STRATIGRAPHY OF THE CAMBRIAN TO DEVONIAN SUCCESSION, CENTRAL ELLESMERE ISLAND

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ABSTRACT

The lower Paleozoic sequence in the Canadian Arctic Islands contains more than 30 regionally extensive T-R (transgressive-regressive) sequences. Most of these are exposed in central Ellesmere Island, and they are arranged into 5 stages that reflect similarities in tectonic setting, sedimentation, and stacking pattern of transgressive-regressive (T-R) sequences. Stage I is latest Proterozoic(?) to Late Cambrian in age, but it is not exposed in central Ellesmere Island. In other parts of the basin, it consist of a thick carbonate-clastic succession, deposited on a rapidly subsiding, passive continental margin. Stage II is Late Cambrian to Middle Ordovician in age and consists of carbonate and evaporites arranged as thick transgressive-regressive sequences, with transgressive, open marine carbonates and regressive, restricted carbonates and evaporites. The shelf margin was a high-relief, organically constructed barrier that caused highly restricted conditions on the shelf. Stage III is Late Silurian to Late Ordovician in age and is the record of deposition under plate convergence. Up to 14 km of synorogenic flysch accumulated on the condensed, deep water chart-mudrock succession of the underlying passive margin sequence. The siliciclastics were derived from the Greenland Caledonides, and their age and composition cannot be related to the stratigraphy of the contiguous shelf. During stage IV (Early to Middle Devonian), basement uplifts profoundly affected depositional settings through large areas. Angular unconformities and localized synorogenic clastic wedges were shed from high angle reverse and normal faults. Stage V (Middle to Late Devonian) was characterized by more widespread siliciclastic deposition in a foreland basin that developed in front of the generally southward and eastward advancing Ellesmerian overthrust wedge.

INTRODUCTION

The present report is a summary of main stratigraphic results of the lower Paleozoic succession in central Ellesmere Island. Field work on the area was conducted from two, helicopter-supported field camps in the summers of 1989 and 1991 (Fig.1).

These were multidisciplinary bedrock geological mapping efforts, which utilized workers in numerous geoscientific disciplines. Preliminary geological interpretations, maps, and structural and stratigraphic cross sections are reported elsewhere (de Freitas *et al.*, in press; Harrison *et al.*, 1994, in press; Thorsteinsson *et al.*, 1994), but this is the first account of the lower Paleozoic stratigraphic history central Ellesmere Island, based on these field seasons.

GEOLOGICAL SETTING

Cambrian to Devonian and possibly latest Proterozoic rocks of the Canadian Arctic Islands form the Franklinian succession, which extends into adjacent North Greenland and northern continental Canada. Although the basal units of the succession are unexposed, seismic reflection studies in the western Arctic Islands indicate that a thick passive margin sequence was deposited over a deeply eroded, slightly deformed Proterozoic succession (Harrison, in press). A thick, Lower Cambrian clastic-carbonate succession overlies the oldest, seismically defined units. Although these units are not exposed central Ellesmere Island, they have been investigated in northern Ellesmere Island (Trettin, 1994), and are presumed to occur beneath the Cass Fjord Formation in the central Ellesmere Island stratigraphic transect (Fig.2).

Passive margin subsidence during the Ordovician was regionally uniform, and similar facies belts extended throughout most of the Arctic Islands and North Greenland. The shelf-to-basin transition was static spatially and evolved into a microbial boundstone-rim feature with up to 1.6 km of submarine relief over coeval basinal chert and shale (Trettin, 1994). Shelfward of the rim, a thick salt-gypsum-carbonate sequence accumulated on a vast, highly restricted shelf. In Early Silurian time, plate convergence in northern Ellesmere Island and northern Greenland greatly affected depositional settings in many areas. Synorogenic clastics advanced primarily

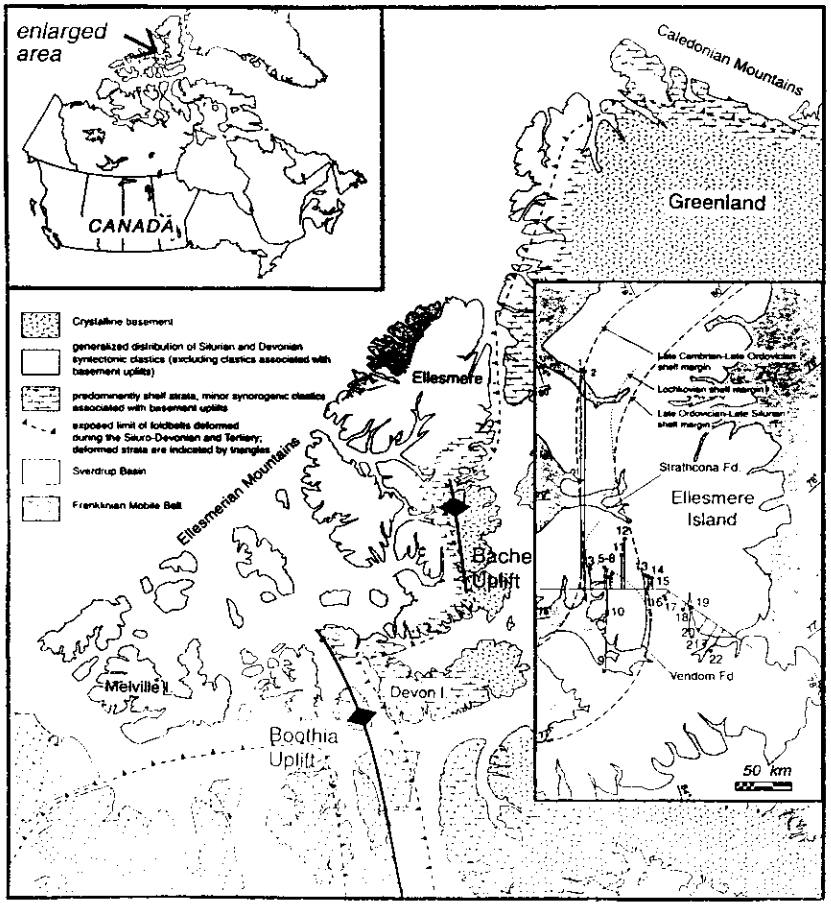


Fig. 1. Location map in the Canadian Arctic Island. The position of the Ellesmerian mountains is speculative. Distribution of syntectonic clastics (grey shade) is assumed to be similar to that of foreland basin depocentre developed during Siluro-Devonian convergent margin tectonics. Line of section is shown in Figure 2.

from the east, from the mature Caledonian Mountain belt in northern and eastern Greenland. During a slightly younger and partly overlapping time interval, Ellesmerian orogenesis occurred along the northern Arctic Islands, and the associated overthrust belt advanced southeastward onto the thick lower Paleozoic passive margin sequence, where it created a flexural downwarp (foreland basin) that received a thick, primarily continental siliciclastic succession. Significant siliciclastic depocentres are preserved in northeastern Ellesmere Island and in Banks, Prince Patrick, and Melville Islands (Gentzis *et al.*, in press; Embry, 1991).

STRATIGRAPHIC TRANSECT

Most data presented herein is preliminary, and space constraints prohibit a detailed treatment of each sequence. The 23 stratigraphic sequences are grouped into 5 stages according to similarities in tectonic setting, sedimentology, and stacking pattern of transgressive-regressive (T-R) sequences (Figs. 2,3). Main lithostratigraphic units contain, or are bounded by, basin margin subaerial unconformities or transgressive surfaces that occur basinward of the unconformity (Embry, 1993). The latter feature is the interpreted contact separating regressive deposits below from transgressive deposits above. The maximum flooding surface is the third stratal surface within most of the sequences, and it separates regressive and transgressive systems tracts.

Stage I *(late Proterozoic? to Late Cambrian)*

The inner shelf part of the transect contains three sequences. Although these occur on Precambrian crystalline basement, they do not represent the oldest Franklinian succession deposits, and more than 5 km of Lower Cambrian strata has been described from northern Ellesmere Island (Long, 1989a,b; Trettin, 1994).

Sequences of this stage are bounded by distinct subaerial unconformities, above which transgressive, shallow marine carbonate, sandy carbonate, and sandstone occur. A maximum flooding surface is identified in only the upper two sequences (Cass Fjord Formation). It comprises trilobitic, argillaceous carbonate, locally with conspicuous microbial mounds up to 12 m thick and 20 m wide. Regressive strata contain sedimentary features suggesting frequent subaerial exposure (polygonal mudcracks) and an upward increase in the number of mature quartz arenite beds. The outer shelf regressive strata is more than 1 km thick and consists of a lower trilobitic, graptolitic, argillaceous limestone and an upper hummocky cross-stratified, sandy, peritidal carbonate.

Stage II *(Late Cambrian to Middle Ordovician)*

The sequences of this stage were deposited on a restricted, carbonate shelf, bounded to the west by a microbial boundstone rim facies (Bulleys Lump Formation). The latter feature is not exposed in the transect, although correlative rock units have been documented in northern Ellesmere Island (Trettin, 1994).

Most sequences are bounded by subaerial conformities, but the lower sequence is associated with a substantial thicknesses of sandstone. The disconformities are generally sharp, with up to 5 m of relief, and these can be aligned with transgressive surfaces in the outer shelf. Transgressive portions of the sequences contain thick, resistant open marine carbonate, locally with abundant microbial mounds (*eg.* top of Christian Elv Formation, Fig.2). In western exposures, some transgressive systems tracts are associated with thick thrombolite boundstone that represent shelfward tongues of the Bulleys Lump Formation (Fig. 2). The maximum flooding surface separating transgressive and regressive systems tracts is not readily identified in outcrop.

Regressive systems tracts are predominantly restricted carbonates and evaporites in the lower part of stage II (Baumann Fiord and Christian Elv formations), and mostly restricted carbonates in the upper part (Bay Fiord Formation). Evaporites are locally arranged in metre-scale, upward-shallowing sequence, capped by subaerially exposed carbonates. Upper parts of regressive systems tracts contain thinner, vague, shallowing upward sequences with locally abundant polygonal mudcracks.

Basinal facies are not exposed in central Ellesmere Island, but the correlative rock units have been investigated in northern Ellesmere and western Melville islands, where they form a chert-mudrock succession. As a comparison, the Lower Cambrian to Lower Silurian basinal Hazen Formation in a an unrestored 100 km basinward distance from the Ordovician shelf margin, is 250 m thick, whereas the equivalent shelf succession is up to 4900 m thick (Trettin, 1994), indicating a shelf-to-basin thickness difference of 4650 m. Closer to the shelf edge, thickness differences were substantially less. Time lines drawn through the Danish River Formation in an shelf edge localities are offset by 1.5 to 2 km vertically (de Freitas, 1991; Trettin, 1994, Fig. 2), a value which approximates the submarine relief of the shelf edge at the onset of siliciclastic deposition in Early Silurian time (see below).

Stage III *(Late Ordovician to Late Silurian)*

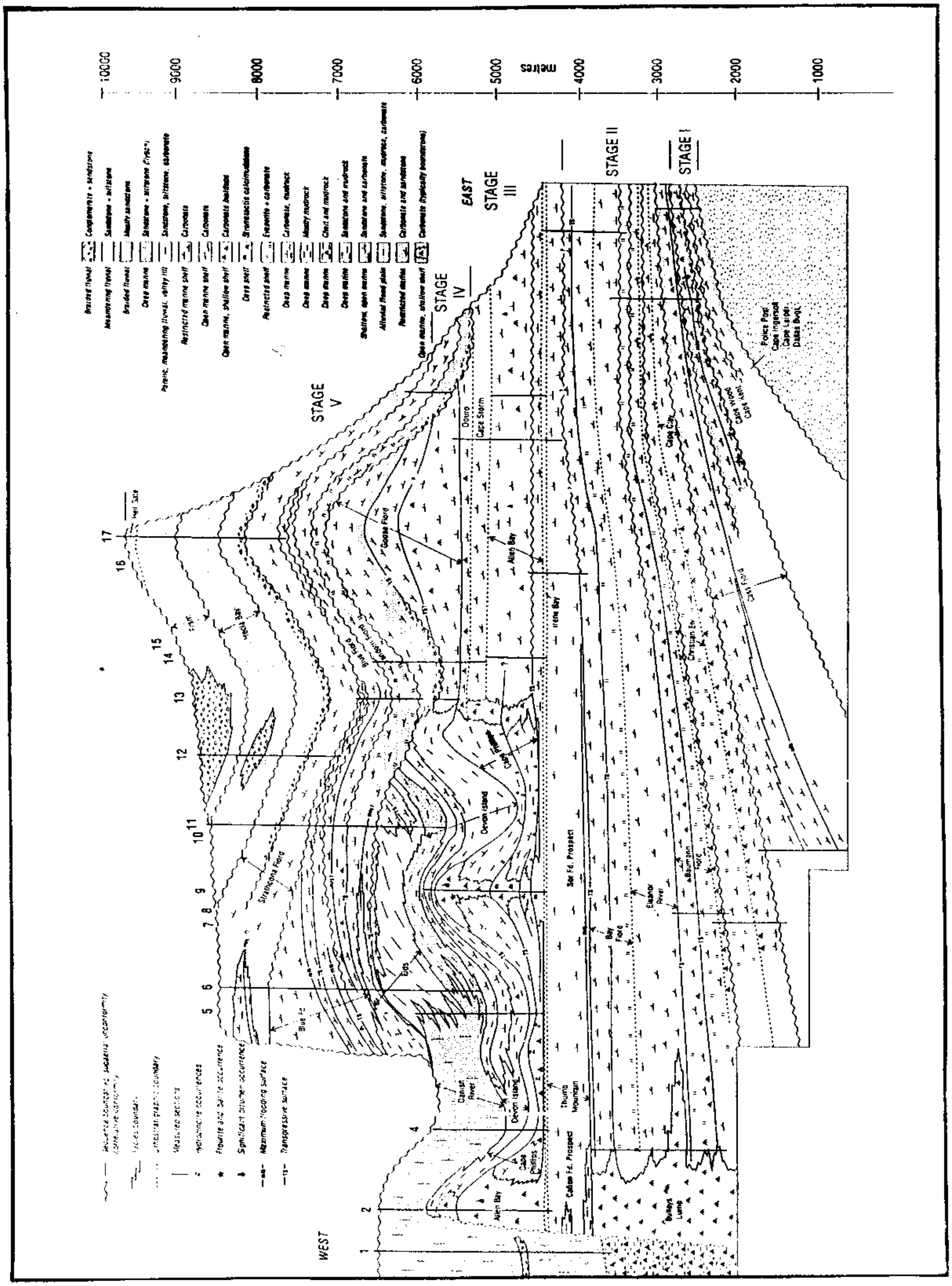
Shelf depositional environments were markedly different than in earlier stages. The microbial shelf edge buildup was terminated, and the shelf-interior was mostly unrestricted (Thumb Mountain Formation). In the inner shelf, the base of Stage III and lowest sequence is subaerial unconformity, but a transgressive surface in the outer shelf, separates open marine carbonates above from restricted mudcracked carbonates below. The lower sequence boundary is overlain by a thick, homogeneous, transgressive succession of open marine, mottled dolomitic limestone (Thumb Mountain Formation) which grades upward to more argillaceous carbonates of the upper Thumb Mountain Formation and Irene Bay Formation.

A thin carbonate unit above the Irene Bay Formation is overlain gradationally by the graptolitic Cape Phillips Formation. This contact is transitional over a 2 m interval and coincides with the most prominent, lower Paleozoic platform step-back event in the Canadian Arctic Islands. The maximum flooding surface is drawn at the mudrock-carbonate contact (base of the Cape Phillips Formation), implying a very thick transgressive systems tract spanning the Irene Bay and Thumb Mountain formations. The regressive systems tract, on the other hand, is very thin, and characterized by restricted carbonates locally in the basal part of the Allen Bay Formation and by a trilobitic mudrocks, carbonate, and lesser siltstone in the deeper water Cape Phillips succession.

Small areas on the shelf maintained depositional rates that were comparable with sea level rise, forming large, kilometre-scale buildup successions. Buildups facies comprise oolites, coral-microbial boundstone, and stromatoporoid boundstone deposited within the surf zone. Buildup geometries and facies mirror base level changes interpreted for the coeval shelf succession. Transgressive strata in the lower part of the buildup successions comprise stromatactis lime mudstone, whereas regressive facies are predominantly stromatoporoid boundstone and coral-microbial boundstone. Depositional relief on these structures was up to 500 m.

Shelf sequences within the time interval following shelf retreat are not well known. In the Cape Phillips Formation, an alternation of condensed and expanded successions are interpreted in terms of T-R sequences, and thus, condensed succession are transgressive, and expanded successions are regressive. In the stratigraphic cross section, most Cape Phillips Formation strata between sequence boundaries are regressive. Shelf sequences can be subdivided into transgressive-regressive couplets, but the biostratigraphic correlation necessary to relate basin and shelf successions is in progress.

A distinguishing feature of this stage is the rapid accumulation of siliciclastic strata (Danish River Formation) in the Hazen deep water basin. Synorogenic clastics are up to 14 km thick in northern Ellesmere Island (Gentzis, *et al.*, 1995) and were likely derived from the Greenland Caledonides and transported by high-velocity density flows to central Ellesmere Island. The clastics rapidly filled the Hazen deep water basin, overstepped the submarine carbonate edifice, then accumulated on the drowned carbonate shelf. The onset of clastic deposition on the drowned shelf was highly diachronous and influenced by the presence of topographically high carbonate buildups, such as shown at locality 2 (Fig. 2).


WEST
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STAGE I
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STAGE III
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metres
10000
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Sequence boundary or subaerial unconformity
Correlative conformity
Facies boundary
Lithostratigraphic boundary
Measured sections
Halokinetic occurrences
Flourite and barite occurrence
Significant bitumen occurrences
Maximum flooding surface
Transgressive surface
Braided fluvial
Meandering fluvial
Deep marine
Restricted marine shelf
Open marine shelf
Open marine, shallow shelf
Deep shelf
Restricted shelf
Alluvial flood plain
Restricted marine
Conglomerate + sandstone
Sandstone + siltstone
Carbonate
Carbonate buildups
Evaporite + carbonate
Chert and mudrock
Sandstone and mudrock
Carbonate and sandstone
Police Post
Cape Ingersoll
Cape Leiper
Dallas Bugt
Cape Wood
Cape Kent
Cass Fjord
Cape Clay
Christian Ev
Baumann Fiord
Eleanor River
Bay Fiord
Sor Fd. Prospect
Caledonian River
Thumb Mountain
Cape Phillips
Allen Bay
Bulleys Lump
Devon Island
Cape Storm
Douro
Goose Fiord
Irene Bay
Strathcona Fiord
Blue Fiord
Hell Gate

← Fig. 2. Cross section of the lower Paleozoic succession of central Ellesmere Island. Line of section is shown in Fig. 1. Localities 1 and 2 based on de Freitas (1991) and Trettin (1979). Locality 11 is partly based on Trettin (1978).

Lochkovian regressive carbonate strata of the Devon Island Formation show an apparent westward progradational geometry over deeper water strata (Fig. 2). Carbonate facies suggest a ramp-like platform profile and a broad shelf-to-basin transition with a prominent platform salient in the region of the transect (Fig. 2). The salient may represent an early phase of vertical movement of the Bache Uplift and reflect the west-trending faults which played a significant role in later, more pronounced uplift, discussed below.

Stage IV *(Late Silurian to Early Devonian)*

Vertical movement of the Bache Uplift[1] significantly influenced shelf configuration and depositional settings in central Ellesmere Island. The onset of syntectonic clastic sedimentation and the associated subaerial unconformity in the upper part of the Goose Fiord Formation forms the base stage IV. Three distinct phases of movement are interpreted for the Bache Uplift, in the upper Goose Fiord Formation, Vendom Fiord Formation, and middle Blue Fiord Formation. In the two oldest phases of diastrophism, clastics were shed from lower Paleozoic carbonates that were uplifted along an enigmatic array of south- and north-trending faults. The area of maximum structural relief (based on the amount of eroded strata) corresponds approximately to the Lochkovian carbonate platform salient, described above. Syntectonic detritus were deposited in braided pebbly stream, playa, nearshore marine, and floodplain settings in the eastern part of the transect, but in the west (vicinities of localities 6 to 11, Fig. 2), marine facies predominated. Eastern exposures are predominantly transgressive, although at locality 11, transgressive and regressive systems tracts are separated by a maximum flooding surface. Transgressive facies are typically coarser grained and contain fluvial conglomerates and floodplain red beds. Regressive units comprise laminated gypsum, siltstone, carbonate, and sandstone deposited in a restricted, tidally influenced shelf.

Extensive carbonate shelves formed during tectonic inactivity and are represented by lower and upper parts of the Blue Fiord Formation and upper part of the Goose Fiord Formation. Transgressive strata of these units are highly fossiliferous with locally well developed reefs, whereas regressive units are more restricted and contain great thicknesses of fenestral lime mudstone.

Danish River Formation turbidites accumulated west of the Ordovician shelf to basin transition in Early Silurian time. As mentioned above, these encountered a substantial submarine carbonate edifice that developed through earlier differential accumulation rates of the passive margin. By Early Devonian time, the deep-water basin was filled, and the siliciclastics overstepped the shelf edge and accumulated on the drowned shelf. Siliciclastic overstep may have been aided by sediment and tectonic loading associated with Ellesmerian overthrust belt to the west or by tectonic loading associated with the Bache Uplift to the east. The flysch was transported over great distances in the deep basin by submarine gravity flows, and their composition, age, and facies do not reflect base-level changes interpreted for the contiguous shelf.

Stage V *(late Early to Late Devonian)*

The base of this stage coincides with the onset of foreland basin sedimentation in front of the eastward and southeastward advancing Ellesmerian overthrust belt. The base of the stage is marked by a subaerial unconformity and the abrupt appearance of redbeds of the Strathcona Fiord Formation, deposited in alluvial, estuary, shoreface, and restricted marine settings. A disconformity is interpreted in the middle of the formation, above which a regionally extensive chert pebble and granule conglomerate was deposited in a braided fluvial setting. The sandstones contain abundant heavy minerals and phylosilicates and are in marked contrast to the chert-rich siliciclastics of the overlying clastic formations.

The upper two sequences consist mainly of braided fluvial and lesser meandering fluvial deposits that are separated by minor hiatuses. The succession coarsens upward, such that the Fram Formation contains ubiquitous pebble and local cobble conglomerate.

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[1] Kerr (1967) originally described the Bache Peninsula Uplift, but "Peninsula" is herein dropped for reasons of brevity and to be consistent with the geographic name of the southern, roughly coeval Boothia Uplift, where "Peninsula" was similarly removed from the name (Boothia Peninsula).

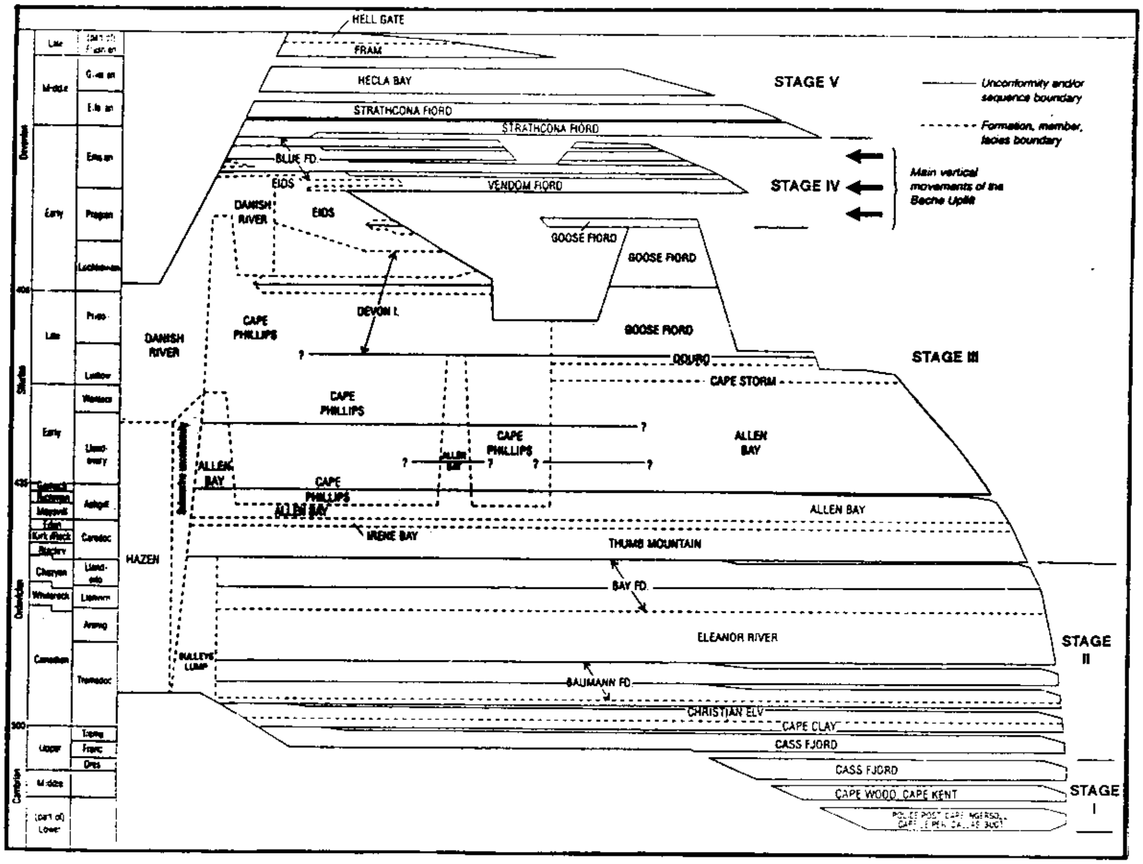

Fig. 3. Ages of lithostratigraphic units shown in Figure 2.
Some age in formation is based on Uyeno (1990).

REGIONAL SETTING AND SUMMARY

Following continental breakup in latest Proterozoic or earliest Cambrian time, clastic and lesser carbonates were deposited over a thermally subsiding passive continental margin (*Stage I*). During the Ordovician (*Stage II*), the continental margin accommodated a thick carbonate-evaporite succession, bounded to the west by a wave-resisted microbial rim. The Early Silurian succession (*Stage III*) in central Ellesmere Island contains features suggesting that the margin had evolved into a regime of tectonic convergence, where voluminous siliciclastics (flysch) were deposited above the condensed chert-mudrock succession of the preexisting passive margin sequence. Direct evidence for Silurian plate convergence occurs in northern Ellesmere Island, where composite terrane amalgamation along oblique slip (?) trajectories, acid and basic volcanism, and deposition of olistostromes indicate active tectonism (Trettin, 1987, in prep.). While these important tectonic events were occurring in northern Ellesmere Island, flysch accumulated rapidly in basinal areas of central Ellesmere Island, but the contiguous Silurian carbonate shelf retained features of a passive margin succession. Kilometre scale buildup successions and the reef-rimmed carbonate platform were accommodated on a uniformly although rapidly subsiding crust. However, in Early Devonian time (*Stage IV*), convergent tectonics (Bache Uplift) occurred in the previously stable carbonate shelf, and coarse synorogenic conglomeratic clastic wedges formed along north and west trending fault scarps. The uplift (Bache Uplift) in central Ellesmere Island was an intraplate contraction feature linked kinematically to stresses generated at the plate margin due to continent-continent collision and formation of the Greenland Caledonides (Okulitch, *et al.*, 1986; de Freitas and Mayr, 1993). In the Canadian Arctic Islands, the redistributed Caledonian stresses reactivated older basement structures, forming the Boothia and Bache uplifts (Figs. 1,2). These positive basement structures were probably inverted extension faults that formed during latest Proterozoic (?) continental breakup.

The youngest syntectonic clastic unit of the Bache Uplift was covered by shelf carbonates. The overlying succession in contrast is a thick syntectonic clastic wedge derived from the Caledonian and Ellesmerian Orogens (*Stage V*). Lithoclasts of the Hecla Bay, Fram, Hell Gate formations are composed overwhelmingly of biogenic chert clasts probably derived from uplifted deep water rocks (*i.e.* Hazen Formation) in the Ellesmerian overthrust belt to the northwest and west. This is in contrast to the detritus in the Strathcona Fiord Formation, whose heavy mineral assemblage suggests derivation from a high grade, regionally metamorphosed source areas such as the mature, Caledonian Orogen or perhaps from the deformed metamorphic rocks northern Ellesmere Island. Sediment composition of the Devonian clastic succession are the converse of that normally reported from convergent margin sedimentary successions, where passive margin sedimentary sources are followed typically by hinterland metamorphic and igneous sources as deeper structural levels are unroofed.

The unique secession of sandstone composition is attributed to the following. Middle and Late Devonian clastics accumulated in the roughly south- and southwest-trending flexural mote caused by tectonic and sediment loading of the Ellesmerian overthrust belt. Initially, this belt was probably overriding preexisting passive margin bathymetry and attenuated continental crust and thus attained little topographic expression. Therefore, it was a minor sediment source during the early stage of foreland basin infill; however, far-travelled sediments derived from the mature, high relief Caledonian Orogen in Greenland were deposited in the foreland basin. Later, as the Ellesmerian overthrust wedge mounted thicker continental crust, greater subaerial relief was attained, and detritus eroded from uplifted, deep water passive margin chert and mudrock and earlier flysch filled the foreland basin.

The evolution of central Ellesmere Island from passive in Cambrian and Ordovician to convergence in Silurian and Devonian time is recorded in a sequence that may be in access of 23 km.

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