

Lower Triassic conodonts from the Canadian Arctic, their intercalibration with ammonoid-based stages and a comparison with other North American Olenekian faunas

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Abstract

Conodont faunas are described from the type sections of Lower Triassic stages in the Canadian Arctic. The collections come largely from ammonoid-bearing strata of the Strigatus (upper Griesbachian), Candidus (lower Dienerian), Romunduri and Tardus (lower and upper Smithian), and Subrobustus (upper Spathian) zones. These demonstrate that diverse late Griesbachian conodont faunas included the first species of *Borinella*, *Neospathodus* and *Scythogondolella*, accompanied by several species of *Neogondolella*. Dienerian faunas are dominated by *Neospathodus*, but explosive radiation led to several Smithian *Scythogondolella* species and diverse cosmopolitan “neospathodid” species of *Conservatella*, *Discretella* and *Neospathodus*. Smithian *Paullella* (nomen novum) and *Wapitiodus* are recorded here for the first time in the Arctic collections, and emphasize the correlation with successions in the Western Canada Sedimentary Basin (WCSB) and in the western USA. Conodonts from the Romunduri Zone differ in the three regions: *Conservatella*, *Discretella* and *Paullella* are rare in the Arctic, are more common in WCSB and are most common in the USA; *Scythogondolella* species are common in the Arctic, less so in WCSB and are virtually absent in the USA. Conodonts from the Tardus Zone, both in the Arctic and elsewhere, contain cosmopolitan *Borinella buurensis*, *Neospathodus waageni*, *Scythogondolella mosheri* and *Scythogondolella milleri*. Spathian conodont faunas from the Subrobustus Zone are dominated by *Neogondolella* species, which also occur in the WCSB associated with *Triassospathodus*. These two genera have an inverse relationship: *Triassospathodus* dominates the USA successions, and is virtually absent in the Arctic. *Scythogondolella ellesmerensis* sp. nov. and *Scythogondolella lachrymiformis* sp. nov. are described.

The Canadian Arctic was central to the development of an ammonoid-based chronology for the northern Pangean Lower Triassic (Tozer 1994), as well as providing the type sections for the constituent North American stages, that is, the Griesbachian, Dienerian, Smithian and Spathian (Tozer 1965, 1967; Fig. 1). The emergence of a calibrated conodont biochronology in the early 1970s included a reconnaissance study by Mosher (1973) that included conodont samples taken from the matrix of Arctic ammonoid faunas in the archives of the Geological Survey of Canada. Mosher (1973) analysed seven samples, of which four produced conodonts. Later, Ogg & Steiner (1991) undertook a magnetostratigraphy study in the Arctic stage stratotypes, and attempted to obtain con-

odonts, but with little success. For this study, many more matrix samples were processed, and in 1996 these were supplemented by direct sampling of the type sections of the stages in Griesbach, Diener (near to) Smith, and Spath creeks. Although rarely abundant, these conodonts serve to characterize the Arctic stages and ammonoid zones, to facilitate their correlation with successions elsewhere, to identify palaeobiogeographic differentiation and, ultimately, to contribute to a refined Triassic biochronology.

In this report, I document the known ammonoid–conodont associations in the Arctic (Fig. 2), compare these with contemporaneous associations known from the Western Canada Sedimentary Basin (WCSB) and the

SERIES	STAGE	SUBSTAGE	AMMONOID ZONE
LOWER TRIASSIC	SPATHIAN		Keyserlingites subrobustus
			Olenikites pilaticus
	SMITHIAN		Anawasatchites tardus
			Euflemingites romunduri
			Hedenstroemia hedenstroemi
	DIENERIAN		Vavilovites sverdrupi
			Proptychites candidus
	GRIESBACHIAN	U	Bukkenites strigatus
			Ophiceras commune
		L	Otoceras boreale
			Otoceras concavum

Fig. 1 Lower Triassic ammonoid zones of the Canadian Arctic (after Tozer 1994).

western USA, and describe and illustrate the Arctic conodont faunas from the Smithian and Spathian stages. Griesbachian and Dienerian collections, partly described by Orchard (2007), are currently being studied by T. Beatty (University of Calgary).

Stratigraphic setting

The Triassic successions in the Arctic are part of the thick Sverdrup Basin succession that accumulated from the late Paleozoic. The Lower Triassic part of this succession, which may be more than 2000 m thick, is assigned to the Blind Fiord Formation, which is predominantly a shale–siltstone package representing deposition in both shelf and basinal palaeoenvironments (Embry 1991). Three constituent members of the formation are recognized in the depocentre of the basin in north-west Ellesmere Island and northern Axel Heiberg Island, and these correspond to three third-order transgressive–regressive sequences that start with shale, and coarsen upwards into mainly siltstone (Embry 1986, 1988). The members are: the Confederation Point Member, which is of Griesbachian to Dienerian age; the Smith Creek Member, which is of Smithian age; and the Svartfjeld Member, which is largely of Spathian age (Fig. 3). Ammonoid-bearing beds that occur in each of these members are widely separated by strata that are devoid

of macrofossils, and that are generally poor in conodonts. Most of the data reported herein come from the calcareous ammonoid beds, which give an imperfect picture of the succession. Nevertheless, the data are of considerable importance in characterizing the ammonoid zones and stages, and the Boreal faunal province in general. In the account below, the authorship of each taxon is given at the first mention.

Conodont–ammonoid calibration

Griesbachian

Strata were sampled in Griesbach Creek (Fig. 2, no. 1), the type section of the Griesbachian stage (Tozer 1994) and from ammonoid matrix samples from the *Otoceras boreale* Zone on Bjarnason Island (Fig. 2, no. 2; Geological Survey of Canada locality [GSC loc.] 47544) and near the head of Blind Fiord (Fig. 2, no. 3; GSC loc. 51588). The latter yielded a specimen of *Neogondolella planata* (Clark), but most samples contained only rare and poorly preserved *Hindeodus* and *Neogondolella* spp. indet. Elsewhere in the Arctic, *Hindeodus parvus* (Kozur & Pjatakova) and a variety of *Neogondolella* species occur in *Otoceras* beds (Henderson & Baud 1997), but these are currently being studied by T. Beatty (University of Calgary), and will not be discussed further here.

Conodont faunas were recovered from the late Griesbachian zone of *Bukkenites strigatus* (Tozer) at several sites. One collection from south of Diener Creek (Fig. 2, no. 4; GSC loc. 51689) was associated with the ammonoids *Bukkenites nitidus* Tozer and *Wordioceras wordiei* (Spath) at 100 m above the base of Blind Fiord Formation (Tozer 1994; Fig. 3). Three additional samples from the Strigatus Zone exposed in bluffs south of Otto Fiord (Fig. 2, no. 5; Fig. 3) yielded conodonts: in ascending stratigraphic order, GSC locations 51667, 51663 and 51664, with the latter co-occurring with *Bukkenites strigatus*.

The Strigatus Zone collections from GSC locations 51663 and 51664 are dominated by members of the *Neogondolella carinata* (Clark) group, including *Ng. planata* and *Neogondolella nevadensis* (Clark). Only rare examples of the derivative species *Neogondolella krystyni* Orchard (at least in GSC loc. 51663) and *Neogondolella discreta* Orchard (at least in GSC loc. 51689) occur, which implies correlation with the Woodwardi and Tibetum zones, and with slightly younger strata in Spiti (Orchard & Krystyn 1998). Elements of *Merrillina? peculiaris* (Sweet) are common in the two collections, and *Merrillina* sp. nov. also occurs in GSC loc. 51663 (Fig. 3). The latter collection also contains a variety of new taxa that reveal the beginning of the first major conodont radiation of the Triassic (Orchard 2007). Among these is the first repre-



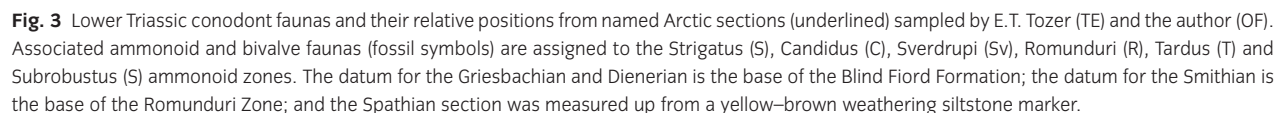
Fig. 2 Map of the Canadian Arctic showing the locations of the Lower Triassic conodont collections discussed in the text.

sentative of *Borinella*, *Borinella megacuspa* Orchard, which may have developed from a second new species, *Neogondolella griesbachensis* Orchard, in the late Griesbachian. The latter species is based on a typical *Neogondolella* segminiplanate P1 element, supporting the view that species of this genus were certainly extant concurrently with similar elements that have been referred to the genus “*Clarkina*” (see Taxonomy). The other major innovation that dates from the late Griesbachian is the first appearance of *Neospathodus*: rare and poorly preserved elements of both *Neospathodus cristagalli* (Huckriede) and *Neospathodus dieneri* Sweet are present in GSC location 51663. Furthermore, the index species *Sweetospathodus kummelli* (Sweet), commonly regarded as Dienerian, occurs in the youngest Strigatus Zone collection (GSC loc. 51664) from Otto Fiord.

Dienerian

A relatively small Candidus Zone conodont collection from strata overlying the Strigatus Zone south of the Otto Fiord (Fig. 2, no. 5; GSC loc. 51665), which co-occurs with the ammonoid *Ambites ferruginus* Tozer, consists of questionable *Ng. discreta*, a further occurrence of *Bo. megacuspa* and questionably the first *Scythogondolella* species. The latter, assigned informally to *Scythogondolella* sp. nov. A by Orchard (2007), shows similarities to early *Neospathodus* in its blade-like form and expanded basal cavity, and yet it is essentially a segminiplanate element with an expanded circular basal cavity like that of Smithian species of *Scythogondolella*.

The type section of the Dienerian stage is south of Diener Creek (Tozer 1967). In this section (Fig. 2, no. 4;



Few conodonts have been recovered from the late Dienerian Vavilovites sverdrupi Zone in the Arctic. One sample from Diener Creek (Fig. 2, no. 4; C-303176) produced only indeterminate ramiform elements, whereas a

second sample from Lindstroem Creek (Fig. 2, no. 6; O-47621) included essentially the same fauna as that known from the type Candidus Zone, namely variants of *Ns. dieneri* plus, at this locality, *Merrillina?* sp. Mosher (1973:185) reported a single questionable *Sweetospathodus kummelli* from the Sverdrupi Zone at Lindstrom Creek (47543), but the fragment is interpreted here as an indeterminate species of *Neospathodus*.

Smithian

The early Smithian ammonoid zone of *Hedenstromia hedenstroemi* (Keyserling) is only known from two localities in the Canadian Arctic (Tozer 1994: 24); notably at Griesbach Creek from where conodont samples did not yield fauna. In contrast, collections from the succeeding zone of *Euflemingites romunduri* Tozer are invariably rich in conodonts, and these testify to the explosive radiation that occurred during the early Smithian (Orchard 2007). Two localities provide the fauna described here. The first was also described by Mosher (1973), based on matrix material from the type locality of the Romunduri Zone near Smith Creek (Fig. 2, no. 7; GSC loc. 28680), which is the type section for the Smithian stage. There, the rich ammonoid fauna (Tozer 1994) comprises the name giver plus *Anaxenaspis krafftii* Tozer, *Arctoceras blomstrandii* (Lindstroem), *Kashmirites borealis* (Tozer), *Meekoceras gracilitatus* White, *Melagathiceras crassum* (Tozer), *Pseudosageceras longilobatum* Kiparisova and *Thermalites canadensis* (Tozer). Two additional samples were collected by the author further to the north in an unnamed creek where Ogg & Steiner (1991) undertook their magnetostratigraphy study (Fig. 2, no. 8). Samples were taken from both the shelly accumulate (C-303178), containing Romunduri Zone ammonoids, including *E. romunduri* and *M. gracilitatus* (GSC Internal Report ETT-1999-5), and from a second bed immediately below (C-303177).

The fauna described by Mosher (1973: table 2) was dominated by a variety of species that he assigned to *Neogondolella* and *Ellisonia*. Some of the *Ellisonia*, along with elements assigned to *Xaniognathus*, are now regarded as components of multielement *Neogondolella* or *Neospathodus* species (Orchard 2005). The identifications of *Neogondolella mombergensis* Tatge, *Ng. nevadensis* and *Ng. planata* by Mosher (1973) are no longer tenable, and these specimens are here assigned to new species of *Scythogondolella*. In addition to these, Mosher (1973) recorded a few specimens of *Neospathodus pakistanensis* Sweet and *Neospathodus waageni* Sweet, and a single specimen of "*Anchignathodus* sp." The latter specimen was subsequently assigned by Burij (1979) to a new Siberian species, *Neospathodus longiusculus* Burij, which later formed the basis of a new genus *Smithodus* introduced

by Budurov et al. (1988). Additional material from the matrix of O-28680 was recovered by the author, and its composition is similar to, but less diverse than, that from the unnamed creek referred to above (C-303178).

The Romunduri Zone collection from C-303178 is dominated by seminiplanate P1 elements herein assigned to *Scythogondolella lachrymiformis* sp. nov., with fewer specimens assigned to *Scythogondolella crenulata* (Mosher), *Scythogondolella ellesmerensis* sp. nov. and *Scythogondolella* sp. nov. F of Orchard 2007. Also present are fewer elements of *Ns. pakistanensis*, *Neospathodus posterolongatus* Zhao & Orchard, *Ns. waageni* and *Wapitiodus robustus* Orchard. *Paullella meeki* (Paull), *Conservatella conservativa* (Müller), *Discretella discreta* (Müller) and *Neospathodus* sp. nov. S of Orchard 2007 are known from single specimens. *Scythogondolella lachrymiformis* and *Scythogondolella* sp. nov. F have good potential as Smithian indices because both occur in the Romunduri Zone strata of the Wapiti Lake area of British Columbia, and the former also appears to be present in central Siberia (Dagis 1984).

Both *Ns. pakistanensis* and *Ns. waageni* were originally described from the Mianwali Formation in the Salt Range of Pakistan (Sweet 1970) as indices of successive conodont zones around the Induan–Olenekian boundary. *Neospathodus waageni*, an index for the base of the Olenekian, is a cosmopolitan species, and appears to range throughout the Smithian stage. *Neospathodus posterolongatus* was introduced as a species from the Euflemingites–Flemingites Zone in the Yinkeng Formation of Chaohu, Anhui Province, China (Zhao et al. 2007), and appears to be equally widespread, and is a useful proxy for the Induan–Olenekian boundary. *Neospathodus* sp. nov. S is also known from the early Olenekian of Spiti (Orchard & Krystyn 2007).

Discretella discreta and *Conservatella conservativa* were originally described from Crittenden Springs, Nevada, where they are associated with ammonoids of uncertain Smithian age (Müller 1956). New collections from that locality demonstrate that both species occur within the Romunduri Zone. Similarly, *P. meeki*, first described from the *Meekoceras* beds of the Thaynes Formation in Bear Lake Hot Springs, Idaho, is known to be a Romunduri Zone index in both the USA and in the Sulphur Mountain Formation in the Wapiti Lake area of British Columbia. In the latter area, as in the Arctic, *P. meeki* is associated with *Wapitiodus robustus*.

The third ammonoid zone of the Smithian is that of *Anawasachites tardus* McLearn, which lies 76 m above the Romunduri Zone bed in Smith Creek (Fig. 2, no. 7; Fig. 3). This zone is dominated by *Scythogondolella mosheri* (Kozur & Mostler), which is a species that was referred to *Ng. nevadensis* by Mosher (1973), who illustrated it from the Tardus Zone (47547) of Smith Creek in association

with the ammonoid *Arctoprionites nodosus* (Frebold) (Tozer 1994). Associated conodont species found to the north at GSC location C-303179 are *Scythogondolella milleri* (Müller), *Ns. waageni*, *Borinella buurensis* Dagis (*Neogondolella jubata* Sweet *sensu* Mosher), and a unique specimen of *Neospathodus* sp. nov. R of Orchard 2007; these occur in association with macrofossils *Wasachites* sp. and *Pseudoclarais* *ovalis* (Whiteaves) (GSC Internal Report ETT-1999-5).

The conodonts found in the Tardus Zone of the Arctic have a wide distribution. *Scythogondolella mosheri* was named for elements from the upper Jakutian of Dolpa, Nepal, as was *Scythogondolella milleri parva* (Kozur & Mostler), a subspecies that appears to be present as a variant in all large collections containing *Sc. milleri*. The type of the latter species came from Crittenden Springs, Nevada, where it also occurs with Tardus Zone ammonoids (Müller 1956, and new collections). *Borinella buurensis* was originally named from collections of the Hedenstroemia hedenstroemi Zone of the Buur River Basin of central Siberia (Dagis 1984), which is an interval of apparently greater scope than the lowermost Smithian. *Borinella buurensis* occurs in Tardus Zone collections from Toad River in northern British Columbia (unpublished collections), and is also known from the Union Wash Formation in California (Stone et al. 1991); a related species also occurs in a new collection from Crittenden Springs, Nevada.

Spathian

Tozer (1967) recognized two Spathian ammonoid zones in the Arctic: a lower zone of *Olenekites pilaticus* (Tozer) and an upper zone of *Keyserlingites subrobustus* (Mojsisovics). The single Pilaticus Zone locality (Fig. 2, no. 9; GSC loc. 101891), south of Svartevaeg on Axel Heiberg Island, produced no conodonts, but did yield a rich silicified microfauna of ammonoids, gastropods and bivalves. Archival Subrobustus Zone matrices came from the type locality in Spath Creek, Ellesmere Island (Fig. 2, no. 10; GSC loc. 47544; Fig. 3), where the ammonoid fauna consists of *Olenekites bombus* Tozer, *Olenekites canadensis* Tozer, *Olenekites triton* Tozer, *Popovites borealis* Tozer, *Svalbardiceras freboldi* Tozer and *Zenoites arcticus* Tozer (Tozer 1994). Nearby, the author collected 12 conodont samples from a 38-m section (Fig. 3) in which *Olenekites* sp. and the bivalve *Posidonia aranea* Tozer occurred at 25 (C-303116) and at 31.5 m (C-303119), and *Olenekites* sp. occurred alone at 31 m (C-303117). *Posidonia aranea* has been regarded as a proxy for the Subrobustus Zone (Tozer 1994).

The type locality of the Subrobustus Zone in Spath Creek (47544) yielded *Neogondolella* sp. A, as did a sample collected nearby (C-303121) that also contains *Neogondolella* ex gr. *regalis* Mosher. A slightly higher sample

(C-303122) in the section yielded the latter species plus elements assigned to *Neogondolella* sp. B and *Neogondolella* sp. C. The significance of these species is unclear. Elements close to *Ng. regalis* occur in the late Spathian and early Anisian in both British Columbia and Nevada, and *Neogondolella* sp. C is known from the early Anisian Japonites welteri beds in Nevada (Orchard, unpublished collections). The full range of these *Neogondolella* species is undetermined at present.

Comparisons with other North American Lower Triassic basins

Largely unpublished Lower Triassic conodont data from the WCSB and from the western USA serve as a comparison for the Arctic successions. Preliminary data from British Columbia was summarized by Orchard & Tozer (1997), and a more general overview was provided by Orchard (2007). Additional data from the Induan of WCSB includes records of *Hindeodus parvus*, *Sweetospathodus kummeli* and several *Neogondolella* and *Neospathodus* species (Henderson 1997; Paull et al. 1997). Although there are few descriptions of these faunas, they do appear to be similar to those known from the Arctic.

Conodont collections from both the Dienerian Candidus and Sverdrupi zones in WCSB contain both *Ns. dieneri* and *Ns. cristagalli*. Near Chowade River, a Candidus Zone ammonoid bed is succeeded by a conodont fauna that includes *Ns. pakistanensis* and *Borinella chowadensis* Orchard. This collection may be late Dienerian in age because Smithian indices are absent. It is also similar to those from the late Induan of Spiti (Orchard & Krystyn 2007), where *Borinella* spp. are common. A comparable fauna is unknown in the Arctic at present, but it may be anticipated because *Borinella* species occur in both older and younger strata, and the genus appears to be common in regions of relatively high Lower Triassic palaeolatitude.

Compared with Smithian conodont faunas from the Arctic, those of WCSB and USA are equally diverse, but have differing compositions (Fig. 4). For example, representatives of *Conservatella* and *Discretella* are rare in Romunduri Zone faunas of the Arctic, but are more common in contemporaneous faunas from the Wapiti Lake area in WCSB, and are even more so in the USA where they dominate collections from the Romunduri Zone at Crittenden Springs, Nevada. Similarly, *P. meeki* is rare in the Arctic, is more common in British Columbia and is dominant in the Romunduri Zone of Hot Springs, Idaho. *Wapitiodus robustus* occurs more commonly in WCSB than in the Arctic, but is unknown farther south. In contrast, *Guangxidella* is more common in the USA Romunduri Zone collections than in WCSB, but is not known in the Arctic. The dominant taxa group in the

		Canadian Arctic	British Columbia	Western USA
SPATHIAN	Subrobustus	* <i>Neogondolella</i> spp. <i>Triassospathodus</i> ? sp.	* <i>Neogondolella</i> spp. * <i>Tr. ex gr. homeri</i>	<i>Chiosella gondolelloides</i> <i>Neogondolella</i> spp. * <i>Tr. ex gr. homeri</i>
SMITHIAN	Tardus	<i>Borinella buurensis</i> <i>Ns. waageni</i> <i>Ns. sp. nov. R</i> <i>Sc. milleri</i> * <i>Sc. mosheri</i>	<i>Borinella buurensis</i> <i>Conservatella</i> sp. <i>Discretella</i> sp. <i>Guangxidella bransoni</i> * <i>Ns. waageni</i> * <i>Sc. milleri</i> * <i>Sc. mosheri</i> <i>Sc. sp. nov. D</i> <i>Spathicuspus</i> sp. <i>Wapitodus</i> sp.	<i>Borinella</i> sp. * <i>Ns. waageni</i> * <i>Sc. milleri</i> * <i>Sc. mosheri</i> <i>Sc. sp. nov. E</i> <i>Spathicuspus</i> sp.
	Romunduri	<i>Bo. aff. buurensis</i> <i>Conservatella</i> sp. <i>Discretella</i> sp. <i>Ns. pakistanensis</i> <i>Ns. posterolongatus</i> <i>Ns. waageni</i> <i>Ns. sp. nov. S</i> <i>Paulella meeki</i> <i>Sc. crenulata</i> <i>Sc. ellesmerensis</i> sp. nov. * <i>Sc. lachrymiformis</i> sp. nov. <i>Sc. sp. nov. F</i> <i>Wapitodus robustus</i>	<i>Conservatella</i> sp. <i>Discretella</i> sp. <i>Guangxidella bransoni</i> <i>Ns. cristagalli</i> <i>Ns. pakistanensis</i> * <i>Ns. posterolongatus</i> * <i>Ns. waageni</i> <i>Ns. sp. nov. U</i> <i>Paulella meeki</i> <i>Sc. lachrymiformis</i> sp. nov. <i>Sc. sp. nov. F</i> <i>Spathicuspus</i> spp. <i>Wapitodus robustus</i>	* <i>Conservatella</i> sp. <i>Discretella</i> sp. <i>Furnishius</i> sp. <i>Guangxidella bransoni</i> <i>Ns. bicuspidatus</i> <i>Ns. waageni</i> * <i>Paulella meeki</i> <i>Scythogondolella</i> ? sp.

Fig. 4 Comparison between Arctic Lower Triassic conodont faunas from the Smithian and Spathian stages and contemporaneous faunas of differing palaeolatitude from the Western Canada Sedimentary Basin and western USA. Taxa marked with asterisks are dominant in the given region.

Romunduri Zone of the Arctic is *Scythogondolella*, some of which are known from WCSB, but few or none of which occur in contemporaneous strata in the USA. Amongst the species of *Neospathodus*, *Ns. waageni* appears to be the most widespread species, but is more common in WCSB and the USA successions, whereas *Ns. pakistanensis* is more common in the Arctic, and *Ns. posterolongatus* is most common in the WCSB.

Tardus Zone conodont faunas show much more uniformity within the North American basins. The conodont fauna described from the Arctic is the same as that from the type locality of the Tardus Zone on Toad River, and from other areas of WCSB. A similar fauna occurs in the Tardus Zone of Georgetown, Idaho, and near Salt Lake City, Utah, but these lack *Borinella buurensis*. The latter genus is known from a single Tardus Zone collection at Crittenden Springs, Nevada, in which the cosmopolitan *Sc. mosheri* is missing and *Ns. waageni* is dominant. The latter is also the most common species in *Xenoceltites*-bearing Tardus Zone collections from both Toad River, British Columbia, and Georgetown, Idaho. Generally, *Sc. mosheri* is the dominant species of this zone in all areas, and *Sc. milleri* is also commonly found (Fig. 4).

Lower Spathian faunas are unknown in the Canadian Arctic so provide no means of comparison with good conodont records in California (Darwin Canyon) and Idaho (Paris Canyon, Hotsprings) (Orchard, unpublished

collections). In those USA localities, conodont faunas are associated with the ammonoids *Tirolites* and *Columbites*, and contain *Icriospathodus* spp., *Columbitella* ex gr. *elongata* (Sweet), *Novispathodus* spp. and, less commonly, *Spathicuspus* ex gr. *spathi* (Sweet), *Aduncodina* sp. and “*Neospathodus*” *brevissimus* Orchard. Some of these are also known in the WCSB, but not in association with ammonoids. Conodonts associated with the younger ammonoids *Subcolumbites* and *Prohungerites* in Idaho (Hammond Creek) and Nevada (Tobin and Humboldt ranges) yield abundant *Triassospathodus* ex gr. *homeri* (Bender) and common *Neostrachanognathus* spp., with fewer “*Neospathodus*” *triangularis* (Bender) and rare *Neogondolella* spp. (Orchard 1995). Most of these conodont taxa, including more common *Neogondolella* spp., occur in distal parts of the WCSB, but none are currently known from the Canadian Arctic.

The late Spathian Subrobustus Zone conodont faunas of the Arctic are composed almost exclusively of *Neogondolella* spp., whereas in the USA collections from the contemporaneous Neopopanoceras haugi Zone in the Humboldt Range of Nevada, and from beds adjacent to the type stratum of that ammonoid zone in Union Wash, California, are dominated by *Triassospathodus homeri*, with very rare *Neogondolella* spp. (Orchard 1995, and unpublished collections). The latest Spathian Courtilloticeris stevensi beds (Galfetti et al. 2007) also contain *Chiosella*

gondolelloides (Bender). Collections of the Subrobustus Zone in WCSB (often identified by the bivalve “*Posidonia aranea*”) contain similar numbers of *Neogondolella* and *Triassospathodus* (Orchard 1994). A single ramiform element from Spath Creek may be the only example of *Triassospathodus* currently known from the Canadian Arctic (Fig. 4).

Summary

Conodont faunas, including several new taxa, are described from the type area of the Lower Triassic stages in the Canadian Arctic. Most of these come from the Strigatus (upper Griesbachian), Candidus (lower Dienerian), Romunduri and Tardus (lower and upper Smithian), and Subrobustus (upper Spathian) ammonoid zones. They demonstrate that late Griesbachian faunas had already achieved a surprising level of diversity, with early representatives of *Borinella*, *Neospathodus* and *Scythogondolella* joining species of *Neogondolella*. Recovered Dienerian faunas are largely dominated by *Neospathodus*, but by the Smithian, an explosive radiation in several stocks led to diverse *Scythogondolella* species and “neospathodids”, including cosmopolitan species of *Conservatella*, *Discretella* and *Neospathodus*. Both *Paullella* and *Wapitiodus* are recorded in Arctic Canada for the first time, and permit correlation with successions in the WCSB and (for *Paullella*) the western USA. Nevertheless, Romunduri Zone conodonts show clear differences when compared with other, more southerly, basins. *Conservatella*, *Discretella* and *Paullella* are more common in the WCSB, and are most common in the USA. Some *Scythogondolella* species are restricted to the Arctic, others also occur in the WCSB (e.g., *Sc. lachrymiformis* and *Scythogondolella* sp. nov. F), but none of these occur in the USA. Tardus Zone faunas with *Sc. mosheri* and *Sc. milleri* are cosmopolitan. After an early Spathian gap in the Arctic record, the late Spathian conodont faunas are dominated by *Neogondolella* species that are also known in the WCSB, but which occur rarely in the USA. *Triassospathodus* has an inverse relationship, being abundant in the more southerly basins and virtually absent in the Arctic.

Systematic palaeontology

The following account includes only Olenekian taxa. Illustrated specimens are housed in the National Type Collections of Invertebrate and Plant Fossils at the Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8.

Genus *Borinella* Budurov and Sudar 1994

- 1988 *Pseudogondolella*—Kozur, p. 244.
- 1993 *Kozurella*—Budurov & Sudar, p. 24.
- 1994 *Borinella*—Budurov & Sudar (June), p. 30.
- 1994 *Chengyuania*—Kozur (September), pp. 529–530.

Discussion. Kozur (2006:68) has argued that *Chengyuania* (type species *Gondolella nepalensis* Kozur & Mostler) is not synonymous with *Borinella* (type species *Neogondolella buurensis* Dagis) because the latter has an unreduced platform, and, by spurious analogy with unrelated Middle Triassic species, must therefore have had a different apparatus. The apparatuses of *Borinella nepalensis* and *Bo. buurensis* have not been described, although the type species of *Bo. chowadensis* is known to be essentially the same as that of *Neogondolella* (Orchard 2007). Until such time as it is demonstrated otherwise, this is assumed to be the case for all species assigned to *Borinella*, which have in common discrete blade-carinal denticles that lengthen towards the anterior. Orchard (2007) recently discussed and illustrated several species of this genus.

Borinella buurensis Dagis 1984

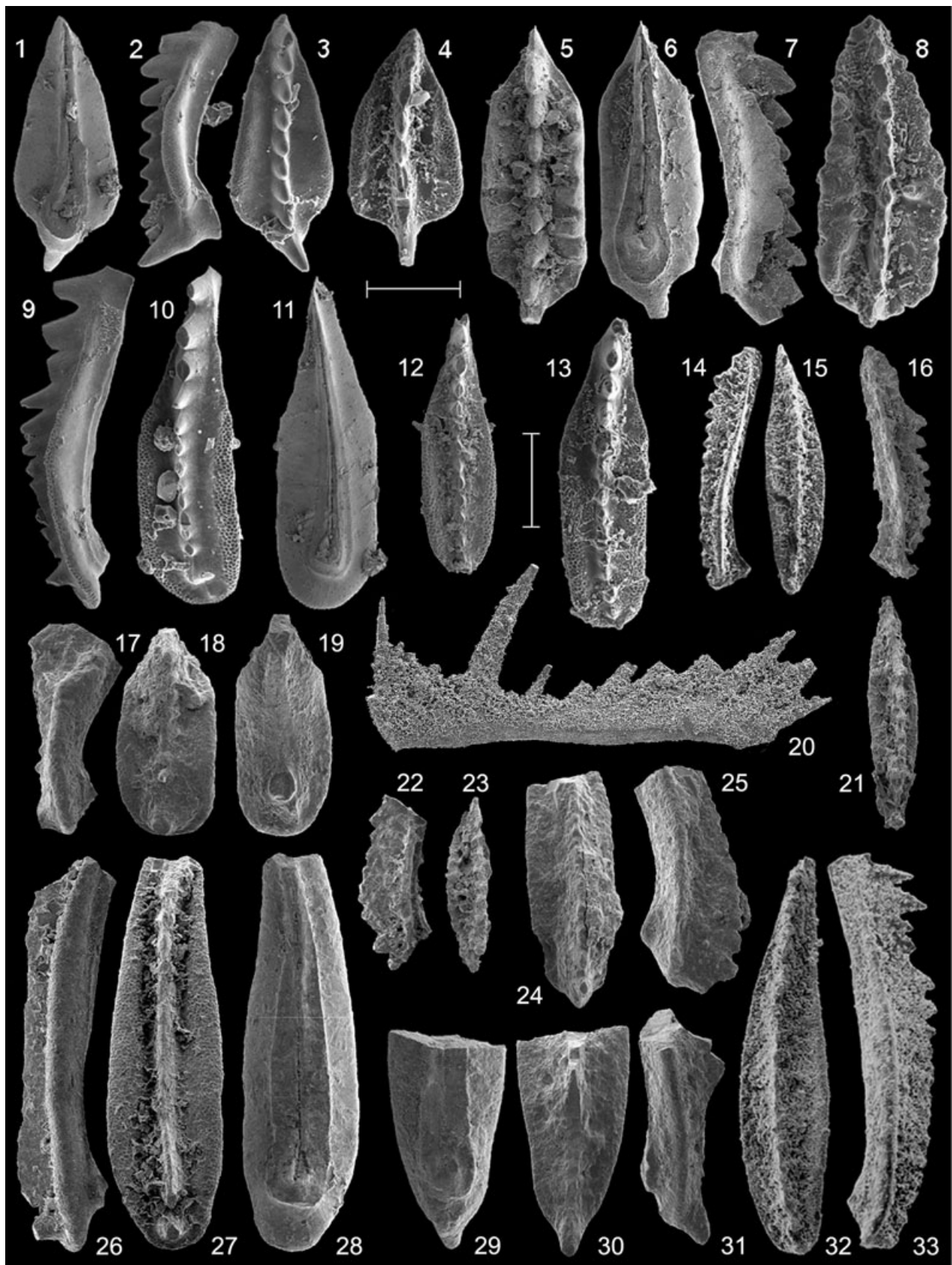
Fig. 5.9–5.13

1973 *Neogondolella jubata* Sweet—Mosher, p. 167, pl. 19, fig. 27.

1984 *Neogondolella buurensis* sp. nov.—Dagis, pp. 12–13, pl. 2, figs. 6–10, ?12; pl. 3, figs. 1, ?2; pl. 11, figs. 1–4; pl. 12, figs. 1, 2; pl. 16, figs. 1–4.

Diagnosis. The segminiplanate P1 element has a fairly broad platform with subparallel margins for much of its length, and an anterior one-third that tapers rapidly and barely extends to the anterior end of the blade. The posterior platform is rounded and is often asymmetrical. The cusp is variable in size and generally accompanied by a

Fig. 5 Upper, lower and lateral views of elements from the Tardus and Subrobustus zones. Scale bars: 200 µm (x80). 5.1–5.4: *Scythogondolella mosheri* (Kozur & Mostler). 5.1–5.3, GSC 120388; and 5.4, GSC 120389; from GSC loc. C-303179, Tardus Zone. 5.5–5.7: *Scythogondolella milleri* (Müller). GSC 120390, from GSC loc. C-303179, Tardus Zone. 5.8: *Scythogondolella milleri parva* (Kozur & Mostler). GSC 120391, from GSC loc. C-303179, Tardus Zone. 5.9–5.13: *Borinella buurensis* (Dagis). 5.9–5.11, GSC 120392; 5.12, GSC 120393; and 5.13, GSC 120394; all from GSC loc. C-303179, Tardus Zone. 5.14–5.16, 5.21, 5.26–5.28, 5.32 and 5.33: *Neogondolella* sp. A. 5.14 and 5.15, GSC 120395; and 5.32 and 5.33, GSC 120396, both from GSC loc. O-47544. 5.16 and 5.21, GSC 120397; and 5.26–5.28, GSC 120398; both from GSC loc. C-303121, Subrobustus Zone. 5.17–5.19: *Neogondolella* sp. C. GSC 120399, from GSC loc. C-303122, Subrobustus Zone. 5.20: *Triassospathodus?* sp. GSC 120400, from GSC loc. C-303117, Subrobustus Zone. 5.22–5.25: *Neogondolella* ex gr. *regalis* Mosher. 5.22 and 5.23, GSC 120401, GSC loc. C-303121; 5.24 and 5.25, GSC 120402, from GSC loc. C-303122; Subrobustus Zone. 5.29–5.31: *Neogondolella* sp. B. GSC 120403, from GSC loc. C-303122, Subrobustus Zone.



smaller accessory posterior node that lies in front of the platform margin, and is offset from the main axis of the carina. The carinal nodes pass anteriorly into blade denticles that become increasingly taller and more discrete to the anterior.

Discussion. Some of the specimens illustrated by Dagis (1984: pl. 2, figs. 13–15) are slimmer and/or have a more prominent posterior carina or terminal cusp than is typical of this species, so they are excluded from it. *Borinella buurensis* is similar in shape to *Borinella sweeti* (Kozur & Mostler), but unlike other species of *Borinella* it typically has a small offset terminal denticle. In *Borinella* aff. *buurensis* Dagis, the offset denticle posterior to the cusp is much more prominent.

Borinella aff. *buurensis* Dagis 1994

Fig. 6.4–6.6

Discussion. This segminiplanate P1 element, which maybe a precursor to *Bo. buurensis*, has a less developed anterior platform than the latter species, and a carina that extends to the posterior end of the platform where well-developed posterior accessory denticles are offset from the main axis of the blade-carina.

Borinella sp.

Fig. 7.21, 7.22

Description. Small segminiplanate P1 elements with a very narrow platform, a terminal cusp, and discrete blade and carinal denticles that become taller towards the anterior end of the element. These elements, which occur immediately below the Romunduri Zone ammonoids, are reminiscent of *Bo. nepalensis* from the late Induan and basal Olenekian of Spiti, but their small size precludes any confident assignment to the species.

Conservatella conservativa (Müller 1956)

Fig. 8.20, 8.21, ?8.28, ?8.29

1956 *Ctenognathodus conservativa* sp. nov.—Müller, p. 821, pl. 95, figs. 25–27.

?2005 *Conservatella* aff. *conservativa* (Müller)—Orchard, pp. 81–82, fig. 7.

Description. An incomplete carminate P1 element with confluent subequal denticles and an extended and upturned posterior basal margin showing inversion of the

basal cavity. A questionable P2 element, known to occur elsewhere with this species, has a large cusp and a short, inturned posterior process.

Discretella discreta (Müller 1956)

Fig. 8.18, 8.19

1956 *Ctenognathodus discreta* sp. nov.—Müller, pp. 821–822, pl. 95, fig. 28.

?2005 *Discretella* sp. A—Orchard, p. 83, fig. 8A–H.

Discussion. This is a small carminate P1 element with discrete denticles, a large terminal cusp and an upturned basal margin. Unlike the larger holotype from Nevada, it lacks a well-developed posterior process, but this is regarded as a result of its early stage of growth.

Genus *Neogondolella* Bender and Stoppel 1965

Discussion. Orchard & Rieber (1999) and Orchard (2005) reconstructed the multielement apparatus of this genus and regarded it as the root stock for most Triassic conodonts. As presently used, *Neogondolella* includes *Clarkina* Kozur, to which mostly Upper Permian species have been referred. Kozur (2005) also assigned the entire *Ng. carinata* group and other Griesbachian species to *Clarkina*, which he regarded as having become extinct at the end of that (sub)stage. According to Kozur (1989), “true” *Neogondolella* did not appear until the Middle Triassic, and he referred post-Griesbachian Lower Triassic neogondolelloid species to a variety of genera, none of which were characterized in multielement terms. Later, Orchard (2005) erected (e.g., *Columbitella*) or accepted (e.g., *Scythogondolella*) new genera based on distinctive reconstructed multielement apparatuses, but viewed these as being derivatives of an extant *Neogondolella* root stock (Orchard 2007). Meanwhile, Henderson (2006) regarded the Induan *Ng. discreta* as the first *Neogondolella* species, and distinguished older *Clarkina* species on the basis of differences in ontogenetic development. Most recently, Henderson & Mei (2007) have referred *Ng. discreta* to a new genus, *Neoclarkina*, and distinguished it from true *Neogondolella* on the basis of its S0 element, which, although it has not been described, was assumed to be like that demonstrated by Orchard & Rieber (1999: pls. 1, 5) for both Permian *Clarkina* and for Triassic neogondolelloid species as young as middle Anisian. As shown originally

Fig. 6 Upper, lower and lateral views of elements from the Romunduri Zone. Scale bars: 200 µm (x80). 6.1–6.3: *Paulella meeki* (Paull), GSC 120366, from GSC loc. C-303178. 6.4–6.6: *Borinella* aff. *buurensis* Dagis, GSC 120367, from GSC loc. C-303178. 6.7–6.9 and 6.17–6.19: *Scythogondolella* aff. *crenulata* (Mosher), 6.7–6.9: GSC 120368, from GSC loc. O-28680. 6.17–6.19: GSC 120372, from GSC loc. C-303178. 6.10–6.16: *Scythogondolella crenulata* (Mosher); 6.10, GSC 120369; 6.11–6.13, GSC 120370; 6.14–6.16, holotype, GSC 29958, a re-illustration of Mosher 1973; all from GSC loc. O-28680.



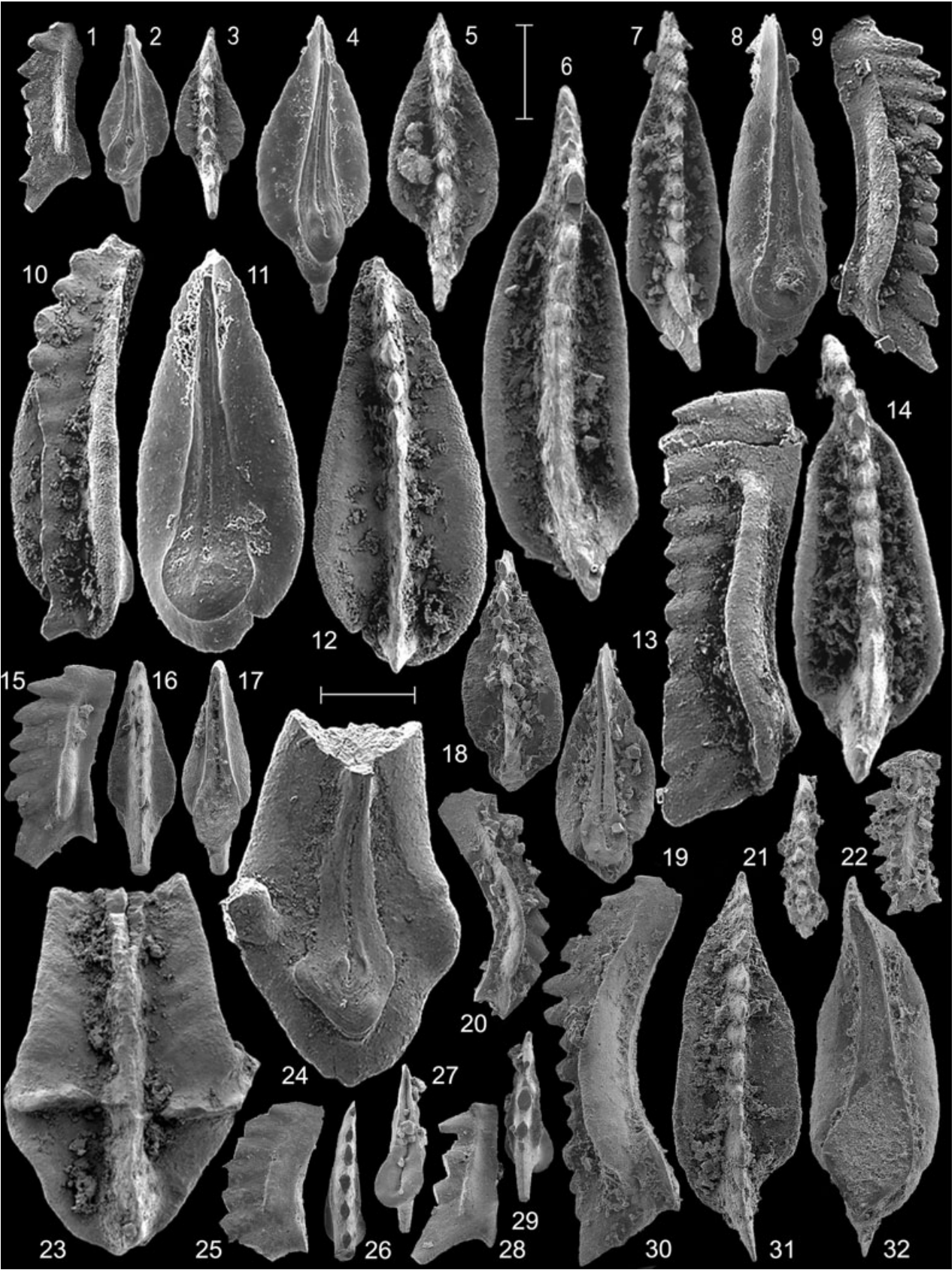


Fig. 7 Upper, lower and lateral views of elements from the Romunduri Zone. Scale bars: 200 μm ($\times 80$). 7.1–7.20 and 7.25–7.29: *Scythogondolella lachrymiformis* sp. nov. 7.1–7.3: GSC 120355. 7.4 and 7.5: GSC 120356. 7.6: GSC 120357. 7.7–7.9: holotype, GSC 120358. 7.10–7.12: GSC 120371. 7.13 and 7.14: GSC 120359. 7.15–7.17: GSC 120360. 7.25 and 7.26: GSC 120361. 7.27–7.29: GSC 120361. 7.18–7.20: GSC 120362. 7.15–7.17 and 7.25–7.29 are from GSC loc. O-28680; all others are from GSC loc. C-303178. 7.21 and 7.22: *Borinella* sp. GSC 120363, from GSC loc. C-303177. Immediately below Romunduri Zone fauna: 7.23, 7.24 and 7.30–7.32, *Scythogondolella* sp. nov. F. 7.23 and 7.24: GSC 120364, from GSC loc. C-303178. 7.30–7.32: GSC 120365, from GSC loc. O-28680.

by Orchard & Rieber (1999) and Orchard (2005), the S0 element of *Neogondolella* species in late Anisian and younger strata are different, as exemplified by the *Ng. constricta* group (Orchard 2005: fig. 10G text). However, a nomenclatural problem arises because both types of S0 element occur in described populations of *Ng. mombergensis*, the type species of *Neogondolella*. Distinguishing *Clarkina* from *Neogondolella*, or *Neoclarkina* from *Neogondolella*, on the basis of their S0 elements may be worthwhile, but the appropriate generic names for constituent species remain unresolved. As there are currently published multielement reconstructions for neither the Lower Triassic “*Neogondolella*” species nor for *Neoclarkina*, I maintain the use of the former generic name for all Triassic neogondolelloid species, which are assumed to have a “standard” *Neogondolella* apparatus (as in *Clarkina*), until shown otherwise.

Late Spathian *Neogondolella* species described herein are neither abundant nor well preserved. Most are therefore kept in open nomenclature.

Neogondolella ex gr. *regalis* Mosher 1970

Fig. 5.22–5.25

1970 *Neogondolella regale* sp. nov.—Mosher, pp. 741–742, pl. 110, figs. 1, 2, 4, 5.

1973 *Neogondolella regale* Mosher—Mosher, p. 169, pl. 19, figs. 21, 28, 29, 32. With synonymy.

Description. These narrow and arched segminiplanate P1 elements have a high carina of laterally compressed, mostly fused denticles, and an unexceptional cusp: features that are common to elements of Spathian to middle Anisian age, and which are currently combined as *Ng. regalis*. There are substantial differences between the holotype of *Ng. regalis* and the illustrated paratypes of Mosher (1970, 1973), in spite of them occurring in a single collection (GSC loc. 68294) from middle Anisian Hayesi Zone (formerly Varium Zone) strata of the Toad Formation in British Columbia. The holotype is larger and much less arched than the paratypes; has larger, fewer, and more fused carinal denticles; and has an upper profile that is almost straight compared with more convex profiles of the paratypes. The Arctic material is closer to the paratypes. Taxonomic revision of this group is pending.

Neogondolella sp. A

Fig. 5.14–5.16, 5.21, 5.26–5.28, 5.32, 5.33

Description. Narrow, lanceolate segminiplanate P1 elements with slightly upturned platform margins that extend the entire length of the element, tapering gradually in both anterior and posterior directions from their broadest point, which lies between the mid-length and the posterior one-third of the element. The posterior margin is pointed in small growth stages, and is increasingly rounded in larger ones, wherein a narrow posterior platform brim may be developed. The upright to slightly inclined, prominent cusp is terminal in position, and is separated from the carinal denticles, which are numerous, small, moderately high and increasingly fused with growth. The largest specimens have a completely fused, flat-topped carina.

Discussion. As seen most clearly in the largest specimen of this species, a distinctive gap occurs between the cusp and the carina to its anterior. This feature is also seen in specimens from both British Columbia and Nevada, suggesting that this species may be a useful guide to late Spathian strata.

Neogondolella sp. B

Fig. 5.29–5.31

Description. This posterior fragment of a segminiplanate P1 element has a pointed posterior platform with a large, strongly inclined cusp that projects from the posterior platform margin. The carinal denticles are broken, but they appear to be tall and connected to the cusp.

Discussion. This specimen most closely resembles the Middle Triassic species *Neogondolella cornuta* Budurov & Stefanov, which is a member of the *Ng. constricta* group. Additional late Spathian examples resembling the latter include *Neogondolella* sp. nov. H of Orchard (2007) from the Spathian–Anisian boundary strata in Nevada, which has a relatively indistinct cusp.

Neogondolella sp. C

Fig. 5.17–5.19

Description. This short and relatively broad segminiplanate P1 element has a prominent upright cusp, which is round

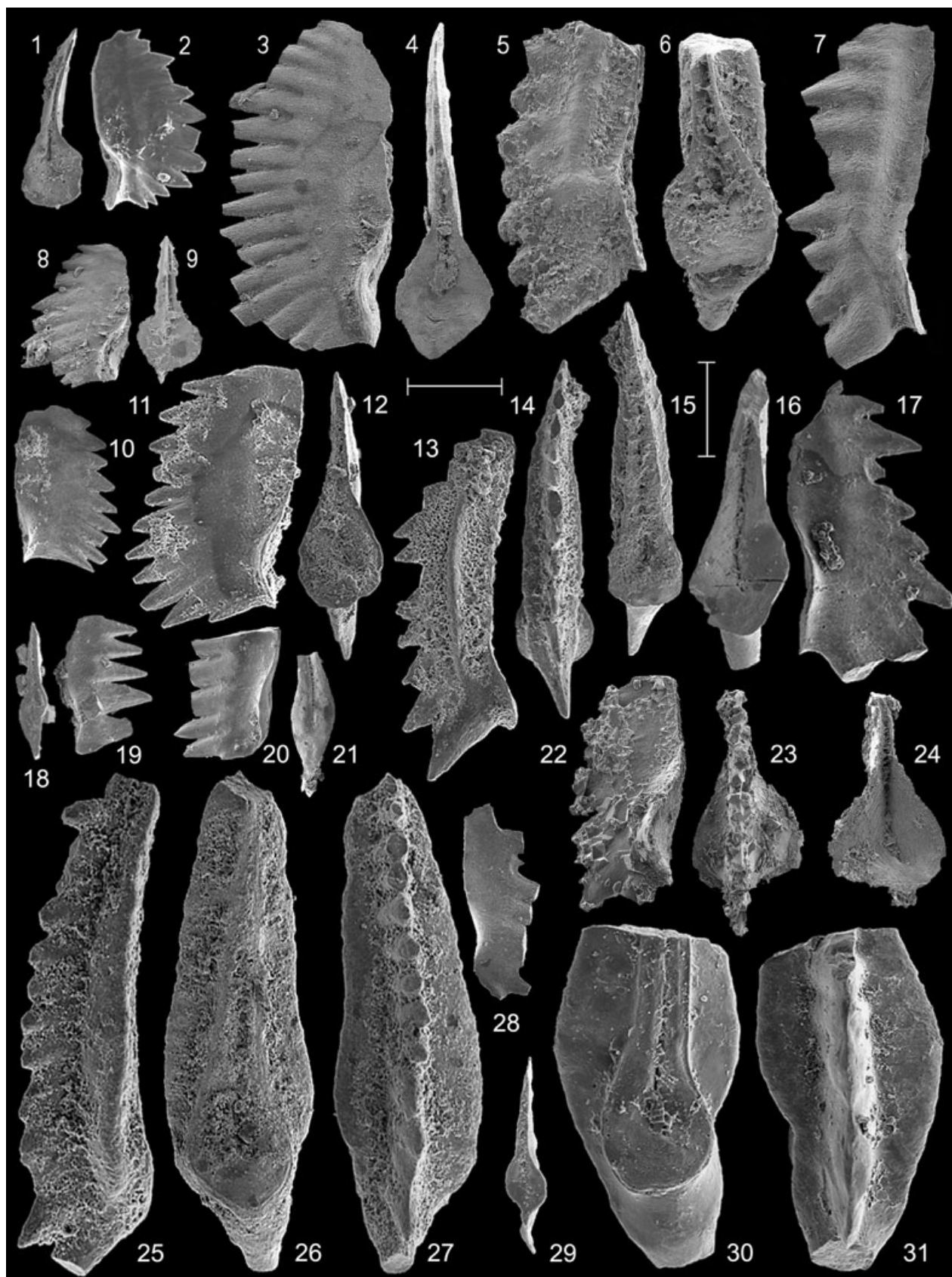


Fig. 8 Upper, lower and lateral views of elements from the Romunduri and Tardus zones. Scale bars: 200 μm ($\times 80$). 8.1, 8.2, 8.8 and 8.9: *Neospathodus waageni* Sweet; morphotype 4 of Orchard & Krystyn (2007). 8.1 and 8.2: GSC 120373. 8.8 and 8.9: GSC 120374, from GSC loc. C-303179, Tardus Zone. 8.3 and 8.4: *Neospathodus posterolongatus* Zhao & Orchard; GSC 120375, from GSC loc. C-303178, Romunduri Zone. 8.5–8.7: *Wapitiodus robustus* Orchard. 8.5 and 8.6, GSC 120376; and 8.7, GSC 120377, from GSC loc. C-303178, Romunduri Zone. 8.10–8.12: *Neospathodus pakistanensis* Sweet. 8.10, GSC 120378; and 8.11 and 8.12, GSC 120379, from GSC loc. C-303178, Romunduri Zone. 8.13–8.15, 8.25–8.27, 8.30 and 8.31: *Scythogondolella ellesmerensis* sp. nov. 8.13–8.15, holotype, GSC 120380, from GSC loc. C-303178; 8.25–8.27, GSC 120381; and 8.30 and 8.31, GSC 120382, from GSC loc. O-28680, Romunduri Zone. 8.16 and 8.17: *Neospathodus* sp. nov. S of Orchard 2007, GSC 120383, from GSC loc. C-303178, Romunduri Zone. 8.18 and 8.19: *Discretella discreta* (Müller), GSC 120384, from GSC loc. C-303178, Romunduri Zone. 8.20, 8.21, 78.28 and 78.29: *Conservatella conservativa* (Müller). 8.20 and 8.21, GSC 120385, from GSC loc. C-303178; 8.28 and 8.29, P2? element, GSC 120387, from GSC loc. O-28680; both Romunduri Zone. 8.22–8.24, *Neospathodus* sp. nov. R, GSC 120386, from GSC loc. C-303179, Tardus Zone.

in cross section and is surrounded by a posterior platform brim. The anterior platform margins appear to end abruptly, leaving a free anterior blade of unknown length.

Discussion. The distinctive cusp and posterior brim is seen in rare specimens from the early Anisian Japonites welteri beds in Nevada (author's collections), and suggest that this taxon may be a useful guide to the Spathian–Anisian boundary interval.

Genus *Neospathodus* Mosher 1968

Discussion. Early *Neospathodus* species, like the type species of the genus, *Ns. cristagalli*, have a multielement apparatus like that of *Neogondolella* (Orchard 2005), but the apparatus of many younger species of “*Neospathodus*” differs. These younger forms have been reassigned to genera such as *Novispathodus* and *Triassospathodus*. No apparatuses of the Arctic species described here have yet been described, so for now they are retained in *Neospathodus*.

Neospathodus pakistanensis Sweet 1970

Fig. 8.10–8.12

1970 *Neospathodus pakistanensis* sp. nov.—Sweet, pp. 254–5, pl. 1, figs. 16, 17.

Description. Subrectangular P1 segminate elements with a height to length ratio of 2 : 3, and a posterior upper edge that forms a convex crest as a result of the denticles diminishing in size towards the posterior end. The basal margin is straight anteriorly, arched upwards in the posterior one-third where the basal cavity flares, and is then turned downwards at the posterior end. The basal cavity is symmetrically expanded, and its posterior margin is rounded.

Discussion. Examples of this species in the Arctic collections do not include large growth stages with incipient platforms, as are associated, for example, in collections from the Induan–Olenekian boundary in Spiti (Orchard & Krystyn 2007). The latter elements have been referred to *Neospathodus novaehollandiea* by McTavish (1973), but, as discussed by Orchard (2007), there appears to be

gradation between (smaller) elements of *Ns. pakistanensis* and (larger) elements of *Ns. novaehollandiea*, including variation in the profile of the basal margin. *Neospathodus waageni*, which may also develop platform flanges (= morphotype 1, see below), differs from the present species in being relatively shorter and more commonly having a wholly upturned posterior basal margin. The two species occur in succession in both Pakistan and Spiti, which lends support to the suggestion that *Ns. waageni* is derived from the present species.

Neospathodus posterolongatus Zhao & Orchard 2007

Fig. 8.3, 8.4

2007 *Neospathodus posterolongatus* sp. nov.—Zhao et al., p. 36, pl. 1, fig. 2A–C.

Discussion. P1 elements of this species resemble those of *Ns. pakistanensis*, but tend to be more elongate as a result of the notable posterior elongation and upturning of the posterior process, and the consequent elliptical outline of the basal cavity that extends beneath it. It has been suggested that this trend continued as further growth of a posterior process and progressive upturning of the posteriormost part of the element produced the successor species *Neospathodus spitiensis* (Orchard 2007).

Neospathodus waageni Sweet 1970

Fig. 8.1, 8.2, 8.8, 8.9

1970 *Neospathodus waageni* sp. nov.—Sweet, pp. 260–261, pl. 1, figs. 11, 12.

1973 *Neospathodus waageni* Sweet—Mosher, pp. 172–173, pl. 20, fig. 5.

Description. The subquadrate segminate P1 elements are relatively short and high (ratio 1 : 1), and have an upper edge that forms an even-crested, arcuate profile as a result of the denticles rising from both the anterior and posterior ends towards a maximum height to the posterior of the element mid-length. Viewed from below, the basal cavity is circular in outline, and in lateral view is seen to be upturned relative to the straight anterior basal margin.

Discussion. Six morphotypes of this species were differentiated by Orchard & Krystyn (2007), one of which corresponded to *Neospathodus waageni eowaageni* Zhao & Orchard (= morphotype 3). The morphotypes vary in lateral thickening, denticle orientation, relative size of the posterior denticles and cusp, and in the lower surface profile. Most of the Arctic specimens are examples of morphotype 2 (= *Ns. w. waageni*), but uncommon specimens of morphotype 4, which is characterized by small posteriormost denticles that lie abruptly lower than those to the anterior, also occur.

Neospathodus sp. nov. R Orchard 2007

Fig. 8.22–8.24

Description. A segminate P1 element with a deep, broadly expanded, circular basal cavity that occupies over one-half of its underside. The blade-carina consists of about nine partially fused, inclined denticles, the posteriormost two of which are broader and more strongly inclined. The element bears fine striations on its flanks and denticles.

Discussion. The large basal cavity distinguishes this unique element from known contemporary species, as do the large and strongly inclined posterior denticles (the posteriormost one is broken). A large basal cavity is a feature of the older *Ns. chaohuensis*, and of several younger, Spathian species (e.g., *Ns. brevissimus*), but the denticulation of the present species is unique.

Neospathodus sp. nov. S Orchard 2007

Fig. 8.16, 8.17

2007 *Neospathodus* sp. nov. S—Orchard & Krystyn, table 1.

2007 *Neospathodus* sp. nov. S—Orchard, fig. 2.

Description. An elongate segminate P1 element with denticles that become larger and increasingly reclined towards the posterior, and end in a terminal, strongly reclined cusp. The basal cavity is extended posteriorly and has a rhomboidal outline.

Discussion. This species differs from *Ns. dieneri* in its more strongly reclined posterior denticles, and particularly in its posteriorly extended basal margin. The Arctic specimen has rather irregular denticulation, but other examples known from the early Olenekian of Spiti (Orchard & Krystyn 2007), on which basis the species will be named, do not.

Genus *Paullella* nom. nov.

Derivation of name. Named in honour of Rachel Paull, whose extensive work on the Lower Triassic of the western USA included the naming of the type species.

Type species. *Gladigondolella meeki* Paull 1983.

Diagnosis. As for the type (and only known) species.

Discussion. This name replaces *Meekella* Orchard 2005, which is pre-occupied by *Meekella* White & St John 1867, a Permian brachiopod.

Paullella meeki (Paull 1983)

Fig. 6.1–6.3

1983 *Gladigondolella meeki*—Paull, pp. 189–191.

2005 *Meekella meeki* (Paull)—Orchard, p. 84, fig. 9

Discussion. This distinctive species is based on a carminiplanate P1 element with a narrow, laterally and downwardly deflected posterior process, and with a well-developed posterior keel. Only a single specimen is known from the Arctic, but the species is common in British Columbia and particularly in western USA. The species was originally referred to *Gladigondolella* on the basis of its posterior process, but, as discussed by Orchard (2005), its apparatus and origins are different: based on multielement considerations, Orchard (2005, 2007: fig. 1) suggested it was related to *Conservatella*. See also *Scythogondolella* sp. nov. F.

Genus *Scythogondolella* Kozur 1989

1989 *Scythogondolella*—Kozur, pp. 414, 429.

2005 *Scythogondolella* Kozur—Orchard, pp. 97–98, fig. 23.

Discussion. This genus was originally introduced for segminiplanate P1 elements with strong marginal platform ornamentation, a variable blade-carina configuration and a rounded basal loop (Kozur 1989). Orchard (2005) redefined the genus based on a reconstructed 15-element apparatus of *Sc. mosheri*, which is a similar and presumably related species. In this work, I also tentatively assign several additional Smithian species to *Scythogondolella*, one of which—*Sc. crenulata*—also has platform ornamentation. All species united under the present genus have a prominent carina and a broad basal scar that expands posteriorly into a distinctive, mostly rounded basal loop that surrounds a small pit. However, none have known multielement apparatuses, so their generic assignment may ultimately change.

Scythogondolella crenulata (Mosher 1973)

Fig. 6.10–6.16

1973 *Neogondolella crenulata* sp. nov.—Mosher, p. 166, pl. 19, figs. 10–14, 16.

Diagnosis. The segminiplanate P1 element has a broad, flat, commonly oblong-shaped platform that is variably ornamented with marginal crenulations that become increasingly developed towards the carina during growth.

The blade-carina is high and composed of partially fused denticles that pass posteriorly into a prominent, inclined terminal cusp.

Discussion. The type locality for this species is the Romunduri Zone near Smith Creek, and the holotype is re-illustrated here as is new topotype material. The strong ornamentation of this species is rivalled only by that in *Sc. milleri*, in which a denticulate ornament is confined to the strongly upturned margins. Specimens assigned to *Sc. aff. crenulata* (Fig. 6.7–6.9, 6.17–6.19) have a similar platform shape and carina, but differ in having relatively smooth platforms in which faint corrugations may be present.

Scythogondolella ellesmerensis sp. nov.

Fig. 8.13–8.15, 8.25–8.27, 8.30, 8.31

Derivation of name. From its type locality on Ellesmere Island.

Holotype. GSC 120380, Fig. 8.13–8.15.

Type locality. GSC loc. C-303178, north of Smith Creek, Ellesmere Island.

Formation and stratigraphic level. Smith Creek Member, Blind Fiord Formation; Romunduri Zone, Smithian.

Material. About 50 specimens.

Diagnosis. Narrow and slightly arched segminiplanate P1 elements with a relatively narrow, flat to convex, smooth and pointed platform that starts at the anterior end of the element, and broadens gradually towards the posterior end, and then narrows again, somewhat asymmetrically, about one or two denticles in front of the large terminal cusp with which it merges. In some large specimens in particular, an indentation may occur on the inner lateral margin of the posterior platform. In lateral view, the fixed blade-carina rises from the anterior end and forms a moderately high crest of partially fused denticles that lie well above the platform surface, and terminates in a massive reclined cusp with a round cross section. The lower surface has a broadly flared, rounded to ovoid basal loop surrounding the pit, and a broadly grooved keel that narrows anteriorly.

Discussion. The largest specimens of this species, in which the posterior platform is partly constricted, mimic the contemporaneous *P. meeki*, which, however, has a keeled posterior process. The basal cavity flare in small- to medium-sized elements is broader than the platform width.

Scythogondolella lachrymiformis sp. nov.

Fig. 7.1–7.14

?1973 *Neogondolella planata* (Clark)—Mosher, p. 166, pl. 19, figs. 15, 20.

?1984 *Neogondolella mosheri* (Kozur & Mostler)—Dagis, pp. 9–10, pl. 3, figs. 5, 6, 8–14; pl. 4, fig. 1; pl. 12, fig. 3.

Derivation of name. Derivation from the latin *lachrym*, referring to the common tear-shaped platform outline.

Holotype. GSC 120357, Fig. 7.7–7.9.

Type locality. GSC loc. C-303178, north of Smith Creek, Ellesmere Island.

Formation and stratigraphic level. Smith Creek Member, Blind Fiord Formation; Romunduri Zone, Smithian.

Material. Several hundred specimens.

Diagnosis. The segminiplanate P1 elements generally have an elongate-oval or lachrymiform-shaped platform when viewed from above, with the broadest part of the platform occurring in the posterior one-third. Platform margins are upturned so as to produce narrow adcarinal grooves. The posterior platform is often constricted or shorter on the inner side. Towards the anterior, the platform tapers gradually to a point close to the anterior end, where it often turns inwards more strongly, and terminates a few denticles in front of the anterior end of the blade. The resulting short free blade is high and extends posteriorly as a fixed blade-carina of uniform height to the posterior end, where a large cusp is generally well defined. The cusp projects posteriorly, but does not rise above the level of the denticles anterior to it, up to half of which are fused in larger specimens.

Discussion. Early growth stages of this species are similar to *Sc. mosheri*, but typically have a longer, more variable platform outline that is more asymmetrically developed posteriorly (compare Fig. 5.4 with Fig. 7.5), and more commonly has a posterior platform brim. The posterior margin of *Sc. mosheri* appears more truncated and less rounded as a result of the maximum width being closer to that end. *Sc. ellesmerensis* has a much narrower and flatter platform.

There is considerable variation exhibited by elements assigned to this species. Some uncommon forms have relatively narrow and elongate platforms with subparallel margins (Fig. 7.6), in contrast with the more common posteriorly broad forms. Some elements have a more defined free blade than others. Specimens with strong posterior constrictions (Fig. 7.18–7.20) mimic the older *Ng. carinata*, but have a more developed carina. Finally, some early growth stages have a less developed platform and a stronger carina than is typical. Most of the specimens illustrated by Dagis (1984) closely resemble *Sc. lachrymiformis* rather than the younger *Sc. mosheri*, but the views available are not sufficient to be sure. Similarly, the

specimen illustrated by Mosher (1973) probably also belongs here, but it has a broken anterior part.

Scythogondolella milleri (Müller 1956)

Fig. 5.5–5.8

1956 *Gondolella milleri*—Müller, p. 823, pl. 95, figs. 1–9.

1973 *Neogondolella milleri* (Müller)—Mosher, p. 167, pl. 19, figs. 22, 23, 25.

1976 *Gondolella milleri parva* subsp. nov.—Kozur & Mostler, pp. 7–8, pl. 1, fig. 7.

Diagnosis. The segminiplanate P1 element has a platform with strongly upturned subparallel margins that taper abruptly near both ends of the element. In lateral view, the blade-carina is composed of strong denticles that become increasingly inclined posteriorly, but which maintain a fairly constant height throughout. The platform margins bear moderately to very strong, often irregularly developed nodes and denticles.

Discussion. This species apparently developed from *Sc. mosheri* by acquiring platform ornamentation. Transitional forms were assigned to “*Gondolella milleri parva*” by Kozur & Mostler (1976), but, as such elements occur in all collections with *Sc. milleri*, I do not differentiate them here. This species is confined to the late Smithian Tardus Zone (cf. Mosher 1973).

Scythogondolella mosheri (Kozur & Mostler 1976)

Fig. 5.1–5.4

1973 *Neogondolella nevadensis* Clark—Mosher, p. 169, pl. 19, figs. 17, 18, 24.

1973 *Neogondolella elongata* Sweet—Mosher, p. 166, pl. 19, fig. 19.

1976 *Gondolella mosheri* sp. nov.—Kozur & Mostler, p. 8, pl. 1, figs. 9–12.

2005 *Scythogondolella mosheri* (Kozur & Mostler)—Orchard, pp. 97–98, fig. 23A–H.

Description. The relatively short segminiplanate P1 elements are subquadrate to subtriangular in outline, with the broadest part of the platform near the posterior end. The smooth, upturned platform margins extend from the lateral edges of the terminal cusp, or a little in front of it, to the anterior end of the blade-carina, tapering progressively or more abruptly in the anterior one-third. The blade-carina is composed of subequal denticles that become higher anteriorly, and which pass posteriorly into a large cusp about twice the size of the adjacent denticle. In profile, the upper edge of the blade-carina maintains a more or less straight upper margin.

Discussion. *Scythogondolella mosheri* appears to be a paedomorphic descendant of *Sc. lachrymiformis* (q.v.) from the

preceding Romunduri Zone, which has a much longer but similarly shaped platform. Early growth stages of the two species may be difficult to distinguish, but larger specimens are distinct. Mosher (1973) illustrated a specimen of this species from the Tardus Zone on Liard River as *Neogondolella* (= *Columbitella*) *elongata*.

Scythogondolella sp. nov. F sensu Orchard 2007

Fig. 7.23, 7.24, 7.30–7.32

2007 *Scythogondolella?* sp. nov. F—Orchard, fig. 1.

Discussion. These elements resemble *Sc. lachrymiformis*, but they differ in having a rhomboidal basal attachment scar surrounding the posterior pit. One large specimen also has a secondary carina on each side of the posterior platform that extends perpendicularly from the main carina to each lateral margin. Well-preserved specimens of this species occur in the Sulphur Mountain Formation in the Wapiti Lake area of north-east British Columbia, on which basis it will be named and fully described in a separate paper.

Triassospathodus? sp.

Fig. 5.20

Description. A bipennate ramiform element with a more or less straight basal margin, an anterior process about one-third of the length of the posterior one, a prominent reclined cusp, anterior denticles that are relatively upright and posterior denticles that become increasingly inclined to the posterior.

Discussion. This element resembles the S3 element of the multielement apparatus of *T. homeri*, as reconstructed by Orchard (2005: 93, fig. 19). Although the segminate P1 element has not been recovered from any of the Arctic collections, this element may be diagnostic for the genus.

Wapitiodus robustus Orchard 2005

Fig. 8.5–8.7

1973 *Neospathodus* sp. A—Mosher, p. 173, pl. 18, fig. 39.

2005 *Wapitiodus robustus* sp. nov.—Orchard, p. 99, fig. 24A–K.

Description. Moderately large segminate P1 elements with narrow and thick platform ledges developed along their flanks for much of their length, and extending as a zone of thickening around the posterior cusp. Subequal denticles of the blade-carina are inclined, and pass posteriorly to a terminal cusp that is the largest of the series. The circular basal cavity is broadly expanded beyond the edge of the platform flanges.

Discussion. This species resembles *Sc. ellesmerensis*, but it differs in lacking a platform in early and medial growth

stages. Only in very large specimens of *Wapitiodus* do the platform flanges extend along the entire length of the element. This record supplements those from the type locality in the Wapiti Lake area of British Columbia, and that of Mosher (1973) from the Romunduri Zone of Needham Creek, British Columbia.

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References

- Birkenmajer K. & Trammer J. 1975. Lower Triassic conodonts from Hornsund, south Spitsbergen. *Acta Geologica Polonica* 25, 299–308.
- Budurov K.J., Buryi G.I. & Sudar M.N. 1988. *Smithodus* n. gen. (Conodonts) from the Smithian Stage of the Lower Triassic. *Mitteilungen der Österreichischen Geologischen Bergbaustud* 34/35, 295–299.
- Budurov K.J. & Sudar M.N. 1993. *Kozurella* gen. n. (Conodonts) from the Olenekian (Early Triassic). *Geologica Balcanica* 23, 24.
- Budurov K.J. & Sudar M.N. 1994. *Borinella* Budurov & Stefanov nomen novum for the Triassic conodont genus *Kozurella* Budurov & Sudar 1993. *Geologica Balcanica* 24, 30.
- Burij G.I. 1979. *Nižnetriasovy konodonty Južnogo Primor'ja*. (Lower Triassic conodonts of the South Primorye.) *Trudy Akademija SSSR, Sibirskoe otделение Instituta Geologii i Geofiziki* 412. Moscow: Nauka.
- Dagis A.A. 1984. *Rannetriasovy konodonty severa Srednej Sibiri*. (Early Triassic conodonts of northern Middle Siberia.) *Trudy Akademija SSSR, Sibirskoe otделение Instituta Geologii i Geofiziki* 554, 3–69.
- Embry A.F. 1986. Stratigraphic subdivision of the Blind Fiord and Bjorne formations (Lower Triassic), Sverdrup Basin, Arctic Islands. *Current Research, Part B, Geological Survey of Canada, Paper 86-1B*, 329–340.
- Embry A.F. 1988. Triassic sea level changes: evidence from the Canadian Arctic Archipelago. In C. Wilgus et al. (ed.): *Sea level changes: an integrated approach. SEPM Special Publication* 42. Pp. 249–259. Tulsa: Society of Economic Paleontologists and Mineralogists.
- Embry A.F. 1991. Mesozoic history of the Arctic Islands. In H. Trettin (ed.): *Geology of the Innuitian Orogen and Arctic Platform of Canada and Greenland. Geology of Canada*. Vol. 3. Pp. 369–433. Ottawa: Geological Survey of Canada.
- Galfetti T., Bucher H., Ovtcharova M., Schaltegger U., Brayard A., Brühwiler T., Goudemand N., Weissert H., Hochuli P.A., Cordey F. & Guodun K. 2007. Timing of the Early Triassic carbon cycle perturbations inferred from new U–Pb ages and ammonoid biochronozones. *Earth and Planetary Science Letters* 258, 593–604.
- Henderson C.M. 1997. Uppermost Permian conodonts and the Permian–Triassic boundary in the Western Canada Sedimentary Basin. *Bulletin of Canadian Petroleum Geology* 45, 693–707.
- Henderson C.M. 2006. Multielement definition of *Clarkina* Kozur. *Permophiles* 48, 23–24.
- Henderson C.M. & Baud A. 1997. Correlation of the Permian–Triassic boundary in Arctic Canada and comparison with Meishan, China. In N. Wang & J. Remane (eds.): *Stratigraphy. Proceedings of 30th International Geological Congress*. Vol. 11. Pp. 143–152. Utrecht: VSP International Science Publisher.
- Henderson C.M. & Mei S. 2007. Geographical clines in Permian and lower Triassic gondolellids and its role in taxonomy. *Palaeoworld* 16, 190–201.
- Kozur H.W. 1988. Division of gondolellid platform conodonts. In W. Ziegler (ed.): *1st International Senckenberg Conference and 5th European Conodont Symposium (ECOS V). Contributions I, Part 2. Courier Forschungsinstitut Senckenberg* 102, 244–245.
- Kozur H. 1989. The taxonomy of the gondolellid conodonts in the Permian and Triassic. *Courier Forschungsinstitut Senckenberg* 117, 409–469.
- Kozur H. 1994. *Chengyuania*, a new name for *Pseudogondolella* Kozur 1988 (Conodonts)[non *Pseudogondolella* Yang 1984 (hybodont fish teeth)]. *Paläontologische Zeitschrift* 68, 529–530.
- Kozur H. 2005. Pelagic uppermost Permian and the Permian–Triassic boundary conodonts of Iran. Part II: investigated sections and evaluation of the conodont faunas. *Hallesches Jahrbuch Geowissenschaften* 19, 49–86.
- Kozur H. 2006. Remarks to the base of the Olenekian. *Albertiana* 34, 66–72.
- Kozur H. & Mostler H. 1976. *Neue conodonten aus dem Jungpaläozoikum und der Trias*. (New conodonts of the Upper Paleozoic and Triassic.) *Geologisch-Paläontologische Mitteilungen Innsbruck* 636(2), 1–40.
- McTavish R.A. 1973. Triassic conodont faunas from western Australia. *Neues Jahrbuch für Geologie und Paläontologie Abhandlungen* 143, 275–303.
- Mosher L.C. 1968. Triassic conodonts from western North America and Europe and their correlation. *Journal of Paleontology* 42, 895–946.
- Mosher L.C. 1970. New conodont species as Triassic guide fossils. *Journal of Paleontology* 44, 737–742.
- Mosher L.C. 1973. Triassic conodonts from British Columbia and the northern Arctic Islands. *Geological Survey of Canada Bulletin* 222, 141–193.
- Müller K.J. 1956. Triassic conodonts from Nevada. *Journal of Paleontology* 30, 818–830.
- Ogg J.G. & Steiner M.B. 1991. Early Triassic magnetic polarity time scale—integration of magnetostratigraphy, ammonite zonation and sequence stratigraphy from

- stratotype sections (Canadian Arctic Archipelago). *Earth and Planetary Sciences* 107, 69–89.
- Orchard M.J. 1994. Conodont biochronology around the Early–Middle Triassic boundary: new data from North America, Oman and Timor. *Proceedings of the Triassic Symposium. Lausanne, Switzerland, October, 1991. Mémoire de Géologie (Lausanne), Helvetia* 22, 105–114.
- Orchard M.J. 1995. Taxonomy and correlation of Lower Triassic (Spathian) segminate conodonts from Oman and revision of some species of *Neospathodus*. *Journal of Paleontology* 69, 110–122.
- Orchard M.J. 2005. Multielement conodont apparatuses of Triassic Gondolelloidea. In M.A. Purnell & P.C.J. Donoghue (eds.): *Conodont biology and phylogeny: interpreting the fossil record. Special Papers in Palaeontology* 73, 73–101.
- Orchard M.J. 2007. Conodont diversity and evolution through the latest Permian and Early Triassic upheavals. *Palaeogeography, Palaeoclimatology, Palaeoecology* 252, 93–117.
- Orchard M.J. & Krystyn L. 1998. Conodonts of the lowermost Triassic of Spiti, and new zonation based on Neogondolella successions. *Revista Italiana di Paleontologia Stratigraphia* 104, 341–368.
- Orchard M.J. & Krystyn L. 2007. Conodonts from the Induan–Olenekian boundary interval at Muth, Spiti. *Albertiana* 35, 30–34.
- Orchard M.J. & Rieber H. 1999. Multielement *Neogondolella* (Conodonta, Upper Permian–Middle Triassic). *Proceedings of the 7th European Conodont Symposium (ECOS 7). Bollettino della Società Paleontologica Italiana* 37, 475–488.
- Orchard M.J. & Tozer E.T. 1997. Triassic conodont biochronology, its calibration with the ammonoid standard, and a biostratigraphic summary for the Western Canada Sedimentary Basin. *Bulletin of Canadian Petroleum Geology* 45, 675–692.
- Paull R.K. 1983. Definition and stratigraphic significance of the Lower Triassic (Smithian) conodont *Gladigondolella meeki* n. sp. in the western United States. *Journal of Paleontology* 57, 188–192.
- Paull R.K., Paull R.A. & Laudon T.S. 1997. Conodont biostratigraphy of the Lower Triassic Mackenzie Dolomite Lentil, Sulphur Mountain Formation in the Cadomin area, Alberta. *Bulletin of Canadian Petroleum Geology* 45, 708–714.
- Stone P., Stevens C.H. & Orchard M.J. 1991. Stratigraphy of the Lower and Middle(?) Triassic Union Wash Formation, east-central California. *US Geological Survey Bulletin* 1928, 1–26.
- Sweet W.C. 1970. Uppermost Permian and Lower Triassic conodonts of the Salt Range and Trans-Indus Ranges, west Pakistan. In B. Kummel & C. Teichert (eds.): *Stratigraphic boundary problems: Permian and Triassic of west Pakistan*. Pp. 207–275. Lawrence, KS: University of Kansas Press.
- Tozer E.T. 1965. *Lower Triassic stages and ammonoid zones of Arctic Canada. Geological Survey of Canada Paper* 65-12. Ottawa: Geological Survey of Canada.
- Tozer E.T. 1967. *A standard for Triassic time. Geological Survey of Canada Bulletin* 156. Ottawa: Geological Survey of Canada.
- Tozer E.T. 1994. *Canadian Triassic ammonoid faunas. Geological Survey of Canada Bulletin* 467. Ottawa: Geological Survey of Canada.
- White C.A. & St. John O.H. 1867. Descriptions of new Subcarboniferous and measure fossils, collected upon the Geological Survey of Iowa, together with new generic characters observed in two species of brachiopods. *Transactions of the Chicago Academy of Sciences* 1(4), 115–127.
- Zhao L., Orchard M.J., Tong J., Sun Z., Zuo J., Zhang S. & Yun A. 2007. Lower Triassic conodont sequence in Chaohu, Anhui Province, China and its global correlation. *Palaeogeography, Palaeoclimatology, Palaeoecology* 252, 24–38.