

## Towards an integrated Jurassic biostratigraphy for eastern Greenland

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**Key words:** Jurassic, integrated biostratigraphy, ammonites, palynology, micropalaeontology, Greenland.

**Abstract.** The thick and relatively complete Jurassic succession of eastern Greenland provides a unique biostratigraphic record for the North Atlantic region. The main biostratigraphic control for the succession has been provided by molluscs, especially ammonites and to a lesser extent by bivalves and belemnites. The late John Callomon and colleagues recognised 93 Boreal ammonite-bearing horizons in the Mid to Late Jurassic. This provides a reliable backbone to the biostratigraphy of these strata, prompting a palynological colleague to comment that they are the “Policemen of Jurassic Stratigraphy”. Other biostratigraphically significant microfossil and palynological groups, can be calibrated against this standard, but on their own cannot achieve the same precision.

The Early Jurassic of eastern Greenland does not have such fine control as later parts of the period. No single biostratigraphic group can be used successfully throughout the interval, and there are only three significant ammonite faunas during this period. Reliance on various different organisms is necessary to cope with the changing range of marine to non-marine environments.

CASP field-work from 1990 to 2012 has resulted in the collection of much biostratigraphic material. In this article, published data are summarised together with previously unpublished data in the form of a unified table. The integrated chart shows detailed columns for the whole eastern Greenland Jurassic. It demonstrates the ammonite, palynological and microfossil events/biozones and horizons which are correlated by time. More limited information is available on belemnites, bivalves and macroflora. This is the first time such an integrated biostratigraphic scheme has been assembled for the Jurassic of eastern Greenland. It will be of value to the offshore oil-industry in the northern North Atlantic and on the Barents Shelf as well as to field geologists in Greenland.

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### INTRODUCTION

Jurassic sedimentary rocks of eastern Greenland are exposed intermittently for over 600 km from Jameson Land and Milne Land in the south, to Store Koldewey in the north (Fig. 1). They are of variable thickness, up to about 1500 m. The term “eastern” Greenland refers to the northern part of the formal regions of East Greenland (Milne Land, Jameson Land) and the southern part of North-East Greenland (Traill Ø north to Store Koldewey).

The whaling captain, William Scoresby Jr collected specimens in 1822 of “*Pectinites*” from beds which are now known as the Rævekløft Formation, from Hurry Inlet in what is now Jameson Land. The specimens were first described by Robert Jameson (1823) of Edinburgh University. The Jurassic as such was first recognised by Hochstetter (1874) and Toulou (1874) who examined material collected by the scientists, including Julius von Payer (surveyor), and Ralph Copeland (biologist), during Captain Karl Koldewey’s cruise on the *Germania* of the 2nd German North-Polar Expedition of

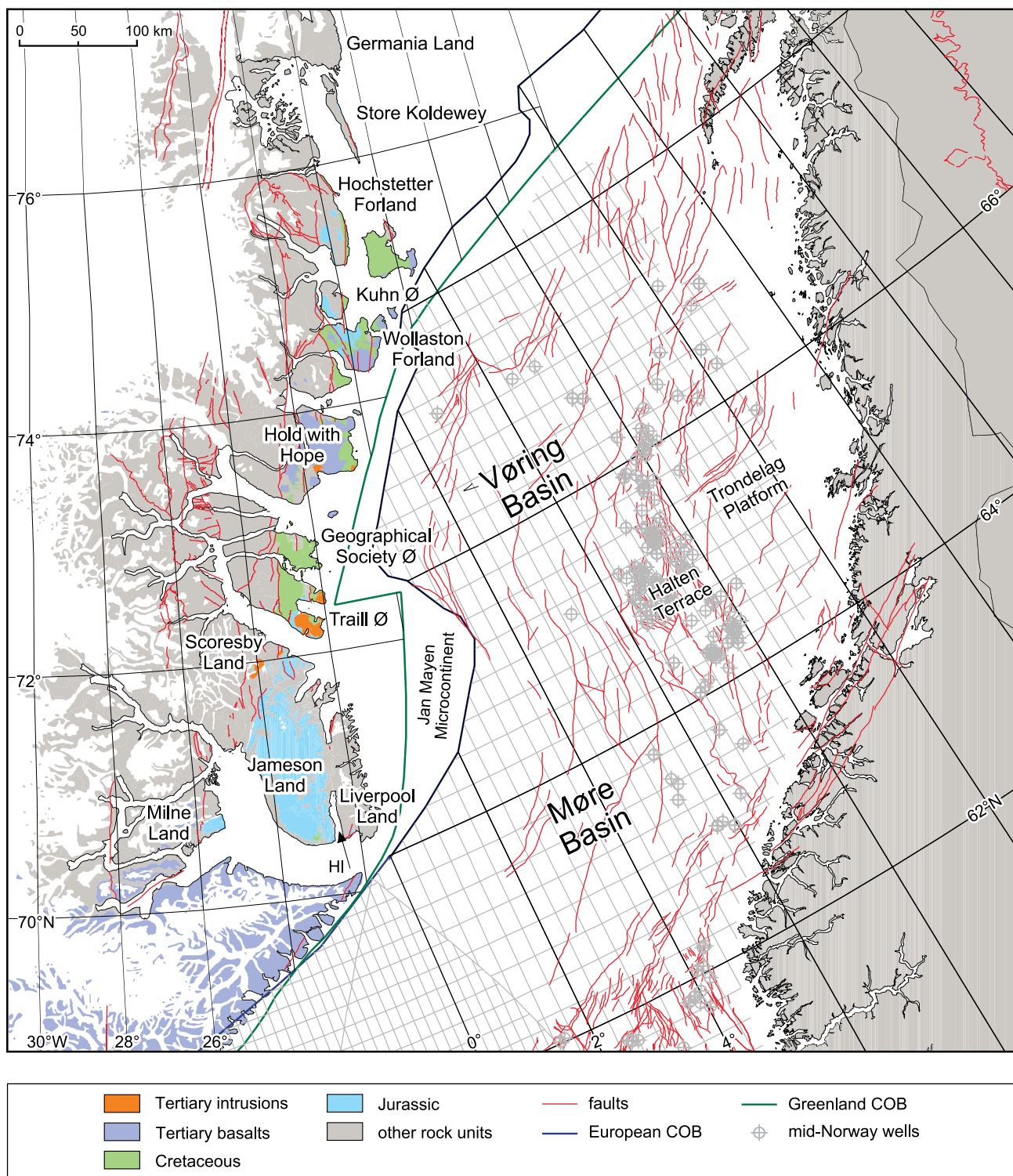
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**Fig. 1.** Pre-breakup reconstruction of the Norway-Greenland region, showing the relative positions of the onshore Mesozoic outcrop in East Greenland, including the Jurassic shown in blue, to the basins of Mid-Norway

Principal areas mentioned in this study are indicated. HI – Hurry Inlet

1869–1870 (Koldewey, 1874). R. Buchholz (biologist) and Gustav Laube (geologist) suffered badly in the aftermath of the loss of the Germania's sister ship, the Hansa, which was destroyed by ice. This was the first truly scientific expedition to eastern Greenland and the problems encountered exemplified the difficulties of weather and wildlife which continue to affect field work in the region today. In 1871, shortly after his return, Laube became Professor of Mineralogy and Geology at Prague Technical University. Most of the subsequent early geological studies were reviewed by Rosenkrantz (1934), Donovan (1957) and Birkelund (1975).

With the development of the Norwegian Shelf (Fig. 1) as an important hydrocarbon prospective area and the understanding of a pre-drift narrow seaway between Greenland and Norway, interest in the whole northern North Atlantic region has come under close geological scrutiny. The nearest geological outcrops lie in Scotland, Norway, Greenland and Svalbard. But the paucity of onshore Jurassic outcrops in Norway, and the distance Svalbard has moved since the commencement of rifting, from a position nearly north of the Sverdrup Basin in Canada, make eastern Greenland particularly important. Here a relatively complete set of Jurassic rocks can be found, with representation of all the Jurassic stages from Hettangian to Tithonian (although use of the Boreal Volgian Stage is preferred here). The succession is largely marine and has a high correlation potential with the offshore area. Greenland and Norway supplied Jurassic sediment onto the Norwegian shelf and both are important source areas in sandstone provenance studies (Morton *et al.*, 2009). Thus the Greenland outcrops enable the geologist and stratigrapher to examine fully an event which can only be surmised from the relatively restricted aspect of offshore boreholes, in a way that is unique and cannot be achieved elsewhere. In modern terms the biostratigraphy can be applied not just to the lithostratigraphy, but to sequence stratigraphy, in the continuous and well-exposed three dimensional outcrops of Jameson Land *e.g.* in the Pelion Formation (Engkilde, Surlyk, 2003), and in the Olympen Formation (Larsen *et al.*, 2003). The lithostratigraphic scheme used here for eastern Greenland is shown in Figure 2.

Modern major Jurassic stratigraphic compilations include those of Surlyk *et al.* (1973) covering Jameson Land, Ineson, Surlyk (2003) and Surlyk (2003) for eastern Greenland, and Stemmerik, Stouge (2004) covering North-East Greenland.

CASP was formerly the acronym for the Cambridge Arctic Shelf Program. However it now stands as the title for the organisation which has current interests well beyond the Arctic. CASP first visited eastern Greenland in 1957, when the late Brian Harland, the founder and director, collected palaeomagnetic samples from a wide range of rocks. Simon Kelly first examined the Jurassic succession in Jameson

Land with Richard Sykes in 1973, supported by Shell (UK). Between 1990 and 2014, CASP has operated every year in eastern Greenland under the geological direction of Andrew Whitham. On most of these expeditions Jurassic samples and data were obtained. Andrew King was initially the palaeontologist and biostratigrapher from 1990–1991, with Simon Kelly from 1995 onwards. Dominic Strogen was involved in Jurassic field work in Greenland from his PhD studies in 1995–1999, to leading the CASP Jurassic project from 2004–2007.

The geological logistics behind this study, as in many CASP projects, are that geological field parties are sent to remote areas where they study the geology, collect samples, log sections, and write reports which are relevant to our supporting hydrocarbon-interested companies. Our field parties often include, unusually in the modern world, a macropalaeontologist with a working knowledge of the macrofauna likely to be encountered, their ages and environmental significance – effectively a walking clock. Thus the non-palaeontological field-geologists have someone with a working knowledge of the macrofossil biostratigraphy right from the beginning of the expedition. In eastern Greenland, thanks to the painstaking research of the late John Callomon and colleagues there were 93 distinct ammonite-bearing horizons known (Fig. 3A–D; Callomon, Birkelund, 1982; Callomon, 1993) from the Bajocian (Mid Jurassic) to the Jurassic/Cretaceous boundary (170.3 Ma – 145.0 Ma = 25.3 Ma; Ogg, Hinnov, 2012), giving an average of *c.* 272,000 years per ammonite unit of time. Within the Mid–Late Jurassic interval there are only 35 palynological biozones in the North Sea and 25 micropalaeontological zones (see Table 1). Whilst macrofossils can be readily identified and dated in the field, giving “instant gratification”, the samples taken for palynology and micropalaeontology have to be transported, processed and then analysed, which, at best, may be months before results are known.

For practical purposes a field party in a marine Jurassic ammonite-bearing succession may need to look no further for biostratigraphic data. However, that is rarely the case. The examined succession may not be entirely marine, and the ammonite succession may be incomplete; bivalves may replace ammonites as useful indicators; parts of the section may be dated (eventually) by palynology and micropalaeontology. Sandstones may be poor in palynomorphs and microfossils, igneous dykes and intrusions may destroy the organic content of palynomorphs. Some of the ranges of data may overlap, and in other places we may have no data at all. Thus, in order to present the best biostratigraphical information we must collect in the field as many biostratigraphically significant groups as possible. After analysis of our samples we use *StrataBugs* to prepare integrated charts on which the taxonomic ranges, allocation to various zonal

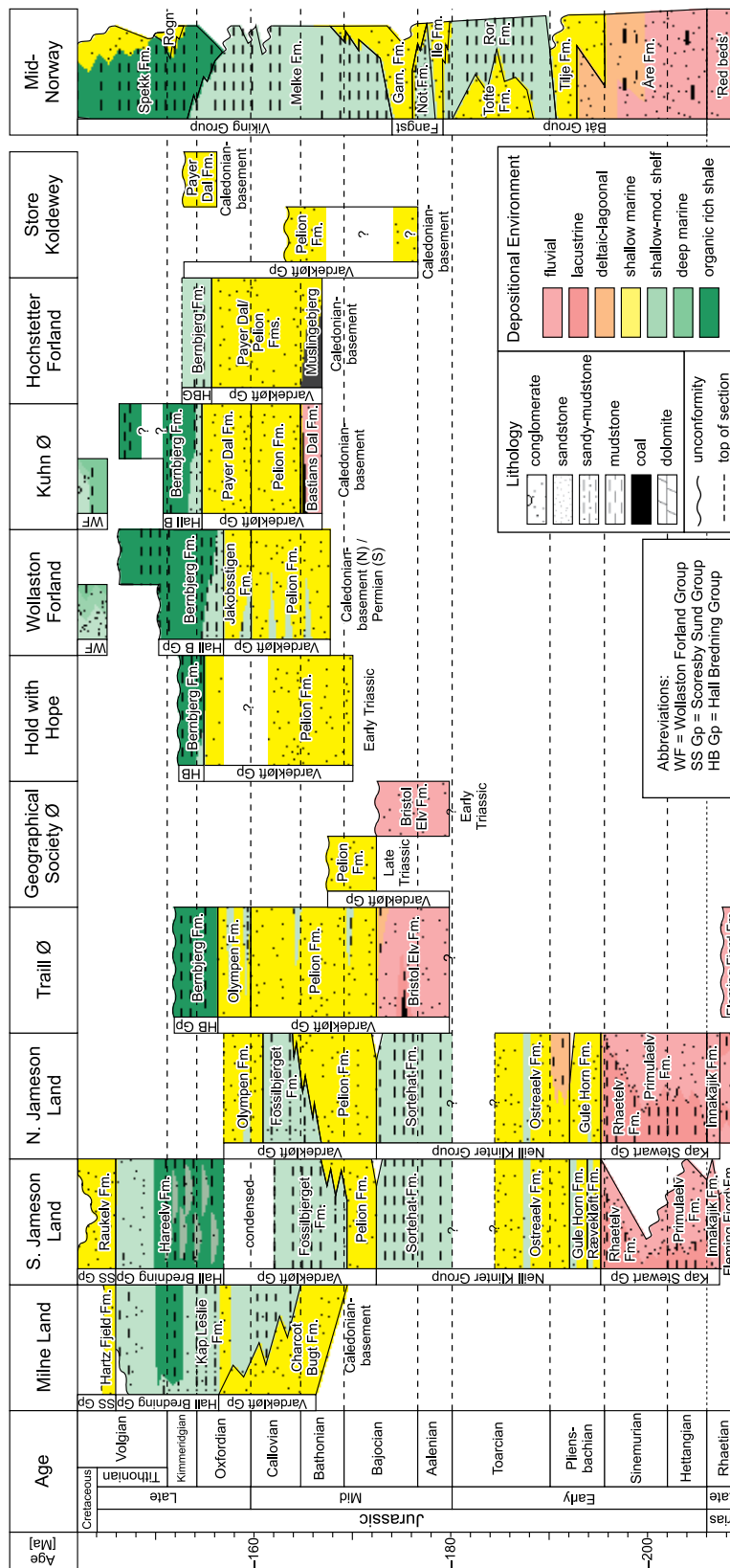


Figure 2. Correlation of the Jurassic stratigraphy of eastern Greenland and Mid-Norway

Greenland data modified from Suriyk (2003) with new data. Mid-Norway data from Dalland *et al.* (1988) and Brekke *et al.* (1999)

schemes of different biotic groups, interpreted ages and palaeoenvironments can be plotted. The detail from these charts is not suitable for presentation here. The present article summarises the important points from this data. Practical and economic reasons will dictate how we proceed with each geological site and all samples may not be analysed on the first pass, but refinements may be made at a later date. The quality of our data is superior to that obtained from boreholes, where analyses based on chippings have been obtained. Collecting directly from outcrop removes the blurring that is associated with data from recovered chippings. Seldom are continuous cores available for analysis from mudstone successions and only rarely are macrofossils such as ammonites recovered from them.

The data supplied to CASP clients will remain confidential usually for at least two years, but then the geologists will be able to publish the results and by doing so make the information available to the general scientific community. This is part of CASP's policy as an educational charitable organisation within the University of Cambridge but financially independent of it.

Like the late Brian Harland (Harland *et al.*, 1990) and Zalasiewicz *et al.* (2004) we do not make the distinction between time-rock units and geological time-units. Our favoured time units may be qualified by "early" and "late", but not by "lower" and "upper". Furthermore we prefer "mid" to "middle" following Harland *et al.* (1990, pp. 41 (Devonian), p. 52 but not p. 53 (Jurassic)) and Zalasiewicz *et al.* (2004, part of Recommendation 4).

## BIOTA

The aim of the present paper is to illustrate graphically the relationships between the biostratigraphically important taxa from the Jurassic of eastern Greenland, which are shown in the composite Figure 3A–D. An abstract of the present work was originally presented by Kelly *et al.* (2014).

## AMMONITES

Although generally scarce in the Early Jurassic of eastern Greenland ammonites are the prime macrofossil biostratigraphic tool in the Mid to Late Jurassic (Fig. 3). The initial records of Early Jurassic ammonites by Rosenkrantz (1934, 1942) from the Pliensbachian and Toarcian have not been improved upon significantly. Callomon (pers. comm.) was always of the opinion that the variously interpreted *Pseudolioceras* faunas were of Toarcian age, and in the writer's opinion at least some of the Toarcian ammonite faunal re-

cords from Greenland can be placed as equivalent of the *Hilloceras bifrons* zone.

The Boreal cardioceratids provide an almost continuous zonal lineage from the Bajocian to the Kimmeridgian (Callomon, 1985). The understanding of the Mid-Late Jurassic ammonite succession (Callomon, 1961, 1993, 1994, 2003; Callomon *et al.*, 2014) allowed reinterpretation of the large number of figures of Spath (1932, 1935, 1936). Repin (2007) introduced the genus *Greencephalites* based on the type specimen of *Cadoceras frebaldi* Spath (see Mitta, Alsen, 2013). Although Mitta (2009) had reservations about the new name, it continued in use by Mitta, Alsen (2014) in the revised dating based on ammonites of the Bathonian and Callovian. They revised the age of the *Cadoceras apertum* Zone from the Early Callovian to Late Bathonian, with the *C. nordenskjoldi* Zone marking the earliest Callovian. But see also Gulyaev (2012) who followed Callomon and drew the boundary within the *C. apertum* Zone. Most of the Greenland ammonite fauna is Boreal, but there are occasional distinctly Tethyan or oceanic derived elements present such as the oppeliids, *Oxycerites* aff. *jugatus* Yershova and Meledina and *Oecotraustes* sp., in association with the *Arcticoceras ishmae* Zone in Jameson Land (Birkelund *et al.*, 1971).

The Oxfordian ammonite zonal succession was established by Sykes, Surlyk (1976) and Sykes, Callomon (1979), the Kimmeridgian by Birkelund, Callomon (1985) (but subsequently refined by Matyja *et al.*, (2006); Wierzbowski *et al.*, (2006)) and the Volgian by Callomon, Birkelund (1982). Rogov (2010) extended the eastern Greenland Mid Volgian based on CASP material from Kuhn Ø, recognising levels above horizon 47 with *Laugeites groenlandicus*, comprising the succeeding assemblages with *L. lambecki*, "*Epilaugeites vogulicus*" and *Praechetaites tenuicostatus*. The Late Volgian is represented by the *Subcraspedites* sp. and *S.* aff. *preplicomphalus* horizons (Surlyk, 1973; Surlyk *et al.*, 1973) which correlate with the eastern England succession (Casey, 1973).

The Cretaceous Ryazanian is characterised by the *Praetollia maynci* and *Hectoroceras kochi* faunas (Spath, 1947, 1952; Donovan, 1964; Surlyk, 1973).

There is considerable erosion at the Jurassic/Cretaceous boundary in Milne Land (Birkelund *et al.*, 1984) and in Jameson Land (Surlyk, 1973, 2003), much of which is rift-related. But perhaps there is also some relationship with the surge event from the Mjølner impact (Smelror *et al.*, 2001). The succession is more complete in eastern Kuhn Ø (Kelly, 2006), and the Jurassic reaches stratigraphically younger than the succession in the central and western part of Kuhn Ø described by Alsgaard *et al.* (2003).

Fig. 3A

PERIOD	STAGE & AGE		NW EUROPEAN AMMONITE ZONES Page, 2003; Callomon, 2003; Zeiss, 2003		GREENLAND AMMONITE HORIZONS Rosenkrantz, 1934; Callomon, Birkelund, 1982; Birkelund, Callomon, 1985; Callomon, 1993; Rogov, 2010; Mitta, Alsen, 2014			PALYNOLOGICAL & PLANT MACROFOSSIL ZONES Harris, 1937; Pedersen, Lund, 1980; Koppelhus, Dam, 2003; Koppelhus, Hansen, 2003		GREENLAND PALYNOLOGICAL ZONES Pedersen, Lund, 1980; Poulsen, Riding, 2003				
	LATE	OXF	Zone	Subzone	Horizon name	Milne Land horizons	East Greenland horizons							
JURASSIC	LATE	OXF	Quenstedtoceras mariae	Quenstedtoceras praecordatum Quenstedtoceras scarburgense	<b>Cardioceras alphacordatum</b> <b>Quenstedtoceras woodhamense</b>	3	39 38			Wanaea fimbriata	DSJ20			
			MID	LATE	163.5 Quenstedtoceras lamberti	Quenstedtoceras lamberti Quenstedtoceras henrici						Wanaea thysanota	DSJ19	
	Peltocheras athleta	Kosmoceras spinosum Kosmoceras phaenium			<b>Longaeviceras keyserlingi</b>	2	37							
	MID.	MID.		Erymocerases coronatum	Kosmoceras grossouvrei Kosmoceras obductum									
				Kosmoceras jason	Kosmoceras jason Kosmoceras medea	<b>Kosmoceras cf. l. jason</b>		36						
	EARLY	EARLY		Sigaloceras calloviense	Sigaloceras enodatum Sigaloceras calloviense	<b>Sigaloceras calloviensis</b>		35			Ctenodinium continuum	DSJ18		
				Proplanulites koenigi	Kepplerites galliaeii Kepplerites curtulobus Kepplerites gowerianus	<b>Kepplerites galliaeii</b> <b>Chamoussetia phillipsi</b> <b>Kepplerites gowerianus</b> <b>Cadoceras septentrionale</b>	1	34 33 32 31						
	MID	BATHONIAN		LATE	166.1 Cadoceras nordenskjoldi		<b>Cadoceras nordenskjoldi β</b> <b>Cadoceras nordenskjoldi α</b>		30 29					
					Cadoceras apertum		<b>Cadoceras cf. / aff. breve</b> <b>Kepplerites tenuifasciculatus MS</b> <b>Cadoceras apertum γ</b> <b>Cadoceras apertum β</b> <b>Cadoceras apertum α</b>		28 27 26 25 24				DSJ17	
				Cadoceras calyx		<b>Kepplerites vardkloeftensis</b> <b>Kepplerites peramplus</b>		23 22						
				Cadoceras variabile		<b>Kepplerites rosenkrantzi</b> <b>Kepplerites inflatus MS</b>		21 20						
			Cadoceras cranocephaloide		<b>Kepplerites tychonis</b> <b>Arcticoceras cranocephaloide</b> <b>Arcticoceras crassiplicatum MS</b>		19 18 17			not allocated	Ctenodinium sellwoodi	DSJ16		
			Arcticoceras ishmae		<b>Arcticoceras ishmae β</b> <b>Arcticoceras ishmae α</b> <b>Arcticoceras harlandi</b>		16 15 14							
			Greencephalites greenlandicus		<b>Greencephalites freboldi</b> <b>Greencephalites greenlandicus</b> <b>Arctocephalites micrumbilicatus MS</b>		13 12 11					DSJ15		
			Arctocephalites arcticus		<b>Arctocephalites delicatus MS</b> <b>Arctocephalites arcticus</b>		10 9							
			LATE	BAJOCIAN	LATE	168.3 Cranocephalites pompeckji		<b>Cranocephalites episcopalis MS</b> <b>Cranocephalites pompeckji</b> <b>Cranocephalites furcatus</b> <b>Cranocephalites carlsbergensis MS</b> <b>Cranocephalites gracilis trans. β</b> <b>Cranocephalites gracilis trans. α</b> <b>Cranocephalites intermissus MS</b>		8 7 6 5 4b 4a 3			Cribroperidinium crispum	DSJ14
						Cranocephalites indistinctus		<b>Cranocephalites indistinctus β</b> <b>Cranocephalites indistinctus α</b>		2b 2a				
	Cranocephalites borealis					<b>Cranocephalites borealis β</b> <b>Cranocephalites borealis α</b>		1b 1a						
	Stephanoceras humphriesianum Otoites sauzei Wichelia laeviuscula Fissiloboceras ovale Hypertioceras discites					[no ammonites recognised]					?			
	EARLY	PLENSEBACHIAN	EARLY	170.3 Graphoceras concavum Ludwigia munchisonae Tmetoceras scissum Leioceras opalinum						<b>Sentusidinium pelionense</b> AZ9 <b>Nannoceratopsis gracilis/senex</b> AZ8 <b>Botryococcus sp.</b> AZ7			DSJ11	
				174.1 Pleydelia aalensis Dumorteria pseudoradiosa Physeogrammoceras dispansum Grammoceras thouarsense Haugia variabilis Hildoceras bifrons Harpoceras serpentinum Dactyloceras tenuicostatum		[no ammonites recognised]					<b>Pterinopollenites elatoides</b> AZ6		Parvocysta nasuta	DSJ10 DSJ9
182.7 Pleuroceras spinatum Amaltheus margaritatus Productyloceras davoei Tragophylloceras ibex Uptonia jamesoni					<b>Hildoceras bifrons</b>					<b>Spheripollenites subgranulatus-</b> <b>Cerebriipollenites macroverrucosus-</b> <b>Luehndia spinosa</b> AZ5		<b>Mancodinium semitabulatum</b>	DSJ8 DSJ7	
									<b>Bisaccates</b> AZ4 <b>Cerebriipollenites thiergartii-</b> <b>Botryococcus</b> AZ3 <b>Nannoceratopsis-</b> AZ2 <b>Botryococcus</b> AZ1 <b>Cerebriipollenites thiergartii-</b> <b>Pinuspollenites minimus-</b> <b>Botryococcus</b> AZ1		<b>Luehndia spinosa</b>	DSJ6 DSJ5		
					<b>Beaniceras sp.</b>						<b>Nannoceratopsis senex</b>	DSJ5		
					<b>Uptonia jamesoni</b>						<b>Mendicodinium reticulatum</b>	DSJ4		
					[no ammonites recognised]							<b>Liasidium variabile</b>	DSJ3 DSJ2	
TRIASSIC	LATE	RHÄTIAN	199.3 Schlotheimia angulata Alsattites liasicus Psiloceras planorbis						<b>Pinuspollenites-</b> <b>Trachysporites</b>	<b>Thaumatopteris</b>	<b>Dapcodinium priscum</b>	DSJ1		
			201.3							<b>Rhaetipollis-</b> <b>Limbosporites</b>	<b>Transition Zone</b> <b>Lepidopteris</b>			

Fig. 3B

NORTH SEA PALYNOLOGICAL ZONES Partington <i>et al.</i> , 1993a	NORTH SEA MICRO-PALAEONTOLOGICAL ZONES Partington <i>et al.</i> , 1993a	SVALBARD FORAMINIFERAL ZONES Nagy, Basov, 1998	BIVALVE ZONES Buchia <sup>1</sup> /inoceramid / trigonid <sup>1</sup> after Surlyk, Zakharov, 1982	BELEMNITE DISTRIBUTION Doyle, 1991; Doyle, Kelly, 1988; Saks, Naf'nyaeva, 1964, 1967	STAGE	PERIOD
<i>Wanaea fimbriata</i> "acme"	PJ24 <i>Lenticulina ectypa costata</i>	ii MJ17			EARLY OXF	LATE
<i>Mendicodinium groenlandicum</i> "acme"	PJ23	c		<i>Praebuchia orientalis</i>	LATE	
<i>Energlynia acollaris</i>	PJ22 <i>Haplophragmoides canui</i>	b MJ16			MIDDLE	CALLOVIAN
<i>Nannoceratopsis pellucida</i> "acme"	PJ21	a			MIDDLE	
<i>Chytroisphaeridia hyalina</i> "acme"	PJ20 <i>Verneuilioides</i> sp. 1	MJ15			EARLY	
<i>P. calloviense</i>	PJ19			<i>Praebuchia anabarensis</i>	EARLY	
<i>H. regalis</i>	PJ18		<i>Trochammina rostlovzevi</i> F1		LATE	
<i>Glomodinium zabros</i>	PJ17 <i>Verneuilioides</i> sp. 2	MJ14		<i>Mylioceramus aff. ambiguus</i> <i>Mylioceramus retrorsus</i> <i>Vaugonia athena</i>	LATE	MIDDLE
<i>Dissilodinium granulatum</i> "acme"	PJ16				MIDDLE	BATHONIAN
<i>Korycysta reticulata</i> "acme"	PJ15 <i>Glomospirella</i> spp.	MJ13			MIDDLE	
<i>Glomodinium scalenum</i>	PJ14				EARLY	
<i>Crussolia labyrinthe</i>	PJ13 unassigned				LATE	JURASSIC
<i>Nannoceratopsis gracilis</i> / <i>senex</i>	PJ12			<i>Trigonia hemisphaerica</i>	BAJOCIAN	
<i>N. gracilis</i> / <i>senex</i> "acme"	PJ11			<i>Mylioceramus cf. substriatus</i> <i>Mylioceramus aff. polylocus</i>	EARLY	
<i>Nannoceratopsis dicyambonis</i>	PJ10				EARLY	
<i>Nannoceratopsis tricerias</i>	PJ9			<i>Trigonia lingonensis</i> <i>Trigonia costata</i> var. <i>lata</i> <i>Trigonia</i> (? <i>Orthotrigonia</i> ) <i>formosa</i> <i>Vaugonia northamptonense</i> <i>Vaugonia literata</i>	EARLY	
<i>Scrinocassis weberi</i>	PJ8				EARLY	
<i>Parvocystis complex</i> "acme"	PJ7 <i>Verneuilioides</i> sp. 1 <i>K. intrepida</i>	MJ12 MJ11			EARLY	TOARCIAN
<i>Luehndia spinosa</i>	PJ6 <i>Ogmoconchella adenticulata</i> <i>Ogmoconcha amalthei</i> <i>Dentalina matutina</i> <i>G. ubiquita</i>	MJ10 MJ9 MJ8 MJ7			EARLY	PLEINSBACHIAN
<i>Liasidium variable</i>	PJ5 <i>Procytheridea acuticostata</i>	MJ6			EARLY	
<i>Liasidium variable</i> "acme"	PJ4 <i>Klinglerella lotharingae</i> <i>E. thuringia</i>	MJ5 MJ4			EARLY	
<i>Krauselisporites reissingeri</i>	PJ3 <i>A. semireticulata</i>	MJ3			EARLY	
<i>Dapcodinium priscum</i>	PJ2 <i>Ogmoconchella ellipsoidea</i>	MJ2			EARLY	
<i>Dapcodinium priscum</i> "acme"	PJ1 <i>Lingulina tenera collaroti</i>	MJ1			EARLY	
				<i>Nannobelus</i> sp. <i>Pseudohastiles</i> sp. <i>Gastrobilus</i> sp. <i>Passaloteuthis</i> sp. <i>Parapassaloteuthis</i> sp. <i>Acrococleus</i> ( <i>Toarobelus</i> ) sp. <i>Acrococleus</i> ( <i>Odontobelus</i> ) sp. <i>Simpsonibelus</i> sp.		
				<i>Hilofitites</i> sp. <i>Cylinroteuthis</i> ( <i>Cylindroteuthis</i> ) <i>Pachyteuthis</i> ( <i>Pachyteuthis</i> )		
				<b>N.B. Total belemnite ranges are incomplete for Early Jurassic</b>		
					RHAETIAN-HETTANGIAN	LATE TRIASSIC





Fig. 3D

NORTH SEA PALYNOLOGICAL ZONES Partington <i>et al.</i> , 1993a		NORTH SEA MICROPALAEONTOLOGICAL ZONES Partington <i>et al.</i> , 1993a		SVALBARD FORAMINIFERAL ZONES Nagy, Basov, 1998		BIVALVE ZONES Buchia <sup>1</sup> / inoceramid / trigoniid <sup>1</sup> after Surlyk, Zakharov, 1982		BELEMNITE DISTRIBUTION Doyle, 1991; Doyle, Kelly, 1988; Saks, NaI'nyaeva, 1964, 1967		STAGE		PERIOD	
<i>Cannosphaeropsis thula</i>	PK1	unassigned		<i>Gaudryina rostellata</i>	F8	<i>Buchia okensis</i> <i>/volgensis</i>	■			EARLY	RUZANIAN	EARLY	CRET
<i>Gochteodinia virgula</i>	PJ47	<i>Praeconocaryomma</i> sp. 2	MJ25	<i>Recurvoides obskiensis</i>	F7	<i>Buchia fischerianus</i> <i>/unschensis</i> <i>B. terebratuloides</i>				LATE			
<i>Egmontodinium polyplacophorum</i>	PJ46	<i>Praeconocaryomma</i> sp. 1	MJ24	<i>Calyptamina praegroidini</i>	F6	<i>Buchia russiensis</i>	<i>Turbitrigonia boudicca</i>						
<i>Ctenidodinium panneum</i>	PJ45	<i>Parvicingula</i> sp. 1 "acme"	MJ23	<i>Ammodiscus zaspelovae</i>	F5	<i>Buchia mosquensis</i>	<i>Myophorella intermedia</i>				MIDDLE	VOLGIAN	
<i>Senonisphaera jurassica</i>	PJ44												
<i>Muderongia</i> sp. A	PJ43												
<i>Muderongia</i> sp. A. "acme"	PJ42												
<i>G. mutabilis</i>	PJ41												
<i>Scrinodinium inritibulum</i>	PJ40												
<i>Oligosphaeridium cf. pulcherrimum</i>	PJ39	<i>Genosphaera</i> sp. 1 "acme"	MJ22	<i>Trochammina praerosacea</i>	F4					EARLY			
<i>O. cf. pulcherrimum</i> "acme"	PJ38	<i>Orbiculiforma lowryensis</i>	MJ21								EARLY	LATE	JURASSIC
<i>Periasphaeridium pannosum</i>	PJ37												
<i>Endoscrinium luridum</i>	PJ36												
<i>Periasphaeridium pannosum</i> "acme"	PJ35	<i>Parvicula blowi</i>	MJ20	<i>Haplophragmoides canuiformis</i>	F3	<i>Buchia tenuistriata</i>				LATE			
<i>Gonyaulacysta jurassica</i>	PJ34	<i>Trochammina globigeriniformis</i>	MJ19			<i>Buchia concentrica</i>					EARLY	LATE	KIMMERIDGIAN
<i>Scrinodinium crystallinum</i>	PJ33												
<i>S. crystallinum</i> "acme"	PJ32	<i>Ammobaculites deceptorius</i>	MJ18								EARLY	LATE	OXFORDIAN
<i>Endoscrinium galeritum</i>	PJ31												
<i>Endoscrinium galeritum</i> "acme"	PJ30												
<i>Compositosphaeridium polonicum</i>	PJ29	<i>Lenticulina ectypa costata</i>	MJ17	<i>Recurvoides scherkalyensis</i>	F2	<i>Praebuchia lata</i>					EARLY	MIDDLE	
<i>Rigaudella aemula</i>	PJ28												
<i>Rigaudella aemula</i> "acme"	PJ27												
<i>Trichodinium scarburghensis</i>	PJ26												
<i>Wanaea fimbriata</i>	PJ25												
<i>Wanaea fimbriata</i> "acme"	PJ24			<i>Trochammina rostovzevi</i>	F1	<i>Praebuchia orientalis</i>				EARLY	CALL	MID	
<i>Mendicodinium groenlandicum</i> "acme"	PJ23	<i>Haplophragmoides canui</i>	MJ16							LATE			

**Bold Text** zone or taxon recognised in Greenland

— stage boundary

for the Jurassic of eastern Greenland

## BELEMNITES

Belemnites are important as macrofossils because of their high preservation potential, and they provide a good secondary set of index taxa for biostratigraphy (Fig. 3). Doyle (1991) described the Early Jurassic belemnites from Jameson Land collected by Rosenkrantz (1934). Later records by Spath (1932, 1936) from the Mid and Late Jurassic can be reassessed in terms of the Svalbard faunas (Doyle, Kelly, 1988) or Russian faunas (Saks, Naln'yeva, 1964, 1970) but are in need of revision.

## BIVALVES

The most valuable bivalve succession for biostratigraphy is that of the Jurassic/Cretaceous boundary buchiid bivalves (Fig. 3), that only extend from the Callovian to the Hauterivian (Surylyk, Zakharov, 1982). Their scheme is used here with slight modifications. These provide important correlation with other Boreal areas (Zakharov, 1981) and Canada (Jeletzky, 1966, 1984). Trigoniid bivalves are an important secondary biostratigraphic tool. *Liotrignia lingonensis* occurs in the Pliensbachian (Rosenkrantz, 1934, 1942). A Toarcian assemblage occurs near the top of the Trefjord Bjerg Member at Hurry Inlet including *Trigonia costata*, *Myophorella formosa*, *Vaugonia northamptonense* and *V. literata* in association with *Pseudolioceras* (CASP collections). *Vaugonia athena* of Poulton, Callomon (1977) characterises the Early–Mid Bathonian of Jameson Land, and *Myophorella intermedia* the Mid Volgian, Pernaryggen Member of Milne Land (Fürsich, 1982).

Inoceramids are remarkably sparse in the Jurassic of Greenland and the North Atlantic, considering their importance in the Boreal North Pacific and Arctic Russia (*e.g.* Sey, Kalacheva, 1992). Whilst *Mytiloceras* Rollier (1914) is probably the senior generic name, and *Retroceramus* (Koshelkina, 1962) is probably a junior name, the precise relationships between these generic names remain unclear (*e.g.* Poulton, 1991). *Mytiloceras* aff. *polylocus* and *I. cf. substriatus* (Münster) occur in the Ostreaelv Formation (Toarcian) of Jameson Land (Rosenkrantz, 1934). *M. retrorsus* group occurs in association with *C. pompeckji* and *Arctioceras ishmae* zone ammonites in the Pelion Sandstone (CASP Collections) and *Mytiloceras* aff. *ambiguus* (Eichwald) with *Arctocéphalites arcticus* Zone ammonites in Jameson Land (Spath, 1932). These inoceramids merit further study to elucidate their stratigraphic significance and relationships with other inoceramid bearing areas (*cf.* Mitta *et al.*, 2014, p. 121; Zakharov *et al.*, 1997).

## MICROFOSSILS

Previous studies and/or published records on the micropalaeontology of the Jurassic in Greenland are sparse. The main aim of this initial Jurassic study was to confirm the presence and extent of Jurassic microfaunas and to tie the subsequent microfossil (micropalaeontology and palynology) distribution and biostratigraphy directly into the onshore ammonite age defined sequences (see also Gregory, 1989, 1995). This tie-in is essential when studying offshore sequence analogues (*e.g.* Faroes-Shetlands basins, North Sea, Northern and mid-Norway) where identifiable macrofossil remains are rare/absent and certainly not consistent enough to use biostratigraphically. Knowledge of this part of the northern Boreal Jurassic has an immense impact on the understanding of the development of the North Atlantic regions and the subsequent oil exploration and production plays (*e.g.* Stemmerik *et al.*, 1998). Previous microfaunal research from onshore ammonite dated Boreal Middle–Late Jurassic (Callovian–Volgian) strata include sections from Scotland (including the Type Boreal Late Jurassic sections on Skye; Gregory, 1995), Svalbard (Nagy, Basov, 1998), Canada (Brooke, Braun, 1972) and the Russian region (Dain, 1967). A further use for this study is to combine known Boreal records of Jurassic radiolaria and foraminifera to allow the full extent of the biostratigraphical and biogeographical ranges of taxa to be firmly established. Additionally, many microfossil events defined for an integrated biostratigraphy of the North Sea (Partington *et al.*, 1993a, b) appear to be present in Greenland. The microfossil biozonation schemes used in Greenland are at present a combination of Nagy, Basov (1998; F Zones) erected for the Svalbard succession and that of Partington *et al.* (1993a, b; MJ Zones) based on the North Sea (Fig. 3). This CASP work also indicates several radiolarian events becoming increasingly important in the Late Jurassic. Of particular importance is a definite Late Oxfordian inception of radiolarian taxa. This event occurs earlier than the inception of radiolaria in the North Sea which occurs in the Early Kimmeridgian (Gregory, 1995). Further comparison should be made with studies involving radiolarian documentation where microfauna occurred in strata well dated by ammonoids, for example the Kimmeridgian of the Timan-Pechora region (Kozlova, 1971), Kimmeridgian of the Moscow Region (Bragin, 1997), Late Volgian–Berriasian of northern Siberia, Nordvik Peninsula (Bragin, 2009, 2011), Oxfordian and Kimmeridgian of the Upper Volga Region (Bragin, Kiselev, 2013).

Microfossil assemblages can also be integrated into palaeoenvironmental analyses outlining basin development.

The main relevance of this work would be in the precise dating of marine sequence stratigraphic events seen in exploration plays within the Mid-Norway Shelf, the UK Celtic Sea and West of Shetland/Faroes, with potential for the Canadian, Barents Sea and Russian areas.

## PLANT MACROFOSSILS

Plant macrofossils are of significance in the earliest Jurassic of eastern Greenland and were collected and monographed in several volumes, culminating in a stratigraphic volume by Harris (1937) (see also Harris, 1946, 1961). They are of value in determining the position of the Triassic/Jurassic boundary in Jameson Land which is recognised by the transition from the *Lepidopteris* to *Thaumatopteris* floras.

## PALYNOLOGY

In Figure 3 we document as standards the palynological zonations of Partington *et al.* (1993a, b) from the North Sea, and of Poulsen, Riding (2003) for NW Europe, much of which can be applied to the eastern Greenland succession. Although there is a considerable literature relating to palynology and dinoflagellate cysts, only some of the documents refer to zonal schemes. Unfortunately detailed comparisons of individual taxa and their biostratigraphic ranges and distributions cannot be achieved in this article. Since the pioneering work of Sarjeant (1972) and Fensome (1979), Jurassic palynology in the Milne Land and Jameson Land area has been dominated by the excellent work of Piasecki based on his PhD thesis on Milne Land (Piasecki, 1980, 1996), and for Jameson Land (Smelror, 1988; Milner, Piasecki, 1996). Three important dinoflagellate cyst publications from North-East Greenland include those of Piasecki *et al.* (2004a) on Hold with Hope, Piasecki, Stemmerik (2004) on Hochstetter Forland, and Piasecki *et al.* (2004b) on Store Koldewey. These document in detail the dinoflagellate distributions against the relatively few ammonite records of Bathonian to Kimmeridgian age, but lack a unifying palynological zonal scheme which makes their significant work difficult to incorporate into Figure 3.

Piasecki and his co-workers concentrated on using dinoflagellate cyst distribution as a means of subdividing the Late Jurassic succession. In contrast other workers (Lund, Pedersen, 1985; Koppelhus, Dam, 2003; Koppelhus, Hansen, 2003) have emphasised the use of spores, pollen and algae in addition to dinoflagellate cysts in order to subdivide the Early and Mid Jurassic sediments in North East Greenland.

## BIOTA THROUGH TIME

The most significant biota distinguishing each stage are briefly reviewed in this section. Space does not allow for a full biotic assessment here, which would involve detailed and extensive *StrataBugs* charts. However, the most important Jurassic biotic elements are summarised in Figure 3. The microfossil study is in its early stage when compared with the palynological study and has so far only concentrated on the Callovian-Volgian interval.

## TRIASSIC/JURASSIC BOUNDARY AND HETTANGIAN STAGE

In Jameson Land the Triassic/Jurassic boundary lies in the Kap Stewart Group, within the Primulaelv Formation (Surlyk, 2003). Here lies the boundary between the Rhaetian *Lepidopteris* and the Hettangian *Thaumatopteris* macrofloras of Harris (1937) separated by the transition zone. Palynologically this approximates to the NW European boundary between the palynological Zone 1, the *Rhaetipollis-Limbo-sporites* Zone of Early/Mid Rhaetian age, which includes the Transition Zone, and Zone 2, the *Pinuspollenites-Trachysporites* Zone of the Hettangian (Pedersen, Lund, 1980). McElwain *et al.*, (2007) investigated floral change at this boundary, concluding a more gradual changing environment than would be expected from a catastrophic impact event at this time of marked but gradual extinction. Floral turnover seems to increase over the boundary.

## SINEMURIAN STAGE

The Sinemurian Stage has not been positively identified in eastern Greenland from any palaeontological remains (Dam, Surlyk, 1993, p. 423). However, the thickness of the Kap Stewart Group, in lacustrine and delta-front facies, and sedimentological continuity suggest that sediment of this age should be present, at least in the central part of the Jameson Land Basin, but there may be a hiatus and unconformity in the southeast part.

## PLIENSBACHIAN STAGE

The base of the Pliensbachian is well documented in the Neill Klintner area of Jameson Land in the base of the Rævekløft Formation, Neill Klintner Group (Dam, Surlyk, 1998). The transgressive marine sandstone contains a rich mollus-

can fauna (Rosenkrantz, 1934; Surlyk *et al.*, 1973), including the ammonite *Uptonia jamesoni*, the first zonal ammonite of the NW European succession (Page, 2003). There is a particularly rich bivalve fauna, as well as belemnites: *Nannobelus*, *Pseudohastites*, *Gastrobelus* and *Passaloteuthis* (Doyle, 1991) representing the Early Pliensbachian *Uptonia jamesoni* to *Tragophylloceras ibex* zones and possibly the *Productylioceras davoei* Zone.

Lund and Pedersen (1985) recognised Assemblage A in the Rævekløft Formation. Koppelhus and Dam (2003) recognised four assemblage zones (AZ1-4) through the Pliensbachian of Jameson Land. These assemblage zones are as follows:

**Assemblage Zone 1.** The first assemblage, *Cerebropollenites thiergartii* – *Pinuspollenites minimus* – *Botryococcus*, was recorded in the Ellis Bjerg Member of the Gule Horn Formation and in the Rævekløft Formation. It is dominated by terrestrial spores and pollen. This zone is wholly equivalent to Lund, Pedersen's (1985) Assemblage A and is considered to be wholly of Early Pliensbachian age.

**Assemblage Zone 2.** *Nannoceratopsis* – *Botryococcus* is marked by the first occurrence of dinoflagellate cysts in North East Greenland represented by *Nannoceratopsis* spp. (especially *Nannoceratopsis senex*). The spore *Kekryphalospora distincta* is also first recorded within this zone and consequently it is considered to be of Late Pliensbachian age.

**Assemblage Zone 3.** *Chasmatosporites* – *Cerebropollenites thiergartii* – *Botryococcus* occurs above AZ2 within the Ellis Bjerg Member of the Gule Horn Formation and is marked by the vertical disappearance of dinoflagellate cysts and the abundance of *Cerebropollenites thiergartii*. It is considered to be of probable Late Pliensbachian age based on essentially negative criteria and the overall similarity of the miospore assemblage to that recorded from AZ2.

**Assemblage Zone 4.** Bisaccate pollen occur within the Albuén Member of the Gule Horn Formation. The zone is based on poorly preserved microfloras dominated by bisaccates. As with the underlying AZ3 a Late Pliensbachian age is inferred based primarily on negative criteria and on its stratigraphic position between AZ3 and AZ5.

The bivalve *Liotrignonia lingonensis* occurs widely in Jameson Land and Liverpool Land (Rosenkrantz, 1934, 1942), occurring with *Uptonia jamesoni* and is also taken as of Pliensbachian age by analogy with Eurasian records (Savel'yev, 1958). The interpretation of the occurrence of

the trigoniid in the Lepidopteriselv Elv Member at Liasryggen is at variance with the palynological dating of a similar horizon from Neill Klintner further south where the Nathorst Fjeld Member is dated as Toarcian (Koppelhus, Dam, 2003), which suggests possible diachronism.

## TOARCIAN STAGE

The appearance of *Dactylioceras groenlandicum* marks the appearance of the Toarcian in the Ostreaelv Formation of Jameson Land (Rosenkrantz, 1934). Callomon (pers. comm.) was always of the opinion that the variously interpreted *Pseudolioceras* faunas were of Toarcian age. It is likely that most of the Toarcian ammonite records from Greenland can probably be placed in the *Hildoceras bifrons* Zone, but this still needs careful study. This level also has a rich belemnite fauna (Doyle, 1991) as well as the bivalves *Mytiloceramus* cf. *substriatus*, *M.* aff. *porrectus* and trigoniids, *Trigonia*, *Myophorella* and *Vaugonia*.

Koppelhus, Dam (2003) recognised two palynological assemblage zones within the Toarcian:

**Assemblage Zone 5.** *Spheripollenites subgranulatus* – *Cerebropollenites macroverrucosus* – *Luehndea spinosa*. This occurs in the Astartekløft and lower part of the Nathorst Fjeld members of the Ostreaelv Formation and is marked by abundances of *Spheripollenites subgranulatus*, *Cerebropollenites macroverrucosus* and small spherical ?algae and by the first appearance of *Luehndea spinosa* and the reappearance of common *Nannoceratopsis* spp. In northwest Germany *Luehndea spinosa* is known to span the Pliensbachian/Toarcian boundary (Morgenroth, 1970; Riding, Thomas, 1992; Koppelhus, Dam, 2003) and the abundance of *S. subgranulatus* and the indeterminate spherical ?algae are also known from Early Toarcian strata. AZ4 is interpreted as being equivalent to Assemblage B of Lund, Pedersen (1985).

**Assemblage Zone 6.** The youngest assemblage that Koppelhus and Dam (2003) recognised in the Toarcian comprises: *Perinopollenites elatoides* which is marked by an acme of the nominate species which occurs in the upper part of the Nathorst Fjeld and in the Trefjord Bjerg members of the Ostreaelv Formation. It equates with Assemblage C of Lund, Pedersen (1985). Based on comparisons with the Danish Basin and the occurrence in AZ6 of *Phallocysta eumekes*, *Walloodinium laganum*, *Scriniocassis* spp. and *Dissilioudinium* spp., Koppelhus, Dam (2003) consider this zone to be of Late Toarcian–Early Aalenian age.

## AALENIAN STAGE

The Aalenian of eastern Greenland cannot be recognised directly by macrofauna, although poorly preserved belemnites occur commonly in the type section of the Sortehat Formation.

**Assemblage Zone 6.** Koppelus, Dam (2003) considered that *Perinopollenites elatoides*, present within the uppermost part of the Ostreaelv Formation, might range into the early part of the Aalenian.

**Assemblage Zone 7.** Within the Sortehat Formation Koppelus, Hansen (2003) recognised three assemblage zones. The lowest *Botryococcus* is marked by the occurrence of abundance of *Botryococcus* and occurs in the uppermost part of the Trefjord Bjerg Member but predominantly occurs within the lowermost part of the Sortehat Formation.

**Assemblage Zone 8.** A major decrease in the abundance of *Botryococcus* and a concomitant increase in *Nannoceratopsis* spp. marks the transition into Assemblage Zone 8: it is characterised by *Nannoceratopsis gracilis* – *Nannoceratopsis senex* as delineated by Koppelus, Hansen (2003) within the Sortehat Formation.

**Assemblage Zone 9.** This is the uppermost of Koppelus and Hansen's (2003) zones recognised within the Sortehat Formation containing *Sentudinium pelionense* which is marked by the vertical decrease/disappearance of significant numbers of *Nannoceratopsis* spp. and by the occurrence of abundant *Sentusidinium pelionense*. Koppelus and Hansen (2003) considered this zone to be of Aalenian to possibly Early Bajocian age.

## BAJOCIAN STAGE

The Early Bajocian is clearly not well defined biostratigraphically in eastern Greenland because it is represented by units such as the fluvio-lacustrine Bristol Elv Formation of Traill Ø (Therkelsen, Surlyk, 2004), rather than fully marine strata.

On Store Koldewey the CASP collections provide an important new indicator for the earliest Bajocian. The occurrence of *Trigonia hemisphaerica* Lycett near the base of the lowest Jurassic sandstone at Gneissnaes on Store Koldewey, invites correlation with Lincolnshire, England occurrences which are of *Hyperlioceras discites* Zone at the base of the NW European Bajocian succession (Parsons *in*: Cope *et al.*, 1980; Kent, 1966). Closely related specimens were identified as *Trigonia* sp. A aff. *T. hemisphaerica* from the Late Sinemurian

of Nevada (Poulton, 1979) and *T. sp. B* aff. *T. hemisphaerica* from the Bajocian of California (Poulton, 1979). It is also relevant to the present meeting that *Trigonia tenuis* of Kitchin (1903) from the Late Jurassic Oomia Group of Kachchh was also originally compared by that author with *T. hemisphaerica*! The Greenland occurrence suggests a level beneath the known Mid Jurassic ammonite succession of eastern Greenland (see next paragraph). However, on Store Koldewey the earliest Jurassic strata recorded by Piasecki *et al.* (2004a) are Early Bathonian, *Arcticoceras ishmae* Zone. Palynologically the *Sentusidinium pelionense* Assemblage Zone 9, which occurs in the top of the Sortehat Formation and in the base of the Pelion Formation, was dated as Late Aalaenian to ?Early Bajocian by Koppelus, Hansen (2003). Furthermore, they show the top of the range of the zone actually overlapping with ammonites in the lower part of the Pelion Formation. As the earliest ammonites there, *Cranocephalites borealis*, are equated with the *Strenoceras subfurcatum* Zone (Callomon, 1985), perhaps the range of *S. pelionense* should be increased into the earliest Late Bajocian.

The Greenland Mid Jurassic ammonite succession commences with a series of species of *Cranocephalites* in the Late Bajocian. The earliest is *Cranocephalites borealis* occurring in the base of the Pelion Formation of Jameson Land (Spath, 1932; Callomon, 1985, 1993), which is traditionally of earliest Late Bajocian in Jameson Land (Callomon, 1985). Ten ammonite levels were attributed to the Late Bajocian (horizons 1–7, some of which are subdivided). Recently these have been correlated with the Pechora River basin, north-west Russia, together with the Early Bathonian by (Mitta, 2009; Mitta, Alsen, 2013). Whilst there is scattered evidence for Bajocian age according to the palynology (*e.g.* Fensome, 1979; Milner, Piasecki, 1996; Koppelus, Hansen, 2003), the excellence and abundance of ammonites in the succession for biostratigraphic control often rules out the need for costly palynological preparation (this is also true for the Bathonian–Callovian).

## BATHONIAN STAGE

The Boreal Bathonian Stage in eastern Greenland has been substantially revised by a proposal of Mitta and Alsen (2014). The Bajocian/Bathonian boundary was conventionally drawn within the *Cranocephalites pompeckji* Zone by Callomon (1985, 1993), although subsequently he drew it higher, just within the *Arctocephalites arcticus* Zone (Callomon, 2003). *C. pompeckji* also occurs reworked at the base of the Cretaceous Hold with Hope Group, in the Steensby Bjerg Formation on Hold with Hope (Kelly *et al.*, 1998). The Early Bathonian was marked by horizons 8–13, including the last *Cranocephalites* and then a series of *Arctocephalites*

*lites*. Mitta and Alsen (2014) proposed the base of the Boreal Bathonian to be now drawn at the base of the *Greencephalites greenlandicus* Zone, at the base of horizon 11. The Mid Bathonian was marked by horizons 14–19, a series of *Arcticoceras* and *Keplerites* levels. At the base was *Arcticoceras harlandi*, a species described first from Svalbard by Rawson (1982) honouring CASP's former director, in horizon 14 at the base of the *A. ishmae* Zone. Mitta and Alsen (2014) now restrict the Mid Bathonian to the *Cadoceras cranocephaloide* Zone, including horizons 17–19 only, which incorporates the first *Keplerites* in horizon 19. The Late Bathonian was marked by horizons 20–25 (Callomon, 2003) characterised by species of *Keplerites* and *Cadoceras*, with the *K. inflatus* horizon 20, at the base of the *Cadoceras variabile* Zone, which is followed by Mitta, Alsen (2014).

### CALLOVIAN STAGE

The beginning of the Callovian in Greenland previously was drawn within the *Cadoceras apertum* Zone, between horizon 25 with *C. apertum*  $\alpha$  and horizon 26 *C. apertum*  $\beta$  (Callomon, 2003). This was a time of maximum Mid Jurassic transgression in Eastern Greenland (Alsen, Surlyk, 2004; Callomon, 2004). Mitta and Alsen (2014) now propose to draw the base of the Callovian between ammonite horizons 28 and 29 at the base of the *Cadoceras nordenskjoldi*  $\alpha$  Subzone. Early Callovian dinoflagellate cysts occur at the base of the Jurassic on Hold with Hope (Piasecki *et al.*, 2004a) and as far north as Store Koldewey (Piasecki *et al.* 2004b).

The Mid Callovian in eastern Greenland commences with *Kosmoceras* cf. or aff. *jasen* in horizon 36 (Callomon, 1993) which is tied in Jameson Land with the appearance of *Mendicodinium groenlandicum* (Milner, Piasecki, 1996). This dinoflagellate cyst is also present on Hold with Hope (Piasecki *et al.*, 2004a).

The Late Callovian is marked by the appearance of *Longaeviceras keyserlingi* in East Greenland, horizon 38 = Milne Land horizon 2, which is associated with the NW European *Peltoceras athleta* Zone. The Jameson Land occurrences are tied with the appearance of *Rhynchodiniopsis cladophora* and *Tubotuberella dangeardii* (Milner, Piasecki, 1996).

Initial microfossil studies indicate abundant and diverse, agglutinated foraminiferid dominated assemblages and positive evidence of the *Trochammina rostovzevi* F1 Zone of Nagy, Basov (1998) based on the first occurrence (FO: evolutionary inception) of *Trochammina rostovzevi* and *Kutzevella instabile*, which when associated with other taxa indicates a restricted Callovian age (MJ17–MJ16 Micro Zones of Partington *et al.*, 1993a, b).

### OXFORDIAN STAGE

The Oxfordian stage is characterised by a succession of cardioceratid ammonite horizons 3–13b of Birkelund, Callomon (1985) in Milne Land that provide overlap with East Greenland horizons 38–41 of Callomon (1993). The ammonite zonation was established by Sykes, Surlyk (1976) with a more detailed analysis of the amoeboceratid zonation by Sykes, Callomon (1979). The first ammonite horizon (3 Milne Land = 38 E Greenland) is *Cardioceras woodhamense* representing the *Cardioceras mariae* Zone and corresponding to the *Wanea fimbriata* Zones of the North Sea (Partington *et al.*, 1993a) and NW Europe (Poulsen, Riding, 2003). This could fall within an equivalent of the *Trochammina rostovzevi* Zone of Svalbard (Nagy, Basov, 1998).

*Cardioceras* cf. *densiplicatum*, horizon 6, marks the base of the Mid Oxfordian on Milne Land with an equivalent *Trichodinium scarburghensis* DS22/PJ26 Palynomorph Zone, and the lower part of the *Recurvoides scherkalyensis* Zone of the Svalbard micropalaeontology succession (Nagy, Basov, 1998). *Praebuchia lata* (= *P. kirghisensis* of Surlyk, Zakharov 1982; see Kelly in Appendix to Wright *et al.*, 2000) is the first occurrence of the genus in eastern Greenland, appearing in the Mid Oxfordian and ranging to the top of the stage, overlapping in the Late Oxfordian with early *Buchia concentrica*. Elsewhere in Boreal regions the earliest *Praebuchia* is *P. anabarensis* of Early Callovian to Late Bathonian age (Zakharov, 1981).

The Late Oxfordian is marked by the appearance of ammonite horizon 9 with *Amoeboceras ilovaiskii*, representing a Subzone of the *A. glosense* Zone. This appears in mid *Scrinodinium crystallinum* Palynomorph Zone and still within the *Recurvoides scherkalyensis* Zone (F2) of the Svalbard micropalaeontology succession (Nagy, Basov, 1998). Oxfordian microfossil assemblages are variable, but the FO of *Trochammina kosyrevae* and *Recurvoides sublustris* allows correlation between the F2 Zone and the MJ17–MJ16 Micro zone of Partington *et al.* (1993a, b). Of further importance is a definite Late Oxfordian inception of taxa recorded. This event occurs earlier than the inception of radiolaria as noted from Scottish outcrops and in the North Sea which occurs in the Early Kimmeridgian (Partington *et al.*, 1993a, b; Gregory, 1995; MJ18–lower MJ19 zonal range). Radiolarian taxa include *Parvincingula deadhorsensis*, *Stichocapsa devorata*, *Ristola firma*, *Paraparvincingula vera* and *Orbiculiforma* spp.

### KIMMERIDGIAN STAGE

The Kimmeridgian stage is dominated by a mixture of aulacostephanid and cardioceratid ammonites, horizons 13b

to 23 of the Milne Land succession of Birkelund, Callomon (1985). Although a tripartite division of the Kimmeridgian was preferred by Zeiss (2003), a simpler bipartite division now tends to be followed by Boreal workers such as Wierzbowski, Rogov (2013), with the Late Kimmeridgian commencing with the *Aulacostephanus mutabilis* Zone. The latter is followed here. The Early Kimmeridgian was marked by Birkelund and Callomon at the appearance of *Amoeboceras bayi* and *Pictonia* aff. *normandiana*, indicating the equivalence of the *Pictonia baylei* Zone of NW Europe. However, the base of the Kimmeridgian is currently placed slightly lower at the base of the *Plasmatisites bauhini* Zone, based on the proposed GSSP and Point at Staffin Bay, Skye, Scotland (Matyja *et al.*, 2006; Wierzbowski *et al.*, 2006). An additional marker of the *P. bauhini* Zone is *Amoeboceras schulginae* (cf. Sykes, Surlyk, 1976, fig. 6 B (as *A. simplex*); see Matyja *et al.*, 2006).

The *Rasenia cymodoce* horizon 17 marks the first occurrence of *Buchia concentrica*, without the presence of *Praebuchia lata*. *B. concentrica* ranges up to ammonite horizon 20 with *Amoeboceras kochi*. The belemnite *Hibolithes* makes a Greenland appearance in the Early Kimmeridgian, although it appears to be a longer ranging European migrant.

The Early Kimmeridgian of eastern Greenland commences within the *Scrinodinium crystallinum* zone, PJ32 of Partington *et al.* (1993a), and the substage is characterised by the three palynological zones of the North Sea, P33–35, including the *Gonyaulacysta jurassica* and part of the *Periasphaeridium pannosum* “acme”. The base of the Greenland Kimmeridgian lies within the *Recurvoides scherkalyensis* Zone of the Svalbard micropalaeontology succession (Nagy, Basov, 1998) and within the more restrictive *Trochammina globigeriniformis* Zone of the North Sea (Partington *et al.*, 1993a). Three influxes of rare to moderately common radiolarian assemblages have been recognised for the first time from the Kimmeridgian and Volgian intervals of Greenland and can be correlated with similar, but much more abundant and diverse assemblages recorded in the deeper water North Sea Basin (Partington *et al.*, 1993a, b) and from NE and NW onshore sections from Scotland (Gregory, 1995). The last occurrence (extinction) (LO) of *Parvicingula blowi* in a number of sections associated with rare agglutinated foraminiferids, including *Trochammina globigerinaeformis*, indicates the presence of MJ20 Micro Zone (Partington *et al.*, 1993a, b). This constrains the age to the mid-Early to Late Kimmeridgian (*Rasenia cymodoce*–*Aulacostephanus autissiodorensis* ammonite zones).

The later part of the Early Kimmeridgian (ammonite horizons 17–22) correlates with the *Haplophragmoides canuiformis* Zone on Svalbard. However it is noted that the *H. canuiformis* Zone ranges down into the Late Oxfordian in the Nordvik Peninsula (Wierzbowski, Rogov, 2013).

The Late Kimmeridgian was represented by the *Aulacostephanus* aff. *kirghizensis* horizon 23 alone (Zeiss, 2003) but now includes down to the *Zonovia borealis* horizon 19. This is also marked by the lower part the range of the *Buchia tenuistriata* bivalve zone. It also corresponds to the upper part of the *Endoscrinium luridum* Zone (DSJ29) and of its overlap with the base of the Svalbard *Trochammina praerosacea* Micro Zone (F4).

## VOLGIAN STAGE

The Early Volgian Substage is marked by the range of the ammonite *Pectinatites* and the base by the appearance of *P. elegans* in Milne Land horizon 24 (Callomon, Birkelund, 1982). In Kuhn Ø (CASP records) the transition from *Buchia tenuistriata* to *B. mosquensis* lies at the appearance of *P. pectinatus*, which fills in the gap in the records of Surlyk, Zakharov (1982). The base of the Volgian can be equated with the appearance of dinoflagellate cysts of the *Glossodinium dimorphum* Zone of NW Europe (Poulsen, Riding, 2003) and the North Sea *Periasphaeridium pannosum* Zone (Partington *et al.*, 1993a). It also ties within the Svalbard micropalaeontological zone of *Trochammina praerosacea* (F4 and intra-F5 of Nagy, Basov, 1998) based on the combined ranges of the radiolarian *Orbiculiforma mclaughlini* and the agglutinated foraminiferid *Haplophragmoides canuiformis*.

The Mid Volgian on Milne Land is characterised by ammonites from horizons 31 with *Dorsoplanites primus* to horizon 47 with *Laugeites groenlandicus* according to Callomon, Birkelund (1982). In Jameson Land there appears to be a *Lagonibelus* belemnite event in the *Dorsoplanites gracilis* Zone (CASP Collection). Horizon 48 of Callomon, Birkelund (1982) in their Milne Land scheme is actually Valanginian, situated above an unconformity. However, on Kuhn Ø (Kelly, 2006) shows further detail from the youngest Jurassic strata than was documented by Surlyk (1978) from Wolaston Forland in the Bernbjerg Formation. Three further ammonite horizons were identified by Rogov (2010) at the top of the Mid Volgian succession based on the CASP collections from eastern Kuhn Ø with *Laugeites lambecki* and “*Epilaugeites vogulicus*” with *Buchia terebratuloides* and *Praechetaites tenuicostatus* with *Buchia fischeriana* to *B. unshensis* at the top of the Mid Volgian. The base of the Mid Volgian lies within the *Glossodinium dimorphum* and *Oligosphaeridium* cf. *pulcherrimum* palynomorph ranges, but is marked by a radiolarian *Cenosphaera* sp. 1 acme on Kuhn Ø.

The position of the Boreal Jurassic/Cretaceous boundary has in the past been placed at the Mid/Late Volgian boundary (e.g. Casey, 1973, table 3), with the base of the Berriasian equating with the base of the Late Volgian. But this is not

followed here (See Ryazanian Stage below) and the Late Volgian is characterised by the *Subcraspedites* sp., *S.* aff. *preplicomphalus* faunas which correlate well with eastern England (Casey, 1973), and the aff. *Chetaites chetae* fauna (Surlyk, 1973). In Greenland the Late Volgian can be identified in the *Gochteodinia virgula* palynological Zone, PJ47 of the North Sea. In terms of the Svalbard succession, this is equivalent to the upper part of the *Calyptamina praegroidini* and lower part of the *Recurvoides obskiensis* foraminiferal zones (upper F6-lower F7 of Nagy, Basov, 1998).

## RYAZANIAN STAGE

To conclude the Jurassic it is necessary to review the earliest Cretaceous biota of eastern Greenland. Modern studies suggest a close relationship between the beginning of the Boreal Ryazanian stage with that of the Berriasian. For example Mitta (2005) equated the Boreal *Chetaites chetae* Zone with the Tethyan *Berriassella jacobi* Zone at the base of the Berriasian. Rogov (2012) placed the *C. chetae* Zone at the end of the Late Volgian. In Jameson Land the Ryazanian is marked by the incoming *Praetollia maynci* and *Hectoroceras kochi* faunas (Surlyk, 1973; Surlyk *et al.*, 1973). The bivalve *Buchia fisheriana/uncitoides* faunas span the Volgian/Ryazanian boundary (Zakharov, 1981; Surlyk, Zakharov, 1982), followed by *B. okensis* and *B. volgensis* faunas appearing with *Hectoroceras kochi*. The dinoflagellate cyst zone of *Gochteodinia villosa* spans the Jurassic/Cretaceous boundary (horizons DSJ38–39), but the boundary itself lies within horizon DSJ39, which is within the *Rotosphaeropsis thula* Subzone (Poulsen, Riding, 2003).

## CONCLUSIONS

The prime achievement of this study is to provide for the first time a comprehensive integrated figure (Fig. 3A–D) showing at a glance all the principal biotic groups used in the Jurassic biostratigraphy of eastern Greenland. This involves both the macrobiota – ammonites, belemnites, bivalves and plant macrofossils, which can be used in the field, and the palynology and micropalaeontology which can only be determined after laboratory processing.

Eastern Greenland is the prime area for study of Jurassic biostratigraphy in the northern North Atlantic region. The reason for its importance is simply that it has the best exposed Jurassic outcrops in the region. Outcrops in Scotland are good, but limited, and those of onshore Norway are very poor. The Svalbard outcrops are significant, but have been moved tectonically from their original position close to the Sverdrup Basin.

The ammonite succession from the Jurassic in eastern Greenland has been long known for its biostratigraphic importance, especially in the Mid and Late Jurassic, but less so in the Early Jurassic. Its association with spores, pollen and microfossils allows calibration and refinement of the various individual stratigraphic schemes. Integration of microfossil and palynomorph data has allowed the dating of sections where ammonite control was poor or lacking. Less important are the bivalves, of which the buchiids are of established value in Jurassic/Cretaceous boundary strata, but less is known about other groups such as the inoceramids which do show potential value as do the belemnites.

As a consequence of the excellent ammonite recovery from the Bajocian through Callovian sections in eastern Greenland, little emphasis was initially placed on acquiring palynological or micropalaeontological data. However, the existence of such well dated sections with ammonites does offer the opportunity to acquire a significant data set of palynological and micropalaeontological material which is precisely calibrated to the Boreal ammonite zonal scheme. Such an investigation would further refine what has been achieved here for Boreal bio- and chronostratigraphy and for correlation with areas lacking macrofossil recoveries, especially offshore. This would also be particularly important for calibration with the proposed Bathonian and Callovian revisionary dating of Mitta and Alsen (2014).

Jurassic samples from eastern Greenland yield moderate to good palynological assemblages and kerogen types comparable to those known from coeval deposits in NW Europe. The occurrence of dinoflagellate cysts in particular is comparable to the known distributions in NW Europe and permits the application of pan-European biozonations at zonal level. Reworking of palynomorphs was recognised in several Late Jurassic sections. Reworked grains were noted of Permo-Triassic, Callovian–Early Oxfordian and Oxfordian–Kimmeridgian ages.

Jurassic rifting is not recorded in the Jameson Land region. In areas from Scoresby Land northwards, rifting is recognised in the Late Bajocian–Mid Oxfordian and again from the Mid Volgian–Valanginian (Surlyk, 2003). In the intervening Late Oxfordian–Early Volgian period, it has been previously unclear whether active rifting occurred or not, due to the poor exposure and fine grain size of the sediments. Reworking of palynomorphs (Permo-Triassic and Mid–Late Jurassic) in the Kimmeridgian–Volgian of Wollaston Fjordland-Kuhn Ø may be evidence of fault block crest emergence and erosion during rifting at this time.

This study represents the first positive identification of rich and diverse Jurassic microfaunas (radiolaria and foraminifera) in East Greenland especially in the Mid–Late Jurassic. Well preserved and diverse agglutinated assemblages have been recovered which correlate very well with



**Table 1**  
**Comparison of Jurassic biostratigraphic values for ammonites, palynomorphs and microfossils in NW Europe, the North Sea and eastern Greenland using timescale from Ogg, Hinnov (2012)**

Biotic Group	NW Europe Early–Late Jurassic Callomon, 1994		North Sea Mid–Late Jurassic Partington, 1993a		Greenland Mid–Late Jurassic (New)	
	No Divisions	Average duration of division (years)	No Divisions	Average duration of division (years)	No Divisions	Average duration of division (years)
Ammonites	450 horizons	140,000			93 horizons	272,000
Palynomorphs	Dinoflag: 16	3,900,000	35 biozones	691,000		
	Nanno: 22	2,800,000				
Microfossils			25 biozones	968,000		

other Boreal sites, particularly Scotland, Svalbard and Canada, as well as offshore North Sea. Excellent radiolarian assemblages have been obtained, especially in Kimmeridgian and younger sediments. Rare occurrences of radiolaria are recorded from the Late Oxfordian succession, which have implications for biogeographical distribution. This group shows considerable potential for further study.

Callomon (1994) showed that the resolution of 450 ammonite horizons recognised in the whole Jurassic of NW Europe gave an average duration of 140,000 years (Table 1); the figures for 16 dinoflagellate cyst and 22 nannofossil zones in the same interval gave average durations of 3.9 Ma and 2.8 Ma respectively. Using the data from only the Mid–Late Jurassic of the North Sea where Partington recognised 35 palynomorph biozones and 25 microfossil zones one can achieve resolutions of 0.691 and 0.968 Ma respectively – and it is expected that a similar figure would eventually be obtainable for eastern Greenland. The Mid–Late Jurassic of Greenland has only half the ammonite resolution of NW Europe, nevertheless at just over 0.25 Ma this demonstrates their very great potential. The figures obtained for the micropalaeontology and palynology of the Middle and Late Jurassic of the North Sea (Table 1) are what we would expect to be the potential eventual results for the eastern Greenland area.

Whilst this article represents the first published account of a comprehensive and integrated Jurassic biostratigraphic scheme for eastern Greenland (Fig. 3), it has many shortcomings. However, it is hoped that future studies will allow illustration of taxa and enable the scheme to be developed further. Its value will not just be for the onshore area where the data was obtained, but also for the offshore parts of the northern North Atlantic.

Although we have so far a fairly robust integrated biostratigraphic scheme for the marine Late Jurassic, the finely tuned ammonite scheme requires much further integration

with palynology and micropalaeontology for the Mid Jurassic. The Early Jurassic, especially the Sinemurian Stage, will remain more difficult to date because of the large scale facies change from the non-marine Kap Stewart Group to the shallow marine Neill Klintor Group. Published microfossil biostratigraphic studies of the Early Jurassic are limited, and there is scope for much research here. With plant macrofossils in the lower part and occasional molluscan dominated levels above there is good potential for further integration of palynological data with further studies on macrospores and microfossils. Furthermore integration with the magnetic stratigraphic scale and with the Boreal carbon-isotope scale (e.g. Wimbledon *et al.*, 2011; Dzyuba *et al.*, 2013) could further refine the stratigraphy of eastern Greenland.

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