:
"*Oistodus*" sp. aff. "*O.*" *nevadensis* Ethington & Schumacher
"*Oistodus*" *venustus* Stauffer
Periodon aculeatus Hadding
Phragmodus sp.
Pygodus sp.
"*Roundya*" *pyramidalis* Sweet & Bergström
"*Tetraprioniodus*" cf. "*T.*" *lindstroemi* Sweet & Bergström

The remaining seven specimens (CAI 4.5) are referable to:
Panderodus gracilis (Branson & Mehl)
Spinodus? sp.
Walliserodus sp.

Remarks. Tipnis (1978) concluded that the sample was of late Llanvirn to Llandeilo age. This is reasonable based on the presence of specimens of *Pygodus*, but other elements, particularly those referred to *Phragmodus*, indicate an early Caradoc age. The specimens assigned to *Phragmodus* belong to a new, as yet unnamed, species first illustrated by Barnes (1974) as *Phragmodus* n.sp. It is known from the lower part of the Thumb Mountain Formation in several parts of the Canadian Arctic Islands (Barnes, 1974; Nowlan, unpublished data) and from Alaska (Blodgett et al., 1988). The sample is probably of early Caradoc age but it may contain a mixed fauna based on the presence of *Pygodus*. The fauna is of mixed provincial affinity, with representatives of the North American Midcontinent Province and North Atlantic Province. This mixing suggests an outer shelf, or more offshore setting.

GSC locality C-194904. Locality F15, Figure 1; NTS 120 C; UTM Zone 19X, 488700E, 9001300N; collected by D.W. Esson, identification by G.S. Nowlan.

Sample weight. 3200 g (89% breakdown).

Fauna. The sample yielded 57 fragmentary conodont elements (CAI 4.5) identifiable as follows:
Drepanoistodus sp. (3)
Eoplacognathus sp. (1)
Histiodella holodentata Ethington and Clark (2)
Parapanderodus asymmetricus (Barnes and Poplawski) (1)
Periodon aculeatus Hadding (30)
Periodon cf. *P. aculeatus* Hadding (11)
Prioniodus sp. (4)
Protopanderodus varicostatus (Sweet and Bergström) (4)

"*Scolopodus*" *gracilis* Ethington and Clark (1)

Remarks. This assemblage is of mixed provincial affinity. The biostratigraphically most diagnostic element, *Histiodella holodentata*, is of Midcontinent Province affinity and is of late Whiterockian (Llanvirn) age. The specimen of *Eoplacognathus*, which might provide a precise correlation with the North Atlantic Province, is too fragmentary to be identified at the specific level. The specimens assigned to *Periodon* are varied; some conform closely with *P. aculeatus*, but others are more like *P. flabellum*. Either this assemblage occurs close to the evolutionary transition between the two species (earliest Llanvirn) or there may be some reworking of older material. The latter is a distinct possibility because *H. holodentata* is usually correlated with a level in the middle to late Llanvirn. The sample is of Llanvirn age.

GSC locality C-54921. Locality F5, Figure 1; knoll 3.75 km southeast of head of Ella Bay; NTS 120 C; UTM Zone 19X; 486000E, 8999800N; identification by G.S. Nowlan.

Sample weight. 2000 g (very good breakdown).

Fauna. The sample yielded a fragmentary collection (CAI 5) of:
- *Periodon* sp.
- *Protopanderodus* sp.

Remarks. Both these genera are typical of the North Atlantic Province and range from the Early Ordovician (Arenig) to Late Ordovician in age (*Protopanderodus* to the Ashgill and *Periodon* to the Caradoc). None of the fragments is sufficiently well preserved to be identified at the specific level. The sample is of Arenig to Caradoc age.

THUMB MOUNTAIN FORMATION

Lowermost strata

GSC locality C-54916. Locality F6, Figure 1, about 1 km northeast of section Ella Bay 3-4; NTS 120 C; UTM Zone 19X, 500400E, 9004200N; basal stratum; identification by G.S. Nowlan

Sample weight. 1398 g (complete breakdown).

Fauna. The sample yielded a highly fragmentary fauna (CAI 5) of elements assignable to the following genera:
- *Drepanoistodus* sp.
- *Eoneoprioniodus* sp.
- *Erismodus* sp.
- *Panderodus* sp.

Remarks. The lower age range indicated by this fauna is constrained by the presence of elements of *Erismodus* and *Panderodus* that first occur in strata of early Middle Ordovician (Chazyan) age. The upper limit is constrained by the presence of elements of *Eoneoprioniodus* that are of a type not present in strata younger than Blackriverian. The sample is of Chazyan to Blackriverian (Middle Ordovician; late Llanvirn to early Caradoc) age.

GSC locality C-54917. Same location as C-54916, 1 m above base of formation; identification by G.S. Nowlan

Sample weight. 2000 g (complete breakdown).

Fauna. The sample yielded only four fragmentary specimens (CAI 5) assignable to the following taxa:
- *Eoneoprioniodus* sp.
- *Panderodus* sp.

Remarks. The fauna indicates a Chazyan to Blackriverian (Middle Ordovician; late Llanvirn to early Caradoc) age. See remarks for C-54916, above.

GSC locality C-75451. Locality F7, Figure 1, about 3 km southwest of section Ella Bay 4-11; NTS 120 C, 505200E, 8998750N; basal strata of formation; identification by G.S. Nowlan.

Fauna. The sample yielded a single, large, black (CAI 5) specimen referable to:
- *Cyrtoniodus* sp. s.f.

Remarks. The single asymmetrical element bears one posterior denticle. It is not identifiable at the specific level and could belong to one of several Ordovician or Silurian multielement genera. Therefore, based on this specimen, the sample is of Middle Ordovician to Silurian age.

GSC locality C-54918. Section Ella Bay 3-4; NTS 120 C; UTM Zone 19X, 499800E, 9003800N; basal stratum of formation; identification by G.S. Nowlan.

Sample weight. 2000 g (complete breakdown).

Fauna. The sample yielded a single specimen (CAI 5?) of the neurodont genus *Curtognathus*.

Remarks. *Curtognathus* is a relatively poorly known genus occurring in strata of Chazyan and Blackriverian (Middle Ordovician; late Llanvirn to early Caradoc) age.

GSC locality C-54903. Location as for C-54918; 1.5-2.0 m above base of formation; identification by G.S. Nowlan.

Sample weight. 1482 g (complete breakdown).

Fauna. The sample yielded an indeterminable fragment and two fragments (CAI 5) probably assignable to:
Erismodus sp.

Remarks. *Erismodus* is a neurodont genus well known in strata of Middle Ordovician, particularly Chazyan and Blackriverian, age. The sample is of Middle Ordovician (late Llanvirn to early Caradoc) age.

GSC locality C-75446. Section Ella Bay 4-11, at creek; NTS 120 C; UTM Zone 19X, 505750E, 8999200N; 0-2 m above base of formation; identification by G.S. Nowlan.

Fauna. The sample yielded two black (CAI 5) simple cone elements assignable to the following taxa:
Panderodus sp. (1)
Trigonodus sp. (1)

Remarks. The co-occurrence of these two genera indicates a Chazyan to Blackriverian age for the sample. Elements of *Trigonodus* are common in the Bay Fiord Formation elsewhere in the Arctic Islands (Nowlan, unpublished data) and occur rarely in basal beds of the Thumb Mountain Formation. The sample is of Llandeilo to early Caradoc age.

GSC locality C-75447. Location as for C-75446; 13-15 m above base of formation; identification by G.S. Nowlan.

Fauna. The sample yielded twenty black (CAI 5) fragmentary simple cones, assignable to the following taxa:
Belodina sp. (1)
Panderodus gracilis (Branson & Mehl) (15)
P. n. sp. (3)

Remarks. Earliest specimens of *Belodina* occur in strata of Chazyan age (Ethington & Schumacher, 1969; Nowlan, unpublished data) and the genus ranges to the top of the Ordovician. Only a fragmentary heel can be referred to this genus and specific identification is not possible. The specimens assigned to *Panderodus* n. sp. have a posteriorly extended portion of the base. *P. gracilis* is a long-ranging early Paleozoic taxon that first appears in the Middle Ordovician. Thus the sample may be of Middle to Late Ordovician (Llandeilo to Ashgill) age.

Uppermost strata

GSC locality C-54907. Section Ella Bay 3-4, upper part; NTS 120 C; UTM Zone 19X, 501100E, 9003800N; 2.5-1.5 m below top of formation; identification by G.S. Nowlan.

Sample weight. 1685 g (complete breakdown).

Fauna. The sample yielded 6 identifiable specimens (CAI 5) and many fragments:
Belodina sp.
Panderodus gracilis (Branson & Mehl)

Remarks. *Panderodus gracilis* is a long-ranging species. The genus *Belodina* ranges from Chazyan (early Middle Ordovician) through to the top of the Ordovician. The specimens recovered from the sample are too fragmentary to permit specific identification.

GSC locality C-54908. Location as for C-54907: 1.5-0 m below top of formation; identification by G.S. Nowlan.

Sample weight. 1452 g (complete breakdown).

Fauna. The sample yielded 7 identifiable specimens (CAI 5) belonging to the following taxa:
?*Belodina compressa* (Branson & Mehl)
Panderodus? *gracilis* (Branson & Mehl)
Paroistodus mutatus (Branson & Mehl)

Remarks. A fragmentary specimen of *Belodina* may belong to *B. compressa*, a species that ranges from the Blackriverian to the Shermanian. An assignment to the younger *B. confluens* cannot be ruled out based on the sparse material, and thus the age range for the sample could be as great as Blackriverian to Gamachian, but is probably restricted to Blackriverian to Shermanian (early to late Caradoc). Other elements of the fauna are not biostratigraphically diagnostic.

IRENE BAY FORMATION

GSC locality C-54909. Section Ella Bay 3-5; NTS 120 C, UTM Zone 19X, 501100E, 9003800N; 0-8.6 m above base of formation; identification by G.S. Nowlan.

Sample weight. 1058 g (complete breakdown).

Fauna. The sample yielded a highly fragmentary fauna (CAI 5) with specimens of the following taxa:
Drepanoistodus suberectus (Branson & Mehl)
Panderodus gracilis (Branson & Mehl)

P. panderi (Stauffer)
Walliserodus sp.

Remarks. *D. suberectus* and *P. gracilis* are long-ranging species. Only a single specimen of *P. panderi* was recovered. One acontiodiform element assignable to *Walliserodus* was also recovered; this is a form similar to *W. amplissimus* (Serpagli) and suggests a late Middle to Late Ordovician (Caradoc–Ashgill) age for the sample.

GSC locality C-75448. Section Ella Bay 4-12; UTM Zone 19X, 505700E, 8999500N; upper part of formation (approximately 115 m above base of formation according to photogrammetry); identification by G.S. Nowlan.

Fauna. The sample yielded 26 specimens that are black (CAI 5) and assignable to the following taxa:
Belodina arca Sweet (1)
Drepanoistodus sp. (3)
Panderodus? *gracilis* (Branson & Mehl) (16)
P. panderi (Stauffer) (1)
Paroistodus? *mutatus* (Branson & Mehl) (2)
Pseudobelodina dispansa (Glenister) (1)
P. vulgaris Sweet (2)

Remarks. This group of panderodan and belodinan cones is typical of strata of Late Ordovician age (see Sweet, 1979; Nowlan and Barnes, 1981). *P. dispansa* and *P. vulgaris* range from late Edenian to Gamachian age. *B. arca* has a limited distribution, being known only from sections in the western midcontinent of North America (Sweet, 1979) from the Bad Cache Rapids Formation of Melville Peninsula (Barnes, 1977), organic-rich units on Baffin Island (McCracken and Nowlan, 1989) and from the uppermost Thumb Mountain and Irene Bay formations (Nowlan, 1976). It ranges in age from middle Edenian to middle Maysvillian. The sample is therefore of middle Edenian–middle Maysvillian (early Late Ordovician) age.

GSC locality C-75449. Same location and approximate stratigraphic position as C-75448 but different stratum; identification by G.S. Nowlan.

Fauna. The sample yielded 55 black (CAI 5) specimens assignable to the following taxa:
Belodina sp. (1)
Culumbodina penna Sweet (2)
Drepanoistodus suberectus (Branson & Mehl) (9)
Panderodus breviusculus Barnes (1)
P. gibber Nowlan & Barnes (2)
P. gracilis (Branson & Mehl) (33)
Plectodina sp. (5)
Walliserodus cf. *W. curvatus* (Branson & Branson) (2)

Remarks. This assemblage is typical of strata of Late Ordovician age (Sweet, 1979; Nowlan & Barnes, 1981). The presence of *Culumbodina penna* and *Panderodus breviusculus* suggests a middle Edenian to middle Maysvillian age. This type of fauna has been recovered from the upper part of the Thumb Mountain Formation and the Irene Bay Formation elsewhere in the Arctic Islands (Nowlan, 1976).

ALLEN BAY FORMATION

GSC locality C-54910. Section Ella Bay 3-6; NTS 120 C; UTM Zone 19X, 501100E, 9003500N; 84.0-85.0 m above base of formation; identification by G.S. Nowlan.

Sample weight. 1350 g (complete breakdown).

Fauna. The sample yielded a highly fragmentary fauna (CAI 5) with specimens of the following taxa:
Drepanoistodus sp.
Panderodus gracilis (Branson & Mehl)
Pseudobelodina vulgaris Sweet

Remarks. This sample contains long-ranging forms with the exception of fragmentary representatives of *P. vulgaris*, a Late Ordovician (Maysvillian–Richmondian) form (Sweet, 1979). The subspecies cannot be determined based on the fragmentary specimen and therefore the age of the sample is Maysvillian to Richmondian (Late Ordovician; Ashgill).

GSC locality C-54911. Same location as C-54910; 301.5-313.5 m above base of formation; identification by G.S. Nowlan.

Sample weight. 1223 g (very good breakdown).

Fauna. The sample yielded 12 specimens (CAI 5) assignable to the following taxa:
Coelocerodontus trigonius (Ethington)
Panderodus gracilis (Branson & Mehl)
Paroistodus? *mutatus* (Branson & Mehl)
Protopanderodus sp.

Remarks. This sample does not contain stratigraphically diagnostic forms; all taxa range from Middle to Late Ordovician in age. The sample is of Middle to Late Ordovician age.

GSC locality C-54913. Same location as C-54910; 316.5 m above base of formation; identification by G.S. Nowlan.

Sample weight. 1373 g (complete breakdown).

Fauna. The sample yielded about 24 identifiable specimens and several fragments (CAI 5). The following taxa are represented:

Decoriconus sp.
Ozarkodina oldhamensis (Rexroad)
Panderodus sp.
Walliserodus curvatus (Branson & Branson)

Remarks. This fauna is of Early Silurian age. *O. oldhamensis* is known from early to mid-Llandovery strata in Europe (Aldridge, 1972) and North America (Rexroad, 1967; Nowlan, 1983; among others).

GSC locality C-54914. Locality F8, Figure 1 at margin of glacier, about 1.4 km northeast of section Ella Bay 3-6; NTS 120 C; UTM Zone 19X, 502200E, 9004100N; from upper part of formation (less than 20 m below top?); identification by G.S. Nowlan.

Sample weight. 2000 g (complete breakdown).

Fauna. The sample yielded 90 specimens (CAI 5) belonging to the following taxa:

?*Amorphognathus* sp.
Belodina confluens Sweet
Drepanoistodus suberectus (Branson & Mehl)
Oulodus rohneri Ethington & Furnish
O. ulrichi (Stone & Furnish)
Panderodus gracilis (Branson & Mehl)
P. liratus Nowlan & Barnes
Plegagnathus nelsoni Ethington & Furnish
Pseudobelodina? *dispansa* (Glenister)
P. vulgaris Sweet

Remarks. This fauna indicates a Late Ordovician (Richmondian) age based on the presence of *O. rohneri*. Although several of the species range into younger (Gamachian) strata, there are no representatives of typical Fauna 13 in the sample. (see McCracken and Nowlan, 1988). It is likely that this sample is of Richmondian (late Ashgill) age.

GSC locality C-75273. Locality F9, Figure 1, about 5 km southwest of section EB4-13; NTS 120 C; UTM Zone 19X, 501600E, 8997300N; upper part of formation (roughly 60 m below top); identification by C.R. Barnes (see Norford, Appendix 3B for macrofossils from same locality).

Sample weight. 3700 g.

Fauna

Drepanoistodus suberectus (Branson and Mehl) (1)
Panderodus gracilis (Branson and Mehl) (2)

Remarks. The three conodonts present belong to long-ranging species and indicate only a Middle to Late Ordovician age.

GSC locality C-94389. Carl Ritter Bay section, 3 km north of Carl Ritter Bay; NTS 120 B; UTM Zone 19X, 528550E, 8989250N; 1-2 m below top of Allen Bay; identification by G.S. Nowlan.

Sample weight. 1680 g.

Fauna. The sample yielded almost 70 conodont specimens that are moderately well preserved (CAI 4) and assignable to the following taxa:

Amorphognathus ordovicicus Branson & Mehl (14)
Drepanoistodus sp. (3)
Eoligonodina sp. s.f. (1)
Panderodus clinatus McCracken & Barnes (1)
P. gracilis (Branson & Mehl) (24)
P. liratus Nowlan & Barnes (3)
Paroistodus? *mutatus* (Branson & Mehl) (8)
Plegagnathus dartoni (Stone & Furnish) (2)
Pseudobelodina vulgaris Sweet (4)
Walliserodus amplissimus (Serpagli) (8)

Remarks. This moderately diverse fauna is characteristic of strata of Late Ordovician (Richmondian) age in the North American Midcontinent Province. *A. ordovicicus* is represented both by well preserved holodontiform and platform elements. *Plegagnathus dartoni* is characteristic of strata of Richmond age assignable to Fauna 12. Although several of the species range into Fauna 13 of Gamachian age (see McCracken and Nowlan, 1988) none of the characteristic elements of Fauna 13 are present. The sample is probably of Richmondian (Late Ordovician; late Ashgill) age.

GSC locality C-94390. Same location, 0-1 m below top of formation; identification by G.S. Nowlan.

Fauna. The sample yielded over 90 conodont elements (CAI 4) assignable to the following taxa:

Amorphognathus ordovicicus Branson & Mehl (10)
Belodina confluens Sweet (3)
Drepanoistodus sp. (2)
Panderodus gibber Nowlan & Barnes (2)
P. gracilis (Branson & Mehl) (25)
P. liratus Nowlan & Barnes (15)

Paroistodus? mutatus (Branson & Mehl) (27)
Plegagnathus dartoni (Stone & Furnish) (3)
Pseudobelodina dispansa (Glenister) (3)
P. vulgaris Sweet (2)

Remarks. This fauna is very similar to that from GSC locality C-94389 and the additional taxa present do not alter the biostratigraphic assignment. This sample is of Late Ordovician (Richmondian; late Ashgill) age.

GSC locality C-75463. Nunatak 30.9 km southeast of head of d'Iberville Fiord; NTS 340 A, UTM Zone 18X, 460400E, 9019600N; identification by G.S. Nowlan.

Fauna. The sample yielded a single fragmentary specimen (CAI 5?) assignable to:
Cyrtoniodus sp. s.f.

Remarks. This cyrtoniodiform element could be part of one of several Ordovician or Silurian multielement genera. The range in age may be Middle Ordovician through Silurian.

GSC locality C-75464. Nunatak 33.8 km southeast of head of d'Iberville Fiord; NTS 340 A, UTM Zone 18X, 461600E, 9017100N; identification by G.S. Nowlan.

Fauna. The sample yielded 21 black (CAI 5) specimens assignable to the following taxa:
Panderodus gracilis (Branson & Mehl) (15)
Paroistodus? *mutatus* (Branson & Mehl) (2)
Plegagnathus dartoni (Stone & Furnish) (2)
Pseudobelodina vulgaris (Sweet) (2)

Remarks. *Plegagnathus dartoni* is known from Richmondian strata in North America (Sweet, 1979; Nowlan & Barnes, 1981). The remaining taxa range through the Upper Ordovician. The sample is of Richmondian (Late Ordovician; late Ashgill) age.

HAZEN FORMATION

GSC locality C-96672. Section Ella Bay 1-2-1; NTS 120 C, UTM Zone 19X, 482100E, 9005250N; 425 m above base of formation in (resedimented) carbonate breccia; identification by G.S. Nowlan.

Sample weight. 1977 g.

Fauna. The sample yielded two fragments (CAI indeterminate) assignable to:
Teridontus? sp.

Remarks. These specimens are not biostratigraphically diagnostic but probably indicate a Late Cambrian to Early Ordovician age for the sample.

GSC locality C-96671. Same locality as C-96672; 426.5 m above base of formation in (resedimented) carbonate breccia; identification by G.S. Nowlan.

Sample weight. 1939 g.

Fauna. The sample yielded a few fragmentary simple cone elements (CAI 5) assignable to the following taxon:
Teridontus nakamurai (Nogami)

Remarks. Based on the presence of *T. nakamurai*, this sample is of latest Cambrian to earliest Ordovician age. The taxon is known to range through the Trempealeauan into conodont Fauna A (= *Cordylodus proavus* Zone) and Fauna B.

GSC locality C-194905. Locality F16 of Figure 1; NTS 120C; UTM Zone 19X, 489000E, 9002200N; from allochthonous block of limestone about 20 m long, wide and high, intensely fractured and cleaved; collected by D.W. Esson; identification by G.S. Nowlan.

Sample weight. 3500 g (92% breakdown).

Fauna. The sample yielded 9 highly fragmentary conodont elements (CAI 4.5) identifiable as follows:
Drepanodus? sp. (2)
'*Scolopodus*' *gracilis* Ethington and Clark (2)
Glyptoconus aff. *G. quadraplicatus* (Branson and Mehl) (4)
Utahconus? sp. (1)

Remarks. This assemblage is highly fragmentary and difficult to identify because only basal portions of elements are complete. The general aspect of the fauna suggests an Early Ordovician (Arenig) age. It is difficult to be more specific based on the material available.

GSC locality C-54826. St. Patrick Bay section; NTS 120 C; UTM Zone 20X, 479100, 9086500N; carbonate member, 0-5 m above base of section; identification by R.V. Tipnis.

Sample weight. 51 g.

Fauna. The sample yielded 12 conodonts; CAI 5 (black):
Coloecerodontus sp.
cf. *Drepenoistodus forceps* (Lindström)
Paltodus variabilis Furnish
cf. *Scandodus furnishi* (Lindström)

Walliserodus sp.

Remarks. Except for *Paltodus variabilis*, all taxa are confined to the late Tremadoc. The provincial affinity is difficult to determine as key elements of both the Midcontinent and North Atlantic faunas are absent; late Tremadoc, coeval with Fauna D of Ethington and Clark, 1971.

GSC locality C-54922. About 12.8 km southwest of head of Ella Bay; NTS 120 B; UTM Zone 19X, 474400 E, 8993300 N; lower part of resistant limestone unit at top of Hazen Formation, carbonate member; identification by G.S. Nowlan.

Sample weight. 2000 g (complete breakdown).

Fauna. The sample contains three fragmentary specimens (CAI 4.5 to mainly 5) assignable to:
?*Belodina compressa* (2)
Panderodus sp. (1)

Remarks. The elements referred to *Belodina* may be *B. compressa* (Branson and Mehl), that ranges from mid-Blackriverian (Middle Ordovician) to Richmondian (Late Ordovician) but the identification is uncertain based on the material available. The sample is of Caradoc to Ashgill age.

GSC locality C-54923. Same locality, upper part of limestone unit; identification by G.S. Nowlan.

Sample weight. 1785 g (complete breakdown).

Fauna. The sample yielded three fragmentary specimens (CAI 4.5 to mainly 5) referable to:
Panderodus sp.
?*Belodina* sp.

Remarks. *Belodina* ranges from Chazyan (Middle Ordovician) to Richmondian (Late Ordovician). The sample is of Llandeilo to Ashgill age.

GSC locality C-96684. (Resedimented) carbonate breccia at top of Hazen Formation; same unit as C-54922 and C-54923 but located 9.6 km southwest of head of Ella Bay; locality F10 of Figure 1; a few cm below contact with Danish River Formation; NTS 120 C; UTM Zone 19X, 476700E, 8994800N; identification by G.S. Nowlan.

Sample weight. 1807 g.

Fauna. The sample yielded over 20 conodont elements (CAI 5) assignable to the following taxa:
Belodina sp.
Coelocerodontus trigonius Ethington
Dapsilodus? sp.
Distomodus staurognathoides (Walliser)
?*Oulodus fluegeli* (Walliser)
Ozarkodina sp.
Panderodus gracilis (Branson & Mehl)
Pseudobelodina? *dispansa* (Glenister)
Walliserodus curvatus (Branson & Mehl)

Remarks. This is a mixed fauna with elements of Late Ordovician and Early Silurian age. Elements assigned to *Belodina, Coelocerodontus* and *Pseudobelodina* occur only in the Ordovician whereas the elements of *Distomodus* and *Oulodus* are known only from the Silurian. It is assumed that the Ordovician material is derived from underlying strata. The Silurian material is of mid Llandovery (C1-C4) age based on the presence of *D. staurognathoides*.