MEDDELELSER OM GRØNLAND
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AN ANNOTATED MAP OF THE PERMIAN AND MESOZOIC FORMATIONS OF EAST GREENLAND

BY

JOHN H. CALLOMON, DESMOND T. DONOVAN
AND RUDOLF TRÜMPY

WITH 9 FIGURES IN THE TEXT,
AND 1 MAP

KØBENHAVN
C. A. REITZELS FORLAG
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Abstract

A map has been compiled on the scale of 1:1 million showing Permian and Mesozoic rocks of East Greenland from 70° to 77° north latitude. The accompanying text briefly summarizes the existing knowledge of these rocks.

Lower Permian (not shown on the map) is represented by non-marine formations which lie conformably on Upper Carboniferous. Upper Permian lies unconformably on Lower Permian and earlier rocks with a basal conglomerate. The remaining Upper Permian rocks include marine strata with arich fauna.

The lowest Triassic beds are marine with an abundant fauna which enables six ammonoid zones to be recognized. The rest of the Trias is almost entirely non-marine, a mainly clastic redbed sequence with some evaporites.

The Trias closes with deltaic beds with an abundant flora, which span the interval from Rhaetian to earliest Jurassic (Hettangian).

The Jurassic succession is incomplete. The Middle Jurassic has yielded important ammonite faunas which make it a zonal standard for the boreal Jurassic, very different from that of Europe. Upper Jurassic rocks, mainly Upper Oxfordian and Lower Kimmeridgian, are widespread. Still higher Jurassic rocks are preserved in Milne Land.

Lowest Cretaceous (Berriasian and Valanginian) rocks have yielded important faunas, which in the Valanginian include both North European and Mediterranean elements. The remainder of the Cretaceous succession is incomplete, and includes a number of horizons from Lower Aptian to Upper Campanian.

The palaeogeography of the present North Atlantic region from the Permian onwards is summarized. During Permian times an arm of the Arctic Ocean extended between Greenland and Norway to join up with the Zechstein Sea. This connection was broken in the early Trias, when the Muschelkalk Sea of Europe became connected with Tethys rather than with the Arctic Ocean. During the Lower Jurassic the Arctic connection was resumed. During the Lower Cretaceous there is, for the first time, evidence for the existence of the North Atlantic Ocean as far south as about 40° north latitude.

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INTRODUCTION

This paper is intended to serve as an explanatory text for a synoptical map of the Permo-Mesozoic deposits in East Greenland. Most of the information has been published already in the relevant monographs. East Greenland being the only region on the eastern margin of the North American continent which shows large outcrops of marine Late Palaeozoic and early to middle Mesozoic formations, the character of these formations has a considerable bearing on the early history of the North Atlantic Ocean. A special chapter, for which the original draft was compiled by D. T. DONOVAN, examines this and is intended to raise questions rather than to answer them.

The map which accompanies this report was printed some years ago and subsequent work has shown it to be inaccurate in some details, especially in Jameson Land. This recent work has been incorporated into the descriptive text.

PERMIAN SYSTEM

by R. TRÜMPY

Lower Permian

Marine Lower Permian (Wolfcampian-Sakmarian) carbonates and shales are known from the northeastern tip of Greenland (Mallemuk Formation of Amdrup Land).

In Central East Greenland, there are only continental, detrital formations of presumably Lower Permian age. They follow conformably upon Upper Carboniferous continental deposits; along the margin of the southern part of the Stauning Alper block, they also rest directly upon the Caledonian metamorphics. The dating of these formations is very poor. In the Mestersvig area, the "Lebachia formation" (WITZIG, 1954) — up to 1500 m of shales and arkoses with intercalations of freshwater limestones — contains a scanty flora (*Calamites*, *Lebachia*, doubtful *Callipteris*). In southern Scoresby Land, KEMPTER (1961) assigns Lower Permian age to his Gurresholmsdal Formation (probably better G. Group), over 2000 m of arkoses, sandstones and conglomerates with granite pebbles, on account of spores and pollen (not specified) found about in the middle of the group. As to the 1000 m of coarse conglomerates and arkoses in the inner reaches of Scoresby Sund (Rødeø-conglomerate; BÜTLER, 1957), its age is quite conjectural. All these Lower Permian (or doubtful Lower Permian) formations mark the last phase of deposition of the "Caledonian Molasse". In this sense, the Lower Permian belongs, tectonically speaking, to the "Upper Palaeozoic" sequence, whereas the "Mesozoic" group begins with the widespread Upper Permian transgression. For this reason, the Lower Permian formations are not shown on the accompanying map.

The Lower Permian sediments show evidence of considerable contemporaneous block-faulting. In contrast, the Upper Permian bears the mark of relative tectonic quiescence. Almost invariably, the Upper Permian lies with a marked unconformity upon its substratum (Caledonian basement and Devonian to Lower Permian terrestrial deposits).

Upper Permian

At the base of the Upper Permian sediments, there is generally a red or purple conglomerate, with well-rounded pebbles, measuring 10 to 200 m and often forming steep cliffs. We have applied WITZIG's term Domkirken Formation to this conglomerate unit, whereas KEMPTER (1961) considers it in all cases simply as a basal conglomerate of the overlying Foldvik Creek Formation. It appears possible that there are in fact two conglomerate units (one or both of which may be absent in certain sections): a lower, red fluviatile deposit (Domkirken Formation) overlain by a grey or yellow conglomerate with broken marine shells (basal member of Foldvik Creek Formation).

The marine Upper Permian of East Greenland may be grouped as *Foldvik Creek Formation.*[1]) It measures 100 to 300 m, generally about 150 m. MAYNC (1961) has given an excellent summary of the stratigraphy, which we follow to a large extent.

The Foldvik Creek Formation can be subdivided into several intertonguing members:

a) *Basal Conglomerate* member (restricted): generally thin, with carbonate cement and fossil debris. In Scoresby Land, this member may pass into shales, sandstones and platy limestones.

b) *Gypsum-dolomite* member: lenses of gypsum associated with shales and bedded dolomites. Monogenic breccias (dissolution breccias and diagenetic breccias of cornieule-type) are frequent.

c) "*Reef*" *Limestone* member: massive, white or cream-coloured limestones, building conspicuous cliffs. In some outcrops, the limestone is fairly homogeneous ("Riffkalk"), while in others it is interbedded with massive dolomites, platy limestones, calcarenites and detrital seams. The abundant benthonic fossils are generally difficult to collect, except in the famous "White Blocks" in Triassic conglomerates of the Kap Stosch area.

d) *Posidonia shale* member: dark, bituminous paper shales with interbeds and concretions of dark blue, micritic limestone. Benthonic fauna absent, except for sponge spicules; pseudo-planktonic bivalves (*Posidonia permica*), fishes, floated land plants.

e) *Martinia shale* member ("Martinienkalk"): gray and greenish, calcareous and micaceous shales and silty limestones. Smooth shelled

[1]) This term is not too satisfactory; there seems to be some uncertainty as to which of the creeks SE of Kap Stosch is understood by Foldvik Creek. KEMPTER (1961) proposes Karstryggen Formation; but this cannot be recommended either, as only part of the formation is preserved on Karstryggen (west of the lower Schuchert Dal).

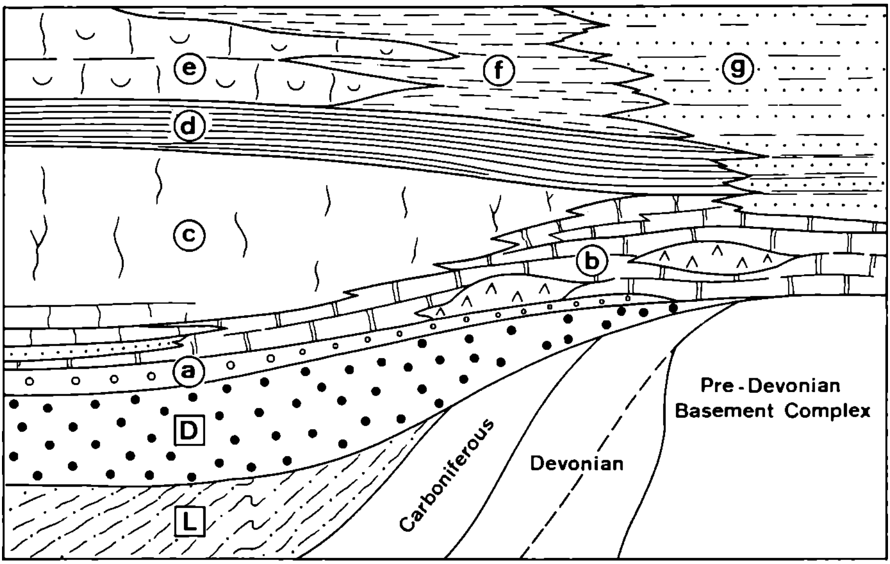

Fig. 1. Diagrammatic sketch illustrating the relationship of Permian formations in central East Greenland.

L: Lebachia formation and Gurreholmsdal formation.
D: Domkirken formation.
a–g: Members of Foldvik Creek formation, see text.

brachiopods, cephalopods (*Cyclolobus*, *Medlicottia* and the remarkable belemnite *Dictyoconites groenlandica*).

f) *Productus limestone* member: generally thin (a few metres), highly fossiliferous limestones (brachiopods, bryozoa, crinoids, simple corals, gastropods, bivalves).

g) *Upper detrital* members: red, calcareous sandstones, arkoses and conglomerates of Wollaston Foreland (Redbed member). Calcareous sandstones intertonguing with members (d)–(f) in eastern Jameson Land.

The complex relationship of the members is illustrated by Fig. 1 of this paper and also by Fig. 2 in Maync (1961). A normal succession would be: (a)–(b), intertonguing upwards with (c)–(c)–(d) — interbedded (e) and (f). The limestone (c) and dolomite-gypsum member (b) may replace each other entirely in many sections. Curiously enough, the restricted dolomite facies rather occupies the centre of the basin, the (ill-named) "reef" facies its margins (Wollaston Foreland, Wegener Halvø, southern Scoresby Land). The euxinic Posidonia shales are generally present, but they may pass upwards and laterally into Martinia shales (e) or sandy equivalents (f). Martinia shales — laid down in slightly deeper waters and on muddy bottoms — and the shoal facies of the Productus limestones interbed and replace each other in an apparently unsystematic fashion. Detrital influence in the higher part of the section (g) occurs mainly along the eastern margin of the basin. The western margin must have lain somewhat west of the present outcrop boundary (Permian pebbles in Triassic conglomerates were derived from a westerly source area).

For the rich Permian fauna, we refer to DUNBAR (1955, 1961, brachiopods), NEWELL (1955, bivalves), MILLER & FURNISH (1940, ammonites) and STENSIÖ (1961, vertebrates, listing also other relevant works on the fish fauna). It is now agreed that the Foldvik Creek Formation belongs to the Upper Permian (Penjabian) and that its "closest faunal ties are with the Zechstein of Germany and the Magnesian limestone of England" (DUNBAR, 1961). Whether or not the very highest Permian, equivalent of the post-*Cyclolobus* zones of Armenia and southwestern China, is represented in Greenland is an open question; the *Cyclolobus* come from the Martinia shales, almost at the top of the formation. TRÜMPY's (1960) statement that sedimentation was continuous over the Permian-Triassic boundary may therefore be subject to caution.

The Foldvik Creek Formation is the youngest major carbonate unit in East Greenland. With its bituminous shales and porous limestones, it might furnish a not uninteresting object for oil prospecting in the Jameson Land basin or its possible offshore prolongation, all the more so as the overlying Triassic sandstones also show good porosities.

TRIASSIC SYSTEM

by R. Trümpy

General Situation

Triassic formations occur in two areas along the coast of East Greenland.

A northern, still incompletely explored and relatively small outcrop region lies in eastern Peary Land (lat. 82°40′ N). Shales and sandstones, measuring at least 630 m, have an Upper Scythian *Arctoceras* fauna at the base and a Lower Anisian fauna in the upper half. Both facies and fauna are quite different from those of central East Greenland and show analogies to the Spitsbergen section (see Kummel, 1953).

The main Triassic outcrops are found in the fjord and island country of central East Greenland, between Scoresby Sund and Wollaston Foreland (lat. 70°30′–74°30′). They occupy a stretch of somewhat over 400 km length and up to 90 km width. The western margin is erosional, but apparently close to synsedimentary faults limiting the Mesozoic trough against the Caledonian highlands. To the northeast the Triassic basin runs out into the sea; in the southernmost area, Triassic formations transgress upon the Caledonian block of Liverpool Land on the east. The southern termination of the basin is not exposed, but the reduction of overall thickness and the wedging out of most formations indicate that it lay little to the south of Scoresby Sund. Judging by the influx of coarse detritus, the tectonic activity was strongest in the Lower Induan (Martini Zone) and especially in the Olenekian (lower part of Mt. Nordenskiöld Formation).

The thickness of the Triassic deposits is very variable, with a maximum of almost 2000 m in the centre of the basin (northern Scoresby Land). They lie conformably on the Permian Foldvik Creek Formation, which however they overstep on the margins of the trough. In the south (Jameson Land), Jurassic formations follow conformably, whereas in the central and northern part of the outcrop area (Traill Ø, Geographical Society Ø, Gauss Halvø and Hold with Hope) the Triassic formations are truncated and directly overlain by higher Jurassic or Cretaceous beds, or by Tertiary plateau basalts.

Only the lowermost Triassic is normally marine. The Olenekian to Norian (?) stages are represented by poorly fossiliferous, largely continental redbeds, the Rhaetian by drab-coloured, continental sandstones.

Wordie Creek Formation ("Lower Triassic" on map)

The lowermost Triassic formation consists of grey or greenish shales with intercalated sandstones (quartz sandstones and arkoses) and conglomerates. Especially in its lower and middle part, it contains a very rich fauna of ammonites and bivalves, also of fishes and gastropods, while brachiopods are subordinate. The ammonites have allowed the establishment of the following zonal scheme:

(top)	*Anodontophora breviformis* beds (no ammonites)	(7)
	Zone of *Proptychites rosenkrantzi*	(6)
	Zone of *Vishnuites* (?) *decipiens*	(5)
	Zone of *Ophiceras commune*	(4)
	Zone of *Otoceras boreale*	(3)
	Zone of *Glyptophiceras* (?) *martini*	(2)
(bottom)	Zone of *Glyptophiceras* (?) *triviale*	(1)

The faunal analogies point to the Canadian Arctic, the Far East and, indirectly, to the Himalayas. Correlation is most obvious with the Canadian Arctic (Tozer, 1961, 1965).

Zones 3 and 4 are practically identical with their Canadian counterparts.[1] New material collected in 1967 makes it very likely that zone 5 corresponds, at least in part, to Tozer's zone of *Pachyproptychites strigatus*. The two lowest zones contain only small Xenodiscids (forerunners of *Metophiceras* and "*Glyptophiceras*"), as well as *Otoceras* sp. It is noteworthy that *Claraia* appears as early as zone 2. These lowermost zones (up to zone 3, with decreasing abundance) are also rich in benthonic faunal elements of "Permian" type (Productid and Spiriferid brachiopods, bryozoa, crinoids), which in most cases do not appear to be reworked.[2]

On Clavering Ø and especially on Hold with Hope, with its classical locality of Kap Stosch (Koch, 1931; Nielsen, 1935; Spath, 1930 and 1935), the Wordie Creek Formation measures about 800 m. The Triviale Zone is represented by up to 30 m of shales with bituminous coquinas. Conglomerates, with the famous "White Blocks", boulders of Permian limestone derived from the west, occur especially in the Martini Zone, (2);

[1] Trümpy's (Defretin *et al.*, 1969) zone of *Metophiceras subdemissum* is here considered as subjective synonym of Tozer's zone of *Otoceras boreale*.

[2] The exact Arctic equivalents of the zone of *Otoceras woodwardi* are not yet established. If the base of this zone in the Himalayas were defined as base of the Triassic system, the consequence might eventually to be place at least zone 1 in the Permian.

FORMATION	Member (*Zone*)	Lithology	m ±	Age
KAP STEWART		sst., sh., (continental)	300	L. Lias - Rhaetian
KAP BIOT	Ørsted Dal	sh., sst.	500	Norian ?
	Fleming Fjord	red mudstones		Carnian ?
	Kap Seaforth	sh., dol., gypsum		Ladinian ?
MT NORDEN - SKIÖLD	Solfaldsdal	sh., gypsum, marine lst.	1000	Anisian
	Paradigma	pink arkoses		
	Rødstaken (fassaensis)	red silty sh., sst., lst.		Olenekian ?
WORDIE CREEK	Breviformis	purple sh., sst.	800	Induan
	rosenkrantzi	gray or green sh. and sst.		
	decipiens			
	commune			
	boreale	Conglomerate and arkose tongues		
	martini			
	triviale			

Fig. 2. Stratigraphic table of Triassic formations in central East Greenland.

arkose sandstones and quartz conglomerates also in the Decipiens and Rosenkrantzi Zones. The latter contains one or a few beds of greenish algal limestone with *Naticopsis*, which are also found further south and constitute good marker horizons. In the *Anodontophora breviformis* beds, ammonites disappear and stegocephalians become frequent. The uppermost unit of the Kap Stosch succession (*Anodontophora fassaensis* beds) is here tentatively attributed to the Mt. Nordenskiöld Formation.

The section on Traill Ø (Putallaz, 1961) is very similar to that of Kap Stosch. A thick sandstone unit occupies the place of the Martini and (partly) Boreale Zones. Another prominent, yellow-weathering arkose layer with pebbles derived from the east lies in the upper part of the poorly fossiliferous Decipens Zone. Strata corresponding to the Rosenkrantzi Zone and to the *breviformis* beds show widespread slump structures (flow-rolls, large load casts; in Jameson Land, according to Birkelund & Perch-Nielsen (1969), also flute casts, which is rather remarkable as most of the other evidence points to shallow water).

In Jameson Land (Noe-Nygaard, 1934; Stauber, 1942; Grasmück & Trümpy in Defretin *et al.*, 1969) the thickness of the Wordie Creek formation is smaller than in the more northerly areas, especially along the eastern, southern and western margin of the basin, where the lower zones wedge out. Along Hurry Inlet, the formation is absent altogether (or, perhaps, replaced in part by continental deposits of the Mt. Nordenskiöld Formation). A "basal" conglomerate overlies shales with *Claraia* and *Glyptophiceras* (?) *martini*. In the higher part of the formation (zones 5–6), ammonites become scarce, indicating less favourable conditions at this southern, landlocked extremity of the bassin. Several arkose intercalations — of which the lowest one correlates with the arkose in the Decipiens Zone of Traill Ø — show conclusive evidence (direction of current-bedding, composition of pebbles) of being derived from the east, from a landmass on the site of the present Scandic, of which the half-foundered basement blocks of Liverpool Land and Canning Land are remnants. This is of importance insofar as it shows that the early Mesozoic sediments of East Greenland were not laid down along the margin of an Atlantic Ocean.

Mount Nordenskjöld Formation ("Middle Triassic" on map)

The most typical development of this formation is found in northern Jameson Land, where its thickness is of the order of 800 m. There are generally two members; a lower one (Paradigma Member) of coarse, pink arkoses with rhyolite and granite pebbles, and an upper one (Solfaldsdal Member) of red siltstones, variegated shales and gypsum layers. The Paradigma arkoses show cross-bedding laminae uniformly inclined to the west; at their base, they pass gradually into and interfinger with the marine shales and sandstones of the Wordie Creek formation. The Solfaldsdal Member contains little coarse detritus. By this time, the Jameson Land basin seems to have been cut off from the sea. In the Fleming Fjord area, however, a thin but constant limestone band with *Myalina*, *Myophoria*, *Halobia* cf. *moussoni* and gastropods marks a marine incursion. The faunule seems to indicate Anisian age; as no major gaps are detectable, the Paradigma arkoses might be Olenekian.

The status of the Rødstaken beds (Aellen, personal communication), purple mudstones and sandstones below the Paradigma arkoses, is not yet clear; their inclusion as lowest member of the Mt. Nordenskiöld Formation is provisional. They seem to correspond to the *Anodontophora fassaensis* beds of Hold with Hope, which however show more marine influence and contain thin beds of oolitic limestone with a still undescribed bivalve fauna.

Kap Biot Formation ("Upper Triassic" on map)

This formation is restricted to Jameson Land and extends further south than the others. Its thickness attains 600 m. Even on air photographs, it can easily be subdivided into three members.

The lower (Kap Seaforth) Member shows variegated, gypsum-bearing shales, followed by well-bedded, chrome-yellow dolomites and siltstones with quartzite layers. In this upper part, there are also oolitic limestones with a very poor bivalve and phyllopod fauna and stromatolitic, presumably algal dolomites with structures absolutely similar to Precambrian *Collenia.* The middle (Fleming Fjord) Member consists of massive red mudstones, forming bold cliffs. An alternation of variegated shales and sandstones, often with fillings of (tidal?) channels, makes up the overlying Ørsted Dal Member; south of Fleming Fjord, its youngest beds are well-bedded dolomites.

The age of the Kap Biot Formation is not well established; the faunule in the Kap Seaforth Member seems to point to Carnian. The uniform facies and the lack of coarse detritus indicate a time of relative tectonic quiescence. Ripple marks, mudcracks, stromatolites and rock salt pseudomorphs are most compatible with deposition on large tidal flats, possibly in a bay adjacent to the Arctic Sea. The type of sedimentation bears analogies to part of the British Keuper and still more to the Lockatong Formation of the Eastern United States, except that in both areas marine influence is absent or at least dubious.

Kap Stewart Formation (grouped with "Lower Jurassic" on map).

This formation is again limited to Jameson Land. It generally measures about 200 m and consists of yellow, usually coarse and feldspathic sandstones alternating with black, carbonaceous shales.[1]) In the Fleming Fjord area, the base of the formation is marked by a thin but very constant bone bed, with fish scales, reptilian teeth and crushed, *Cardinia*-like bivalves. The rest of the formation is non-marine. The very rich flora studied by Harris (numerous papers; summary 1961) indicates Rhaetic and Lower Liassic age (*Lepidopteris* and *Thaumatopteris* floral zones); analogies with southern Sweden are especially obvious but many species are also in common with other European and Asian localities.

[1]) In the original definition of Rosenkrantz (1930), the Kap Stewart Formation included also what is now considered to be the Ørsted Dal Member of the Kap Biot Formation.

The sharpest sedimentary break, however, lies clearly above the Ørsted Dal Member, and the rich flora occurs only in the beds here attributed to the (restricted) Kap Stewart Formation (Grasmück *in* Defretin *et al.*, 1969, p. 55).

JURASSIC SYSTEM

by John H. Callomon

Jurassic rocks were discovered in East Greenland in 1870. They are now known in a long, narrow, discontinuous strip along the coast between 70° and 77° N, a belt about 700 km long and up to 130 km wide at its widest in the south in Scoresby Sund. Exposure varies from very poor, obscured by ice, drift and Tertiary basalts, to excellent in clean scarps bordering sheets of almost horizontal beds. To the west they show consistent evidence of not far distant shorelines, reflected in sublittoral facies and wedging out of beds. Their facies as a whole indicate never more than shallow marine shelf conditions with deltaic interludes, and there is no evidence whatever of the proximity of a deep North Atlantic ocean.

Locally the beds are highly fossiliferous, and the profusion of ammonites has produced a stratigraphy that makes the succession one of the standards of the Boreal Jurassic. The faunas show the closest affinities with those now known from all round the Arctic Ocean, in Spitsbergen, Arctic Russia, Siberia, Alaska and the Canadian Archipelago. In contrast, similarities with European faunas further south are sufficient to indicate direct connections but are nevertheless more limited. Comparisons make most sense in a framework of reconstructed continents (see below) giving the region a central position on one of the main straits joining the Tethyan and Boreal Oceans not long before drift separated the continents. The Jurassic of East Greenland is therefore of much more than passing or specialized interest.

For convenience the coastal strip may be divided into five regions, from south to north:

1. Milne Land
2. Jameson Land
3. Traill Ø — Geographical Society Ø
4. Wollaston Forland — Kuhn Ø
5. Store Koldeway Ø.

In each the Jurassic occurs in a different characteristic development.

Stratigraphical Table of the Jurassic

<table>
<tr><th></th><th></th><th colspan="2">Stages</th><th colspan="3">Formations in East Greenland</th></tr>
<tr><td rowspan="15">Jurassic</td><td rowspan="7">Upper</td><td></td><td>Upper Volgian</td><td colspan="3">(Not recognized, absent?)</td></tr>
<tr><td>Portlandian</td><td rowspan="2">Lower Volgian</td><td colspan="2" rowspan="2">Lingula Bed of Milne Land
Glauconitic Series of Milne Land</td><td rowspan="2">Sandstones and shales in southern Jameson Land</td></tr>
<tr><td>Upper</td></tr>
<tr><td colspan="2">Lower Kimmeridgian</td><td colspan="2">Kimmeridge Shales of Milne Land</td><td rowspan="2">Koch Fjeld Formation of Jameson Land; Black and Grey Series of Traill Ø, Kuhn Ø and Wollaston Forland; Store Koldewey</td></tr>
<tr><td rowspan="3">Oxfordian</td><td>Upper</td><td colspan="2">Pecten Sandstone
Cardioceras Shales</td></tr>
<tr><td>Middle</td><td colspan="2">Charcot Bugt Sandstone</td><td rowspan="3">Sandstones of Yellow Series facies in central Jameson Land and southern Traill Ø</td></tr>
<tr><td>Lower</td><td colspan="2">Shales and sandstones in Jameson Land</td></tr>
<tr><td rowspan="4">Middle</td><td colspan="2">Callovian</td><td rowspan="3">Vardekløft Formation of Jameson Land</td><td>Upper</td></tr>
<tr><td colspan="2">Boreal Bathonian</td><td>Middle</td><td>“Yellow Series” of Jameson Land, Traill Ø, Geographical Society Ø, Kuhn Ø and Wollaston Forland. Trækpas Formation, Store Koldewey</td></tr>
<tr><td colspan="2" rowspan="2">Bajocian</td><td>Lower</td><td>Black shales, Traill Ø</td></tr>
<tr><td colspan="3">(? Non-sequence)</td></tr>
<tr><td rowspan="4">Lower</td><td colspan="2">Toarcian</td><td colspan="2">“Oyster Bed”, marine facies</td><td rowspan="2">Neill Klinter Formation of Jameson Land and Kap Hope</td></tr>
<tr><td colspan="2">Pliensbachian</td><td colspan="2">Shales, silts and sandstones
Uptonia Bed, marine faunas</td></tr>
<tr><td colspan="2">Sinemurian</td><td colspan="3" rowspan="2">Kap Stewart Formation of Jameson Land and Kap Hope, southern Liverpool Land (deltaic facies, plant beds)</td></tr>
<tr><td colspan="2">Hettangian</td></tr>
</table>

Milne Land

The Jurassic succession commences with thick sandstones of the Upper Oxfordian resting with basal conglomerate on an undulating surface of Caledonian gneiss rising to the west. This basal sandstone and conglomerate, firmly dated by rare ammonites to the Plicatilis Zone, *i.e.* of the same age as the Corallian Beds of England, has recently yielded many bored but otherwise fresh corals ascribed to a single species of *Actinastrea* (Håkansson *et al.*, 1971). Thereafter the Upper Jurassic succession, consisting of shales, sandstones and glauconites, is thick, largely complete and highly fossiliferous up to and including almost the whole of the Lower Volgian (Portlandian). A small angular unconformity near the top does not coincide with the Jurassic-Cretaceous boundary, which falls somewhere in a series of barren sandstones. These are followed by three isolated horizons yielding *Tollia groenlandica* of the Ryazanian/Boreal Berriasian and more thick sandstones containing only plant remains. The fossils were described in two classic monographs by Spath (1935, 1936), and the stratigraphy was revised and summarized by the present author (Callomon, 1961) on the basis of much new material subsequently collected bed by bed.

Jameson Land

The map reflects the gently-dipping basin-shape of the deposits, the edge forming a more or less dissected scarp running south-north from Hurry Inlet to Carlsberg Fjord and then turning west. Outliers continue up to Kong Oscars Fjord as hills rising to 1000 m. The western edge of the basin is fault-bounded against the high crystalline mountains of Scoresby Land, which are not reflected in the Mesozoic lithofacies and are therefore probably younger. The eastern margin is governed by Liverpool Land, another crystalline range, which however may have existed as a positive feature in the Jurassic, albeit an inconspicuous one; for there are conglomerates, and the beds thin somewhat and become more shaly away westwards.

The transition from Trias to Jurassic is gradual and conformable, in a series of thick deltaic sandstones. The plants have been monographed by Harris (summarized 1961) who dated them as Rhaeto-Liassic and compared them with similar successions in southern Sweden and elsewhere. The rest of the Lias follows as more sandstones or silts, mostly unfossiliferous, but with three principal marine horizons. The lower two are in the Pliensbachian, Jamesoni and Davoei Zones, and occur only at Hurry Inlet. The third forms the top of the formation and is Lower Toarcian, Bifrons Zone. It thickens northwards, from 50 m in Neill Klinter, Hurry

Inlet, to 350 m + at Antarctic Havn, Kong Oscars Fjord, where it stops abruptly: no Lias is known further north. The fjord therefore probably follows one of the many major faults of the region which were intermittently active since the Palaeozoic, including the Jurassic.

The Middle Jurassic is the most important part of the Jurassic of East Greenland for it has yielded a succession of ammonite faunas characteristic of the whole of the Arctic but in major part quite unknown further south. This succession is the basis for the current scheme of standard zones for the whole of the Arctic. The scheme put forward in 1959 (CALLOMON, 1959) has had to be amplified and modified as a result of new discoveries in 1968 and 1970 (BIRKELUND, HÅKANSSON & SURLYK, 1970; BIRKELUND & CALLOMON, to be published), the units retained here as full Zones being in almost every case further divisible into Subzones.

	Lower Callovian	
(top)	Zone of *Sigaloceras calloviense*	(7)
	Zone of *Cadoceras nordenskjoldi* sp. nov.	(6)
	Zone of *Cadoceras* sp. nov. B.	
	Boreal Bathonian	
	Zone of *Cadoceras calyx*	(5)
	Zone of *Cadoceras variabile*	
	Zone of *Arcticoceras* sp. nov. A.	(4)
	Zone of *Arcticoceras ishmae*	(3)
	Zone of *Arctocephalites arcticus*	(2)
	Zone of *Cranocephalites pompeckji*	(1)
	? Upper Bajocian	
(bottom)	Zone of *Cranocephalites borealis*	

Notes:

(1) Two subzones, previously Indistinctus and Pompeckji Zones

(2) Two subzones, previously Nudus and Greenlandicus Zones

(3) Two subzones, the lower previously called Kochi Zone, the higher based on the true *A. ishmae* (KEYSERLING) which has now been found in quantity *in situ.*

(4) Appearance of the first *Kepplerites.* Two subzones based on this genus: the first with forms described by SPATH as *K. tychonis* var. *fasciculata*; the second with the true *K. tychonis* RAVN, now found *in situ.*

(5) Formerly the Tychonis Zone. The true *K. tychonis* does not occur in these beds, which are characterized by large *Cadoceras* (described by SPATH as aff. *victor*) and *Kepplerites rosenkrantzi* SPATH, *K. peramplus* SPATH.

(6) MS name for the species one specimen of which was figured by MADSEN (1904, pl. 10, fig. 2) as *?Olcostephanus*. Much new material has how been found *in situ* and will be described elsewhere.

(7) Three subzones. The lowest with *Cadoceras* cf. *septentrionale* FREBOLD, the second with *Kepp. gowerianus* (SOWERBY), and the top with *Sigaloceras calloviense*, *Cadoceras sublaeve*, *Chamoussetia* and *Proplanulites*.

Resting on the Toarcian is a series of black shales (80–100 m) whose exact age is unknown but which recalls "Opalinuston" of the Lower Bajocian (Aalenian). It is very uniform in thickness and apparently crosses Kong Oscars Fjord into Traill Ø. There follow the ammonite beds, some 115 m of shales with horizons of concretions full of fossils at the south end of Hurry Inlet, thickening rapidly northwards and changing to mainly yellow sandstones at least 550 m thick. Most of the ammonites were also described by SPATH (1932), and the stratigraphy was here also again worked out through detailed collecting by the present author (CALLOMON, 1959).

The beds of the Calloviense Zone are followed in places by several hundred metres of higher beds whose ages are variable. New finds in the south indicate thin shales of Middle Callovian age followed by black shales and sandstones several hundred metres thick of Upper Oxfordian to Upper Kimmeridgian ages. These were previously called the Koch Fjeld Formation but the name may have to be changed on grounds of priority (SURLYK personal communication, 1971) and original definition. These beds are followed in turn by several hundred metres of further sandstones and shales of Lower Cretaceous age (q.v.), Berriasian to Valanginian. In central Jameson Land the Calloviense Zone is followed by further thick shales of Middle and Upper Callovian, Coronatum and Athleta Zones with *Kosmoceras* and *Longaeviceras* (BIRKELUND, HÅKANSSON & SURLYK, 1971), and lying on these is a very thick formation of black shales and sandstones resembling in facies the Upper Oxfordian-Kimmeridgian Koch Fjeld Formation of the south, but dated here to Lower and Middle Oxfordian by rare ammonites (*Cardioceras*), with no Cretaceous preserved on top.

Traill and Geographical Society Øer

Knowledge is limited because of poor exposures. Much of the Jurassic lies down-faulted under Cretaceous cover against Trias or Palaeozoic margins, or is obscured by basalts.

The oldest Jurassic present appears to be the same series of black shales, possibly of Bajocian age, which rest on Toarcian south of Kong

Oscars Fjord, but which here rest on Trias. Then follows the Middle Jurassic, at least 600 m thick, a straightforward northward continuation of its development in Jameson Land. Upper Jurassic is locally present in southern Traill Ø as sandstone or black shales of Oxfordian–Kimmeridgian ages, but these are then cut out progressively northwards by unconformable Cretaceous, an Albian conglomerate coming to rest on *Cranocephalites* beds.

Wollaston Foreland and Kuhn Ø

Numerous scattered sections have been recorded but conditions are made even more difficult by extensive block-faulting. Middle Jurassic consisting of up to 200 m of yellow sanstone, as further south, appears to rest on Caledonian basement. Proven ages range from ?Arcticus to Variabile Zones. Upper Jurassic shales have produced many ammonites of Upper Oxfordian–Lower Kimmeridgian ages, but not in continuous profiles as in Milne Land. They are locally cut out by thick conglomerates from which ammonites of Volgian–Ryazanian ages have been obtained (DONOVAN, 1964). These are of great interest in connection with the problems of the Boreal Jurassic–Cretaceous boundary, but although found in place and in sequence they are unfortunately too poorly preserved to be of much use.

Store Koldewey

This is of interest only as being the most northerly, and among the first, places in East Greenland from which Jurassic fossils have so far been obtained. Patches of sandstone rest on crystalline basement, possibly close to the Jurassic shoreline. Ammonites indicate the Variabile Zone of the Middle Jurassic (including the holotype of *Kepplerites tychonis* RAVN), Upper Oxfordian, and Kimmeridgian, Mutabilis Zone (*Aulacostephanus groenlandicus*), and Valanginian.

Further outcrops of probable Jurassic age have been reported by observers during flights to the north over Germania Land, but no ground observations appear to have yet been made.

CRETACEOUS SYSTEM

by Desmond T. Donovan

The Cretaceous rocks of East Greenland have the same southern limit as the Jurassic, the Gåsefjord–Scoresby Sund line which must mark a major fault, at about 70° N., but they extend further north to Germania Land where some Aptian beds occur at about 77° N. There is also an isolated outcrop of late Cretaceous beds further south at Kangerdlugssuaq (between 68° and 69° N.), not shown in the map. These latter are the only known sedimentary rocks between Kap Farvel and Scoresby Sund.

The sediments are almost wholly clastic — shales, sandstones and conglomerates. There are rare, thin beds of limestone, mainly in the Lower Cretaceous. The Chalk facies which is almost universal in the European Upper Cretaceous is unknown. Although the present distribution of the outcrops, near and parallel to the outer coast line, is partly due to later faulting, their disposition is also consistent with having been deposited near the edges of a sea which transgressed from the east. For example in the Valanginian of Wollaston Forland and Turonian of Traill Ø thick, coarse clastic sediments pass rapidly eastwards into thinner and finer-grained deposits.

Berriasian rocks, all of clastic type, occur in the Scoresby Sund and Wollaston Forland areas. In Wollaston Forland sedimentation was probably continuous with the Valanginian, and at the "Niesen" there are about 600 m of coarse clastic deposits of Berriasian and Valanginian age. The topmost 200 m or so yield *Polyptychites*, and at the very summit *Lytico-ceras* has been found.

Elsewhere the Valanginian is thinner and represented by a shale-limestone facies, which is unusual in the Mesozoic of East Greenland. The principal areas where this facies has been studied are in the hinterland of Albrechts Bugt, northeastern Wollaston Forland, and on the west flank of the Mols Bjerge, in northeastern Traill Ø. The limestones yield a striking fauna, difficult to collect except where weathering has been favourable. Ammonites, belemnites, and bivalves of the genus *Buchia* predominate. Among the ammonites, *Polyptychites* and allied genera are the most common forms, but there are also several genera which would not be expected so far north: *Phylloceras*, *Lytoceras*, *Acan-*

Stratigraphical Table of the Cretaceous

	Stages	Formations in East Greenland
Upper Cretaceous	Maestrichtian	(Absent)
	Campanian	Scaphites Beds of Traill Ø and Geographical Society Ø
		(Non-sequence?)
	Santonian	Sphenoceramus Beds of Traill Ø and Geographical Society Ø. Knudshoved Beds of Hold with Hope
	Coniacian	(Non-sequence?)
	Turonian	Inoceramus lamarcki Beds of Traill Ø and Geographical Society Ø
	Cenomanian	(Unconformity?)
Lower Cretaceous	Albian	Middle Cretaceous shale series and Inoceramus Beds; the former extending up into the Lower Cenomanian in Traill Ø and Geographical Society Ø
	Aptian	Mainly coarse clastic rocks representing Lower and Upper Aptian
	Barremian	(Absent)
	Hauterivian	
	Valanginian	Upper Niesen Beds (clastic facies), and shale-limestone facies; Store Koldewey, Wollaston Forland area, and Traill Ø
	Berriasian	Sandy and conglomeratic facies in the Scoresby Sund and Wollaston Forland areas

thodiscus, and *Leopoldia*. The common belemnite is *Pachyteuthis*, but more rarely there are *Hibolites* and *Pseudobelus*, the latter again, a "southern" genus. The most surprising find was the perforate brachiopod *Pygope*, the previously known distribution of which was confined to the countries bordering the Mediterranean in Europe. Some illustrations of the fauna have been published by DONOVAN (1953).

The polyptychitid ammonites are not very difficrent from those of Speeton (Yorkshire, England) and north Germany, and a direct marine connection with the North Sea Basin may readily be assumed. Such a direct connection is shown even more forcefully by the distribution of the peculiar genus *Hectoroceras*, first described from Jameson Land and now known in quantity from eastern England (CASEY ,1961). The Mediterranean elements, however, are unknown from the North Sea Basin and therefore an independent sea connection with the Tethys is postulated (Fig. 8). The only practicable route is west of the British Isles and the Atlantic or proto-Atlantic must have been in existence at this time. It may, of course, have been wider than can be shown on the pre-drift base map used here, if Europe and North America had already started to move apart.

The Hauterivian and Barremian stages are unknown in East Greenland. Deposition was resumed in the Aptian. The Lower Aptian has been found only in two areas: the northern part of Hold with Hope, where coarse clastic rocks at least 170 m thick unconformably overlie Triassic strata, and in shale facies in southeastern Kuhn Ø. Both occurrences have yielded the ammonite *Deshayesites.*

The Upper Aptian is more widely distributed, from Traill Ø in the south to Germania Land in the north, but faunas are poor except in Store Koldewey, where E. NIELSEN collected, and FREBOLD described, a marine fauna of about fifty species, principally molluscs (FREBOLD, 1935). The cephalopod fauna is not prolific or well preserved; it is characterized by *Sanmartinoceras* and *Lytoceras polare* RAVN.

In some places, sedimentation may have been continuous from the Aptian into the Albian, which spreads over wide areas in a number of districts north of Kong Oscars Fjord (72° N). The Albian is largely represented by dark shales, with subsidiary sandstones, and stratigraphical study is obstructed by the numerous basic intrusions. Lower, Middle, and perhaps Upper Albian are present, but fossils are almost without exception poorly preserved, and the number of species recorded is small. *Arcthoplites* is perhaps the most noteworthy ammonite, but the ten ammonite genera recorded from the whole of the stage make a poor comparison with the prolific faunas known in many parts of the world. Other fossils are, for the most part, rare, except the ubiquitous *Inoceramus anglicus* WOODS, which appears to be identical with European examples.

During the Lower Cenomanian, black shale sedimentation continued in Traill Ø and Geographical Society Ø, sandstones being present but only achieving importance near the shoreline, which lay in the neighbourhood of 23° W. Several hundred metres of Cenomanian rocks are preserved, and, as in the case of the Albian, fossils are scarce and species few. Several occurrences are securely dated by the ammonite *Schloenbachia*, and the most common fossil is *Inoceramus crippsi* MANTELL. The total thickness of the Albian and Lower Cenomanian shales is believed to be over 700 m, but stratigraphical details are little known because of the scarcity of fossils and the abundance of igneous intrusions.

In Traill Ø and Geographical Society Ø the Lower Cenomanian is succeeded by Upper Turonian rocks, which commence with sandstones and conglomerates indicative of an important episode of erosion, perhaps preceded by earth movements along one of the major north-south faults in the area. Shales with *Inoceramus lamarcki* PARKINSON have been found in a number of places in the two islands and are dated as Upper Santonian or Lower Campanian on the basis of *Inoceramus* (*Sphenoceramus*) *patootensis* de LORIOL and allied species, which also occur in the Patût beds, presumed to be of similar date, in West Greenland. Both occurrences consist of shales and sandstones. It is not known whether there was an interval of non-deposition between Inoceramus lamarcki Beds and the Sphenoceramus Beds, or whether the apparent gap is merely a result of failure to find intervening faunas.

The latest Cretaceous rocks in East Greenland have been found only in screes in Traill Ø and Geographical Society Ø. Here they consist of glauconitic, sandy shales or argillaceous sandstones, and have yielded *Scaphites greenlandicus* DONOVAN, a species allied to *S. roemeri* SCHLÜTER. *Scaphites* of this group are characteristic of rocks of Upper Campanian age in northern Europe and North America.

A more detailed summary of the East Greenland Cretaceous, including faunal lists and a full bibliography, will be found in DONOVAN (1957).

PERMIAN AND MESOZOIC PALAEOGEOGRAPHY

by D. T. DONOVAN and R. TRÜMPY

East Greenland is the only region on the eastern margin of the North Atlantic continent where marine Upper Permian, Triassic, Jurassic and Early Cretaceous deposits are preserved. For this reason, the Mesozoic of East Greenland is of special interest for the light that it may throw on the history of the North Atlantic Ocean. The palaeogeography may be examined first and some general implications later. A series of palaeogeographic reconstructions is presented on the assumption that the arrangement of present landmasses during Late Palaeozoic time was as reconstructed by BULLARD *et al.*, (1965); this implies that the North Atlantic Ocean did not exist in Late Palaeozoic times.

During the Lower Permian, an Arctic sea left deposits in Spitsbergen, North-East Greenland and on Bear Island. In Central East Greenland, the Lower Permian is represented by continental redbeds, as in Europe. A major change in palaeogeography took place between the Lower and Upper Permian; the sea receded from Spitsbergen and North-East Greenland, but encroached on Central East Greenland and flooded the Zechstein depression. During the Upper Permian (Fig. 3), the connection between the European area of sedimentation, *i.e.* the Zechstein sea, and open ocean is assumed to have lain to the north, between Greenland and Norway. This is corroborated by the absence of any proven marine connection to the west, south and east of the Zechstein area of deposition, and by the existence of marginal facies on these three sides of the Zechstein basin. A direct marine connection between East Greenland and northern Central Europe is also attested by the marine faunas of the Upper Permian of Greenland, which according to DUNBAR (1962), show a close resemblance to that of the European Zechstein. On the whole, the Upper Permian of Greenland bears the stamp of more obviously marine conditions than that of northern Europe, although gypsum and dolomite deposits occur also within the Foldvik Creek Formation.

During the early Eotriassic, marine rocks were laid down in East Greenland, which carry a fauna finding its parallels in the Himalayas, Eastern Asia and the Canadian Arctic, but unknown in Europe. The connection with the ocean is therefore again assumed to be to the north,

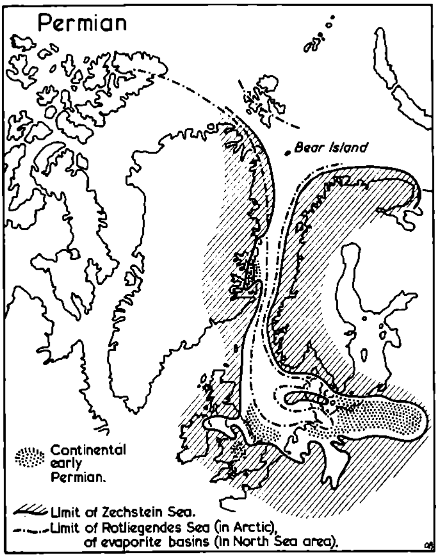

Fig. 3.

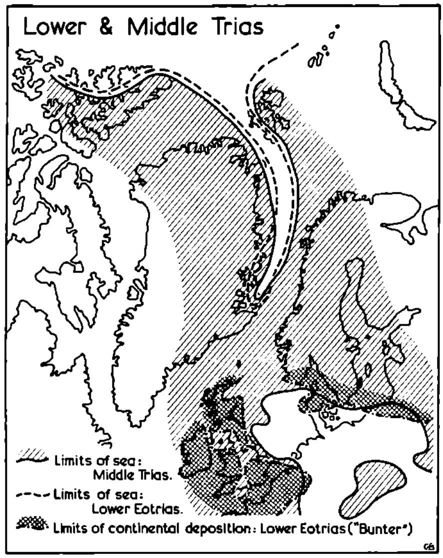

Fig. 4.

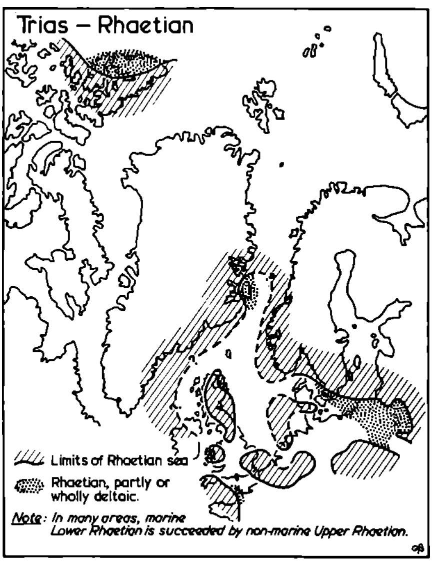

Fig. 5.

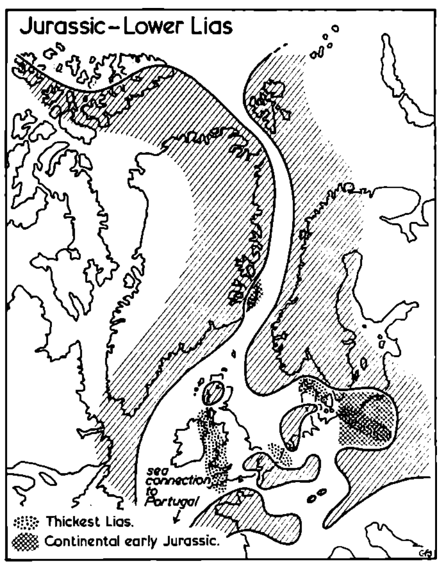

Fig. 6.

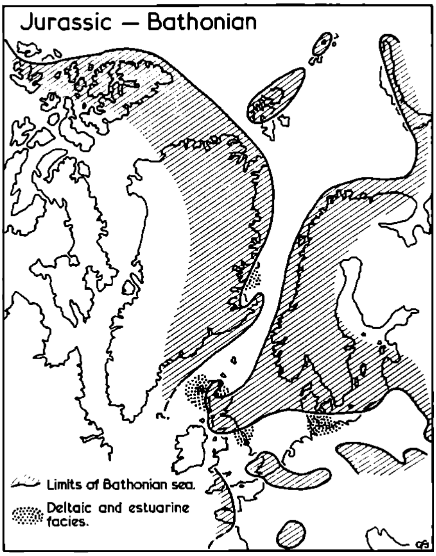

Fig. 7.

Fig. 8.

Fig. 9.

Fig. 3–9. Palaeogeographical reconstructions for the area of Greenland and northwest Europe from the Permian to the Cretaceous. The base map is taken from BULLARD *et al.*, 1965. Further explanation will be found in the text.

with a channel linking the Arctic and Indo-Pacific realms via Eastern Siberia. Trümpy (1961, p. 253) has commented on the possibility that the saline, non-fossiliferous deposits of the Upper Zechstein might be coeval with the marine Eotriassic deposits of Greenland, but this hypothesis is not confirmed by recent palynological research. Lower Eotriassic rocks are also present on Spitsbergen and in the Canadian Arctic. By the end of the Lower Triassic, the sea must have retreated northward (Fig. 4); normal marine deposits of this age are only found in Spitsbergen and in North-East Greenland. In Central East Greenland, conditions became rapidly continental, but short marine incursions took place as late as the Anisian and (?) Carnian and as far south as lat. 72°. Connections with western Europe were now definitely broken; in northwestern Europe, sedimentation as this time was largely non-marine, and the transgression at the end of the Lower Triassic arrived through southwestern Poland.

In the Middle Triassic, central Europe and the North Sea basin were flooded by the Muschelkalk sea, which did not reach quite as far as eastern England. This basin was connected with the Tethys or proto-Mediterranean, at first through southern Poland and later through the Jura Mountains and the Western Alps. Middle Triassic marine deposits of the same age, but with a totally different cephalopod fauna are also found in Spitsbergen. There is no indication of a direct connection between the Arctic sea and the German basin (Fig. 4; see especially Kent, 1967, p. 13).

In the area under consideration Upper Triassic marine rocks are known only from Bear Island. The Kap Biot Formation of East Greenland shows some evidence of deposition on tidal flats bordering an arm of the Arctic sea which probably did not extend further south.

During the Lower Jurassic (Fig. 6), the sea was much more extensive, although many of the areas flooded by the Liassic sea had been areas of continental sedimentation during the late Trias, for example in the British Isles. In Britain, the Lias thickens to the west, the thickest Liassic successions being found in the Bristol Channel area, in Cardigan Bay, in northern Ireland and western Scotland. Preserved deposits are too fragmentary to indicate whether they were part of one or more basins of deposition; some diversification is likely, as in the better known area of the main English outcrop. There is no indication of the western limit of this thick sedimentation but it must have lain to the east of the present coasts of south-east Greenland and Newfoundland where no Lower Jurassic is known. It may be significant that the Lias in Portugal is also thick (600 m; Hölder, 1964, p. 446). Thick sedimentation also occurred in the North Sea basin, and in northern Germany.

During the earliest part of the Jurassic, the Hettangian, sedimentation in East Greenland, as in southernmost Sweden and much of Poland, was non-marine. By the Lower Pliensbachian Stage conditions in East Greenland had become marine and in this and in the Toarcian, a direct connection with the British Isles is suggested by the marine faunas. Whether this sea in earliest Jurassic times had an outlet to the north, between north-east Greenland and Spitsbergen, is not known. The Hettangian faunas of Western Canada are of European type, but suggest that while they were probably in direct connection with the Western European area, this connection may have lain further south via the western end of Tethys. By the Pliensbachian, however, a northern connection is suggested by the existence in Canada of ammonites of the families Liparoceratidae and Amaltheidae, which flourished in northern Europe at the time, but which were rare or absent from Tethyan localities. Sinemurian ammonite faunas of British type are also known from Richardson Mountains in northern Yukon and from the North-West Territories.

In the Middle Jurassic (Fig. 7), we again find a change of the palaeogeographical scene. This period is commonly regarded as a time of regression, compared with the Lower Jurassic. Extensive deltaic deposits are found in northern Britain, and in East Greenland also much of the Middle Jurassic (the Yellow Series of the Traill Ø area), although marine, indicates shallow, marginal conditions, with much coarse clastic debris. The ammonite faunas of the British and East Greenland areas are so strikingly different that an effectively complete barrier must be assumed, although this could have been ecological rather than physical. Faunal marine connection was only re-established in the early Callovian, when common faunal elements are again found in East Greenland and Britain. Related faunas are also found in Spitsbergen and Petchora, and a continuous seaway is therefore assumed from the Western European area through to what is now the Arctic Ocean. The rest of the Upper Jurassic calls for little comment, similar ammonite faunas being found in Britain, East Greenland and Spitsbergen, and a continuous marine connection being therefore assumed. At some time during the Upper Jurassic at least, the sea transgressed on to northern Norway, where a clastic marginal facies was deposited in Andoya, although the exact dating of these rocks is not yet well established.

In the Lower Cretaceous, the Valanginian fauna of East Greenland has an important bearing on palaeogeography (Fig. 8). The most abundant members of the fauna are Polyptychitid ammonites, related to ones found in the North Sea basin (Yorkshire, Northern Germany) and Russia. Connections with these areas must therefore be presumed. The fauna also contains, however, Mediterranean elements belonging to three separate groups (ammonites, belemnites and brachiopods) which are found neither in the North Sea basin nor in Russia. Because of these elements, a direct independent connection with the Tethys is strongly suggested, and this can only have passed west of the British Isles. Because the Lower Cretaceous was in general a time of regression, the existence of this sea connection must have been due to tectonic causes, in other words, to the existence of a precursor of the North Atlantic Ocean as far south at least as the present lat. 40° N.

There is little to say regarding the Upper Cretaceous (Fig. 9). The presence of rocks of this age in central East Greenland forms an exception to their general absence from the North Atlantic shores, north of about 60° latitude, an absence which is the more surprising in view of the otherwise wide distribution of Upper Cretaceous rocks. The explanation may be that the North Atlantic Ocean was by now well established and its coastal areas had already become the areas of positive relief that they are today. The sea now reached West Greenland for the first time, probably from the north as indicated by Birkelund (1965, Fig. 125, p. 171) on the basis of faunal affinities of the West Greenland Upper Cretaceous with the corresponding rocks in North America.

HISTORY OF THE NORTH ATLANTIC OCEAN

By DESMOND T. DONOVAN

The palaeogeographic maps here presented show that by late Permian times, there was a seaway in existence between Greenland and Norway. Judging from the marginal faulting roughly parallel to the present coast-line, which characterizes East Greenland and the continental shelf off Norway, the earliest Atlantic in this region may have occupied a kind of rift valley structure; in East Greenland the rifting began after the deposition of the Upper Carboniferous and before deposition of the Upper Permian Foldvik Creek Formation. The Proto-Atlantic was in connection with the present North Sea basin. Whether there was a continuation of the Norway and East Greenland rift west of the British Isles we do not know; at any rate there is no direct evidence of the existence of an oceanic basin between the British Isles, Greenland and Newfoundland. It may be more than a curious coincidence that the first, mid-Permian opening of the Proto-Atlantic Ocean corresponds in time with the opening of an abortive Indian Ocean, between Baluchistan and Mozambique, which has left marine deposits in East Africa and in western Madagascar.

The Permian North Sea basin shows no evidence of marginal faulting and appears to have been caused by crustal thinning. There is no good evidence for tension, and this may have died out southwards, or alternatively have extended to produce rifts in the present Irish Sea region or to the west of Ireland.

Rifting in the East Greenland trough went on during Triassic times. In East Greenland the sea retreated northward, but the continental to paramarine Triassic basins extended somewhat further south than those of Permian time; their southern prolongation is hidden below the basalts of Knud Rasmussen's land. One of us has suggested (TRÜMPY *in* DEFRETIN *et al.*, 1969, p. 57) that the Triassic basins of eastern continental North America, between Nova Scotia and the Carolinas, might represent a continuation of the East Greenland rift belt. Marine Triassic deposits have not been reported from this area, but they might theoretically be expected between Newfoundland and the offshore area of southeastern Greenland.

In the Jurassic we find quite a different palaeogeographical pattern. The North Sea basin is no longer evident as a single entity. Sedimentation occurred over a widespread area which included a number of smaller basins, stretching from north Germany to western Britain, in which thick sediment accumulated. Some of these basins are determined by basins in which continental sedimentation occurred in Keuper times. The present Irish Sea area was the site of thick Liassic sedimentation, but there is no positive evidence for an oceanic area west of this. Indirect evidence of an apparently weak tidal regime during the Lias suggests that there was no ocean of any size lying to the west of the British Isles during the Jurassic period.

During the Lower Cretaceous, we have, for the first time, faunal evidence for the existence of a sea to the west of the British Isles for at least a short period during a time of general regression. This may, therefore, be an extension of the present Atlantic Ocean further south than had previously been the case. By the Upper Cretaceous sedimentary rocks are found beneath the continental shelves of both eastern and western North Atlantic and the ocean is generally agreed to have been in existence. Baffins Bay had also begun to open by this time.

Tuzo Wilson (1966) has suggested the existence of a Lower Palaeozoic Atlantic Ocean which later closed. Be this as it may, there seems to be no good evidence for the existence of a North Atlantic Ocean during the Devonian or Carboniferous Periods. A reconstruction of the Old Red Sandstone continent by House (1968) shows the whole of the countries bordering the Atlantic north of the British Isles as part of this continent. During the Carboniferous, however, there existed a series of elongated basins in which non-marine rocks, largely coal measures, were laid down. These extend from the south-eastern United States to East Greenland and lie to the west of the western margin of the Atlantic and roughly parallel to it. They may indicate that tension was beginning to be felt along the North Atlantic zone by this time. The coal basins east of the Atlantic (Europe, Morocco) are not parallel to the ocean margin, but lie mainly east and west; some of the later basins, oriented south-west and north-east, or SSW–NNE, again show evidence of rifting.

By the late Permian we can postulate the existence of a proto-Atlantic at least as far south as Scotland, opening into the North Sea. The beginning of the Atlantic opening at about 30° N was suggested to have been about 250 m.y. ago by Ewing *et al.* (1966), by extrapolation from the ages of deep-sea sediments. This would agree well enough with the Permian opening further north having regard to the likely wide margin of error in the calculations.

From the Lias onwards there is evidence for sea extending further south than before, although it may have been closed to the south at about latitude 30° N. Fig. 6 does not extend far enough to the south to show this. In the Upper Jurassic and Lower Cretaceous this proto-Atlantic seems still to have been very restricted. The major part of the widening out to form the present ocean presumably took place from the Upper Cretaceous onwards.

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Explanation of Map

Map on the scale of 1:1 million of the Upper Permian and Mesozoic rocks of East Greenland. The divisions shown on the map correspond with those employed in the text. New field-work in 1970–71 has shown that most of the area in Jameson Land here shown as Lower Cretaceous is in fact still Upper Jurassic. Lower Cretaceous is preserved only in the southernmost 20 km.

Please note that some place names are given in unauthorized form.


LEGEND
Upper Cretaceous
Undivided C.
Lower C. and Cenomanian
Upper Jurassic
Middle J.
Lower J. (incl. Rhaetic)
Upper Triassic
Middle T.
Lower T.
Upper Permian
KONG FREDERIK VIIs LAND
Nordmarken
Ile de France
Skærfjorden
GERMANIA LAND
STORSTRØMMEN
DRONNING LOUISE LAND
CARLSBERGFONDET LAND
DOVE BUGT
Borgfjorden
STORE KOLDEWEY
KONG WILHELMS LAND
Bessels Fjord
HOCHSTETTERS FORLAND
Bredefjord
Stor borgen
Smallefjord
Ardencaple Fjord
C. H. OSTENFELDS LAND
Shannon Sund
SHANNON
Grandjeans Fjord
TH. THOMSENS LAND
Kuhn Ö
Hochstetter Bugten
Lindemanns Fjord
Sabine Ö
KONG CHRISTIAN Xs LAND
BARTHOLINS LAND
Wordies Gletscher
Stenos Land
PAYERS LAND
WOLLASTON FORLAND
CLAVERING Ö
Daneborg
Young Sund
OLE RÖMERS LAND
Godthaabs Golf
Gael Hamkes Bugt
Jacksons Ö
STRINDBERGS LAND
Gerards Fjord
HUDSON LAND
Loch Fyne
HOLD WITH HOPE
Nordfjord
Moskusoxe Fjord
GAUSS HALVÖ
ANDREES LAND
Kejser Franz Josephs Fjord
Isfjord
FRÆNKELS LAND
Nordenskiølds Gletscher
YMERS Ö
Dusens Fjord
FOSTER BUGT
Antarctics Sund
Borgøen
Bontekoe Ö
Sofia Sund
SUESS LAND
GEOGRAPHICAL SOCIETY Ö
Videnskabelig Station
Ella Ö
Kempes Fjord
Vega Sund
LYELLS LAND
TRAILL Ö
Mountnorris Fjord
Eugenie Fjord
Segelsällskapets Fjord
Alpefjord
KONG OSCARS FJORD
NATHORSTS LAND
Mesters Vig
Dromme Bugten
Davy Sund
GRØNLANDSHAVET
SCORESBY LAND
Fleming Fjord
Nathorst Fjord
Carlsberg Fjord
Nordvest Fjord
RENLAND
JAMESON LAND
LIVERPOOL LAND
Bjørneøer
Heden
Charcot Havn
HALL BREDNING
MILNE LAND
Hurry Fjord
Neill Klinter
Roscoe Bjerge
Flakkerhuk
Scoresbysund
Rosenvinges Bugt
Unarteq
Danmarks Ö
GAASELAND
SCORESBY SUND
Gaasefjord
VOLQUART BOONS KYST
Savoya Halvö
KONG CHRISTIAN DEN IXs LAND
76°
74°
72°
70°
28°
24°
20°
16°