VOLUMINA JURASSICA, 2015, XIII (1): 43–64
DOI: 10.5604/17313708 .1148657

# Towards an integrated Jurassic biostratigraphy for eastern Greenland

Simon R.A. KELLY[1], F. John GREGORY[2], William BRAHAM[3],
Dominic P. STROGEN[4], Andrew G. WHITHAM[1]

**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 In this article, published data are summarised together with previously unpublished data in the form of a unified table.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.

## 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 Toula (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

---

[1] CASP, West Building, 181a Huntingdon Road, Cambridge CB3 ODH, United Kingdom; e-mail: simon.kelly@casp.cam.ac.uk.

[2] PetroStrat Ltd, Tan-y-Craig, Parc Caer Seion, Conwy, Wales LL32 8FA, United Kingdom; e-mail: john.gregory@petrostrat.com.

[3] 11 Corner Hall, Hemel Hempstead, Herts HP3 9HN, United Kingdom; e-mail: billbraham1957@yahoo.co.uk.

[4] GNS Science, 1 Fairway Drive, Avalon, PO Box 30-368, Lower Hutt, New Zealand; e-mail: dominic.strogen@gmail.com.

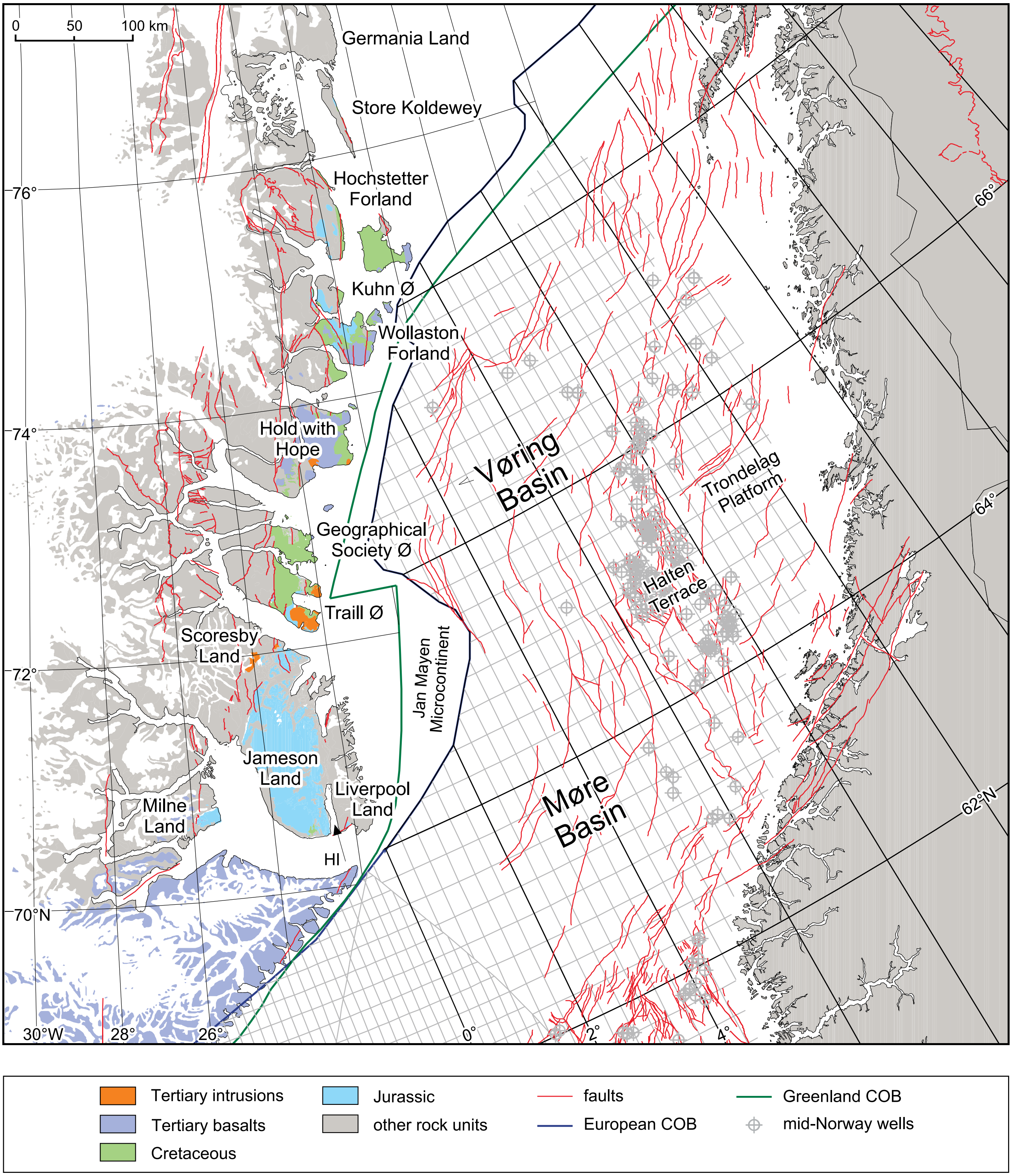


**Fig. 1. Pre-breakup reconstruction of the Norway-Greenland region, showing the relative positions of the onshore Mesozoic outcrop in East Greenland, including the Jurassic shown in blue, to the basins of Mid-Norway**

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

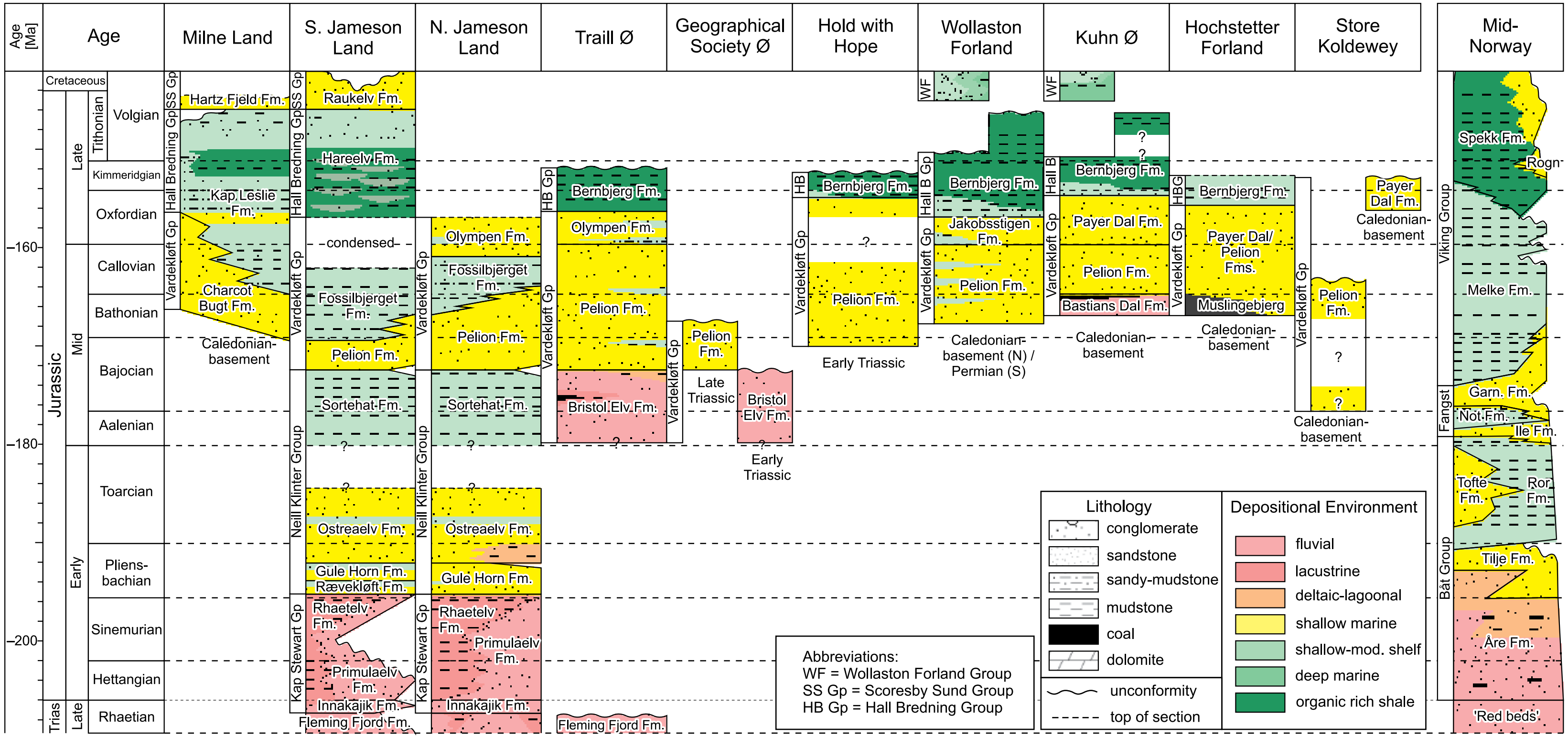


**Figure 2. Correlation of the Jurassic stratigraphy of eastern Greenland and Mid-Norway**

Greenland data modified from Surlyk (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 records from Greenland can be placed as equivalent of the *Hildoceras bifrons* zone.

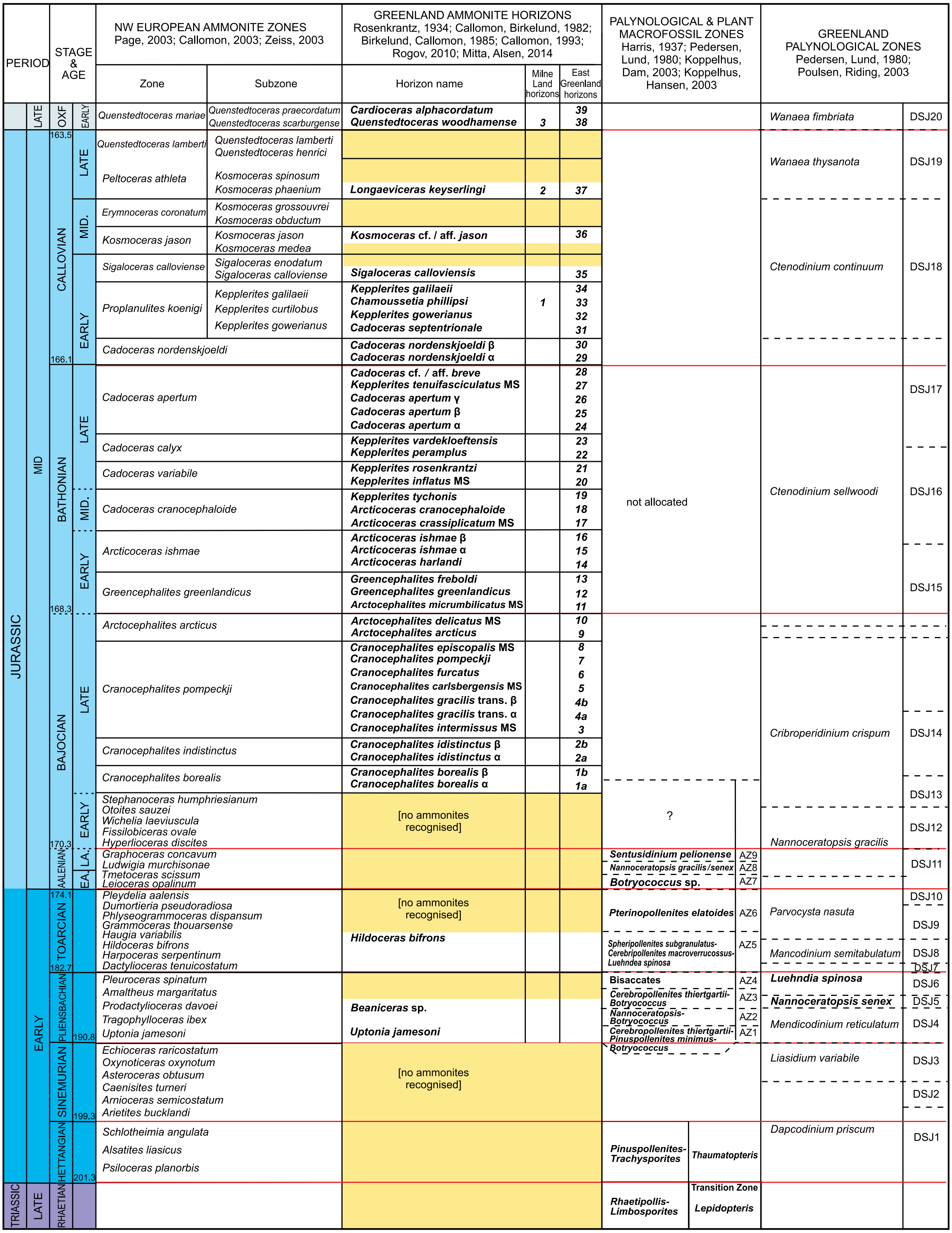
The Boreal cardioceratids provide an almost continuous zonal lineage from the Bajocian to the Kimmeridgian (Callomon, 1985). The understanding of the Mid-Late Jurassic ammonite succession (Callomon, 1961, 1993, 1994, 2003; Callomon *et al.*, 2014) allowed reinterpretation of the large number of figures of Spath (1932, 1935, 1936). Repin (2007) introduced the genus *Greencephalites* based on the type specimen of *Cadoceras freboldi* 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. nordenskjoeldi* 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 Mjølnir 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 — Zone | Subzone | GREENLAND AMMONITE HORIZONS Rosenkrantz, 1934; Callomon, Birkelund, 1982; Birkelund, Callomon, 1985; Callomon, 1993; Rogov, 2010; Mitta, Alsen, 2014 — Horizon name | Milne Land horizons | East Greenland horizons | 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 | EARLY | | *Quenstedtoceras mariae* | *Quenstedtoceras praecordatum*<br>*Quenstedtoceras scarburgense* | ***Cardioceras alphacordatum***<br>***Quenstedtoceras woodhamense*** | 3 | 39<br>38 | | | *Wanaea fimbriata* | DSJ20 |
| JURASSIC | MID | CALLOVIAN | LATE | 163.5 | *Quenstedtoceras lamberti* | *Quenstedtoceras lamberti*<br>*Quenstedtoceras henrici* | | | | | | *Wanaea thysanota* | DSJ19 |
| | | | | | *Peltoceras athleta* | *Kosmoceras spinosum*<br>*Kosmoceras phaenium* | ***Longaeviceras keyserlingi*** | 2 | 37 | | | | |
| | | | MID. | | *Erymnoceras coronatum* | *Kosmoceras grossouvrei*<br>*Kosmoceras obductum* | | | | | | *Ctenodinium continuum* | DSJ18 |
| | | | | | *Kosmoceras jason* | *Kosmoceras jason*<br>*Kosmoceras medea* | ***Kosmoceras* cf. / aff. *jason*** | | 36 | | | | |
| | | | EARLY | | *Sigaloceras calloviense* | *Sigaloceras enodatum*<br>*Sigaloceras calloviense* | ***Sigaloceras calloviensis*** | | 35 | | | | |
| | | | | | *Proplanulites koenigi* | *Kepplerites galilaeii*<br>*Kepplerites curtilobus*<br>*Kepplerites gowerianus* | ***Kepplerites galilaeii***<br>***Chamoussetia phillipsi***<br>***Kepplerites gowerianus***<br>***Cadoceras septentrionale*** | 1 | 34<br>33<br>32<br>31 | | | | |
| | | | | 166.1 | *Cadoceras nordenskjoeldi* | | ***Cadoceras nordenskjoeldi* β**<br>***Cadoceras nordenskjoeldi* α** | | 30<br>29 | | | | |
| | | BATHONIAN | LATE | | *Cadoceras apertum* | | ***Cadoceras* cf. / aff. *breve***<br>***Kepplerites tenuifasciculatus* MS**<br>***Cadoceras apertum* γ**<br>***Cadoceras apertum* β**<br>***Cadoceras apertum* α** | | 28<br>27<br>26<br>25<br>24 | | | | DSJ17 |
| | | | | | *Cadoceras calyx* | | ***Kepplerites vardekloeftensis***<br>***Kepplerites peramplus*** | | 23<br>22 | | | *Ctenodinium sellwoodi* | DSJ16 |
| | | | | | *Cadoceras variabile* | | ***Kepplerites rosenkrantzi***<br>***Kepplerites inflatus* MS** | | 21<br>20 | | | | |
| | | | MID. | | *Cadoceras cranocephaloide* | | ***Kepplerites tychonis***<br>***Arcticoceras cranocephaloide***<br>***Arcticoceras crassiplicatum* MS** | | 19<br>18<br>17 | not allocated | | | |
| | | | EARLY | | *Arcticoceras ishmae* | | ***Arcticoceras ishmae* β**<br>***Arcticoceras ishmae* α**<br>***Arcticoceras harlandi*** | | 16<br>15<br>14 | | | | DSJ15 |
| | | | | 168.3 | *Greencephalites greenlandicus* | | ***Greencephalites freboldi***<br>***Greencephalites greenlandicus***<br>***Arctocephalites micrumbilicatus* MS** | | 13<br>12<br>11 | | | | |
| | | BAJOCIAN | LATE | | *Arctocephalites arcticus* | | ***Arctocephalites delicatus* MS**<br>***Arctocephalites arcticus*** | | 10<br>9 | | | *Cribroperidinium crispum* | DSJ14 |
| | | | | | *Cranocephalites pompeckji* | | ***Cranocephalites episcopalis* MS**<br>***Cranocephalites pompeckji***<br>***Cranocephalites furcatus***<br>***Cranocephalites carlsbergensis* MS**<br>***Cranocephalites gracilis* trans. β**<br>***Cranocephalites gracilis* trans. α**<br>***Cranocephalites intermissus* MS** | | 8<br>7<br>6<br>5<br>4b<br>4a<br>3 | | | | |
| | | | | | *Cranocephalites indistinctus* | | ***Cranocephalites idistinctus* β**<br>***Cranocephalites idistinctus* α** | | 2b<br>2a | | | | |
| | | | | | *Cranocephalites borealis* | | ***Cranocephalites borealis* β**<br>***Cranocephalites borealis* α** | | 1b<br>1a | | | | DSJ13 |
| | | | EARLY | 170.3 | *Stephanoceras humphriesianum*<br>*Otoites sauzei*<br>*Wichelia laeviuscula*<br>*Fissilobiceras ovale*<br>*Hyperlioceras discites* | | [no ammonites recognised] | | | ? | | *Nannoceratopsis gracilis* | DSJ12 |
| | | AALENIAN | LA. | | *Graphoceras concavum*<br>*Ludwigia murchisonae* | | | | | ***Sentusidinium pelionense***<br>***Nannoceratopsis gracilis/senex*** | AZ9<br>AZ8 | | DSJ11 |
| | | | EA. | | *Tmetoceras scissum*<br>*Leioceras opalinum* | | | | | **Botryococcus sp.** | AZ7 | | |
| | EARLY | TOARCIAN | | 174.1 | *Pleydelia aalensis*<br>*Dumortieria pseudoradiosa*<br>*Phlyseogrammoceras dispansum*<br>*Grammoceras thouarsense* | | [no ammonites recognised] | | | ***Pterinopollenites elatoides*** | AZ6 | *Parvocysta nasuta* | DSJ10<br>DSJ9 |
| | | | | 182.7 | *Haugia variabilis*<br>*Hildoceras bifrons*<br>*Harpoceras serpentinum*<br>*Dactylioceras tenuicostatum* | | ***Hildoceras bifrons*** | | | ***Spheripollenites subgranulatus-Cerebripollenites macroverrucossus-Luehndea spinosa*** | AZ5 | *Mancodinium semitabulatum* | DSJ8<br>DSJ7 |
| | | PLIENSBACHIAN | | | *Pleuroceras spinatum*<br>*Amaltheus margaritatus* | | | | | **Bisaccates** | AZ4 | ***Luehndia spinosa*** | DSJ6 |
| | | | | | *Prodactylioceras davoei* | | ***Beaniceras* sp.** | | | ***Cerebropollenites thiertgartii-Botryococcus*** | AZ3 | ***Nannoceratopsis senex*** | DSJ5 |
| | | | | | *Tragophylloceras ibex* | | | | | ***Nannoceratopsis-Botryococcus*** | AZ2 | *Mendicodinium reticulatum* | DSJ4 |
| | | | | 190.8 | *Uptonia jamesoni* | | ***Uptonia jamesoni*** | | | ***Cerebropollenites thiertgartii-Pinuspollenites minimus-Botryococcus*** | AZ1 | | |
| | | SINEMURIAN | | 199.3 | *Echioceras raricostatum*<br>*Oxynoticeras oxynotum*<br>*Asteroceras obtusum*<br>*Caenisites turneri*<br>*Arnioceras semicostatum*<br>*Arietites bucklandi* | | [no ammonites recognised] | | | | | *Liasidium variabile* | DSJ3<br>DSJ2 |
| | | HETTANGIAN | | 201.3 | *Schlotheimia angulata*<br>*Alsatites liasicus*<br>*Psiloceras planorbis* | | | | | ***Pinuspollenites-Trachysporites*** | ***Thaumatopteris*** | *Dapcodinium priscum* | DSJ1 |
| TRIASSIC | LATE | RHAETIAN | | | | | | | | ***Rhaetipollis-Limbosporites*** | **Transition Zone**<br>***Lepidopteris*** | | |

**Fig. 3B**

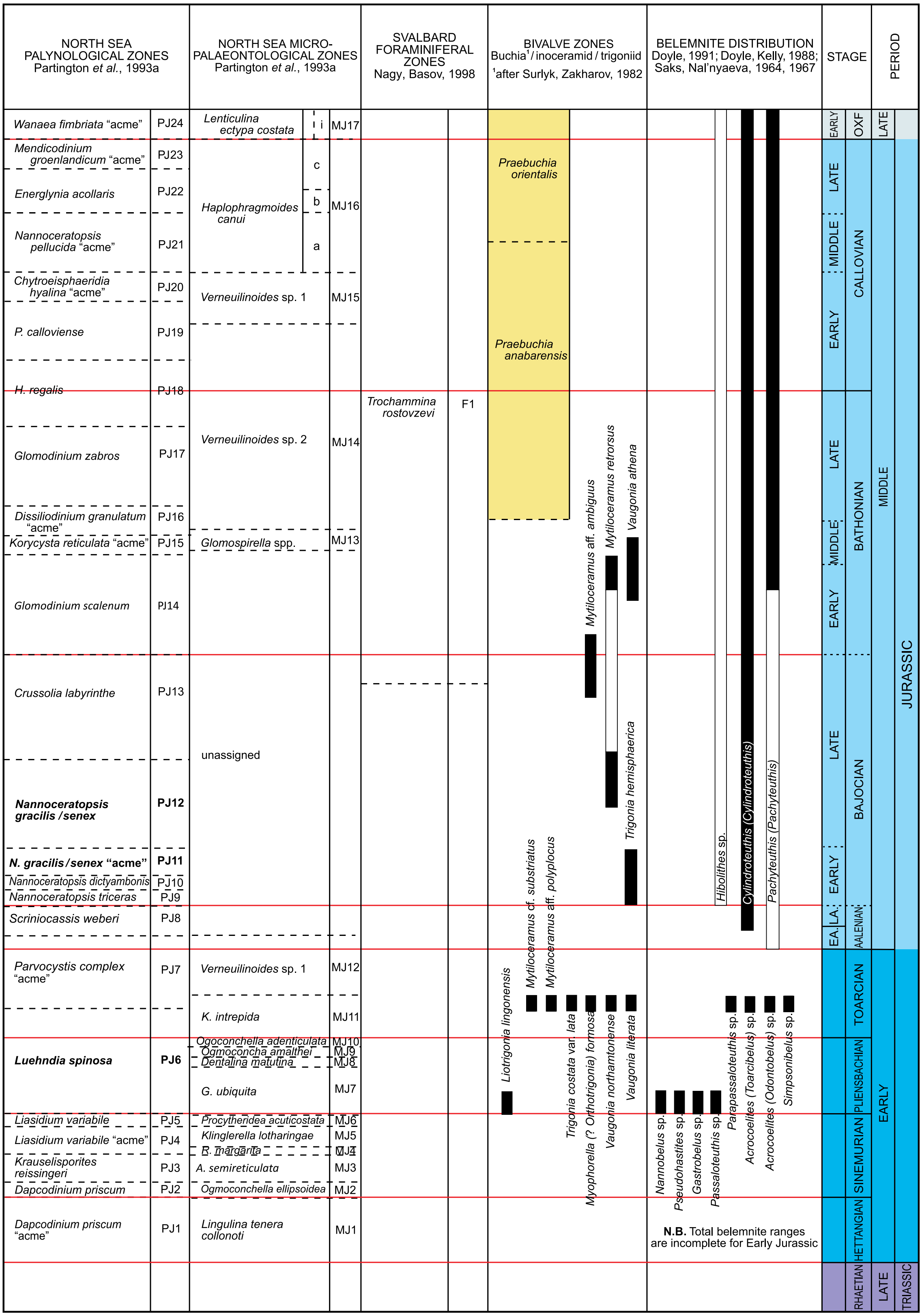

NORTH SEA PALYNOLOGICAL ZONES Partington et al., 1993a
NORTH SEA MICRO-PALAEONTOLOGICAL ZONES Partington et al., 1993a
SVALBARD FORAMINIFERAL ZONES Nagy, Basov, 1998
BIVALVE ZONES Buchia¹ / inoceramid / trigoniid ¹after Surlyk, Zakharov, 1982
BELEMNITE DISTRIBUTION Doyle, 1991; Doyle, Kelly, 1988; Saks, Nal'nyaeva, 1964, 1967
STAGE
PERIOD
Wanaea fimbriata "acme" PJ24
Mendicodinium groenlandicum "acme" PJ23
Energlynia acollaris PJ22
Nannoceratopsis pellucida "acme" PJ21
Chytroeisphaeridia hyalina "acme" PJ20
P. calloviense PJ19
H. regalis PJ18
Glomodinium zabros PJ17
Dissiliodinium granulatum "acme" PJ16
Korycysta reticulata "acme" PJ15
Glomodinium scalenum PJ14
Crussolia labyrinthe PJ13
Nannoceratopsis gracilis / senex PJ12
N. gracilis / senex "acme" PJ11
Nannoceratopsis dictyambonis PJ10
Nannoceratopsis triceras PJ9
Scriniocassis weberi PJ8
Parvocystis complex "acme" PJ7
Luehndia spinosa PJ6
Liasidium variabile PJ5
Liasidium variabile "acme" PJ4
Krauselisporites reissingeri PJ3
Dapcodinium priscum PJ2
Dapcodinium priscum "acme" PJ1
Lenticulina ectypa costata i MJ17
Haplophragmoides canui c b a MJ16
Verneuilinoides sp. 1 MJ15
Verneuilinoides sp. 2 MJ14
Glomospirella spp. MJ13
unassigned
Verneuilinoides sp. 1 MJ12
K. intrepida MJ11
Ogoconchella adenticulata MJ10
Ogmoconcha amalthei MJ9
Dentalina matutina MJ8
G. ubiquita MJ7
Procytheridea acuticostata MJ6
Klinglerella lotharingae MJ5
R. margarita MJ4
A. semireticulata MJ3
Ogmoconchella ellipsoidea MJ2
Lingulina tenera collonoti MJ1
Trochammina rostovzevi F1
Praebuchia orientalis
Praebuchia anabarensis
Mytiloceramus aff. ambiguus
Mytiloceramus retrorsus
Vaugonia athena
Trigonia hemisphaerica
Mytiloceramus cf. substriatus
Mytiloceramus aff. polyplocus
Liotrigonia lingonensis
Trigonia costata var. lata
Myophorella (? Orthotrigonia) formosa
Vaugonia northamtonense
Vaugonia literata
Hibolithes sp.
Cylindroteuthis (Cylindroteuthis)
Pachyteuthis (Pachyteuthis)
Nannobelus sp.
Pseudohastites sp.
Gastrobelus sp.
Passaloteuthis sp.
Parapassaloteuthis sp.
Acrocoelites (Toarcibelus) sp.
Acrocoelites (Odontobelus) sp.
Simpsonibelus sp.
N.B. Total belemnite ranges are incomplete for Early Jurassic
EARLY OXF LATE
LATE MIDDLE EARLY CALLOVIAN
LATE MIDDLE EARLY BATHONIAN
LATE EARLY BAJOCIAN
LA. EA. AALENIAN
MIDDLE
JURASSIC
TOARCIAN
PLIENSBACHIAN
SINEMURIAN
HETTANGIAN
EARLY
RHAETIAN LATE TRIASSIC

**Fig. 3C**

| PERIOD | STAGE & AGE | | | NW EUROPEAN AMMONITE ZONES Page, 2003; Callomon, 2003; Zeiss, 2003 | | GREENLAND AMMONITE HORIZONS Rosenkrantz, 1934; Birkelund, Callomon, 1985; Callomon, 1993; Callomon, Birkelund, 1982; Rogov, 2010 | | | PALYNOLOGICAL & PLANT MACROFOSSIL ZONES Koppelhus, Dam, 2003; Koppelhus, Hansen, 2003; Pedersen, Lund, 1980; Harris, 1937 | GREENLAND PALYNOLOGICAL ZONES Pedersen, Lund, 1980; Poulsen, Riding, 2003 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Zone | Subzone | Horizon name | Milne Land horizons | East Greenland horizons | | | |
| **CRET** | EARLY | RYAZANIAN | EARLY | *Hectoroceras kochi* | | ***Hectoroceras kochi*** | | | | *Gochteodinia villosa* | DSK1 |
| | | | | *Runctonia runctoni* | | ***Praetollia maynci*** | | | | | |
| **JURASSIC** | LATE | 145.0<br>VOLGIAN | LATE | *Subcraspedites lamplughi*<br>*Subcraspedites preplicomphalus*<br>*Subcraspedites primitivus* | | ***Subcraspedites* aff. *preplicomphalus***<br>***Subcraspedites* sp.** | | | | | DSJ39 |
| | | | MIDDLE | *Praechetaites tenuicostatus* | | ***Praechetaites tenuicostatus*** | | | | | DSJ38 |
| | | | | *"Epilaugeites vogulicus"* | | ***"Epilaugeites vogulicus"*** | | | | | |
| | | | | *Laugeites groenlandicus* | | ***Laugeites lambecki***<br>***Laugeites groenlandicus*** | 47 | | | | |
| | | | | *Crendonites anguinus* | | ***Crendonites anguinus***<br>***Pavlovia* aff. *subgorei*** | 46<br>45 | | | *Dingodinium spinosum* | DSJ37 |
| | | | | *Epipallasiceras pseudapertum* | | ***Dorsoplanites intermissus***<br>***Pavlovia groenlandica***<br>***Epipallasiceras pseudapertum***<br>***Epipallasiceras acutifurcatum*** | 44<br>43<br>42<br>41 | | | *Dichadogonyaulax culmula* | DSJ36 |
| | | | | *Dorsoplanites gracilis* | | ***Epipallasiceras rotundiforme***<br>***Dorsoplanites gracilis delta***<br>***Dorsoplanites antiquus*** | 40<br>39<br>38 | | | *Glossodinium dimorphum* | DSJ35<br>DSJ34 |
| | | | | *Dorsoplanites liostracus* | | ***Dorsoplanites liostracus***<br>***Dorsoplanites gracilis beta*** | 37<br>36 | | | | |
| | | | | *Pavlovia communis* | | ***Pavlovia variocostata***<br>***Pavlovia communis*** | 35<br>34 | | | | |
| | | | | *Pavlovia rugosa* | | ***Pavlovia rugosa*** | 33 | | | | DSJ33 |
| | | | | *Pavlovia iatriensis*<br>*Dorsoplanites primus* | | ***Pavlovia iatriensis***<br>***Dorsoplanites primus*** | 32<br>31 | | | | |
| | | | EARLY | *Pectinatites pectinatus* | *P. paravirgatus*<br>*P. eastlecottensis* | ***Paravirgatites* sp. B**<br>***Paravirgatites* sp. A**<br>***Pectinatites eastlecottensis***<br>***Pectinatites groenlandicus*** | 30<br>29<br>28<br>27 | | | | DSJ32 |
| | | | | *Pectinatites hudlestoni* | | ***Pectinatites* cf. *abbrevatus*** | 26 | | | | DSJ31 |
| | | | | *Pectinatites wheatleyensis* | | ***Sphinctoceras spp.*** | 25 | | | | |
| | | 152.1 | | *Pectinatites elegans* | | ***Pectinatites elegans*** | 24 | | | | DSJ30 |
| | | KIMMERIDGIAN | LATE | *Aulacostephanus autissiodorensis* | | ***Aulacostephanus* cf. *kirghizensis*** | 23 | | | ***Endoscrinium luridum*** | **DSJ29** |
| | | | | *Aulacostephanus eudoxus* | | ***Amoeboceras elegans***<br>***Hoplocardioceras decipiens***<br>***Amoeboceras kochi*** | 22<br>21<br>20 | | | | |
| | | | | *Aulacostephanus mutabilis* | | ***Zonovia borealis*** | 19 | | | | |
| | | | EARLY | *Rasenia cymodoce* | | ***Rasenia* aff. *evoluta***<br>***Rasenia cymodoce***<br>**? *Pachypictonia* sp.**<br>***Rasenia inconstans*** | 18<br>17<br>16<br>15 | | | | DSJ28 |
| | | 157.3 | | *Pictonia baylei* | *A. (Plasmatites) bauhini* | ***Pictonia* cf. *normandiana***<br>***Amoeb. (Plasmatites) bauhini*** | 14<br>13b | | | | DSJ27<br>DSJ26 |
| | | OXFORDIAN | LATE | *Amoeb. rosenkrantzi* | *A. (Prionod.) marstonense* | ***Amoeb. (Prionod.) marstonense*** | 13a | | | ***Scrinodinium crystallinum*** | |
| | | | | *Amoeb. regulare* | *A. (Amoeb.) regulare* | ***Amoeb. (Amoeb.) regulare*** | 12 | | | | DSJ25 |
| | | | | *Amoeb. serratum* | *A. (Prion.) serratum*<br>*A. (Amoeb.) koldeweyense* | ***Amoeb. (Prionod.) serratum***<br>***Amoeb. (Amoeb.) koldeweyense*** | 11b<br>11a | | | | |
| | | | | *Amoeb. glosense* | *A. (Prionod.) glosense*<br>*A. (Amoeb.) ilovaiskii* | ***Amoeb. (Prionod.) glosense***<br>***A. (A.) ilovaiskii [D. lintonensis]*** | 10<br>9 | 41 | | | **DSJ24** |
| | | | MIDDLE | *Card. tenuiserratum* | *C. (Cawtoniceras) blakei*<br>*C. (Mitic.) tenuiserratum* | ***Card. (Miticard.) tenuiserratum*** | 8 | | | | DSJ23 |
| | | | | *Card. densiplicatum* | *C. (Malton.) maltonense*<br>*C. (Verteb.) vertebrale* | ***Cardioceras* cf. *densiplicatum*** | 7<br>6<br>5 | 40 | | ***Trichodinium scarburghensis*** | DSJ22 |
| | | | EARLY | *Cardioceras cordatum* | *Cardioceras cordatum*<br>*Cardioceras costicardia*<br>*Cardioceras bukowskii* | ***Cardioceras* cf. *costicardia*** | 4 | | | | **DSJ21** |
| | | 163.5 | | *Cardioceras mariae* | *Cardioceras praecordatum*<br>*Cardioceras scarburgense* | ***Cardioceras alphacordatum***<br>***Cardioceras woodhamense*** | 3 | 39<br>38 | | *Wanaea fimbriata* | DSJ20 |
| | MID | CALL | LATE | *Quenstedt. lamberti* | *Quenstedtoceras lamberti*<br>*Quenstedtoceras henrici* | 🟨 | | | | *Wanaea thysanota* | DSJ19 |

🟨 not recognised by ammonites in Greenland

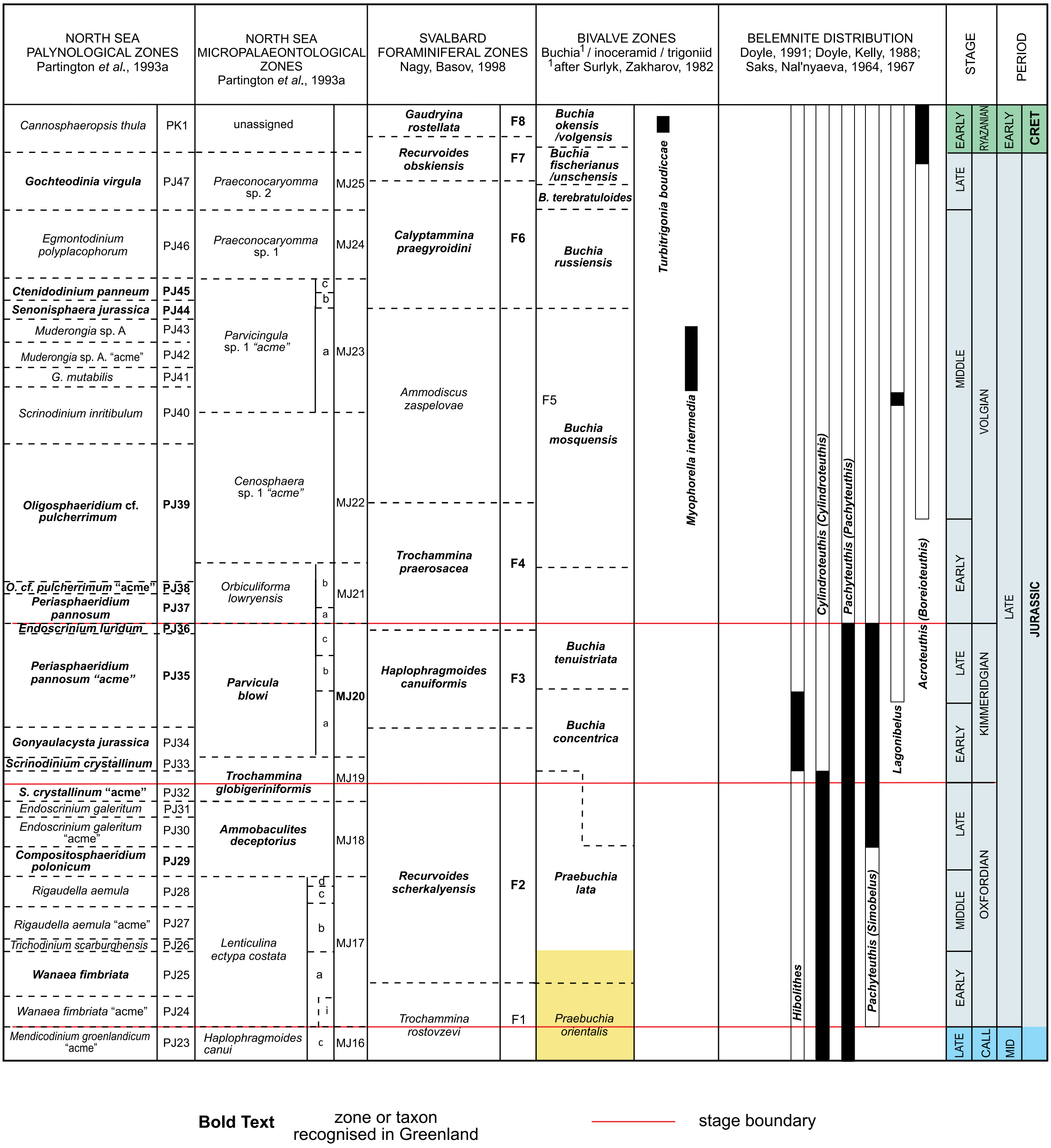
Greenland distribution in black

non-Greenland distribution in white

**Fig. 3. Integrated biostratigraphic chart**

**A**, **B** – the Early-Mid Jurassic; **C**, **D** – the Late Jurassic; time scale taken from Ogg, Hinnov (2012)

Fig. 3D



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'yaeva, 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 (Surlyk, 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. *Liotrigonia 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 *Mytiloceramus* 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). *Mytiloceramus* aff. *polyplocus* 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 *Arcticoceras ishmae* zone ammonites in the Pelion Sandstone (CASP Collections) and *Mytiloceramus* aff. *ambiguus* (Eichwald) with *Arctocephalites 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-Limbosporites* 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 Klinter area of Jameson Land in the base of the Rævekløft Formation, Neill Klinter Group (Dam, Surlyk, 1998). The transgressive marine sandstone contains a rich molluscan 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 Pleinsbachian *Uptonia jamesoni* to *Tragophylloceras ibex* zones and possibly the *Prodactylioceras 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 – Botryocccus* is marked by the first occurrence of dinoflagellate cysts in North East Greenland represented by *Nannoceratopsis* spp. (especially *Nanoceratopsis 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 – Cerebropolenites 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 Albuen Member of the Gule Horn Formation. The zones 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 *Liotrigonia 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 Klinter 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 Ostrealev Formation. It equates with Assemblage C of Lund, Pederson (1985). Based on comparisons with the Danish Basin and the occurrence in AZ6 of *Phallocysta eumekes*, *Wallodinium laganum*, *Scriniocassis* spp. and *Dissilioudodinium* 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 Koppelhus, Hansen (2003) recognised three assemblage zones. The lowest *Botryococcus* is marked by the occurrence of abundance of *Botryoccus* 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 Koppelhus, Hansen (2003) within the Sortehat Formation.

**Assemblage Zone 9.** This is the uppermost of Koppelhus 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*. Koppelhus 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 occurence of *Trigonia hemisphaerica* Lycett near the base of the lowest Jurassic sandstone at Gneissnaes on Store Koldewey, invites correlation with Lincolnshire, England occurences 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. hemispaerica* 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 occurence 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 *Sentusidium 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 Koppelhus, 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; Koppelhus, 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 *Arctocepha-*

*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 *Kepplerites* 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 *Kepplerites* in horizon 19. The Late Bathonian was marked by horizons 20–25 (Callomon, 2003) characterised by species of *Kepplerites* 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* α and horizon 26 *C. apertum* β (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 nordenskjoeldi* α 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. *jason* 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 rostovsevi* 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 occurence 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 Kimmerdgian (Partington *et al.*, 1993a, b; Gregory, 1995; MJ18-lower MJ19 zonal range). Radiolarian taxa include *Parvicingula deadhorsensis*, *Stichocapsa devorata*, *Ristola firma*, *Paraparvicingula 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 mutabili*s 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 *Plasmatites 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 *Trochamina 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 Wollaston 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. unschensis* 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 successsion, this is equivalent the upper part of the *Calyptammina praegyroidini* 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 *Berriasella 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 Forland-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 Klinter Group. Published macrofossil 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.

**Acknowledgements.** The authors thank the subscribing companies to the CASP East Greenland Project for their continued support. The late John Callomon and Andrzej Wierzbowski (Polish Geological Institute, Warsaw), provided information on ammonite stratigraphy. Steve Vincent (CASP), Peter Alsen (Geus, Copenhagen), Mikhail Rogov and Victor Zakharov (Geological Institute, Moscow) made valuable comments on the original drafts of this article.

## REFERENCES

ALSEN P., SURLYK F., 2004 — Maximum Middle Jurassic transgression in East Greenland: evidence from new ammonite finds, Bjørnedal, Traill Ø. With an Appendix by J.H. Callomon. *In*: The Jurassic of North-East Greenland (eds L. Stemmerik, S. Stouge). *Geological Survey of Denmark and Greenland, Bulletin*, **5**: 31–49.

ALSGAARD P.C., FELT V.L., VOSGERAU H., SURLYK F., 2003 — The Jurassic of Kuhn Ø, North-East Greenland. *In*: The Jurassic of Denmark and Greenland (eds J.R. Ineson, F. Surlyk).

*Geological Survey of Denmark and Greenland Bulletin*, **1**: 865–892.

BIRKELUND T., 1975 — A review of the Jurassic of East Greenland. *In*: Jurassic northern North Sea symposium 1975 proceedings (eds K. Finstad, R. Selley): 6.1–6.27. Norwegian Petroleum Society, Stavanger.

BIRKELUND T., CALLOMON J.H., 1985 — The Kimmeridgian ammonite faunas of Milne Land, central East Greenland. *Grønlands Geologiske Undersøgelse, Bulletin*, **153**: 1–56, 23 pls.

BIRKELUND T., CALLOMON J.H., FÜRSICH F.T., 1984 — The stratigraphy of the Upper Jurassic and Lower Cretaceous sediments of Milne Land, central East Greenland. *Grønlands Geologiske Undersøgelse, Bulletin*, **147**: 1–56.

BIRKELUND T., HÅKANSSON E., SURLYK F., 1971 — New finds of Bathonian, Callovian, and Oxfordian ammonites in northern Jameson Land, East Greenland. *Bulletin of the Geological Society of Denmark*, **20**: 240–259.

BRAGIN N.Yu., 1997 — Radiolaria from the phosphorite basal horizons of the Volgian Stage in the Moscow Region (Russia). *Review of Micropaleontology*, **40**, 4: 283–296.

BRAGIN N.Yu., 2009 — Echinocampidae fam. nov., a new family of Late Jurassic–Early Cretaceous radiolarians of Arctic Siberia. *Paleontological Journal*, **43**, 4: 356–369.

BRAGIN N.Yu., 2011 — Radiolarians of the Volgian and Berriasian Stages of the north of Central Siberia. *Stratigraphy and Geological Correlation*, **19**, 2: 173–187.

BRAGIN N.Yu., KISELEV D.N, 2013 — Radiolarians from Upper Jurassic (Middle Oxfordian and Upper Kimmeridgian) deposits of Yaroslavl Oblast. *Stratigraphy and Geological Correlation*, **21**, 6: 628–636.

BREKKE H., DAHLGREN S., NYLAND B., MAGNUS C., 1999 — The prospective of the Vøring and Møre basins on the Norwegian Sea continental margin. *In*: Petroleum Geology of NW Europe: Proceedings of the 5th Conference (eds A.J. Fleet, S.A.R. Boldy): 261–274. Geological Society, London.

BROOKE M.M., BRAUN W.K., 1972 — Biostratigraphy and microfaunas of the Jurassic System of Saskatchewan. Department of Mineral Resources, Saskatchewan, Report, **161**: 321–339, figs 1–9, pls 1–23.

CALLOMON J.H., 1961 — The Jurassic System in East Greenland. *In*: Geology of the Arctic Vol. 1 (Ed. G.O. Raasch): 258–268. Toronto, Toronto University Press.

CALLOMON J.H., 1985 — The evolution of the Jurassic ammonite family Cardioceratidae. *Special Papers in Palaeontology*, **33**: 49–90.

CALLOMON J.H., 1993 — The ammonite succession in the Middle Jurassic of East Greenland. *Bulletin of the Geological Society of Denmark*, **40**: 83–113.

CALLOMON J.H., 1994 — Jurassic ammonite biochronology of Greenland and the Arctic. *Bulletin of the Geological Society of Denmark*, **41**: 128–137.

CALLOMON J.H., 2003 — The Middle Jurassic of western and northern Europe: its subdivisions, geochronology and correlations. *In*: The Jurassic of Denmark and Greenland (eds J.R. Ineson, F. Surlyk). *Geological Survey of Denmark and Greenland Bulletin*, **1**: 61–74.

CALLOMON J.H., 2004 — Appendix: Description of a new species of ammonite, *Kepplerites tenuifasciatus* n.sp., from the Middle Jurassic, Lower Callovian of East Greenland. *In*: Maximum Middle Jurassic transgression in East Greenland: evidence from new ammonite finds, Bjørnedal, Traill Ø (eds P. Alsen, F. Surlyk). *In*: The Jurassic of North-East Greenland (eds L. Stemmerik, S. Stouge). *Geological Survey of Denmark and Greenland, Bulletin*, **5**: 42–49.

CALLOMON J.H., ALSEN P., SURLYK F., 2014 — The Upper Bajocian *Cranocephalites* succession in East Greenland: achieving the highest possible biostratigraphic resolution. *In*: 9th International Congress on the Jurassic System, Jaipur India, Abstracts (eds D.K. Pandey *et al.*). *Beringeria*, Special Issue, **8**: 32–33.

CALLOMON J.H., BIRKELUND T., 1982 — The ammonite zones of the Boreal Volgian (Upper Jurassic) in East Greenland. *In*: Arctic geology and geophysics (eds A.F. Embry, H.R. Balkwill): 349–369. Canadian Society of Petroleum Geologists, Calgary.

CASEY R., 1973 — The ammonite succession at the Jurassic-Cretaceous boundary in eastern England. *In*: The Boreal Lower Cretaceous (eds R. Casey, P.F. Rawson). *Geological Journal Special Issue*, **5**: 193–266.

COPE J.C.W., DUFF K.L., PARSONS C.F., TORRENS H.S., WIMBLEDON W.A., WRIGHT J. K. 1980 — A correlation of Jurassic rocks in the British Isles. Part Two: Middle and Upper Jurassic. *Special Report of the Geological Society of London*, **15**: 1–109.

DAIN J.G., 1967 — K sistematike nekotorykh foraminifer iz semeystva Ceratobuliminidae [On the systematics of some foraminifera of the family Ceratobuliminidae]. *In*: Trudy IV seminara po microbiostratigrafiya [Report of the IV seminar on microbiostratigraphy]: 42–45. Leningrad [in Russian].

DALLAND A., WORSLEY D., OFSTAD K., 1988 — A lithostratigraphic scheme for the Mesozoic and Cenozoic succession offshore mid- and northern Norway. *Norwegian Petroleum Directorate Bulletin*, **4**: 1–65.

DAM G., SURLYK F., 1993 — Cyclic sedimentation in a large wave- and storm-dominated anoxic lake; Kap Stewart Formation (Rhaetian-Sinemurian), Jameson Land, East Greenland. *In*: Sequence stratigraphy and facies associations (eds H.W. Posamentier *et al.*). *International Association of Sedimentologists Special Publication*, **18**: 419–448.

DAM G., SURLYK F., 1998 — Stratigraphy of the Neill Klinter Group: a Lower-lower Middle Jurassic tidal embayment succession, Jameson Land, East Greenland. *Bulletin Grønlands Geologiske Undersøgelse*, **175**: 1–80.

DONOVAN D.T., 1957 — The Jurassic and Cretaceous systems in East Greenland. *Meddelelser om Grønland*, **155**, 4: 1–214.

DONOVAN D.T., 1964 — Stratigraphy and ammonite fauna of the Volgian and Berriasian rocks of East Greenland. *Meddelelser om Grønland*, **154**, 4: 1–34.

DOYLE P., 1991 — Belemnites from the Lower Jurassic of East Greenland and their biostratigraphical and biogeographical significance. *Bulletin Geological Society Denmark*, **39**: 123–141.

DOYLE P., KELLY S.R.A., 1988 — Jurassic and Cretaceous belemnites of Kong Karls Land. *Norsk Polarinstitutt Skrifter*, **189**: 1–72.

DZYUBA O.S., ISOKH O.P., SHURYGIN B.N., 2013 — Carbon isotope excursions in Boreal Jurassic-Cretaceous boundary sections and their correlation potential. *Palaeogeography, Palaeoclimatology and Palaeoecology*, **381/382**: 33–46.

ENGKILDE M., SURLYK F., 2003 — Shallow marine syn-rift sedimentation: Middle Jurassic Pelion Formation, Jameson Land, East Greenland. *In*: The Jurassic of Denmark and Greenland (eds J.R. Ineson, F. Surlyk). *Geological Survey of Denmark and Greenland, Bulletin*, **1**: 813–863.

FENSOME R., 1979 — Dinoflagellate cysts and acritarchs from the Mid and Upper Jurassic of Jameson Land, East Greenland. *Grønlands Geologiske Undersøgelse, Bulletin*, **132**: 1–98, 9 pls.

FÜRSICH F.T., 1982 — Upper Jurassic bivalves from Milne Land, East Greenland. *Grønlands Geologiske Undersøgelse, Bulletin*, **144**: 1–126.

GREGORY F.J., 1989 — Palaeoenvironmental interpretation and distribution of the Lower Kimmeridgian foraminifera from the Helmsdale-Brora outlier, northeast Scotland. *In*: North Western micropalaeontology and palynology (eds D.J. Batten, M.C. Keen): 173–192. Ellis Horwood, Chichester.

GREGORY F.J., 1995 — Jurassic Foraminifera and Radiolaria of Scotland, biostratigraphy and palaeoenvironmental analysis: An integrated approach. [PhD Thesis]. University of Hull, Hull [unpublished].

GULYAEV D.B., 2012 — K revizii ammonitov roda *Paracadoceras* (Cardioceratidae) is verkhnego bata i nizhnego kelloveya vostochnoy Grenlandii [On the revision of ammonites of the genus *Paracadoceras* (Cardioceratidae) from the Upper Bathonian and Lower Callovian of East Greenland]. *In*: Contributions to current Cephalopod research: morphology, systematics, evolution, ecology and biostratigraphy (eds T.B. Leonova *et al.*): 69–72. Russian Academy of Sciences, Borissiak Paleontological Institute, Moscow (in Russian with English summary).

HARLAND W.B., ARMSTRONG R.L., COX A.V., CRAIG L.A., SMITH A.G., SMITH D.G., 1990 — A geologic time scale 1989. Cambridge University Press, Cambridge.

HARRIS T.M., 1937 — The fossil flora of Scoresby Sound, East Greenland. Part 5: stratigraphic relations of the plant beds. *Meddelelser om Grønland*, **112**, 2: 1–114.

HARRIS T.M., 1946 — Liassic and Rhaetic plants collected in 1936–38 from East Greenland. *Meddelelser om Grønland*, **114**, 9: 1–40.

HARRIS T.M., 1961 — The Rhaeto-Liassic flora of Scoresby Sound, central East Greenland. *In*: Geology of the Arctic, Vol. 1 (Ed. G.O. Raasch): 268–273. University of Toronto Press, Toronto.

HOCHSTETTER F. VON, 1874 — Geologie Ostgrönlands zwischen dem 73. und 76. nördl. Br. Mit einer geologischen Kartenskizze. Die zweite deutsche Nordpolarfahrt. Vol 2. Brockhaus, Leipzig.

INESON J.R., SURLYK F. (eds), 2003 — The Jurassic of Denmark and Greenland. *Geological Survey of Denmark and Greenland Bulletin*, **1**: 1–948.

JAMIESON R., 1823 — Appendix. List of specimens of the rocks brought from the eastern coast of Greenland. *In*: Journal of a voyage to the northern whale fishery including discoveries on the eastern coast of West Greenland made in the summer of 1822, in the ship Baffin of Liverpool (Ed. W. Scoresby Jr): 1–399. Archibald Constable, Edinburgh.

JELETZKY J.A., 1966 — Upper Volgian (Latest Jurassic) ammonites and buchias of Arctic Canada. *Geological Survey of Canada, Bulletin*, **128**: 1–51, 58 pls.

JELETZKY, J.A., 1984 — Jurassic-Cretaceous boundary beds of western and arctic Canada and the problem of the Tithonian-Berriasian stages in the boreal realm. *In*: Jurassic-Cretaceous biochronology and palaeogeography of North America (Ed. G.E.G. Westermann). *Geological Association of Canada Special Paper*, **27**: 175–255.

KELLY S.R.A., 2006 — Abstract: Perisphinctes Ravine – a key Jurassic-Cretaceous boundary succession in Kuhn Ø, NE Greenland. *Palaeontological Association Newsletter*, **63**: 61.

KELLY S.R.A., GREGORY F.J., BRAHAM B., STROGEN D.P., WHITHAM A.G., 2014 — Abstract: Towards an integrated Jurassic biostratigraphy for eastern Greenland. In: 9th International Congress on the Jurassic System, Jaipur India, Abstracts (eds D.K. Pandey *et al.*). *Beringeria*, Special Issue, **8**: 92.

KELLY S.R.A., WHITHAM A.G., KORAINI M.A., PRICE S.P., 1998 — Lithostratigraphy of the Cretaceous (Barremian–Santonian) Hold with Hope Group, North East Greenland. *Journal of the Geological Society*, London, **155**: 993–1008.

KENT P.E., 1966 — A review of the correlation of the Lincolnshire Limestone (Inferior Oolite). *Transactions of the Leicester Literary and Philosophical Society*, **60**: 57–69.

KITCHIN F.L., 1903 — The Jurassic fauna of Cutch. The Lamellibranchiata; No. 1, genus *Trigonia*: *Palaeontographica Indica*, Series 9, **3**, 2: 1–122, pls 121–110.

KOLDEWEY K., 1874 — Die zweite deutsche Nordpolarfahrt in den Jahren 1869 und 1870 unter Fuhrung des Kapitan Karl Koldewey. Vol 1. Brockhaus, Leipzig.

KOPPELHUS E.B., DAM G., 2003 — Palynostratigraphy and palaeoenvironments of the Rævekløft, Gule Horn and Ostreaelv formations (Lower-Middle Jurassic), Neill Klinter Group, Jameson Land, East Greenland. *In*: The Jurassic of Denmark and Greenland (eds J.R. Ineson, F. Surlyk). *Geological Survey of Denmark and Greenland Bulletin*, **1**: 723–776.

KOPPELHUS E.B., HANSEN C.F., 2003 — Palynostratigraphy and palaeoenvironments of the Middle Jurassic Sortehat Formation (Neill Klinter Group), Jameson Land, East Greenland. *In*: The Jurassic of Denmark and Greenland (eds J.R. Ineson, F. Surlyk). *Geological Survey of Denmark and Greenland Bulletin*, **1**: 777–812.

KOSHELKINA Z.V., 1962 — Polevoy atlas rukovodyashchikh faun yurskikh otlozheniy Vilyuyskoy sineklisy i preverkhoyanskogo krayevogo progiba [Field atlas of the guide fauna of the Jurassic deposits of the Vilyui Syneclise and the Verkhoyansk marginal foredeep], Magadan, SVKNII, 136 pp [in Russian].

KOZLOVA G.E., 1971 — O nahodke radiolyarii v nizhnekimeridzhskih otlozheniyah Timano-Ural'skoi Oblasti [On radiolarians from the Lower Kimmeridgian deposits of the Timan-Prechora region]. *Doklady Akademiya Nauk SSSR*, **201**, 5: 1175–1177 [in Russian].

LARSEN M., PIASECKI S., SURLYK F., 2003 — Stratigraphy and sedimentology of a basement-onlapping shallow marine sandstone succession, the Charcot Bugt Formation, Middle-Upper Jurassic, East Greenland. *In*: The Jurassic of Denmark and Greenland (eds J.R. Ineson, F. Surlyk). *Geological Survey of Denmark and Greenland Bulletin*, **1**: 893–930.

LUND J.J., PEDERSEN K.R., 1985 — Palynology of the marine Jurassic formations in the Vardekløft Ravine, Jameson Land, East Greenland. *Bulletin of the Geological Society of Denmark*, **33**: 371–399.

MATYJA B.A., WIERZBOWSKI A., WRIGHT J.K., 2006 — The Sub-Boreal/Boreal ammonite succession at the Oxfordian/Kimmeridgian boundary at Flodigarry, Staffin Bay (Isle of Skye), Scotland. *Transactions of the Royal Society of Edinburgh, Earth Sciences*, **96**: 387–405.

MCELWAIN J.C., POPA M.E., HESSELBO S.P., HAWORTH M., SURLYK F., 2007 — Macroevolutionary responses of terrestrial vegetation to climate and atmospheric change across the Triassic/Jurassic boundary in East Greenland. *Paleobiology*, **33**, 4: 547–573.

MILNER P.S., PIASECKI S., 1996 — Boreal Middle Jurassic dinoflagellate cyst stratigraphy of Jameson Land, East Greenland. *In*: Formation of source and reservoir rocks in a sequence stratigraphic framework, Jameson Land, East Greenland (eds S. Piasecki *et al.*). *Danmarks og Grønland Geologiske Undersøgelse Rapport*, **30**, 2: 1–49.

MITTA V.V., 2005 — New data on the age of the Ryazanian stage basal layers. *Stratigraphy and Geological Correlation*, **13**, 5: 503–511.

MITTA V.V., 2009 — The Upper Bajocian-Lower Bathonian of Pechora River Basin and Boreal-Tethyan Correlation. *Stratigraphy and Geological Correlation*, **17**, 1: 68–78.

MITTA V.V., ALSEN P., 2013 — Ammonity i zonal'naya shkala batskogo Grenland [Ammonites and zonal scale of the Bathonian of Greenland]. *In*: Yurskaya sistema Rossii: problemy stratigrafii i paleogeografii [Jurassic system of Russia: problems of stratigraphy and palaeogeography], 149–151. Nauka, Ekaterinburg [in Russian].

MITTA V.V., ALSEN P., 2014 — Abstract: Ammonite zonation of the Boreal Bathonian Stage of Greenland. In: 9th International Congress on the Jurassic System, Jaipur India, Abstracts (eds D.K. Pandey *et al.*). *Beringeria*, Special Issue, **8**: 118–119.

MITTA V.V., KOSTYLEVA V., DZYUBA O.S., GLINSKIKH L., SHURYGIN B.N., SELTZER V., IVANOV A., URMAN O., 2014 — Biostratigraphy and sedimentary settings of the Upper Bajocian-Lower Bathonian of the vicinity of Saratov (Central Russia). *Neues Jahrbuch für Geologie und Paläontologie*, Abhandlungen, **271**, 1: 95–121.

MORGENROTH P., 1970 — Dinoflagellate cysts from the Lias Delta of Lühnde, Germany: *Neues Jahrbuch für Geologie und Paläontologie*, Abhandlungen, **136**: 345–359.

MORTON A., HALLSWORTH C., STROGEN D., WHITHAM A., FANNING M., 2009 — Evolution of provenance in the NE Atlantic rift: The Early-Middle Jurassic succession in the Heidrun Field, Halten Terrace, offshore Mid-Norway. *Marine and Petroleum Geology*, **26**, 7: 1100–1117.

NAGY J., BASOV V., 1998 — Revised foraminiferal taxa and biostratigraphy of Bathonian to Ryazanian deposits in Spitsbergen. *Micropaleontology*, **44**: 217–255.

OGG J.G., HINNOV L.A., 2012 — Jurassic. *In*: The geologic time scale (eds F.M. Gradstein *et al.*): 731–791. Elsevier, Amsterdam.

PAGE K.N., 2003 — The Lower Jurassic of Europe: its subdivision and correlation. *In*: The Jurassic of Denmark and Greenland (eds J.R. Ineson, F. Surlyk). *Geological Survey of Denmark and Greenland Bulletin*, **1**: 23–59.

PARTINGTON M.A., COPESTAKE P., MITCHENER B.C., UNDERHILL J.R., 1993a — Biostratigraphic calibration of genetic stratigraphic sequences in the Jurassic-lowermost Cretaceous (Hettangian-Ryazanian) of the North Sea and adjacent areas. *In*: Petroleum Geology of Northwest Europe: Proceedings of the 4th Conference. Volume 1 (Ed. J.R. Parker): 371–386. Geological Society, London.

PARTINGTON M.A., MITCHENER B.C., MILTON N.J., FRASER A.J., 1993b — Genetic sequence stratigraphy for the North Sea Late Jurassic and Early Cretaceous: distribution and prediction of Kimmeridgian Late Ryazanian reservoirs in the the North Sea and adjacent areas. *In*: Petroleum Geology of Northwest Europe: Proceedings of the 4th Conference. Volume 1 (Ed. J.R. Parker): 347–370. Geological Society, London.

PEDERSEN K.R., LUND J.J., 1980 — Palynology of the plant-bearing Rhaetian to Hettangian Kap Stewart Formation, Scoresby Sund, East Greenland. *Review of Palaeobotany and Palynology*, **31**: 1–69.

PIASECKI S., 1980 — Mid to Late Jurassic dinoflagellate cyst stratigraphy from Milne Land and Jameson Land (East Greenland). Ph.D. thesis, University of Copenhagen [unpublished].

PIASECKI S., 1996 — Boreal Middle Jurassic dinoflagellate cyst stratigraphy of Middle to Upper Jurassic sediments of Milne Land, East Greenland. *In*: Formation of source and reservoir rocks in a sequence stratigraphic framework, Jameson Land, East Greenland (eds S. Piasecki *et al.*). *Danmarks og Grønland Geologiske Undersøgelse Rapport*, **30**, 1: 1–100.

PIASECKI S., CALLOMON J.H., STEMMERIK L., 2004a — Jurassic dinoflagellate cyst stratigraphy of Store Koldewey, North-East Greenland. *In*: The Jurassic of North-East Greenland (eds L. Stemmerik, S. Stouge). *Geological Survey of Denmark and Greenland, Bulletin*, **5**: 99–112.

PIASECKI S., LARSEN M., THERKELSEN J., VOSGERAU H., 2004b — Jurassic dinoflagellate cyst stratigraphy of Hold with Hope, North-East Greenland. *In*: The Jurassic of North-East Greenland (eds L. Stemmerik, S. Stouge). *Geological Survey of Denmark and Greenland, Bulletin*, **5**: 73–88.

PIASECKI S., STEMMERIK L., 2004 — Jurassic dinoflagellate cysts from Hochstetter Forland, North-East Greenland. *In*: The Jurassic of North-East Greenland (eds L. Stemmerik, S. Stouge). *Geological Survey of Denmark and Greenland, Bulletin*, **5**: 89–97.

POULSEN N.E., RIDING J.B., 2003 — The Jurassic dinoflagellate cyst zonation of Subboreal Northwest Europe. *In*: The Jurassic of Denmark and Greenland (eds J.R. Ineson, F. Surlyk). *Geological Survey of Denmark Greenland, Bulletin*, **1**: 115–146.

POULTON T.P., 1979 — Jurassic trigoniid bivalves from Canada and western United States of America. *Geological Survey of Canada, Bulletin*, **282**: 1–82.

POULTON T.P., 1991 — Hettangian through Aalenian (Jurassic) guide fossils and biostratigraphy, northern Yukon and adjacent territories. *Geological Survey of Canada, Bulletin*, **410**: 1–95.

POULTON T.P., CALLOMON J.H., 1977 — A new species of trigoniid bivalve from the boreal Bathonian (Jurassic) of central East Greenland. *Bulletin of the Geological Society of Denmark*, **26**: 155–159.

RAWSON P.F., 1982 — New Arctocephalitinae (Ammonoida) from the Middle Jurassic of Kong Karls Land, Svalbard. *Geological Magazine*, **119**, 1: 95–100, pl. 102.

REPIN YU.S., 2007 — Ammonitovaya shkala Pechorskoy yury [Ammonite scale for the Pechora Jurassic]. *Byulleten' Moskovskogo obshchestva, Ispytateley Prirody, Otdel Geologicheskiy*, **82**: 24–31 [in Russian].

RIDING J.B., THOMAS J.E., 1992 — Dinoflagellate cysts of the Jurassic System. *In*: A stratigraphic index of dinoflagellate cysts (Ed. A.J. Powell): 7–99. British Micropalaeontological Society and Chapman & Hall, London.

ROGOV M.A., 2010 — New data on ammonites and stratigraphy of the Volgian Stage in Spitzbergen. *Stratigraphy and Geological Correlation*, **18**, 5: 42–59.

ROGOV M.A., 2012 — Latitudinal gradient of taxonomic richness of ammonites in the Kimmeridgian-Volgian in the Northern Hemisphere, *Paleontological Journal*, **46**, 2: 148–156.

ROLLIER L., 1914 — Fossiles nouveaux ou peu connus des terrains secondaires du Jura et des contrées environnantes. *Abhandlungen der Schweizerischen Paläontologischen Gesellschaft*, **40**: 321–444, pls 321–328.

ROSENKRANTZ A., 1934 — The Lower Jurassic rocks of East Greenland. *Meddelelser om Grønland*, **110**, 1: 1–122, 13 pls.

ROSENKRANTZ A., 1942 — The Lower Jurassic rocks of East Greenland. Part II, the Mesozoic sediments of the Kap Hope area southern Liverpool Land. *Meddelelser om Grønland*, **110**, 2: 1–56, 54 pls.

SAKS V.N., NAL'NYAEVA T.I., 1964 — Verkhneyurskiye i nizhnemelovyye belemnity severa SSSR, rody *Cylindroteuthis* i *Lagonibelus* [Upper Jurassic and Lower Cretaceous belemnites of northern USSR, genera *Cylindroteuthis* and *Lagonibelus*]. Nauka, Leningrad [in Russian].

SAKS V.N., NAL'NYAEVA T.I., 1970 — Ranne- i sredneyyurskiye belemnity severa SSSR, Nannobelinae Passaloteuthinae i Hastitidae [Early and Middle Jurassic belemnites of northern USSR, Nannobelinae Passaloteuthinae and Hastitidae]. Nauka, Leningrad [in Russian].

SARJEANT W.A.S., 1972 — Dinoflagellate cysts and acritarchs from the Upper Vardekløft Formation (Jurassic) of Jameson Land, East Greenland. *Meddelelser om Grønland*, **195**: 1–69.

SAVEL'YEV A.A., 1958 — Nizhnemelovyye trigoniidy mangyshlaka i zapadnoy turkmenii [Lower Cretaceous trigoniids from Mangyshlak and western Turkmeniya]. Trudy VNIGRI, **125**: 1–518 [in Russian].

SEY I.I., KALACHEVA E.D., 1992 — Dvustvorchatyye mollyuski i ammonoidei sredney i verkhney yury Dalnego Vostoka [Bivalve molluscs and ammonoids from the Middle and Upper Jurassic of the Far East]. *In*: Atlas Rukovodyashchikh grupp fauny mezozoya yuga i vostoka SSSR [Atlas of the index fossil fauna of the Mesozoic of the south and east of the USSR] (eds T.D. Zonova, K.O. Rostovtsev): 80–102, pls 144–160. Nedra, St Petersburg [in Russian].

SMELROR M., 1988 — Late Bathonian to Early Oxfordian dinoflagellate cyst stratigraphy of Jameson Land and Milne Land, East Greenland. *Grønlands Geologiske Undersøgelse, Rapport*, **137**: 135–159.

SMELROR M., KELLY S.R.A., DYPVIK H., MORK A., NAGY J., 2001 — Mjølnir (Barents Sea) meteorite impact ejecta offers a Volgian-Ryazanian boundary marker. *Newsletters in Stratigraphy*, **38**, 2/3: 129–140.

SPATH L.F., 1932 — The invertebrate faunas of the Bathonian-Callovian deposits of Jameson Land (East Greenland). *Meddelelser om Grønland*, **87**, 7: 1–158, pls 1–26.

SPATH L.F., 1935 — The Upper Jurassic invertebrate faunas of Cape Leslie, Milne Land; I, Oxfordian and Lower Kimmeridgian. *Meddelelser om Grønland*, **99**, 2: 1–82.

SPATH L.F., 1936 — The Upper Jurassic invertebrate faunas of Cape Leslie, Milne Land. II. Upper Kimmeridgian and Portlandian. *Meddelelser om Grønland*, **99**, 3: 1–180.

SPATH L.F., 1947 — Additional observations on the invertebrates (chiefly ammonites) of the Jurassic and Cretaceous of East Greenland. I. The *Hectoroceras* fauna of S.W. Jameson Land. *Meddelelser om Grønland*, **132**, 3: 1–7, pls 1–5.

SPATH L.F., 1952 — Additional observations on the invertebrates (chiefly ammonites) of the Jurassic and Cretaceous of East Greenland. II. Some infra-Valanginian ammonites from Lindemans Fjord, Wollaston Forland; with a note on the base of the Cretaceous. *Meddelelser om Grønland*, **133**, 4: 1–40, pls 1–4.

STEMMERIK L., DAM G., NOE-NYGAARD N., PIASECKI S., SURLYK F., 1998 — Sequence stratigraphy of source and reservoir rocks in the Upper Permian and Jurassic of Jameson Land, East Greenland. *Grønlands Geologiske Undersøgelse, Bulletin*, **180**: 43–54.

STEMMERIK L., STOUGE S. (eds), 2004 — The Jurassic of North-East Greenland. *Geological Survey of Denmark and Greenland, Bulletin*, **5**: 1–112.

SURLYK F., 1973 — The Jurassic-Cretaceous boundary in Jameson Land, East Greenlan. *In*: The Boreal Lower Cretaceous (eds R. Casey, P.F. Rawson). *Geological Journal Special Issue*, **5**: 81–100. Seel House Press, Liverpool.

SURLYK F., 1978 — Submarine fan sedimentation along fault scarps on tilted fault blocks (Jurassic-Cretaceous boundary), East Greenland. *Grønlands Geologiske Undersøgelse, Bulletin*, **128**, 1–108, 9 pls.

SURLYK F., 2003 — The Jurassic of East Greenland: a sedimentary record of thermal subsidence, onset and culmination of rifting. *In*: The Jurassic of Denmark and Greenland (eds J.R. Ineson, F. Surlyk). *Geological Survey of Denmark and Greenland, Bulletin*, **1**: 659–720.

SURLYK F., CALLOMON J.H., BROMLEY R.G., BIRKELUND T., 1973 — Stratigraphy of the Jurassic-Lower Cretaceous sediments of Jameson Land and Scoresby Land, East Greenland. *Grønlands Geologiske Undersøgelse, Bulletin*, **105**: 1–76.

SURLYK F., ZAKHAROV V.A., 1982 — Buchiid bivalves from the Upper Jurassic and Lower Cretaceous of East Greenland. *Palaeontology*, **25**, 4: 727–753.

SYKES R.M., CALLOMON J.H., 1979 — The *Amoeboceras* zonation of the Boreal Upper Oxfordian. *Palaeontology*, **22**, 4: 839–903, pls 112–121.

SYKES R.M., SURLYK F., 1976 — A revised ammonite zonation of the Boreal Oxfordian and its application in northeast Greenland. *Lethaia*, **9**: 421–436.

THERKELSEN J., SURLYK F., 2004 — The fluviatile Bristol Elv Formation, a new Middle Jurassic lithostratigraphic unit from Traill Ø, North-East Greenland. *In*: The Jurassic of North-East Greenland (eds L. Stemmerik, S. Stouge). *Geological Survey of Denmark and Greenland, Bulletin*, **5**: 19–30.

TOULA F., 1874 — Beschreibung mesozoischer Versteinerungen von der Kuhn Insel. *In*: Die zweite deutsche Nordpolarfahrt in den Jahren 1869 und 1870 unter Führung des Kapitän Karl Koldeway (Ed. K. Koldeway), 497–507, 2 pls. Brockhaus, Leipzig.

WIERZBOWSKI A., COE A., HOUNSLOW M.W., MATYJA B.A., OGG J.G., PAGE K.A., WIERZBOWSKI H., WRIGHT J.K., 2006 — A potential stratotype for the Oxfordian/Kimmeridgian boundary: Staffin Bay, Isle of Skye, UK. *Volumina Jurassica*, **4**: 17–33.

WIERZBOWSKI A., ROGOV M.A., 2013 — Biostratigraphy and ammonites of the Middle Oxfordian to lowermost Upper Kimmeridgian in northern Central Siberia. *Russian Geology and Geophysics*, **54**: 1083–1102.

WIMBLEDON W.A.P., CASELLATO C.E., REHÁKOVÁ D., BULOT L.G., ERBA E., GARDIN S., VERRUESSEL R.M.C.H., MUNSTERMAN D.K., HUNT C.O., 2011 — Fixing a basal Berriasian and Jurassic/Cretaceous (J/K) boundary – is there perhaps some light at the end of the tunnel? *Rivista Italiana di Paleontologia e Stratigrafia*, **117**, 2: 295–307.

WRIGHT J.K., KELLY S.R.A., PAGE K.N., 2000 — The stratigraphy of the 'Corallian' facies Middle Oxfordian (Upper Jurassic) deposits at Upware. *Proceedings of the Geologists' Association*, **111**: 97–110.

ZAKHAROV V.A., 1981 — Buchiidy i biostratigraphiya boreal'noy verkhney yuri i neocoma [Buchiids and biostratigraphy of the boreal Upper Jurassic and Neocomian]. *Trudy Instituta Geologii i Geofiziki*, Novosibirsk, **458**: 1–271, pls 1–60 [in Russian].

ZAKHAROV V. A., BOGOMOLOV Y.I., IL'INA V.I., KONSTANTINOV A.G., KURUSHIN N.I., LEBEDEVA N.K., MELEDINA S.V., NIKITENKO V.L., SOBOLEV E.S., SHURYGIN, B.N., 1997 — [Boreal zonal standard and biostratigraphy of the Mesozoic of Siberia. *Geologiya Russian Geology and Geophysics*, **38**, 5: 965–993 [in Russian and English].

ZALASIEWICZ J., SMITH A., BRENCHLEY P., EVANS J., KNOX R., GALE A.S., GREGORY F.J., RUSHTON A., GIBBARD P., HESSELBO S.P., MARSHALL J., OATES M., RAWSON P.F., TREWIN N., 2004 — Simplifying the stratigraphy of time: *Geology*, **32**: 1–4.

ZEISS A., 2003 — The Upper Jurassic of Europe: its subdivision and correlation. *In*: The Jurassic of Denmark and Greenland (eds J.R. Ineson, F. Surlyk). *Geological Survey of Denmark and Greenland Bulletin*, **1**: 75–114.