Upper Proterozoic and Lower Palaeozoic strata in northern East Greenland

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The Caledonides of East Greenland contain the best exposures of Upper Riphean to Ordovician sediments in the Arctic – North Atlantic region. At its thickest the sequence contains 13 km of Eleonore Bay Group clastic sediments and carbonates, the 0.8 km thick Tillite Group and 3 km of Cambro-Ordovician strata (Henriksen & Higgins, 1976; Henriksen, 1985). These sediments crop out in a belt stretching for nearly 300 km through the fjord region, between 71° 38′ and 74° 25′N. Those in the northern part of the region, between Brogetdal in Strindberg Land and southern Payer Land, and especially Albert Heim Bjerge and C. H. Ostenfeld Nunatak, were the subject of investigation during 1988 (figs 1, 2).

Upper Proterozoic

The Tillite Group and uppermost Eleonore Bay Group were investigated by M. J. H. The strata represent an interval of time characterised by marked climatic fluctuations, including two periods of glaciation (Hambrey & Spencer, 1987 for review of literature). Recently, the Cambridge expeditions of 1984 and 1985 investigated these sediments in the area south from Kap Weber (73° 30′N) (e.g. Hambrey & Spencer, 1987; Moncrieff, in press; Herrington & Fairchild, in press). This work indicated a remarkable range of facies, ranging from terrestrial, through shallow marine and slope, to deep water. The character of the northern part of the basin, however, has remained unknown, apart from a summary description of a section at Albert Heim Bjerge by Cowie & Adams (1957). The 1988 work thus completes the present survey of the latest Proterozoic strata in East Greenland.

No published descriptions exist of the northernmost outcrops of the Tillite Group in Payer Land or on C. H. Ostenfeld Nunatak (fig. 1, localities 1 and 2). The outcrops in Payer Land are highly tectonised and attenuated, and the succession obtained was only estimated during a two-hour traverse. The northern tip of C. H. Ostenfeld Nunatak was mapped by Koch & Haller (1971) as Tillite Group overlying Limestone-Dolomite 'series'. Unexpectedly, the succession was found to range from the lower part of the Tillite Group up into Cambro-Ordovician strata. Indeed, all the rocks on the Nunatak mapped as Limestone-Dolomite 'series' appear to be of Cambro-Ordovician age. The strata are steeply dipping to the east and are disrupted by bedding-parallel thrusting and later faulting.

At Albert Heim Bjerge an apparently continuous section through the Tillite Group was described briefly by Cowie & Adams (1957). A composite section measured in 1988 provides a near-complete section through the Tillite Group, but a more discontinuous one through the upper Limestone-Dolomite 'series' (locality 4). The rocks in this area are much affected by faulting, and a series of NE–SW trending faults progressively step down the strata to the south-east. In addition, earlier thrusting, some of it subtle and parallel to bedding, has locally thickened the sequence.

On the northern side of lower Brogetdal in Strindberg Land (fig. 1, locality 8) a section was measured through the Spiral Creek Formation (which is missing to the north), while the contact between the Limestone-Dolomite 'series' and the Ulvesø Formation was examined on the southern side (locality 9). The rocks are affected by faulting and earlier thrusting in a similar manner to Albert Heim Bjerge.

Sedimentary logs were measured in the Tillite Group in Brogetdal, at Albert Heim Bjerge, on C. H. Ostenfeld Nunatak and in Payer Land; the uppermost parts of Bed group 18 and Bed group 19 of the Limestone-Dolomite 'series' were logged at Albert Heim Bjerge (figs 1, 2).

Bed group 18. A discontinuous section through the upper 300 m was examined at Albert Heim Bjerge. Lower flaggy grey and black limestones (146 m) are mainly parallel-laminated, although oolites, pisolites, synaeresis cracks, scouring, trough cross-lamination and intraformational breccias occur locally. Above lies an incomplete section through a more or less brecciated dolostone, while the upper 55 m, where exposed, consist of light to dark grey, laminated, oolitic and channelled limestone. A deposit of sulphur, associated with a fault, occurs within this unit.

Bed group 19. At Albert Heim Bjerge this unit is only

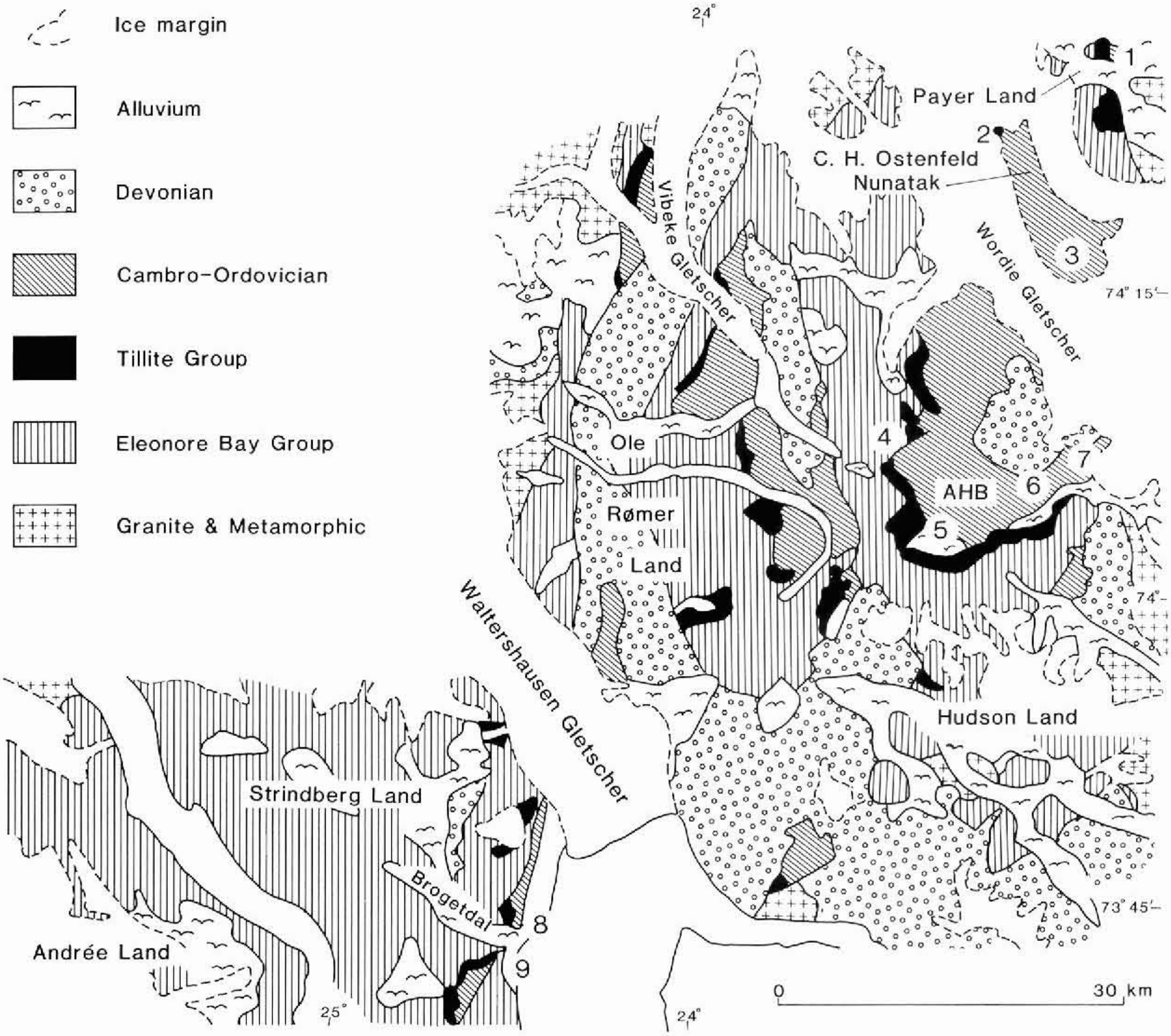

Fig. 1. Geological map of the Payer Land – Strindberg Land region of northern East Greenland showing general localities (numbered 1 to 9) visited during 1988. AHB, Albert Heim Bjerge.

35 m thick and consists of grey dolomitic shales, interbedded with yellow-weathering dolostones. Trough cross-lamination and syn-sedimentary faulting are evident locally. The unit is not exposed on C. H. Ostenfeld Nunatak and not recorded in Payer Land.

Bed group 20. Within the area studied, this unit occurs only on the south side of Brogetdal where it amounts to about 90 m in thickness. It is mainly a bluish black or greenish grey, parallel-laminated limestone, strongly sheared in its upper part with brittle-style folding.

The Limestone-Dolomite 'series' – Tillite Group contact. On the south side of Brogetdal the contact is between Bed group 20 and the Ulvesø Formation and is a thrust, with strong shearing and folding in the limestone. This is similar to the contact at Kap Weber (Hambrey & Spencer, 1987).

Further north, at Albert Heim Bjerge (fig. 1, locality 4), Ulvesø Formation diamictites rest with variable contact on a thin Bed group 19. Although Bed group 20 is missing, black limestone clasts resembling it (or Bed group 18) occur within the diamictite.

Ulvesø Formation. This is a variable formation with a wide range of facies, individual beds generally being uncorrelatable beyond a few kilometres. In the most complete section, at Albert Heim Bjerge (locality 4), the dominant facies is weakly stratified diamictite, but there is also massive diamictite, sandstone, conglomer-

System		Group		Formation
Ordovician	M			Heimbjerge
				Narwhale Sound
	L			Cape Weber
				Antiklinalbugt
Cambrian	M+U?			Dolomite Point
				Hyolithus Creek
	L			Ella Island
				Bastion
				Kløftelv
Vendian	Ediacaran / Varanger	Tillite		Spiral Creek
				Canyon
				Storeelv
				Arena
				Ulvesø
Late Riphean	(Sturtian)	Eleonore Bay	Limestone -Dolomite 'series'	Bed group 20
				Bed group 19
				Bed group 18

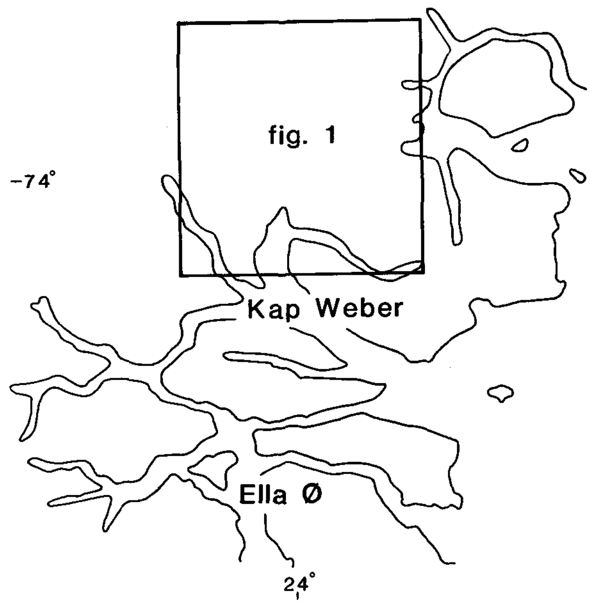

Fig. 2. Upper Proterozoic and Cambro-Ordovician stratigraphy, northern East Greenland. Accompanying map locates fig. 1.

ate and breccia. Planar concentrations of boulders are present in diamictites and there is much evidence of soft-sediment deformation. Payer Land has an equally varied section, but C. H. Ostenfeld Nunatak (locality 2) has a uniform diamictite throughout the exposed part of the section. In Brogetdal (localities 8, 9) the formation is thin with only a few metres of diamictite, sandstone being dominant. The yellowish grey colour reflects the high dolomite content, and all the clasts appear to be derived from the underlying Limestone-Dolomite 'series'.

Arena Formation. This was examined only at Albert Heim Bjerge where it comprises dolomitic shale in the upper and lower part and dolomitic sandstone in the middle. The upper shales additionally contain thin beds of dolomitic sand.

Storeelv Formation. Like the Ulvesø Formation, this shows marked facies changes. At Albert Heim Bjerge it is 94 m thick and comprises two weakly stratified diamictite horizons, although the bulk of it is sandstone. In contrast, the C. H. Ostenfeld Nunatak section comprises 170 m of interbedded weakly- to well-stratified diamictite units, rhythmites (including some with dropstones), sandstones and thin conglomerates and siltstones. Most clasts are intrabasinal, but a few igneous and crystalline lithologies were noted. Sandstone dominates in Payer Land (locality 1) and no diamictites were observed.

Canyon Formation. This formation was examined at Albert Heim Bjerge and C. H. Ostenfeld Nunatak where it rests with sharp contact on sandstone or diamictite of the Storeelv Formation. After a few metres of laminated orange dolostone, grey, shaly dolomitic mudstone accounts for the bulk of the 270 m thick formation. Dolomitic and calcium carbonate-rich nodules or lensoid layers characterise the middle of the formation.

In Payer Land the formation is similar, but highly attenuated as a result of deformation. In each locality it is in sharp, but apparently conformable, contact with the Cambrian Kløftelv Formation. However, the absence of the Spiral Creek Formation, which occurs in Brogetdal and further south, suggests a regionally unconformable relationship.

Spiral Creek Formation. Of the localities studied in 1988, this formation is present only in Brogetdal. On the north side of the valley it is characterised by a lower part (11 m) of sandstone with well-preserved hopper pseudomorphs of halite (as on Ella Ø), and an upper part of interbedded siltstone and sandstone. The top of the formation is in sharp contact with the Kløftelv Formation.

Discussion. The Late Proterozoic succession in northern East Greenland bears many similarities to that further south: predominantly carbonate slope and shelf facies (Bed groups 19 and 20), followed by glaciation in a marginal marine setting (Ulvesø Formation), then predominantly deeper water turbiditic sedimentation (Arena Formation), another phase of marginal marine glaciation (Storeelv Formation), a postglacial phase of shallow shelf to offshore deposition (Canyon Formation). Final shallowing-up to emergent conditions are represented by the upper Canyon Formation and Spiral Creek Formation only in Brogetdal and areas to the south, the erosional truncation of the uppermost Upper Precambrian sequence becoming greatest towards the north.

Although nonglacial formations tend to show individual members that can be traced throughout the region, the glacial formations are characterised by marked facies and thickness variations, as would be expected in a marginal glacio-marine setting.

Cambro-Ordovician

Cambro-Ordovician sediments were examined by J. S. P. and M. P. S. at Albert Heim Bjerge and on C. H. Ostenfeld Nunatak (fig. 1). The sequence at Albert Heim Bjerge is fully described by Cowie & Adams (1957). C. H. Ostenfeld Nunatak was visited briefly by John Haller in 1956 (cf. Cowie & Adams, 1957) and by Peter Frykman in 1977 (Frykman, 1978, 1979). Koch & Haller (1971) mapped the extreme western side of the nunatak and its eastern promontory as Proterozoic. With the exception of outcrops of the Tillite Group at the extreme northern tip, noted above, the 1988 field work demonstrated that all the nunatak is composed of Cambrian and Ordovician sediments.

Cambrian and Ordovician macrofossils from East Greenland were described by Poulsen (1932, 1937), although Cowie & Adams (1957) presented long faunal lists. Few macrofossils were collected in 1988. Limestone samples for acid digestion in search of phosphatic microfossils were collected from both the Bastion Formation and the Ella Island Formation of Early Cambrian age. Ordovician limestones were sampled for processing for conodonts. This sampling programme was intended to supplement the extensive suite of samples collected by P. Frykman in 1977, many of which were described by Smith (1985).

Kløftelv Formation. This prominent pale weathering quartzite, with two distinctive, reddish coloured, sandstone bands containing poorly preserved horizontal burrows, is well described by Cowie & Adams (1957) who measured a thickness of about 70 m. The sharply defined junction with black shales of the underlying Canyon Formation is discussed above.

Bastion Formation. Dark, recessive sandstones, shales and siltstones of the Bastion Formation (thickness about 150 m) were examined in the immediate area of the section described by Cowie & Adams (1957, pp. 50–58) in south-western Albert Heim Bjerge and at the northern tip of C. H. Ostenfeld Nunatak (localities 2 and 5 in fig. 1). Cowie & Adams (1957) noted trace fossils within the lowest portion of the formation and some material was subsequently described by Cowie & Spencer (1970). The potential interest of East Greenland for the study of trace fossils adjacent to the Precambrian–Cambrian boundary (see Crimes 1987, p. 114) prompted collection from the rich ichnofauna of the lowest Bastion Formation at locality 5 in 1988. The boundary with the overlying Ella Island Formation is gradational but can be drawn at the top of the last shale-siltstone bed in the transition zone.

Ella Island Formation. At Albert Heim Bjerge this limestone formation attains a thickness of almost 95 m (Cowie & Adams, 1957), although a well-exposed section along the glacier margin at the northern tip of C. H. Ostenfeld Nunatak is 140 m thick. The boundary with the overlying Hyolithus Creek Formation is marked by a change from limestone to dolomite but can be difficult to perceive due to the similarity of bedding form.

Hyolithus Creek Formation. Dolomites of this formation were only briefly examined at Albert Heim Bjerge and on C. H. Ostenfeld Nunatak. *Salterella* was collected from several horizons within the approximately 210 m thick unit.

Dolomite Point Formation. The formation, which Cowie & Adams (1957) measured to 370–420 m thick, was examined briefly at localities 2 and 5 (fig. 1) at Albert Heim Bjerge and on C. H. Ostenfeld Nunatak, respectively. The lower boundary with the Hyolithus Creek Formation is gradational and is expressed as an upward decrease in the proportion of dark to light beds. Since the first pale beds occur rather low in the section, the boundary was placed directly above the highest major dark unit. The remainder of the formation comprises pale buff weathering, mid-grey dolomites with common chert nodules.

Antiklinalbugt Formation. A complete section was logged through the unit at locality 5 (fig. 1) where it is 200 m thick. The lower boundary with the Dolomite Point Formation was placed at the abrupt change from cherty laminated dolomites to mid-grey micrites with current lamination, scours and intraformational conglomerates. Above about 10 m, the formation is dominated by a cyclic alternation of recessive, silty beds with massive beds of wavy laminated and burrow-mottled micrites. The former are made up of nodular grey micrites with abundant silty partings whilst the latter also contain chert bands, intraformational conglomerates and stromatolites. Around 100 m above the base of the formation, an abundant macrofauna was recovered, dominated by the trilobite *Hystricurus*, gastropods (including *Sinuopea*) and orthid brachiopods.

Cape Weber Formation. The formation was the most intensively studied of the Cambro-Ordovician units during the 1988 season, with some or all of the unit examined at localities 2, 3, 5–7 (fig. 1). None of the sections concerned was complete including, significantly, the reference section of Cowie & Adams (1957, the present locality 7); the top of this section is faulted against the Heimbjerge Formation rather than being conformably overlain by the Narwhale Sound Formation as claimed by Cowie & Adams. The thickness of 1042 m measured by P. Frykman (written communication, 1977) in Promenadedal at locality 6 (fig. 1) is the best estimate available, although the influence of minor faulting on this figure cannot be ruled out.

The lower boundary of the Cape Weber Formation is placed where typical Antiklinalbugt Formation lithologies are overlain by massive, burrow-mottled, pale to mid-grey, brown weathering micrites without silty horizons. Although the formation is generally described as a monotonous sequence of pale grey mudstones, several subdivisions are consistently recognisable. The lowest of these is a stromatolitic reef complex in the lower 100 m of the formation in both Albert Heim Bjerge and on C. H. Ostenfeld Nunatak (localities 3 and 7 in fig. 1). Others include, in ascending stratigraphic order, a unit of burrow-mottled micrite to laminated dolomite shallowing upward cycles (100–150 m), the thin-bedded, macrofossiliferous 'Black Limestones' of Cowie & Adams (1957), which occur approximately 540–625 m above the base of the formation, a unit with abundant (up to 50%) bedding-parallel cherts and, immediately below the Narwhale Sound Formation, a second sequence of mottled micrite to laminated dolomite shallowing upward cycles around 100 m thick. The formation is poorly fossiliferous, although the 'Black Limestones' yielded a fauna of trilobites and brachiopods. The uppermost 150 m yielded silicified opercula of the gastropod *Ceratopea*, and other gastropods and occasional cephalopods.

Narwhale Sound Formation. Only the upper and lower boundaries of this formation were logged. The lower boundary is difficult to identify in the area around Wordie Gletscher since there is no gross change in lithology from the Cape Weber Formation to the Narwhale Sound Formation; the most useful criterion is a change in weathering character from relatively massive to recessive. On Ella Ø, Cowie & Adams (1957) placed the lower boundary at the base of a coarsely crystalline dolomite. There can be no assurance that these two boundaries are precisely equivalent lithostratigraphically; preliminary conodont studies indicate significantly different ages. The matter is complicated by the common presence in sections examined during 1988 of tectonised boundaries; intense disharmonic deformation of the Narwhale Sound Formation between the more massive and less deformed Cape Weber and Heimbjerge Formations is widespread.

Heimbjerge Formation. The lower boundary of the formation was examined at locality 3 (fig. 1) where cycles of alternating burrow-mottled and laminated micrites give way to pale grey, massive micrites, sometimes with faint, dispersed mottling. The formation continues as a relatively uniform sequence of very pale to pale grey micrites with calcite veining. This uniformity is interrupted by occasional traces of burrow-mottling, algal lamination and stromatolites. Pink staining of both sediment and veins is common, probably as a result of the proximity to the pre-Devonian unconformity surface. Frykman (1979) estimated a thickness of over 1200 m on C. H. Ostenfeld Nunatak, in contrast to measured thicknesses on Albert Heim Bjerge of 320 m (Cowie & Adams, 1957) and 550 m (P. Frykman, written communication, 1977). Conodont samples were collected at the top of the formation in 1988 in order to confirm the early Middle Ordovician (Whiterockian) age based on scattered samples collected by P. Frykman in 1977 (Smith, 1982).

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Sedimentological and structural investigations of the Devonian basin, East Greenland

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Sedimentological and structural studies of the Middle to Upper Devonian deposits in East Greenland were initiated in 1986 (Marcussen *et al.*, 1987) and continued in 1987 (Marcussen *et al.*, 1988) and in 1988. Field work was carried out from late June to late August, but during a three week period from late July to early August it was hampered by bad weather in the region. The 1988 activities were concentrated around Moskusoksefjord, on Gauss Halvø west of Gastisdal and in Moskusokselandet. Shorter periods were spent in Ole Rømer Land and in northern Hudson Land, with short visits to Ymer Ø and Geographical Society Ø (fig. 1).

Prior to the field work a 1:100 000 preliminary photogeological map was produced in GGU based partly on previous observations and partly on new stereographic studies of aerial photographs (1:150 000) of the area north of Kejser Franz Joseph Fjord. The field work benefited greatly from this map and from a series of oblique photographs along Kejser Franz Joseph Fjord, Nordfjord and Moskusoksefjord, taken in 1987.

Two teams operated in the field. One team (H. Olsen & U. G. Wilken) studied the sedimentology of the Devonian succession and the other (P.-H. Larsen & F. O. Rasmussen) the structural evolution of the basin.