Triassic palynoevents in the circum-Arctic region

Gunn Mangerud[1*], Niall W. Paterson[2] and Jonathan Bujak[3]

1. Department of Earth Science, University of Bergen, Allégaten 41, N-5007 Bergen, Norway
2. CASP, West Building, Madingley Rise, Cambridge, CB3 0UD, UK
3. Bujak Research (International), 114 Abbotsford Road, Blackpool, Lancashire FY3 9RY, UK
*Corresponding author: <gunn.mangerud@uib.no>

ABSTRACT

Triassic successions of the present-day Arctic contain abundant and diverse assemblages of nonmarine palynomorphs that have provided important biostratigraphic information. Dinoflagellate cyst are biostratigraphically useful in marine intervals in the Upper Triassic. Based on published records, we present a compilation of 78 last occurrences (LOs), first occurrences (FOs), and some abundance events that are anticipated to have correlation potential in the Arctic region. Palynological work has been carried out in many Arctic areas, with extensive palynological research published on the Triassic successions of the Norwegian Barents Sea and Svalbard. An updated, recent palynological zonation scheme exists for that region, integrating previous schemes and illustrating the chronostratigraphic value of palynology in the Triassic. For the Lower and Middle Triassic, good ammonoid control ties the palynological zones to the chronostratigraphic scale. Independent control is sparse, and resolution is lower in the Upper Triassic, so that palynology is commonly the only biostratigraphic discipline available for chronostratigraphic dating and correlation.

RÉSUMÉ

Les successions triassiques de l'Arctique actuel abritent des assemblages abondants et diversifiés de palynomorphes terrestres qui ont livré des renseignements biostratigraphiques précieux. Les kystes dinoflagellés sont utiles sur le plan biostratigraphique dans les intervalles marins du Trias supérieur. Nous présentons, à partir de documents déjà publiés, une compilation de 78 dernières récurrences (DO) et premières récurrences (PO) ainsi que de certains phénomènes d'abondance entre lesquels nous anticipons des possibilités de corrélation dans la région arctique. Des travaux palynologiques ont été réalisés dans de nombreux secteurs de l'Arctique et des recherches palynologiques poussées ont été publiées sur la succession triassique de la zone norvégienne de la mer de Barents et Svalbard. Il existe pour cette région un schèma de zonation palynologique récent, mis à jour, qui intègre des schèmas antérieurs et illustre la valeur chronostratigraphique de la palynologie au cours du Trias. Dans le cas du Trias inférieur et moyen, une présence révélatrice d'ammonites relie les zones palynologiques à l'échelle chronostratigraphique. Le contrôle indépendant possible est clairsemé et la résolution est inférieure dans le cas du Trias supérieur, de sorte que la palynologie constitue communément la seule discipline biostratigraphique dont on dispose pour la datation et la corrélation chronostratigraphique.

[*Traduit par la redaction*]

INTRODUCTION

This article is a contribution to the Circum-Arctic Palynological Events (CAPE) project, providing a scheme of selected events for the Triassic Period. The Triassic extended from 251.90 to 201.36 Ma according to Gradstein *et al.* (2020). The Triassic Period is divided into three epochs, Early Triassic, Middle Triassic (with a base at 246.70 Ma) and Late Triassic (with a base at 237.00 Ma). As palynomorphs are the most common and often the only fossil group preserved from this period, palynology is crucial for dating and refining biostratigraphical correlations of Triassic rocks. Triassic palynomorphs are primarily miospores (pollen and spores), although acritarchs, algae and foraminiferal linings also occur throughout. The algae include dinoflagellate cysts, which first occur globally in the latest part of Middle Triassic and reach a Triassic maximum in the early Norian. Triassic forms largely become extinct by the end of the Triassic period, but a few taxa survived the end-Triassic extinction into the Jurassic (Mangerud *et al.* 2018). Dinoflagellates cysts thus have biostratigraphical value in the Upper Triassic.

The present Triassic compilation will complement those for other periods in the CAPE series of papers in Atlantic

Geology. When all papers in the series are complete, these will be provided as a "CAPE datapack" in Time Scale Creator (TSC; https://timescalecreator.org/index/index.php) and thus can be used with other data in TSC to make plots like that shown in Fig. 1. Figure 1 includes the age calibration in millions of years (Ma) using the 2020 version of TSC and in Gradstein *et al.* (2020).

The events compiled herein include last occurrences (LOs), first occurrences (FOs), and some abundance events. Their relationship to other fossil zonal schemes is shown in Fig. 1. Where possible, each event is correlated with the base of a chronostratigraphical unit, for example an ammonoid zone or a formal stage. If the event is not equivalent to the base of such a unit, then an estimation is given as a percentage above the base of the chronostratigraphical unit relative to the entire unit. Details of how a biostratigraphic datapack is constructed in TSC from such information are given in Bringué *et al.* (in press).

PALYNOSTRATIGRAPHY

Our approach in selecting events has been to use those with multiple reports from several locations, especially those that have a consistent stratigraphical position relative to other events, so that we can achieve a robust scheme. In order to provide independent age control, we emphasize events that are correlated with independently dated sections and especially those that have been dated using the standard ammonoid zonations. In addition, two rhenium–osmium (Re–Os) geochronological dates around the Anisian/Ladinian boundary (Xu *et al.* 2009) and the Ladinian/Carnian boundary (Xu *et al.* 2014) are available from the Norwegian Arctic, providing two important independent ties to the absolute timescale.

A distinct Arctic event biostratigraphy is important because many taxa have different ranges from those in central Europe, and the quantitative composition of Arctic assemblages varies greatly from that region (Vigran *et al.* 2014; Paterson and Mangerud 2015). For the Late Triassic, the longest epoch in the period, challenges remain, as localities with independent age control from age-diagnostic macrofossils are rare, but a few important successions with, for example ammonoid control, have been documented (e.g., Paterson and Mangerud 2015).

In the Sverdrup Basin (Canadian Arctic Islands), previous published palynostratigraphic work is restricted to Fisher (1979) for the entire period, plus several publications for the earliest Triassic (Utting 1985, 1989, 1994) and the Late Triassic (including Felix 1975; Fisher and Bujak 1975; Bujak and Fisher 1976; Felix and Burbridge 1978; Suneby and Hills 1988). Additional data for the Sverdrup Basin is provided in Appendix C herein for dinocyst taxa in Romulus C-67 well.

Fisher (1979) provided a full Triassic zonation based on outcrops and wells in the Sverdrup Basin. He designated palynofloral zones I to IX, and discussed uncertainties related to calibration, independent dating and potential caving in cuttings samples in wells. He also described the assemblages characterizing his nine zones and provided a simplified range chart.

Utting (1989, 1994) provided short descriptions of lowermost Triassic assemblages from several sections in the basal parts of the Bjorne and Blind Fiord formations. He also studied the Bjorne Formation in five wells on Melville Island (Utting, 1989), and about 20 outcrop samples from the Blind Fiord Formation on Ellesmere Island (Utting 1989, 1994). He did not provide any quantitative data and stated that "the assemblages were not subject to the same investigations as the Permian ones" (Utting 1994, p. 21) and established only the *Tympanicysta stoschiana – Striatoabieites richteri* Assemblage Zone.

Fisher and Bujak (1975) recorded Late Triassic assemblages from the Sverdrup Basin, including mostly informally named dinoflagellate cysts. The taxa were described in detail by Bujak and Fisher (1976) and their biostratigraphic utility has been confirmed by Bujak (Appendix C herein).

Suneby and Hills (1988) provided a palynological zonation of the Upper Triassic to Lower Jurassic successions of the Sverdrup Basin, involving the Barrow and Heiberg formations. They reported rich palynomorph assemblages of mostly miospores, but including dinoflagellate cysts, from four outcrop sections on Ellesmere Island (Fig. 2). They established four palynomorph zones, of which three are in the Upper Triassic section and the other in the Lower Jurassic section. Their oldest biozone (*Triancoraesporites ancorae – Camarozonosporites laevigatus* Biozone) was divided into two subzones, the *Kyrtomosporis speciosus – Aratrisporites coryliseminis* Subzone and the *Noricysta pannucea – Heibergella asymmetrica* Subzone. The oldest subzone was assigned an ?early Norian to late middle Norian age based on palynological correlation; the youngest subzone was assigned a late Norian – ?early Rhaetian age based on bivalves and a single ammonoid (Norford *et al.* 1973; Embry 1982). The two youngest Triassic biozones are the *Limbosporites lundbladiae – Ricciisporites tuberculatus* Biozone and the *Retitriletes austroclavatidites – Chasmatosporites magnolioides* Biozone, which they assigned to the latest Norian to Rhaetian, and latest Rhaetian to early Hettangian (Early Jurassic) respectively. However, Lindström (2016) considered both zones to be Rhaetian and suggested that they represent a pre-end Triassic extinction and extinction palynofloras respectively.

In offshore northern Alaska and the Chukchi Sea, palynostratigraphical work is restricted to exploration wells that mostly have unpublished and confidential data. Exceptions are Fireweed 1 (offshore northern Alaska) and Klondike OCS-Y-1482 (Chukchi Sea) for which Triassic species abundances and events are documented in Appendix C herein.

From the Barents Sea area, Hochuli *et al.* (1989) published

Figure 1. (next page) Chronostratigraphic plot of stratigraphically significant Triassic palynological events. Modified from a Time Scale Creator plot and using the GTS 2020 time scale (Gradstein *et al.* 2020).
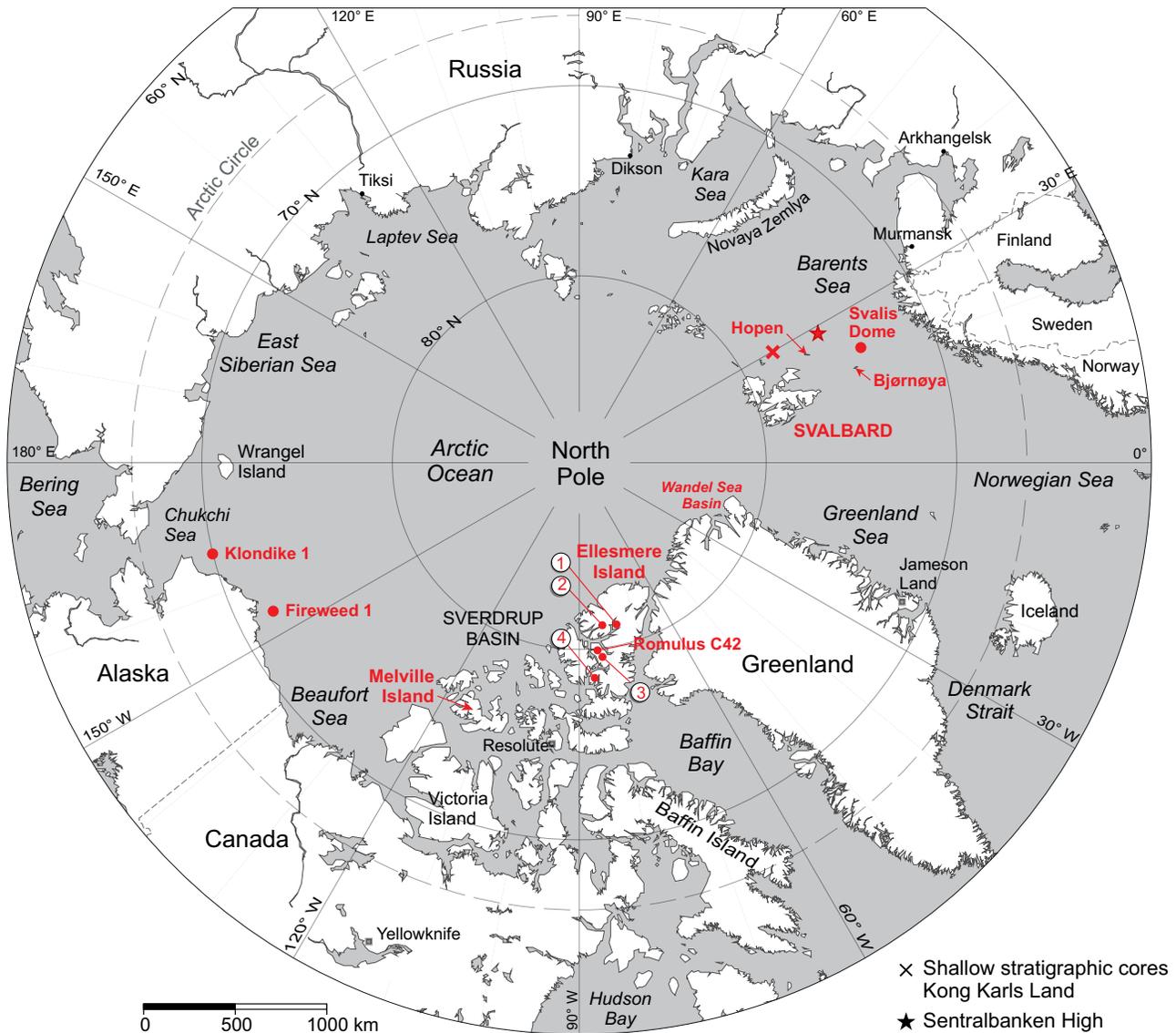
Marine Macrofossils (Mesozoic-Paleozoic)

Ma	Period	Epoch	Age/Stage	Substage	Geomagnetic Polarity	Tethyan Ammonoids	Sub-Boreal Ammonoids / Sub-Boreal ammonite zone	Boreal Ammonoids High Boreal (Siberia) ammonoids	Triassic Arctic palynomorph events (this paper)

Standard Chronostratigraphy

The figure is a detailed Triassic chronostratigraphic correlation chart spanning approximately 202 to 254 Ma.

Period: Triassic (Permian at base)

Epoch: Late, Middle, Early (Triassic); Lopingian (Permian)

Age/Stage: Rhaetian, Norian, Carnian, Ladinian, Anisian, Olenekian, Induan; Changhsingian (Permian)

Substage: Sevatian, Alaunian, Lacian, Tuvalian, Julian, Cordevolian, Longobardian, Fassanian, Illyrian, Pelsonian, Bithynian, Aegean, Spathian, Smithian, Dienerian, Griesbachian

Geomagnetic Polarity zones: E24n, E24, E23, E22, E21, E20, E19, E18, E17, E16, E15, E14, E13, E12, E11, E10, E9, E8, E7, E6, E5, E4, E3, E2, UT10n, UT4r, UT3r, UT2n, UT1n, MT13, MT11r, MT11n, MT9n, MT8r, MT7n, MT6r, MT4r-5r, MT4n, MT3n, MT1-2, CG10r, CG9n-10n, CG7r-8n, CG5n, CG3n-4n, Chang-N

Tethyan Ammonoids:
Choristoceras marshi, Vandaites stuerzenbaumi, Sagenites reticulatus, Metasibirites spinescens, Sagenites quinquepunctatus, Halorites macer, Himavatites hogarti, Cyrtopleurites bicrenatus, Juvavites magnus, Malayites paulckei, Guembelites jandianus, Anatropites spinosus, Tropites subbullatus, Tropites dilleri, Austrotrachyceras austriacum, Trachyceras aonoides, Trachyceras aon, Daxatina canadensis, Frankites regoledanus, Protrachyceras neumayri, Protrachyceras longobardicum, "Eotrachyceras" gredleri, Protrachyceras margitosum, Eoprotrachyceras curionii, Nevadites secedensis, Reitziites reitzi, Kellnerites felsoeoersensis, Paraceratites trinodosus, Schreyerites binodosus, Balatonites balatonicus, Kocaella, Paracrochordiceras (Nev.), Lenotropites caurus (Nev.), Silberlingites mulleri (Nev.), Pseudokeyserlingites gracei (Nev.), Japonites welteri, Neopopanoceras haugi, Subcolumbites, Procolumbites, Columbites parisianus, Columbites - Tirolites, Glypt. sinuatum - Wasatchites distractus, Owenites, Brayardites compressus, Flemingites flemingianus, Rohillites rohilla, Flemingites bhargavai / Kashmirites, Flemingites flemingianus, Gyronites frequens, Pleurogyronites planidorsatus, Otoceras woodwardi, Hypophiceras changxingense, Hypophiceras martini, Paratirolites waageni, Sevuroceras sevurovi, Dzhulfites spinosus, Iranites transcaucasius, Phisonites triangulus, Vedioceras ventroplanum

Sub-Boreal Ammonoids / Sub-Boreal ammonite zone:
Choristoceras crickmayi, [gap?], Paracochloceras amoenum, Gnomohalorites cordilleranus, Mesohimavatites columbianus, Drepanites rutherfordi, Juvavites magnus, Malayites dawsoni, Pinacoceras verkhoyanikum, Stikinoceras kerri, Klamathites macrolobatus, Tropites welleri, Tropites dilleri, Sirenites nanseni, Austrotrachyceras obesum, Trachyceras desatoyense, Daxatina canadensis, Frankites sutherlandi, Maclearnoceras maclearni, Meginoceras meginae, Tuchodiceras poseidon, Eoprotrachyceras matutinum, Frechites chischa, Eogymnotoceras deleeni, Anagymnotoceras varium, Czekanowskites decipiens, Lenotropites caurus, Silberlingites mulleri, [un-named], Keyserlingites subrobustus, Subolenekites pilaticus, [gap], Anawasatchites tardus, Euflemingites romunderi, Hedenstroemia hedenstroemi, Vavilovites sverdrupi, Proptychites candidus, Bukkenites strigata, Ophiceras commune, upper Otoceras boreale, lower O. boreale, Otoceras concavum, [un-named]

Boreal Ammonoids High Boreal (Siberia) ammonoids:
Neosirenites armiger - Yakutosirenites, Otkhotrachyceras seimkanense, Yanosirenites kurdlikensis, Seimkanites aculeatus, Boreotrachyceras omkutchanicum, Stolleyites tenuis, Nathorstites lindstroemi, Nathorstites macconnelli, Nathorstites macleani, Indigirites krugii, Tsvetkorites nenensis, Tsvetkorites constantis, Eonathorstites olsshkoi, Frechites nevadanus, Gymnotoceras rotelliformis, Arctohungarites kharaulakhensis, Grambergia taimyrensis, Olenekites spiniplicatus, [gap], Parasibelites grambergi, Nordophiceras contrarium, Bajarunia euomphala, Wassachites tardus, Lepiskites kolymensis, Hedenstroemia hedenstroemi, Kingites? korostelevi, Vavilovites turgidus, Vavilovites sverdrupi, [un-named], Wordieoceras decipiens, Tompophiceras morpheaus, Tompophiceras pascoei, Otoceras boreale, Otoceras concavum, "Striatosirenites" kinasovi, "Striatosirenites" kedonensis, Sirenites yakutensis, Yakutosirenites pentastichus, Trachyceras weileri

Triassic Arctic palynomorph events (this paper):
- Ricciisporites umbonatus
- Polycingulatisporites crenulatus
- Dinocysts: Hebecysta spp., Heibergella spp., Noricysta spp., Rhaetogonyaulax spp., Svedrupiella spp., excluding S. mutabilis
- Limbosporites lundbladiae (consistent), Quadraeculina anellaeformis (consistent), Ricciisporites tuberculatus (common)
- Kraeuselisporites cooksonae, Porcellispora longdonensis
- Classopollis torosus, Limbosporites lundbladiae (sporadic), Quadraeculina anellaeformis (sporadic), Ricciisporites tuberculatus (consistent), and the dinocysts Hebecysta, Heibergella, Noricysta, Rhaetogonyaulax
- Aulisporites astigmous (sporadic), Illinites chitonoides (consistent), Protodiploxypinus spp. (abundant), Schizaeosporites worsleyi (consistent)
- Kyrtomisporis spp. (consistent), Leschikisporis aduncus (dominant), Protodiploxypinus spp. (abundant)
- Dyupetalum vicentinense, Kyrtomisporis moerki
- Camarozonosporites rudis (consistent), Kyrtomisporis moerki, Ricciisporites tuberculatus (sporadic), Podosporites vignaniae (common), Uvaesporites argentaeformis (rare)
- Cordelina gunyalensis (sporadic), Echinitosporites iliacoides, Semiretisporis hochulii (common)
- Aulisporites astigmous (consistent), Camerosporites secatus (sporadic), Enzonalasporites vigens (sporadic)
- Echinitosporites iliacoides, Ovalipollis pseudoalatus, Schizaeosporites worsleyi (consistent), Staurosaccites quadrificus (consistent), Triadispora verrucata (consistent), Semiretisporis hochulii (sporadic to abundant)
- Chasmatosporites (consistent/common), Protodiploxypinus decus, Protodiploxypinus ornatus (consistent)
- Densoisporites nejburgii (consistent)
- Jerseyiaspora punctisporosa (consistent)
- Dyupetalum vicentinense (consistent)
- Carnisporites spiniger (consistent), Illinites chitonoides (consistent)
- Cordelina gunyalensis (consistent)
- Pechorosporites disertus (common)
- Naumovaspora striata (sporadic), Punctatisporites fungosus (common)
- Propriisporites pocockii (sporadic)
- Cycadopites spp. (common), Pretricolpipollenites spp. (common)
- Cyclotriletes oligoipanifer, Jerseyiaspora punctisporosa, Protodiploxypinus spp., Striatella grauberganus
- Pechorosporites disertus (common)
- Punctatisporites fungosus (common to abundant)
- Densoisporites nejburgii (common), Maculatasporites spp. (consistent)
- Aratrisporites spp. (consistent), Propriisporites novia&censis
- Vittatina spp.
- Ephedripites sleevealei, Lunatisporites novia&censis
- Uvaesporites imperialis (common)
- Uvaesporites imperialis (common), Reduviasporonites chalastus
- Lunatisporites novia&censis, Gnetaceaepollenites sleevesii

Figure 2. Circumpolar projection map showing the main Triassic localities discussed. Numbers 1 to 4 on Ellesmere Island refer to localities in Suneby and Hills (1988): McKinley Bay, Blackwalder Anticline, Fosheim Ancticline and Raanes Peninsula respectively.

an informal palynozonation comprising 16 zones, encompassing the entire Triassic based on last occurrence and relative abundance data, but they provided little documentation. Based on shallow-core material from the Svalis Dome in the central Barents Sea, Vigran *et al.* (1998) defined eight Lower to Middle Triassic (Induan to Ladinian) concurrent range zones, six of which had ammonoid control. These shallow stratigraphical cores, each a maximum of 580 m long and drilled with piggyback coring technique using a diamond bit (Rise and Sættem 1994), provide a unique database for the Norwegian Barents Sea area. All coring sites are associated with high resolution seismic, enabling correlation to conventional seismics.

Vigran *et al.* (2014) published the most comprehensive Triassic zonation to date from the Arctic, encompassing the Sassendalen Group and the Triassic parts of the overlying

Kapp Toscana Group for Svalbard and the Barents Sea. This study involved samples from outcrops, shallow cores and exploration wells, and extended from about 70–78° N. They defined 15 formal composite assemblage zones (CAZ), including seven spanning the uppermost Permian (Changhsingian) to Olenekian, four in the Middle Triassic, and four covering the Upper Triassic (Fig. 3). They described each zone, integrated previous zonations, assigned ages and reference sections, and discussed earlier palynological work from the Norwegian Arctic. They also provided range charts and descriptions of the palynological assemblages for each locality. The authors acknowledged, however, that a weakness was that their study was based on separate investigations done over several years, each with a different aim and approach.

More recently, several studies have been published on the

Middle to Upper Triassic palynostratigraphy of the Norwegian Arctic, focusing especially on a refinement of the palynostratigraphy of the Upper Triassic (Paterson and Mangerud 2015, 2017, 2019; Paterson *et al.* 2016, 2017, 2018), including quantitative data for all localities. Paterson *et al.* (2018) tied their Assemblage SBH-II from the lower to middle de Geerdalen Formation on Sentralbanken (Fig. 2) to the Ladinian/Carnian boundary based on Re–Os radiometric dating from offshore Kong Karls Land cores 7831/2-U-1 and 2-U-2 (Xu *et al.* 2014). This synthesis culminated in Paterson and Mangerud (2019), which integrated the zonation of Vigran *et al.* (2014), adding resolution to the Upper Triassic palynostratigraphy of the Norwegian Arctic. The palynomorph ranges included herein are mainly based on palynological work from the Barents Sea area. Of special importance are the palynological zones that are tied to ammonoid zones (Hochuli *et al.* 1989; Mørk *et al.* 1990, 1999; Mangerud and Rømuld 1991; Vigran *et al.* 1998, 2014; Paterson and Mangerud 2015, 2019).

So far, no palynological work exists from the Triassic of the Wandel Sea Basin in northeastern Greenland, except for a recent paper by Lindström *et al.* (2020). Farther south, in East Greenland, a few palynological studies of Rhaetian stra-ta have been published (Pedersen and Lund 1980; Mander 2011, Mander *et al.* 2010, 2013); however, these show closer afffinities to palynofloras from northwestern Europe. In contrast, although data is relatively sparse, older Triassic floras from East Greenland closely resemble coeval assemblages from the Barents Sea area (Balme 1980; Piasecki 1984; Schneebeli-Hermann *et al.* 2017). This resemblance is also seen in the palynological records from mid-Norway, which occupied approximately the same latitude as East Greenland during the Triassic (e.g., Bugge *et al.* 2002b; Hochuli *et al.* 2009).

Substantial palynological work has been done on Triassic successions in Russia, but most have focused on systematics, and most are in Russian (sometimes with short English abstracts). The different taxonomic approach and general lack of illustrations used for Russian miospores makes compari-son with other data difficult and will require future collaboration between Russian and non-Russian workers. The only comparisons so far were by Mørk *et al.* (1993), who attempted to compare palynological assemblages of the Russian and Norwegian sectors of the Barents Sea, and by Gilmullina *et al.* (2020). The latter authors indicated that several of the Norwegian zones described by Vigran *et al.* (2014) and Paterson and Mangerud (2019) are recognizable in the Russian sector. Among Russian publications, Yaroshenko *et al.* (1991) reported on Lower Triassic palynology of the Pechora area. Works on the Upper Triassic include those of Fefilova (1986, 1988, 1990) and of Ilyina and Egorov (2008), who published on palynology from the Carnian of Siberia.

PALYNOEVENTS

A summary of the following events in spreadsheet format is provided as Appendix B. All taxon names with authorship are listed in Appendix A.

FO of common *Uvaesporites imperialis*

The FO for common *Uvaesporites imperialis* is based on occurrences from multiple localities. In the Sverdrup Basin it is recorded from near the base of the Blind Fiord Formation (Fisher 1979, Utting 1994), where records exist of the ammonoid *Otoceras concavum*, a taxon previously regarded as representing the base of the Triassic. However, with the recent designation of a GSSP at the base of the Triassic, the *Otoceras concavum* Zone is now within the uppermost Permian. In Svalbard, *Uvaesporites imperialis* has been recorded at various locations, including the Deltadalen and Festningen sections, where the ammonoid *Otoceras boreale* was also recorded (Mørk *et al.* 1999; Vigran *et al.* 2014). In both the Norwegian and Canadian Arctic, and in North East Greenland, *Uvaesporites imperialis* commonly occurs in tetrads. Abundant *Uvaesporites imperialis* is also recorded on the Finnmark Platform, Barents Sea, where two shallow stratigraphic cores provide detailed palynology (Mangerud 1994; Hochuli *et al.* 2010) across the Permian/Triassic boundary. Palynology that was linked to high-resolution carbon isotope curves across the boundary layers (Looy *et al.* 2001; Twitchett *et al.* 2001; Hermann *et al.* 2010; Hochuli *et al.* 2010) provides important understanding of the boundary interval and correlation to the global stratotype. Vigran *et al.* (2014) linked the base of abundant *Uvaesporites imperialis* to the very latest Permian (Changhsingian), although for practical purposes, this event is often related to the base of the Triassic.

The FO of common *Uvaesporites imperialis* is taken as the base of the ammonoid *Otoceras concavum* zone.

FO of *Reduviasporonites chalastus*

The FO of *Reduviasporonites chalastus* is based on multiple records from the Arctic, including the Sverdrup Basin, where Utting (1994) defined his oldest Triassic palynology zone based on this species (Utting used the name *Tympanicysta stoschiana*, now considered a taxonomic junior synonym of *Reduviasporonites chalastus*). Utting (1985, 1989) recorded the species from the Blind Fiord Formation. It has also been recorded from the Norwegian Arctic, including the Finnmark Platform, Barents Sea (Mangerud 1994; Hochuli *et al.* 2010) and Svalbard (Mørk *et al.* 1999; Vigran *et al.* 2014). *Reduviasporonites chalastus* is of probable algal origin (Foster *et al.* 2002; Hochuli 2016). For discussion of age, see also *Uvaesporites imperialis*.

The FO of *Reduviasporonites chalastus* is taken as the base of the ammonoid *Otoceras concavum* zone.

FO of *Lunatisporites noviaulensis*

The FO of *Lunatisporites noviaulensis* is based on multiple records from the Arctic, including from the Blind Fiord and

Figure 3. Correlation of published Triassic palynological schemes for the Arctic. Abbreviations: P = *Proprisporites*, R = *Reduviasporonites*. Note that *Tympanicysta stoschiana* (bottom Triassic row from Utting 1989) is now considered a taxonomic junior synonym of *Reduviasporonites chalastus*.

Bjorne formations in the Sverdrup Basin (Utting 1985, 1989, 1994). *Lunatisporites noviaulensis* has also been recorded from basal Triassic on the Finnmark Platform (Mangerud 1994), with the FO slightly above the base of the *Uvaesporites*

imperialis acme.

The FO of *Lunatisporites noviaulensis* is taken as the base of the Griesbachian (equivalent to the Induan).

FO of *Ephedripites steevesii*

The FO of *Ephedripites steevesii* is based on multiple records from the Arctic, including the Sverdrup Basin (Utting 1985, 1989, 1994, from the Blind Fiord Formation) and Spitsbergen (Vigran *et al.* 2014). On the Finnmark Platform of the Barents Sea, one of us (NWP) has observed that this species appears abruptly in a short interval corresponding to the Permian/Triassic boundary carbon isotope excursion.

The FO of *Ephedripites steevesii* is here taken as the base of the Griesbachian (equivalent to the Induan).

LO of common *Uvaesporites imperialis*

In the Sverdrup Basin, *Uvaesporites imperialis* occurs in the Bjorne and Blind Fiord Formation, where the ammonoid *Otoceras boreale* is also recorded (Tozer 1967). In the Barents Sea, the LO of common *Uvaesporites imperialis* occurs close to the base of the Triassic according to Hermann *et al.* (2010). Mangerud (1994) also noted this event. The event is linked to high-resolution carbon-isotope curves across the boundary layers (Hermann *et al.* 2010; Hochuli *et al.* 2010), providing correlation to the global stratotype and indicating a LO of common *Uvaesporites imperialis* at about 20–30 ka above its FO, which is at the base of the ammonoid *Otoceras concavum* Zone. In Svalbard the event is recorded at various locations, including the Deltadalen section, where the ammonoid *Otoceras boreale* was also recorded (Mørk *et al.* 1999; Vigran *et al.* 2014). In both the Norwegian and Canadian Arctic, *Uvaesporites imperialis* commonly occurs in tetrads (e.g., Mangerud 1994; Hochuli *et al.* 2017; GM, personal observations).

The LO of common *Uvaesporites imperialis* is here taken as 5% above the base of the Griesbachian (equivalent to the base of the Induan).

FO of consistent *Proprisporites pocockii*

The FO of consistent *Proprisporites pocockii* is based on multiple records from the Arctic, including those from the Sverdrup Basin (Utting 1985, from the Bjorne Formation). It has been also recorded from the Finnmark Platform of the Barents Sea (Mangerud 1994), and from the Vardebuka Formation on Svalbard (Mangerud and Konieczny 1993; Mørk *et al.* 1999). Based on multiple datasets, Vigran *et al.* (2014) used this species to define their *Proprisporites pocockii* Composite Assemblage Zone. This zone correlates to similar assemblages in the Svalis Dome (Vigran *et al.* 1998), where records occur of the ammonoid *Ophiceras*, which is assigned to the ammonoid *Ophiceras commune* Zone of late Griesbachian age.

The FO of consistent *Proprisporites pocockii* is here taken as the base of the ammonoid *Ophiceras commune* zone.

FO of consistent *Aratrisporites*

The FO of consistent *Aratrisporites* is based on multiple records from the Norwegian Arctic. Based on several datasets, Vigran *et al.* (2014) placed the FO of this event at the base of their *Proprisporites pocockii* Composite Assemblage Zone, which correlates to similar assemblages in the Svalis Dome (Vigran *et al.* 1998). At the latter locality, records occur of the ammonoid *Ophiceras*, which is assigned to the ammonoid *Ophiceras commune* Zone of late Griesbachian age. In East Greenland Schneebeli-Hermann *et al.* (2017) recorded *Aratrisporites* in the Griesbachian succession.

The FO of consistent *Aratrisporites* is is here taken as the base of the ammonoid *Ophiceras commune* Zone.

LO of *Vittatina*

The LO of *Vittatina* occurs near the top of the Griesbachian Substage. *Vittatina* is regarded as a typical Permian taxon, fading out gradually above the Permian/Triassic boundary, although there has been debate as to whether Triassic records represent reworking (e.g., Hochuli *et al.* 1989; Mangerud 1994; Utting *et al.* 2004; Vigran *et al.* 2014). Vigran *et al.* (2014) concluded that *Vittatina* ranges sporadically up to the top of their *Proprisporites pocockii* Composite Assemblage Zone. The assemblage characterizing this zone correlates with similar assemblages in the Svalis Dome (Vigran *et al.* 1998), where records occur of the ammonoid *Ophiceras*, which is assigned to the ammonoid *Ophiceras commune* Zone of late Griesbachian age. The LO of *Vittatina* is also recorded further south: in East Greenland, Schneebeli-Hermann *et al.* (2017) recorded *Vittatina* ranging into the Dienerian.

The LO of *Vittatina* is taken as 70% up from the base of the Griesbachian (equivalent to the base of the Induan).

FO of common *Densoisporites nejburgii*

The FO of common *Densoisporites nejburgii* is based on multiple records from the Arctic, including those from the Sverdrup Basin (Fisher 1979) and from the Norwegian Arctic (Vigran *et al.* 2014).

The FO of common *Densoisporites nejburgii* is taken here as the base of the Boreal ammonoid *Vavilovites sverdrupi* Zone.

FO of consistent *Maculatasporites*

The FO of consistent *Maculatasporites* is based on multiple records from the Norwegian Arctic. It defines the base of the *Maculatasporites* Composite Assemblage Zone of Vigran *et al.* (2014), who correlated assemblages from the Svalis Dome containing *Maculatasporites* spp. to similar assemblages from Bjørnøya (Mørk *et al.* 1990); at the latter locality, Dienerian ammonoids of the ammonoid *Vavilovites sverdrupi* Zone were recorded from the Urd Formation. The early Induan is dominated by taeniate bisaccates, but there seems generally to be a major turnover in the Dienerian, continuing in the Smithian.

The FO of consistent *Maculatasporites* is taken here as the base of the Boreal ammonoid *Vavilovites sverdrupi* Zone.

LOs of common *Cycadopites* and *Pretricolpipollenites*

The LO of common *Cycadopites* and *Pretricolpipollenites* is based on multiple records from the Norwegian Arctic. Their LOs corresponds with the top of the *Maculatasporites* Composite Assemblage Zone of Vigran *et al.* (2014), who correlated assemblages with these taxa to similar assemblages from Bjørnøya (Mørk *et al.* 1990), where ammonoids of the *Vavilovites sverdrupi* Zone of Dienerian age were recorded from the Urd Formation. Hochuli *et al.* (1989) also mentions a distinctive palynoflora with common *Cycadopites* and *Pretricolpipollenites* from a sample dated Dienerian by ammonoids in the Bertilryggen section on Spitsbergen.

The LOs of common *Cycadopites* and *Pretricolpipollenites* are taken as the base of the Smithian (lower Olenekian).

FO of common–abundant *Punctatisporites fungosus*

The FO of common to abundant *Punctatisporites fungosus* is based on multiple records from the Norwegian Arctic. It has been recorded by Vigran *et al.* (2014) and Rossi *et al.* (2019) from the base of the *Naumovaspora striata* Composite Assemblage Zone from several surface sections and wells. The zone is dated by its co-occurrence with the ammonoid *Wasachites tardus* from the Svalis Dome (Vigran *et al.* 1998, 2014); however, a gap occurs in the coring between this core and the underlying core, so the FO could be somewhat older. Common *Punctatisporites fungosus* has also been recorded in assemblages from beds with the early Olenekian (Smithian) ammonoid *Eufleminigites romunderi* at Vikinghøgda (Mørk *et al.* 1999), from Peary Land, North-East Greenland (Lindström *et al.* 2020) and at Bjørnøya (Mørk *et al.* 1990); at that locality, ammonoids were recorded from the middle parts of the Urd Formation. Similarly, in the Russian Barents Sea, the FO of *Punctatisporites fungosus* is recorded in the Smithian T_1O_1 palynocomplex (Mørk *et al.* 1993; Fefilova 2013a).

The FO base of common to abundant *Punctatisporites fungosus* is taken here as the base of the Boreal ammonoid *Euflemingites romunderi* Zone.

LO of sporadic *Proprisporites pocockii*

The LO of sporadic *Proprisporites pocockii* is based on data from Vigran *et al.* (1998, 2014), who recorded infrequent occurrences of this species ranging up to the middle of their *Naumovaspora striata* Composite Assemblage Zone. The assemblage comprising the latter zone was recorded in beds where the ammonoid *Wasatchites tardus* Zone was defined in the Svalis Dome. On Bjørnøya, *Proprisporites pocockii* occurs sporadically in the Urd Formation (Mørk *et al.* 1990).

The LO of sporadic *Proprisporites pocockii* is taken as 50% up from the base of the ammonoid *Wasatchites tardus* Zone.

LO of sporadic *Naumovaspora striata*

The LO of sporadic *Naumovaspora striata* is based on multiple records from the Norwegian Arctic. The LO of *Naumovaspora striata* defines the top of the *Naumovaspora striata* Assemblage Zone (Vigran *et al.* 2014), which has been recorded in multiple localities. In the reference section for this zone (a core at the Svalis Dome in the Barents Sea), the latest Olenekian (late Smithian) ammonoid index taxon *Wasachites tardus* was recorded. A similar assemblage was also documented on Bjørnøya, from beds with the slightly older ammonoid *Euflemingites romunderi* (Mørk *et al.* 1990).

The LO of sporadic *Naumovaspora striata* is taken here as the base of the Spathian (upper Olenekian).

LO of common *Punctatisporites fungosus*

The LO of common to abundant *Punctatisporites fungosus* is based on multiple records from the Norwegian Arctic. It partly defines the base of the *Naumovaspora striata* Assemblage Zone of Vigran *et al.* (2014), which was recorded from a core from Svalis Dome. Vigran *et al.* dated this zone as Smithian based on records of the ammonoid *Wasachites tardus*. In wells from the Barents Sea, this event corresponds to the transition between the Havert and Klappmyss formations (Rossi *et al.* 2019). A similar assemblage was recorded at Bjørnøya, from beds containing the ammonoid *Euflemingites romunderi* (Mørk *et al.* 1990).

The LO of common *Punctatisporites fungosus* is taken here as the base of the Spathian (upper Olenekian).

FO of common *Pechorosporites disertus*

The FO of common *Pechorosporites disertus* is based on multiple records from the Norwegian Arctic. Its FO defines the base of the *Pechorosporites disertus* Assemblage Zone according to Vigran *et al.* (2014), dated as early Spathian. However, little faunal evidence exists for the age of this zone, as it occurs between ammonoid-dated Smithian and late Spathian sections in the Svalis Dome.

The FO of common *Pechorosporites disertus* is taken here as the base of the Spathian (upper Olenekian).

LO of common *Pechorosporites disertus*

The LO of common *Pechorosporites disertus* is based on multiple records from the Norwegian Arctic. Its LO defines the top of the *Pechorosporites disertus* Assemblage Zone (Vigran *et al.* 1998, 2014) and has been recorded in the upper-most Klappmyss Formation, where it has been assigned an early Spathian age. However, little faunal evidence exists for the age of this zone, as it occurs between ammonoid-dated Smithian and late Spathian sections. The appearance of the taxon in the Russian Barents Sea seem to be slightly earlier, with occurrences reported in the Dienerian T1i2 palyno-complex (Fefilova 2013a, b).

The LO of common *Pechorosporites disertus* is taken here as the base of the ammonoid *Keyserlingites subrobustus* Zone.

FO of *Jerseyiaspora punctispinosa*

The FO of *Jerseyiaspora punctispinosa* is based on multiple records from the Norwegian Arctic. It was reported by Mangerud and Rømuld (1991) from the Svalis Dome, in beds with the ammonoid *Keyserlingites subrobustus*. It has also been recorded in various localities in Svalbard, including the type section of the Vikinghøgda Formation (from the upper part of the Vendomdalen Member; Mørk *et al.* 1999), and from several exploration wells (Vigran *et al.* 2014; Paterson and Mangerud 2017; Rossi *et al.* 2019). The FO of *Jerseyiaspora punctispinosa* defines the base of the *Jerseyiaspora punctispinosa* Composite Assemblage Zone (Vigran *et al.* 2014).

The FO of *Jerseyiaspora punctispinosa* is taken here as the base of the late Spathian Boreal ammonoid *Keyserlingites subrobustus* Zone.

FO of *Protodiploxypinus*

The FO of *Protodiploxypinus* is based on multiple records from the Norwegian Arctic. Mangerud and Rømuld (1991) reported its FO from the Svalis Dome, in beds containing the ammonoid *Keyserlingites subrobustus*. The FO of *Protodiploxypinus* also partly defines the base of the *Jerseyiaspora punctispinosa* Composite Assemblage Zone (Vigran *et al.* 2014).

The FO of *Protodiploxypinus* is taken here as the base of the Boreal ammonoid *Keyserlingites subrobustus* Zone.

FO of *Cyclotriletes oligogranifer*

The FO of *Cyclotriletes oligogranifer* is based on multiple records from the Norwegian Arctic. It was reported by Mangerud and Rømuld (1991) from the Svalis Dome, with its LO in beds with the late Spathian ammonoid *Keyserlingites subrobustus*. It has also been recorded in various localities in Svalbard (Vigran *et al.* 2014), appearing approximately at the same time as other species of *Cyclotriletes* such as *Cyclotriletes pustulatus*.

The FO of *Cyclotriletes oligogranifer* is taken here as the base of the Boreal ammonoid *Keyserlingites subrobustus* Zone.

FO of sporadic *Striatella seebergensis*

The FO of sporadic *Striatella seebergensis* is based on multiple records from the Arctic, including the Sverdrup Basin (Fisher 1979). In the Norwegian Arctic it was reported by Mangerud and Rømuld (1991) from the Svalis Dome, in beds with the late Spathian ammonoid *Keyserlingites subrobustus*. It has also been recorded from various localities in Svalbard, including the type-section of the Vikinghøgda

Formation (from the upper part of the Vendomdalen Member; Mørk *et al.* 1999), and from several exploration wells (Vigran *et al.* 2014; Rossi *et al.* 2019). Its FO partly defines the base of the *Jerseyiaspora punctispinosa* Composite Assemblage Zone (Vigran *et al.* 2014).

The FO of sporadic *Striatella seebergensis* is taken here as the base of the Boreal ammonoid *Keyserlingites subrobustus* Zone.

FO of consistent *Carnisporites spiniger*

The FO of consistent *Carnisporites spiniger* is based on multiple records from the Norwegian Arctic. Mangerud and Rømuld (1991) and Vigran *et al.* (1998) recorded its consistent FO from the Steinkobbe Formation at the Svalis Dome, from a core with the ammonoid *Karangatites evolutus*, which is dated as early Anisian. Vigran *et al.* (2014) defined the *Carnisporites spiniger* Composite Assemblage Zone (called *Anapiculatisporites spiniger* Assemblage Zone therein) based on the FO of consistent *Carnisporites spiniger*. Its FO has been also recorded from a shallow core in the Sentralbanken area, together with ammonoids of the *Lenotropis caurus* Zone (Vigran *et al.* 2014), demonstrating that it ranges up into the Anisian. The LO *Carnisporites spiniger* was also noted by Paterson and Mangerud (2017) in the lower Kobbe Formation from the Nordkapp Basin, southern Barents Sea.

The FO of consistent *Carnisporites spiniger* is taken here as the base of the Boreal ammonoid *Karangatites evolutus* Zone.

FO of consistent *Illinites chitonoides*

The FO of consistent *Illinites chitonoides* is based on multiple records from the Norwegian Arctic. Mangerud and Rømuld (1991) and Vigran *et al.* (1998) recorded its FO from the Svalis Dome, from a core with the ammonoid *Karangatites evolutus*, which is regarded as early Anisian. Vigran *et al.* (2014) also noted that its consistent FO corresponds with the base of their *Carnisporites spiniger* Composite Assemblage Zone (called *Anapiculatisporites spiniger* Assemblage Zone therein).

The FO of consistent *Illinites chitonoides* is taken here as the base of the Boreal ammonoid *Karangatites evolutus* Zone.

FO of consistent *Cordaitina gunyalensis*

Mangerud and Rømuld (1991) and Vigran *et al.* (1998) recorded the FO of consistent (and in some intervals common) *Cordaitina gunyalensis* from the middle part of the middle Anisian ammonoid *Anagymnotoceras varium* Zone in the Svalis Dome. However, Vigran *et al.* (2014) reported a considerably older FO for the taxon, at the base of their early Spathian *Pechosporites disertus* Composite Assemblage Zone (Vigran *et al.* 2014, fig 3b), indicating some uncertainty as to its FO. This distinct monosaccate pollen is a good index species; but because of its large size (often around

200 μm) it may not always survive routine palynological laboratory procedures intact and is often recorded as specimens with a missing corpus.

The FO of consistent *Cordaitina gunyalensis* is taken here as the base of the Anisian.

FO of consistent *Dyupetalum vicentinense*

The FO of consistent *Dyupetalum vicentinense* is based on multiple records from the Norwegian Arctic. Although rare, the species has been recorded from many localities and is a characteristic element of the *Triadispora obscura* Composite Assemblage Zone (Vigran *et al.* 2014). This zone has been found in in association with the ammonoid *Anagymnotoceras varium* in the Svalis Dome, Barents Sea (Mangerud and Rømuld 1991). Hochuli *et al.* (1989) recorded this species with a lowest occurrence at or near the base of their Assemblage K, dated as late Anisian; however, it was later recorded in older sections dated by ammonoids. A single occurrence of *Dyupetalum vicentinense* was also noted in the Klappmyss Formation, from shallow-core material from the Barents Sea, in association with the late Spathian *Jerseyiaspora punctispinosa* Composite Assemblage Zone (Vigran *et al.* 2014, p. 145).

The FO of consistent *Dyupetalum vicentinense* is taken here as the base of the middle Anisian Boreal ammonoid *Anagymnotoceras varium* Zone.

LO of consistent *Densoisporites nejburgii*

The LO of consistent *Densoisporites nejburgii* is based on multiple records from the Norwegian Arctic. Hochuli *et al.* (1989) noted that its first downhole occurrence was around the top of the middle Anisian (their Assemblage L). In the Barents Sea, Mangerud and Rømuld (1991) recorded its youngest occurrence in the middle of their *Anagymnotoceras varium* ammonoid Zone in the Svalis Dome. Vigran *et al.* (2014) noted its LO within their *Carnisporites spiniger* Composite Assemblage Zone (called *Anapiculatisporites spiniger* Assemblage Zone therein) of early Anisian age.

The LO of *Densoisporites nejburgii* is taken here as 50% up from the base of the ammonoid *Anagymnotoceras varium* Zone.

LO of consistent *Jerseyiaspora punctispinosa*

The LO of consistent *Jerseyiaspora punctispinosa* is based on multiple records from the Norwegian Arctic. In the Barents Sea, Mangerud and Rømuld (1991) and Vigran *et al.* (1998) recorded its consistent occurrence in the Svalis Dome from a core with the ammonoid *Anagymnotoceras varium*, corresponding to the top of the middle Anisian. Only one occurrence is recorded in a younger core at the same location, probably representing reworking. Vigran *et al.* (2014) also recorded it as common from exploration wells and defined its LO as the top of their *Triadispora obscura* Com-

posite Assemblage Zone, an observation supported also by records from Hochuli *et al.* (1989). From the southern Barents Sea, Paterson and Mangerud (2017) noted the LO of consistent *Jerseyiaspora punctispinosa* in the middle part of the Kobbe Formation. Somewhat younger occurrences of *Jerseyiaspora punctispinosa* in the Ladinian *Echinitosporites iliacoides* and Carnian *Aulisporites astigmosus* Composite Assemblage Zone were interpreted by Vigran *et al.* (2014, p. 130, 149) as reworking.

The LO of consistent *Jerseyiaspora punctispinosa* is taken here as 50% up from the base of the Anisian.

FO of consistent/common *Chasmatosporites*

The FO of consistent to common *Chasmatosporites* is based on multiple records from the Norwegian Arctic. This taxon was recorded from the base of the *Protodiploxypinus decus* Composite Assemblage Zone of Vigran *et al.* (2014) with ammonoids of the *Frechites laqueatus* Zone, which is regarded as late Anisian (Vigran *et al.* 1998). Mueller *et al.* (2016) reported consistent *Chasmatosporites* from the base of the Tschermakfjellet Formation on Spitsbergen, which they assigned to the Julian (lower Carnian).

The FO of consistent to common *Chasmatosporites* is taken here as the base of the late Anisian ammonoid *Frechites laqueatus* Zone.

FO *Protodiploxypinus decus*

The FO of *Protodiploxypinus decus* is based on multiple records from the Norwegian Arctic. In the Barents Sea, it was recorded from the upper part of the Steinkobbe Formation in the Svalis Dome by Vigran *et al.* (1998). Its FO was used to define the *Protodiploxypinus decus* Composite Assemblage Zone of Vigran *et al.* (2014) and was calibrated to the upper Anisian ammonoid *Frechites laqueatus* in the same core. Note that Vigran *et al.* (2014, p. 71) erroneously stated that the LO (rather than FO) of *Protodiploxypinus decus* is in this ammonoid zone. Those authors also reported rare occurrences of *Protodiploxypinus decus* in the early Anisian *Anapiculatisporites spiniger* Composite Assemblage Zone, but these are likely misidentified.

The FO of *Protodiploxypinus decus* is taken here as the base of the ammonoid *Frechites laqueatus* Zone.

FO of consistent *Protodiploxypinus ornatus*

The FO of consistent *Protodiploxypinus ornatus* is based on multiple records from the Norwegian Arctic. Its FO corresponds to the base of *Protodiploxypinus decus* Composite Assemblage Zone of Vigran *et al.* (2014), which is calibrated to ammonoid records of the *Frechites laqueatus* Zone, of late Anisian age. Note that Vigran *et al.* 2014 (p. 71) erroneously stated that the LO (rather than the FO) of *Protodiploxypinus ornatus* is in this ammonoid zone.

The FO of consistent *Protodiploxypinus ornatus* is taken here as the base of the ammonoid *Frechites laqueatus* Zone.

FO of *Echinitosporites iliacoides*

The FO of *Echinitosporites iliacoides* is based on multiple records from the Norwegian Arctic. Its base defines the base of the *Echinitosporites iliacoides* Composite Assemblage Zone of Vigran *et al.* (2014), which was established at the base of the Ladinian Stage. This event is constrained by late Anisian ammonoid dating just below. *Echinitosporites iliacoides* is not very common but is a very distinctive marker species. It is reported from several locations in the Barents Sea (Hochuli *et al.* 1989; Mørk *et al.* 1990; Bugge *et al.* 2002a; Vigran *et al.* 1998, 2014; Paterson and Mangerud 2017, 2019; Paterson *et al.* 2018) and from Svalbard (Mørk *et al.* 1990, 1999); despite its small size and relatively rare occurrence, it is an important marker.

The FO of *Echinitosporites iliacoides* is taken here as the base of the Ladinian.

FO of consistent *Schizaeoisporites worsleyi*

The FO of consistent *Schizaeoisporites worsleyi* is based on multiple records in the Norwegian Arctic. It was first described by Bjærke and Manum (1977) from Hopen Island. Vigran *et al.* (1998) recorded it in three Ladinian cores in the Svalis Dome, Barents Sea. No independent faunal evidence exists from the three Ladinian cores in the Svalis Dome, but the cored succession overlies upper Anisian successions dated by ammonoids. The range base of *Schizaeoisporites worsleyi* corresponds approximately to the base of the *Echinitosporites iliacoides* Composite Assemblage Zone of Vigran *et al.* (2014), which is set at the base of the Ladinian Stage. Similarly, in the Russian Barents Sea, *Schizaeoisporites worsleyi* has an FO in the Ladinian T_2l Zone (Mørk *et al.* 1993). A single occurrence of this taxon has been reported from the middle Anisian *Triadispora obscura* Composite Assemblage Zone from central Spitsbergen (Vigran *et al.* 2014, p. 98). In the Barents Sea, a few records of *Schizaeoisporites worsleyi* extend down to the early Anisian *Anapiculatisporites spiniger* Composite Assemblage Zone (Vigran *et al.* 2014, p. 189).

The FO of consistent *Schizaeoisporites worsleyi* is here taken as the base of the Ladinian.

FO of consistent *Triadispora verrucata*

The FO of consistent *Triadispora verrucata* is based on multiple records from the Norwegian Arctic (e.g., Hochuli *et al.* 1989; Vigran *et al.* 1998; Paterson and Mangerud 2017). Its base corresponds approximately to the base of the *Echinitosporites iliacoides* Composite Assemblage Zone of Vigran *et al.* (2014), which is correlated with the base of the Ladinian Stage. On central Spitsbergen, rare occurrences of *Triadispora verrucata* are known from the late Anisian *Protodiploxypinus decus* Composite Assemblage Zone (Vigran *et al.* 2014, p. 98). Similarly, Paterson and Mangerud (2017) recorded specimens of *Triadispora verrucata* from the middle Anisian *Triadispora obscura* Composite Assemblage

Zone in exploration wells from the southern Barents Sea.

The FO of consistent *Triadispora verrucata* is taken here as the base of the Ladinian.

FO of *Ovalipollis pseudoalatus*

The FO of *Ovalipollis pseudoalatus* is based on multiple records from the Norwegian Arctic. The species was recorded in all three Ladinian cores in the Svalis Dome, Barents Sea (Vigran *et al.* 1998). Its base corresponds approximately to the base of the *Echinitosporites iliacoides* Composite Assemblage Zone of Vigran *et al.* (2014), the base of which is set at the base of the Ladinian. An FO of *Ovalipollis pseudoalatus* at the base Ladinian was also reported by Hochuli *et al.* (1989).

The FO of *Ovalipollis pseudoalatus* is taken here as the base of the Ladinian.

FO of consistent *Staurosaccites quadrifidus*

The FO of consistent *Staurosaccites quadrifidus* is based on multiple records from the Norwegian Arctic. The species was recorded in all three Ladinian cores in the Svalis Dome, Barents Sea (Vigran *et al.* 1998). Its base corresponds approximately to the base of the *Echinitosporites iliacoides* Composite Assemblage Zone of Vigran *et al.* (2014), which is set at the base of the Ladinian. We note that rare older occurrences of *Staurosaccites quadrifidus* have been reported from assemblages assigned to the early Anisian *Anapiculatisporites spiniger* Composite Assemblage Zone, for example from western Spitsbergen and Barentsøya (Vigran *et al.* 2014). Elsewhere, Paterson and Mangerud (2017) recorded rare specimens of *Staurosaccites quadrifidus* from the late Anisian *Protodiploxypinus decus* Composite Assemblage Zone in exploration wells from the southern Barents Sea.

The FO of consistent *Staurosaccites quadrifidus* is taken here as the base of the Ladinian.

FO of common to abundant *Semiretisporis hochulii*

The FO of common to abundant *Semiretisporis hochulii* is based on multiple records from the Norwegian Arctic. The taxon has variously been reported informally in the literature as *Semiretisporis* "barentszi" (van Veen 1985), *Semiretisporis* sp. A (Vigran *et al.* 1998, pl. 9, fig. 2), *Semiretisporis* sp. 1 (Hounslow *et al.* 2008, fig. 7) and *Semiretisporis* sp. A ("barentzii") (Vigran *et al.* 2014). The species was formally described as *Semiretisporis hochulii* by Paterson and Mangerud (2019). Vigran *et al.* (1998) recorded it from the base of their oldest Ladinian core at the Svalis Dome, Barents Sea, co-occurring with *Echinitosporites iliacoides*. Paterson *et al.* (2018) recorded common *Semiretisporis hochulii* from the lower part of the De Geerdalen Formation at Sentralbanken.

The FO of common to abundant *Semiretisporis hochulii* is taken here as the base of the Ladinian.

FO of sporadic *Enzonalasporites vigens*

The FO of sporadic *Enzonalasporites vigens* is based on multiple records from the Norwegian Arctic, including several localities on Svalbard (Vigran *et al.* 2014). Hochuli *et al.* (1989) also reported *Enzonalasporites vigens* in their early Carnian Assemblage "F". Vigran *et al.* (2014) reported the FO of *Enzonalasporites vigens* from the base of their *Aulisporites astigmosus* Composite Assemblage Zone, corresponding to the base of the Carnian. While most typical of the early Carnian succession, rare occurrences of the taxon have been recorded in assemblages assigned to the Ladinian *Echitosporites iliacoides* Composite Assemblage Zone from Spitsbergen and the Barents Sea (Vigran *et al.* 2014).

The FO of *Enzonalasporites vigens* is taken here as the base of the Carnian.

FO of sporadic *Camerosporites secatus*

The FO of sporadic *Camerosporites secatus* is based on multiple records from the Norwegian Arctic. Vigran *et al.* (2014) recorded the species from the base of their *Aulisporites astigmosus* Composite Assemblage Zone, corresponding to the base of the Carnian Stage.

The FO of *Camerosporites secatus* is taken here as the base of the Carnian.

FO of consistent *Aulisporites astigmosus*

The FO of consistent *Aulisporites astigmosus* is based on multiple records from the Norwegian Arctic. Vigran *et al.* (2014) recorded the species from the base of their *Aulisporites astigmosus* Composite Assemblage Zone, corresponding to the base of the Carnian. Hochuli *et al.* (1989) also reported *Aulisporites astigmosus* in their early Carnian Assemblage "F", while Mueller *et al.* (2016) designated their *Aulisporites astigmosus* pollen assemblage zone as Julian 2 (lower Carnian), integrated with organic-carbon isotope data linked to the geomagnetic polarity time scale. Paterson *et al.* (2017) recorded *Aulisporites astigmosus* from an early Carnian core drilled in the Snadd Formation of off-shore Kong Karls Land; this occurrence is constrained by Re–Os geochronology from an underlying core at the same site. While generally typical of the early Carnian, *Aulisporites astigmosus* may have sporadic occurrences in the *Echinitosporites iliacoides* and the *Protodiploxypinus decus* composite assemblage zones of Ladinian and late Anisian age respectively (Vigran *et al.* 2014).

The FO of consistent *Aulisporites astigmosus* is taken here as the base of the Carnian.

LO of sporadic *Cordaitina gunyalensis*

The LO of sporadic *Cordaitina gunyalensis* is based on multiple records from the Norwegian Arctic, including Vigran *et al.* (1998, 2014) from the Svalis Dome, Barents Sea, where it was recorded in three Ladinian cores. No independent faunal evidence exists from the three Ladinian cores, but the cored intervals overlie upper Anisian successions dated by ammonoids. Occurrences of *Cordaitina gunyalensis* in shallow cores penetrating the Snadd Formation in the Sentralbanken High and offshore Kong Karls Land areas of the Barents Sea indicate a LO within the lower part of the *Aulisporites astigmosus* Composite Assemblage Zone. Rhenium–osmium geochronology from the latter location (Xu *et al.* 2014), indicates that the LO of *Cordaitina gunyalensis* is no older than earliest Carnian. On Spitsbergen, the species so far has not been reported above the Anisian, and its absence within Carnian strata may be due to poor preservation.

The LO of *Cordaitina gunyalensis* is taken here as 10% up from the base of the Carnian.

LO of *Echinitosporites iliacoides*

The LO of *Echinitosporites iliacoides* is based on multiple records from the Norwegian Arctic. It was recorded at Bjørnøya in beds with the ammonoid *Daxatina* cf. *canadensis* (Mørk *et al.* 1990), which is of early Carnian age. This horizon would previously have been placed in the Ladinian, but the base of the Carnian has been designated a GSSP defined by the lowest occurrence of the cosmopolitan ammonoid *Daxatina* (base of *Daxatina canadensis* Subzone, lowest subzone of *Trachyceras* Zone) (Gradstein *et al.* 2012). Hochuli *et al.* (1989) used the LO of *Echinitosporites iliacoides* as a good downhole marker, and Vigran *et al.* (2014) recorded it from various locations in the Norwe-gian Arctic. Paterson and Mangerud (2017, 2019) and Paterson *et al.* (2017) recorded it from several places in the Barents Sea.

The LO of *Echinitosporites iliacoides* is here taken as 10% up from the base of the Carnian.

LO of common *Semiretisporis hochulii*

The LO of *Semiretisporis hochulii* is based on multiple records from the Norwegian Arctic. It was noted by Mueller *et al.* (2016) from the lower De Geerdalen Formation in Spitsbergen. Paterson *et al.* (2018) record-ed common occurrences of the taxon (as *Semiretisporis* sp. A) (in their Assemblage SBH-1) from cores in the lower De Geerdalen Formation in the Sentralbanken area, having the LO of its common occurrence coeval with the LO of *Echinitosporites iliacoides*. Paterson and Mangerud (2017) also recorded that this LO is coeval with the top of *Echinitosporites iliacoides* in the lowermost Snadd Formation (in their assemblage SBS-VII); they correlated it with Assemblage G of Hochuli *et al.* (1989), which is now assigned to the early Carnian based on new ammonoid evidence (see Vigran *et al.* 2014 for discussion). The LO of common *Semiretisporis hochulii* marks the top of *Semiretisporis hochulii* Zone of Paterson and Mangerud (2019).

The LO of common to abundant *Semiretisporis hochulii* is taken here as 10% up from the base of the Carnian.

FO of common *Podosporites vigraniae*

The FO of common *Podosporites vigraniae* is based on multiple records from the Norwegian Arctic. The age assignment of this event approximately corresponds to the LO of *Echinitosporites iliacoides*, which is recorded in beds containing the early Carnian ammonoid *Daxatina* cf. *canadensis* (Mørk *et al.* 1990). Paterson and Mangerud (2019) described the *Podosporites vigraniae* Zone, originally described as the "*Podosporites* cf. *amicus* Assemblage" (Paterson *et al.* 2016). They recorded this taxon from the Snadd Formation at core 7534/4-U-1, Sentralbanken High, Barents Sea.

The FO of common *Podosporites vigraniae* is taken here as 10% up from the base of the Carnian.

FO of sporadic *Ricciisporites tuberculatus*

The FO of sporadic *Ricciisporites tuberculatus* is based on multiple records from the Norwegian Arctic. Vigran *et al.* (2014) reported its FO as somewhat above the base of their *Aulisporites astigmosus* Composite Assemblage Zone and included it as part of the definition of that zone. The age assignment of this event approximately corresponds to the LO of *Echinitosporites iliacoides*, which is recorded in beds containing the early Carnian ammonoid *Daxatina* cf. *canadensis* (Mørk *et al.* 1990). Paterson and Mangerud (2017) recorded *Ricciisporites tuberculatus* in exploration wells from the Barents Sea, but not extending down to the LO of *Echinitosporites ilicoides*; the same is the case from the Sentralbanken area (Paterson *et al.* 2017). However, rare specimens have been recorded from the Ladinian Kobbe and Snadd formations, assigned to the *Echinitosporites iliacoides* Composite Assemblage Zone, in the southern Barents Sea (Vigran *et al.* 2014).

The FO of sporadic *Ricciisporites tuberculatus* is taken here as 10% up from the base of the Carnian.

FO of consistent *Camarozonosporites rudis*

The FO of consistent *Camarozonosporites rudis* is based on multiple records from the Norwegian Arctic. Vigran *et al.* (2014) recorded it somewhat above the base of, and as part of the definition of, their *Aulisporites astigmosus* Composite Assemblage Zone. Paterson and Mangerud (2015) recorded it ranging throughout the De Geerdalen Formation on Hopen. From the Kong Karls Land area, Paterson *et al.* (2017) recorded it throughout an early Carnian core drilled in the Snadd Formation constrained by Re–Os geochronology from an underlying core at this site. The age assignment of the consistent FO of *Camarozonosporites rudis* corresponds approximately to the LO of *Echinitosporites iliacoides*, which is calibrated to beds with the early Carnian ammonoid *Daxatina* cf. *canadensis* (Mørk *et al.* 1990). However, sporadic occurrences of *Camarozonosporites rudis* have been recorded in Barents Sea wells from the Anisian Kobbe and Steinkobbe formations, corresponding with the

Protodiploxypinus decus (Vigran *et al.* 2014, p. 138, 140) and *Triadispora obscura* (Paterson and Mangerud 2017) composite assemblage zones.

The FO of consistent *Camarozonosporites rudis* is taken here as 10% up from the base of the Carnian.

FO of rare *Uvaesporites argentaeformis*

The FO of rare *Uvaesporites argentaeformis* is based on multiple records from the Norwegian Arctic. Vigran *et al.* (2014) listed the species as appearing somewhat above the base of, but part of the definition of, their *Aulisporites astigmosus* Composite Assemblage Zone, to which they assigned an early to middle Carnian age. Paterson and Mangerud (2015) recorded rare *Uvaesporites argentaeformis* through the De Geerdalen Formation at Hopen, but did not record the range base because the base of the formation there is below sea level. The age assignment approximately corresponds to, or is close to, the LO of *Echinitosporites iliacoides*, which has a LO in beds with the early Carnian ammonoid *Daxatina* cf. *canadensis* (Mørk *et al.* 1990).

The FO of rare *Uvaesporites argentaeformis* is taken here as 10% up from the base of the Carnian.

FO of *Kyrtomisporis moerki*

This recently described taxon was previously recorded as *Kyrtomisporis* sp. A by Paterson *et al.* (2017, pl. 2, figs. 12–15) throughout an early Carnian core from the Snadd Formation in the Kong Karls Land area; the age is constrained by Re–Os geochronology from an underlying core at the site. The age assignment of the FO of *Kyrtomisporis moerki* corresponds approximately to, or near the FO of, *Echinitosporites iliacoides* in this core. It was later recorded from a core in the middle part of the De Geerdalen Formation in the Sentralbanken area (Paterson *et al.* 2018). Its short range makes it a very good marker, and it is a diagnostic component of the *Podosporites vigraniae* Zone of Paterson and Mangerud (2019).

The FO of *Kyrtomisporis moerki* is taken here as 10% up from the base of the Carnian.

LO of *Kyrtomisporis moerki*

Kyrtomisporis moerki (*Kyrtomisporis* sp. A of Paterson *et al.* 2017, pl. 2, figs. 12–15) was recorded throughout an early Carnian core from the Snadd Formation in the Kong Karls Land area; the age is constrained by Re–Os geochronology from an underlying core at the site. *Kyrtomisporis moerki* has so far not been recorded above the early Carnian. It was also recorded from a core in the middle part of the De Geerdalen Formation in the Sentralbanken area (Paterson *et al.* 2018). Its short range makes it a very good marker species.

The LO of *Kyrtomisporis moerki* is taken here as the base of the Tuvalian (upper Carnian).

FO of consistent *Kyrtomisporis* spp.

The FO of consistent *Kyrtomisporis* spp. (*Kyrtomisporis laevigatus*, *Kyrtomisporis gracilis* and *Kyrtomisporis speciosus*) is based on multiple records in the Norwegian Arctic. The FOs of these taxa were recorded by Bjærke and Manum (1977) and Paterson and Mangerud (2015) from upper De Geerdalen Formation (Hopen Member; Lord *et al.* 2014) at Hopen. On Spitsbergen, Mueller *et al.* (2016) recorded the FO of *Kyrtomisporis* spp. somewhat below the *Leschikisporis aduncus* acme. The base of *Kyrtomisporis* spp. in the Sverdrup Basin is still unknown, but their occurrence was reported by Suneby and Hills (1988) in younger Triassic successions. Older occurrences of *Kyrtomisporis laevigatus* might represent misidentifications of *Concavisporites crassexinus*, *Dictyophyllidites mortonii* or *Iraqispora labrata*.

The FO of consistent *Kyrtomisporis* spp. (*Kyrtomisporis laevigatus, Kyrtomisporis gracilis* and *Kyrtomisporis speciosus*) is taken here as the base of the Tuvalian (upper Carnian).

LO of *Dyupetalum vicentinense*

The LO of *Dyupetalum vicentinense* is based on multiple records from the Norwegian Arctic. Although rare, it is recorded in many localities; its youngest occurrence was regarded as intra-Ladinian by Hochuli *et al.* (1989). However, rare specimens were recorded in younger successions by Paterson *et al.* (2017), from shallow-core material in the Snadd Formation, offshore Kong Karls Land. Rhenium–osmium geochronology from other cores in the region (Xu *et al.* 2014) indicate an age no older than earliest Carnian. Similarly, early Carnian occurrences have been noted in exploration wells and shallow stratigraphic cores from the southern Barents Sea and Sentralbanken High, respectively (Paterson and Mangerud 2017, Paterson *et al.* 2018).

The LO of *Dyupetalum vicentinense* is taken here as the base of the Tuvalian (upper Carnian).

FO of dominant *Leschikisporis aduncus*

The FO of dominant *Leschikisporis aduncus* is based on multiple records from the Norwegian Arctic. Bjærke and Manum (1977) first recorded this acme from outcrop sections on Hopen, and later Paterson and Mangerud (2015) and Paterson *et al.* (2015) recorded it from the middle De Geerdalen Formation, also from Hopen, approximately dated as late Carnian. Hochuli *et al.* (1989) noted that *Leschikisporis aduncus* is common in their "middle" Carnian Assemblage D. In Spitsbergen, Nagy *et al.* (2011), Vigran *et al.* (2014) and Mueller *et al.* (2014, 2016) recorded this event from the upper parts of the De Geerdalen Formation. This event is also recognized in cores from Sentralbanken area of the Barents Sea (Paterson *et al.* 2018) and in exploration wells (e.g., Hochuli and Vigran 2010; Vigran *et al.* 2014; Paterson and Mangerud 2017, 2019). Note that Paterson *et al.* (2017) recorded abundant, but not dominant, *Leschikisporis aduncus*

in an early Carnian core drilled in the Snadd Formation from offshore Kong Karls Land. These Snadd Formation assemblages were more diverse and different from those on Hopen, which were totally dominated by *Leschikisporis aduncus*. The former are probably of older, early Carnian age, as they are constrained by Re–Os geochronology from an underlying core.

The FO of dominant *Leschikisporis aduncus* is taken here as the base of the Tuvalian (upper Carnian).

FO of abundant *Protodiploxypinus*

The FO of abundant *Protodiploxypinus* is based on multiple records from the Norwegian Arctic. It was recorded by Paterson and Mangerud (2015) from the upper De Geerdalen Formation (Hopen Member) on Hopen. They named their *Protodiploxypinus* Assemblage from this acme and assigned it a late Carnian (Tuvalian) age (see discussion in Paterson and Mangerud 2015). This event is also recognized in cores from Sentralbanken area in the Barents Sea (Paterson *et al.* 2018), and from exploration wells in the upper Snadd Formation in the southern Barents Sea (Hochuli and Vigran 2010; Paterson and Mangerud 2017, 2019).

The FO of abundant *Protodiploxypinus* is taken here as the base of the Tuvalian (upper Carnian).

LO of dominant *Leschikisporis aduncus*

The LO of abundant to dominant *Leschikisporis aduncus* is based on multiple records from the Norwegian Arctic. Paterson and Mangerud (2015) recorded this event in the De Geerdalen Formation, where *Leschikisporis aduncus* is abundant up to the base of the Hopen Member. They defined their *Leschikisporis aduncus* Assemblage partly from this event and assigned it a late Carnian (middle Tuvalian) age (see Paterson and Mangerud 2015). Nagy *et al.* (2011) recorded this event from the upper part of the same formation in Spitsbergen. It is also recognized as an important event in Barents Sea exploration wells (e.g., Hochuli and Vigran 2010; Vigran *et al.* 2014; Paterson and Mangerud 2017). As discussed by Paterson *et al.* (2018), the apparent lack of *Leschikisporis aduncus* in the Sverdrup Basin may be because the Carnian samples analyzed from wells in the Schei Point Formation (Fisher and Bujak 1975) are younger than the *Leschikisporis aduncus* acme. In the Russian Barents Sea, this taxon remains dominant until the Norian (Mørk *et al.* 1993), suggesting that its range top in the Norwegian Barents Sea is facies controlled (see Paterson *et al.* 2016 and Paterson and Mangerud 2019). Note that the LO of abundant to dominant *Leschikisporis aduncus* is corresponding the the FO, indicating that this was a short-lived event.

The LO of dominant *Leschikisporis aduncus* is taken here to correspond to the base of the Tuvalian (upper Carnian).

FO of rare *Rhaetogonyaulax*

The FO of rare *Rhaetogonyaulax* (including *Rhaetogonyaulax*

arctica and *Rhaetogonyaulax rhaetica*) is based on multiple records from the Norwegian Arctic. This includes records from the middle parts of the De Geerdalen Formation dated as late Carnian (Paterson and Mangerud 2015, 2019 and Paterson *et al.* 2016). *Rhaetogonyaulax* has been recorded in the Sverdrup Basin (Fisher and Bujak 1975; Bujak and Fisher 1976; Felix and Burbridge 1978) and Alaska (Wiggins 1973).

The FO of rare *Rhaetogonyaulax* is taken here as the base of the Tuvalian (upper Carnian).

LO of consistent *Schizaeoisporites worsleyi*

The LO of consistent *Schizaeoisporites worsleyi* is based on multiple records from the Norwegian Arctic. This species was first described from the Carnian on Hopen (Bjærke and Manum 1977). Paterson and Mangerud (2015) later recorded it ranging to the top of the De Geerdalen Formation, just below the overlying ammonoid-dated Norian succession. Vigran *et al.* (1998) recorded it from three Ladinian cores in the Svalis Dome, Barents Sea. Vigran *et al.* (2014) found rare occurrences of *Schizaeoisporites worsleyi* in their *Limbosporites lundbladiae* Composite Assemblage Zone, which may be reworked. *Schizaeoisporites worsleyi* is generally recorded in low numbers, but it is very distinct and thus a good marker.

The LO of consistent *Schizaeoisporites worsleyi* is taken here as the base of the Norian.

LO of sporadic *Aulisporites astigmosus*

The LO of sporadic *Aulisporites astigmosus* is based on multiple records from the Norwegian Arctic. Paterson and Mangerud (2015) recorded this species from the De Geerdalen Formation, occurring up to the base of the Hopen Member on Hopen. Vigran *et al.* (2014) defined an early to middle Carnian *Aulisporites astigmosus* Composite Assemblage zone. However, Paterson *et al.* (2018) refined the palynological zonation and verified the palynological division between the lower and middle Carnian suggested by Hochuli *et al.* (1989), designating zones SBH I to SBH III.

The LO of sporadic *Aulisporites astigmosus* is taken here as the base of the Norian.

LO of abundant *Protodiploxypinus*

The LO of abundant *Protodiploxypinus* is based on multiple records from the Norwegian Arctic. It was first recorded as a reliable first downhole occurrence by Hochuli *et al.* (1989), and as a typical component of their late Carnian Assemblage C. *Protodiploxypinus* was also recorded by Paterson and Mangerud (2015) from the upper De Geerdalen Formation (Hopen Member) at Hopen. They named their *Protodiploxypinus* Assemblage from this acme and assigned it to the latest Carnian (see discussion in Paterson and Mangerud 2015). Paterson and Mangerud (2017) recorded abundant *Protodiploxypinus* from exploration wells in the upper Snadd Formation in the Barents Sea.

The LO of abundant *Protodiploxypinus* is taken here as the base of the Norian.

LO of consistent *Illinites chitonoides*

The LO of consistent *Illinites chitonoides* is based on multiple records from the Norwegian Arctic. It was reported from within the middle De Geerdalen Formation by Vigran *et al.* (2014). However, Paterson and Mangerud (2015) recorded it to the top of the De Geerdalen Formation (i.e. top Hopen Member) on Hopen, a horizon that they assigned a latest Carnian (Tuvalian) age. Paterson *et al.* (2018) recorded sporadic occurrences of *Illinites chitonoides* up into the early Norian Flatsalen Formation in cores from the Sentral-banken High, Barents Sea.

The LO of consistent *Illinites chitonoides* is taken here as the base of the Norian.

FO of common *Rhaetogonyaulax*

The FO of common *Rhaetogonyaulax* (including *Rhaetogonyaulax arctica* and *Rhaetogonyaulax rhaetica)* is based on multiple records from the Norwegian Arctic (Mangerud *et al.* 2018). Paterson and Mangerud (2015) and Paterson *et al.* (2016) recorded common *Rhaetogonyaulax* from the base of the Flatsalen Formation, where ammonoids of the ammonoid *Mojsisovicsites kerri* Zone of Norian age are recorded. Note that on Hopen, the *Rhaetogonyaulax arctica* peak is older than the *Rhaetogonyaulax rhaetica* peak. However, we consider that the difference reflects paleoenvironmental conditions rather than stratigraphic range. *Rhaetogonyaulax arctica* favours conditions closer to shore, and is thus more abundant than *Rhaetogonyaulax rhaetica* during the early stages of a transgression. *Rhaetogonyaulax rhaetica* probably favours outer shelf settings because it is most abundant in association with maximum flooding surfaces (Paterson *et al.* 2016). This interpretation is consistent with the overall lower abundance of *Rhaetogonyaulax rhaetica* in more proximal localities in the Barents Sea area, as in the Nordkapp Basin (Paterson *et al.* 2018) and Sentralbanken area (Paterson *et al.* 2017). One of us (JB; Appendix C) has also recorded the FO of common *Rhaetogonyaulax rhaetica* in Norian sidewall core sample 9188 ft (2801 m) in the Fireweed 1 well off northern Alaska; the age is based on the occurrence of age-diagnostic miospores in the same interval.

The FO of common *Rhaetogonyaulax* is taken here as the base of the Norian.

FOs of *Hebecysta, Heibergella, Noricysta* and *Sverdrupiella*

The FOs of dinocysts *Hebecysta brevicornuta, Heibergella aculeata, Heibergella asymmetrica, Heibergella salebrosacea, Noricysta fimbriata, Noricysta pannucea, Noricysta varivallata, Sverdrupiella baccata, Sverdrupiella manicata, Sverdrupiella mutabilis, Sverdrupiella ornaticingulata,*

Sverdrupiella raiaformis, Sverdrupiella sabinensis, Sverdrupiella septentrionalis, Sverdrupiella spinosa, and *Sverdrupiella usitata* are based on their occurrences in the oldest Norian sample (sidewall core 9188 ft; 2801 m) in the Fireweed 1 exploration well, offshore northern Alaska. The sample is dated as Norian based on associated miospore events shown for the well in Appendix C herein. The dinocyst species were originally described by Bujak and Fisher (1976) in eight Sverdrup Basin well sections that were assigned a Norian age based on associated miospore assemblages by Fisher and Bujak (1975). They also characterize strata dated as Norian based on associated miospore events in exploration wells Klondike OCS-Y-1482 (Chukchi Sea) and Romulus C-67 (Sverdrup Basin), but the absence of sidewall- or conventional-core samples in these wells precludes confident age assignment of their oldest occurrences.

Species of *Hebecysta, Heibergella, Noricysta* and *Sverdrupiella* are restricted to the *Noricysta pannucea – Heibergella asymmetrica* (PA) Subzone of the *Triancoraesporites ancorae – Camarozonsporites laevigatus* (AL) Zone of Suneby and Hills (1988). The PA Subzone occurs in the lower part of the Romulus Member of the Heiberg Formation exposed at McKinley Bay, Blackwelder Anticline, Fosheim Anticline and Raanes Peninsula on Elsemere Island, in strata assigned a Norian age by Embry (1982) based on bivalves and ammonoids.

Paterson and Mangerud (2015) recorded rare *Sverdupiella* from the base of the Flatsalen Formation on Hopen, where taxa of the Norian ammonoid *Mojsisovicsites kerri* Zone are recorded. As with *Rhaetogonyalaux*, the stratigraphic range of *Sverdrupiella* in the circum-Arctic region likely varies according to paleoenvironment: the genus is apparently more common and diverse in the Sverdrup Basin as shown above (e.g., Bujak and Fisher 1976; Suneby and Hills 1988), which was likely in closer communication with the open ocean compared to the Barents Sea area (Sømme et. al. 2018).

The FO of *Hebecysta, Heibergella, Noricysta, Sverdrupiella* is taken here as the base of the Norian.

FO of *Classopollis torosus*

The FO of *Classopollis torosus* is based on multiple records from the Norwegian Arctic. It is recorded from the base of the Flatsalen Formation on Hopen, a horizon assigned an early Norian age based on ammonoids typical of the *Mojsisovicsites kerri* Zone (Paterson and Mangerud 2015). The taxon also gave its name to Paterson and Mangerud's *Classopollis torosus* Assemblage. *Classopollis torosus* was previously recorded by Smith *et al.* (1975) and Bjærke and Manum (1977) from Hopen Island. Paterson *et al.* (2017) reported the FO of *Classopollis torosus* in their Norian SBH-V Assemblage from Sentralbanken in the Barents Sea. Paterson and Mangerud (2017) reported common *Classopollis torosus* in their Norian Assemblage SBS-II based on exploration wells in the southern Barents Sea. In the Russian Barents Shelf, a similar influx in *Classopollis* is recorded at the base of the Norian T3k-n Zone (Fefilova

1988; Pavlov *et al.* 1985; Mørk *et al.* 1993).

The FO of *Classopollis torosus* is taken here as the base of the Norian.

FO sporadic *Limbosporites lundbladiae*

The FO of sporadic *Limbosporites lundbladiae* is based on records from multiple localities in the Arctic; although relatively rare in the Norian, it seems to be a robust marker. Fisher and Bujak (1975) reported *Limbosporites lundbladiae* co-occurring with dinoflagellate-cyst assemblages typical for the Norian successions in the Sverdrup Basin, but their work was based mainly on cuttings samples, so that taxon bases are unreliable. Working on out-crop sections in the Sverdrup Basin, Suneby and Hills (1988) recorded *Limbosporites lundbladiae* ranging from within their oldest Norian SC Subzone in the Heiberg Formation, but did not study older sections to verify the true FO. From the Barents Sea area, Hochuli *et al.* (1989) reported the FO of *Limbosporites lundbladiae* in their Assemblage B-2 and Vigran *et al.* (2014) used the FO of this species as the base of their Norian *Limbosporites lundbladiae* Composite Assemblage Zone. Paterson and Mangerud (2015) also used the FO of abundant *Limbosporites lundbladiae* to define the base of their *Limbosporites lundbladiae – Quadraeculina anellaeformis* Assemblage, corresponding to basal Flatsalen Formation on Hopen, which is assigned an early Norian age based on ammonoids; however, *Limbosporites lundbladiae* occurs sporadically from the base of the Flatsalen Formation. Paterson *et al.* (2017) recorded a few specimens of *Limbosporites lundbladiae* from the uppermost De Geerdalen Formation from shallow cores in the Sentralbanken area; this occurrence is close to the Carnian/Norian transition.

The FO of sporadic *Limbosporites lundbladiae* is taken here as the base of the Norian.

FO of sporadic *Quadraeculina anellaeformis*

The FO of sporadic *Quadraeculina anellaeformis* is reported from multiple localities in the Arctic. Suneby and Hills (1988) recorded *Quadraeculina anellaeformis* ranging from within their oldest Norian SC Subzone in the Heiberg Formation, Sverdrup Basin; however, the FO is unknown, and the species ranges up into the Jurassic. From the Barents Sea area, Hochuli *et al.* (1989) reported the FO of *Quadraeculina anellaeformis* in their Assemblage B-2, while Vigran *et al.* (2014) reported the species from the base of their *Limbosporites lundbladiae* Composite Assemblage Zone, which corresponds to the base of the Norian. Paterson and Mangerud (2015) recorded the FO of sporadic *Quadraeculina anellaeformis* from the basal Flatsalen Formation on Hopen, a horizon assigned an early Norian age based on ammonoids typical of the *Mojsisovicsites kerri* Zone (Paterson and Mangerud 2015). However, *Quadraeculina anellaeformis* occurred more consistently from the base of the overlying Svenskøya Formation, from which they defined their *Limbosporites lundbladiae –*

Quadraeculina anellaeformis Assemblage. Older rare occurrences of *Quadraeculina anellaeformis* have been recorded from the De Geerdalen Formation (Mueller *et al.* 2016) and in strata dated as late Carnian in cores from the Sentralbanken High area of the Barents Sea (Paterson *et al.* 2018).

The FO of sporadic *Quadraeculina anellaformis* is taken here as the base of the Norian.

FO of consistent *Riccisporites tuberculatus*

The FO of consistent (to abundant) *Riccisporites tuberculatus* is based on records from Suneby and Hills (1988). However, Felix (1975) first recognized *Riccisporites tuberculatus* as an important stratigraphic marker in the Heiberg Formation on Ellef Ringnes Island, Sverdrup Basin. He reported abundant *Riccisporites tuberculatus* in all samples from the Triassic part of the formation. Later, Suneby and Hills (1988) reported *Riccisporites tuberculatus* from the base of their studied section (AL Biozone), dated as early Norian. From farther south, in East Greenland, Pedersen and Lund (1980) and Mander *et al.* (2013) recorded abundant *Riccisporites tuberculatus* from the Kap Stewart Formation, a classic Rhaetian plant-macro-fossil locality, but most likely representing a mixed flora. Paterson *et al.* (2017) reported *Riccisporites tuberculatus* from the basal Flatsalen Formation equivalent, based on core material from the Sentralbanken area, Barents Sea. On nearby Hopen Island, the lower part of the Flatsalen Formation was dated as early Norian based on ammonoids. Although the age of this FO is somewhat uncertain, its consistent FO is inferred to be at the base of the Norian.

FO of consistent *Riccisporites tuberculatus* is here taken here as the base of the Norian.

LO of *Kraeuselisporites cooksoniae*

The LO of *Kraeuselisporites cooksoniae* is based on records by Paterson and Mangerud (2015) from Hopen, where this taxon was recorded to the top of the Flatsalen Formation; its LO is coeval with that of the dinoflagellate cyst *Rhaetogonyaulax*, occurring slightly above early Norian ammonoids.

The LO of *Kraeuselisporites cooksoniae* is taken here as 50% up from the base of the Norian.

LO of *Porcellispora longdonensis*

The LO of *Porcellispora longdonensis* is based on data from Paterson and Mangerud (2015) from Hopen Island, where this taxon ranges to the top of the Flatsalen Formation, its LO being coeval with the LO of *Rhaetogonyaulax*. The LO of *Porcellispora longdonensis* occurs somewhat above early Norian ammonoids, but still below typical Rhaetian palynological assemblages at this location. A few specimens are reported in younger sections in the Hammerfest Basin (Vigran *et al.* 2014) and in the Sverdup Basin (Suneby and Hills 1988).

The LO of Porcellispora longdonensis is taken here as 50% up from the base of the Norian.

FO of consistent *Limbosporites lundbladiae*

The FO of consistent *Limbosporites lundbladiae* is based on multiple reports from the Arctic and seems to be a robust marker. From outcrop sections in the Sverdrup Basin, Suneby and Hills (1988) recorded common *Limbosporites lundbladiae* from outcrop sections above typical Norian dino flagellate cyst assemblages and ranging up from within their oldest Norian SC Subzone in the Heiberg Formation, but with the FO unknown. Felix (1975) and Fisher and Bujak (1975) also reported *Limbosporites lundbladiae* but did not provide quantitative data. Hochuli *et al.* (1989) reported the lowest occurrence of *Limbosporites lundbladiae* in their Assemblage B-2. Vigran *et al.* (2014) named their Norian palynological zone the *Limbosporites lundbladiae* Compos-ite Assemblage Zone and defined the base of the zone on the FO of the species, equating the event with the base of the Norian. Paterson and Mangerud (2015) recorded the consistent FO of *Limbosporites lundbladiae* from the base of the Svenskøya Formation at Hopen and defined the base of their *Limbosporites lundbladiae – Quadraeculina anellaeformis* Assemblage at this level. They assigned to the event a ?late Norian age based on palynological evidence in combination with the age assignment of the underlying assem-blages. Pedersen and Lund (1980) also recorded abundant *Limbosporites lundbladiae* from the Kap Stewart Formation of East Greenland. Since independent age control is very limited in this part of the succession, age determination is problematic.

The FO of consistent *Limbosporites lundbladiae* is taken here as 50% up from the base of the Norian.

FO of consistent *Quadraeculina anellaeformis*

The FO of consistent (to common) *Quadraeculina anellaeformis* has been reported from multiple localities in the Arctic. From outcrop sections, Suneby and Hills (1988) reported *Quadraeculina anellaeformis* as ranging from within their oldest Norian SC Subzone in the Heiberg Formation, albeit with an unknown FO as they did not include older successions. They recorded *Quadraeculina anellaeformis* ranging up into the Jurassic. Paterson and Mangerud (2015) defined the base of their *Limbosporites lundbladiae – Quadraeculina anellaeformis* Assemblage as corresponding to the basal Svenskøya Formation, with *Quadraeculina anellaeformis* be-ing common in the upper part of the formation. The species has also been recorded as common from the Knorringfjellet Formation in Spitsbergen (Mueller *et al.* 2016).

The FO of consistent *Quadraeculina anellaeformis* is taken here as 50% up from the base of the Norian.

FO of common *Riccisporites tuberculatus*

The FO of common to abundant *Riccisporites tuberculatus* is based on Suneby and Hills (1988), but the species was first recognized as an important stratigraphic marker by Felix (1975) in materials from Ellef Ringnes Island, Sverdrup

Basin. He reported this species as abundant in all samples from the Triassic part of the Heiberg Formation. Suneby and Hills (1988) reported its common occurrence from the Heiberg Formation at the base of their LT Biozone, which is of latest Norian to early Rhaetian age. In the Barents Sea region, the FO of common *Ricciisporites tuberculatus* occurs above early Norian ammonoids and below typical Rhaetian palynological assemblages.

The FO of common *Riccisporites tuberculatus* is taken here as 50% up from the base of the Norian.

FO of *Polycingulatisporites crenulatus*

Paterson and Mangerud (2015) reported *Polycingulatisporites crenulatus* from the upper part of the Svenskøya Formation on Hopen, and tentatively correlated it with Assemblage A of Hochuli *et al.* (1989). It is a rare, but very distinct taxon, and its FO is probably of stratigraphic significance. As it co-occurs with the typical Triassic palynomorph *Aratrisporites* in "typical Rhaetian" palynological assemblages distinct from those in older strata, a Rhaetian age is inferred.

The FO of *Polycingulatisporites crenulatus* is taken here as the base of the Rhaetian.

LOs of *Hebecysta*, *Heibergella*, *Noricysta* and *Sverdrupiella* excluding *Sverdrupiella mutabilis*

The LOs of dinocysts *Hebecysta brevicornuta*, *Heibergella aculeata*, *Heibergella asymmetrica*, *Heibergella salebrosacea*, *Noricysta fimbriata*, *Noricysta pannucea*, *Noricysta varivallata*, *Sverdrupiella baccata*, *Sverdrupiella manicata*, *Sverdrupiella ornaticingulata*, *Sverdrupiella raiaformis*, *Sverdrupiella sabinensis*, *Sverdrupiella septentrionalis*, *Sverdrupiella spinosa,* and *Sverdrupiella usitata* are based on their occurrence in the youngest samples dated as Norian in exploration wells Fireweed 1 (offshore northern Alaska), Klondike OCS-Y-1482 (Chukchi Sea) and Romulus C-67 (Sverdrup Basin). This date is interpreted from miospore events that occur in the well sections (Appendix C). The dinocyst species are restricted to the *Noricysta pannucea* – *Heibergella asymmetrica* (PA) Subzone of the *Triancoraesporites ancorae* – *Camarozonsporites laevigatus* (AL) Zone defined by Suneby and Hills (1988). The PA Subzone occurs in the lower part of the Romulus Member of the Heiberg Formation exposed at McKinley Bay, Blackwelder Anticline, Fosheim Anticline and Raanes Peninsula on Elsemere Island in strata assigned a Norian age by Embry (1982) based on bivalves and ammonoids.

The LOs of *Hebecysta brevicornuta*, *Heibergella aculeata*, *Heibergella asymmetrica*, *Heibergella salebrosacea*, *Noricysta fimbriata*, *Noricysta pannucea*, *Noricysta varivallata*, *Sverdrupiella baccata*, *Sverdrupiella manicata*, *Sverdrupiella ornaticingulata*, *Sverdrupiella raiaformis*, *Sverdrupiella sabinensis*, *Sverdrupiella septentrionalis*, *Sverdrupiella spinosa,* and *Sverdrupiella usitata* are taken here as the base of the Rhaetian.

LO of *Ricciisporites umbonatus*

The LO of *Ricciisporites umbonatus* was reported by Suneby and Hills (1988) to occur slightly below the LO of *Limbosporites lundbladiae* and to be coeval with the LO of common *Limbosporites lundbladiae* and *Ricciisporites tuberculatus*. Vigran *et al.* (2014) also reported this event as intra-Rhaetian. Precise age assignment is difficult, but a relative occurrence of this event can be proposed based on experience.

The LO of *Ricciisporites umbonatus* is taken here to be 30% up from the base Rhaetian.

LO of common *Limbosporites lundbladiae*

Suneby and Hills (1988) reported the LO of common *Limbosporites lundbladiae* at the top of their *Limbosporites lundbladiae* – *Ricciisporites tuberculatus* Biozone and suggested its age is latest Norian or early Rhaetian. However, they indicated uncertainty regarding the age assignment. Vigran *et al.* (2014) reported the LO of common *Limbosporites lundbladiae* as an intra-Rhaetian event. Paterson and Mangerud (2015) defined their *Limbosporites lundbladiae* – *Quadraeculina anellaeformis* Assemblage from the Svenskøya Formation and recorded common *Limbosporites lundbladiae* to the top of the formation. Since there have been no reports of *Limbosporites lundbladiae* from the Jurassic, this LO is inferred to coincide with the base of the Jurassic.

The LO of common *Limbosporites lundbladiae* is taken here as the base of the Jurassic.

LO *Aratrisporites*

The LO of *Aratrisporites* has been reported from the Sverdrup Basin (Felix 1975, Suneby and Hills 1988), with its LO at the top of the Triassic (within the Heiberg Formation). Vigran *et al.* (2014) also listed several species of *Aratrisporites* as having their LO at the top of the Triassic. Paterson and Mangerud (2015) recorded several *Aratrisporites* species in their uppermost samples from the Svenskøya Formation on Hopen, including *Aratrisporites scabratus*, *Aratrisporites laevigatus*, *Aratrisporites macrocavatus* and *Aratrisporites tenuispinosus*. To our knowledge, there are no records of *Aratrisporites* younger than Triassic in the circum- Arctic region.

The LO of *Aratrisporites* is taken here at the base of the Hettangian (Jurassic).

LO of taeniate bisaccate pollen

The LO of taeniate bisaccate pollen has been reported from multiple localities from the Arctic. Vigran *et al.* (2014) used the LO of taeniate bisaccate pollen as a top Triassic event. Suneby and Hills (1988) listed *Lunatisporites rhaeticus* (as *Taeniasporites rhaeticus*) as extending to the top of the Triassic in the Sverdrup Basin. That species was also recorded by Felix (1975) and Paterson and Mangerud (2015), the latter authors recording it as a single specimen in their

uppermost sample from the Norian–Rhaetian Svenskøya Formation on Hopen.

The LO of taeniate bisaccate pollen is taken here at the base of the Hettangian (Jurassic).

LO of *Sverdrupiella mutabilis*

Sverdrupiella mutabilis has a longer stratigraphic range than other species of *Sverdrupiella.* Its LO is based on their occurrence in the youngest samples dated as Norian in the wells Fireweed 1 (offshore northern Alaska), Klondike OCS-Y-1482 (Chukchi Sea) and Romulus C-67 (Sverdrup Basin) in which its age assignment is constrained by Triassic miospore and Jurassic events that occur in the underying and overlying sections (Bujak *et al.*, in press c).

The LO of *Sverdrupiella mutabilis* is taken here at the base of the Hettangian (Jurassic).

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Editorial responsibility: Robert A. Fensome

Appendices on following pages

APPENDIX A: TAXON NAMES WITH AUTHORSHIPS

Miospores

Anapiculatisporites spiniger Leschik 1955 (now *Carnisporites spiniger*)

Aratrisporites Leschik 1956

Aratrisporites coryliseminis Klaus 1960

Aratrisporites laevigatus Bjærke and Manum 1977

Aratrisporites macrocavatus Bjærke and Manum 1977

Aratrisporites scabratus Klaus 1960

Aratrisporites tenuispinosus Playford 1965

Aulisporites astigmosus (Leschik 1955) Klaus 1960

Camarozonosporites laevigatus Schulz 1967

Camarozonosporites rudis (Leschik 1955) Klaus 1960

Camerosporites secatus (Leschik 1956) Scheuring 1978

Carnisporites spiniger (Leschik 1955) Morbey 1975

Chasmatosporites Nilsson 1958

Chasmatosporites magnolioides (Erdtman 1948) Nilsson 1958

Concavisporites crassexinus Nilsson 1958

Classopollis torosus (Reissinger 1950) Klaus 1960

Cordaitina gunyalensis (Pant and Srivastava 1964) Balme 1970

Cycadopites Wodehouse 1933

Cyclotriletes Mädler 1964

Cyclotriletes oligogranifer Mädler 1964

Cyclotriletes pustulatus Mädler 1964

Densoisporites nejburgii (Schulz 1964) Balme 1970

Dictyophyllidites mortonii (de Jersey 1959) Playford and Dettmann 1965

Dyupetalum Jansonius and Hills 1979

Dyupetalum vicentinense Brugman 1983

Echinitosporites iliacoides Schulz and Krutzsch 1961

Enzonalasporites vigens Leschik 1955

Ephedripites steevesii (Jansonius 1962) de Jersey 1968

Illinites chitonoides Klaus 1964

Iraqispora labrata Singh 1964

Jerseyiaspora punctispinosa Kar et al. 1972

Kraeuselisporites cooksoniae (Klaus 1960) Dettmann 1963

Kyrtomisporis Mädler 1964

Kyrtomisporis gracilis Mädler 1964

Kyrtomisporis laevigatus Mädler 1964

Kyrtomisporis moerki Paterson and Mangerud 2019

Kyrtomisporis speciosus Mädler 1964

Kyrtomisporis sp. A of Paterson et al. (2017) (now *Kyrtomisporis moerki*)

Lunatisporites noviaulensis (Leschik 1956) Scheuring 1970

Lunatisporites rhaeticus (Schulz 1967) Warrington 1974

Leschikisporis aduncus (Leschik 1955) Potonié 1958

Limbosporites lundbladiae Nilsson 1958 (epithet commonly cited as *lundbladii*, but since nominal individual was female the corrected epithet is used herein; Turland *et al*. 2018, Article 60.8b).

Naumovaspora striata Jansonius 1962

Ovalipollis pseudoalatus (Thiergart 1949) Schuurman 1976

Pechorosporites disertus Yaroshenko and Golubeva 1989

Podosporites vigraniae Paterson and Mangerud 2019

Polycingulatisporites crenulatus Playford and Dettmann 1965

Porcellispora longdonensis (Clarke 1965) Morbey 1975

Pretricolpipollenites Danzé-Corsin and Laveine 1963

APPENDIX A: Continued.

Proprisporites pocockii Jansonius 1962

Protodiploxypinus Samoilovich 1953

Protodiploxypinus decus Scheuring 1970

Protodiploxypinus ornatus Scheuring 1970

Punctatisporites fungosus Balme 1963

Retitriletes austroclavatidites (Cookson 1953) Döring, Krutzsch, Mai and Schulz in Krutzsch 1963

Quadraeculina anellaeformis Malyavkina 1949

Ricciisporites tuberculatus Lundblad 1954

Ricciisporites umbonatus Felix and Burbridge 1977

Schizaeoisporites worsleyi Bjærke and Manum 1977

Semiretisporis "barentszi" of van Veen (1985) and Vigran et al. (2014) (name not validly published; now *Semiretisporis hochulii*)

Semiretisporis sp. A of Vigran et al. (1998) (now *Semiretisporis hochulii*)

Semiretisporis sp. 1 of Hounslow et al. 2008 (now *Semiretisporis hochulii*)

Semiretisporis hochulii Paterson and Mangerud 2019

Staurosaccites quadrificus Dolby in Dolby and Balme 1976

Striatella seebergensis Mädler 1964

Striatoabieites richteri (Klaus 1955) Hart 1964

Taeniasporites rhaeticus (Schulz 1967) Warrington 1974

Triadispora obscura Scheuring 1970

Triadispora verrucata (Schulz 1966) Scheuring 1970

Triancoraesporites ancorae (Reinhardt 1961) Schulz 1967

Uvaesporites argentaeformis (Bolkhovitina 1953) Schulz 1967

Uvaesporites imperialis (Jansonius 1962) Utting 1994

Vittatina Samoilovich 1953 ex Wilson 1962

Dinoflagellates

Hebecysta brevicornuta Bujak and Fisher 1976

Heibergella Bujak and Fisher 1976

Heibergella asymmetrica Bujak and Fisher 1976

Heibergella salebrosacea Bujak and Fisher 1976

Noricysta Bujak and Fisher 1976

Noricysta fimbriata Bujak and Fisher 1976

Noricysta pannucea Bujak and Fisher 1976

Noricysta varivallata Bujak and Fisher 1976

Rhaetogonyaulax Sarjeant 1966

Rhaetogonyaulax arctica (Wiggins 1973) Stover and Evitt 1978

Rhaetogonyaulax rhaetica (Sarjeant 1963) Loeblich Jr. and Loeblich III 1968

Sverdrupiella Bujak and Fisher 1976

Sverdrupiella baccata Bujak and Fisher 1976

Sverdrupiella manicata Bujak and Fisher 1976

Sverdrupiella mutabilis Bujak and Fisher 1976

Sverdrupiella ornaticingulata Bujak and Fisher 1976

Sverdrupiella raiaformis Bujak and Fisher 1976

Sverdrupiella sabinensis Bujak and Fisher 1976

Sverdrupiella septentrionalis Bujak and Fisher 1976

Sverdrupiella spinosa Bujak and Fisher 1976

Sverdrupiella usitata Bujak and Fisher 1976

Other groups

Maculatasporites Döring 1964

Reduviasporonites chalastus (Foster 1979) Elsik 1999

Tympanicysta stoschiana Balme 1980 (considered a taxonomic junior synonym of *Reduviasporonites chalastus*)

APPENDIX B: SPREADSHEET SUMMARIZING PALYNOEVENTS

Event	Summary of TsC link
FO of common *Uvaesporites imperialis*	base of the *Otoceras concavum* ammonoid zone
FO of *Reduviasporonites chalastus*	base of the *Otoceras concavum* ammonoid zone
FO of *Lunatisporites noviaulensis*	base of the Griesbachian
FO of *Ephedripites steevesii*	base of the Griesbachian
LO of common *Uvaesporites imperialis*	5% above the base of the Griesbachian
FO of consistent *Proprisporites pocockii*	base of the *Ophiceras commune* ammonoid zone
FO of consistent *Aratrisporites*	base of the ammonoid *Ophiceras commune* Zone
LO of *Vittatina*	70% up from base Griesbachian
FO of common *Densoisporites nejburgii*	base of the Boreal ammonoid *Vavilovites sverdrupi* Zone
FO of consistent *Maculatasporites*	base of the Boreal ammonoid *Vavilovites sverdrupi* Zone
LOs of common *Cycadopites* and *Pretricolpipollenites*	base of the Smithian
FO of common/abundant *Punctatisporites fungosus*	base of the Boreal ammonoid *Euflemingites romunderi* Zone
LO of sporadic *Proprisporites pocockii*	50% up from the base of the ammonoid *Wasatchites tardus* Zone
LO of sporadic *Naumovaspora striata*	base of the Spathian
LO of common *Punctatisporites fungosus*	base of the Spathian
FO of common *Pechorosporites disertus*	base of the Spathian
LO of common *Pechorosporites disertus*	base of the ammonoid *Keyserlingites subrobustus* Zone
FO of *Jerseyiaspora punctispinosa*	base of the late Spathian Boreal ammonoid *Keyserlingites subrobustus*
FO of *Protodiploxypinus*	base of the Boreal ammonoid *Keyserlingites subrobustus* Zone
FO of *Cyclotriletes oligogranifer*	base of the Boreal ammonoid *Keyserlingites subrobustus* Zone
FO of sporadic *Striatella seebergensis*	base of the Boreal ammonoid *Keyserlingites subrobustus* Zone
FO of consistent *Carnisporites spiniger*	base of the Boreal ammonoid *Karangatites evolutus* Zone
FO of consistent *Illinites chitonoides*	base of the Boreal ammonoid *Karangatites evolutus* Zone
FO of consistent *Cordaitina gunyalensis*	base of the Anisian
FO of consistent *Dyupetalum vicentinense*	base of the middle Anisian Boreal ammonoid *Anagymnotoceras varium*
LO of consistent *Densoisporites nejburgii*	50% from the base of the ammonoid *Anagymnotoceras varium* Zone
LO of consistent *Jerseyiaspora punctispinosa*	50% up from the base Anisian
FO of consistent/common *Chasmatosporites*	base of the late Anisian ammonoid *Frechites laqueatus* Zone
FO *Protodiploxypinus decus*	base of the ammonoid *Frechites laqueatus* Zone
FO of consistent *Protodiploxypinus ornatus*	base of the ammonoid *Frechites laqueatus* Zone
FO of *Echinitosporites iliacoides*	base of the Ladinian
FO of consistent *Schizaeoisporites worsleyi*	base of the Ladinian
FO of consistent *Triadispora verrucata*	base of the Ladinian
FO of *Ovalipollis pseudoalatus*	base of the Ladinian
FO of consistent *Staurosaccites quadrifidus*	base of the Ladinian
FO of common to abundant *Semiretisporis hochulii*	base of the Ladinian
FO of sporadic *Enzonalasporites vigens*	base of the Carnian
FO of sporadic *Camerosporites secatus*	base of the Carnian
FO of consistent *Aulisporites astigmosus*	base of the Carnian
LO of sporadic *Cordaitina gunyalensis*	10% up from the base of the Carnian
LO of *Echinitosporites iliacoides*	10% up from the base of the Carnian
LO of common *Semiretisporis hochulii*	10% up from the base of the Carnian
FO of common *Podosporites vigraniae*	10% up from the base of the Carnian
FO of sporadic *Ricciisporites tuberculatus*	10% up from the base of the Carnian
FO of consistent *Camarozonosporites rudis*	10% up from the base of the Carnian
FO of rare *Uvaesporites argentaeformis*	10% up from the base of the Carnian
FO of *Kyrtomisporis moerki*	10% up from the base of the Carnian
LO of *Kyrtomisporis moerki*	base of the Tuvalian (upper Carnian)
FO of consistent *Kyrtomisporis spp*	base of the Tuvalian (upper Carnian)
LO of *Dyupetalum vicentinense*	base of the Tuvalian (upper Carnian)
FO of dominant *Leschikisporis aduncus*	base of the Tuvalian (upper Carnian)
FO of abundant *Protodiploxypinus*	base of the Tuvalian (upper Carnian)
LO of dominant *Leschikisporis aduncus*	base of the Tuvalian (upper Carnian)

APPENDIX B: Continued.

FO of rare *Rhaetogonyaulax*	base of the Tuvalian (upper Carnian)
LO of consistent *Schizaeoisporites worsleyi*	base of the Norian
LO of sporadic *Aulisporites astigmosus*	base of the Norian
LO of abundant *Protodiploxypinus*	base of the Norian
LO of consistent *Illinites chitonoides*	base of the Norian
FO of common *Rhaetogonyaulax*	base of the Norian
FOs of *Hebecysta, Heibergella, Noricysta* and	base of the Norian
FO of *Classopollis torosus*	base of the Norian
FO sporadic *Limbosporites lundbladiae*	base of the Norian
FO of sporadic *Quadraeculina anellaeformis*	base of the Norian
FO of consistent *Riccisporites tuberculatus*	base of the Norian
LO of *Kraeuselisporites cooksonae*	50% up from the base of the Norian
LO of *Porcellispora longdonensis*	50% up from the base of the Norian
FO of consistent *Limbosporites lundbladiae*	50% up from the base of the Norian
FO of consistent *Quadraeculina anellaeformis*	50% up from the base of the Norian
FO of common *Riccisporites tuberculatus*	50% up from the base of the Norian
FO of *Polycingulatisporites crenulatus*	base of the Rhaetian
LOs of *Hebecysta, Heibergella, Noricysta* and excluding *Sverdrupiella mutabilis*	base of the Rhaetian
LO of *Ricciisporites umbonatus*	30% up from the base Rhaetian
LO of common *Limbosporites lundbladiae*	base of the Jurassic
LO of *Aratrisporites*	base of the Jurassic
LO of *taeniate bisaccate pollen*	base of the Jurassic
LO of *Sverdrupiella mutabilis*	base of the Jurassic

APPENDIX C: Charts showing palynological analyses of selected wells, providing supporting evidence for selected palynoevents, especially those involving dinocysts.