

# Triassic conodonts from Svalbard and their Boreal correlations

Hans Arne Nakrem,<sup>1</sup> Michael J. Orchard,<sup>2</sup> Wolfgang Weitschat,<sup>3</sup> Mark W. Hounslow,<sup>4</sup> Tyler W. Beatty<sup>5</sup> & Atle Mørk<sup>6,7</sup>

1 Natural History Museum, University of Oslo, P.O. Box 1172 Blindern, NO-0318 Oslo, Norway

2 Geological Survey of Canada, 101-605 Robson Street, Vancouver, BC V6B 5J3, Canada

3 Geological-Palaeontological Institute and Museum, University of Hamburg, Bundesstrasse 55, DE-20146 Hamburg, Germany

4 Centre for Environmental Magnetism and Palaeomagnetism, Geography, Lancaster Environment Centre, Lancaster University, Bailrigg, Lancaster, LA1 4YQ, UK

5 Department of Geoscience, University of Calgary, 2500 University Drive, NW Calgary, Alberta, T2N 1N4, Canada

6 SINTEF Petroleum Research, NO-7465 Trondheim, Norway

7 Department of Geology and Mineral Resources Engineering, Norwegian University of Sciences and Technology, NO-7491 Trondheim, Norway

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## Corresponding author

Hans Arne Nakrem, Natural History Museum, University of Oslo, P.O. Box 1172 Blindern, NO-0318 Oslo, Norway. E-mail: h.a.nakrem@nhm.uio.no

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## Abstract

Conodont faunas are described from Triassic sections of Svalbard, and their occurrences are locally correlated with established ammonoid zones. With a synthesis of previous conodont-based publications, the current work presents a taxonomically up-to-date compilation of conodont data for the Triassic of Svalbard that is used to construct a conodont-based biochronology, indexed to the current lithostratigraphic nomenclature. Twenty-eight taxa spanning the earliest Griesbachian to the earliest Carnian are presented in a range chart. The examined conodont faunas are correlated with well-established conodont zonations of the Canadian Arctic, and in turn also form the basis for regional correlations.

In the Svalbard Archipelago, Triassic strata are well exposed and are the subject of numerous stratigraphic, palaeontologic and geochemical studies. Previously, fossil collections were described from units identified in local terminologies, but in the present contribution we follow the lithostratigraphic nomenclature of Mørk, Dallmann et al. (1999), and refer older descriptions to this. This paper represents a synthesis of previous conodont-based work, and presents a taxonomically up-to-date compilation of conodont data for the Triassic. These data are herein used to construct a conodont-based biochronology, indexed to current lithostratigraphic nomenclature (i.e., Mørk, Dallmann et al. 1999), forming the basis for regional correlations.

The Triassic succession of Svalbard (Fig. 1) is dominated by clastic sediments. In the Lower and Middle Triassic of western Spitsbergen, shale and sandstone form upward coarsening sequences representing deposition in coastal, deltaic and shallow marine environments that grade eastwards into shelf deposits (Mørk et al. 1982). In the Late Triassic the main sediment input shifted to the south-east, and prodelta sediments prograded over marine shale, and were followed by the deposition of shallow marine to deltaic sandstone, shale and, in some of the eastern locali-

ties, coal (Lock et al. 1978; Mørk et al. 1982; Riis et al. 2008 [this issue]). The Triassic basin extended southwards into the region now occupied by the Barents Sea. During the Triassic this basin formed an extensive embayment of the Panthalassa Ocean into the northern margin of the Pangaea supercontinent (Mørk et al. 1992; Riis et al. 2008; Worsley 2008 [this issue]).

Conodonts have been recovered from throughout the Lower and Middle Triassic succession of Svalbard, as well as from the lowermost part of the Upper Triassic. The main focus in the following account is on the Lower and Middle Triassic units: the Vardebukta, Tvillingodden and Bravaisberget formations in the southern and western areas, and the Vikinghøgda and Botneheia formations in the central parts of Spitsbergen (Fig. 2). These formations comprise the Sassendalen Group (Mørk, Dallmann et al. 1999).

## Sassendalen Group (Lower and Middle Triassic)

In western Spitsbergen, Lower and Middle Triassic strata approach 500 m in thickness. Here, three formations comprise the Sassendalen Group: the Lower Triassic Vardebukta and Tvillingodden formations, and the Middle Triassic Bravaisberget Formation (Fig. 2). These represent

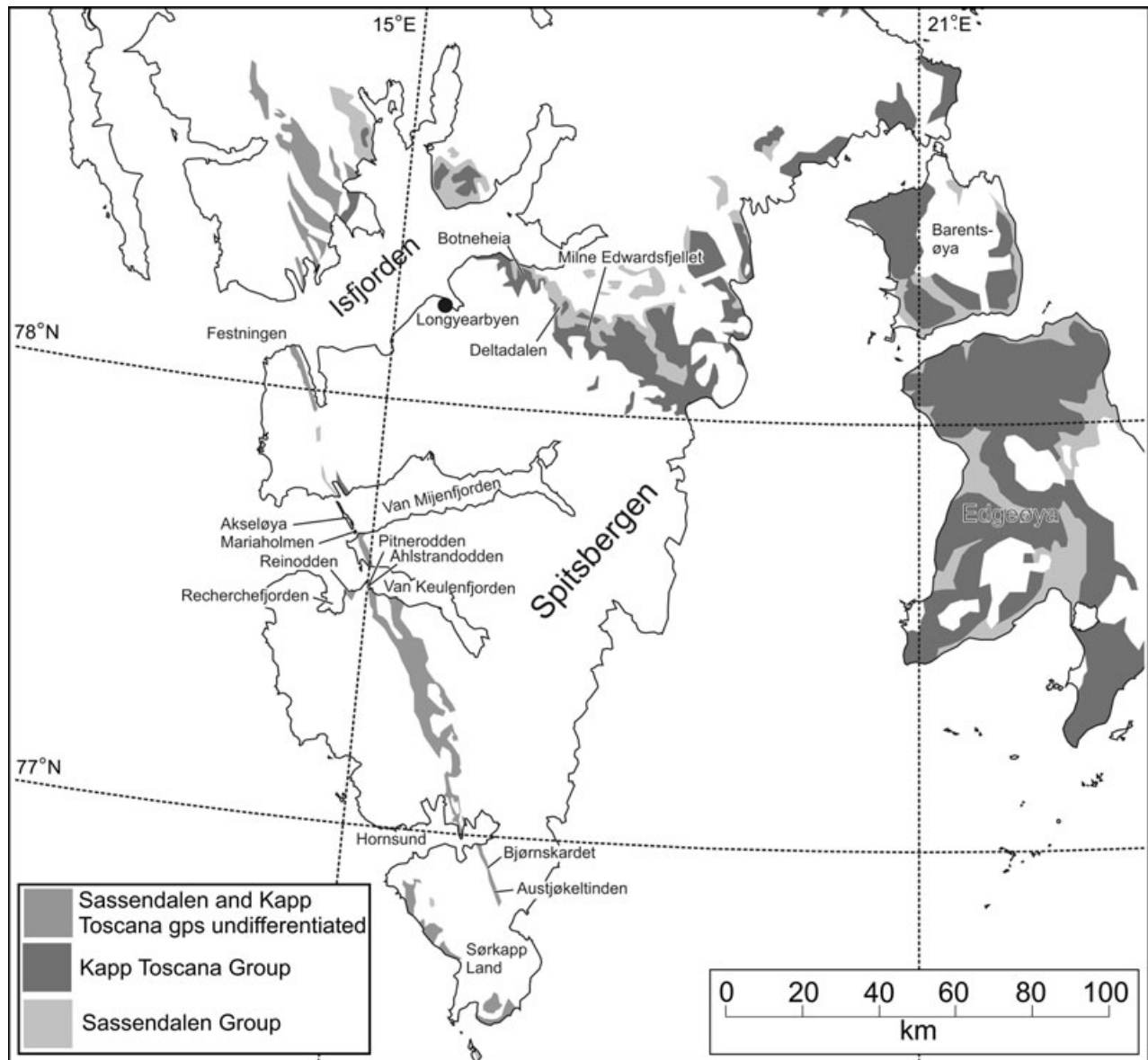
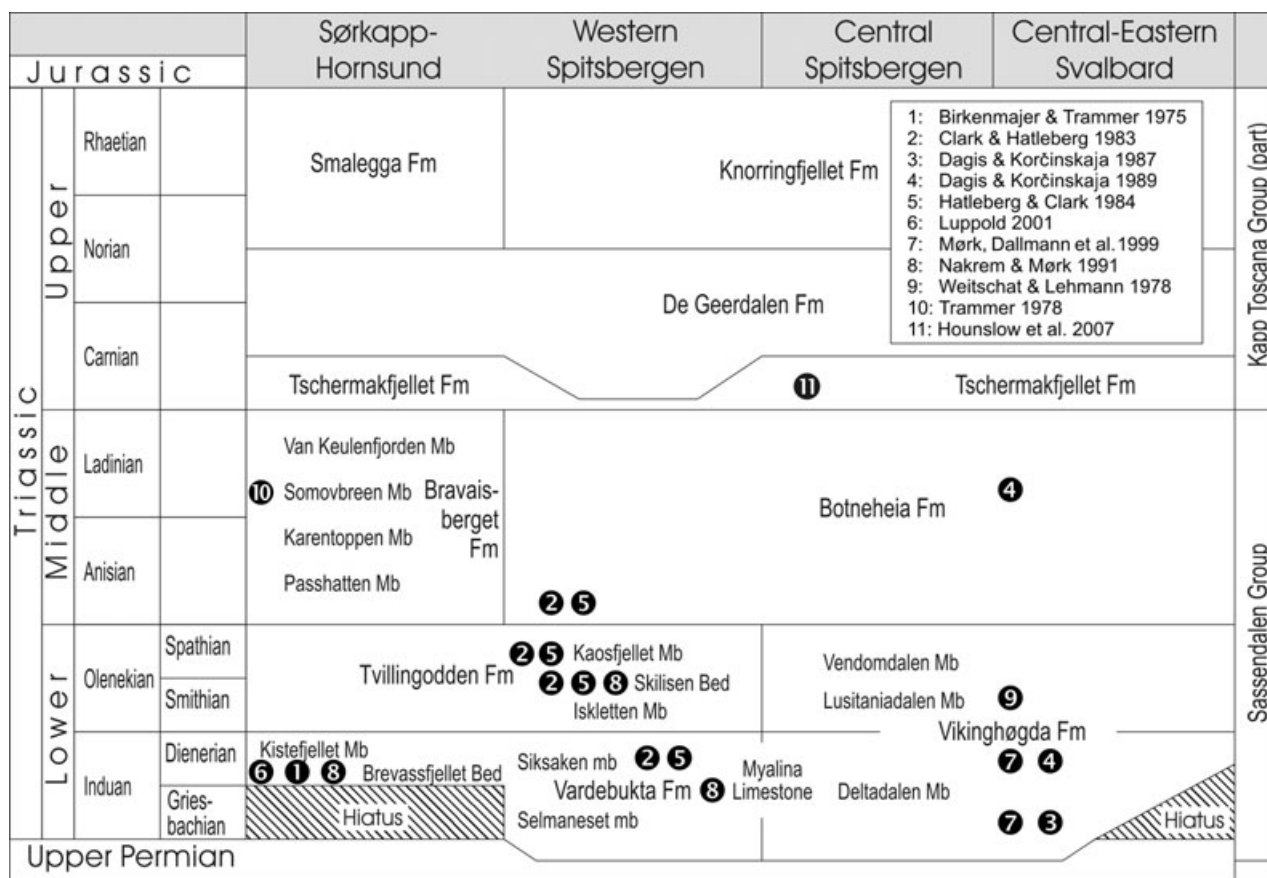


Fig. 1 Map of Svalbard indicating the localities mentioned in the text. The geology is from Dallmann (1999: fig. 1.04).

an overall progradational succession, with the three formations constituting barrier bar/lagoon, shallow marine bars/storm beds and deltaic lobe environments, respectively (Mørk, Dallmann et al. 1999; Krajewski et al. 2007). Two distinct sandy biosparites serve as marker horizons in this region: the *Myalina* limestone in the upper part of the Vardebukta Formation, and the Skilisen Bed (the *Retzia* limestone) in the lower part of the Tvilvingodden Formation (Mørk et al. 1982; Mørk, Dallmann et al. 1999). A major transgression in the early Anisian initiated deposition of the Bravaisberget Formation. At Festningen, a limestone conglomerate with brachiopods

and bivalves represents the initial transgressive deposits of the Middle Triassic (Hoel & Orvin 1937; Egorov & Mørk 2000), whereas elsewhere, poorly indurated shale overlies the siltstone of the underlying formation. A major sediment input from the west resulted in a coarsening upward and prograding succession, so that the open marine shaly lower Passhatten Member of the Bravaisberget Formation is succeeded by sandy delta front sediments of the Somovbreen Member (Mørk et al. 1982; Krajewski et al. 2007).

In Sørkapp Land in the southern part of Spitsbergen, Early Triassic sedimentation was controlled by the



**Fig. 2** Triassic lithostratigraphy of the areas of Svalbard discussed in the text, with published conodont occurrences. The lithostratigraphy is from Mørk, Dallmann et al. (1999).

Sørkapp–Hornsund High, a late Palaeozoic topographic high that was emergent until the mid-Induan (late Griesbachian–Dienerian) (Birkenmajer 1977; Mørk et al. 1982; Nakrem & Mørk 1991). On this high the Lower Triassic succession is thin (<50-m thick), and contains a basal polymict conglomerate that is locally rich in bivalves (*Promyalina* sp.), and is referred to the Brevassfjellet Bed: this bed defines the base of the Kistefjellet Member of the Vardebukta Formation (Mørk, Dallmann et al. 1999).

In central and eastern Svalbard, the Vikinghøgda Formation (Mørk, Elvebakk et al. 1999) is equivalent to the Vardebukta and Tvillingodden formations in western Spitsbergen, and the Botneheia Formation is a distal equivalent to the Bravaisberget Formation. The Vikinghøgda Formation comprises silty shale and storm-generated siltstone deposits, with rare carbonate concretions and discrete horizons enriched in bivalves, brachiopods, ammonoids and vertebrate remains. Transgressive beds deposited on an eroded Permian surface occur at two localities on Edgeøya. An early Olenekian ammonoid fauna was collected from one of these beds

(i.e., Krokå; WW, pers. obs.), implying that the lower part of the Triassic succession is missing in these eastern areas, as it is in Sørkapp Land. The Botneheia Formation in central and eastern Spitsbergen, and on the eastern islands of Barentsøya and Edgeøya, consists of dark shale with rare thin siltstone beds and calcareous shale (Mørk, Dallmann et al. 1999). In general, these sediments are of marine origin, and are very organic-rich (Mørk & Bjørøy 1984).

### **Kapp Toscana Group (from Middle–Upper Triassic transition to Middle Jurassic)**

The Kapp Toscana Group overlies the Sassendalen Group. In Svalbard the contact approximates the Ladinian–Carnian boundary (Weitschat & Dagens 1989; Dagens & Weitschat 1993), but southwards in the Barents Sea the group transition is older (from the base to the late Ladinian) (Mørk, Dallmann et al. 1999). The group, which continues into the Middle Jurassic, contains several condensed sections and hiatuses. The Kapp Toscana Group

has a composite thickness of up to 475 m on Svalbard, thickening to over 1000 m in southern shelf areas (Mørk, Dallmann et al. 1999).

In Svalbard there is an abrupt change from the dark, organic-rich sediment of the Botneheia Formation to grey sediments, with abundant siderite nodules of the overlying Tschermakfjellet Formation (Mørk et al. 1982). The Tschermakfjellet Formation represents a distal prodelta depositional environment, and overlies the Botneheia Formation and, locally, the Bravaisberget Formation, although in the most western areas it is missing (Mørk et al. 1982). The Tschermakfjellet Formation grades up into the De Geerdalen Formation: the formational boundary is defined by the appearance of the first prominent sandstone of the prograding delta (Lock et al. 1978; Mørk et al. 1982; Mørk, Dallmann et al. 1999; Riis et al. 2008).

Biostratigraphically, the boundary between the Kapp Toscana and Sassendalen groups has been the subject of controversy. In the classical view of Frebold (1929a, b), the “Nathorstites beds” belong to the Carnian, and the Middle/Upper Triassic boundary coincides with the change in facies that is coincident with the modern lithostratigraphic group boundary. Buchan et al. (1965) placed the transition between the groups at the top of the Anisian, and subsequently most authors placed it somewhere in the Ladinian (Tozer & Parker 1968; Lock et al. 1978; Mørk et al. 1982). Korčinskaja (1982) revived Frebold’s ideas, and placed the Ladinian/Carnian boundary at the lithostratigraphic group boundary. Observations by Dagys & Weitschat (1993), especially in the eastern areas of the exposure at Wichebukta and Agardhbukta, supported these ideas. They described a characteristic early Carnian ammonoid and bivalve fauna from immediately above the group boundary, which indicates that the typical change in facies coincides with the Middle/Upper Triassic boundary. Because diagnostic latest Ladinian ammonoids have not been discovered on Svalbard, the authors interpreted a minor break between the Ladinian and Carnian stages. Phosphatic pebble conglomerates at the boundary support this suggestion.

## Material and methods

Material from the Triassic of Milne Edwardsfjellet (Fig. 1) has been processed for the current study. This includes 81 samples from the Vikinghøgda Formation (from the base of the Lusitaniadalen Member and from the upper part of the Vendomdalen Member), the Botneheia Formation and the lowermost part of the Tschermakfjellet Formation. Material mentioned, but not systematically described in Nakrem & Mørk (1991), and in Mørk, Elvebakk et al. (1999), has been re-investigated, and some

revisions are presented herein (Appendix 1). This includes material from the Vardebukta and Tvillingodden formations of Akseløya, Bjørnskardet and Austjøkeltingen, and material from the Vikinghøgda Formation in Deltadalen.

## Previous work

Since 1975, several papers describing scattered conodont occurrences from the Triassic of Svalbard have been published: Birkenmajer & Trammer (1975), Trammer (1978), Weitschat & Lehmann (1978), Clark & Hatleberg (1983), Hatleberg & Clark (1984), Dagis & Korčinskaja (1987, 1989), Nakrem & Mørk (1991), Mørk, Elvebakk et al. (1999), Luppold (2001) and Nakrem et al. (2001). Since the publication of these data, the taxonomy of Triassic conodonts has in many cases been refined (e.g., Orchard 2007b), and most taxa in the aforementioned publications from Svalbard have now been reassigned to taxa according to modern nomenclature.

Extensive fieldwork and geological study of the Triassic succession of Svalbard have also led to refinement of the lithostratigraphy and biostratigraphy of these units. The *Lithostratigraphic lexicon of Svalbard* (Dallmann 1999) is the most up-to-date work regarding the lithostratigraphic units discussed in this paper, and includes a biostratigraphic zonation of the Triassic succession compiled by Mørk & Vigran (1999) and Mørk & Smelror (1999). Conodont occurrences described in this contribution, coupled with previously established ammonoid zonations, add new knowledge to Boreal correlations, and supplement the lexicon with biostratigraphical data (Fig. 3).

Illustrated specimens (Figs. 4, 5), with Paleontologisk Museum, Oslo (PMO) prefixes, are housed in the collection of type and illustrated palaeontological material of the Natural History Museum, University of Oslo; remaining specimens are housed in the collection of the Geological–Palaeontological Institute and Museum, University of Hamburg. A list of all taxa referred to in this paper is appended for archival purposes (Appendix 2).

## Lower Triassic

### Vikinghøgda Formation, Deltadalen Member

From the Lusitania River, southern side of Sassenfjorden, Dagis & Korčinskaja (1987) (3 in Fig. 2) reported the presence of two conodont assemblages 6 m above the base of the formation. The lower assemblage contained *Neogondolella carinata* and its probable constituent rami-form elements, co-occurring with *Otoceras boreale*, *Glyptopliceras nielsenii*, *Ophiceras* (*Lytophicerias*) *spathi*,



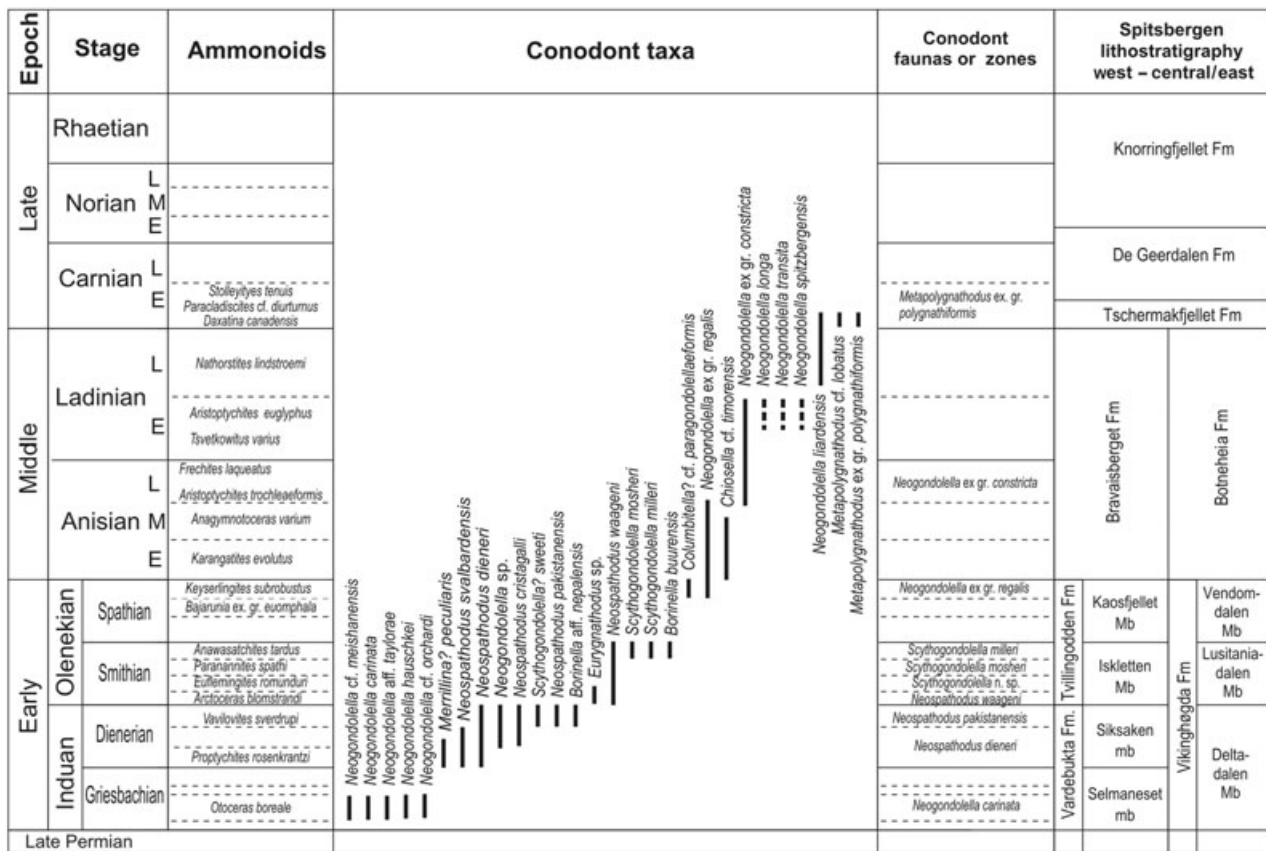


Fig. 3 Range chart of the Triassic conodonts of Spitsbergen. The lithostratigraphy is from Mørk, Dallmann et al. (1999); the ammonoids are from Dagens & Weitschat (1993). Conodont faunas are mostly informal, and are based partly on Orchard & Tozer (1997).

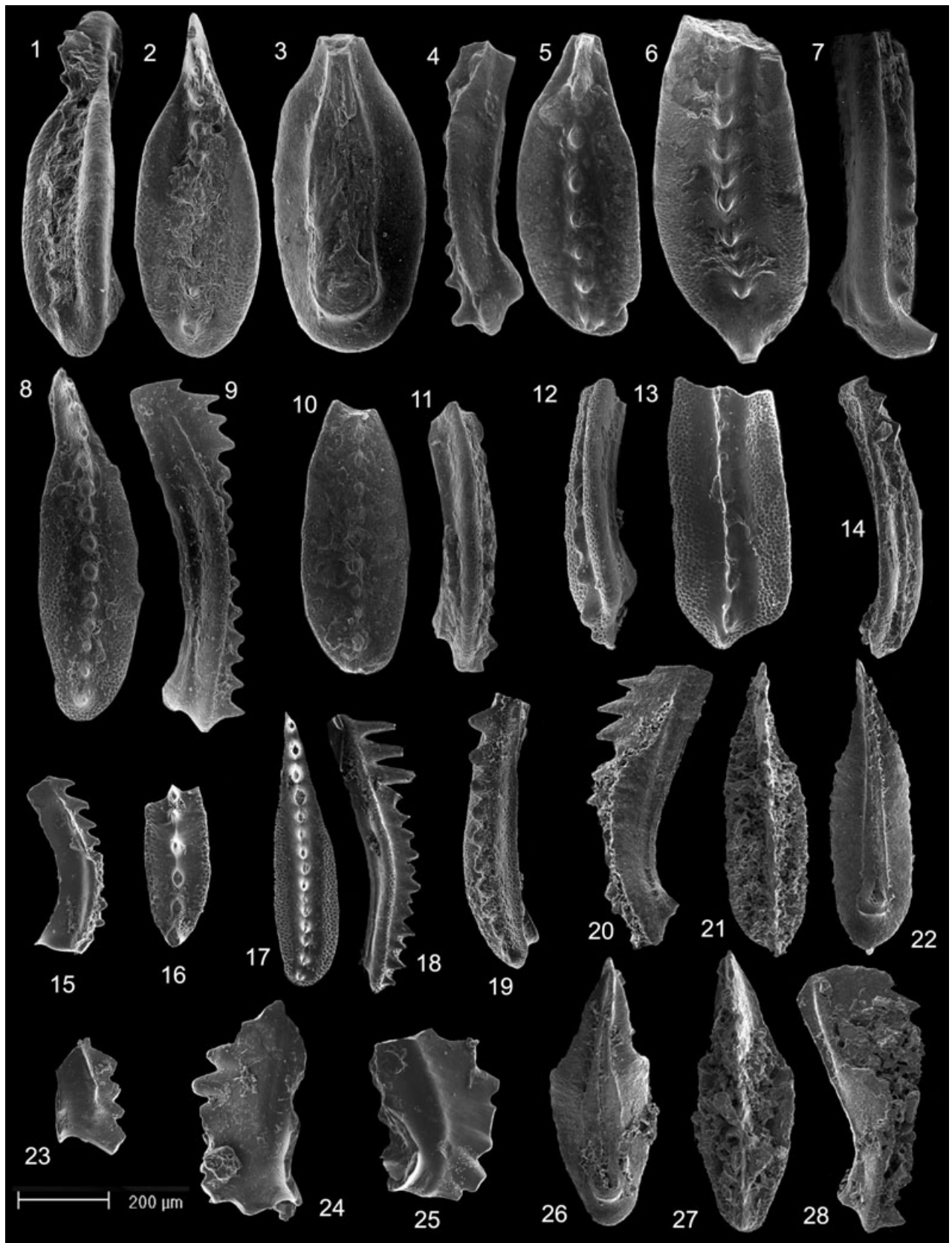
*Ophiceras* (*Lyttophiceras*) sp. cf. *compressum*, *Ophiceras* (*Lyttophiceras*) sp. cf. *kochi*, *Ophiceras* (*Acanthophiceras*) sp. cf. *poulsenii*, *Paravishnuites paradigma*, *Paravishnuites oxynotus*, *Promyalina* sp. cf. *degeeri*, *Unionites* sp. cf. *breviformis* and *Bellerophon borealis*. The conodont species appears in the latest Permian, and occurs throughout the Griesbachian, but its association with the ammonoids indicates an early Griesbachian age for the lower part of the Vikinghøgda Formation (Deltadalen Member) at this locality.

From a higher level in the Deltadalen Member, Dagens & Korčinskaja (1989) (4 in Fig. 2) reported *Neospathodus* aff. *cristagalli*, *Neospathodus svalbardensis* and *Neogondolella* sp. occurring with *Proptychites* species (*Proptychites rosenkrantzi*, *Proptychites simplex*, *Proptychites* cf. *candidus* and *Proptychites* cf. *strigatus*) indicative of the basal Dienerian. This was regarded as equivalent to the fauna reported from the basal Dienerian in the Hornsund region by Birkenmajer & Trammer (1975), which included *Merrillina? peculiaris* (formerly *Neospathodus*), *Neospathodus dieneri* and the types of *Ns. svalbardensis*.

From Ahlstrandodden and localities on the eastern shores of Recherchefjorden and Van Keulenfjorden, Dagens

& Korčinskaja (1989) described *Ns. dieneri*, *Neospathodus pakistanensis*, *Neospathodus* aff. *svalbardensis* and a new conodont species *Neogondolella sweeti*. This level may be identical to the *Myalina* limestone (=Brevassfjellet Beds elsewhere), because Dagens & Korčinskaja (1987) refer to the conodonts coming from a sample with abundant *Promyalina degeeri*, as well as *Vavilovites spitzbergensis*: this implies equivalence with the upper Dienerian sverdrupi Zone of Canada. The conodonts are consistent with this age.

Dagens & Korčinskaja (1989) included in their new species, *Ng. sweeti*, a specimen illustrated by Sweet (1970b) that had earlier formed the basis of a second new species, *Gondolella sweeti* Kozur & Mostler, 1976. Many Triassic species referred to *Gondolella* were subsequently moved to *Neogondolella*, creating a potential nomenclatural conflict. (The genus *Neogondolella* is used in this paper for some species that others refer to *Clarkina*. MJO prefers this usage for reasons explained elsewhere; Orchard 2008 [this issue]) However, "*G.*" *sweeti* is now referred by Kozur to the genus *Paragondolella*, whereas Orchard (2007b) has referred it to *Borinella*. The



**Fig. 4** Illustrated specimens with Paleontologisk Museum, Oslo (PMO) prefix numbers are housed in the collection of type and illustrated palaeontological material of the Natural History Museum, University of Oslo; the remaining specimens are housed in the collection of the Geological–Palaeontological Institute and Museum, University of Hamburg. (4.1–4.3) *Neogondolella* aff. *taylorae* Orchard, from Deltadaldalen, Vikinghøgda Formation, Deltadalen Member, 5 m above base of formation (4.1 and 4.2, PMO 170.990/1; 4.3, PMO 170.990/2). (4.4 and 4.5) *Neogondolella carinata* (Clark) from Deltadaldalen, Vikinghøgda Formation, Deltadalen Member, 5 m above base of formation (PMO 170.990/5). (4.6 and 4.7) *Neogondolella* cf. *meishanensis* (Zhang, Lai, Ding & Liu) from Deltadaldalen, Vikinghøgda Formation, Deltadalen Member, 5 m above base of formation (PMO 170.990/4). (4.8 and 4.9) *Neogondolella* cf. *orchardi* (Mei), from Deltadaldalen, Vikinghøgda Formation, Deltadalen Member, 11.5 m above base of formation (PMO 170.993/2). (4.10 and 4.11) *Neogondolella hauschkei* (Kozur), from Deltadaldalen, Vikinghøgda Formation, Deltadalen Member, 5 m above base of formation (PMO 170.990/6). (4.12 and 4.13) *Neogondolella* sp. A, from Mariaholmen, Vardebukta Formation, Siksaken member, Myalina limestone (PMO 170.991/2). (4.14) *Neogondolella* sp. B, from Austjøkeltinden, Tvillingodden Formation, Skilisen Bed, sample AJT-107 (specimen lost). (4.15 and 4.23) *Scythogondolella?* sp., from Akseløya, Tvillingodden Formation, Skilisen Bed (4.15, PMO 170.992/5; 4.23, specimen lost). (4.16) *Borinella?* sp., from Akseløya, Tvillingodden Formation, Skilisen Bed (PMO 170.992/6). (4.17 and 4.18) *Borinella* aff. *buurensis* (Dagis), from Sassenfjorden, Vikinghøgda Formation, Lusitaniadalen Member (Type Cat. No. 2166; Weitschat & Lehmann 1978: pl. 13, fig. 3). (4.19) *Borinella buurensis* (Dagis), from Austjøkeltinden, Tvillingodden Formation, Skilisen Bed, sample AJT-107 (specimen lost). (4.20–4.22) *Columbitella?* sp. nov. K of Orchard 2007b, from Milne Edwardsfjellet section MES, Tvillingodden Formation, Vendomdalen Member, sample 311 at 36 m above base of formation (PMO 170.994/1). (4.24 and 4.25) *Neospathodus pakistanensis* Sweet, from Akseløya, Tvillingodden Formation, Skilisen Bed (24, PMO 170.992/1; 25, PMO 170.992/2). (4.26–4.28) *Columbitella? paragondolellaeformis* (Dagis), from Milne Edwardsfjellet section MES, Tvillingodden Formation, Vendomdalen Member, sample 316 at 54.4 m above base of formation (PMO 170.995/1).

specimens that formed the basis of *Ng. sweeti* might better be referred to the genus *Scythogondolella*, although the available illustrations are poor: it is not regarded as the same species as that from Pakistan (Sweet 1970b), although it is in part contemporaneous with that species.

Mørk, Elvebakk et al. (1999) (7 in Fig. 2) reported the presence of *Ng. carinata* from calcareous nodules 5.0 and 11.5 m above the base of the Vikinghøgda Formation. *Neogondolella* cf. *meishanensis*, *Neogondolella hauschkei*, *Neogondolella* cf. *orchardi* and *Neogondolella* aff. *taylorae* are also present in the lower sample (5.0-m sample). These conodonts were found together with *O. boreale*, *Claraia stachei*, *B. borealis* and *Tompophiceras* cf. *gracile*. *Neogondolella meishanensis* straddles the Permian–Triassic boundary, whereas the ammonoid association suggests an early Griesbachian age. *Ng.* aff. *taylorae* is similar to elements that Kozur (2004) described as *Clarkina praetaylorae* from the latest Permian of Iran. Both in Iran (Kozur 2005) and in the Canadian Arctic (Beatty et al. 2006), the co-occurrence of *Ng. meishanensis* and *Ng. hauschkei* is also considered to be indicative of the latest Changhsingian. Thus, the basal part of the Sassendalen Group may be latest Permian in age, as suggested by palynological (Hochuli et al. 1989), isotope/geochemical (Wignall et al. 1998) and magnetostratigraphic (Hounslow, Peters et al. 2008) data. Higher up in the Deltadalen Member, from a sample 79.0 m above the base of the member, *Neospathodus* cf. *svalbardensis* is identified, and serves as a proxy for the base of the Dienerian.

### Vikinghøgda Formation, Lusitaniadalen Member

A single sample from 2 m below the top of the Lusitaniadalen Member (MES section, Milne Edwardsfjellet,

west, see Hounslow, Hu et al. 2008 [this issue]: fig. 4) yielded specimens of *Neospathodus waageni*. This species co-occurs here with an ammonoid fauna of *Xenoceltites subevolutus*, *Anawasatchites* sp., *Arctoprionites nodosus* and *Anasibirites* sp., indicating the late Smithian Wasatchites tardus Zone.

Weitschat & Lehmann (1978) (9 in Fig. 2) reported the presence of the following species in samples from a level approximately 7 m below the top of this member, collected from the southern shore of Sassenfjorden, close to Botneheia, from the *Anawasatchites tardus* Zone: *Scythogondolella milleri*, *Scythogondolella mosheri*, *Borinella* aff. *buurensis* (originally described as *Neogondolella planata*, *Neogondolella nevadensis* and *Neogondolella jubata*, respectively) and *Ns. waageni*. The age of this fauna is late Smithian, which correlates with the *Scythogondolella milleri* Zone of Sweet et al. (1971). The results of a similar reassessment of this fauna by Dagis & Korčinskaja (1989) concur with this age determination, although they regarded the elements of *Ng. jubata* as examples of *Neogondolella jakutensis*, a similar Smithian species from Siberia.

### Vikinghøgda Formation, Vendomdalen Member

Four conodont collections were recovered from the upper part of the Vendomdalen Member at the Milne Edwardsfjellet locality, at 31, 48, 49.1 and 54.4 m above the base of the Vendomdalen Member (for sample points, see Hounslow, Hu et al. 2008: fig. 4). Each contains gondolellids, some of which resemble the Spathian species *Columbitella?* sp. nov. K of Orchard (2007b), and, at a higher stratigraphic level, the Siberian species *Columbitella? paragondolellaeformis*, described from the latest







**Fig. 5** Illustrated specimens with Paleontologisk Museum, Oslo (PMO) prefix numbers are housed in the collection of type and illustrated palaeontological material of the Natural History Museum, University of Oslo; the remaining specimens are housed in the collection of the Geological–Palaeontological Institute and Museum, University of Hamburg. (5.1–5.3) *Scythogondolella milleri* (Müller), from Sassenfjorden, Vikinghøgda Formation, Lusitaniadalen Member (PMO 170.996/1) (5.4–5.6, 5.12 and 5.13) *Scythogondolella mosheri* (Kozur & Mostler), Sassenfjorden, Vikinghøgda Formation, Lusitaniadalen Member (5.4–5.6, PMO 170.996/2; 5.12 and 5.13, Type Cat. No. 2172; Weitschat & Lehmann 1978: pl. 14, figs. 1, 2). (5.7, 5.8 and 5.11) *Neospathodus waageni* Sweet, from Sassenfjorden, Vikinghøgda Formation, Lusitaniadalen Member (5.7 and 5.8, PMO 170.996/3; 5.11, Type Cat. No. 2182; Weitschat & Lehmann 1978: pl. 14, fig. 12). (5.14) *Neospathodus waageni* Sweet, from Milne Edwardsfjellet section MES, Vikinghøgda Formation, Lusitaniadalen Member, sample 301 at 3 m above base of formation (PMO 170.997/1). (5.9 and 5.10) *Chiosella* aff. *timorensis* (Nogami), from Milne Edwardsfjellet section ME, Botneheia Formation, sample 14 at 21.5 m above base of formation (PMO 170.998/1.). (5.15–5.17) *Metapolynathus* ex. gr. *polygnathiformis* (Budurov & Stefanov), from Milne Edwardsfjellet section MEE, Tschermakfjellet Formation, sample 214 at 1 m above base of formation (PMO 170.999/1). (5.18–5.20) *Neogondolella* ex. gr. *constricta* (Mosher & Clark), from Milne Edwardsfjellet section ME, Botneheia Formation, sample 78 at 91 m above base of formation (PMO 171.000/1). (5.21–5.23) *Neogondolella liardensis* Orchard, from Milne Edwardsfjellet section MEE, Tschermakfjellet Formation, sample 214 at 1 m above base of formation (PMO 170.999/2). (5.24–5.26) *Neogondolella regalis* Mosher, from Milne Edwardsfjellet section ME, Botneheia Formation, sample 83 at 96 m above base of formation, sample 14 at 21.5 m above base of formation (5.24, PMO 171.001/1; 5.25 and 5.26, PMO 170.998/2).

Olenekian of Siberia (Dagis 1984; Klets 1998). At Milne Edwardsfjellet, these productive levels occur low in the range of the ammonoid *Keyserlingites* sp., with *K. subrobustus* at 36 m above the base of the Vendomdalen Member.

Dagis & Korčinskaja (1989) reassigned some specimens illustrated by Hatleberg & Clark (1984; from the Kaosfjellet Member, Sticky Keep Formation) as *Ng. jubata*. These were associated with the ammonoids of the Keyserlingites subrobustus Zone (*K. subrobustus*, *Svalbardiceras spitzbergense* and “*Posidonia*” *aranea*). The illustrated conodonts appear to be more closely related to *Neogondolella* ex. gr. *regalis*, which appears in the latest Olenekian (Spathian) in the Canadian Arctic.

### Vardebukta Formation, Brevassfjellet Bed

Conodonts have been reported from the basal Triassic beds of the Sørkapp–Hornsund area (the Brevassfjellet *Myalina* Bed of Birkenmajer 1977; 25–30 m above the base of the Vardebukta Formation) by Birkenmajer & Trammer (1975) (1 in Fig. 2), Nakrem & Mørk (1991) (8 in Fig. 2) and Luppold (2001) (6 in Fig. 2). Conodonts mentioned in Sweet (1970b: 216), Sweet et al. (1971: 451) and Trammer (1978: 283) from Spitsbergen were supplied by G. Hamar, and also from samples from the Brevassfjellet *Myalina* limestone of this area. An early–middle Dienerian age was proposed, and is supported here based on the presence of *Ellisonia triassica*, *Ns. dieneri*, *Ns. svalbardensis* and *Merrillina? peculiaris* (formerly *Neospathodus*).

### Vardebukta Formation, Siksaken member

Clark & Hatleberg (1983) (2 in Fig. 2) and Hatleberg & Clark (1984) (5 in Fig. 2) reported conodonts from the Siksaken member at Ahlstrandodden, Pitnerodden and

Reinodden (southern side of Van Keulenfjorden), 105–115 m above the base of the Vardebukta Formation. They recorded (Hatleberg & Clark 1984: table 2) *E. triassica*, *Ns. dieneri*, *Neospathodus cristagalli*, *Ns. svalbardensis*, *Ns. pakistanensis*, *Neospathodus peculiaris*, *Neogondolella elongata*, *Neogondolella* sp. aff. *momburgensis*, *Neogondolella* sp. A, *Neogondolella* sp. B and *Neogondolella* sp.

A re-study of these collections confirms the presence of the key species *Ns. cristagalli*, *Ns. dieneri*, *Ns. pakistanensis* and *Borinella* sp., implying a Dienerian age; the reassessment of the elements illustrated by Hatleberg & Clark (1984) is given in Appendix 1. Early species of both *Borinella* and ?*Scythogondolella* may be represented, although the named *Neogondolella* species are not. At least some records of *Ns. svalbardensis* may be better interpreted as *Ns. pakistanensis*, with thickened flanges (i.e., “*Neospathodus novaehollandiae*”). *M.? peculiaris* also supports an Induan age. Dagis & Korčinskaja (1989) concluded that *Neogondolella* (= *Borinella* herein) aff. *nepalensis* was represented in the fauna described by Hatleberg & Clark (1984), and also identified their new species *Ng. sweeti* (= *Scythogondolella? sweeti*, see above). These are all consistent with a late Induan age.

Conodonts were reported from the *Myalina* limestone of the Siksaken member at Mariaholmen (Bellsund), 125 m above the base of the Vardebukta Formation, by Nakrem & Mørk (1991). The conodont fauna from this unit was originally assigned to *Ng. elongata*, *Ns. cf. svalbardensis* and *E. triassica*. Two *Neogondolella* specimens restudied here lack the attributes of the first taxon, but are insufficiently preserved to assign them to an alternative species.

### Tvillingodden Formation, Iskletten Member

Clark & Hatleberg (1983) and Hatleberg & Clark (1984) recovered conodonts from the Iskletten Member at

Pitnerodden. The conodont *Sc. mosheri* (*Ng. nevadensis*, *sensu* Hatleberg & Clark 1984) was found in the stratigraphically lowest collection, thereby indicating a Smithian age. Higher in that section, Hatleberg & Clark (1984: table 2) recorded *Neospathodus collinsoni*, *Neospathodus homeri*, *Neospathodus* cf. *triangularis*, *Ng. elongata* and *Ng. jubata*, which is a typical Spathian association. However, none of these taxa can be verified, and the illustrated specimens appear to be older. The unusual element referred to *Ns. collinsoni* appears closer to a *Eurygnathodus* sp., whereas that from the stratigraphically highest sample, referred to *Ng. jubata*, is close to the Smithian *B. buurensis*. *Ng. elongata* is a Spathian species, and the reported occurrences of this species in the Dienerian and Smithian of Svalbard probably represent a species of *Borinella*. The *Neospathodus* species from this member are also more readily compared with late Dienerian–early Smithian taxa (Fig. 3). Dągis & Korčinskaja (1989) came to similar conclusions about the age of the fauna, which they compared with those from the Hedenstroemi Zone of Siberia (Dągis 1984). However, Dągis's revision differed from the present one in regarding the neospathodids as largely representative of *Ns. waageni*, and the gondolellids as examples of the Siberian *Neogondolella* aff. *composita*.

Conodonts were reported from the Skilisen Bed of the Iskletten Member at Akseløya, Bjørnskardet and Austjøkelinden (4, 20 and 2 m above the base of the bed, respectively) by Nakrem & Mørk (1991). The conodont fauna from this unit was originally assigned to *Ng. elongata*, *Ns.* cf. *svabardensis* and *E. triassica*. Restudied elements from Akseløya are revised here as *Borinella?* sp., *Neogondolella* sp. B, *Ns. pakistanensis* and *Scythogondolella?* sp. Gondolellid elements from Austjøkelinden appear to correspond to *B. buurensis*.

### Tvillingodden Formation, Kaosfjellet Member

Clark & Hatleberg (1983) and Hatleberg & Clark (1984) recovered conodonts from the Kaosfjellet Member at Reinodden. The significant taxa recorded by those authors were *Neogondolella mombergensis* and *Ng. nevadensis*. The latter species was also recorded from the Iskletten Member, but illustrations of those specimens (from the Iskletten Member) clearly identify a Smithian age. However, the only elements illustrated from the present member were assigned to *Ng. mombergensis*, a species typical of the Middle Triassic. Dągis & Korčinskaja (1989) reinterpreted the taxa as *Ng. jubata*, a typical Spathian species, into which various forms have been submerged. In this work, the species is assigned to *Ng. ex. gr. regalis*, an equally broad concept that is known to range from the late Spathian through the middle Anisian. The presence

of *K. subrobustus* and "*P.*" *aranea* in this member indicates a probable latest Spathian age for the unit (Tozer 1994).

## Middle Triassic

### Botneheia Formation

Conodonts extracted from the lower Botneheia Formation at the Milne Edwardsfjellet locality include *Ng. ex. gr. regalis* and a single specimen of *Chiosella* cf. *timorensis*, which imply an early–middle Anisian age, based on new data from China and Japan.

*Neogondolella ex. gr. constricta* from the middle part of the formation implies a late Anisian–early Ladinian age.

From the top 0.2 m of the Botneheia Formation the conodont *Neogondolella liardensis* implies a position close to the Ladinian–Carnian boundary (Orchard 2007a).

From the Botneheia Formation of Sassenfjorden (Botneheia), Dągis & Korčinskaja (1989) reported and illustrated the species *Neogondolella longa*, *Neogondolella transita* and *Neogondolella spitzbergensis*, for which they conclude an early Ladinian age. The rather poor illustrations of these conodonts do not lend themselves to confident reassignment, particularly because of the lack of crucial views. However, amongst them appear examples of *Ng. ex. gr. regalis* and, probably, *Ng. ex. gr. constricta*, which together argue for an Anisian age. The co-occurrence of the ammonoids *Aristoptychites* cf. *euglyphus* and *Indigiophyllites spetsbergensis* points to an earliest Ladinian age.

### Bravaisberget Formation

Clark & Hatleberg (1983) and Hatleberg & Clark (1984) published conodonts from the basal beds of the Botneheia Formation (now the Passhatten Member of the Bravaisberget Formation) at Reinodden, and from a single sample at Pitnerodden. At the first locality, the species *Neogondolella regale* = *Ng. ex. gr. regalis* was recorded, and a single specimen was illustrated. Such elements might also be expected in the late Spathian, although they are far more common in the early–middle Anisian. The single specimen of *Ng. elongata* recorded from Pitnerodden suggests an older age, but it was only illustrated in lateral view, and cannot be identified.

Conodonts interpreted to be Ladinian in age were also reported by Trammer (1978) from samples collected at Treskelen, within the Somvbreem Member of the Bravaisberget Formation (Drevvbreem Formation of Birkenmajer 1977 and Trammer 1978). These comprise *Ng. mombergensis* subspp. and *Neogondolella haslachensis trammeri*. As with other Spitsbergen material, the published illustrations are rather poor, but they appear to

represent various growth stages of one or two species for which the given names are regarded as inappropriate here. They could be as old as Anisian, but re-examination is necessary to be sure.

## Upper Triassic

### Tschermakfjellet Formation

Conodonts reported by Hounslow et al. (2007) (11 in Fig. 2) from the lowermost part of the Tschermakfjellet Formation at Milne Edwardsfjellet include a Carnian fauna comprising *Ng. liardensis*, *Metapolygnathus* ex. gr. *polygnathiformis* and *Metapolygnathus* cf. *lobatus*. The first and last of these taxa were recently described by Orchard (2007a) from the Ladinian–Carnian boundary beds in western Canada.

### Triassic conodont biostratigraphy and Boreal correlation

#### Correlation with the Canadian Arctic (the Sverdrup Basin)

Conodont faunas from the Sverdrup Basin of the Canadian Arctic are relatively poorly known, but the systematic descriptions of Lower Triassic faunas have been provided by Orchard (2007b), and elsewhere in this issue (Orchard 2008). Further data, particularly from the Permian–Triassic interval and the basal Triassic, have been presented by Henderson (1993), Henderson & Baud (1997) and Beatty et al. (2006).

The lowermost conodont fauna in the Triassic of Svalbard, from the Vikinghøgda Formation, is associated with the ammonoid *Otoceras boreale*, and contains rare *Ng.* cf. *meishanensis*, *Ng.* aff. *taylorae* and *Ng. hauschkei*, and the more common *Ng. carinata*. This fauna is correlative with assemblage C or D of Henderson & Baud (1997) from the lower part of the Blind Fiord Formation, Otto Fiord section, Ellesmere Island. Their assemblage D also contains *Hindeodus parvus*, which is the index for the base of the Triassic, but, as they state, “in the Canadian Arctic, *H. parvus* is exceptionally rare” (Henderson & Baud 1997: 150). These authors also recorded *Ng. taylorae* from their assemblage D, a species that was introduced by Orchard et al. (1994), based on faunas from the *Otoceras* beds of Selong, and that formed the basis of the basal Triassic *taylorae* Zone in Spiti (Orchard, in Krystyn & Orchard 1996; see also Jiang et al. 2007), and was later subsumed in the *meishanensis* Zone of Orchard & Krystyn (1998). Henderson & Baud (1997) also point out the biostratigraphic impor-

tance of this species for the recognition of the Permian–Triassic boundary, as gondolellids are richer in both species, and specimens in the deeper and colder water deposits of the Boreal and Notal areas, as compared with the type area in China. Beatty et al. (2006) also reported the presence of rare *Ng. meishanensis* and *Ng. hauschkei*, and the more common *Ng. carinata*, together with *O. boreale*, in the lower part of several sections of the Blind Fiord Formation, although in each of these cases, where *H. parvus* was present it succeeded this assemblage.

The latest Griesbachian strigatus Zone of the Arctic contains *Ng. carinata*, *M.? peculiaris*, *Ns. cristagalli* and *Ns. dieneri* (Orchard 2008), all of which are also known in Svalbard in the lower parts of both the Vikinghøgda and Vardebukta formations. (Species reported in Orchard [2008] from the Canadian Arctic but *not* found in the Triassic of Svalbard are *not* considered in the following discussion.) In particular, *Ns. dieneri* ranges up through the Dienerian, and is especially common in the candidus Zone on Ellesmere Island. The same species is common on Svalbard, but the fauna from the late Dienerian Vavilovites sverdrupi Zone of the Deltadalen Member is more diverse, and includes elements that are only known from the younger romunduri Zone in Canada (e.g., *Ns. pakistanensis*). *Ns. svalbardensis* has a Dienerian range in both Arctic Canada and Svalbard, and is also known from the Dienerian Havert Formation of the Barents Shelf (Nakrem et al. 2001).

Conodonts of the late Smithian Wasatchites tardus Zone have several species in common in both Arctic Canada and Svalbard: notably *Sc. milleri*, *Sc. mosheri*, *Ns. waageni* and *B. buurensis*. These species also have ranges outside the Boreal basin, and provide good biostratigraphic correlations elsewhere (Orchard 2008).

The Spathian successions in both Svalbard and in Arctic Canada are sparse in terms of both conodonts and ammonoids. No Spathian conodonts older than the Keyserlingites subrobustus Zone are known from Canada or from the Svalbard succession. This ammonoid zone is recorded from both the Vendomdalen and Kaosfjellet members, where it contains elements of *Ng.* ex. gr. *regalis*, as it does in Canada (Orchard 2008). A second group of gondolellids tentatively referred to *Columbitella?* spp. occur in the Vendomdalen Member, and may be a little older. Lower–middle Spathian elements reported from the Iskletten Member by Hatleberg & Clark (1984) are re-interpreted herein as Smithian.

Middle Triassic conodonts from the Canadian Arctic are known from the Murray Harbour Formation on Ellesmere Island, but they have yet to be studied in detail. Comparisons may nevertheless be made with the faunas of the Botneheia and Bravaisberget formations of



Svalbard, through the common occurrences of both *Ng. ex. gr. regalis* and *Ng. ex. gr. constricta*. All of these collections are dominated by *Neogondolella* species, some of which are almost certainly new. Unlike in Svalbard, *Chiosella* has not been found in the Canadian Arctic.

Conodonts are known from around the Middle–Upper Triassic (Ladinian–Carnian) boundary in both the Hoyle Bay Formation in Canada and the Tschermakfjellet Formation in Svalbard. In common with the Tschermakfjellet Formation collections, the Canadian collections contain early metapolygnathids, in addition to ubiquitous *Neogondolella* species, implying a Carnian age. The youngest Late Triassic conodonts in the Canadian Arctic are those associated with late Carnian welleri Zone ammonoids in the Blaa Mountain Formation of Axel Heiberg Island. This site produced the type specimens of *Metapolygnathus reversus* (Mosher 1973). Conodonts of this age or younger (Norian and Rhaetian) are still to be found within the Upper Triassic of Svalbard.

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## Appendix 1

Taxonomic reassessments of previously published conodonts from Svalbard are shown in the table below.

### Hatleberg & Clark (1984)

#### Vardebukta Formation, Siksaken member

Ahlstrandodden section

Pl. 1, Fig. 6 Ah-1-79

Pl. 2, Fig. 9 Ah-1-79

Pl. 2, Fig. 10 Ah-1-79

Pl. 1, Fig. 3 Ah-7-79

Pitnerodden section

Pl. 1, Fig. 7 Pt-1-79

Pl. 1, Fig. 17 Pt-1-79

Pl. 2, Figs. 2, 3 and 5 Pt-1-79

Pl. 1, Figs. 4 and 8 Pt-2-79

Pl. 1, Figs. 11 and 14 Pt-2-79

Pl. 1, Fig. 19 Pt-2-79

Reinodden section

Pl. 1, Fig. 1 Rn-7-79

Pl. 2, Fig. 6 Rn-7-79

Pl. 1, Fig. 22 Rn-8-79

Pl. 2, Fig. 8 Rn-8-79

Pl. 1, Fig. 20 Rn-9-79

#### Tvillingodden Formation (Sticky Keep Formation), Kaosfjellet Member

Reinodden section

Pl. 2, Fig. 11 Rn-29-79

Pl. 2, Fig. 13 Rn-29-79

#### Tvillingodden Formation (Sticky Keep Formation), Iskletten Member

Pitnerodden section

Pl. 2, Fig. 7 Pt-4-79

Pl. 2, Figs. 14 and 15 Pt-4-79

Pl. 1, Fig. 2 Pt-7a-79

Pl. 1, Fig. 9 Pt-7a-79

Pl. 1, Figs. 12 and 13 Pt-7a-79

Pl. 1, Fig. 18 Pt-7a-79

Pl. 1, Figs. 15 and 16 Pt-7a-79

Pl. 2, Figs. 16 and 18 Pt-7a-79

Pl. 2, Fig. 17 Pt-7a-79

Pl. 2, Figs. 1 and 4 Pt-7b-79

#### Botneheia Formation

Reinodden section

Pl. 2, Fig. 12 Rn-30-79

Pitnerodden section

Pl. 1, Fig. 10 Pt-17-79

### Weitschat & Lehmann (1978)

#### Botneheia Formation, tardus Zone

Pl. 13, Figs. 1–5

Pl. 13, Fig. 6

Pl. 13, Figs. 7–10

Pl. 14, Figs. 1–10

Pl. 14, Figs. 11 and 12

*Neospathodus dieneri*

*Ellisonia triassica*

*Neospathodus peculiaris*

*Neogondolella* sp. B

*Neogondolella elongata*

*Neospathodus svalbardensis*

*Neogondolella* sp.

*Neogondolella elongata*

*Neogondolella elongata*

*Neospathodus cristagalli*

*Neospathodus dieneri*

*Ellisonia triassica*

*Neospathodus cristagalli*

*Neogondolella* sp. A

*Neospathodus svalbardensis*

*Neogondolella mombergensis*

*Neogondolella mombergensis*

*Ellisonia triassica*

*Neogondolella nevadensis*

*Neospathodus homeri*

*Neospathodus homeri*

*Neospathodus homeri*

*Neospathodus homeri*

*Neospathodus* sp. aff. *triangularis*

*Neospathodus collinsoni*

*Neospathodus* sp.

*Neogondolella jubata*

*Neogondolella regale*

*Neogondolella elongata*

*Neogondolella jubata*

*Neogondolella jubata*

*Neogondolella milleri*

*Neogondolella planata*

*Neospathodus waageni*

### Revision by M.J. Orchard

*Neospathodus dieneri*

*Ellisonia triassica*

*Merrillina? peculiaris*

*Scythogondolella?* sp.

?*Scythogondolella?* sp. nov. A

?*Neospathodus pakistanensis*

*Borinella* sp.

?*Scythogondolella?* sp. nov. A

*Borinella* sp.

*Neospathodus cristagalli*

*Neospathodus dieneri*

*Ellisonia triassica*

*Neospathodus cristagalli*

*Neogondolella?* sp. indet.

?*Neospathodus pakistanensis*

?*Neogondolella* ex. gr. *regalis*

*Neogondolella* sp. indet.

ramiform indet.

*Scythogondolella mosheri*

?*Neospathodus waageni*

?

?*Neospathodus pakistanensis*

?

?*Neospathodus dieneri*

*Eurygnathodus?* sp.

?*Neospathodus pakistanensis*

*Borinella* aff. *buurensis*

*Neogondolella* ex. gr. *regalis*

?

*Borinella buurensis*

*Borinella buurensis?*

*Scythogondolella milleri*

*Scythogondolella mosheri*

*Neospathodus waageni*

## Appendix 2

Taxa mentioned in the text are listed below. See Orchard (2008) for further taxonomic revisions of the conodonts.

### Conodonts

*Borinella* aff. *nepalensis* (Kozur & Mostler, 1976)  
*Borinella buurensis* (Dagis, 1984)  
*Chiosella* cf. *timorensis* (Nogami, 1968)  
*Columbitella?* *paragondolellaeformis* (Dagis, 1984)  
*Ellisonia triassica* Müller, 1956  
*Eurygnathodus* sp.  
*Hindeodus parvus* (Kozur & Pjatakova, 1976)  
*Merrillina?* *peculiaris* (Sweet, 1970a) (formerly *Neospathodus*)  
*Metapolygnathus* cf. *lobatus* Orchard, 2007  
*Metapolygnathus* ex. gr. *polygnathiformis* (Budurov & Stefanov, 1965)  
*Neogondolella carinata* (Clark, 1959)  
*Neogondolella* ex. gr. *regalis* Mosher, 1970  
*Neogondolella haslachensis trammeri* Kozur in Kozur & Mock (1972)  
*Neogondolella hauschkei* (Kozur, 2004)  
*Neogondolella jubata* Sweet, 1970a  
*Neogondolella liardensis* Orchard, 2007  
*Neogondolella longa* (Budurov & Stefanov, 1965)  
*Neogondolella* cf. *meishanensis* (Zhang, Lai, Ding & Liu, 1995)  
*Neogondolella mombergensis* (Tatge, 1956)  
*Neogondolella* cf. *orchardi* (Mei, 1996)  
*Neogondolella sweeti* Dagis & Korčinskaja, 1989 (= *Scythogondolella sweeti*)  
*Neogondolella* aff. *taylorae* Orchard, 1994  
*Neogondolella transita* Kozur & Mostler, 1971  
*Neogondolella* ex. gr. *constricta* (Mosher & Clark, 1965)  
*Neogondolella spitzbergensis* Dagis & Korčinskaja, 1989  
*Neogondolella* aff. *composita* Dagis, 1984  
*Neospathodus* cf. *triangularis* (Bender, 1970)  
*Neospathodus collinsoni* Solien, 1979  
*Neospathodus dieneri* Sweet, 1970a

*Neospathodus homeri* (Bender, 1970)  
*Neospathodus svalbardensis* Trammer, 1978  
*Neospathodus waageni* Sweet, 1970a  
*Neospathodus* aff. *crisagalli* (Huckriede, 1958)  
*Neospathodus pakistanensis* Sweet, 1970a  
*Scythogondolella milleri* (Müller, 1956)  
*Scythogondolella mosheri* (Kozur & Mostler, 1976)

### Ammonoids

*Anawasatchites tardus* (McLearn, 1945)  
*Arctoceras blomstrandii* (Lindström, 1865)  
*Arctoprionites nodosus* (Frebold, 1930)  
*Aristoptychites euglyphus* (Mojsisovics, 1886)  
*Glyptopliceras nielseni* Spath, 1935  
*Indigirophyllites spetsbergensis* (Öberg, 1877)  
*Keyserlingites subrobustus* (Mojsisovics, 1886)  
*Ophiceras (Acanthopliceras)* sp. cf. *poulsenii* Spath, 1935  
*Ophiceras (Lyttopliceras)* sp. cf. *compressum* Spath, 1935  
*Ophiceras (Lyttopliceras)* sp. cf. *kochi* Spath, 1935  
*Ophiceras (Lyttopliceras)* *spathi* Trümpy, 1969  
*Otoceras boreale* Spath, 1935  
*Paravishnuites oxynotus* Spath, 1935  
*Paravishnuites paradigma* Trümpy, 1969  
*Proptychites* cf. *candidus* Tozer, 1961  
*Proptychites* cf. *strigatus* Tozer, 1961  
*Proptychites rosenkrantzi* Spath, 1930  
*Proptychites simplex* Spath, 1935  
*Svalbardiceras spitzbergense* Frebold, 1930  
*Tompophiceras* cf. *gracile* (Spath, 1935)  
*Unionites* sp. cf. *breviformis* Spath, 1935  
*Vavilovites spitzbergensis* Korčinskaja, 1986  
*Xenoceltites subevolutus* Spath, 1934

### Other

*Bellerophon borealis* Spath, 1930  
*Claraia stachei* Bittner, 1901  
*Posidonia aranea* Tozer, 1961  
*Promyalina degeeri* Lundgren, 1887