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Abstract

The Middle and Upper Cambrian strata on northeast Ellesmere Island are placed in a single unit, the Cass Fjord Formation, with Lower, Middle, and Upper members. The boundary between the Lower and Middle members of the Cass Fjord Formation is chosen at the base of a variegated unit that is readily traced in the field and on airphotos. The boundary between the Middle and Upper members of the Cass Fjord Formation is chosen at a major unconformity that is difficult to recognize in the field and on airphotos. The Lower and Middle members comprises a major unconformity-bounded sequence containing four shallowing-upward cycles that correlate with the deeper water Hazen Formation unit C. The Upper Member comprises a major unconformity-bounded sequence containing two shallowing-upward cycles and correlates with Hazen Formation unit D.

Résumé

Dans la partie nord-est de l'île d'Ellesmere, les strates du Cambrien moyen et supérieur forment une entité unique, la Formation de Cass Fjord, comportant un membre inférieur, un membre intermédiaire et un membre supérieur. La base d'une unité bigarrée facilement identifiable sur le terrain et sur les photographies aériennes établit la limite entre les membres inférieur et intermédiaire de la Formation de Cass Fjord. Une discordance difficilement identifiable sur le terrain et sur les photographies aériennes marque la frontière entre les membres intermédiaire et supérieur. Les membres inférieur et intermédiaire comprennent une importante séquence délimitée par une discordance, où s'observent quatre cycles témoignant de milieux aux eaux de moins en moins profondes vers le haut, que l'on peut corréler avec l'unité C de la Formation de Hazen, associée à un milieu d'eaux plus profondes. Quant au membre supérieur, il comprend une importante séquence délimitée par une discordance, où ont été identifiés deux cycles témoignant de milieux aux eaux de moins en moins profondes vers le haut, que l'on peut corréler avec l'unité D de la Formation de Hazen.

INTRODUCTION

The nomenclature for strata comprising the Middle Cambrian to Lower Ordovician on Ellesmere Island has long been controversial. Thorsteinsson (1963) named the Parrish Glacier Formation at Copes Bay on eastern Ellesmere Island for a 265 m thick sequence of alternating limestone, shale, siltstone, and argillaceous limestone, containing red- and purple-weathering bands. This formation yielded Middle Cambrian trilobites near its base. The overlying Copes Bay Formation (Thorsteinsson, 1963) was named for 1460 m of unfossiliferous limestone and argillaceous limestone with common shallow-water sedimentary structures and gypsum. The Copes Bay Formation is overlain by the Baumann Fiord Formation. Kerr (1967) mapped the Parrish Glacier Formation beyond the type area as 265–650 m of varicoloured limestone, argillaceous limestone, and siltstone, with oolitic grainstone at the base and interbedded limestone and sandstone at the top. Kerr also mapped the Copes Bay Formation and suggested it was in part correlative with the Cass Fjord and Cape Clay formations on Greenland (Troelsen, 1950). These latter formations were retained by Christie (1967) for the Bache Peninsula (Fig. 1).

Subsequently other authors recognized that the upper part of the Parrish Glacier Formation correlates with the lower part of the Cass Fjord Formation (Mayr, 1978; Nowlan, 1985; Thorsteinsson and Mayr, 1987) and that the Copes Bay Formation correlates with the Cass Fjord, the Cape Clay, and the Christian Elv formations. The Greenland nomenclature has been used on northeast Ellesmere Island, with the recognition that the Parrish Glacier–Cass Fjord contact remains difficult to recognize (Trettin, 1994; de Freitas and Fritz, 1995; de Freitas, 1998a, b, c).

The problem of uncertain correlation is compounded by the fact that the lower portion of the Middle Cambrian to Lower Ordovician interval (the “Parrish Glacier Formation” and correlative “oolitic unit” of Trettin, 1994) are very resistant to weathering in the north and are more easily mapped as part of the underlying Scoresby Bay Formation, whereas this interval is less resistant in the south and blends lithologically with the Cass Fjord Formation. Redbeds, commonly used to distinguish the Parrish Glacier and Cass Fjord formations, are inconsistently developed. In this study the redbeds, where present, serve to distinguish the Middle Member of the Cass Fjord Formation. Where absent, only a single unit can be mapped between the Scoresby Bay and Cape Clay formations.

The rocks previously referred to as ‘Parrish Glacier Formation’ or ‘unnamed oolitic unit’ are herein included in the Lower Member of the Cass Fjord Formation (Fig. 1). A previous differentiation of the Cass Fjord and Parrish Glacier formations was based on biostratigraphic data from rare trilobites (de Freitas and Fritz, 1995; de Freitas 1988a, b, c). Although this approach is possible locally, it was found to be impractical for regional mapping.

GEOLOGICAL SETTING

The stratigraphic succession on Judge Daly Promontory features Lower Cambrian through Silurian shelf, slope, and basin sediments. Differentiation into a distinct carbonate shelf and deeper water basin took place in the Early Cambrian and persisted throughout the remainder of the Cambrian and Ordovician. Shelf strata are dominated by shallow-water carbonate rocks, anhydrite, and minor siliciclastics with a maximum thickness of about 4000 m. The shelf-slope break runs northeast-southwest along the spine of Judge Daly Promontory. Slope and basinal strata comprise the Hazen Formation, featuring five locally mappable units, collectively in excess of 600 m thick. Flysch sediments originating in the Caledonian orogeny on East Greenland filled the basin and spilt onto the platform, ending carbonate sedimentation, starting in the Llandovery and extending into the Devonian.

Zinc-lead occurrences on northeast Ellesmere Island (Harrison et al., 1999) and on Washington Land, Greenland (Dawes et al., 2000) occur in the uppermost Scoresby Bay, as well as Cass Fjord, and Cape Clay formations. The age of mineralization is unknown, but postdates at least some Ellesmerian folding, and predates Tertiary thrusting (Harrison et al., 1999).

The present study is part of a regional mapping operation conducted by the Geological Survey of Canada in co-operation with the Bundesanstalt für Geowissenschaften und Rohstoffe of Hannover, Germany.

MEASURED SECTIONS

Six measured sections from the upper Scoresby Bay Formation to the lower Cape Clay Formation are presented graphically in **Figure 3**, showing the correlation of units within this interval. Section locations are shown in **Figure 2**. Section 175 was measured by Tim de Freitas and Paul Crowley at Cape Camperdown, Bache Peninsula (79°01.22′ N; 74°37.17′ W). Section 178 was measured by Dave Beedell and Tim de Freitas at the mouth of Dobbin Bay (79°41.47′ N; 72°45.20′ W). Section 00-DTA-03 was measured by Keith Dewing and PJ Akeeagok at the mouth of the first river south of Carl Ritter Bay (81°51.0′ N; 68°0.0′ W). Section 00-DTA-07 was measured by Keith Dewing and Tiffani Fraser 5 km northwest of Carl Ritter Bay (81°57.5′ N; 67°47.5′ W). Section 00-DTA-46 was measured on Packdog Creek by Keith Dewing and Lori Beattie (81°21′ N; 66°50′ W). Section 00-DTA-49 was measured at the head of Ella Bay by Keith Dewing and Lori Beattie (81°05.4′ N; 70°03′ W). The line of section between section 175 and 00-DTA-07 is modestly oblique to depositional strike, with the northernmost section closer to the shelf margin than the southernmost. The section between 00-DTA-07 and 00-DTA-49 is perpendicular to the trend of the shelf margin, with sections 00-DTA-46 and 00-DTA-49 measured through the basinal Hazen Formation.

The section is hung on the base of the Cape Clay Formation, a regional unconformity approximating the Cambro-Ordovician boundary. Choice of this datum is effective for showing the relationship between units on the shelf, but gives a misleading visual impression that the Hazen Formation in 00-DTA-46 and 00-DTA-49 is the other side of a basin. It is thin because it is a condensed, deep-water sequence. **Figure 4** shows the time-stratigraphic interpretation.

PLATFORM STRATIGRAPHY

Uppermost Scoresby Bay Formation (unit 1, Early Cambrian, Bonnia-Olenellus Zone)

Unit 1a

The uppermost 25 m of the Scoresby Bay Formation consists of medium to coarsely crystalline, commonly fenestral, dark-grey-weathering dolostone. At 00-DTA-07 the upper 7 m consists of chaotically bedded dolostone with discontinuous lenses of doloarenite, and rotated blocks of laminated dolostone, inferred to be an unconformity-related karst breccia. A later dolomitization is superimposed on the upper Scoresby Bay and lower Cass Fjord formations. It consists of bedding-parallel zones of replacive, white, saddle dolomite, locally forming pseudobreccia and mosaic breccia and with late-stage quartz. It consists, at outcrop scale, of white bands, 5–10 m thick, that obscures the Scoresby Bay–Cass Fjord formational contact. Small grains of sphalerite, and copper staining of fractures occur locally in this interval.

Lower Cass Fjord Formation (unit 2, 70–275 m, Middle Cambrian, Glossopleura to Bolaspidella zones)

Lower oolitic unit (unit 2a, 0–55 m)

Decimetre- to metre-scale interbeds of oolitic and oncolitic grainstone and burrow-mottled lime mudstone with minor fenestral dolomudstone dominate this unit. The unit as a whole weathers medium grey. Thin sandstone is found at the top of the unit in the area around Radmore Harbour; this thins to the south, disappearing south of Radmore Harbour. Replacive dolospar is common in oolitic grainstone beds in the lower part of the unit. It is resistant to weathering and contains *Glossopleura* or *Bathyuriscus* zone trilobites.

Upper oolitic unit (unit 2b, 30–115 m)

Burrow-mottled lime mudstone and medium grey, fissile shale occur at base, overlain by rhythmically bedded lime mudstone and dolosiltstone. Oolitic and oncolitic grainstone and intraformational conglomerate layers become abundant upsection. Oolitic beds are less common towards the south of the area. The beds are mudcracked, stromatolitic, or with trough crossbedded doloarenite at top. The unit displays recessive weathering at base, but resistant weathering at the top, and contains *Bolaspidella* Zone trilobites.

Microbial unit (unit 2c, 0–45 m)

A burrow-mottled lime mudstone at the base of the unit is overlain locally by fenestral dolomudstone with a prominent, microbial or stromatolitic bed up to 9 m thick at unit top. This stromatolitic bed is resistant and distinctively white weathering. It thins to zero thickness south of Radmore Harbour.

Lower mixed carbonate-clastic unit (unit 2d, 40–115 m)

This unit is composed of burrow-mottled, massive, or fenestral lime and dolomudstone and intraformational conglomerate with decimeter-scale interbeds of very fine-grained, rippled or trough crossbedded quartz sandstone and minor green shale. It is more argillaceous and less sandy to the south. The upper contact is at the base of the first purple- or red-weathering bed.

Middle Cass Fjord Formation (unit 3, 60–400 m, Upper Cambrian, Crepicephalus-Cedaria Zone)

Variegated unit (unit 3a, 60–400 m)

The lowest 60 m is a very finely crystalline, thinly bedded dolomudstone with ripples, mudcracks, and teepee structures in 1–2 m beds, interbedded with shale and siltstone, red, purple, and green weathering in half to one metre thick beds. Thrombolites and intraformational conglomerate beds were noted near top. It is pink weathering at outcrop scale along the length of Judge Daly Promontory. The upper 340 m present in Dobbin Bay and Radmore Harbour areas consists of thickly bedded, fine- to coarse-grained quartz sandstone with herringbone and trough crossbedding, interbedded on a metre scale with thinly bedded lime mudstone. In section 178 the unit forms four shallowing-upward cycles that are each 30–130 m thick and consist typically of burrow-mottled lime mudstone at the base, overlain by intraformational conglomerate beds interbedded with lime mudstone containing mudcracks and evaporite casts, overlain by thrombolitic and stromatolitic boundstone, overlain by thin quartz sandstone.

Upper Cass Fjord Formation (220–290 m, Upper Cambrian, Taenicephalus to Saukia zones)

Lower clastic unit (unit 4a, 10–25 m)

The 10–25 m thick sandstone interval contains 50 cm to 1 m thick beds of herringbone crossbedded quartz arenite interbedded with sandy limestone beds 1–2 m thick, and intraformational conglomerate. The entire unit weathers recessive at outcrop scale.

Ledge-forming unit (unit 4b, 100–120 m)

This resistant-weathering, ledge-forming unit at outcrop or airphoto scale is comprised of thinly bedded lime mudstone, and calcisiltstone and dolosiltstone; parallel and wavy laminations, ripples, minor burrow mottles, intraformational conglomerate, evaporite casts, and stromatolites commonly occur at unit top.

Upper recessive unit (unit 4c, 25–55 m)

Recessive, typically covered, and locally red weathering, this unit of dolomudstone and shale is thin to medium bedded, finely crystalline, with ripple marks, flaser lamination, and intraformational conglomerate containing sandy matrix.

Upper mixed carbonate-clastic unit (unit 4d, 90–125 m)

This unit is composed of dolostone with rip-up clasts and parallel laminations, interbedded with argillaceous limestone with parallel lamination or ripples, sandstone, shale, and gypsum. Evaporite occurs in section 178 and consists of gypsum interbedded with thinly bedded dolostone. The upper 0–10 m with trough or herringbone crossbedded quartz sandstone contains well rounded, high-sphericity grains. This upper sand unit is equivalent to the Kap Coppinger Member on Greenland (Bryant and Smith, 1990). Close to the shelf margin, this upper sandstone unit can become enormously thick (>200 m; 99-HBB-168 *in* Harrison et al. (1999)) with local interbeds of dolostone.

Lowermost Cape Clay Formation (Early Ordovician)

This unit is massive to burrow-mottled, thickly bedded, resistant, cliff-forming limestone, locally with 1–10 m thick bedding-parallel zones of coarse dolomite with saddle dolomite-filled vugs and pseudobreccia. Sphalerite has been noted in some locations (Harrison et al., 1999).

BASIN STRATIGRAPHY

Hazen Formation

Units of the Hazen Formation have been described in greater detail by Harrison et al. (2000).

Unit 6a

Unit 6a is thinly bedded, dark grey and recessive-weathering lime mudstone and shale, with minor sandstone in decimetre beds. A very recessive shale unit, 7–20 m thick, was noted at the unit top. The base of unit 6a is drawn above the siliciclastic Kane Basin where lime mudstone becomes a dominant component of the section.

Unit 6b (10–75 m)

Carbonate packbreccia and doloarenite dominate this unit. Breccia consists of poorly sorted clasts in point-to-point contact. The clasts are subangular, massive to laminated dolostone up to 20 cm in diameter. The matrix is medium to coarsely crystalline doloarenite with common pyrite. Unit 6b forms a prominent and continuous marker throughout the region, but thins away from the shelf edge.

Unit 6c (35–70 m)

Interbedded shale and lime mudstone with minor sandstone make up this unit. The shale is thin bedded, pyritic, and cherty. The lime mudstone is massive with concretions or wavy bedded. The sandstone beds are thin, fine-grained, well rounded quartz arenite. Lithotypes are arranged in one to four shallowing-up cycles with distal sections showing fewer shallowing-upward cycles than proximal sections. The lowest of the four cycles is capped by sandstone, the second by carbonate packbreccia, the third by lime mudstone, and the fourth by mixed carbonate-clastic beds. Middle Cambrian trilobites occur in concretions within the second cycle.

Unit 6d (240 m)

Unit 6d is carbonate packbreccia and rhythmically bedded carbonate. Breccia consists of massive or laminated, angular and poorly sorted limestone clasts up to 14 cm long, in a medium crystalline doloarenite matrix. Lime mudstone and dolomudstone, rhythmically bedded on a centimetre to decimetre scale, are massive to parallel laminated. Local rippled sandy limestone occurs in the lower part and in the uppermost beds. A massive breccia bed occurs at the base at section 00-DTA-49, but many breccia beds occur in this interval elsewhere.

Unit 6e

Unit 6e consists of thinly bedded, parallel-laminated graptolitic lime mudstone and chert. Conglomerate beds are very rare.

CORRELATION BETWEEN PLATFORM AND BASIN

The units described reflect transgression and regression across the shelf and associated reciprocal sedimentation along the toe of the shelf margin during lowstands. Correlation between shelf and basin sediments is based on matching maximum flooding surfaces and is constrained by coarse paleontological control and major exposure surfaces.

The carbonate breccia of Hazen Formation unit B is interpreted to have formed when sea level fell below the shelf margin and actively eroded the platform during the unconformity postdating Scoresby Bay Formation deposition. Hazen Formation unit B is a lowstand wedge that thins away from the shelf margin. The Lower Cass Fjord Formation contains three and a half shallowing-upward cycles. The lower oolitic unit represents the initial transgression across the shelf; the maximum flooding surface is located within the burrow-mottled units in the lower part of the unit. Maximum transgression did not extend as far landward as sections 178 and 175. Sandstone, locally preserved at the top of the lower oolitic unit, indicates rapid progradation of the shore line and possible subareal exposure. Correlation with the Hazen Formation is to the first shallowing-upward cycle in Hazen Formation unit C.

The second shallowing cycle in the Lower Cass Fjord Formation is the upper oolitic unit. The maximum flooding surface is in the shaly interval in the lower third. Transgression extended across the study area and as far landward as northwest Greenland. Sedimentation outstripped sea-level rise and shallow-water oolitic grainstones, planar crossbedded calcarenite, stromatolitic boundstone, and mudcracked argillaceous limestone cap the unit. A possible exposure surface is indicated by the presence of a carbonate breccia bed at the top of the second shallowing cycle in Hazen Formation unit C (Harrison et al., 2000).

The third shallowing-upward cycle in the Lower Cass Fjord Formation consists of burrow-mottled limestone, containing the maximum flooding surface, overlain by a thick microbial boundstone. The correlation with the Hazen Formation is to the third shallowing cycle in Hazen Formation unit C.

The next shallowing-upward cycle straddles the contact between the Lower and Middle members of the Cass Fjord Formation. The maximum flooding surface is within the burrow-mottled limestones at the base of the lower mixed carbonate-clastic unit. The shallowing-upward cycle is manifest by the upward transition into mixed carbonate and clastic rocks displaying common shallow-water sedimentary structures, overlain by the variegated unit containing abundant intraformational conglomerate units, mudcracks, and teepee structures indicative of a tidal flat. This unit is overlain by an unconformity. The boundary between the Lower and Middle Cass Fjord Formation is drawn at the base of the variegated unit. This unit is an easily identified marker in the field and on airphotos and hence makes a suitable mapping boundary. In contrast, none of the sequence boundaries has a mappable physiographic expression.

A major unconformity is inferred at the top of this shallowing cycle on several grounds. First, an unconformity spanning four trilobite zones was documented in the middle of the Cass Fjord Formation on central Ellesmere Island by de Freitas and Fritz (1995). Second, the variegated unit preserved in section 178 is made up of four shallowing cycles comprised of an upward change from burrow-mottled limestone through microbial boundstone to quartz sandstone. These units are not preserved in sections 175 or 00-DTA-03 indicating that deposition occurred longer in the middle of the study area or was eroded to the north and south. Indeed, there is a marked thickening of the Cass Fjord Formation between Dobbin Bay and Radmore Harbour, although much of the thickening may be due to structural repeat caused by closely spaced thrusts. The lower clastic unit at the base of the Upper Member of the Cass Fjord Formation is herringbone cross-stratified quartz sand interbedded with interbedded dolostone and limestone. This unit is continuous and of uniform thickness across most of the study area, and is herein interpreted as resulting from transgression back over the shelf following the unconformity.

Correlation of the shallowing-upward cycle comprising the lower mixed carbonate-clastic unit and the variegated unit is to the shale at the top of Hazen Formation unit C and to the abundant breccia beds at the base of Hazen Formation unit D. The upper shale in Hazen Formation unit C is a condensed section equivalent to the preserved strata on the shelf, and the breccia beds at the base of Hazen Formation unit D are lowstand deposits formed during the unconformity or submarine slides caused by either a lowering of storm wave base such that wave pumping disturbed the sediment or by seismic activity along the margin (Trettin, 1994).

The Upper Member of the Upper Cass Fjord Formation contains two shallowing-upward cycles. The first of these comprises the lower clastic unit, the ledge-forming unit, and the upper recessive unit. These are equivalent to the middle part of Hazen Formation unit D, with the large breccia bed at about 500 m in section 00-DTA-49 possibly equivalent to an unconformity somewhere within the upper recessive unit. The upper shallowing-upward cycle comprises the upper mixed carbonate-clastic unit. This unit is capped by a discontinuous quartz sandstone with herringbone crossbedding. This uppermost sandstone is equivalent to the Kap Coppinger Member on Greenland and represents the initial transgression over the terminal Cambrian unconformity. Traces of this sand body are found at the top of Hazen Formation unit D where 3 m of sandstone are locally preserved.

MINERALS

Dawes et al. (2000) reported Zn-Pb-Ag mineralization containing spectacular galena crystals on Washingston Land, Greenland, about 100 km south and east of Carl Ritter Bay within the “lower massive unit” of the Cass Fjord Formation. Mineralization occurs within brown-weathering, ferroan dolomite. This rock type has not been recognized on Ellesmere Island. Probable correlation is to either the variegated unit or the ledge-forming unit, as these are the only two thick carbonate units in the Upper Cass Fjord Formation. Given the mineralization on Greenland, these units should be considered prospective on northeast Ellesmere Island as well.

CONCLUSIONS

The name Parrish Glacier Formation is abandoned due to the difficulty in recognizing it as a mappable entity across northeast Ellesmere Island. Rather, the entire Middle and Upper Cambrian sequence is placed in a single unit, the Cass Fjord Formation, that has Lower, Middle, and Upper members that can be recognized in most parts of the study area. In the northern part of the study area, the boundary between the Lower and Middle Cass Fjord Formation is chosen at the base of a variegated unit that is readily traced in the field and on airphotos. In the southern part it is based tentatively on biostratigraphy and subtle topographic features. The sequence boundary forms the contact between the Middle and Upper members. It is difficult to map as it has no topographic expression.

There are two major unconformity-bounded units in the Cass Fjord Formation. The lower is comprised of four shallowing-upward cycles and the upper one contains two shallowing-upward cycles. The lower unconformity-bounded unit correlates with Hazen Formation unit C, whereas the upper unconformity-bounded unit, as well as the unconformity that separates the two, correlates with Hazen Formation unit D.

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Geological Survey of Canada Project 990028

Thorsteinsson (1963), Kerr (1967)	Christie (1967)	Trettin (1994)	de Freitas (1998a, b, c)	This study
Cornwallis Group	Cornwallis Fm.	Ninnis Glacier	Baumann Fiord	Baumann Fiord
Copes Bay	Map unit 6		Christian Elv	Christian Elv
	Cape Clay	Cape Clay	Cape Clay	Cape Clay
	Cass Fjord	Cass Fjord	Cass Fjord	Upper Cass Fjord
Parrish Glacier	Cape Wood	Unnamed oolitic unit	Parrish Glacier	Lower Cass Fjord
Thule Group	Cape Kent	Scoresby Bay	Scoresby Bay	Scoresby Bay
	Police Post			

Figure 1. Correlation of Middle Cambrian to Early Ordovician unit names from northeast Ellesmere Island.

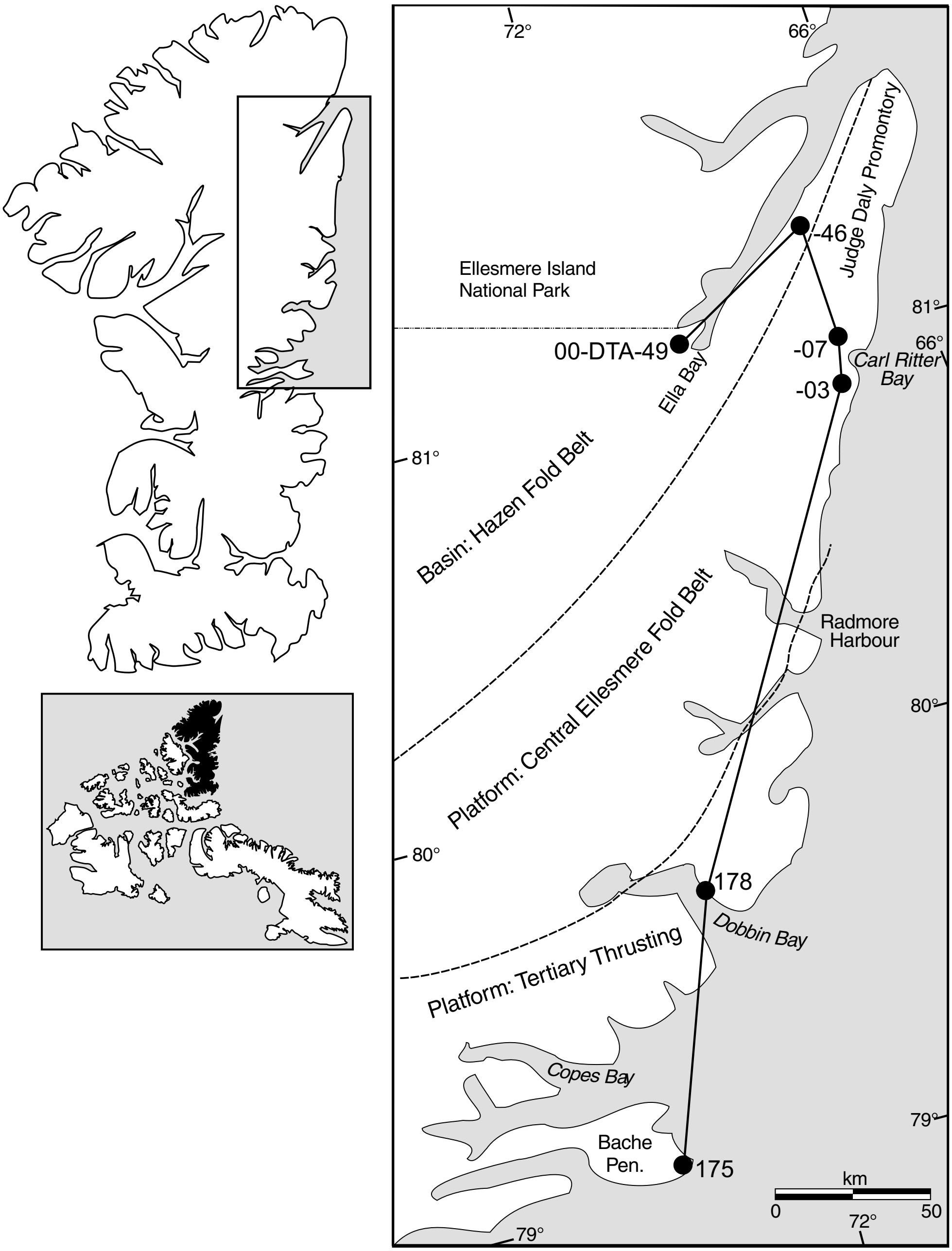

Figure 2. Location of the stratigraphic sections. The Late Devonian Ellesmerian orogeny divided the study area into two geological domains: 1) platform carbonate units (central Ellesmere fold belt) are folded into long wavelength, open and upright folds; 2) slope and basin sedimentary rocks (Hazen fold belt) are folded into tight, asymmetrical folds with well developed cleavage in shale beds. Tertiary deformation caused by the separation of Greenland from North America created thrust faults and numerous zones of strike-slip movement across the study area.

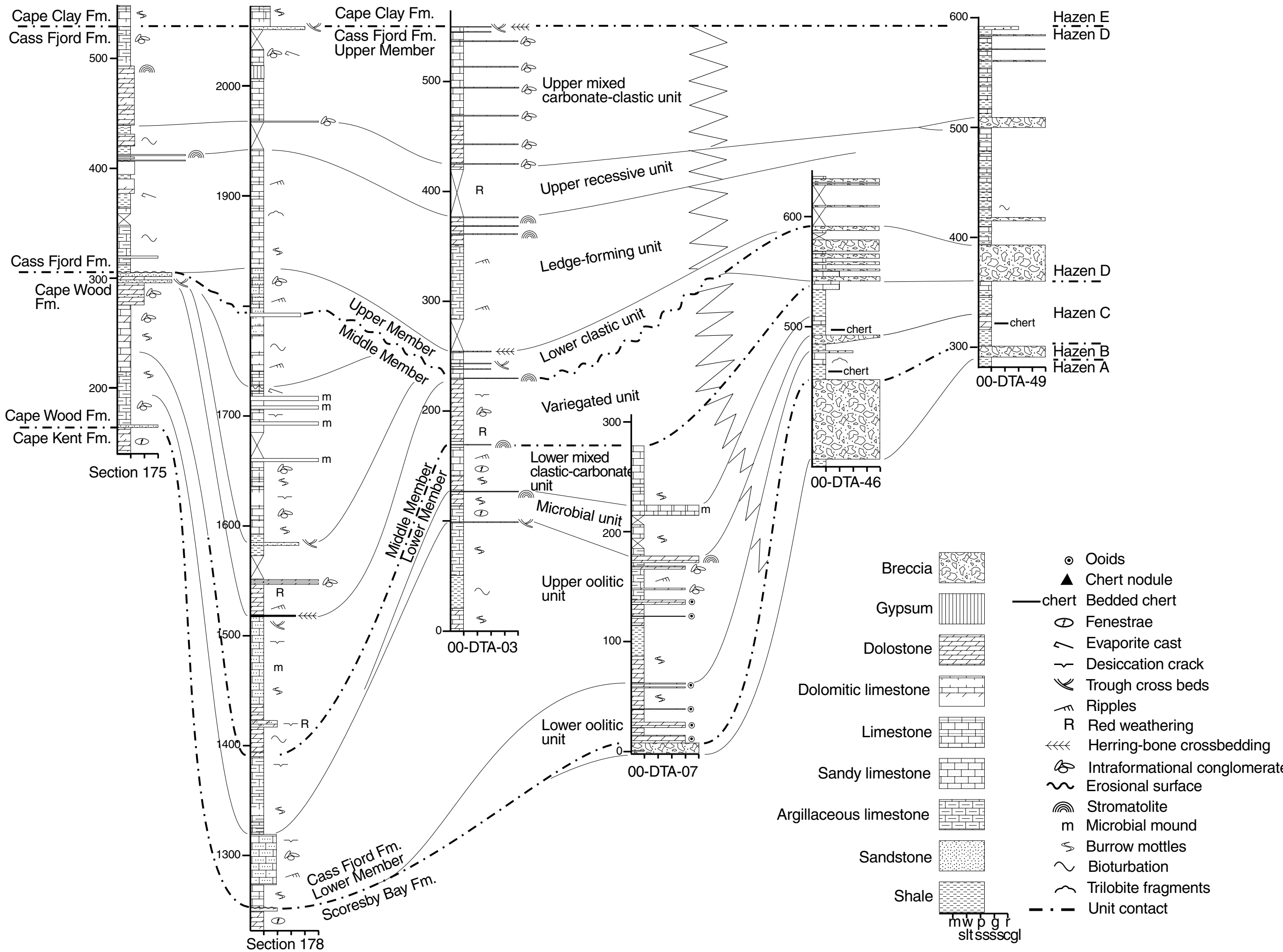

Figure 3.

Correlation of stratigraphic sections. Locations of sections shown in Figure 2. Note the change in nomenclature between Bache Peninsula (section 175) and the rest of the platformal sediments on Judge Daly Promontory.

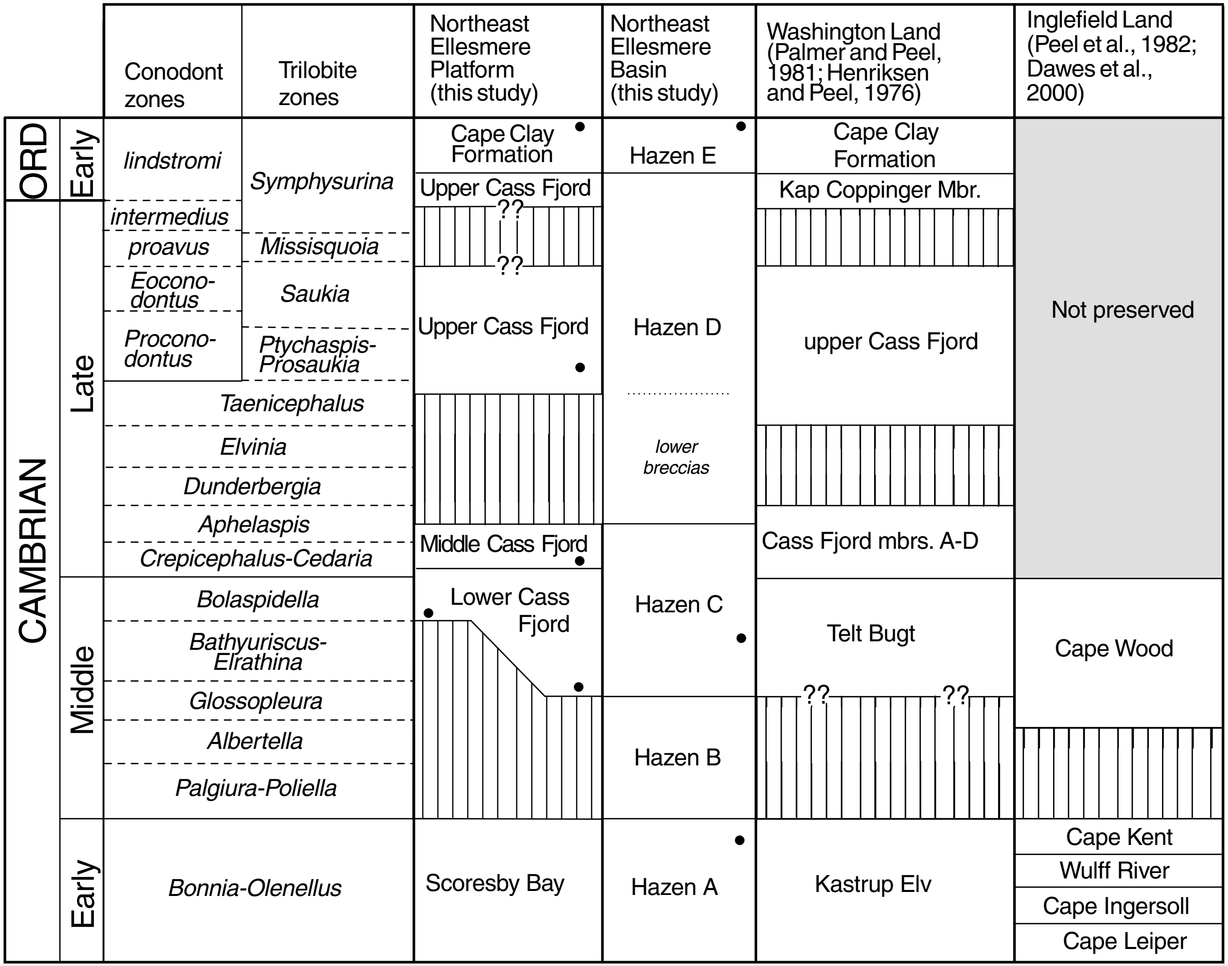

Figure 4. Time-stratigraphic interpretation of the Cass Fjord Formation and correlative units on Greenland. Biostratigraphic control indicated by black dots. ORD=Ordivician.