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The stratigraphy of the Upper Jurassic and Lower Cretaceous sediments of Milne Land, central East Greenland

by

Tove Birkelund, John H. Callomon and Franz T. Fürsich

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Abstract

The upper part of the Jurassic to Lower Cretaceous succession of Milne Land, described in the present paper, represents an unusually complete, highly fossiliferous sequence of Kimmeridgian, Lower and Middle Volgian and poorly fossiliferous ?Lower Valanginian to Hauterivian deposits.

On the basis of some 50 recorded sections the succession is described with respect to lithology and fossil content and placed within a lithostratigraphical framework. The Upper Callovian – Middle Volgian Kap Leslie Formation (overlying the Charcot Bugt Formation) is divided into eight members, the upper four of which are described in detail (Gråkløft Member, Krebsedal Member, Pernaryggen Member and Astartedal Member), while the Middle Volgian – Hauterivian Hartz Fjeld Formation above is divided into two members (Hennigryggen Member and Pinnadal Member).

A succession of 34 ammonite faunas has been recorded from the Kimmeridgian to Middle Volgian succession of the area. The Kimmeridgian to Lower Volgian faunas match British faunas so closely that the standard zonation of Great Britain can be used. The 17 faunas of the Middle Volgian are closer to successions of northern Russia and Siberia, and the succession has been made the basis of a new regional zonation of nine standard zones for the Boreal Province. One Lower Cretaceous ammonite fauna has been recorded, having ?Early Valanginian age and uncertain affinities.

The faunal horizons of Volgian ammonites from Milne Land figured by Spath (1936) in his classical monograph have been determined. Stratigraphically important species found since then have been described elsewhere (Callomon & Birkelund, 1982).

The three main areas of outcrops, the Hartz Fjeld area, the Kronen area and the Bays Fjelde area, are correlated in detail on the basis of ammonite occurrences. The depositional environments and tectonic evolution of the Milne Land area are outlined.

Some key sections of particular stratigraphical importance are described in an appendix.

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CONTENTS

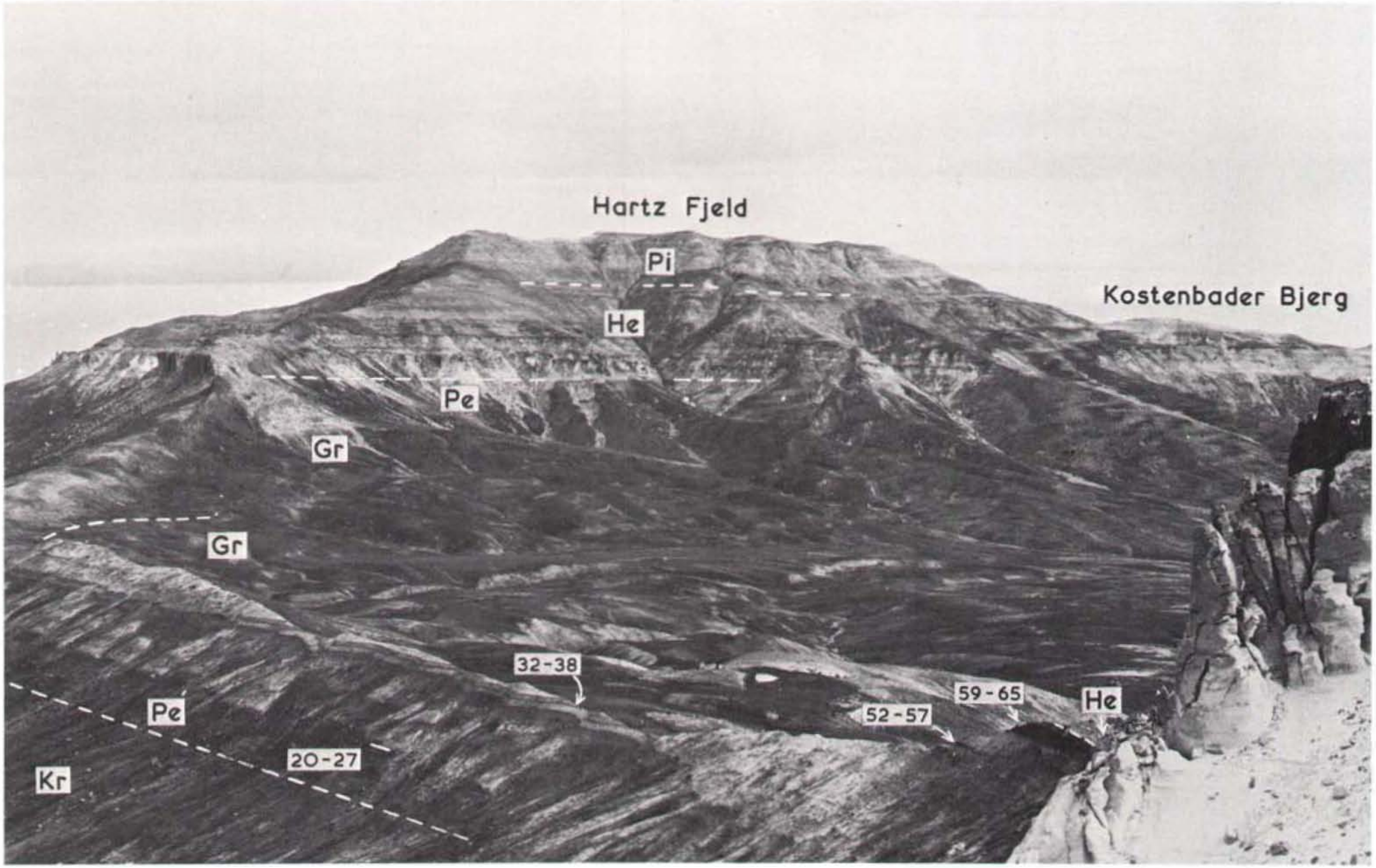

Fig. 1. View of Hartz Fjeld from Kronen looking east. Pernaryggen in the foreground. Kap Leslie Formation: Gr, Gråkløft Member; Kr, Krebsedal Member; Pe, Pernaryggen Member, beds numbered as in text. Hartz Fjeld Formation: He, Hennigryggen Member; Pi, Pinnadal Member.

INTRODUCTION

Mesozoic rocks have been known from Milne Land since they were first reported by Bay (1895) and identified as such by Rosenkrantz (1929). They consist of some 1200 m of sandstones and shales forming but a relict of their former extent, resting on a gently rising erosion-surface of Caledonian crystalline basement in the south-east corner of the island, around Kap Leslie. Upwards they are truncated by plateau basalts of Tertiary age. Serious exploration began with the expeditions led by Lauge Koch during 1926–33. The results of the early field work by A. Rosenkrantz and H. Aldinger were presented in three classical monographs, describing the stratigraphy with the first map (Aldinger, 1935), and the rich and beautifully preserved faunas that had been collected (Spath, 1935, 1936). These revealed the presence of what was probably an unrivalled succession from Oxfordian to Portlandian/Middle Volgian, followed after a gap by sparse representatives of some ?Lower Valanginian. Detailed bed-by-bed collecting started during Koch's last two expeditions in 1957–1958 and produced large quantities of new material, mainly ammonites, recovered from some 50 recorded sections now spanning the whole area. The faunal succession could then be amplified somewhat (Callomon, 1961); however, one of the obstacles that lay in the way of closer correlations with other parts of the world was the lack of sufficiently precise descriptions of the faunas of the standard classical successions themselves, in Britain and the USSR. These have in the meantime also become available.

The third phase commenced as part of a general programme of geological mapping of the east coast between 70° and 72°N by the Geological Survey of Greenland. New results obtained in 1970 were outlined by Håkansson, Birkelund, Heinberg & Willumsen (1971), and the geological map on a scale of 1:200 000 is published. The principal features are shown in fig. 2. Work concentrated on the definition and delimitation of lithostratigraphical units, and a consistent scheme of formations and their members was set up. Some remaining problems of stratigraphy were taken in hand during yet another visit in 1977. These related particularly to the lowest parts of the succession which were least understood, being very sparsely fossiliferous and well exposed only in the more remote parts of the area. The results obtained during this visit were summarized by Birkelund, Callomon & Fürsich (1978) and described in more detail by Callomon & Birkelund (1980). They were in part surprising, for they showed that the age of the Jurassic transgression onto the crystalline basement was considerably earlier than previously thought, being Middle Jurassic, Bathonian, rather than Upper Jurassic, Oxfordian. Studies were also made of sedimentology, ichnology, invertebrate palaeoecology and the

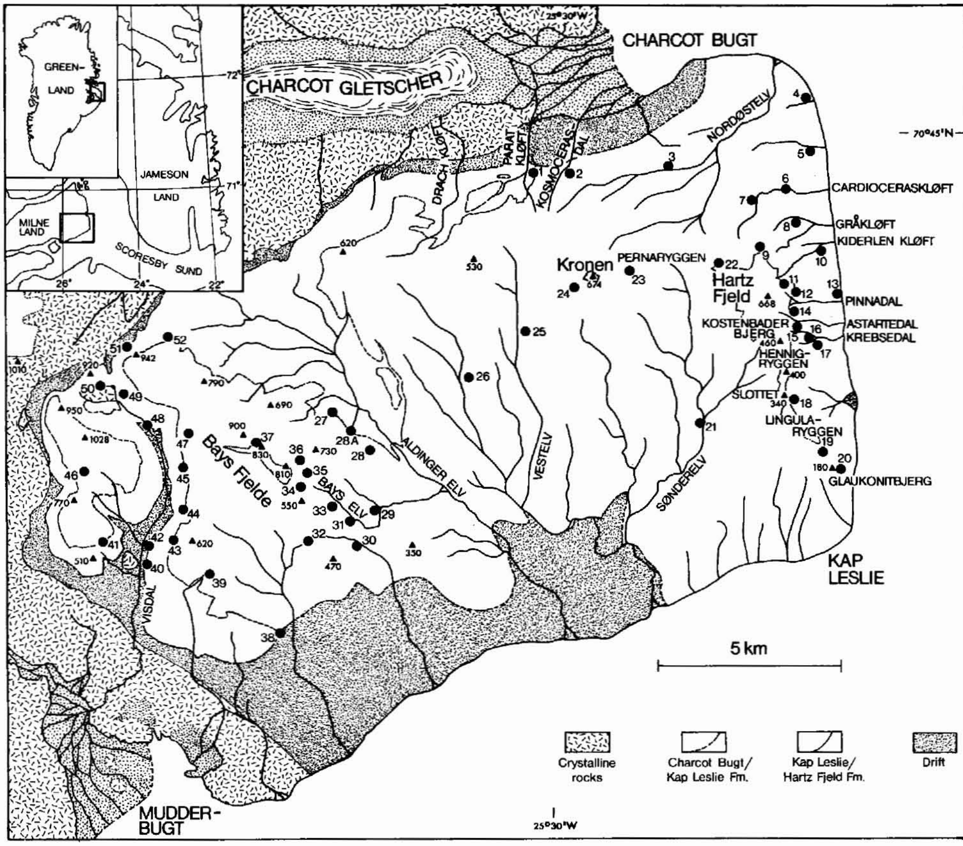

Fig. 2. Map of the Jurassic and Cretaceous deposits in Milne Land, giving place names and the location of the principal sections that have been measured and collected (nos. M1–M52).

dinoflagellate succession. A revision by one of us of the systematic classification of the immensely rich bivalve faunas has been published (Fürsich, 1982a). The purpose of the present paper is to present the litho-, bio- and chronostratigraphical framework for the description of the results.

Lithologies are typical of shallow shelf-sea clastic deposition, and sections are usually sharply divisible into well-defined beds ranging from a few centimetres to some metres in thickness. Facies and thickness change rapidly from place to place, and fossils, including the ammonites, tend to occur in a section at often widely-separated horizons, usually concretionary and of limited areal extent. The regional sequence of faunas had therefore to be pieced together from material found in many sections, as had the changes in lithology marking the regional boundaries of formations and their members, by matching faunas and lithologies as best one could. Sections and beds have been numbered for reference, and the logs are filed in the records of the Geological Survey of Greenland, Copenhagen. The locations of 52 of the more important of them are shown on fig. 2. Some key sections are reproduced here in full in the Appendix.

The description of the succession is conveniently divided into two parts, of which the first part has already been published (Callomon & Birkelund, 1980). It covered the lower formations which had previously been least understood, ranging from the basal beds resting on gneiss, of Middle Jurassic, Bathonian age, to the lower part of the Kimmeridgian. The present account describes the rest of the succession, covering the higher parts of the Kimmeridgian, the Lower and the Middle Volgian, and what little there is preserved of the Lower Cretaceous at the top.

AMMONITE ZONATION AND CHRONOSTRATIGRAPHY

A succession of 48 ammonite faunas has now been worked out in Milne Land, numbered consecutively and labelled with the names of their most characteristic members for reference. In many cases they are represented by large collections from single well-defined horizons, showing a variability that indicates homogeneity and close synchroneity, i.e. stratigraphical purity. In others, material is less sharply localized, less plentiful and more scattered. The combination of such small samples into effectively a single fauna is to some degree arbitrary and implies that the fauna may be subdivisible as more material becomes available.

The faunas have already been described in outline (Callomon & Birkelund, 1980, 1982). Faunas 1–13 range from the Middle Jurassic to the top of the Oxfordian. In this range the ammonites are almost identical with those found in standard sequences elsewhere – in Jameson Land in the Middle Jurassic, and in Britain in the Oxfordian – and while serving to date the local succession in Milne Land, they contribute little new to problems of wider interest. Faunal lists almost suffice.

Faunas 14–23 cover the Kimmeridgian and are listed in table 1. They, too, are so similar to those of Britain that the same standard zonation can be used. They differ, however, in detail and emphasis, reflecting the increasing effects and importance of faunal provincialism, and a fuller account is being prepared by Birkelund & Callomon.

Faunas 24–30 span the Lower Volgian (Middle or lower Upper Kimmeridgian *sensu anglico*) and also match British faunas very closely; but they are sparser and mostly rather poorly preserved. The zonal classification used is that of the classical succession in Dorset (Cope, 1967).

Faunas 31–47 belong to the Middle Volgian. They represent the major part of the magnificently preserved material that has made Milne Land famous through the monograph by Spath (1936). The similarities with Britain now become so slight, however, that the same zonal classification (see Cope, 1978, 1980) cannot be used.

Table 1. Summary of the post-Oxfordian ammonite faunas and their zonation in Milne Land (after Callomon & Birkelund, 1982)

	FAUNAS	ZONES AND SUBZONES			
48	*Tollia groenlandica*	*Tollia klimovskiensis*			VALANG.
47	*Laugeites groenlandicus*	*Laugeites groenlandicus*		MIDDLE	VOLGIAN
46	*Crendonites anguinus*	*Crendonites anguinus*			
45	*Pavlovia* aff. *subgorei*				
44	*Dorsoplanites intermissus* n.sp.	*Epipallasiceras pseudapertum*			
43	*Pavlovia groenlandica*				
42	*Epipallasiceras pseudapertum*				
41	*Epipallasiceras acutifurcatum* n.sp.				
40	*Epipallasiceras rotundiforme*	*Dorsoplanites gracilis*			
39	*Dorsoplanites gracilis* δ				
38	*Dorsoplanites antiquus*				
37	*Dorsoplanites liostracus* n.sp.	*Dorsoplanites liostracus*			
36	*Dorsoplanites gracilis* β				
35	*Pavlovia variocostata* n.sp.	*Pavlovia communis*			
34	*Pavlovia communis*				
33	*Pavlovia rugosa*	*Pavlovia rugosa*			
32	*Pavlovia iatriensis*	*Pavlovia iatriensis*			
31	*Dorsoplanites primus* n.sp.	*Dorsoplanites primus*			
30	*Paravirgatites* sp. *B*	*Pectinatites pectinatus*	*P. paravirgatus*	LOWER	
29	*Paravirgatites* sp. *A*				
28	*Pectinatites eastlecottensis*		*P. eastlecottensis*		
27	*Pectinatites groenlandicus*				
26	*Pectinatites* cf. *abbreviatus*	*Pectinatites hudlestoni*			
25	*Sphinctoceras* spp.	*Pectinatites wheatleyensis*			
24	*Pectinatites elegans*	*Pectinatites elegans*			
23	*Aulacostephanus* cf. *kirghizensis*	*Aulacostephanus autissiodorensis*			KIMMERIDGIAN
22	*Amoeboceras elegans*	*Aulacostephanus eudoxus*			
21	*Hoplocardioceras decipiens*				
20	*Amoeboceras kochi*				
19	*Xenostephanus borealis*	*Aulacostephanoides mutabilis*			
18	*Rasenia* aff. *evoluta*	*Rasenia cymodoce*			
17	*Rasenia cymodoce*				
16	? *Pachypictonia* sp.				
15	*Rasenia inconstans*				
14	*Pictonia* cf. *normandiana*	*Pictonia baylei*			

Such similarities as exist are now equally strong with the successions of northern Russia and Siberia, although these in turn are so far known only in broad outlines. The Milne Land succession has therefore been made the basis of a new, regional zonation, the 17 faunas being grouped into a scale of nine standard zones (Callomon & Birkelund, 1982) as shown in table 1. Correlation with other areas in the Boreal Realm suggests that the Milne Land succession is probably the most complete (table 2), and the new zonal scheme has therefore been put forward as a standard for the whole of the Boreal Province. To describe all the new material fully would be a major monographic undertaking. Fortunately, the majority of

Table 2. Correlation chart for the Volgian in the Boreal Realm

	ENGLAND		E GREENLAND	N & NW SIBERIA	VOLGA BASIN			
	Kochi		Kochi J W	Kochi	Kochi			RYAZANIAN
	Runctoni		(Maynci) J W (*Chetaites* sp) J W	Sibiricus Chetae	Rjazanensis			RYAZANIAN
	Lamplughi			Taimyrensis	? Nodiger	Nodiger Mosquensis	UPPER	VOLGIAN
	Preplicomphalus			Originalis	Subditus		UPPER	VOLGIAN
	Primitivus		(Tenuicostatus) W	Okensis Exoticus	Fulgens	Okensis Fulgens	UPPER	VOLGIAN
PORTLANDIAN	Oppressus	Oppressus Anguiformis			?		MIDDLE	VOLGIAN
PORTLANDIAN	Kerberus			?	Blakei		MIDDLE	VOLGIAN
PORTLANDIAN	Okusensis				?		MIDDLE	VOLGIAN
PORTLANDIAN	Glaucolithus		(Vogulicus) J W Groenlandicus 47	Vogulicus Groenlandicus	Nikitini		MIDDLE	VOLGIAN
PORTLANDIAN	Albani		Anguinus 46 45 Pseudapertum 43 44 41 42	*Crendonites* spp Maximus	Virgatus	Rosanovi	MIDDLE	VOLGIAN
UPPER KIMMERIDGIAN	Fittoni		Gracilis 39 40 38 Liostracus 37 36	Ilovaiskii ?	Virgatus	Virgatus	MIDDLE	VOLGIAN
UPPER KIMMERIDGIAN	Rotunda		Communis 35 34 Rugosa 33	Strajevskyi	Panderi	Zaraiskensis Pavlowi	MIDDLE	VOLGIAN
UPPER KIMMERIDGIAN	Pallasioides		Iatriensis 32 Primus 31	Iatriensis	?		MIDDLE	VOLGIAN
UPPER KIMMERIDGIAN	Pectinatus	Paravirgatus Eastlecott'sis	Pectinatus 29 30 28 27	Lideri	Tenuicostata		LOWER	VOLGIAN
UPPER KIMMERIDGIAN	Hudlestoni	Encombensis Reisiformis	Hudlestoni 26	?	Pseudoscythica		LOWER	VOLGIAN
UPPER KIMMERIDGIAN	Wheatley'sis	Wheatley'sis Smedmor'sis	Wheatleyensis 25	Subcrassum	Sokolovi		LOWER	VOLGIAN
UPPER KIMMERIDGIAN	Scitulus		Scitulus	Magnum	Sokolovi		LOWER	VOLGIAN
UPPER KIMMERIDGIAN	Elegans		Elegans 24	?	Klimovi		LOWER	VOLGIAN

Numbers in the second column refer to the ammonite faunas in Milne Land. J: Jameson Land (see Surlyk, 1973); W:Wollaston Forland (see Surlyk, 1978). The columns are regarded as standard zonations for the areas in question (uncertain zones shown in brackets) and the nomenclature recommended in the British guide to stratigraphical procedure (Holland *et al.*, 1978) is therefore used in this scheme (after Callomon & Birkelund, 1982).

forms have already been well described in Spath's monograph, although the exact horizons from which they came were usually not known. This can now be rectified, for almost all his species have been recollected *in situ*. Their horizons are listed in table 3. The entries refer to types and figured specimens only (now in the collections of the Geological Museum in Copenhagen); other specimens that he refers to

Table 3. The faunal horizons of Volgian ammonites from Milne Land figured by Spath (1936)

Name	Plate/Figure	Fauna
Pectinatites		
P. groenlandicus Spath (M)	*6/1; *7/5; *8/5	27
Subdichotomoceras sp.? [*Virgatosphinctoides* sp.]	1/1	24
Subplanites sp. [*Virgatosphinctoides* sp.]	1/2,3	24
P. aff. *eastlecottensis* (Salfeld) (M)	2/1	28
P. sp. (m) + (M)	2/3; 3/1,4	28
P. cf. *boidini* (de Loriol) (m)	13/2	29
P. aff. *devillei* (de Loriol) (m)	7/2	29
Pavlovia		
P. allovirgatoides Spath (m)	*14/3; 4/4	33(c)
P. jubilans Spath (m)	*39/1; 35/4	32
P. alterneplicata (M)	*11/1; *17/2	33(c)
P. communis Spath (m)	*4/1; 4/3,6; 5/4,7	34
P. inflata Spath (M)	*14/1	33(c)
P. kochi Spath (M)	*15/1	33(c)
P. perinflata Spath (m)	*5/2; 5/3; 11/3	34
P. regularis Spath (m)	*4/2; 3/3; 10/3	34
P. rotundiformis Spath (m) [*Epipallasiceras*]	*19/3	40
P. rugosa Spath (m)	*11/2	33(a)
P. aff. *rugosa* Spath (m) [*Epipallasiceras* cf. *rotundiforme*]	12/1	40
P. similis (m)	12/4	33(c)
P. subaperta Spath (m)	*26/4; 6/2; 11/4	34(b)
P. variabilis Spath (M)	*10/1	33(g)
Behemoth groenlandicus Spath (M) [*Pavlovia* or *Glaucolithites*]	*23/1; *24/1	43
Epipallasiceras		
E. costatum Spath (m)	*7/1	42
E. aff. *costatum* Spath (m) [*E. rotundiforme*]	10/7; 18/3	40
E. praecox Spath (M)	*25/1	42
E. pseudapertum Spath (m)	*16/1; 9/3,4; 39/2; 8/1; 16/4; 11/1; *non* 20/1; *nec* 18/1	42
E. pseudapertum (m) [*Crendonites euglyptus*]	18/1	46
E. tumidum (M)	*17/1	42

Name	Plate/Figure	Fauna
Crendonites		
C. anguinus Spath (m)	*21/2, *6/5	46
C. euglyptus Spath (m)	*9/1; 9/3	46
C. lesliei Spath (m)	*13/1; 10/4,5; 19/1; 22/1,5	46
C. subregularis Spath (m)	*13/4; 13/5; 18/5; 20/3; 21/3	46
Dorsoplanites		
D. aldingeri Spath (m)	*5/1, 34/2	40
D. antiquus Spath (m)	*31/4; 24/4; 2/6,7; 29/1; 31/2; 32/4; 33/7,8; 34/3	38
D. aff. *antiquus* Spath (m)	26/3	32
D. crassus Spath (m)	*29/5; 31/3?	40
D. dorsoplanoides Spath (m)	*26/2	38?
D. flavus Spath (M) [*Paravirgatites* sp.?]	*34/1	29–30
D. gracilis Spath (m)	*29/2; 28/3; 33/2,3,, 5,6	40(b)
D. gracilis var. *flexuosus* Spath (m) [*D. antiquus*]	35/3	38
D. jamesoni Spath (m)	*29/3	40?
D. maximus Spath (M)	*26/1; *28/1	42
D. subpanderi Spath (m) [*Pavlovia iatriensis*]	*31/1	32
D. subpanderi Spath (m)	27/5	39?
D. transitorius Spath (m) [*D. antiquus*]	*33/9; 14/4	38
D. triplex [crushed, indet.]	*35/2	?
D. triplex var. *mutabilis* (M)	32/1	40
Laugeites		
L. groenlandicus Spath (M)	*38/1; 36/1; 37/1	47
Tollia		
Subcraspedites groenlandicus Spath	*36/3; 36/4,5; 38/3–5	48
Craspedites ferrugineus Spath	*22/3	48
Craspedites leptus Spath	*37/5	48

Holotypes marked with asterisks; square brackets: corrected identifications.

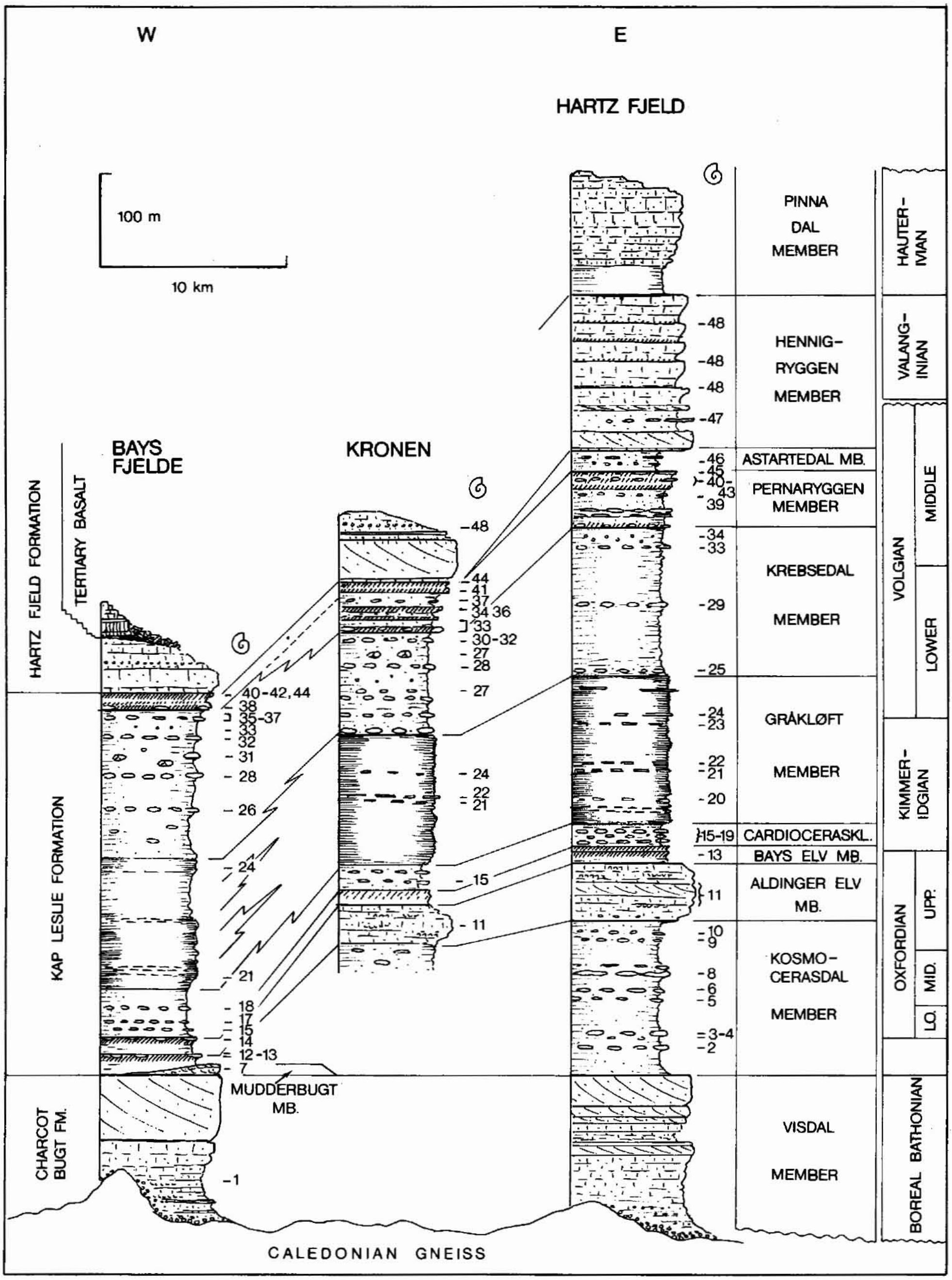

Fig. 3. Composite sections in three main areas of outcrop, showing the relations between litho-, bio- and chronostratigraphy. Numbers refer to ammonite faunas (nos. 1–48). Oblique hatch indicates glauconitic horizons.

in the text appear to be lost. Previously completely unknown forms are relatively few. Six of the more important were also described by Callomon & Birkelund (1982); five of them label faunas in table 1. With the help of table 3 as key it should therefore be possible to use Spath's monograph to obtain a good impression of the faunal succession.

The highest Volgian fauna, no. 47, of the *Laugeites groenlandicus* Zone, can still be correlated quite closely with the British Lower Portlandian (see discussion of correlations in Callomon & Birkelund, 1982). The Middle Volgian of Milne Land is therefore incomplete, truncated by a major faunal non-sequence of which there is little evidence in the lithological succession.

The highest ammonite fauna in Milne Land, no. 48, contains poorly preserved ammonites of early Valanginian age and a shaly sequence near the top is dated as Hauterivian on the basis of the dinoflagellate cysts it contains (Piasecki, 1979).

The relation between litho-, bio- and chronostratigraphy is illustrated in fig. 3, in which the positions and correlations of the numbered ammonite faunas are indicated in three sections representative of the three principal areas of Mesozoic outcrop in Milne Land.

LITHOSTRATIGRAPHY

The formational units now recognized in the Mesozoic of Milne Land are summarized in table 4. Those up to and including the Cardioceraskløft Member of the Kap Leslie Formation were described previously (Callomon & Birkelund, 1980).

The Cardioceraskløft Member is very uniform in thickness and consistency over the whole of the Jurassic outcrop and makes a good base for the discussion of the higher members. These become progressively more variable upwards in thickness, facies and fossil contents, the general tendency being to thin northwestwards. It is useful therefore to divide the area into three parts, each characterized by its own standard succession. The first is in the east, based on the numerous fine sections exposed on the eastern slopes of Hartz Fjeld (H), the best being at Krebsedal (section M17; see Appendix). The second is in the centre around Kronen (K), based particularly on the sections exposed on Pernaryggen, the ridge running from the peak eastwards (section M23; see Appendix). The third is the most westerly, around Bays Fjelde (B), in the very good exposures there on the southeast slopes leading up to point 810 (sections M33–36; see Appendix). The lateral variations of facies between these points are shown diagrammatically in fig. 3.

Table 4. Summary of lithostratigraphical formations and members

FORMATIONAL UNITS		Aldinger, 1935 Spath, 1935,36	DESCRIPTIONS	
Hartz Fjeld Formation	Pinnadal Mb (n)	Hartzfjaeld Sandstone	Sandstones, non-marine	~100 m
			Shales, lagoonal, Hauterivian	~30 m
	Hennigryggen Mb (n)	- ooo	Sandstones with marine *Tollia* beds, L. Valanginian, fauna 48	~180 m
		Lingula Bed	Sandstones with *Lingula* Bed, M. Volgian, fauna 47	~30 m
Kap Leslie Formation	Astartedal Mb (n)	Glauconitic - oooα	Fine micaceous shales, non-glauconitic, M. Volgian, fauna 46	0-25 m
	Pernaryggen Mb (n)	Series	Glauconitic shales and sandstones, many shell-beds, M. Volgian faunas 37-45	15-60 m
	Krebsedal Mb (n)	*Pallasiceras* Beds - oooβ *Pectinatites* Beds	Fine micaceous shales, variably glauconitic in upper part, with layers of concretions, L.-M. Volgian, faunas 25-36	~200 m ?
	Gråkløft Mb (n)	Oil Shales	Laminated black shales, Kimmeridgian-L.Volgian, faunas 20-24	160 m
	Cardioceraskløft Mb (CB)	- oooγ *Amoebites* - oooδ	Bioturbated dark shales, L. Kimmeridgian, faunas 15-19	30 m
	Bays Elv Mb (CB)	Shales	Fine micaceous shales with glauconites, U. Oxfordian-L. Kimmeridgian, faunas 12-14	20 m
	Aldinger Elv Mb (CB)	*Pecten* Sandstone	Cross-bedded sandstone with shell-banks, U. Oxfordian, fauna 11	0-70 m
	Kosmocerasdal Mb (CB)	*Cardioceras* Shales	Bioturbated dark shales, U. Callovian-U. Oxfordian, faunas 2-10	5-170 m
Charcot Bugt Formation	Mudderbugt Mb (CB)	Charcotbucht Sandstone	Coarse cross-bedded sandstone: M. Oxfordian, fauna 7	0-6 m
	Visdal Mb (CB)		Cross-bedded sandstone: Bathonian - ?, fauna 1	~200 m

n: new; CB: Callomon & Birkelund (1980); –ooo : layers of concretions labelled by Aldinger (1935).

Charcot Bugt Formation

This formation is described in Callomon & Birkelund (1980) and is not repeated here.

Kap Leslie Formation

Rosenkrantz, 1929, amended Callomon & Birkelund, 1980.

The base of the Kap Leslie Formation is defined by the sharp change from clean sands to shales at the top of the Charcot Bugt Formation. The boundary with the overlying sandstones of the Hartz Fjeld Formation is usually gradual and defined by the first appearance of non-micaceous quartz sand layers.

The formation can be divided into eight members, the lower four of which were described by Callomon & Birkelund (1980) and are therefore only summarily recorded below.

Kosmocerasdal Member

The Kosmocerasdal Member consists of up to 170 m soft, grey bioturbated sandy siltstones with a number of more strongly indurated horizons and layers of concretions containing a very complete Upper Callovian – Upper Oxfordian ammonite succession. A number of ammonites from this member is described in Sykes & Callomon (1980). Key sections: M2 and M4.

Aldinger Elv Member

The Aldinger Elv Member is Aldinger's Pecten Sandstone (1935) renamed. It consists of yellow-weathering fine to medium-grained, partly cross-bedded sandstones and varies in thickness from 70 m in the east to a few metres of sand in the west. The member is described in detail by Fürsich & Heinberg (1983).

Bays Elv Member

The Bays Elv Member consists of dark, micaceous siltstones or fine-grained sandstones many of which are glauconitic. The lower boundary is sharp. The upper boundary is defined by the termination of a widely recognizable greensand. The member is up to 20 m thick and very uniformly developed. Ammonites indicate an Upper Oxfordian – lowermost Kimmeridgian age. Key Sections: M6 and M39.

Cardioceraskløft Member

The Cardioceraskløft Member consists of grey, bioturbated, highly micaceous siltstones with a number of layers of concretionary sandstone or doggers. It is up to 30 m thick and very uniformly developed. Ammonites indicate an early Kimmeridgian age. Key sections: M7, M8 and M30.

Gråkløft Member

new member

'Oil Shales' of Aldinger, 1935 and Spath, 1935.
'*Amoebites* Shales' (pars) of Spath, 1935.
Name. From the gorge Gråkløft at the east coast of Milne Land.

Type locality. The north slopes of Gråkløft (section M8; fig. 4).

Other sections. Parts of the member are well exposed in other gorges at the east coast of Milne Land (sections M10, M13, M17) and at Sydflod (section M21).

Thickness. The member attains a thickness of 160 m at the east coast. To the west, around Kronen and Bays Fjelde, it is poorly exposed. Combined information from sections M30 and M33 at Bays Fjelde may indicate thicknesses of as little as only 30–40 m here. Some sections are shown in fig. 5.

Lithofacies. Black, finely laminated, non-bioturbated carbonaceous silty shales dominate. Very small-scale ripple lamination is seen at a few levels. Bioturbated horizons do occur, most commonly in the middle part. Thin pyritic horizons are scattered throughout the member and calcareous concretionary beds or horizons are found at a few levels.

Boundaries. The lower boundary is defined by the first appearance of non-bioturbated laminated shales, well exposed in the type section. The upper boundary is defined by a sharp change to more porous sediments of coarser grain size and lighter colour belonging to the overlying Krebsedal Member (see below). In the type section this boundary is marked by a spring line.

Lateral correlation. To the east, in southern Jameson Land, deposits of similar age are referred to the upper part of the Hareelv Formation (see Surlyk *et al.*, 1973). The corresponding levels are very similar in respect to high organic content and non-bioturbation. Parts of the Bernbjerg Formation, exposed north of Kong Oscars Fjord and including deposits of the same age are also similar (Surlyk, 1977).

Trace fossils. Missing, or indeterminate small endichnia.

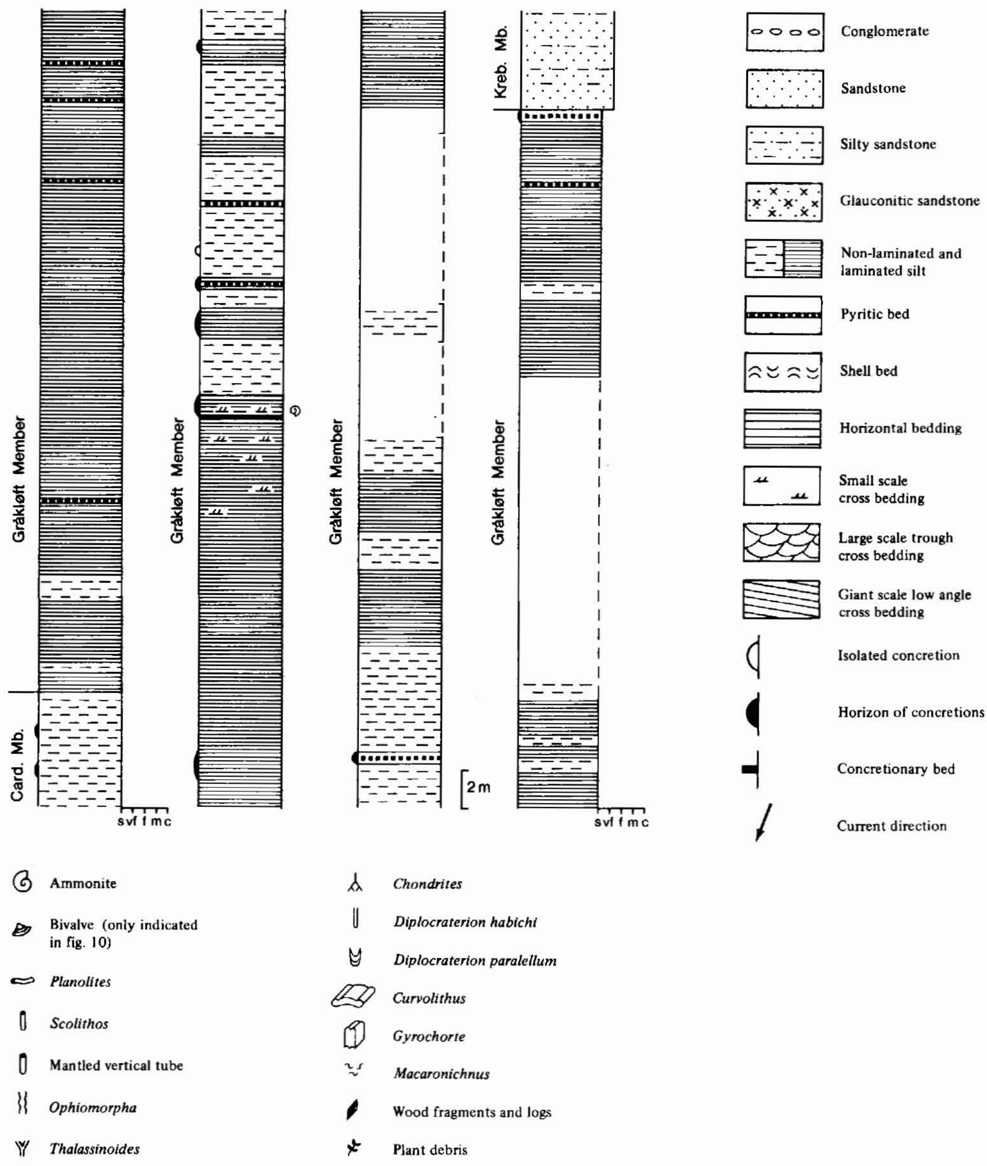

Fig. 4. Lithological log of the type section of the Gråkløft Member, M8, Hartz Fjeld east slopes. Measured by S. Piasecki. Legend covering figs 4,6,8,10,11. Grain size scales indicate silt, very fine, fine, medium and coarse-grained sand.

Macrofauna. Ammonites occur in calcareous concretions at a few levels, often together with near-monotypic benthic assemblages forming shell pavements or very thin shell beds. These shell beds are dominated by epifaunal bivalves, either

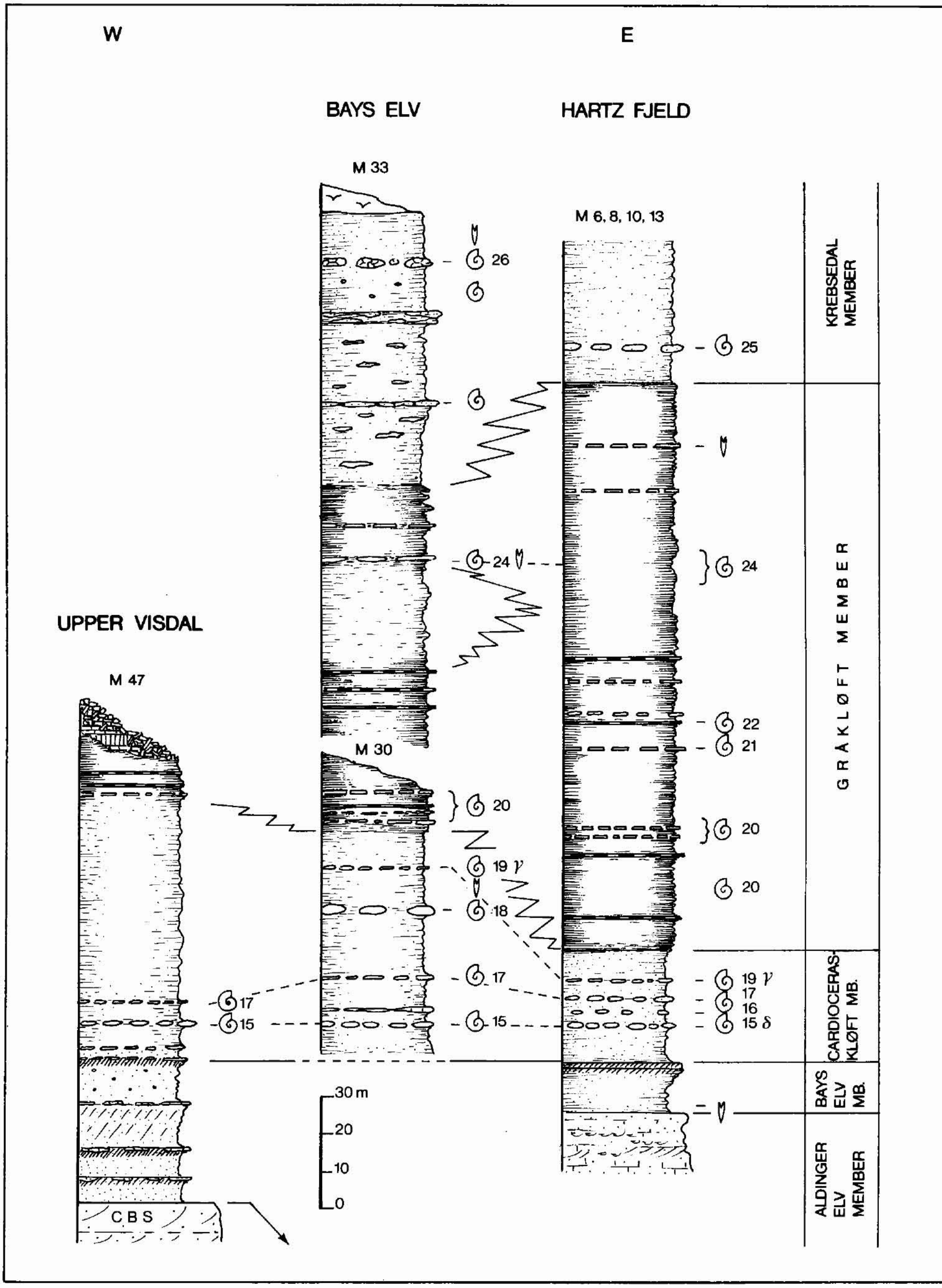

Fig. 5. Schematic sections through the lower part of the Kap Leslie Formation from Bays Elv to Krebsedal Members. The reference plane is drawn at the level of fauna 15, *Rasenia inconstans,* Aldinger's horizon δ, which can be followed through the whole region. Section M33 is drawn to correlate with Hartz Fjeld at the level of fauna 24. CBS: Charcot Bugt Formation. Oblique hatch indicates glauconitic horizons.

Prorokia, Buchia or a very small species of *Inoceramus*. Except for these horizons the shales are nearly barren.

Geological age. The member includes ammonite faunas 20–24, belonging to the *A. eudoxus, A. autissiodorensis* and *P. elegans* Zones of the Kimmeridgian and Lower Volgian.

Krebsedal Member

new member

'*Pectinatites* Beds' and '*Pallasiceras* Beds' of Spath, 1936.
Name. From the valley Krebsedal at the east coast of Milne Land.

Type locality. The ridge south of Krebsedal (section M17; figs 6, 7, and Appendix).

Other sections. The member is exposed along the east side of Hartz Fjeld, from the northwest corner to the ridge south of Krebsedal, best in sections M12, M14, M15, and M22. It is well exposed in sections M23 (see Appendix) and M24 at Kronen and also recorded in sections M35–39 in Bays Fjelde. Sections M23 and M36 are chosen as reference sections.

Thickness. At the type locality the member attains about 160 m. To the north, at Pinnadal (sections M12, M14) it is up to 150 m in thickness. Between Hartz Fjeld and Kronen (Pernaryggen, section M23) it is only about 100 m thick. Further westwards, the thickness increases again, reaching perhaps 200 m around Bays Fjelde. Ammonite occurrences show that these variations reflect highly diachronous facies boundaries (see below).

Lithofacies. Grey, fine to very fine-grained shaly sandstone with no or little glauconite, and then mostly in the upper part. Very fine-grained sands or sandstones dominate. Carbonaceous plant debris is common. Layers and doggers of indurated sandstone and calcareous or phosphatic concretions occur at a number of levels. Very fine-grained sandstone doggers in the lower part of the member in Astartedal (section M15) contain glauconite grains at the base as well as large, well rounded quartz pebbles (up to 2 cm in diameter). This type of doggers has not been met with in any other section. On the north ridge of Kronen large yellow-grey doggers lying 37 m below the top exhibit large-scale trough cross-bedding. The measured palaeocurrent direction was 210°.

Boundaries. The lower boundary is defined by the sharp change from black laminated shales to grey sandstones, well exposed in the type section south of Krebsedal and marked in many places by a prominent spring-line. It is di-

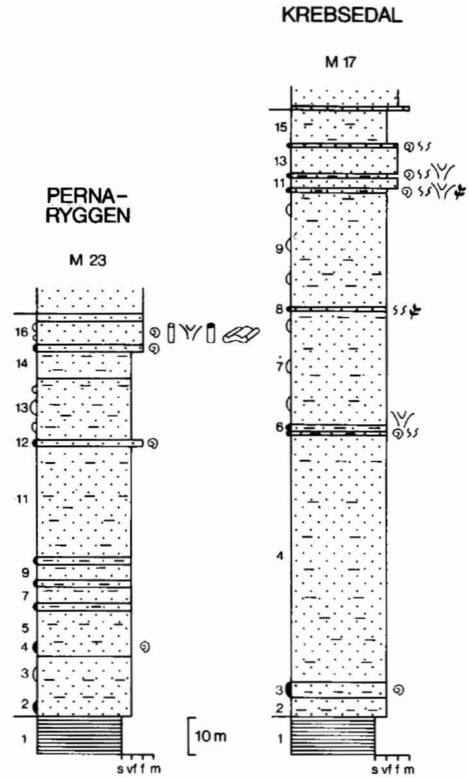

Fig. 6. Lithological log of the Krebsedal Member at Pernaryggen, M23, and the type section, at Krebsedal, M17. Legend as for fig. 4. Same section shown in fig. 7.

achronous. On the east coast, around Pinnadal, it lies about 40–50 m above fauna 24 and immediately below fauna 25. In the area west of Kronen and around Bays Fjelde the laminated black shales of the underlying Gråkløft Member appear to give way upwards to bioturbated micaceous shales gradually and to persist above fauna 24 only as very minor features, so that the boundary in this area is taken to lie only some 20 m above a thin indurated fissile shale carrying fauna 24.

The upper boundary is largely arbitrary, as more and more glauconitic and coarser-grained sandstones come in at various levels. The facies of the Krebsedal and Pernaryggen Members interdigitate. Around Kronen and the northwestern slopes of Hartz Fjeld the upper boundary of the Krebsedal Member can be drawn sharply at the base of the first prominent medium to coarse-grained glauconitic sandstone containing fauna 33 (see fig. 7). Further south it becomes less prominent. The lowest glauconites in the area of Pinnadal run out in the direction of Kap Leslie, and in the type section at Krebsedal (M17) all that remains is a layer of reddish-weathering concretions in reddish silts with fine quartz grains (bed 16), correlating with adjacent beds carrying fauna 37. The top of the Krebsedal Member

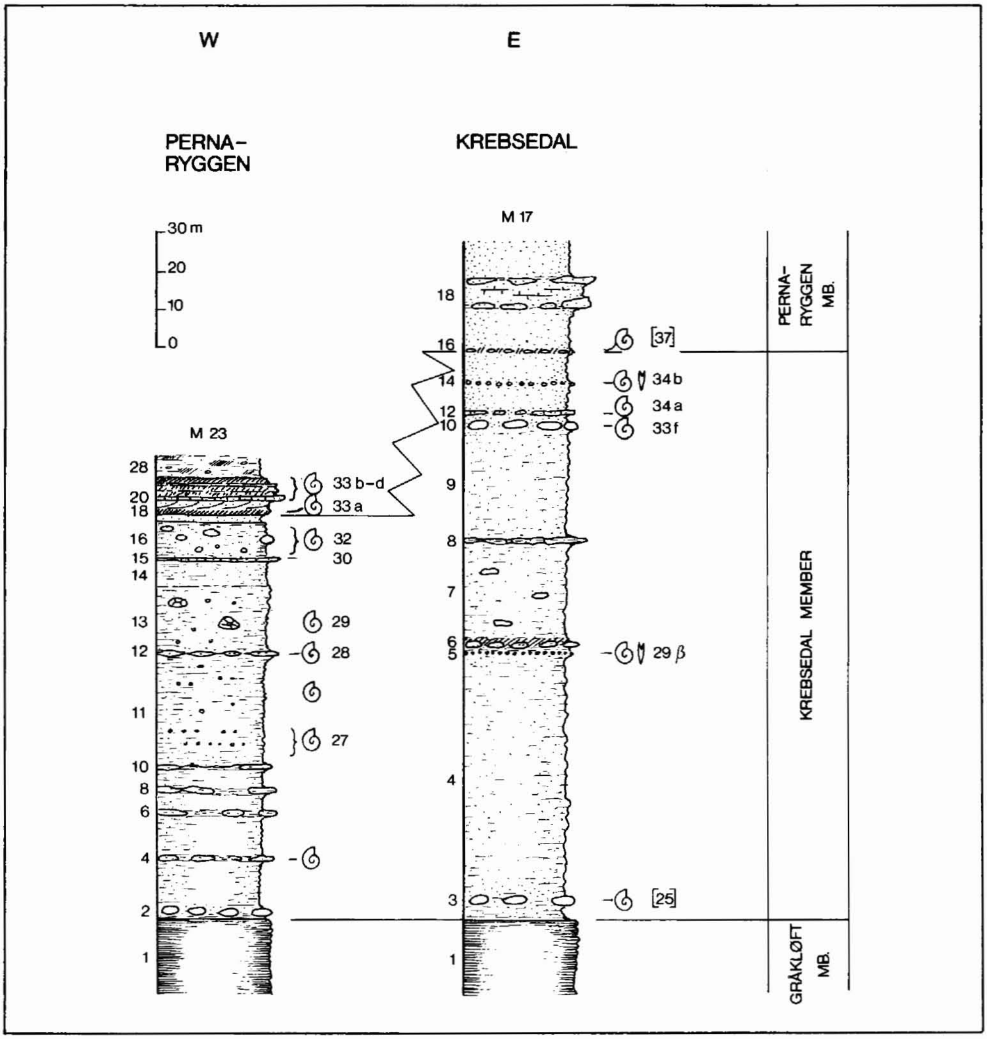

Fig. 7. Schematic sections through the Krebsedal Member at Pernaryggen, M23 and the type section, at Krebsedal, M17. For detailed descriptions see the Appendix. Oblique hatch indicates glauconitic horizons.

is here then taken at the base of this bed. Around Bays Fjelde the upper boundary is again sharp, at the base of the lowest strongly glauconitic sands lying above fauna 37, best seen in sections M34–35.

Trace fossils. The commonest trace fossil is *Macaronichnus* sp. followed by *Thalassinoides suevicus, Planolites, Curvolithus, Skolithos,* and vertical mantled tubes.

Macrofauna. The macrofauna is less abundant than in the overlying Pernaryggen Member and is concentrated in concretionary sandstone doggers. Faunal density increases towards the top. Besides ammonites and belemnites autochthonous bivalve assemblages dominate. Near the top *Isognomon volaticum, Pleuromya uniformis, Camptonectes praecinctus* dominate whilst the remaining parts of the member are characterized by low-diversity assemblages of *Grammatodon schourovskii, Dentalium* sp., *Protocardia striatula, Thracia incerta, Entolium orbiculare* and a nuculid bivalve. A unique assemblage, dominated by *Grammatodon schourovskii* and *Discomiltha lirata* in life position has been found in the upper part of the member in Pinnadal (section M14). *Buchia* occurs at many levels. In addition, remains of crustaceans, ichthyosaurs and plesiosaurs are common.

Lateral correlation. No comparable units have been described from other parts of East Greenland.

Geological age. The member includes ammonite faunas 24–37 belonging to the *Pectinatites elegans – Dorsoplanites liostracus* Zones of Lower to Middle Volgian ages.

The great number of successive ammonite faunas preserved in concretionary horizons of more or less restricted extent has caused some confusion. Thus, Aldinger (1935) named a certain type of concretions characterized by *Macaronichnus* (Aldinger: 'Crustacean coprolites') as 'concretions β', believing that they characterized a distinct horizon; but this type of concretion occurs at many different levels.

Pernaryggen Member

new member

'Glaukonitserie' of Aldinger, 1935 (pars) and 'Glauconitic Series' of Spath, 1936.

Name. From Pernaryggen, the western slope of the pass between Hartz Fjeld and Kronen: see fig. 1, foreground.

Type locality. Pernaryggen, east of Kronen (section M23; figs 8, 9, and Appendix).

Other sections. Good exposures are found along the east side of Hartz Fjeld, from the northwest corner to the ridge south of Krebsedal (sections M22, M11, M12, M14–17). At Bays Fjelde a good exposure is found south of peak 810 (section M34). Section M17 is chosen as a reference section.

Thickness. 53 m at the type locality. This thickness remains fairly constant towards the southeast, whereas around Bays Fjelde it is reduced to only 15 m.

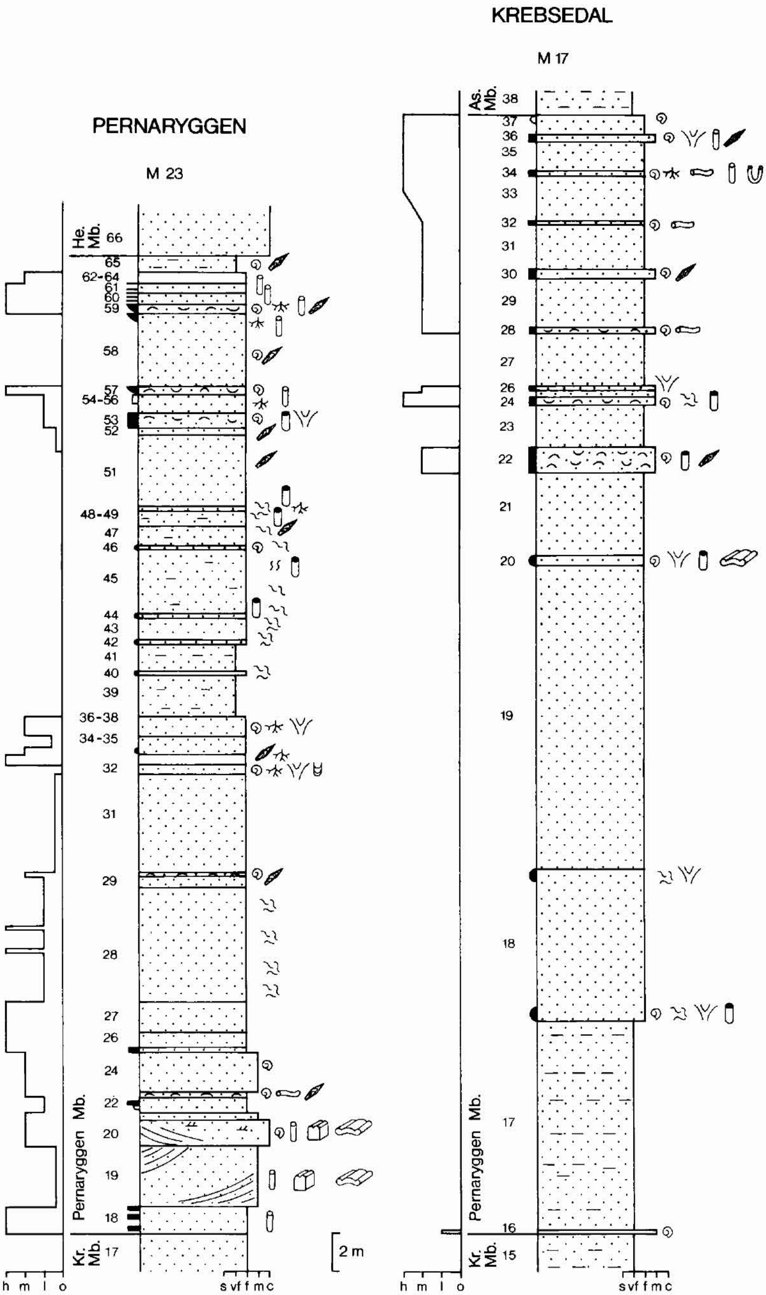

Fig. 8. Lithological log of the Pernaryggen Member at the type locality on Pernaryggen east of Kronen, M23, and on the eastern slopes of Hartz Fjeld at Krebsedal, M17. Glauconite content is indicated to the left; l: low; m: medium; h: high. Legend as for fig. 4. Same sections shown in fig. 9.

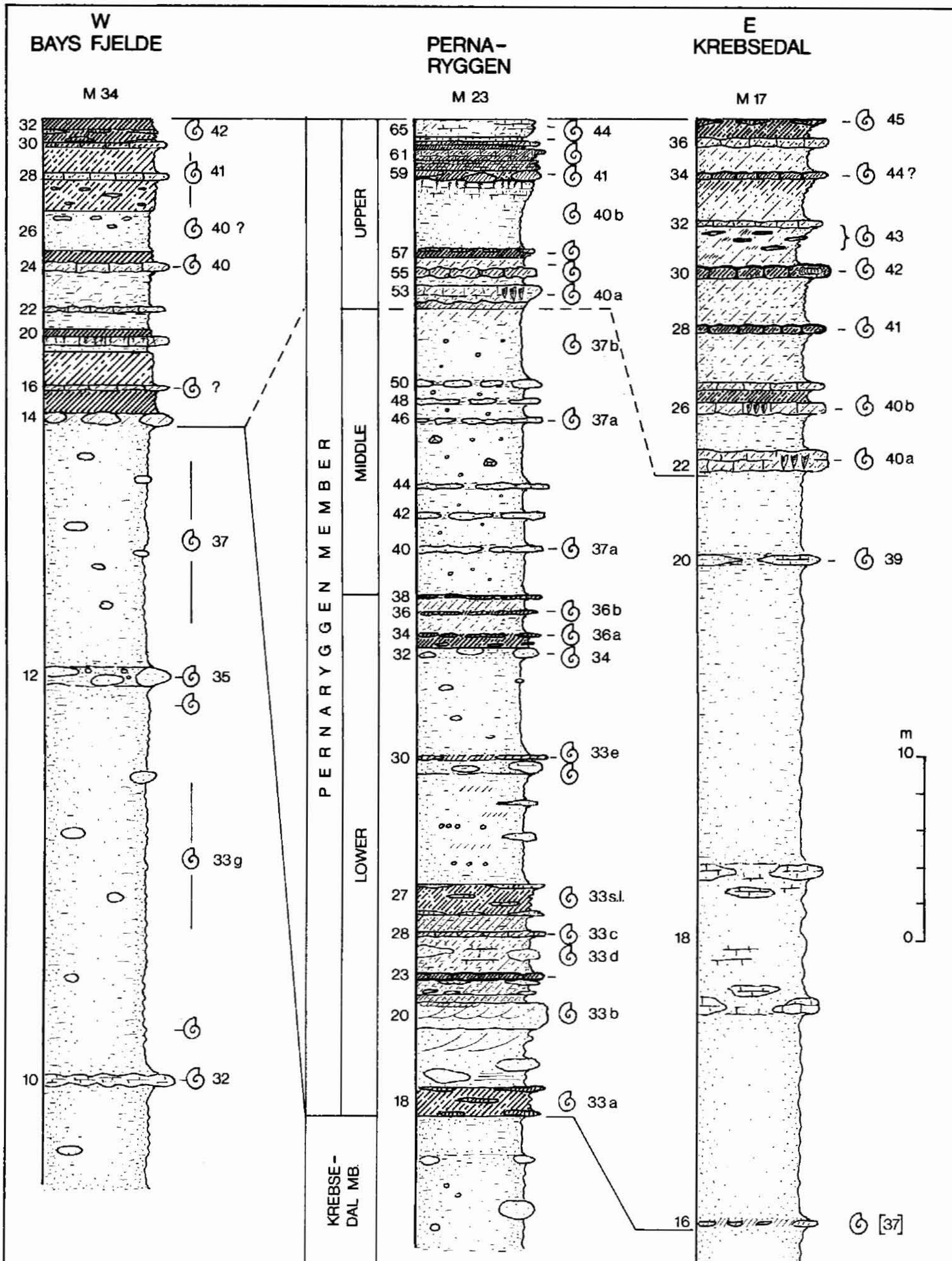

Fig. 9. Schematic sections through the Pernaryggen Member at the southern end of Bays Fjelde, M34; at the type locality on Pernaryggen, east of Kronen, M23; and on the eastern slopes of Hartz Fjeld at Krebsedal, M17. Beds are numbered as in the detailed descriptions given in the Appendix. Oblique hatch indicates glauconitic horizons.

Lithofacies. The member consists of bioturbated micaceous and variably glauconitic sands and sandstones. The grain size varies from silty fine grained to coarse grained, but fine to very fine-grained sands and sandstones dominate, coarse sandstones occurring only at the base. The main difference from the members above and below lies in the prominence of the glauconite, which gives the Pernaryggen Member a striking appearance. The successions are made up of alternating and well-defined beds of loose sands, indurated or concretionary sandstones and levels of concretions, the glauconite content varying from negligible in light grey silts to over 70% in dark greensands, in bed thicknesses from a few cm to a few m, typically 10–30 cm. Sometimes the changes in glauconite content are gradational, but in other cases, particularly in the greensands, the boundaries can be sharp. The glauconite appears to be authigenic or only slightly allochthonous, is usually medium grained, and is often coarser than the associated clastic sediment. (Two samples have given K/Ar ages of around 110 Ma, Dodson *et al.,* 1964). It weathers to give limonitic crusts, and a brown or pink coloration in sandstones and concretions is usually the most sensitive indicator of its presence in what would otherwise be grey sediments. Strongly glauconitic beds can weather into dark brown or claret-coloured heavy ironstones, sometimes in part reduced to pyrite. Phosphatic concretions also occur at many levels but are not particularly associated with glauconite.

Primary sedimentary structures have been almost completely destroyed by bioturbation. An exception lies in the basal beds of the member at its type locality, consisting of a conspicuous medium to coarse-grained glauconitic sandstone varying between 1.5 and 3 m in thickness. It shows large-scale trough cross-bedding and small-scale cross-beds indicating current directions that were fairly constant towards the southwest, varying around the northern slopes of Hartz Fjeld between 220° and 240°. The glauconite is concentrated in seams, indicating some transport and current-sorting.

The glauconite content of beds varies rapidly both vertically and horizontally. Around the type area, between Kronen and Hartz Fjeld, the Pernaryggen Member may be roughly subdivided into three parts (see fig. 9): a lower glauconite (section M23, beds 18–38, 29 m); a middle, almost non-glauconitic part (beds 39–51, 15 m); and an upper glauconite (beds 52–65, 10 m). Of these, the upper division can be followed through the area with least difficulty. It expands slightly westwards, to 15 m in Bays Fjelde (sections M34–36), and also southeastwards, to 20 m in section M17 (Krebsedal). The middle division, or its equivalents, is also everywhere represented, as shown by ammonites. But the faciel distinction between the middle and the lower divisions disappears as one goes away from the type area around Pernaryggen, for the lower division becomes progressively less glauconitic. Westwards, the equivalents of the lower glauconite have become essentially non-glauconitic around Bays Fjelde, although the ammonites indicate that the sediments have hardly changed in thickness. They cannot here be separated from the

Krebsedal Member below, in which they are therefore included; and the whole of the Pernaryggen Member in this area is thus equivalent to only the upper division in the type locality (see fig. 9). Southeastwards, the glauconites also fade but with some increase in thickness, so that the 40 m of lower-middle divisions at Pernaryggen have some 70 m of equivalents at Krebsedal, section M17, as shown by ammonites. However, all that remains of the glauconite is a few cm of lightly glauconitic sandstone in bed 16, taken as the basal bed of the Pernaryggen Member in this area. Instead, along the eastern slopes of Hartz Fjeld an isolated bed of glauconite appears half-way up the Krebsedal Member below (section M17, bed 6, fauna 29), having no glauconitic equivalents either in the Pernaryggen or in the Bays Fjelde area. There are thus major shifts in glauconite concentrations over distances of the order of 10 km.

At a more detailed level of interest are the thin and intensely glauconitic greensands found in many sections, typically 5–30 cm thick, and often sharply bounded below or above. In some cases they, too, can be followed over considerable distances, e.g. beds 33 and 36–38 in the lower division on Pernaryggen (section M23) recognizable as beds 23 and 27 on Hartz Fjeld NW (section M22), a distance of 5 km; or the *pseudapertum* bed of Krebsedal (section M17, bed 30) in the upper division, clearly discernible as a single bed all along the 4 km of the eastern slopes of Hartz Fjeld and still recognizable on Bays Fjelde 18 km to the WSW. In other cases they are seen at only a single locality in what are clearly channelled deposits.

The close control of age correlation by ammonites combined with the glauconite as lithic colour-indicator provides an unusally clear insight into the sedimentary processes that formed the Pernaryggen Member. There can be little doubt that deposition was mostly below storm wave-base in conditions of tranquillity and that it was highly intermittent. The glauconite was probably not transported far from its place of formation. If one makes what seems a reasonable hypothesis namely that the rate of formation was roughly constant, the glauconitic content of a bed is then inversely proportional to the rate of influx of non-glauconitic clastics, and hence the horizons of greensands represent long periods of time during which influx was negligible (see also Fürsich, 1982b). The gradual transition from feebly glauconitic silts and sandstones of the Krebsedal Member to the intensely glauconitic upper division of the Pernaryggen Member would then reflect a reduction in the rate of deposition, regionally, of land-derived sediment particles. The abrupt but conformable change from the greensands of the Pernaryggen Member back to thick non-glauconitic micaceous silts of the Astartedal Member above would then have signalled a return to higher rates of sedimentation. Such a picture receives support from the vertical density of the ammonite faunas. Even allowing for all the local, detailed fluctuations, the 100–150 m of sparsely glauconitic Krebsedal Member are covered by only 8 faunas, nos. 25–32, whereas the 50 m of highly glauconitic Pernaryggen Member at its type locality span at least 13, nos. 33–45, and the 25 m of the top division of the member along the east slopes of Hartz Fjeld span 7, nos.

39–45. The 20 m of overlying non-glauconitic Astartedal Member in the same area contain only one, no. 46. The assumption of quasi-autochthonous glauconite deposition is, however, probably only partially correct. Current transport must have played a role, for, as mentioned above, where sedimentary structures are preserved the glauconite tends to be streaky, indicating a degree of current-sorting.

The structures and formation of glauconites have recently been discussed in detail by Odin & Matter (1981). Our observations of the formations as a whole are fully in accord with Odin & Matter's descriptions.

Boundaries. The lower boundary has already been discussed in connection with the underlying Krebsedal Member. The two members interdigitate so that the boundary is diachronous. At the type locality on Pernaryggen, section M23, bed 18 forms the base of the lower division of the member; at Krebsedal, section M17, bed 16 is roughly equivalent to the middle division at the type section; and around Bays Fjelde, section M34, bed 15 is equivalent to the base of the upper division at the type locality.

Along the eastern slopes of Hartz Fjeld, the upper boundary is defined by the base of the overlying Astartedal Member, and the lithological boundary from greensand and ironstone to light, silty micaceous shales is everywhere sharp. The Astartedal Member appears, however, to be itself cut out unconformably, wedging out westwards, for from the north slopes of Hartz Fjeld across to Bays Fjelde the Pernaryggen Member is immediately succeeded by the quartzose sands of the Hartz Fjeld Formation. Around Kronen and Bays Fjelde the Hartz Fjeld Formation appears to have cut down into the Pernaryggen Member some way and removed its final greensand by erosion, for here the highest beds are only lightly glauconitic fine micaceous shales with the ammonites of fauna 44. The transition from Pernaryggen Member to Hartz Fjeld Formation is sometimes somewhat gradational, micaceous silts and quartzose sands alternating over a metre or two, perhaps as a result of gentle erosion and redeposition of the fine silts by the currents marking the onset of the new regime of coarse clastic sedimentation. The boundary is drawn at the first intercalation of medium to coarse-grained yellow sand free of mica flakes and glauconite.

Trace fossils. The rocks are highly bioturbated. The commonest trace fossil is *Macaronichnus* sp., followed by vertical mantled tubes, *Chondrites, Thalassinoides suevicus, Skolithos* and *Curvolithus.* The coarser basal layer is usually characterized by *Skolithos* and *Diplocraterion habichi* together with *Gyrochorte, Thalassinoides suevicus* and *Planolites.*

Macrofauna. Molluscs are very abundant, particularly in the cemented layers. Apart from ammonites and belemnites, there is a rich benthic fauna dominated by bivalves (recently reviewed by one of us (Fürsich, 1982)) and brachiopods, with serpulids, gastropods and crustaceans of lesser significance. The fauna is well preserved with no signs of mechanical erosion or transport; many burrowing forms are found in life position (see also Aldinger, 1935). The benthic fauna occurs in several distinct associations. The more common ones are characterized by the numerical dominance of *'Terebratula rosenkrantzi'/Grammatodon schourovskii; Isocyprina birkelundi; Grammatodon keyserlingi; Entolium orbiculare/Pleuromya triangularis; 'Terebratula rosenkrantzi'/Entolium orbiculare;* and *Isognomon volaticum.*

What appears to be a marker bed found at many localities from Krebsedal to Kronen, is the so-called *Pinna* bed of Aldinger (1935) in which numerous *Pinna lanceolata* occur, often in position of growth. Although lithologically and faunistically fairly uniform (medium-grained, moderately glauconitic shelly sandstone) its age can differ in various parts of Milne Land.

Lateral correlation. Contemporaneous deposits in southern Jameson Land are included in the Raukelv Formation (see Surlyk *et al.*, 1973).

Geological age. The member includes faunas 33–45, belonging to the *Pavlovia rugosa-Crendonites anguinus* Zones of Middle Volgian age.

The lower boundary is diachronous, ranging from fauna 33 north of Kronen to fauna 37 at the east slope of Hartz Fjeld and fauna 39 around Bays Fjelde.

The youngest fauna on the east slope of Hartz Fjeld belongs to fauna 45 (sections M17 and M12). At Kronen (section M23) and in Bays Fjelde the youngest fauna belongs to fauna M44. The differences of age of the top of the member appear to be due to a slight unconformity.

Astartedal Member

new member

'Sandy Shales with horizon α' of Spath, 1936.

Name. From Astartedal, one of the valleys on the east side of Hartz Fjeld.

Type locality. Ridge south of Krebsedal (section M17; figs 10, 13 and Appendix).

Other sections. Moderately well exposed sections are found from Pinnadal southwards and on the eastern slopes of the Lingularyggen.

Thickness and distribution. At the type locality, the member attains 21 m. Along the southeastern slopes of Hartz Fjeld and east of Lingularyggen, the thickness varies between 20 and 26 m. Towards the north, the member decreases in thickness

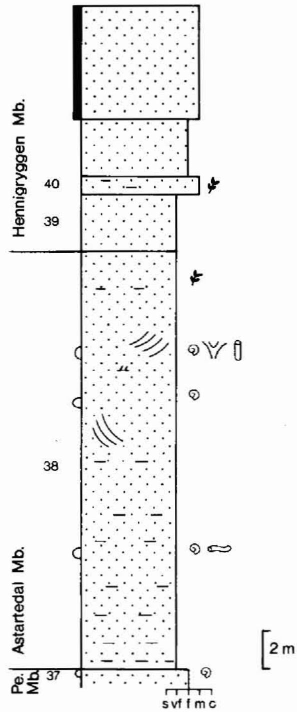

Fig. 10. Lithological log of the Astartedal Member at Krebsedal, section M17. Legend as for fig. 4.

to 16 m on the ridge north of Pinnadal (section M12) and has completely disappeared within a further few hundred metres (section M11). Thence, as well as around the northern slopes of Hartz Fjeld and Bays Fjelde, the Pernaryggen Member is directly overlain by the Hartz Fjeld Formation.

Lithofacies. Light grey, highly micaceous, silty, very fine-grained sands. Large sandstone concretions are common particularly in the middle part, and seem to occur at least at three levels. Scattered glauconite grains may occur for the first 1.5 m above the base, which is more silty.

Sedimentary structures have been partly destroyed by bioturbation, but where preserved consist of large-scale cross-bedding. On the foresets of the cross-beds thin shell layers may occur. Ferruginous concretions are found rarely in the upper third. Plant debris and wood fragments are common at some levels and include pieces of petrified wood logs.

Boundaries. The lower boundary is marked by the change from red-brown weathering glauconitic sandstones (Pernaryggen Member) to whitish-grey micaceous silts. It is usually very sharp, but towards the north scattered glauconite grains may range up into the base of the Astartedal Member.

The upper boundary is usually gradational over a short interval, thin intercalations of yellow quartz sands gradually increasing in thickness until massive medium to coarse-grained yellow sandstones take over. The boundary is drawn at the first appearance of quartz-sand layers containing no mica. Only in one case is the boundary sharp, marked by a 10–15 cm thick layer of coarse-grained ferruginous rubble.

Trace fossils. Parts of the sediments are highly bioturbated. *Macaronichnus* is common, followed by *Skolithos, Planolites,* mantled vertical tubes and *Thalassinoides suevicus.*

Macrofauna. Ammonites and, rarely, belemnites occur at various levels. The benthic fauna is either dispersed, forming thin shell layers on the foresets of cross-beds, or is concentrated in small nests and pockets. It is now found only within sandstone concretions. It is dominated by molluscs (*Thracia incerta, Grammatodon schourovskii, Dentalium* sp., *Hartwellia, Protocardia striatula* and nuculid bivalves) which form a distinct association. On the ridge north of Astartedal (section M14) thin shell-layers occur which consist, apart from some ammonites, nearly exclusively of *Buchia.*

Lateral distribution. The member has a very restricted extent on Milne Land. Comtemporaneous deposits in southern Jameson Land belong to the Raukelv Formation (Surlyk *et al.,* 1973).

Geological age. The member includes fauna 46 belonging to the *Crendonites anguinus* Zone of Middle Volgian age, and the ammonites appear to be concentrated at two levels, *c.* 3 and 11 m above the base (fauna 46 (a) and 46 (b)).

Hartz Fjeld Formation

Rosenkrantz, 1929. 'Hartzfjaeldsandstein' *sensu* Aldinger, 1935.

The base of the Hartz Fjeld Formation is defined by the prominent change from silty, highly micaceous very fine-grained sand to yellowish-grey, medium to coarse-grained quartzitic sands and sandstones frequently cemented to form massive bluffs. Due to erosion, its former upper boundary is not known. The formation consists largely of cross-bedded sands and sandstones and can be divided into two members (see fig. 1).

Hennigryggen Member

new member

Lower section of Sykes & Brand, 1976.

Name. From Hennigryggen, south of Hartz Fjeld, on the east coast of Milne Land.

Type locality. At the northeast corner of Hartz Fjeld (section M9; fig. 11). This section was recorded by Lars Stemmerik.

Other sections. The member is well exposed at Kronen, its lower parts also around Slottet (sections 15–19: see figs 12, 13, and Appendix).

Lithofacies. The member consists of a series of upward coarsening cyclic sedimentary sequences averaging about 10 m in thickness, described in some detail by Sykes & Brand (1976). The lowest one may be up to 50 m thick. The sequences are usually terminated by a ferruginous crust bearing witness to arrested sedimentation.

The facies within the sequences may range from siltstone to pebbly sandstone, but medium-grained, moderately to well-sorted clean sands and sandstones dominate by far. The amount of mica varies and is higher in the finer-grained sediments. Glauconite occurs at various levels, particularly in a 10 m thick medium-grained sandstone, 93 m above base at the northeast corner of Hartz Fjeld and within the top 20 m at Kronen. Carbonaceous matter is common, usually concentrated at certain horizons, and so are casts of wood logs and fragments (see also Aldinger, 1935, figs 20, 21).

Sedimentary structures consist either of large to giant-scale planar or trough cross-bedding, less commonly of small-scale trough cross-bedding, parallel lamination or coarsely interlayered bedding. At the base of giant planar cross-beds at Kronen climbing ripples are frequently developed. Palaeocurrent measurements give values predominantly around 180°. A marker bed which occurs about 30 m above base is the so-called *Lingula* Bed (Aldinger, 1935), a 1–3 m thick shelly, fine to medium-grained, glauconitic sandstone which can be followed from the Glaukonit Bjerg northwards along the Lingularyggen, but disappears south of Krebsedal. It is last seen in the form of well-separated, round, fossiliferous concretions lithologically indistinguishable from its more massive continuous development further south, set in totally barren loose sands giving no signs of its former presence between the concretions. This suggests that there may well have been other fossil horizons in the Hartz Fjeld sandstone subsequently wholly lost by decalcification.

The cyclic character of the member is accentuated by the ferruginous crusts developed at the top of most of the sequences, usually associated with coarse-grained, sometimes pebbly sands and sandstones. A high glauconite content and

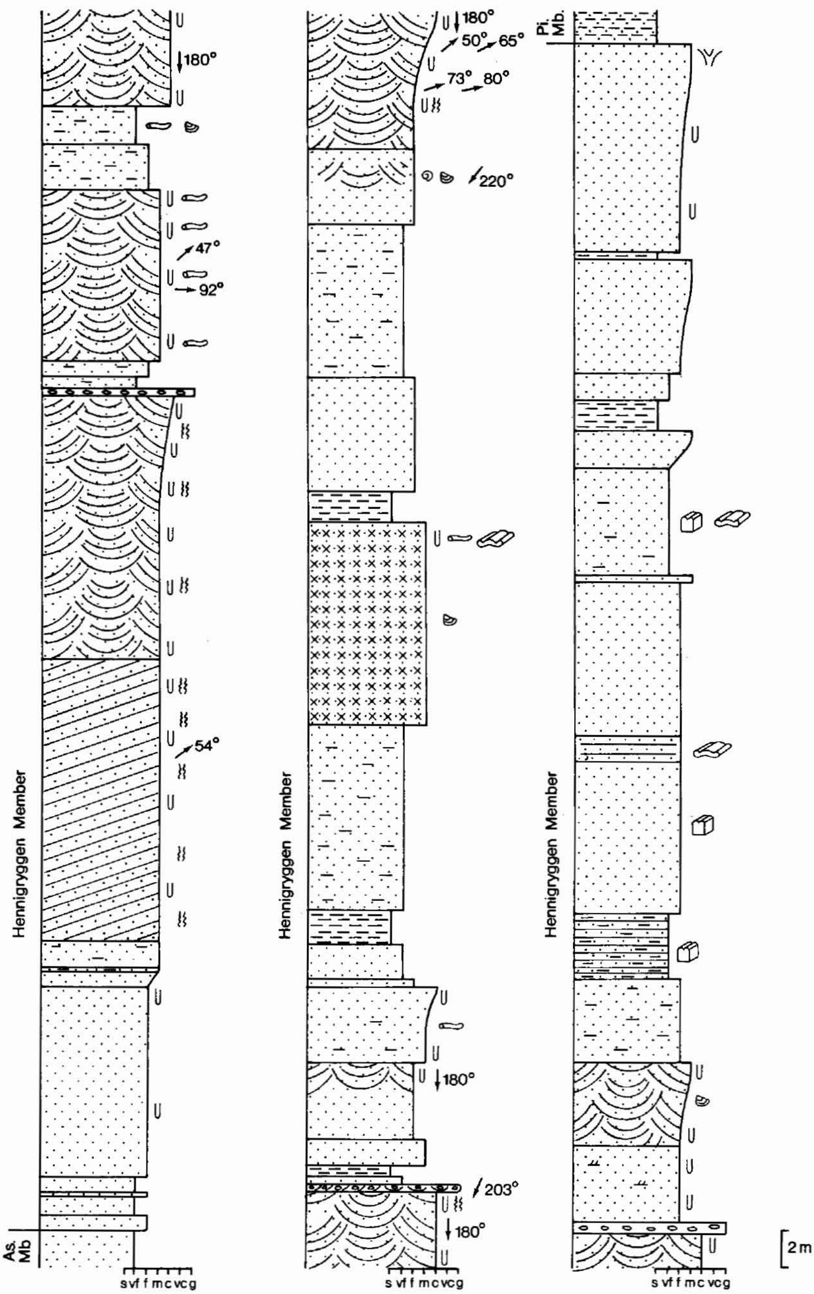

Fig. 11. Lithological log of the Hennigryggen Member at its type locality, section M9. Measured by L. Stemmerik. Legend as for fig. 4.

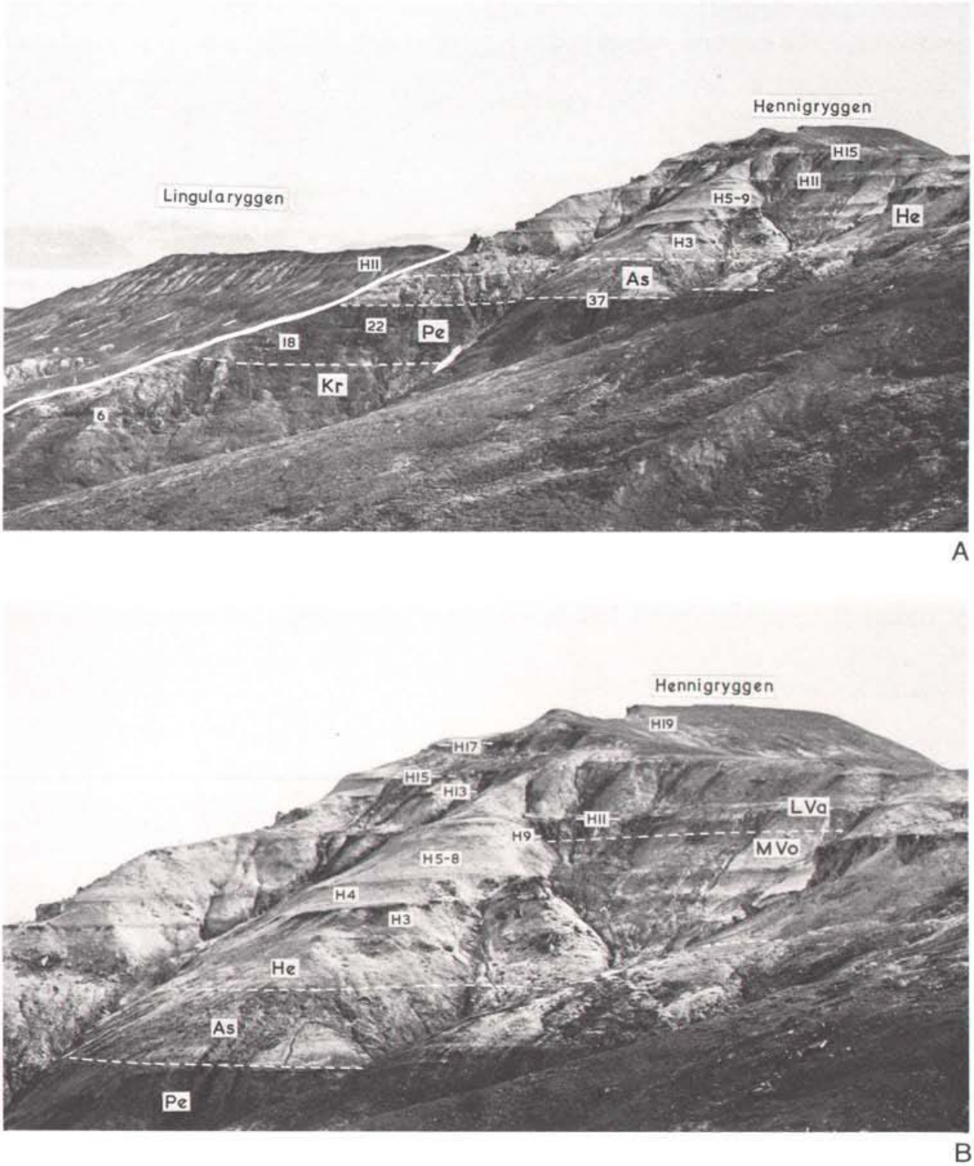

Fig. 12. A. General view of the eastern slopes of Hennigryggen and Lingularyggen. The gully rising from the lower left foreground to the summit of Hennigryggen is Krebsedal; section M17 is the ridge immediately beyond it. B. More detailed view of the Hennigryggen Member. Kr: Krebsedal Member Pe: Pernaryggen Member; As: Astartedal Member; He: Hennigryggen Member. MVo: Middle Volgian; LVa: Lower Valanginian. Beds numbered as in the Appendix.

occurrence of phosphatic nodules at these levels indicate periods of non-deposition or erosion, further supported by some concentration of ammonites, bivalves and wood fragments at these levels. Also the trace fossil *Diplocraterion habichi* is especially concentrated at these top parts of the rhythmic sequences (see below).

Boundaries. The lower boundary is defined by the change from highly micaceous fine sands to quartz sand free of mica. At most localities the change is gradual over a metre or so of sediment, and the boundary is drawn at the first layer of quartz sand without mica. The upper boundary occurs at one of the levels of arrested sedimentation, and is marked by a sharp change from pebbly sandstones to silty, very finely sandy shales.

Trace fossils. Although bioturbation is not very intensive, trace fossils are found at numerous horizons throughout the member. Within the basal 45 m at Hartz Fjeld and Slottet *Ophiomorpha* dominates, a form confined to the lower half of the member. Throughout the member narrow vertical U-shaped spreiten burrows, *Diplocraterion habichi,* occur. These burrows may be especially concentrated at the sedimentary breaks marking the termination of cycles and were identified by Sykes & Brand (1976) as rootlets. Less common are *Planolites, Skolithos, Curvolithus* and *Gyrochorte; Thalassinoides suevicus* and *Chondrites* are rare. Large wood fragments are frequently bored by bivalves.

Macrofauna. A number of scattered horizons, often confined to the top of the cycles, contain body-fossils. Aldinger (1935) even recorded 9 levels in the Hartz Fjeld region yielding bivalves. Besides very rare ammonites, belemnites and vertebrate fragments, bivalves can be quite common at these levels, although they are only poorly preserved so that precise identification is usually impossible. The commonest forms include *Pleuromya, Entolium orbiculare, Thracia, Pholadomya, Eriphyla* (*Lyapinella*), *Pinna, Lingula,* and *Buchia.* Only in the *Lingula* Bed is the fauna well preserved. It has a high diversity, and besides the ubiquitous *Lingula ovalis* there are numerous bivalves, which have been described by Spath (1936) and Fürsich (1982). The *Lingula* Bed is not a uniform shell bed but consists of levels at some of which shells are reworked, mainly one-valved and current-orientated, whereas more rarely at others, parts of the fauna such as semi-infaunal *Pinna* and *Modiolus* are preserved in life position.

Lateral correlation. Deposits of similar age are included in Raukelv Formation and Hesteelv Formation in Jameson Land (Surlyk *et al.*, 1973) and in Lindemans Bugt Formation and Palnatokes Bjerg Formation in northern East Greenland (Surlyk, 1977, 1978).

Geological age. The lower part of the member, including the *Lingula* Bed, belongs to the *Laugeites groenlandicus* Zone (fauna 47), dated firmly to the Middle Volgian

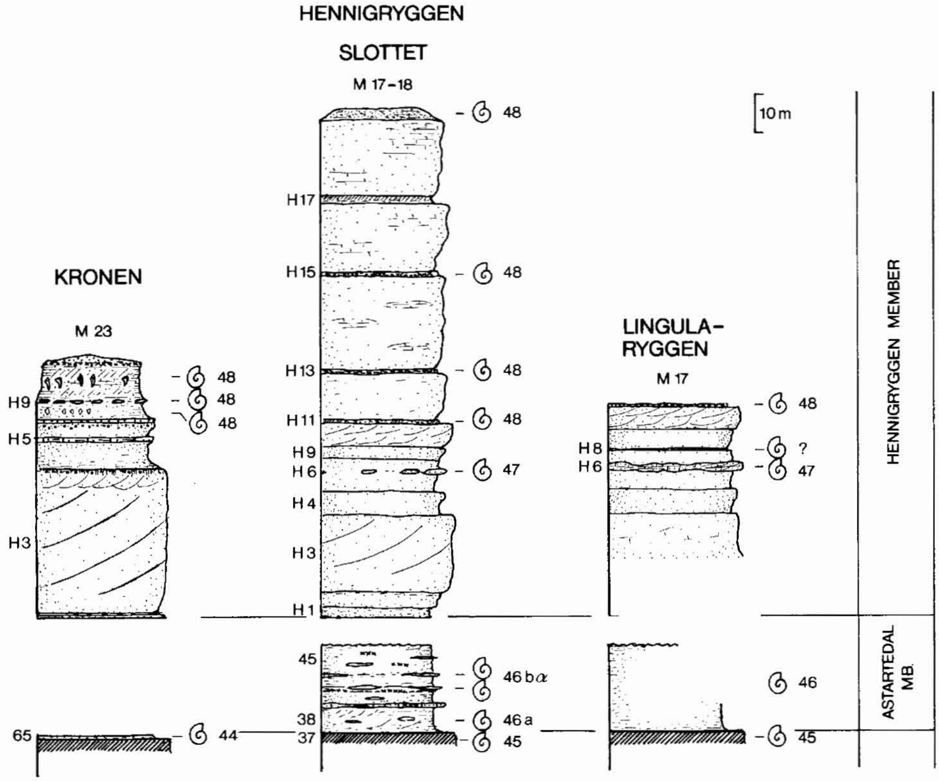

Fig. 13. Schematic sections through the Hennigryggen Member on the eastern slopes of Hartz Fjeld at Hennigryggen and Slottet, M17–18; at Lingularyggen, M17; and at Kronen, M23. Beds numbered as in the Appendix and as in fig. 12.

by the presence in it of species of *Crendonites* very similar to those found in the lower Portland Sand of Britain. A fragment of a '*Titanites* sp.' found by Aldinger 53 m above the base at Astartedal and described by Spath (1936, p. 67) is readily explained as the macroconch. These Middle Volgian ammonites have been found mainly in the southeast corner of the outcrop, in the *Lingula* Bed, but a single specimen of *Crendonites* from near the base of the Hartz Fjeld Formation at Bays Fjelde indicates that the lower part of the Hennigryggen Member is of Middle Volgian age throughout the whole area. The upper part of the member is characterized by an entirely different fauna, no. 48, identified as *Tollia groenlandica* (Spath). Only 15 m of sandstone separate the Middle Volgian *Lingula* Bed from the first of at least three ammonite horizons spanning the upper part of the Hennigryggen Member. They are separated by periods of non-deposition that may represent considerable intervals of time, but although the preservation is poor, the faunas are sufficiently similar to suggest that they all belong to the same ammonite zone.

The dating of fauna 48 has always presented problems. New material collected since the descriptions by Spath (1936) and Donovan (1964) has amplified our understanding of the species, including now as it does fragments of the adult macroconch. It confirms the individuality of the species as one that continues to be unknown from anywhere else, either in Greenland or further abroad. But it does little to resolve the generic assignment. Spath (1936) referred the species to *Subcraspedites* from England, since described in much greater detail by Casey (1973). Its age is Late Volgian. Donovan (1964) preferred *Tollia* Pavlow, 1914, from northern Siberia, and its age is Early Valanginian. Finally, Jeletzky (1979, p. 46) referred the species to *Praetollia* Spath, 1952 of Early Ryazanian age. Characteristic differences between the genera seem to include a stronger ventral projection of the secondary ribbing and a shallower umbilicus with sloping walls in *Tollia,* as may be seen in Siberian material discussed by Shulgina (1972, particularly pls 17, 19, 23). On balance, we believe the resemblance of fauna 48 favours *Tollia,* and the upper part of the Hennigryggen Member is therefore assigned to the Lower Valanginian. Even if this assignment should turn out to be incorrect, the comparison of fauna 48 would have to be with the youngest *Subcraspedites* from the *S. lamplughi* Zone (Casey, 1973), at the very top of the Upper Volgian (table 2), or the *Praetollia* beds of the lowermost Ryazanian. While this would reduce the size of the time gap between faunas 47 and 48, which would then not include the Ryazanian or major parts of that stage, the non-sequence would still be very large, including 4 or 5 whole ammonite zones (see table 2). In Jameson Land ammonite and *Buchia* occurrences indicate a more complete sequence from that period of time, but the fossil record is scanty (Surlyk *et al.*, 1973; Surlyk & Zacharov, 1982).

Pinnadal Member

new member

Upper section of Sykes & Brand, 1976.
The description of this member is partly based on Sykes & Brand (1976).

Name. From Pinnadal, one of the valleys on the eastern flank of Hartz Fjeld, eastern Milne Land.

Type locality. At the northeast corner of Hartz Fjeld (section M9).

Other sections. Hartz Fjeld is the only region where the member is still preserved (see figs 1 and 3).

Thickness. 102 m at the type locality.

Lithofacies. The grey, yellowish-brown to reddish sediments consist of alternating layers, ranging from carbonaceous, micaceous silty mudstones to coarse-grained sandstones. Three types of facies can be distinguished that sometimes form upward-coarsening sequences: a) alternating shale and sandstone with lenticular, flaser and wavy bedding; b) coarse-grained sandstone frequently topped by rootlet horizons and exhibiting small-scale tabular or trough cross-bedding: sometimes coarse pebbly sandstones may occur in this facies; and c) carbonaceous mudstone and pebbly siltstone. Measurements of cross-bed dips indicate a southeasterly current direction (Sykes & Brand, 1976, fig. 6). The lowest 28 m of the member consists of carbonaceous, soft, micaceous, silty shales, in contrast to the often coarse sandstones and conglomerates found higher up.

Boundaries. The lower boundary is defined by the sharp change from pebbly sandstone to thick, dark-grey silty shale. The upper boundary is today the summit of Hartz Fjeld.

Trace fossils. In contrast to the underlying Hennigryggen Member distinct trace fossils are rare, as are bioturbation structures in general. *Planolites, Skolithos* and *Curvolithus* occur scattered throughout the section nearly to the top.

Macrofauna. None found so far.

Lateral correlation. The erosional relict of Hartz Fjeld is the only occurrence remaining. No contemporaneous deposits are known from other parts of East Greenland.

Geological age. Dinoflagellate cysts from the lower shaly part indicate an Hauterivian age (Piasecki, 1979) and a single species found in the topmost beds may indicate an upper Hauterivian age (S. Piasecki, personal communication, 1980).

DEPOSITIONAL ENVIRONMENTS AND TECTONIC EVOLUTION

In the Upper Jurassic of East Greenland sedimentation was largely controlled by synsedimentary tectonic movements of fault blocks. Judging from the difference in sedimentary evolution compared with that of neighbouring areas in Jameson Land (Surlyk *et al.*, 1973; Surlyk *et al.*, 1981), Milne Land seems to have belonged to a separate fault block from late Callovian times onwards. The facies development from Bathonian to early Kimmeridgian times has been summarized by Callomon & Birkelund (1980). After the late Bathonian transgression and deposition of thick, nearshore coarse clastic units (Charcot Bugt Formation), mainly offshore sandy siltstones were deposited (Kosmocerasdal Member, Callovian – Upper Oxfordian), and these were followed by the very shallow-water offshore bar sands of the

Aldinger Elv Member (Upper Oxfordian) (Fürsich & Heinberg, 1983). The partly glauconitic silts and fine-grained sandstones of the overlying Bays Elv Member (Upper Oxfordian – Lower Kimmeridgian) as well as the still younger silts and sandstones of the Cardioceraskløft Member (Lower Kimmeridgian) indicate a return to slightly deeper and quieter conditions.

In the Kimmeridgian to Lower Volgian, the black carbonaceous laminated silty shale of the Gråkløft Member indicates a very uniform and tranquil depositional environment. The lack – with few exceptions – of benthic faunal elements or bioturbation suggests a largely anoxic environment similar to that which existed at the same time in many other parts of northwestern Europe (Kimmeridge Clay) and East Greenland (Hareelv Formation of Jameson Land; parts of the Bernbjerg Formation of Wollaston Forland). Rare levels with monotypic bivalve associations and small-scale ripples reveal minor fluctuations in this environment. Depth of deposition was probably slightly greater than in the underlying Bays Elv Member. Black-shale formation may have been partly determined by the local palaeogeographic setting moulded by tectonic activity, and partly by a eustatic deepening of the seas in early Kimmeridgian times (Hallam, 1978; see also Surlyk, 1977 p. 48). Although there is little evidence for tectonic activity on the Milne Land block during this time, the occurrence of large slumped sand bodies and sandstone dykes within the Hareelv Formation on Jameson Land indicates strong tectonic activity, and movements of the Jameson Land and other fault blocks may have created a submarine topography on which black shales could form. Towards the west, in the direction of the presumed coast line, the thickness of the black shales decreases drastically – probably a reflection of a change to shallower, more oxygenated conditions.

Some local tectonic activity is evident in the Lower to Middle Volgian Krebsedal Member. Deposited in shallower, well oxygenated environments the highly bioturbated siltstones and fine-grained sandstones change in thickness over short distances. Ammonite evidence shows that around Kronen the upper part is condensed, and the member reaches greatest thickness around Bays Fjelde. These variations in thickness were probably caused by gentle undulations of the sea floor, which resulted in slower deposition on topographic highs than on shallow depressions in between. Benthic faunal elements increase in diversity and abundance towards the top of the member and are typical of sublittoral shelf environments below wave base. The occurrence on the north slope of Kronen of channels with large-scale cross-beds which give a southwesterly current direction augments the evidence for some relief of the sea floor. On the neighbouring Jameson Land block the sedimentary history is quite different, the deposition of the laminated shales persisting throughout the Hareelv Formation.

In the Middle Volgian, the sedimentary pattern changed again. A characteristic feature of the highly fossiliferous Pernaryggen Member is its high glauconite content – suggesting periods of very low clastic influx. Some large-scale trough cross-beds found at the base in medium to coarse-grained sandstones which disappear towards the south indicate a constant current direction and sediment transport towards the southwest. The base of the glauconitic facies is highly diachronous which may be partly explained by current patterns and an onshore-offshore gradient, but might also reflect some tectonic activity: the onset of glauconite formation and sedimentation reached the Bays Fjelde area much later than it did in the northeastern parts of Hartz Fjeld. The rich benthic fauna must have lived below wave base, for transport can be excluded on biostratinomic grounds and reworking seems to have been largely due to storms which affected parts of the sea floor otherwise well below wave influence. The glauconite formed *in situ* on the sea floor, as the grains have shrinkage cracks and are mostly larger than the associated sediment particles, while in Jameson Land the coarse clastic sandstones and pebble sandstones of the Raukelv Formation, transported from the northwest, indicate very shallow conditions.

In the southeast corner of Milne Land, around Cape Leslie, the highly glauconitic sands and silts of the Pernaryggen Member are abruptly overlain by the highly micaceous silty shales of the Astartedal Member. This member, partly bioturbated, partly exhibiting large-scale cross-beds, seems on the whole to reflect higher depositional rates and shallower water depth than the preceding rock unit.

The Astartedal Member appears to be unconformably cut by the Hartz Fjeld Formation.

Lack of ammonite faunas 45 and 46 from Bays Fjelde and Kronen below the sandstones of the Hartz Fjeld Formation suggests erosion also of parts of Pernaryggen Member at this level (Birkelund *et al.*, 1978).

The Middle Volgian – Valanginian Hennigryggen Member of the Hartz Fjeld Formation has been interpreted by Sykes & Brand (1976) as built up of fluvial sand bars at the base followed by numerous upward-coarsening sequences of fan-delta deposits. Abundant horizons with marine trace fossils (interpreted by Sykes & Brand, 1976 as root horizons) and several levels with marine body fossils (bivalves, ammonites) make a fully marine environment of the sequence likely (see also Birkelund *et al.*, 1978). The sequential arrangement, trace fossils and sedimentary structures indicate periodic, rapid, highly episodic deposition in a shallow water, high energy environment alternating with long periods which – according to the ammonites – left no signs in the sedimentary record.

The sandstones are followed by a shaly intercalation (basal Pinnadal Member) of Hauterivian age, possibly representing lagoonal environments whilst the higher parts of the Pinnadal Member can be interpreted in accordance with Sykes & Brand (1976) as representing lagoonal/bay deposits with intercalations of fan-delta sediments. Dinoflagellate cysts and trace fossils demonstrate some marine influences continued to the end of the preserved sedimentary sequence.

The late Middle Volgian to early Cretaceous sequence in Milne Land clearly represents the gradual – although not complete – infilling of a sedimentary basin, probably in conjunction with tectonic rejuvenation of source areas in the northwest. Sedimentation rates seem to have varied considerably from time to time as shown by the fossil record, interspersed by long periods of little or no deposition. Similarly in Jameson Land, the sedimentary basin was gradually filled in by fan-delta sedimentation largely under marine influence. Tectonic activity seems here to have been more pronounced (Surlyk, 1973, 1975, 1978; Surlyk *et al.*, 1981; Surlyk & Zacharov, 1982).

In summary, the Upper Jurassic to Lower Cretaceous sediments of Milne Land represent various stages of the infilling of a sedimentary basin. Synsedimentary tectonic movements along fault lines and tilting of the fault block produced a varied and complicated facies pattern which differed for most of the time from that of the neighbouring Jameson Land fault block.

APPENDIX

Description of some leading sections

Abbreviations: (M) and (m) refer to ammonite macro- and microconchs. (VR): very rare, (R): rare, (O): occasional, (C): common, (VC): very common. Call. & Birk.: Callomon & Birkelund.

Section M17: Krebsedal

The lower beds are exposed in the gully of Krebsedal. Exposures of higher beds become good on the ridge south of the gully from about 120 m above sea-level up to the base of the Hartz Fjeld Formation at about 300 m. This section is one of the finest in Greenland and includes the type sections of the Krebsedal and Astartedal Members as well as a reference section of the Pernaryggen Member. It continues upwards through the Hennigryggen Member to the summit of Hennigryggen, and this part is described separately below. See figs 5–9 and 11–13. Records of ammonites include material from some closely adjacent ridges (sections M15, M16) in which beds crop out unchanged.

From below:

		Thickness (metres)
	Kap Leslie Formation, Gråkløft Member	
1	Shales, silty, black, finely laminated, subdivisible as follows: (a) Black shales; (b) Layer of thin concretions packed with plant remains at 23 m, *Lingula;* (c) Shales, continued; some ammonites at this level in a small gully 1200 m south of Pinnadal (*Pectinatites* (*Virgatosphinctoides*) *major* Cope (fauna 24))	12
	(d) Layer of thin, hard flat concretions, unfossiliferous, at 35 m; (e) Shales, continued	25
	(f) Another layer of thin, hard, flat concretions at 60 m; (g) Shales, continued	5
	(h) Siltstone, concretionary, hard, finely laminated, weathering in big blocks at 65 m, belemnites, embedded at angles transversing the laminations; (i) Shales, continued	15
	Sharp boundary, spring line at 80 m	

	Krebsedal Member (153 m)	Thickness (metres)
2	Sandstone, very fine-grained, micaceous, weathering into soft, grey shales, bioturbated	5
3	Layer of large concretions in silt or fine-grained sandstone, bioturbated. Rare ammonites: *Pectinatites* sp. indet. (m). Correlates with concretions at a similar level in section M12, Pinnadal, 1.5 km north yielding *Sphinctoceras* sp. (M) and (m), fauna 25	
4	Sands, fine-grained, micaceous, light, not well exposed	*c.* 65
5	Layer of small concretions, grey, hard, round, partly phosphatized, some with the trace fossil *Macaronichnus*. Well-preserved ammonites, fauna 29: *Pectinatites* aff. *devillei* (de Loriol) (m) (C), *P.* cf. *boidini* (de Loriol) (m) (C), *P.* (*Paravirgatites*) sp. (M), belemnites, crustaceans	
6	Shales or very fine-grained sandstone, micaceous, highly bioturbated, in two parts: (a) Layer of large rubbly doggers, weathering yellow-brown, with plant debris and burrowed with *Thalassinoides suevicus,* moderately fossiliferous, Aldinger's horizon *β* partim; *Pectinatites* sp. indet., belemnites, decapod crustaceans; (b) Shales, glauconitic, a light greensand	1
7	Sands, shaly, fine-grained, grey, with occasional isolated doggers at various levels	30
8	Sandstone, silty to very fine-sandy, micaceous, yellow-grey, rubbly, heavily bioturbated with *Macaronichnus* and plant debris	0.50
9	Sands, as bed 7, continued	30
10	Layer of large doggers, weathering yellow-brown, of very fine-grained micaceous sandstone, rubbly, heavily bioturbated; traces: *Thalassinoides suevicus* and *Macaronichnus;* plant debris; fairly fossiliferous, Aldinger's horizon *β* partim; *Dorsoplanites* sp. indet. (m), *Pavlovia variabilis* Spath, 1936, the type, pl. 10, fig. 1, fauna 33f, belemnites, *Dentalium* sp. (R), bivalves: *Grammatodon schourovskii* dominant, *Thracia depressa* (O)	
11	Sands, fine-grained, grey	3
12	Sandstone, very fine-grained, micaceous, impersistently indurated into rounded or angular concretions, grey to brown, highly bioturbated with *Thalassinoides suevicus* and *Macaronichnus;* highly fossiliferous; *Pavlovia* cf. *perinflata* Spath, 1936, the type, pl. 5, fig. 2 probably from here (fauna 34a), *Dentalium* sp. (VC), bivalves: *Grammatodon schourovskii*	0.20
13	Sands, fine-grained, grey	8
14	Layer of small concretions of fine-grained sandstone, round, hard, phosphatized, grey, heavily bioturbated, a mass of trace-fossils: *Macaronichnus.* Many perfectly preserved ammonites with phragmocones of calcitic or pyritic infill, fauna 34b: *Pavlovia communis* Spath (m) + (M) (including *P. regularis, P. subaperta* and perhaps *P. inflata,* the holo- and numerous topotypes figured by Spath from here) (C), belemnites (VC), decapod crustaceans (C)	
15	Sands, very fine-grained, grey	9

	Pernaryggen Member (61 m)	
16	Layer of small to medium-sized ferruginous concretions, red, of silt with fine quartz grains, the colour probably originating from altered glauconite, many built round a single large fossil; *Camptonectes praecinctus,* large (C), *Grammatodon schourovskii, 'Terebratula'* sp. (R)	
17	Sands, very fine-grained, grey	11
18	Sands, fine-grained, cemented into doggers of rubbly, yellow-weathering sandstone at the base and top; mantled vertical tubes, *Macaronichnus* and *Thalassinoides suevicus;* plant debris. Fairly fossiliferous at the base; dominant elements *Entolium orbiculare, Isognomon volaticum, Thracia incerta, 'Terebratula'* sp. in nests (VC)	
19	Sands, fine-grained, micaceous, grey	16

		Thickness (metres)
20	Sandstone, fine-grained, fissile, discontinuous, doggery; many traces: *Curvolithus, Thalassinoides suevicus, Teichichnus* and lined vertical tubes. Highly fossiliferous, locally a shell bed. Poorly preserved ammonites, fauna 39: *Pavlovia* (*Pallasiceras*) sp. (m) (cf. Spath, 1936, pl. 4, fig. 5), *Dorsoplanites gracilis* Spath, δ, belemnites, bivalves: *Isocyprina birkelundi,* dominant, *Grammatodon schourovskii* (C), *Nanogyra nana* (O), *Pleuromya uniformis* in life-position (O), occasional *Pinna lanceolata, Astarte praeveneris* and *Camptonectes morini;* gastropods: *Pseudomelania* sp.	0.50
21	Sands, fine-grained, micaceous, light grey	4.50
22	Lower *Pinna* bed: sandstone, medium-grained, hard, massive, moderately glauconitic, yellowish-grey, traces of mantled vertical tubes. Highly fossiliferous, large *Pinna* in life-position conspicuous. Ammonites abundant, fauna 40a: *Dorsoplanites triplex* var. *mutabilis* Spath (M), *D. gracilis* Spath (m), ε, (including *D. aldingeri* Spath and *D. crassum* Spath), types from this bed or bed 24, *Pavlovia* (*Pallasiceras*) sp. (m) (R), *Epipallasiceras rotundiforme* (Spath) (m) (including *E.* aff. *costatum* Spath, cf. 1936, pl. 10, fig. 7); relative abundance of *Dorsoplanites* and *Epipallasiceras* about 3:1; belemnites, bivalves: dominant elements *Pinna lanceolata* (VC), *Isocyprina birkelundi* (C), *Buchia mosquensis* (C), *Camptonectes morini* (O), *Pleuromya uniformis* (C), *Entolium orbiculare* (C); subsidiary fauna *Modiolus elongatus* (R), *Myophorella* sp. (R), *Astarte praeveneris* (O), *Protocardia striatula* (R), *Isognomon volaticum* (R), *Nanogyra nana* (R), *Pseudomelania* sp. (O), *Delphinula* sp. (R); *Orbiculoidea latissima* (O), *Cycloserpula intestinalis* (R), *'Terebratula' rosenkrantzi* (O)	1
23	Sands, fine-grained, micaceous, light grey	2.20
24	Upper *Pinna* bed: sandstone, medium-grained, hard, micaceous, glauconitic, weathering light reddish-grey, shelly; traces: *Macaronichnus* and mantled vertical tubes. Highly fossiliferous, large *Pinna* in life-position conspicuous. Ammonites abundant, differing only slightly from those in bed 22, fauna 40b: *Dorsoplanites triplex* var. *mutabilis* Spath (M), *D. gracilis* Spath (m), ε, *Pavlovia* sp. (m) (R), *Epipallasiceras rotundiforme* (Spath) (m); relative abundance of *Dorsoplanites* and *Epipallasiceras* about 4:1; bivalves: dominant elements *Pleuromya uniformis, P. triangularis,* mostly in life-position (VC), *Entolium orbiculare* (C), *Pinna lanceolata;* subsidiary fauna *Buchia mosquensis* (O), *Camptonectes morini* (O), *Isognomon volaticum* (O), *Pseudomelania* sp. (O); *Lingula zeta* (C), *'Terebratula' rosenkrantzi* (C), *Cycloserpula intestinalis* (O), decapod crustaceans	0.40
25	Greensand, strongly glauconitic, medium-grained, dark olive green	0.40
26	Sandstone, medium-grained, micaceous, hard, glauconitic, weathering greenish-brown; *Thalassinoides suevicus* at top, *Entolium orbiculare* (C) at base	0.20
27	Sands, fine-grained, micaceous, slightly glauconitic, light greenish-grey	2.80
28	Sandstone, highly ferruginous, or ironstone, medium-grained, highly glauconitic, dark green, weathering dark red-brown, shelly; traces of *Planolites.* Abundantly fossiliferous, the ammonites with characteristic yellow calcitic phragmocones, fauna 41: *Epipallasiceras acutifurcatum* Call. & Birk. (m) and (M) (VC), *E. rotundiforme* (Spath) (VR), belemnites, bivalves: *Entolium orbiculare* dominant, *Camptonectes morini* (C), *C. praecinctus* (R), *Isognomon volaticum,* in clusters (O), *Pleuromya triangularis* (O), *Pleuromya uniformis* (O), *Liostrea plastica* (O), *Buchia mosquensis* (O); *Cycloserpula intestinalis* (O), *'Terebratula' rosenkrantzi* (O)	0.30
29	Sand, fine-grained, micaceous, glauconitic, greenish-brown	2.60
30	Pseudaperta bed. Sandstone, intensely ferruginous and glauconitic, or ironstone, medium-grained, weathering dark red-brown, bioturbated, a mass of fossils. Many perfectly preserved ammonites, all lying on their sides in a layer 5 cm thick, 15 cm below the top, one or both sides with an adherent oyster. Many bivalves in the lower part of the bed, *Pinna* in life-position, and fossil wood, fauna 42: *Epipallasiceras pseudapertum* Spath (m) (including *E. costatum* Spath (m)), *E. praecox* (M)	

Bed	Description	Thickness (metres)
	(including *E. tumidum* Spath (M)), all the types from here, *Dorsoplanites maximus* Spath (M), type from here, *D. gracilis* Spath (m), *η*; relative abundances of *Dorsoplanites* and *Epipallasiceras* about 1:10; bivalves: *Astarte praeveneris* (VC) dominant in basal part, absent in higher parts of the bed, *Entolium orbiculare* dominant in upper part, *Camptonectes praecinctus* (O), *Pleuromya uralensis* (R), *Liostrea plastica* (C), *Buchia mosquensis* (R), *Plagiostoma incrassatum* (R), *Pseudomelania* sp.; *Pleurotomaria* sp., *'Terebratula' rosenkrantzi* (R), *Orbiculoidea latissima* (R), *Lingula zeta* (R), belemnites	0.50
31	Sand, fine-grained, moderately and variably glauconitic, greenish-grey, with lenticles of dark ironstone above the lowest 70 cm. Sparsely fossiliferous in the ironstones except for local nests of brachiopods; *Pleuromya uniformis, 'Terebratula' rosenkrantzi* (VC), *Entolium orbiculare, Isognomon volaticum*	2.30
32	Sandstone, fine-grained, micaceous, glauconitic, weathering pinkish-grey; *Planolites; Dorsoplanites* sp., *'Behemoth' groenlandicus* Spath from this level, *Pleuromya uniformis* (C) in life-position, *Isognomon volaticum, 'Terebratula' rosenkrantzi*	0.20
33	Sand, fine-grained, greenish-grey, becoming intensely glauconitic upwards, a dark greensand at the top	2.30
34	Sandstone or ironstone, fine-grained, glauconitic, weathering dark red-brown; numerous trace fossils: *Chondrites, Planolites, ?Diplocraterion parallelum, Arenicolites,* vertical tubes; *Dorsoplanites* sp. (m), *Pleuromya triangularis* dominant (VC), *Entolium orbiculare* (C), *Buchia mosquensis* (C)	0.30
35	Sand, fine-grained, glauconitic, olive-green	1.50
36	Sandstone, medium-grained, glauconitic, weathering pinkish-grey; *Thalassinoides suevicus,* vertical tubes. Sparsely fossiliferous; *Pleuromya* sp. (O), *Isognomon volaticum* (O), *Camptonectes praecinctus* (R), belemnites (C)	0.40
37	Sand, fine-grained, highly glauconitic, dark green, with lenticles of glauconitic ironstone in the upper third weathering brown. Sparsely fossiliferous, except for clusters of brachiopods; *Pavlovia* cf. *subgorei* (m) (fauna 45); *Grammatodon keyserlingi* (R), *Pleuromya uniformis* (R), *Isognomon volaticum* (R), *'Terebratula' rosenkrantzi* (C) in clusters	1.00
	Sharp boundary	

Astartedal Member beds 38–45 (22 m)

Bed	Description	Thickness (metres)
	Sands, fine-grained, highly micaceous, silty at the base, white to light grey; locally hardened into doggers which may show small-scale to large-scale cross-bedding. Fossils occur throughout, but tend to be concentrated at a few horizons, sometimes in lenticles showing clear signs of current-accumulation. Dominant elements: *Thracia depressa* (C), *Protocardia striatula* (O), *Hartwellia groenlandica* (O), *Pleuromya uniformis* (O), *Dentalium* sp. (C); with *Pinna lanceolata, Hartwellia kharoschovensis, Grammatodon schourovskii, Eriphyla saemanni, Mesosaccella choroschovensis* as subsidiary elements. Fossil wood and other plant remains common, the logs often heavily bored.	
38	Sands, light, with impersistent lenticles of white fine-grained sandstones throughout. Ammonites about 3 m up, fauna 46a: *Crendonites anguinus* Spath (m) (including *C. euglyptus* Spath (m), *C. lesliei* Spath (m), *C. subregularis* Spath (m)), *Crendonites* sp. (M), fragments, large	7
39	Sandstone, a more persistent feature, with ferruginous breccia (oxydized pyrite)	1
40	Sands, white, micaceous, with stone lenticles	3
41	Sands with ferruginous breccia	0.50
42	Sandstone, grey, impersistent, fossiliferous, with ammonites (see bed 44)	0.50
43	Sands, micaceous, light	2
44	Sandstone, grey, impersistent, locally very shelly, fauna 46b: *Crendonites anguinus*	

		Thickness (metres)
	Spath (m) (C), *Dorsoplanites-Laugeites* sp. (m), *Laugeites* cf. *parvus* Donovan (m) (1964, pl. 3, figs 1,8 only), *Buchia russiensis*	0–0.50
45	Sands, micaceous, white, with impersistent layers of sandstone doggers and ferruginous breccia	8

Hartz Fjeld Formation above, to summit of Hennigryggen, see separate description

Sections M15 – M19: Lingularyggen – Slottet – Hennigryggen

The following is a composite summary of the stratigraphic succession in the lower Hartz Fjeld Formation in the area between Lingularyggen and Hennigryggen (see figs 10–12). Some of the boundaries between beds form conspicuous steps or platforms that persist for long distances and make possible correlation of otherwise featureless sandstones. Other beds or markers are more local and not everywhere recognizable. Closer correlation with the type section further north, or the sedimentary cycles of Sykes & Brand (1976), is not yet possible.

Hartz Fjeld Formation, Hennigryggen Member

H1	Sands, very fine-grained, micaceous, with intercalations of yellow, less micaceous sands; on Krebseryggen (section M17)	*c.* 3
H2	Sands, medium-grained, quartzose, yellowish to white, with plant-bearing thin shale laminae in the lower part and alternating with layers of light grey, fine-grained micaceous sands in the upper part	*c.* 4
H3	Sandstone, medium-grained, non-micaceous, more or less massive, yellowish, with large-scale cross-bedding; around Slottet	*c.* 20
H4	Sandstone, quartzose, softer, locally blue	6
H5	Sands or soft sandstone, yellow	5
H6	*Lingula* Bed. Sandstones, medium-grained, sparsely but coarsely micaceous, somewhat glauconitic, highly variable, thinning rapidly northwards from its greatest thickness at the south end of Lingularyggen, to some residual well-spaced doggers in otherwise featureless sands at the north end of Slottet and leaving no sign on the slopes of Hennigryggen. Further north, scattered finds of fossils suggest that its equivalents may be present throughout the region. The bed shows rapid lateral and vertical variations in structure. It may show parallel lamination, grading up into or followed by bioturbated, unbedded sandstone; shallow trough cross-bedding, seen to 30 cm, sometimes cutting down into parallel laminations; and asymmetric ripple-marks, 10–15 cm between crests. Fossil content varies from barren to very shelly, often concentrated into layers, some with unsorted fauna, some with fauna in life-position, e.g. *Pinna*, some with pavements of *Lingula*, and is highly diverse in various associations. Rare ammonites, fauna 47: *Crendonites* cf. *elegans* Spath (m), *Laugeites groenlandicus* (Spath) (m) and (M); dominant bivalves: *Modiolus elongatus, Entolium orbiculare, Camptonectes morini, Pinna lanceolata, Eriphyla saemanni, Unicardium aceste;* subsidiary elements: *Myophorella* sp., *Tancredia hartzi, Corbicellopsis unioides, C.* aff. *portlandica, Pleuromya uniformis, Protocardia striatula, Oxytoma inequivalve;* belemnites, *Lingula zeta* (VC)	0 to *c.* 3
H7	Sands or soft sandstone, yellow	3
H8	Sandstone, rubbly, ferruginous, greenish-brown, with fragments of indeterminable ammonites. Seen in section M19	0.30

		Thickness (metres)
H9	Sands or soft sandstone, light blue	3 to 5
H10	Sandstone, yellow, locally massive, cross-bedded, forming the turret of Slottet	6 to 10
H11	Sandstone, ferruginous, rubbly, somewhat glauconitic, brown; prominent step; *Tollia* sp. (fauna 48a), pectinids	*c.* 1
H12	Sands or soft sandstones, light, somewhat micaceous (section M15)	12
H13	Sandstone, ferruginous, rubbly, brown, fairly fossiliferous (Aldinger, 1935, p. 83, level at 394 m); *Tollia* sp. (Spath, 1936, pl. 39, fig. 6) (fauna 48b), *Buchia* sp. indet., pectinids, gastropods	*c.* 1
H14	Sands or soft sandstones, light, with fissile doggers	*c.* 25
H15	Sandstone, ferruginous, rubbly, with small round blue or olive-green phosphatic nodules at the base; prominent step; *Tollia* sp. (fauna 48c), bivalves	
H16	Sands or soft sandstones	*c.* 18
H17	Sands, fine-grained, soft, shaly, with a bed of highly glauconitic greensands, forming a step	*c.* 2
H18	Sands or soft sandstones	*c.* 20
H19	Sandstone, coarse-grained, rubbly or fissile, weathering rusty. Forms the summit of Hennigryggen and a ledge on the higher beds to the north that can be followed far along the west slopes of Hartz Fjeld. Ammonites throughout (fauna 48d): *Tollia groenlandica* (Spath) (m) and (M), *Pleuromya* sp., *Entolium orbiculare, Buchia* sp. indet., pectinids	*c.* 3
H20	Sands and sandstones	*c.* 20
H21	Sandstone, coarse, ferruginous, with ironstone concretions. Summit of Kostenbader Fjeld and a prominent platform further north	

Pinnadal Member

Section M23 Pernaryggen

The section runs along the ridge rising westwards towards the eastern buttress of Kronen. The lower part of the succession in the Krebsedal Member is better exposed on the northeastern slopes of Kronen, and a few records of ammonites from these are incorporated.

From below:

Kap Leslie Formation, Gråkløft Member

1	Shales, black, laminated, patchily exposed on the lower slopes. Sharp boundary, spring line at 410 m	

Krebsedal Member (110 m)

2	Shales, sandy, soft, micaceous, lighter, bioturbated, with a layer of huge doggers, going into	
3	Shales, sandy, micaceous, light, with occasional huge doggers, together	16
4	Shales, indurated, sandy, micaceous, bioturbated, locally cemented into doggers. Rare ammonites: ?*Sphinctoceras* sp. indet.	*c.* 1
5	Shales, sandy, micaceous, as below	12
6	Another layer of indurated, sandy, micaceous shales with doggers	
7	Shales, sandy, micaceous, as before	6

		Thickness (metres)
8	Another layer of indurated, sandy, micaceous shales with doggers	
9	Shales, sandy, micaceous, as before	6
10	Another layer of indurated, sandy micaceous shales with doggers	
11	Shales, sandy, micaceous, with scattered small to medium-sized grey concretions at times enclosing well-preserved ammonites, particularly 5–10 m above the base (fauna 27): *Pectinatites groenlandicus* Spath (M), *P.* cf. *cornutifer* (Buckman) (m), *P.* aff. *eastlecottensis* (Salfeld) (m) and (M)	30
12	Layer of sandstone, fine-grained, micaceous, in lenticles, light brownish-grey; ammonites (fauna 28): *Pectinatites pectinatus* (Phillips) (m); *Modiolus bipartitus*	
13	Shales, sandy, micaceous, with septarian doggers, weathering slightly red, and small to medium-sized smooth, rounded but irregular grey concretions; ammonites (fauna 29): *Paravirgatites* sp. A (M), *Paravirgatites* aff. *devillei* (de Loriol) (m)	18
14	Shales, sandy, micaceous, clean	7
15	Layer of fissile sandstone doggers; some bivalves, and imprints of ammonites (fauna 30): *Paravirgatites* sp. (m)	
16	*Pavlovia* bed. Shales, micaceous, sandy, with medium to large round fissile sandstone doggers weathering light brownish-grey ('giants' marbles') and small to medium-sized micaceous concretions, grey, sometimes packed with accumulations of fossils at all angles, particularly ammonites, and enclosing bivalves frequently in life-position. Heavily bioturbated, with many trace fossils: *Curvolithus, Skolithos, Thalassinoides suevicus,* and mantled vertical tubes. The bed can be widely recognized in the area, but its profusion of well-preserved fossils is localized very much around Kronen. The ammonites consist overwhelmingly of microconchs, probably but of a single species, and are mostly mature adults (fauna 32): (m):(M) *c.* 50:1; *Pavlovia iatriensis* Ilovaisky, 1917 (m) (VC) and (M) (includes *P. jubilans* Spath, and *Dorsoplanites subpanderi* Spath), *Dorsoplanites* (?) cf. or aff. *dorsoplanus* (Vishniakoff) (R), belemnites; dominant bivalves: *Pleuromya uniformis* (C) frequently in life-position, *Isognomon volaticum* (C); subsidiary fauna: *Camptonectes praecinctus,* some *Serpula*-encrusted (O), *Buchia* cf. *rugosa* in clusters (O), *Liostrea plastica* commonly encrusting ammonites (O), *Pleuromya uralensis* (R), '*Rhynchonella*' sp. in clusters (O)	8
17	Sands, fine-grained, micaceous, dark grey	2

Pernaryggen Member, 54 m

Lower division: beds 18–38, 29 m

18	Greensands, strongly glauconitic, micaceous, with three thin intercalations of cherry-red ferruginous sandstone; traces of vertical tubes. Few fossils; *Pavlovia rugosa* Spath (m) (fauna 33a), belemnites	1.50
19	Sands, medium-grained, slightly glauconitic, yellowish-grey, some concretionary sandstone in the lower half. Retains some sedimentary structures, including large-scale cross-bedding and horizontal lamination in places; *Curvolithus, Skolithos, Gyrochorte*	3.20
20	Sandstone, medium to coarse-grained, the coarser grains layered; and small-scale ripple-lamination and shallow large-scale trough cross-bedding preserved in places near the top. Moderately glauconitic, weathering reddish-brown. Trace fossils: *Curvolithus, Macaronichnus, Gyrochorte, Skolithos.* Moderately fossiliferous (fauna 33b): *Dorsoplanites* sp. nov. *multiconstrictus* MS (m); dominant bivalves: *Plagiostoma incrassatum* in layers (C), *Buchia mosquensis* (O), *Liostrea plastica* (O), *Oxytoma inequivalve* (O), *Entolium orbiculare* (O), large logs of fossil wood, some bored by bivalves	1.40
21	Sand, medium-grained, micaceous, glauconitic greenish-grey	0.40

Bed	Description	Thickness (metres)
22	Sand, fine-grained, micaceous, glauconitic, greenish-grey, with intercalations of layers of sandstone and concretions. Sparsely fossiliferous; *Camptonectes praecinctus* (O), *Pleuromya triangularis* (R), *Goniomya literata* (R), belemnites	0.80
23	Sandstone or ironstone, highly ferruginous and glauconitic, fine-grained, weathering dark red-brown; traces: *Planolites*. Highly fossiliferous (fauna 33d): *Pavlovia* cf. *allovirgatoides* Spath (m), *P.* aff. *rugosa* Spath (m), *Dorsoplanites* sp. nov., small (m): belemnites (VC); dominant bivalves: *Entolium orbiculare* (VC), *Camptonectes morini* (C), *Liostrea plastica* (C), *Pleuromya triangularis* (C), *Camptonectes praecinctus* (C); subsidiary fauna: *Limatula consobrina* (R), *Plagiostoma incrassatum* (R), *Buchia mosquensis* (C), *Eriphyla saemanni* (O), *Pholadomya hemicardia* (R), *Isognomon volaticum* (R), *Sulcoactaeon peroskianus*, '*Terebratula*' *rosenkrantzi* (R), '*Rhynchonella*' sp. (R)	0.30
24	Sands, fine to medium-grained, micaceous, moderately glauconitic, grey, in places hardened into lenses and nodules containing some fauna; *Camptonectes praecinctus* (O)	2
25	Sandstone, fine-grained, glauconitic, weathering red-brown; fossiliferous (fauna 33c): *Pavlovia allovirgatoides* Spath, belemnites (VC), *Isognomon volaticum* (C), *Pleuromya uniformis*, many in life-position (C), *Camptonectes praecinctus* (O), *Eriphyla saemanni* (O), *Entolium orbiculare* (O), *Pleuromya uralensis* (O)	0.20
26	Sand, fine-grained, micaceous, strongly glauconitic, greenish-grey	0.80
27	Greensand, fine-grained, strongly glauconitic, dark green, with four impersistent layers of ironstone. Abundantly fossiliferous; *Pavlovia* cf. or aff. *similis* Spath (fauna 33 *s.l.*), belemnites, *Entolium orbiculare*, dominant, in layers (VC), *Isognomon volaticum* (R), *Isocyprina birkelundi* (C), '*Terebratula*' *rosenkrantzi* in nests (C)	1.60
28	Shales, sandy, fine-grained, micaceous, only slightly glauconitic, with small grey concretions at several levels and some thin intercalations of glauconitic shales that are locally indurated, but contain the same fauna as the grey concretions; traces of *Macaronichnus*; *Grammatodon keyserlingii* abundant and almost exclusively dominant	6
29	Sand, fine-grained, micaceous, light grey, with only rare glauconitic grains, locally hardened into yellow doggers, bioturbated; *Pavlovia* sp. cf. *communis* (fauna 34 *s.l.*) (R), *Grammatodon schourovskii* dominant, *Thracia depressa* (C), *Isocyprina birkelundi* (C), *Entolium orbiculare*, *Pleuromya uniformis* in life-position (C), *Plagiostoma incrassatum* (R), *Pinna lanceolata* (R)	0.70
30	Sands or sandstone, locally concretionary ironstone, micaceous, shelly, moderately glauconitic, weathering red-brown; *Dorsoplanites* cf. *aldingeri* Spath (m) (R) (fauna 33e), belemnites, *Grammatodon keyserlingii*, dominant, in nests (VC), *Entolium orbiculare* (C), *Pleuromya triangularis* (R), *Isognomon volaticum* (O); *Turritella* aff. *molarium* (C), '*Terebratula*' *rosenkrantzi* (O), '*Rhynchonella*' sp., in nests (R)	0.20
31	Shales, fine-grained, micaceous, weathering light grey, with only rare grains of glauconite; occasional grey concretions containing abundant bivalves of rare species; *Grammatodon keyserlingii* (VC)	5.3
32	Sands, fine-grained, weathering light grey, with a layer of concretions or cemented locally into yellow doggers. Trace fossils: *Chondrites*, *Thallasinoides suevicus* and *Diplocraterion parallelum*, the descending burrows filled with glauconite from the overlying bed. Concretions abundantly fossiliferous (fauna 34 b): *Pavlovia perinflata* Spath (m), *P. regularis* Spath (m) (C), *Dorsoplanites gracilis* α (m), belemnites; dominant bivalves: *Grammatodon schourovskii* (VC), *Thracia depressa* (C), *Pleuromya triangularis*, in life-position (O), *Entolium orbiculare* (O), *Hartwellia borealis* (C), subsidiary fauna: *Isognomon volaticum* (O), *Astarte* aff. *veneris*; '*Terebratula*' *rosenkrantzi* (R)	0.45
33	Greensand, fine-grained, olive-green, with ironstone concretions in the lower half; belemnites (VC), *Entolium orbiculare*, dominant (VC), *Thracia depressa* (R), *Astarte* sp. (R), '*Terebratula*' *rosenkrantzi* (C)	0.50

		Thickness (metres)
34	Sandstone or ironstone, fine-grained, nodular, weathering red-brown, moderately fossiliferous (fauna 36a): *Dorsoplanites gracilis* Spath β (m), belemnites profuse, *Entolium orbiculare* (C), *Pleuromya triangularis* in life-position (R), *Pinna lanceolata* in life-position (R), *Hartwellia borealis* (R), *Isognomon volaticum* (C), *Astarte* aff. *veneris* (R), '*Terebratula*' *rosenkrantzi* in clusters (VC)	0.10
35	Shales, fine-grained, sandy, slightly glauconitic, weathering grey; belemnites (C), *Isognomon volaticum* (O)	1
36	Sandstone or ironstone, fine-grained, nodular, weathering red-brown, in greensand; *Chondrites, Thalassinoides suevicus*. Fairly fossiliferous (fauna 36b): *Dorsoplanites gracilis* Spath β (m), belemnites (VC); dominant bivalves: *Grammatodon schourovskii* (C), *Isognomon volaticum* (C); other fauna: *Pleuromya uralensis* in life-position (R), *Pleuromya triangularis* (R), *Pinna lanceolata* (R), *Camptonectes praecinctus* (R), '*Terebratula*' *rosenkrantzi* (VC) in nests	0.15
37	Sands, fine-grained, micaceous, glauconitic, dark grey; sparsely fossiliferous; belemnites (C), *Isognomon volaticum* (O), *Camptonectes praecinctus* (R)	0.60
38	Sandstone or ironstone, fine-grained, nodular, weathering red-brown, moderately fossiliferous; *Thalassinoides suevicus, Chondrites;* belemnites (C), *Grammatodon schourovskii* (C), *Isognomon volaticum* (C), *Camptonectes praecinctus* (R), *Grammatodon keyserlingii* (O), *Entolium orbiculare* (R), '*Terebratula*' *rosenkrantzi* (VC) in nests	0.10

Middle division: beds 39–51 (15 m)

The middle division consists of almost non-glauconitic micaceous shales and sandstones, sparsely to moderately fossiliferous with a restricted fauna that is much the same throughout. The few ammonites found are a rather heterogeneous lot, not sufficiently abundant to be further subdivisible into separate faunas, and are therefore mostly combined into a single fauna 37.

39	Sands, very fine-grained to silty, micaceous, light grey, with occasional small concretions; moderately fossiliferous, fauna as in bed 40	2.20
40	Sandstone, fine-grained, micaceous, nodular and lenticular, grey; traces of *Macaronichnus*. Fauna often in nests or clusters. *Dorsoplanites gracilis* γ (m) (fauna 37a), *Grammatodon schourovskii* (VC) dominant, *G. keyserlingii* (C) in clusters, *Thracia depressa* (R), *Isognomon volaticum* (O), *Pinna lanceolata* (R), *Hartwellia kharoschovensis* (R), '*Terebratula*' *rosenkrantzi* in nests (VC)	0.25
41	Sand, very fine-grained to silty, micaceous, light grey, with occasional small concretions; moderately fossiliferous, fauna as in 40	1.40
42	Layer of concretions, sandstone, fine-grained, micaceous; *Macaronichnus; Grammatodon schourovskii,* dominant (VC), '*Terebratula*' *rosenkrantzi* (C)	0.25
43	Sand, fine-grained, highly micaceous, with some small concretions; *Macaronichnus*. Moderately fossiliferous, in clusters, both in sands and in concretions; *Grammatodon schourovskii,* dominant	1.20
44	Sandstone, fine-grained, concretionary very irregular, grey, mantled vertical tubes, *Macaronichnus*. Fauna slightly more diverse, as in bed 40. Nests of '*Terebratula*' in orientations indicating burial in life-position	0.30
45	Sand, fine-grained to silty, micaceous, light grey, with occasional small concretions, some of them septarian, at various levels; *Macaronichnus* and mantled vertical tubes; *Grammatodon schourovskii* (O), *G. keyserlingii* (O), *Camptonectes praecinctus* (R), '*Terebratula*' *rosenkrantzi* (VC)	3.40
46	Sandstone, fine-grained, micaceous, slightly ferruginous, concretionary, weathering yellowish-grey; *Macaronichnus,* sparsely fossiliferous (fauna 37a): *Dorsoplanites gracilis* γ (m), *Hartwellia* sp. (R)	0.20
47	Sand, fine-grained to silty, micaceous, light grey, with scattered small concretions; *Macaronichnus;* sparsely fossiliferous; *Pavlovia corona* Call. & Birk. (M), *Camptonectes praecinctus* (O), fossil wood, bored	1

Bed	Description	Thickness (metres)
48	Sandstone, fine-grained, nodular, grey, impersistent, somewhat carbonaceous; *Macaronichnus,* vertical mantled tubes; *Isognomon volaticum* (R)	0.15
49	Sand, fine-grained to silty, micaceous, light grey, with scattered small concretions; *Macaronichnus; Thracia incerta* (R), *Hartwellia* sp. (R), *Isognomon volaticum* (R), *Camptonectes praecinctus* (R)	0.60
50	Layer of sandstone concretions, fine-grained, micaceous, yellowish-grey; *Chondrites, Macaronichnus,* mantled vertical tubes; fossils sparse, as below	0.30
51	Sands, fine-grained, micaceous, becoming slightly glauconitic towards the top, with small concretions at several horizons, weathering light grey. Moderately fossiliferous (fauna 37b): *Pavlovia corona* Call. & Birk. (M), *Dorsoplanites* sp. cf. *liostracus* Call. & Birk., belemnites, *Entolium orbiculare* (C), *Isognomon volaticum* (C), *Camptonectes praecinctus* (C), *Pinna lanceolata* in life-position (R), *Pleuromya uniformis* in life-position (O), *Pholadomya* sp. in life-position (R), *Isocyprina birkelundi* (O), *'Terebratula' rosenkrantzi* in nests (C), *'Pentacrinus'* ossicles in a cluster, *Cycloserpula intestinalis* (O), fossil wood	3.80
	Sharp boundary	

Upper divison: beds 52–65 (10 m)

Bed	Description	Thickness (metres)
52	Sand, fine-grained, micaceous, somewhat glauconitic, weathering olive-green; moderately fossiliferous, fauna as in bed 51	0.30
53	*Pinna* bed. Sandstone, fine-grained, doggery, moderately glauconitic, the basal 20 cm only weakly cemented, weathering yellowish-grey; mantled vertical tubes, *Thalassinoides suevicus.* Abundantly fossiliferous, the burrowing forms frequently in life-position, (fauna 40a): *Pavlovia* sp. nov. transitional to *Epipallasiceras, Dorsoplanites gracilis* Spath ε (m) (C), *D. antiquus* Spath (m) (R), belemnites, *Pinna lanceolata* (VC), *Pleuromya uniformis* (VC), *Entolium orbiculare* (VC), *Isocyprina birkelundi* (VC), *Protocardia striatula* (C), *Camptonectes morini* (C), *Astarte* sp. (C), *Isognomon volaticum* (C), *Eriphyla saemanni* (R), *Pleuromya uralensis* (R), *Modiolus elongatus* (O), *M. czekanowskii* (R), *Buchia mosquensis* (R), *Hartwellia kharoschovensis* (R), *Pseudomelania* sp. (C), *Delphinula* sp. (O), *'Terebratula' rosenkrantzi* (C), *Cycloserpula intestinalis* (O), fossil wood (C)	0.80
54	Sand, fine-grained, micaceous, slightly glauconitic, grey	0.40
55	Sandstone, fine-grained, glauconitic, concretionary, or indurated sand, abundantly fossiliferous; *Isocyprina birkelundi* (VC) in nests, *Entolium orbiculare* (VC), *Delphinula* sp. (C) and other elements as in bed 53	0.50
56	Sand, fine-grained, micaceous, somewhat glauconitic, greenish-grey; *Chondrites, Skolithos;* moderately and diversely fossiliferous as in beds 51 and 53, and rich in gastropods, *Dorsoplanites* cf. *transitorius* (fauna 40), *Pseudomelania* sp. (C), *Brachytrema incerta* (R), *Delphinula* sp. (O), *Sulcoactaeon peroskianus* (O), pentacrinoid ossicles in nests	0.60
57	Greensand, fine-grained, heavily glauconitic, shelly, with some concretions in the upper part, weathering brown. Profusely fossiliferous, a layer of burrowing bivalves at the base followed by a layer of large bivalved *Camptonectes. Dorsoplanites gracilis* (fauna 40), belemnites, profuse, *Camptonectes praecinctus* (VC), *Isocyprina birkelundi* (VC), *Pinna lanceolata* (R), *Isognomon volaticum* (C), *Entolium orbiculare* (C); fossil wood logs, bored (C)	0.40
58	Sands, fine-grained, micaceous, shaly, light grey, the top part indurated and the top very irregular; burrowed intensively from the top, the burrows filled with glauconite; traces of *Chondrites* and *Skolithos; Epipallasiceras rotundiforme* Spath (m) (fauna 40b), *Dorsoplanites gracilis* Spath, *Entolium orbiculare* dominant, in lenses, *Protocardia striatula* (C), *Pleuromya triangularis* in life-position (O), *Goniomya literata* in life-position (R), *Isocyprina birkelundi* (C), *Modiolus czekanowski* (R), *Astarte praeveneris* (O), *Buchia mosquensis* (O)	3.80
	Sharp boundary	

Bed	Description	Thickness (metres)
59	Sandstone and greensand, fine-grained, strongly glauconitic, rubbly, shelly, dark, weathering red-brown; *Chondrites, Skolithos.* Abundantly fossiliferous; layer of burrowing bivalves at the base, followed by a layer of large *Camptonectes, Epipallasiceras acutifurcatum* Call. & Birk. (m) (C) (fauna 41), *Dorsoplanites gracilis* Spath (m), belemnites, profuse, *Camptonectes praecinctus* (VC), *Isognomon volaticum* (VC), locally clusters, *Entolium orbiculare* (C), *Pleuromya triangularis,* in life-position (C), *Astarte* sp. (R), *Grammatodon keyserlingii* (O)	0.50
60	Sandstone, fine-grained, heavily glauconitic, weathering red-brown, in three layers, the lowest softer and shaly; vertical tubes. Only sparsely fossiliferous, fauna as in bed 59	0.50
61	Sandstone, fine-grained, heavily glauconitic, red-brown, shaly, in several layers, the lower part softer; vertical tubes. Moderately fossiliferous, particularly in the top layer; *Dorsoplanites* sp., belemnites (C), *Astarte praeveneris* (C), *Isognomon volaticum* (C), *Pleuromya uralensis,* in life-position (O), *Camptonectes praecinctus* (O), *'Terebratula' rosenkrantzi,* in clusters (C)	0.60
62	Sand, fine-grained, strongly glauconitic and ferruginous from oxidized pyrite, rusty-coloured	0.20
63	Sandstone, fine-grained, glauconitic, weathering greenish-grey and brown; sparsely fossiliferous; *Camptonectes praecinctus* (R), *Isognomon volaticum* (R)	0.15
64	Sand, fine-grained, micaceous, with some large grains of glauconite, weathering yellowish; much fossil wood. *Dorsoplanites intermissus* Call. & Birk. (m) (fauna 44)	0.15
65	Sand, fine-grained, highly micaceous, or soft shaly sandstone, slightly glauconitic; much fossil wood. *Dorsoplanites intermissus* Call. & Birk. (m) (C) (fauna 44), belemnites (C)	0.90
	Sharp boundary	

Hartz Fjeld Formation, Hennigryggen Member

Bed	Description	Thickness (metres)
H1	Sands, quartzose, medium-grained, yellow	1
H2	Shales, fine-grained, highly micaceous, base gradational with some quartzose grains and with plant debris	0.6
	Kronen, northeast corner:	
H3	Sandstones, medium to coarse-grained, quartzose, massive, cliff-forming, mostly light yellow, but dissected pinnacles in the upper parts weathering in spectacular shades of orange, red, brown, green and blue. The lowest 6–7 m are structureless; the main body of the bed in giant-scale cross-sets to within 6–7 m of the top; the highest part trough cross-bedded. The top 0.5 m is heavily bioturbated: *Ophiomorpha* abundant, with small quartz pebbles at the bottom of the layer. Long vertical U-tubes of *Diplocraterion habichi* penetrate the sandstone below to another 0.5 m. The unit is terminated by an iron-crust full of casts of plant remains	37
	Sharp boundary	
H4	Siltstones, highly micaceous, ferruginous, becoming more sandy upwards	7
H5	Sandstone, fine-grained, well laminated, forming a small step	*c.* 1
H6	Sandstones, soft, passing into loose white quartzose sand with quartz conglomerate at the top	4
H7	Sandstone, ferruginous, forming a step	0.5
H8	Sandstones, fine-grained, or shales, ferruginous, soft; layer of casts of body-fossils 2 m up; *Pleuromya* sp. (VC), *Tollia* sp. fragments	5
H9	Layer of dark, heavy, hard, pyritic ironstone concretions; *Tollia* sp. fragments	
H10	Shales and sands, soft, variable, more or less ferruginous and glauconitic; body-fossils in rubbly coarse yellow sands with some ironstone 4 m up; *Tollia groenlandica* (Spath), *Pleuromya* sp.	10
H11	Layer of ironstone and quartz conglomerate	
H12	Sandstones, medium to coarse-grained, ferruginous, forming the top of Kronen, seen	*c.* 1

Sections M33 – M36: Bays Fjelde

The basalt-topped peaks at the southeastern end of Bays Fjelde form a large coomb around the headwaters of Bays Elv, between points 550–810–730 m, and the gorges of Bays Elv and the slopes of the coomb together expose the whole succession of the Upper Jurassic from the Upper Oxfordian Aldinger Elv Member of the Kap Leslie Formation to the lowest part of the Middle Volgian Hennigryggen Member of the Hartz Fjeld Formation. Exposures are, however, discontinuous and rarely as good as in the other two principal sections described here, so that the succession has had to be pieced together from several localities. Lithologies have been examined only in outline and have produced little that is new. The principal interest of the area lies in the ammonite succession, which has yielded well-preserved faunas from some levels that are non-fossiliferous elsewhere in Milne Land. Conversely, the correlations there provide controls on the variations in facies and thicknesses over a much wider area. The following is a composite summary of the succession from about the base of the Lower Volgian upwards.

Section M33: BAYS ELV, river gorge

From below:

Kap Leslie Formation, Gråkløft Member (15 m +)		Thickness (metres)
1	Shales, micaceous, dark; seen	*c.* 6
2	Shales, pyritic, nodular	0.30
3	Sands, shaly, micaceous, dark	4
4	Shales, indurated, nodular, pyritic	0.30
5	Sands, highly micaceous	4
6	Shales, indurated, nodular, pyritic	0.30

Krebsedal Member (220 m)

The boundary is arbitrary, for the beds are strongly weathered and poorly exposed

7	Sands, fine-grained, micaceous, light grey, unfossiliferous	30
8	Layer of sandstone doggers, hard, well-bedded, fissile, discontinuous, weathering in yellow-brown slabs, in indurated shales; *Pectinatites* (*Virgatosphinctoides*) *elegans* Cope (M) (fauna 24), belemnites	0.15
9	Sands, micaceous, poorly exposed	9
10	Layer of doggers in oblong blocks, unfossiliferous	0.15
11	Sands, micaceous, alternating with indurated shales over the lowest 10 m; then changing to light sands with occasional doggers, somewhat ferruginous, yellow, grey or red, with angular fracture	33
12	Shales, micaceous, indurated, with layer of flat, hard, ferruginous paving-stone concretions weathering dark red; *Pavlovia*? sp. indet.	1
13	Sands, micaceous, with doggers, as bed 11	21
14	Shales, sandy, micaceous, with concretions and slabby doggers	3
15	Sands, fine-grained, micaceous, light, with occasional small nodular concretions; *Pectinatites* sp. (fauna 26?)	12

		Thickness (metres)
16	Layer of large sandstone doggers, fine-grained, with conchoidal fracture, *Pectinatites* (*Virgatosphinctoides*) cf. or aff. *abbreviatus* Cope (M), *P.* (*V.*) spp. (m) and (M) (fauna 26)	
	Higher beds covered; transfer to	

Section M34: ridge rising south of point 810

1	Sands, micaceous, light, with occasional small grey nodular concretions and fissile sandstone doggers with angular fracture; overlaps with beds 15 and 16 of the previous section, (fauna 26): *Pectinatites* cf. *eastlecottensis* (Salfeld) (m), *Pectinatites* sp., small, coarse-ribbed (m)	
2	Shales, indurated, or sandstone	0.50
3	Sands, fine-grained, micaceous, with indurated lenticles of hard shales	18
4	Shales, indurated; *Pectinatites* sp.	0.50
5	Sands, micaceous, and shales, with occasional small nodular concretions	19
6	*Pectinatus* bed. Shales, indurated, or lenticular well-bedded fissile sandstone. Ammonites moderately common, easily recognized, making this a widespread marker (fauna 28): *Pectinatites* (*Pectinatites*) *eastlecottensis* (Salfeld) (m), *P.* (*Wheatleyites*) *rarescens* Buckman (M)	0.50
7	Sands, micaceous, light. On the adjacent section M35, still fauna 28: *Pectinatites* (*Pectinatites*) *eastlecottensis* (Salfeld) (M), *P.* (*Wheatleyites*) sp.	15
8	Shales, indurated	0.50
9	Sands, micaceous, fine-grained, with concretions and badly crushed ammonites. On the adjacent section M35, faunas 31, 32: *Dorsoplanites primus* Call & Birk. (M), *Pectinatites* sp. (M), *Pavlovia iatriensis* (m) (R)	21
10	Sandstones, doggery, fissile; *Pavlovia* sp. cf. *variabilis* Spath (fauna 33 partim)	0.50
11	Sands, fine-grained, micaceous, with large grey nodular concretions, (fauna 33g): *Pavlovia* cf. *variabilis* Spath (M), *P.* cf. *allovirgatoides* Spath (M), *Dorsoplanites* sp. aff. *primus* Call. & Birk. (M)	21
12	Layer of large fissile doggers in micaceous sands, with some smaller nodular concretions; many ammonites (fauna 35): *Pavlovia variocostata* Call. & Birk. (m), *P.* cf. *corona* Call. & Birk. (M)	
13	Sands, micaceous, with medium to large concretions and numerous macroconch ammonites (fauna 37): *Pavlovia corona* Call. & Birk. (m) (C), *Dorsoplanites liostracus* Call. & Birk. (M) (C), *D. gracilis* Spath (m)	13
14	Layer of giant brown and grey sandstone doggers, micaceous, fine to medium-grained, heavily bioturbated, moderately fossiliferous; *Thalassinoides suevicus,* commonly retrusive, vertical tubes; *Pavlovia* and *Dorsoplanites* sp. indet., commonly embedded vertically, *Grammatodon keyserlingi* (C), *Isognomon velaticum* (C), *Pleuromya uniformis, Entolium* sp., *'Terebratula' rosenkrantzi* (C) in nests	0.60
	Sharp boundary	

Pernaryggen Member (15 m)

(equivalent to the upper division in the type section on Pernaryggen, M23, only)

15	Greensand, fine-grained, highly glauconitic and micaceous, very dark; sparsely fossiliferous; *Isognomon volaticum,* occasional belemnites	1.20
16	Sandstone, fine-grained, glauconitic, weathering red-brown, moderately fossiliferous; *Skolithos* and *Macaronichnus; Dorsoplanites* sp. (R), *Pleuromya triangularis* (C), *Entolium orbiculare* (C), *Hartwellia borealis* (O), *Grammatodon schourovskii* (O), *'Terebratula' rosenkrantzi* (C), *'Rhynchonella'* sp. (O), *Turritella* aff. *molarium* (VC), sometimes in nests	0.20
17	Greensand, fine-grained, olive-green	1.80
18	Sand, fine-grained, micaceous	0.30

Bed	Description	Thickness (metres)
19	Sandstone, fine-grained, shelly, only lightly glauconitic, weathering grey or cherry-red; heavily bioturbated, trace fossils: *Diplocraterion, Chondrites* and *Thallassinoides suevicus,* the burrows originating at the top of the bed and filled with glauconite from the overlying greensand; occasional burrowing bivalves found in life-position near the top of the bed, probably belonging to the same phase of colonization as the trace fossils; *Grammatodon keyserlingii,* profuse and dominant, *Pleuromya uniformis* (R), *Homomya* sp. (R)	0.40
20	Greensand, fine-grained, micaceous, dark green	0.30
21	Shales, micaceous, fine-grained, light grey	1
22	Sandstone, fine-grained, slightly glauconitic, shelly, weathering light grey; bioturbated with vertical lined tubes. Highly fossiliferous; *Grammatodon keyserlingii* (VC), disarticulated valves, *Camptonectes morini* (O), *C. praecinctus* (R), *Pinna lanceolata* (R), in life-position, *'Terebratula' rosenkrantzi* (O)	0.20
23	Shales, fine-grained, micaceous, slightly glauconitic, brownish-grey	2
24	Sandstone, fine-grained, rubbly, micaceous, moderately glauconitic, grey; *Thalassinoides suevicus; Dorsoplanites gracilis* Spath (fauna 40), *Grammatodon keyserlingii,* dominant, *Entolium orbiculare* (O), *Isognomon volaticum* (O), *Buchia mosquensis* (O), *Pleuromya uralensis* (O), *P. uniformis* (R), *'Terebratula' rosenkrantzi* (C)	0.40
25	Greensand, fine-grained, dark green; belemnites, *Grammatodon keyserlingii* (VC) in nests, *Camptonectes praecinctus* (O)	0.60
26	Sands, fine-grained, micaceous, weathering grey-beige; burrowed with *Thallassinoides suevicus.* Some small fossiliferous concretions near the top, (fauna 40?): *Dorsoplanites transitorium* Spath (m), *D.* cf. *gracilis* (m), *Dorsoplanites* sp. juv., in nests, embedded at all angles ('ammonite cake'). *Entolium orbiculare* (C), *Buchia mosquensis* (C), in clusters round ammonites, *Pleuromya uniformis* (C), *Mesosaccella choroschowensis* (C), *Modiolus* (*Strimodiolus*) sp. (R)	2.20
27	Greensand, fine-grained, dark olive-green, with sparsely-fossiliferous ironstone concretions; *Entolium orbiculare* (O), *Camptonectes praecinctus* (R)	1.60
28	Sandstone, fine-grained, glauconitic, weathering red-brown; moderately fossiliferous; *Astarte praeveneris* abundant, dominant, scattered or in loosely-packed layers of disarticulated shells. *Entolium orbiculare* (C), rare *Liostrea plastica, Camptonectes praecinctus, Pleuromya triangularis, Isognomon volaticum, Plagiostoma* sp. *Hartwellia kharoschovensis*	0.30
29	Greensand, fine-grained, dark olive-green	1.40
30	Sandstone, fine-grained, strongly glauconitic, weathering red-brown, sparsely fossiliferous; *Camptonectes praecinctus*	0.25
31	Greensand, fine-grained, dark green, with several thin bands of ironstone, the highest up to 30 cm thick	0.70
32	Greensand, fine-grained, clean, dark green	0.60

Beds 27–32 are exposed at a small clean outcrop on an adjacent ridge (section M35, northeast of point 810)

- *Epipallasiceras acutifurcatum* Call. & Birk. (m) and (M), abundant and beautifully preserved (fauna 41)
- at various localities, particularly M35 within the top 1.6 m (beds 30–32): *Epipallasiceras pseudapertum* Spath (m) (fauna 42)

This appears to be the highest level of the Pernaryggen Member to be preserved in the area; beds with faunas 43–45 and probably 46 seem to have been cut out by the overlying Hartz Fjeld Formation. Glauconitic sandstone with abundant *Dorsoplanites intermissus* Call. & Birk. of fauna 44 occurs at M37, only 2 km northwest

Sharp boundary

Hartz Fjeld Formation, Hennigryggen Member (*c.* 40 m)	Thickness (metres)
– Sands, fine-grained, somewhat indurated, or sandstone, micaceous, with occasional large grains of glauconite, light grey or blue-grey; much plant debris and some wood fragments; *Crendonites* cf. or aff. *anguinus* Spath (m) (fauna 46 or 47), grading upwards into	0.50
– Sands and sandstones, quartzose, medium to coarse-grained, more or less massive, yellow; seen, *c.* 10 m, then obscured by basalt, but total thickness	*c.* 40

Some of the higher beds are visible on the ridge to the northwest, at section M37. At about 35 m above the base, sandstones with

– Pebble conglomerate: bed of quartzite pebbles, well rounded, up to 20 cm diameter, and interbeds up to 5 cm thick of pure very coarse-grained white mica	*c.* 1
Near the top:	
– Sandstone, very coarse-grained, to gravel-stone, very poorly sorted, with scattered pebbles up to 10 cm in diameter, horizontally bedded, weathering purple-brown; terminated by a concretionary dark purple iron-crust	*c.* 1.50
At the top:	
– Sands, very fine-grained, micaceous, interbedded with micaceous silt, all very soft and dark-coloured. These top beds resemble the top beds on Kronen, which yielded *Tollia* of fauna 48, Lower Valanginian	*c.* 3

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Note added in proof (conc. p. 36)

Forms very close to *Tollia groenlandica* and identified as such have recently been described by Zakharov *et al.* (1983, p. 77, pl. 8, fig. 1) from the upper *Bojarkia mesezhnikowi* Zone of the Pakhsa Peninsula, Anabar Bay, northern Siberia, assigned there to the top of the Berriasian immediately below the Valanginian.

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