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Carboniferous conodont biostratigraphy

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Carboniferous conodont biostratigraphy

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Abstract: Carboniferous conodont biostratigraphy comprises regional zonations that reflect the paleogeographic distribution of taxa and distinct shallow-water and deep-water conodont biofacies. Some species have a global distribution and can effect high quality correlations. These taxa are incorporated into definitions of global Carboniferous chronostratigraphic units. A standard global Carboniferous zonation has not been developed. The lowermost Mississippian is zoned by *Siphonodella* species, except in shallow-water facies, where other polygnathids are used. *Gnathodus* species radiated during the Tournaisian and are used to define many Mississippian zones. A late Tournaisian maximum in diversity, characterized by short-lived genera, was followed by lower diversity faunas of *Gnathodus* species and carminate genera through the Viséan and Serpukhovian. By the late Viséan and Serpukhovian, *Lochriea* provides better biostratigraphic resolution. Shallow-water zonations based on *Cavusgnathus* and *Mestognathus* are difficult to correlate. An extinction event near the base of the Pennsylvanian was followed by the appearance of new gnathodid genera: *Rhachistognathus, Declinognathodus, Neognathodus, Idiognathoides,* and *Idiognathodus*. By the middle of the Moscovian, few genera remained: *Idiognathodus, Neognathodus* and *Swadelina.* During the middle Kasimovian and Gzhelian, only *Idiognathodus* and *Streptognathodus* species were common. Near the end of the Gzhelian, a rediversification of *Streptognathodus* species extended into the Cisuralian.

Over the past fifty years conodonts have become the primary way by which regional and global correlations of Carboniferous strata are effected. Conodont biostratigraphy has complemented and often replaced zonations based on ammonoids, foraminifers, and other faunal groups. Most of the chronostratigraphic boundaries and GSSPs of the Carboniferous have, or will be, defined with reference to ranges of conodont species. The application of conodonts to biostratigraphic and chronostratigraphic work has been successful for several reasons. They can be easily extracted using chemical techniques from a broad range of sedimentary rocks representing the full spectrum of marine environments. Their small size permits them to be obtained from subsurface cores, as well as from surface exposures. Detailed stratigraphic collections can be made to determine species distributions and ranges that can be then directly integrated with geochemical events, and other paleontological and geological events. As research continues today, more range data is being collected, more detailed taxonomic studies are being completed, some using biometric procedures, and revisions of species concepts, species ranges, and consequently zones are occurring. Regional Carboniferous conodont faunas differ because of many factors, the more important of which are paleogeography, leading to endemic faunas, and the differences between offshore open marine and shallow water restricted conodont biofacies. Some progress has been made toward a uniform "standard" conodont zonation for the Carboniferous, which will likely be based on open marine, offshore faunas. However, this "standard" zonation will not completely replace the local zonations that may work better within regional basins and in the more restricted environments. Because much of this research has been regional in extent, in this paper conodont faunas and zonations are described by region. Different co-authors assumed primary responsibly for the major regions and all authors reviewed the collated parts: North America (Barrick, Lambert, Ritter), Western Europe (Blanco-Ferrera, Sanz-López, Nemyrovska), Russia and adjacent countries (Alekseev, Goreva), Ukraine and Turkey (Nemyrovska), East Asia (Hu, Qi), North Africa and South America (Blanco-Ferrera, Sanz-López), Iran to Australia (Barrick).

The earliest paper on Carboniferous conodonts dates back to Pander (1856), but conodont work until the 1950's was essentially in a pre-biostratigraphic phase where numerous species were named from different localities and little attempt was made to place then in a zonal succession. These older conodont species names have continued to plague more recent attempts to modernize taxonomy because of uncertainty to which revised species the older name should be applied. For example, many old names commonly seen in zonations, such as *Gnathodus delicatus*, *Gn. semiglaber*, *Gn. texanus*, *Idiognathodus delicatus*, and *I. magnificus*, may refer to a variety of different, often unrelated morphotypes of somewhat different ages.

During the late 1950's–1960's conodont zonations for the Mississippian developed in Midcontinent North America that were tied to the lithostratigraphic order of the type Mississippian Valley Succession. This led to the Mississippian zonations summarized by Collison *et al.* (1972) for North America. Early conodont zonations in Europe were tied to the ammonoid succession and were summarized by Rhodes & Austin (1972). Although later syntheses have tried to create a general composite zonation for the global Mississippian (e.g. Sandberg *et al.* 1978; Lane *et al.* 1980), regional zonations that better reflect the local species succession are more commonly used, such as the North American Midcontinent Zonation of Lane & Brenckle (2005). The greatest difficulty in Mississippian conodont biostratigraphy is how to correlate shallow water restricted faunas (e.g. *Patrognathus*, *Clydagnathus*, *Taphrognathus*, and *Mestognathus* faunas), where species commonly used for offshore zonations are rare to absent.

Research on Pennsylvanian conodont faunas lagged behind those of the Mississippian, in part because of the widespread application of existing well-defined fusulinid and ammonoid zonations. The loss of marine units in Western Europe above the Lower Pennsylvanian limited work in that region and the cyclothemic nature of the Pennsylvanian strata in the North American Midcontinent region imposed limits on the resolution of short-lived zones. The work of Ellison (1941) depicted Pennsylvanian conodont species having long ranges, which may have discouraged further biostratigraphic research. Although Merrill (in Lane *et al.* 1972) proposed a possible Pennsylvanian zonation for the Appalachian Basin, his later papers (e.g. Merrill & von Bitter 1976) suggested that short-ranging species could not be resolved within the "*Idiognathodus-Streptognathodus* plexus" and that local ecological effects were more significant than time in the composition of conodont faunas. It was not until the 1980's that recognition that Midcontinent cyclothems possessed short-ranging conodont species (e.g., Swade 1985; Heckel 1989) did the first versions of the Midcontinent zonation discussed here appear. As Pennsylvanian conodont faunas from Russia (e.g. Barskov &Alekseev 1975; 1979) and Ukraine (e.g. Kozitskaya *et al.* 1978) became better known, regional zonations were developed that included a mixture of taxa assigned to North American species and endemic forms. Later work recognized the high level of endemism between North America and Eurasia and lead to more robust conodont zonations for Eurasia. As work in other regions expanded, especially in South China, (e.g. Xiong & Zhai 1985; Wang & Qi 2003*a*; Hu *et al.* 2020*a*) local zonations were proposed that incorporated parts of both of North America Midcontinent and Eurasian zonations. Revisions of species and species lineages continue to provide new information and improved zonal concepts.

Conodonts and chronostratigraphic boundaries

Conodonts have become extremely important for the regional and global correlation of the boundaries of Carboniferous chronostratigraphic units. The boundaries of the Mississippian and Pennsylvanian subsystems, although established over 20 years ago with conodont species as the correlation events, are being reconsidered based on new studies of conodont taxonomy and global events. The boundaries of most of the stages have yet to be established and only a few stratotypes have been selected. A short summary of the most recent assessment of conodont biostratigraphy relative to each chronostratigraphic boundary is given below. Additional details for zonations in each geographic region can be found elsewhere in this paper. The recent focus on chronostratigraphic boundaries has produced a large volume of literature about conodont taxonomy and distribution across the critical boundary intervals. However, the conodont taxonomy and the zonal subdivisions within the stages are much less well known.

Base of Carboniferous System (Mississippian Subsystem; Tournaisian Stage)

The base of the Carboniferous (Mississippian Subsystem) was placed at the first occurrence of *Siphonodella* (*Eosiphonodella*) *sulcata* in the La Serre section, Montagne Noire, France in 1991 (Paproth *et al.* 1991). Since that time, Kaiser (2009) demonstrated that the first occurrence of *S. (Eo.) sulcata* does not occur at the GSSP level in the La Serre section. The taxonomy of the *S. (Eo.) praesulcata-S. (Eo.) sulcata* transition that formed the basis for the biostratigraphic event for the boundary has also been called into question (Kaiser & Corradini 2011). Alternatively, the boundary at the base of the Carboniferous could be recognized at the FAD (first appearance datum) of *Protognathodus kuehni* (*S. sulcata-Pr. kuehni* Zone after Becker *et al*. 2016). More recent papers suggest that an older datum at the FAD of *Pr. kockeli* may be a better biostratigraphic event and replace the *S. sulcata* Zone with the *Pr. kockeli* Zone at the base of the Carboniferous (Corradini *et al.* 2017; Aretz & Corradini 2019). However, Kaiser *et al.* (2019) suggested that the complex taxonomy of *Pr. kockeli* may also cause problems in definition and correlation. The possibility of using some level within the global Hangenberg Crisis (Kaiser *et al.* 2016) to define the boundary has been discussed, but this may prove to be difficult (Becker *et al.* 2016). A new GSSP will likely be selected (Aretz & Task Group 2018).

Viséan Stage

The stratotype for the base of the Viséan is the Pengchong section in South China and the GSSP corresponds with the FAD of the foraminifer *Eoparastaffella simplex* (Devuyst *et al.* 2003). It lies just below the FOD (first occurrence datum) of *Pseudognathodus homopunctatus* in the stratotype section, which defines the base of the Belgium/French *Pd. homopunctatus* Zone (Groessens 1976; Perret & Delvolve 1994) or the *Gnathodus texanus*-*Pd. homopunctatus* Zone of other authors (Perri & Spalletta 1998). However, a continuous *Eoparastaffella* lineage is not known from North America (Lane & Brenckle 2005). The GSSP level is just above the occurrence of *Scaliognathus anchoralis europensis*, which is also not known from North America, but it is considered to be the ancestor to *Sc. a. anchoralis* (Lane & Brenckle 2005), which occurs in FU 4L and 4U. Lane & Brenckle (2005, p. 89) indicated that the Tournaisian-Viséan boundary lies within Faunal Unit 4L. However, *Pd. homopunctatus* first occurs in northeastern Oklahoma in Biozone 1 of Godwin *et al*. (2020), which corresponds to a level within Faunal Unit 7 of Lane & Brenckle (2005). The Tournaisian-Viséan boundary should lie somewhere above FU 4 and below the top of FU 7 in the Midcontinent succession, but its exact position is unclear.

Serpukhovian Stage

Nikolaeva *et al.* (2019) recently discussed the status of the search for a GSSP for the base of the Serpukhovian Stage. They considered the most suitable biostratigraphic event to characterize the boundary to be the FAD of *Lochriea ziegleri* in the lineage of *L. nodosa* to *L. ziegleri*. They reviewed the geographic distribution of *L. ziegleri*, the relation of its FOD to FODs of other taxa, and considered potential stratotype sections. Alekseev *et al*. (2018*b*) and Qi *et al*. (2018) have also discussed the *Lochriea* lineages and the geographic occurrences of the species. Nikolaeva *et al*. (2019) indicated that more taxonomic work on the numerous transitional morphotypes between *Lochriea* species is required to clarify species characteristics. Another concern is that the presence of *L. ziegleri* in North American sections has yet to be demonstrated, although a single specimen was reported from central Texas (Qi *et al.* 2010; Richards 2010). Nemyrovska (2017) correlated the *L. ziegleri*-*Cavusgnathus naviculus* Zone in the Donets Basin with the *C. naviculus* Zone (FU 11) in North America, at the same level indicated by Lane & Brenckle (2005, fig. 1) to be the base of the Serpukhovian.

Pennsylvanian Subsystem (Bashkirian Stage)

The base of the Pennsylvanian was defined to lie at the first occurrence of *Declinognathodus noduliferus sensu lato* within the lower Bird Spring Formation at Arrow Canyon, Nevada (Lane *et al.* 1999). At that time few species of *Declinognathodus* were known and the evolutionary history of the genus poorly understood. Subsequent research has shown that a variety of *Declinognathodus* species exist, some of which may appear before *Dec. noduliferus sensu lato* (e.g. Nigmadganov & Nemirovskaya 1992; Nemyrovska 1999; Nemyrovska *et al.* 2011; Sanz-López *et al.* 2006; 2013; Sanz-López & Blanco-Ferrera 2013). The holotype of *Dec. noduliferus* is a juvenile element recovered from the late Bashkirian Dimple Limestone in west Texas, which is full of reworked conodonts (Ellison & Graves 1941). Younger species of *Declinognathodus* occur in the Dimple, such as *Dec. marginodosus* (Proctor 1991), and it is uncertain to which current species the holotype can confidently be assigned. Sanz-López *et al.* (2013) showed that *Dec. inaequalis* has been reliably identified in numerous areas at the correlated position of the base of the Pennsylvanian. Hu *et al.* (2019) indicated that *Dec. noduliferus* was derived from the older species *Dec. inaequalis,* as well as providing a revised diagnosis for the species. In the restudy of the conodonts from Arrow Canyon, Lane *et al.* (2019) reported that the specimens originally identified as *Dec. noduliferus s. l.* (Brenckle *et al.* 1997; Lane *et al.* 1999) are *Dec. inaequalis*, according to the recent taxonomic revisions. The zonation they present also shows that the base of the "*Declinognathodus noduliferus-Rhachistognathus primus* Zone" at the base of the Pennsylvanian is defined by the FAD of *Dec. noduliferus s.l.* (=*Dec. inaequalis*). Given our better understanding of *Declinognathodus* evolution and to preserve the current GSSP, it may be better to use the species *Dec. inaequalis*, as opposed to the revised *Dec. noduliferus*, to characterize the base of the Pennsylvanian.

Moscovian Stage

Although the approximate level at which to place the base of the Moscovian is generally agreed upon, the selection of the marker and section for the Bashkirian-Moscovian GSSP is still in progress (Alekseev & Task Group 2017; 2018). The best potential biostratigraphic markers for the base of the Moscovian are two conodont species, *Declinognathodus donetzianus* and *Diplognathodus ellemerensis*. Of the two species, *D. ellesmerensis* probably has a more cosmopolitan distribution, for the presence of *Dec. donetzianus* in North America and Asia has not been demonstrated. Both species appear at nearly the same level in the Basu section in the South Urals (Alekseev *et al.* 2018*a*; 2019). Hu *et al.* (2020*b*) recently demonstrated the lineage leading to *D. ellesmerensis* and recommended using the FAD of it as the biostratigraphic marker for the boundary. If the task group of the Subcommission on Carboniferous Stratigraphy (SCCS) votes to place the base of the Moscovian at the FAD of *D. ellesmerensis*, then the Baskirian-Moscovian boundary will slightly precede the *N. atokaensis* Zone in North America.

Kasimovian Stage

It has been extremely difficult for the task group of the SCCS to decide on the level at which to place the base of the Kasimovian, and consequently no progress has been made toward selecting a GSSP. The strong provinciality of conodont and fusulinid faunas during this time appears to be the greatest impediment. Two possible solutions, both involving conodont species, remain active, but the proposed levels differ by about 1 myr. The first possible level is one substage higher than the traditional base of the Kasimovian, near the middle of the Khamovnikian Regional Substage, which was considered because of the possibility of using *Idiognathodus sagittalis*, *I. turbatus* or *I. heckeli* for global correlation (Villa & Task Group 2008; Ueno & Task Group 2014). The second solution is to retain the base of the Kasimovian at the level near its traditional base at the base of the Krevyakinian Regional Substage in the Moscow Basin. This is the level shown in the *Geological Time Scale 2012*, which Davydov *et al.* (2012) suggested could be justified on the basis of fusulinid faunas. Alekseev (Ueno & Task Group 2017) has also proposed to retain the original definition because in Eurasia the conodont *Swadelina subexcelsa* is a reliable biostratigraphic index to this level. However, *Sw. subexcelsa* has not been recovered from North America, and correlation to the Midcontinent region would need to rely on correlation of eustatic cycles (e.g. Heckel *et al.* 2007).

Gzhelian Stage

The task group of the SCCS charged with establishing the Kasimovian-Gzhelian boundary agreed to use the FAD of *Idiognathodus simulator* as the biostratigraphic marker for the base of the Gzhelian (Heckel *et al.* 2008; Villa *et al.* 2009b). *Idiognathodus simulator* and closely related species (the *I. simulator* group) occur widely and permit reliable correlation of the base of the Gzhelian. However, little progress has been made to select a GSSP because the lineage leading to *I. simulator* is poorly known. Recent works on the *I. simulator* group in North America (Hogancamp *et al.* 2016) and South China (Qi *et al.* 2020) have clarified species concepts using biometric studies, but details of the lineage have not been resolved.

North America

Midcontinent Mississippian

The oldest comprehensive Mississippian conodont zonation for Midcontinent North America was published by Collinson *et al.* (1962), which was based largely on faunas from the Upper Mississippian Valley region, the type area for the Mississippian Subsystem and the regional Mississippian series. Collinson *et al.* (1972) provided a more thorough discussion of the original North American/Mississippi Valley zonation. They presented a brief history of Mississippian conodont studies in North America, which showed that most of the zonal species had been originally described by several workers from widely dispersed localities across Midcontinent North America and that the ranges were later composited by merging occurrences from these localities. Sandberg *et al.* (1978) redefined the *Siphonodella* zones (Kinderhookian), incorporating information from the Midcontinent region, western United States and Europe.

Thompson (1967) and Thompson & Fellows (1970) subdivided and redefined zones for the latest Kinderhookian through the Osagean, based on faunas from southwestern Missouri. Instead of using the Mississippi Valley zonation or the Thompson & Fellows (1970) zones, Lane (1974) proposed a series of numbered faunal units (FUs) to subdivide and correlate units in the lower Mississippian Lake Valley succession in New Mexico. These faunal units have been used in New Mexico (e.g. Lane & Ormiston 1982; Carman 1987), applied in the Midcontinent region (Lane 1978; Lane & Dekeyser 1980), and were integrated into a series of proposed global zones for the lower Mississippian (Lane *et al*. 1980). Chauff (1981, 1983), however, pointed out discrepancies in ranges and abundances between the southwestern Missouri and the New Mexico succession. Lane *et al*. (2000) combined the Mississippi Valley zones with the New Mexico faunal units into a single North American zonation in a paper proposing the use of biothems (unconformity bounded biostratigraphic units), but did not provide an explanation of the zones and their composition. Lane & Brenckle (2005) updated the combined zonation scheme, clarified and refined the zonal boundaries, and discussed the boundaries of North American regional stages relative to the conodont zones. Recently, Boardman *et al.* (2013) emphasized that the zonation of Lane & Brenckle (2005) was inadequate to characterize the lower Mississippian faunas along the western margin of the Ozark Plateau (southwestern Missouri and adjacent Arkansas and Oklahoma) and they proposed an alternative series of local zones based on the older zonation of Thompson & Fellows (1970). In addition to demonstrating differences in the ranges of some species, Boardman *et al.* (2013) were critical of the poor understanding of the taxonomy of

Gnathodus species, arguing that the many species concepts of Lane *et al.* (1980) were incorrect or at least misleading. Here we present essentially the zonation of Lane & Brenckle (2005), which has become the standard for North America (Fig. 1), but recognize that the criticisms of Boardman *et al.* (2013) are valid and need to be addressed in future work.

Kinderhookian. Faunal Units 1A through 1G of Lane & Brenckle (2005) comprise the seven *Siphonodella* zones of Sandberg *et al.* (1978) with one minor alteration. In the Midcontinent region the lower five zones are limited to outcrops in the upper Mississippi River Valley. Faunal Unit 1A, the base of which is defined by the transition from *S. praesulcata* to *S. sulcata,* which designated the base of the Mississippian Subsystem. Isolated lowermost Mississippian faunas (FU 1) have been recovered from the Appalachian Basin (Repetski & Stamm 2009), and just above the top of the Late Devonian black shale facies in the Illinois Basin (Huddle 1934; Evans *et al.* 2013), Tennessee (Over *et al.* 2019), and Oklahoma (Over 1992). Sandberg *et al.* (1978) originally defined the base of FU 1G (*S. isosticha*–Upper *S. crenulata* Zone as the FAD of *Gnathodus delicatus,* but Lane & Brenckle (2005) changed this level to the LAD of *S. crenulata.* Boardman *et al.* (2013) reported *Siphonodella* faunas comprising three local zones that are approximately equivalent to FU 1E to 1G from the Bachelor Shale and Compton Formation in the western Ozark region. Across much of the western Midcontinent region lowermost Mississippian strata appear to be no older than FU 1G or FU 2 (e.g. Lane 1974, 1978).

Hogancamp *et al.* (2019) revised the *Siphonodella* zones for North America, using the appearances of distinctive morphological features in *Siphonodella* species. The *Protognathodus kockeli* Zone was the oldest Mississippian zone. They replaced the upper part of the *S. sulcata* Zone with the *S. bransoni* Zone, based on the FAD of *S. bransoni* and the appearance of a rostrum. The Lower *S. duplicata* Zone became just the *S. duplicata* Zone, based on the FAD of that species and appearance of a keel. Instead of retaining the Upper *S. duplicata* Zone, the FADs of *S. hassi* and *S. obsoleta* were used to define the base of the *S. cooperi* Zone, where nodose caudal platforms appear. This zone was followed by the *S. sandbergi* Zone (numerous adcarinal ridges) and the *S. crenulata* Zone (smooth unridged rostral platforms). The appearance of *Gnathodus delicatus* defined the base of the *Gn. delicatus* Zone.

Osagean. The appearance of *Gnathodus punctatus* (*sensu* Hass 1959) defines the base of FU 2, which has been used to approximate the base of the Osagean Series (Lane & Brenckle 2005), although Boardman *et al.* (2013) consider FU 2 to be latest Kinderhookian in age. It corresponds to the lower part of the Lower *Gn. typicus* Zone of Lane *et al.* (1980). The name *Gn. punctatus* has been applied to a variety of early Mississippian morphotypes with an expanded ornamented rostral platform (Lane & Brenckle 2005) and care needs to be taken in the identification of this species. Boardman *et al.* (2013) recognized an older and a younger subspecies of *Gn. punctatus* in a lineage leading from an unnamed *Protognathodus* species. The youngest *Siphonodella* species range into FU 2, co-occurring with *Gn. punctatus* (*S. isosticha* according to Lane & Brenckle 2005; *S. cooperi hassi* according to Boardman *et al.* 2013). Hogancamp *et al.* (2019) used the FAD of *Gn. punctatus* to define the base of their zone of that name and reported *S. cooperi* and *S. hassi* as disappearing in this zone.

Lane & Brenckle (2005) subdivided the lower Osagean FU 3 of Lane (1974) into two units, 3A and 3B, and abandoned the use of the *Gnathodus typicus* Zone of Lane *et al*. (1980). Faunal Units 3A/3B correspond with a major flooding event across North America that led to the formation of the Burlington Shelf in the Midcontinent and the Lake Valley Shelf in New Mexico (Lane 1978; Lane & DeKeyser 1980). The base of FU 3A was defined by the FAD of *Neopolygnathus communis carinus*, which disappears at the top of the zone. The base of the *Ne. carinus* Zone of Hogancamp *et al.* (2019) is the same as the base of FU 3A. The base of FU 3B was defined by the FAD of *Pseudopolygnathus multistriatus*, and the base of the overlying FU 4L was defined by the FAD of *Doliognathus latus.* Boardman *et al.* (2013) recognized three comparable zones for the 3A–3B interval in their work, the lower two of which correspond approximately with FU 3A and 3B. The base of the third zone, the Upper *Ps. multistriatus*–*Gn. cuneiformis* Zone, was defined by the FAD of *Gn. cuneiformis* below that of *Do. latus.* Lane & Brenckle (2005, fig. 4) show *Gn. cuneiformis* as appearing in FU 4. The reported difference in ranges may be a result of contrasting views of the taxonomy of Osagean *Gnathodus* species, for Boardman *et al*. (2013) introduced a large number of unnamed (numbered) species of *Gnathodus* as well as redefining some existing species.

Lane & Brenckle (2005) subdivided the *Scaliognathus anchoralis*–*Doliognathus latus* Zone of Lane *et al.* (1980) into three subunits, FU 4L, 4U, and 5. The *Do. latus* Subzone (4L) was defined at its base by the FAD of *Do. latus*; the *Bactrognathus lanei* Subzone (4U) was defined by the FAD of *Ba. lanei,* and the *Eotaphrus burlingtonensis* Subzone (5) was defined by the FADs of *Polygnathus mehli* and *E. burlingtonensis.* Boardman *et al.* (2013) recognized a comparable series of three zones with similar names and definitions. Conodont diversity attains the greatest levels during FU 4L and 4U, and then starts to decline in FU 5.

The base of FU 6 was defined by the FAD of *Gnathodus bulbosus*. Most of the characteristic taxa of the Osagean have disappeared by this level and a variety of *Gnathodus* species dominate faunas. A sea-level lowstand during this zone limits its distribution in the

Midcontinent region (Lane *et al.* 2000). The base of FU 7 in Lane & Brenckle (2005) was defined by the FAD of *Gn. texanus* and the faunal unit ranges from the upper Osagean into the Meramecian. Boardman *et al.* (2013) discussed the serious problems with the taxonomy and ranges of the *Gn. texanus* group, and substituted three zones for FU 7: the Lower *Gn. "texanus"* Zone (first abundance of *Gn. texanus* morphotypes); the Middle *Gn. "texanus"–Gn. pseudosemiglaber* Zone (FAD of *Gn. pseudosemiglaber*, *Gn. linguliformis*, or *Taphrognathus varians*); the Upper *Gn. "texanus"* Zone (FAD of *Gn.* sp. 15).

Meramecian. Lane & Brenckle (2005) indicated that the FAD of *Hindeodus penenscitulus* (one discrete element; maybe a *Synclydognathus* species) may occur near the base of the Meramecian within FU 7, which ranges through most of the Meramecian Series as a low diversity interval. Across much of Midcontinent North America, Meramecian strata are dominated by shallow water carbonate facies and *Hindeodus, Apatognathus* and *Taphrognathus* species occur with *Gnathodus texanus* morphotypes. Near the top of the Meramecian, occur *Taphrognathus–Cavusgnathus* transitional forms, which formed the original definition of FU 8 (Lane 1974). Lane & Brenckle (2005) redefined the base of FU 8 as the FADs of of *Hindeodus scitulus* and *Apatognathus scalenis* (both elements of *Synclydognathus geminus* and *Sy. libratus* according to Rexroad & Varker 1992). The oldest *Cavusgnathus* species appear in FU 8 as redefined.

The base of their Upper *Gnathodus "texanus"* Zone corresponds to the Osagean–Meramecian boundary according to Boardman *et al.* (2013). In northeastern Oklahoma Godwin (2017) and Godwin *et al.* (2020) proposed a series of four biozones that range from the approximate base of the Meramecian into lower Chesterian strata. Biozone 1 is the Upper *Gn. "texanus"* Zone of Boardman *et al.* (2013), which was defined by the appearance of *Gn.* n. sp. aff. *punctatus* and *Gn.* sp. A (Godwin *et al.* 2020, plate 1). *Taphrognathus varians* becomes common and *Pseudognathodus homopunctatus* appears in Biozone 1. The base of Biozone 2 was defined by multiple events: the highest occurrences of *Gn.* n. sp. aff. *punctatus, Gn. pseudosemiglaber* and *Gn.* sp. A, and the lowest occurrences of *Hindeodus cristula* and species of *Cavusgnathus*. The base of Biozone 3 was defined by the highest occurrence of *Taphrognathus.* The lowest occurrence of *Hindeodontoides spiculus* lies near the base of Biozone 3. Godwin *et al.* (2020) roughly correlated their Biozone 3 within uppermost part of Faunal Unit 7 and all of FU 8 of Lane & Brenckle (2005). However, Lane & Brenckle (2005) show the lowest occurrences of *Cavusgnathus* species as occurring at the base of FU 8, whereas Godwin *et al*. (2020) show *Cavusgnathus* species appearing at the base of their underlying Biozone 2.

Chesterian. Two distinct faunal associations occur in Chesterian strata in the Midcontinent region where shallow water faunas comprising *Hindeodus*, *Cavusgnathus*, and *Vogelgnathus* dominate (e.g. Rexroad 1957; Collinson *et al.* 1972) and the Chesterian zones reflect this environmental bias. Along the southern margin of North America, in deeper water shales like the Barnett Shale (e.g. Hass 1953), *Gnathodus bilineatus* and *Lochreia commutata* are more common and the shallow-water taxa occur rarely. Lane *et al.* (1980, p. 118, tab.1) designated the *Gn. bilineatus* Zone, but did not formally define it. Lane & Brenckle (2005) defined the base of the zone to be the FAD of *Gn. bilineatus* and subdivided the zone into two faunal units, FU 9 and 10. The base of FU 9 appears to correspond with the base of the Chesterian Series. In addition to *Gn. bilineatus*, FU 9 marks the appearance of several characteristic upper Mississippian species, in addition to common members of the *Gn. texanus* group: *Gn. girtyi*, *Lochriea commutata*, *Cavusgnathus altus* and *Rhachistognathus* sp. of Lane & Brenckle (2005). The base of FU 10 was defined by the LAD of *Rhachistognathus* sp. Several other species appear in FU 10 and range into higher zones such as *C. unicornis, C. altus, C. convexus, C. regularis, Vogelgnathus campbelli,* and *Magnilaterella robusta.*

Godwin (2017) and Godwin *et al.* (2020) placed their Biozone 4 at the base of the Chesterian and used the FADs of *Gnathodus girtyi girtyi* and *Lochriea commutata* to define the base of the biozone. Biozone 4 was tentatively subdivided in the three subzones based mainly on the ranges of *Gn. bilineatus* morphotype 1 (4M) and *Gn. bilineatus* morphotype 2 (4U). They also recognized the occurrence of *Rhachistognathus* sp. in subzones 4L and 4M. Subzones 4L and 4M correlate with FU 9 and Subzone 4U correlates with the lower part of FU 10. Godwin *et al.* (2020, fig. 12) presented a chart illustrating how the zones of Boardman *et al.* (2013) and Godwin *et al.* (2020) correlate with the zonations of Collinson *et al.* (1972) and Lane & Brenckle (2005) and with lithostratigraphic units from the upper Mississippi Valley west to New Mexico and south into Texas.

Faunal Unit 11 of Lane & Brenckle (2005) is substantially different from FU 11 of Lane (1974). The base of FU 11 of Lane and Brenckle (2005) was defined by the FAD of *Cavusgnathus naviculus,* a widely occurring species, making it the same as the *C. naviculus* Zone of Baesemann & Lane (1985). Faunal Unit 12 of Lane & Brenckle (2005) is the same as FU 11 of Lane (1974). The base was defined by the FAD of *Adetognathus unicornis.* Most species found in FU 11 and 12 range up from FU 10. The youngest conodont fauna in the Mississippi Valley region is FU 12. Faunal Units 13 and 14 are based largely on faunas from western North America (Baesemann & Lane 1985). The base of FU 13 was defined by the FAD of *Rhachistognathus muricatus,* and *Gnathodus girtyi simplex* first occurs in this zone. The base of FU 14 was defined by the FAD of *Adetognathus latus*. Faunal Units 13 and/or 14 occur in southern Oklahoma, and possibly in eastern Oklahoma, northern Arkansas, and far west Texas (Lane & Straka 1974).

Repetski & Stamm (2009) presented a slightly different series of zones for Chesterian shallow water strata in the Appalachian Basin that were based on the original Mississippi Valley zones of Collinson *et al.* (1972). *Cavusgnathus* and *Kladognathus* species are more important in the Appalachian zones, but these zones can be correlated easily to the Lane & Brenckle (2005) zones using species ranges. A fauna with *Gnathodus postbilineatus* was recovered from the Bramwell Member of the Bluestone Formation in West Virginia, which indicates an age approximately equivalent to FU 13/14, making it the youngest Mississippian conodont fauna in the region.

Eastern Canada Late Mississippian

Late Mississippian conodont faunas from the Winder Group in eastern Canada constitute a unique biofacies association (*Clydagnathus*, *Hindeodus*, *Mestognathus*, *Taphrognathus*, and uncommon *Gnathodus* species) that formed in extremely shallow water environmental conditions of variable salinity (von Bitter 1976). Globensky (1967) suggested a Viséan age for the Windsor Group, and von Bitter (1976) suggested a Viséan to possible early Namurian age. In a series of papers, von Bitter & Plint-Geberl (1982), Plint & von Bitter (1986), and von Bitter & Plint (1987) developed a local zonation of the Windsor Group comprising four zones, in ascending order: the *Diplognathodus*, *Taphrognathus transatlanticus*, *Clydagnathus windsorensis*, and *Gnathodus* zones. *Mestognathus* species from the Windsor Group were included in a proposed zonation using *Mestognathus* species (von Bitter *et al.* 1986). Because *M. bipluti* ranges from the *Cly. windsorensis* Zone into the *Gnathodus* Zone, these units were correlated with the upper part of the Viséan *Cauvusgnathus* Zone and the lower part of the *C. naviculus* Zone (von Bitter *et al.* 1986), which is now considered to be earliest Serpukhovian in age.

Western North America Mississippian

New Mexico. The lower Mississippian Midcontinent conodont (late Kinderhookian–Osagean) zonation was based in part on faunas from Lake Valley Shelf in the Sacramento Mountains in south-central New Mexico, which forms the western extension of the Burlington Shelf (Lane 1974; Lane & Dekeyser 1980; Lane & Ormiston 1982). Subsequent work by DeKeyser *et al.*

(1985) and Proske (2013) recognized comparable conodont faunas westward along the Lake Valley Shelf in the San Andres Mountains. Moore & Barrick (1988) reported similar faunas farther to the west in the Cookes Range and as far west as the Silver City region in western New Mexico. The oldest Mississippian conodont faunas in the Caballero Formation at the base of the Lake Valley succession appear to be no older than FU 1G or FU 2 (Carman 1987; Dekeyser *et al*. 1985; Moore & Barrick 1988; Proske 2013). The faunas of the overlying Andrecito, Lake Valley, Arcente and Doña Ana formations (nomenclature of Dekeyser 1983) range from FU 2 through FU 7, through most of the Osagean into the lowermost Meramecian. Although the lithological succession of lower Mississippian units on the Redwall-Escabrosa Shelf in Arizona and New Mexico (Gutschick & Sandberg 1983) differs from those on the Lake Valley Shelf, the conodont succession is similar. The Bugle Member at the base of the Keating Formation bears FU 1G and 2 faunas, which are succeeded by FU 3A and 3B in the lower part of the overlying Witch Member (Moore & Barrick 1988). Repetski (in Armstrong & Mamet 1988) reported Osagean conodonts from the lower part of the overlying Hatchita Formation in Arizona and New Mexico. Younger Mississippian strata (Meramecian-Chesterian) in New Mexico have produced fewer conodonts. Lane (1974) reported FU 8 and 9 from the Rancheria Formation in the Sacramento Mountains. The overlying Helms Formation in the Sacramento Mountains produced FU 10 and 11 faunas and to the south, in the Hueco Mountains, a FU 12 fauna (FU 12 of Lane & Brenckle, 2005; revised from Lane 1974). On the Redwall-Escabrosa Shelf, the uppermost Mississippian unit, the Paradise Formation has produced only a few conodonts (Norby 1971). Wilkening (1984) recovered a FU 12 fauna near the top of the Paradise Formation in the Big Hatchet Mountains.

Great Basin-Rocky Mountains. Knechtel & Hass (1938) initiated work on Mississippian conodonts in the western United States with their description of a lower Mississippian fauna from the basal Lodgepole Limestone of Montana. By the end of the 1960’s, a patchwork of western studies, many of limited stratigraphic scope, had appeared in the literature. Klapper (1966) described two lower Mississippian *Siphonodella*-based zones from the basal Madison Limestone/Group and basal Lodgepole Limestone in Montana and Wyoming and correlated these with the European zones of Voges (1960). Sandberg & Klapper (1967) recognized three lower Mississippian conodont zones in the Cottonwood Canyon Member of the Madison Limestone/Group in Montana and Wyoming that they compared to the Mississippi valley *S. sulcata* and *S. sandbergi*-*S. duplicata* zones of Collinson *et al*. (1962) and the European *S. crenulata* Zone of Voges (1960). The first published zonal scheme for an entire western Mississippian section was that of Pierce & Langenheim (1972, 1974) in southern Nevada. They subdivided the middle Kinderhookian through Chesterian Monte Cristo Group into nine zones, and used similarities in species ranges to correlate to the Mississippi Valley zonation of Collinson *et al.* (1962). In 1967, stratigraphers from the U.S. Geological Survey published the first in a long series of studies that culminated in Poole & Sandberg's (1977, 1991) classic papers on the zonation, tectonism, and sedimentation of the Mississippian System of the western United States.

Zonation of the Kinderhookian Series in the western United States (Fig. 2) is based upon first occurrences of species of *Siphonodella* as used by Sandberg *et al.* (1978). The Devonian-Mississippian boundary is represented by a hiatus of variable duration throughout the western United States and the lower three zones are present only in southern Nevada (Crystal Pass Limestone), in north-central Utah (upper Fitchville Dolomite), and in west-central Utah (upper member of the Pilot Shale). Widespread flooding of the area west of the Transcontinental Arch began with deposition of the Lower *S. crenulata* Zone and continued into the Osagean epoch from Arizona to Montana. Upper Kinderhookian strata are, however, absent from central and western Utah where regional uplift (Sevier Island of Poole & Sandberg 1991) prevented deposition of the Lower *S. crenulata* through *S. isosticha* zones. The *Siphonodella* zonation was applicable mainly to open-marine and offshore stratigraphic sections, leading Sandberg & Gutschick (1983) to distinguish an offshore *Siphonodella* biofacies and a nearshore *Patrognathus-Pandorinellina* biofacies.

The Osagean zonation proposed for the Great Basin and Rocky Mountains by Poole & Sandberg (1991) was a slight modification of the post-*Siphonodella* zonation proposed by Lane *et al.* (1980). The base of the Osagean Series is coincident with the first occurrence of *Gnathodus typicus* Morphotype 2 at the base of the Lower *Gn. typicus* Zone and with the extinction of the siphonodellids. Middle to upper Osagean strata were divided into the Upper *Gn. typicus*, *Scaliognathus anchoralis-Doliognathus latus*, and *Polygnathus mehli-Lower Gn. texanus* zones. The base of the Upper *Gn. typicus* Zone was defined by the first occurrence of either *Pseudopolygnathus oxypageus* or *Ps. nudus*. The base of the *Sc. anchoralis-Do. latus* Zone was defined by the FAD of either of the zonal name bearers. The upper Osagean zone was defined the first occurrence of *P. mehli* above the last occurrences of *Do. latus* and succeeded by the FAD of *Gn. texanus*. All four zones are well represented in carbonate platform, slope, and starved basin deposits of the Great Basin and Rocky Mountains, extending from Montana to southern Nevada (Poole & Sandberg 1991). The *Sc. anchoralis-Do. latus* and *P. melhi*-Lower *Gn. texanus* zones are represented by the Delle Phosphatic Member of the Deseret Limestone throughout southern Idaho, western Utah, and eastern Nevada (Sandberg & Gutschick 1984). Correlation of the *Sc. anchoralis-Do. latus* Zone from the starved-basin deposits of eastern Nevada and western Utah into the inner platform and lagoonal deposits of northeastern Utah and central Wyoming permitted Sandberg and Gutschick (1979, 1980, 1984) to develop a biofacies model for this particular zone.

Poole & Sandberg (1991) divided the Meramecian Series into two broadly recognizable zones in the western United States; the *Gnathodus* (=*Pseudognathodus*) *homopunctatus*-Upper *Gn. texanus* and the Lower *Cavusgnathus* zone, based partly on Tynan's (1980) study of the Chainman Shale in western Utah. The base of the lower zone was defined by the FAD of *Pd. homopunctatus* and the base of the overlying zone was defined by the FAD of *Cavusgnathus*. These zones are widely distributed throughout the Basin and Range and Rocky Mountains, comprising several coeval lithostratigraphic units ranging from shallow-marine lithofacies in the east to carbonate platform and offshore mixed carbonate siliciclastic lithofacies farther west. Upper Meramecian strata are areally restricted reflecting a major drawdown of sea level that commenced during middle Meramecian time.

During Chesterian time, sedimentation was aerially restricted over much of the western United States. The Surprise Canyon Formation was deposited in incised valleys carved into older Mississippian rocks in the Grand Canyon region (Martin & Barrick 1999). A narrow carbonate bank extended from southern Nevada to eastern Idaho, flanked on the updip (east) side by thick shale deposits assigned to the Heath Formation and the Manning Canyon, Doughnut, and Horseshoe shales, and on the west by Antler foreland basin sequences assigned to the Chainman, Indian Springs, and Rest Springs shales. Poole & Sandberg (1991) divided these strata into five zones named, in ascending order, the *Gnathodus bilineatus*-Upper *Cavusgnathus*, *C. naviculus*, *C. unicornis, Rhachistognathus muricatus,* and *Rh. primus* zones based upon the FAD of the nominate species. The base of the latter zone was coincident with the LAD of *Cavusgnathus* and FAD of *Rh. websteri*.

Late Mississippian to Early Pennsylvanian conodonts in east-central Idaho and adjacent Montana allowed biostratigraphic subdivision of continuously deposited Antler foreland basin sequences (Abplanalp *et al.* 2009). Four Chesterian and one Morrowan conodont biozones were defined within a carbonate mud-dominated succession in Idaho's foreland basin and traced to thinner platform strata in Montana The *Hindeodus/Vogelgnathus* Zone (lower Chesterian) was based on the FADs of *H. cristula* or *V. campbelli.* The *Cavusganthus naviculus* Zone (middle Chesterian) was based on the FAD of *C. naviculus.* The *Adetognathus unicornis* Zone (upper Chesterian) was based on the FAD of *A. unicornis*. The *A. lautus* Zone (uppermost Chesterian) was based on the FAD of *A. lautus.* The lowest Morrowan zone, the *Rhachistognathus primus*

Zone, was based on the FADs of *Rh. primus*, *Rh. havlenai*, and *Rh. websteri* and the top of zone was the LAD of *Rh. primus*.

Western Canada Sedimentary Basin. Mississippian strata of the Western Canada Sedimentary Basin are divided into tectono-stratigraphic assemblages named, in ascending order, the Banff (Kinderhookian), Rundle (Osagean to lower Meramecian), and Mattson (Meramecian to Missourian) assemblages (Richards *et al.* 1994). Each is composed of several regionally restricted groups and formations. Kinderhookian strata were divided into the *Siphonodella* zones of Sandberg *et al.* (1978) and Osagean strata are correlated using the zones of Lane *et al.* (1980) (Higgins *et al.* 1991; Richards *et al.* 1994, fig. 14.2). Meramecian strata were assigned to a generalized *Cavusgnathus* Zone. Chesterian rocks were divided into four zones: the *Gnathodus* cf. *texanus*, the *Gn. girty*–*Gn. collinsoni*, the *Gn. girtyi*–*Gn. simplex*, and the *Rhachistognathus muricatus* zones. Similar faunas occur in the pericratonic Kootenay terrane (Orchard 1985).

Sverdrup Basin: Only late Mississippian conodonts (*Paragnathodus* (=*Lochriea*) *commutatus* Zone) have been reported from the lower part of the Nansen Formation (Higgins 1987, in Beauchamp *et al.* 1989, fig. 3).

Alaska and western terranes. Elements of the standard Midcontinent zonation were applied to Mississippian strata in the eastern Brooks Range of the Arctic-Alaska terrane by Krumhardt *et al.* (1996) and Harris *et al.* (1997). In this area, Kinderhookian through Meramecian strata are absent and the Chesterian Alapah and lower Wahoo formations (Lisburne Group) were assigned to the Upper *Rhachistognathodus muricatus* Subzone (Krumhardt *et al.* 1996) and to the coeval *Adetognathus lautus* Zone in a subsequent U.S. Geological Survey report by Harris *et al*. (1997). The bases of both zones were defined by the FAD of *A. lautus* and the tops by the FAD of *Declinognathodus noduliferus*. Dumoulin & Harris (1993), Dumoulin *et al*. (1993) and Mull *et al.* (1997) reported Kinderhookian, Osagean, and Meramecian conodonts from the western Brooks Range, but they did not subdivide the Kinderhookian to Osagean Kayak Shale (upper Endicott Group) or overlying Lisburne Group into formal zones. AMOCO stratigraphers used conodont and small foraminiferan data from surface and subsurface strata on the North Slope (Baesemann *et al.* 1998) to establish regional graphic correlations of the Lisburne Group, but likewise did not subdivide the strata into zones.

Isolated Mississippian conodont faunas have been reported from several of the exotic terranes in British Columbia and southeastern Alaska. In the Cariboo terrane, the Greenberry

Formation produced faunas that Orchard & Struik (1985) interpreted to be mostly Early Mississippian in age. Orchard (1986) recovered a *Siphondella–Pseudopolygnathus* fauna and a late Mississippian *Gnathodus* fauna from cherts in the Sicker and Slide Mountain terranes. Late Mississippian conodonts (*Gn. bilineatus* and *Vogelgnathus*) were reported from the Pinantan Lake Formation of the Quesnel terrane (Orchard 1987). Late Mississippian conodonts were also described from the Peratrovich Formation in the Alexander terrane in southeastern Alaska (Faulhaber 1977; Fredericks & Barrick 2018).

Midcontinent Pennsylvanian

Barrick *et al*. (2004, 2013*a*) summarized the Pennsylvanian conodont zonation of Midcontinent North America, and further modifications are presented here (Figs. 2, 3). Glacio-eustatic sea-level fluctuations produced a distinctive sedimentological regime on Midcontinent Pennsylvanian stratigraphy, and the ranges of conodont species are closely tied to the cyclothem-dominated stratigraphy that is the product of these sea level events (Heckel 2013). In the original stages of development of the zonation, distinctive conodont morphotypes recovered from highstand deposits were used to characterize and correlate individual eustatic cycles (e.g. Swade 1985; Heckel 1989; Barrick & Boardman 1989; Heckel & Weibel 1991). The large number of older poorly characterized named species of the dominant genera *Idiognathodus* and *Streptognathodus* (Gunnell 1931; Stauffer & Plummer 1932; Gunnell 1933; Ellison 1941) hindered the transformation of these informal cyclothem-based index species into a formal zonation, and taxonomic uncertainties still complicate the application of the zonation today. An important aspect of the Midcontinent conodont zonation is its reliance on faunas obtained from highstand deposits, typically dark gray to black deep-water shales (core shales; Heckel 2002). Although the highstand conodont faunas are abundant and diverse, they represent only a portion of the marine lithofacies and conodont biofacies present in the cyclothems. These highstand facies also constitute only a fraction of the time represented by the cyclothem, and some of the contrast between successive cyclothems may be enhanced by the unstudied time of the intervening shallow water facies and lowstand terrestrial deposits. Also, correlations into shallower water, carbonate-dominated sections are difficult to effect unless the diagnostic index species of the "highstand fauna" can be recovered. Classic, fully developed cyclothem stratigraphy is widely recognized from the upper Desmoinesian Marmaton Group through the remainder of the Pennsylvanian record. The lack of fully developed cyclothems in Morrowan and Atokan strata up into the lower Desmoinesian Cherokee Group partly resulted from initial infilling of the antecedent topography carved into the Mississippian surface by the major mid-Carboniferous lowstand. As the fluctuating sea-levels continued through a longer-term, lower-order trend of sea-level rise, sedimentary deposits progressively filled incised valleys and other antecedent topography until the depositional surface became much less rugged (e.g. Thompson & Lambert 2017). The Midcontinent zonation is best expressed on the northern Midcontinent Shelf (northern Oklahoma through Kansas and Missouri to Iowa), but many of the zones have been recognized in the Illinois Basin, the Appalachian Basin, north-central Texas, New Mexico, and Utah (Barrick *et al*. 2013*a*).

Morrowan. The Mid-Carboniferous (Mississippian-Pennsylvanian Subsystem) GSSP was placed at the level of the first appearance of *Declinognathodus noduliferus* in Arrow Canyon, Nevada (Lane *et al*. 1999). The base of the *Dec. noduliferus–Rhachistognathus primus* Zone is defined by the first occurrence of either *Dec. noduliferus* or *Rh. primus*, the latter restricted to western North America. In the Midcontinent, the entire zone is called the *Dec. noduliferus* Zone, and has been reported from the Rhoda Creek Formation in the Ardmore Basin of southern Oklahoma (Grayson *et al.* 1985; Grayson 1990). The base of the overlying *Idiognathoides sinuatus* Zone of Lane (1977) is defined in the Midcontinent by the first appearance of *Id. sinuatus*. For sections in western North America, Lane & Baesemann (1982) modified this zone by adding *Rh. minutus* as an index, and renaming the zone the *Id. sinuatus–Rh. minutus* Zone. The *Id. sinuatus–Rh. minutus* Zone occupies several meters of strata in the Golf Course Formation of southern Oklahoma (Lane 1977) and the upper Hale and lower Bloyd formations in northwestern Arkansas (Baesemann & Lane 1985).

The *Neognathodus higginsi* Zone, defined on the appearance of *N. higginsi*, was proposed by Grayson (1990) for the entire lower Morrowan, but corresponds to just the *Dec. noduliferus* and *Id. sinuatus* zones in the Ardmore Basin as used here. The overlying *N. symmetricus* Zone is defined by the first appearance of *N. symmetricus*. It has been applied consistently for the middle Morrowan since originally proposed (Lane 1967; Lane & Straka 1974), and has been reported from a number of localities from western North America to the Appalachian Basin. The *N. bassleri* Zone is defined by the first occurrence of *N. bassleri*. Its base also has been applied consistently since originally proposed (Lane 1967; Lane & Straka 1974).

No consistent zonation has been widely adopted for the succeeding Morrowan conodont record. The *Idiognathodus sinuosus* Zone, next younger zone in many papers, is defined by the range overlap of *Neognathodus bassleri* and *I. sinuosus* (Lane & Straka 1974; Baesemann & Lane 1985). The overlying *I. klapperi* Zone of Lane & Straka (1974) was defined by the presence of *I. klapperi*. Grayson *et al.* (1989, 1990) expanded the concept of *I. klapperi* to include P_1 elements in which the anterior extensions of adcarinal ridges are incorporated into the platform and applied the name to a series of distinctive late Morrowan to early Atokan P_1 elements. The overlying *Idiognathoides convexus* zone was tentatively defined as the range of *Id. convexus* below the appearance of *Id.* n. sp. of Lane *et al.* (1972) by Lane & Straka (1974). This zone is most often indicated by the first occurrence of *Id. convexus* following the appearance of *N. bassleri*, and usually *I. sinuosus*, whether or not *I. klapperi* is present below. Zones based on *Id.* n. sp. of Lane & Straka (1974) and *Id. ouachitensis* have also been used (Grayson 1979, 1984; Lane & Baesemann 1982; Baesemann & Lane 1985).

Barrick *et al.* (2013*a*) suggested expanding the *Neognathodus bassleri* Zone to include the *Idiognathodus sinuosus* and *I. klapperi* zones in an entirely *Neognathodus*-based zonation. For the succeeding *Neognathodus*-based conodont zone, Barrick *et al.* (2013*a*) used the appearance of *N. nataliae*, which occurs in the top of the Wapanucka Formation of southern Oklahoma (Grayson 1984), and the Burgner Formation of Missouri (Thompson & Lambert 2017).

Atokan. A conodont-based Morrowan–Atokan boundary has variously been assigned to lie at the base, top, or within the *Neognathodus nataliae* Zone. When the base of the Atokan is identified on the appearance of the foraminifer *Eoschubertella* (Groves 1986), the boundary falls within this zone. *Idiognathodus* P_1 elements that Grayson *et al.* (1989) and Grayson *et al.* (1990) assigned to *I. incurvus* appear at or near the base of the Atokan. The *N. atokaensis* Zone of Grayson (1984) extends from the first occurrence of *N. atokaensis* upward to the first appearance of *N. colombiensis*, and represents the middle part of the Atokan. *Neognathodus uralicus* is a distinctive morphotype that is common in this zone in the southern Midcontinent.

The base of the *Neognathodus colombiensis* Zone is defined by the appearance of *N. colombiensis*, which is characterized by triangular morphotypes with a relatively flat, symmetrical upper surface. *Neognathodus colombiensis* occurs in the upper Atoka Formation in southeastern Oklahoma (based on Grayson 1984), the Riverton Shale in Missouri (Thompson & Lambert 2017), in the Seville Limestone in Illinois and in the upper Lead Creek Limestone beds in the southern Illinois Basin (Heckel *et al*. 2017). During the time represented by the *N. colombiensis* zone, *Declinognathodus* and *Idiognathoides* disappeared in North America.

Desmoinesian. The exact position of the Atokan–Desmoinesian boundary remains unresolved, but it has been commonly equated with the base of the *Fusulina* (*Beedeina*) Zone (e.g. Lambert & Heckel 1990; Wahlman 2013). However, until the base of the Desmoinesian is formally defined in a stratotype section, uncertainly about its exact level will remain. Barrick *et al.* (2004; 2013*a*) showed the *Neognathodus colombiensis* Zone as ranging from the uppermost Atokan into the lowermost Desmoinesian. Lowermost Desmoinesian *Neognathodus* faunas are characterized by morphotypes similar to the holotype of *N. bothrops* (symmetrical biconvex platform and long carina) and *N. colombiensis* (triangular platform), which are followed upward by the appearance of *N. caudatus*. Here we insert the *N. bothrops* Zone at the base of the Desmoinesian above the *N. colombiensis* and below the *N. caudatus* Zone. The first appearance of *N. bothrops* in Iowa is in the marine zone above the Blackoak Coal (Heckel & Witzke 2018) and occurs in the Seville, Perth, and Curlew limestones in the Illinois Basin (Heckel *et al.* 2017). The first occurrence of *N. bothrops* corresponds approximately with the first occurrence of *Beedeina* in New Mexico sections (Lucas *et al.* 2016).

The base of the next higher lower Desmoinesian *Neognathodus caudatus* Zone is defined by the first appearance of the nominate taxon in the McCurtain cyclothem in east-central Oklahoma, rather than in the Doneley cyclothem as shown in Barrick *et al.* (2013*a*). The McCurtain is not the local base of the Desmoinesian, which lies at the base of the underlying thick and widespread terrestrial Hartshorne Formation, which rests directly above the type Atokan Formation and which contains at least one cyclothemic coal zone below the McCurtain. The *N. caudatus* Zone has been recovered from the subsurface in the Illinois Basin (Heckel & Witzke 2018) and reported from the Hugoton Embayment of western Kansas (Youle *et al.* 1994), and the Lester Limestone in the Ardmore Basin of southern Oklahoma (Sutherland & Grayson 1992).

The *Neognathodus asymmetricus* Zone is defined by the occurrence of *N. asymmetricus*, which includes many early Desmoinesian forms incorrectly identified as either *N. medadultimus* or *N. medexultimus*. The carina on the P_1 element of *N. asymmetricus* is deflected near mid-length so that it lies next to, and parallel with, the rostral margin of the platform. *Neognathodus asymmetricus* appears in the Inola cyclothem and extends upward into the Fleming cyclothem on the northern Midcontinent Shelf, where it occurs with increasing numbers of other morphotypes. *Gondolella pulchra* occurs abundantly in the Upper Tiawah cyclothem from Oklahoma to Iowa. This unique *Gondolella* acme zone in the Upper Tiawah is an important marker horizon near the base of the middle Cherokee Group across the Midcontinent. In the Illinois Basin, *N. asymmetricus* first appears in the Holland Limestone of southwestern Indiana and the Creal Springs Limestone of southern Illinois (Heckel *et al.* 2017).

The *Neognathodus roundyi* Zone is defined by the occurrence of *N. roundyi*. Its first definite appearance is in the Verdigris cyclothem of the upper Cherokee Group and it ranges through the overlying Marmaton Group to near the top of the Desmoinesian. One distinctive Verdigris species, *N. intrala,* may be restricted to uppermost Cherokee strata (Stamm & Wardlaw 2003). The Verdigris cyclothem also contains the youngest non-crenulated gondolellid, *G. pohli*, which was named from the equivalent Oak Grove Member in Illinois.

Idiognathodus P_1 elements from basal Desmoinesian strata of the lower part of the *Neognathodus bothrops* Zone comprise slender, curved forms that have been assigned to *I. praeobliquus* (Boardman *et al.* 2004), *I.* cf. *praeobliquus* (Marshall 2010), or left in open nomenclature (*I.* sp. H of Lucas *et al*. 2016). The similar species*, I. amplificus* first appears higher, in the McCurtain and certainly by the Doneley cyclothem, where *I. obliquus* is present. Barrick *et al.* (2013*a*) indicated that the base of the *I. amplificus /I.obliquus* Zone corresponds with the base of the Desmoinesian, but the base of the zone may lie one or two cyclothems higher, at the McCurtain cyclothem.

The *Idiognathodus rectus*/*I. iowaensis* Zone encompasses the middle and upper Cherokee Group. The *I. iowaensis* Zone of Barrick *et al.* (2004) was identified in the middle and upper Cherokee Group by the presence of *I. iowaensis*. Barrick *et al*. (2013*a*) renamed this zone the *I. rectus*/*I. iowaensis* Zone, because they recognized that *I. rectus* and *I. attenuatus* dominate the faunas. *Idiognathodus* cf. *robustus*, *I. ignisitus*, and *I. crassadens* occur in this zone (Stamm & Wardlaw 2003). Most morphotypes in this zone are characterized by relatively coarser, more irregular and widely spaced transverse ridges, generally numbering up to seven on mature specimens, features that help to distinguish middle and upper Cherokee faunas from the lower Cherokee faunas. In the Illinois Basin, coarse-ribbed *I. rectus* and *I. attenuatus* dominate the Carrier Mills Shale where the *Gondolella pulchra* acme Zone appears in that region (Heckel *et al.* 2016).

Conodont faunas of the upper Desmoinesian Marmaton Group are zoned using species of idiognathodid genera. The *Idiognathodus delicatus* Zone of Barrick *et al.* (2004, 2013*a*) was interpreted to span the lower and middle Marmaton Group from the Lower Fort Scott through Coal City cyclothems, but *I. acutus* dominates the faunas in the Lower Fort Scott cyclothem and *I. delicatus* is not present (Nestell *et al.* 2016). The basal zone of the upper Desmoinesian should be the *I. acutus* Zone, which is defined by the appearance of *I. acutus* in the Excello Shale, and which is followed by the *I. delicatus* Zone. *Idiognathodus* morphotypes from the overlying Upper Fort Scott and Pawnee cyclothems, include a variety of forms and the presence of *I. delicatus*, once better defined, needs to be confirmed in these cyclothems. The Coal City cyclothem (Heckel *et al.* 2003) contains the type species of *Idiognathodus, I. claviformis* Gunnell 1931, and the holotype of *I. delicatus* Gunnell 1931. New collections suggest that *I. delicatus* may not be present above the Coal City cyclothem.

The *Swadelina neoshoensis* Zone of Barrick *et al.* (2004, 2013*a*) appears just above the Coal City cyclothem with the first appearance of *Sw. neoshoensis* in the Farlington cyclothem (Heckel 1999, 2002), and it includes the overlying Altamont cyclothem. This zone is now recognized in the base of the Farmington Shale just above the Danville Coal and in the overlying Piasa Limestone in the Illinois Basin. *Idiognathodus expansus* appears in the *Sw. neoshoensis* Zone. The *Sw. nodocarinata* Zone of Barrick *et al.* (2004, 2013*a*) is defined by the entry of *Sw. nodocarinata* in the Norfleet cyclothem, and includes the latest Desmoinesian Lost Branch cyclothem. This zone can be recognized in a thin shale associated with the Lonsdale Limestone of western Illinois and the middle West Franklin Limestone of southern and eastern Illinois (Heckel & Weibel 1991) and in the East Mountain Shale of north-central Texas (Boardman & Heckel 1989). This zone also contains the first appearance of *I. swadei*, which survived the extinction event that terminated the lineages of *Neognathodus*, *Swadelina*, and other idiognathodids at the disconformity above the Lost Branch cyclothem.

Gondolella attained its characteristic platform crenulation with the appearance of *G. wardlawi* in the Excello Shale of the Lower Fort Scott cyclothem at the base of the Marmaton Group. Although not found through most of the Marmaton Group, *Gondolella* reappears abundantly as the more ornately crenulate *G. magna*, along with the non-platformed *G*. cf. *G. denuda* in the Lost Branch cyclothem.

Heckel *et al.* (2002) redefined the base of the Missourian Stage to lie at the base of the Exline cyclothem, slightly above the traditional base of the Missourian at the disconformable base of the Pleasanton Group in Kansas and the Seminole Formation in Oklahoma. The latest Desmoinesian minor Checkerboard–South Mound cyclothem lies just above the terminal late Desmoinesian extinction event and only three species of *Idiognathodus* have been recovered: *I. swadei*, which survived the extinction event, and the first occurrences of *I. sulciferus* and *I. harkeyi*. This short interval was not designated as a formal zone by Barrick *et al.* (2004, 2013*a*), but was implicitly included in top of the *Swadelina nodocarinatus* Zone. Because it comprises a short distinctive lower diversity interval immediately after the extinction event, we designate it here as the latest Desmoinesian *I. sulciferus* Zone.

Missourian. The basal Missourian *Idiognathodus eccentricus* Zone is defined by the first appearance of *I. eccentricus* in the Exline cyclothem and extends up to the first appearance of *I. turbatus in* the Hertha cyclothem. *Idiognathodus eccentricus* differs from the older species *I.*

sulciferus in the development of an eccentric groove on the platform. *Idiognathodus heckeli* appears at the same level, which differs from its ancestral form *I swadei*, also through the development of an eccentric groove. The appearance of eccentric grooves is the first step in the morphological diversification of early Missourian *Idiognathodus* species (Rosscoe & Barrick 2009, 2013). The *Idiognathodus turbatus* Zone is defined by the first appearance of *I. turbatus*, which bears a long discontinuous medial carina, in the Hertha cyclothem and extends up to the first appearance of *I. cancellosus* in the Swope cyclothem. Species diversity begins to increase as more forms radiate in the *I. sulciferus* and *I. swadei* linages: *I. corrugatus, I. gemiformis,* and *I. vorax*. The *I. cancellosus* Zone is defined by the appearance of *I. cancellosus* in the Swope cyclothem and ranges up to the appearance of *I. confragus* in the Dennis cyclothem. A maximum in morphological diversity is attained in the Swope cyclothem, with species ranging up from the older cyclothems and with the appearance of *Idiognathodus* species with medial grooves (*I. clavatulus*), nodose platform surfaces (*I. papulatus*), and forms with a long medial carina and parapet-like platform margins (*I. cancellosus, I. biliratus*, *I. pseduocarinatus*), as well as the occurrence of the similar Eurasian species, *I. neverovensis*. Rosscoe & Barrick (2013) interpret the stepwise morphological radiation of *Idiognathodus* species from the *I. eccentricus* through the *I. cancellosus* zones to be a response to the increasingly widespread and deep flooding of the Northern Midcontinent during the early Missourian.

The *Idiognathodus confragus* Zone is defined by the appearance of *I. confragus* in the Dennis cyclothem and extends up to the appearance of *Streptognathodus gracilis* in the Hogshooter cyclothem. Many of the characteristic nodose and grooved species of the *I. cancellosus* Zone disappear at the top of that zone and the *I. confragus* Zone displays a reduced variety of morphological features. The more prominent species, *I. corrugatus, I. cherryvalensis,* and *I magnificus,* conform to a more conservative *Idiognathodus* morphology of a flat upper surface with continuous transverse ridges.

The *Streptognathodus gracilis* Zone is defined by the first appearance of the genus *Streptognathodus*, the most characteristic species of which are *St. gracilis*, *St. excelsus*, and *St. elegantulus*. The *St. gracilis* Zone ranges through six cyclothems, up to the first appearance of *Idiognathodus eudoraensis* in the Stanton cyclothem. Unlike the older Missourian *Idiognathodus* species, the *Streptognathodus* species possess a deep, clearly defined medial trough.

Idiognathodus magnificus is the most common *Idiognathodus* species. It differs from older *Idiognathodus* species in possessing asymmetrical P1 elements, as well as by the large caudal lobe (Hogancamp *et al.* 2017). It is difficult to distinguish individual cyclothems within the *St. gracilis* Zone. The Dewey cyclothem level is characterized by the acme of a robust *I. magnificus* fauna that has been recognized across the Midcontinent region (Barrick *et al.* 2013*a*) and westward into New Mexico (Hogancamp *et al*. 2017). Cyclothems above the Dewey cyclothem tend to have strongly *Streptognathodus*-dominated faunas.

The *Idiognathodus eudoraensis* Zone is defined by the appearance of *I. eudoraensis* in the core shale (Eudora Shale) of the Stanton cyclothem and extends up to the first appearance of *Streptognathodus zethus* in the Cass cyclothem. Species of the *St. gracilis* group disappear completely at the base of the Eudora Shale. The Eudora core shale fauna is dominated by at least five species of the *I. eudoraensis* group, all of which possess strongly asymmetrical platform pairs with a distinct eccentric groove (Hogancamp & Barrick 2018). Specimens of the *I. eudoraensis* group are rare above the Stanton cyclothem. The Eudora shale contains the highest level of platformed species of *Gondolella* in the Midcontinent. In the upper part of the Eudora Shale and especially in shallower water facies in New Mexico, *St. firmus* is the common form. This species possesses a biconvex platform outline and a carina that extends to the dorsal tip and is probably an immigrant from Eurasia (Barrick *et al*. 2000). In the overlying South Bend and Iatan cyclothems, the long carina of *St. firmus* rapidly shortens to form the species *St. pawhuskaensis*, a deeply troughed platform with simple margins and a short carina. In the Iatan cyclothem, some specimens of *St. pawhuskaensis* may bear one or a few simple nodes on the platform margins.

Virgilian. The base of the *Streptognathodus zethus* Zone is defined by the first appearance of *St. zethus* and the zone extends up to the first appearance of *Idiognathodus simulator* in the Oread cyclothem (Barrick *et al*. 2004, 2013*a*). *Streptognathodus firmus* and common *St. pawhuskaensis* range up into the Cass cyclothem where *St. zethus* appears. *Streptognathodus zethus* was derived from *St*. *pawhuskaensis* by the development of a prominent caudal lobe and a smaller rostral lobe.

The base of the *Idiognathodus simulator* Zone is defined by the first appearance of *I. simulator* in the Oread cyclothem and the zone ranges up to the first appearance of *Streptognathodus vitali*. *Idiognathodus simulator* is one species among a group of species, the *I. simulator* group, that possess strongly asymmetric P_1 elements with an eccentric groove (Hogancamp *et al.* 2016). The sudden appearance of the other four species of the *I. simulator* group in the Oread cyclothem and equivalent units in Midcontinent North America and their disappearance at the top of the cyclothem represent a major short-lived event in the conodont succession. Species of *I. tersus* group, which have more symmetrical, ungrooved P_1 elements (Hogancamp & Barrick 2016), appear in the upper part of the Oread cyclothem. *St. firmus*, and *St. pawhuskaensis* range through the zone and characterize the upper two cyclothems of the zone.

The base of the *Streptognathodus vitali* Zone is defined by the first appearance of *St. vtiali* in the Lecompton cyclothem and ranges up the first appearance of its descendent, *St. virgilicus*, in the overlying Avoca cyclothem. *Streptognathodus vitali* and the similar co-occurring species *St. ruzhencevi* differ from other *Streptognathodus* species in the possession of a carina with dorsal nodes that extends to the dorsal tip and a narrowly biconvex platform. The *St. vitali* Zone, which is restricted to the Lecompton cyclothem, contains the highest occurrence of *Idiognathodus* species (*I. tersus* group) and *Gondolella* species (*G. postdenuda*) in Midcontinent North America.

The *Streptognathodus virgilicus* Zone ranges from the first appearance of *St. virgilicus* through thirty cyclothems of all scales (13 intermediate and major; Boardman 1999) to the first appearance of *St. bellus* in the Brownville cyclothem. *Streptognathodus virgilicus* is similar to *S. vitali*, but differs in the shorter continuous carina, extending only one-half of the platform length. It occurs with the similar species, *St. pawhuskaensis*, but the platform of *St. virgilicus* is broader, with a V-shaped groove, and the transverse ridges are longer (Ritter 1995). The low species diversity of the *St. virgilicus* Zone makes subdivision difficult. *Streptognathodus holtensis,* which has a short lingulate platform, a shallow platform and long transverse ridges, appears to be restricted to the Topeka cyclothem (Ritter 1994, 1995).

The first appearance of *Streptognathodus bellus* defines the base of the *St. bellus zone,* which extends up to the first appearance of *St. flexuous* in the Five Point cyclothem. The appearance of *St. bellus* marks the start of the rapid diversification of *Streptognathodus* species at the cyclothem level in the latest Pennsylvanian and early Permian (Boardman *et al.* 2009). Older Virgilian *Streptognathodus* species disappear before the *St. bellus* Zone and *St. brownvillensis* appears at the base of the zone. The *St. flexuous Zone* is confined to the Five Point cyclothem, and the top of the zone is defined by the appearance of *St. farmeri* in the overlying Americus cyclothem. The *St. farmeri* Zone is defined by the first occurrence of *St. farmeri* and extends through two major cyclothems to the first appearance of *St. binodosus* in the Upper Hughes Creek cyclothem. The *St. binodosus* Zone is restricted to the Upper Hughes Creek cyclothem and its top is defined by the appearance of *St. isolatus* in the overlying Red Eagle cyclothem. The base of the Permian (Asselian Stage) is recognized by the appearance of *St. isolatus* (Chernykh *et al.* 1997).

Western North America Pennsylvanian

The Midcontinent Pennsylvanian conodont zonation relies heavily on faunas obtained from highstand core shales of mixed siliciclastic-carbonate cyclothems that are difficult to correlate to with many of the shallower, carbonate-dominated and often conodont-poor depositional cycles that characterize many sections in the western United States. Faunas in the western North America derive from one of three tectonostratigraphic settings, each with unique factors that controlled the occurrence of conodont faunas and the character of cyclic, conodont-bearing strata: 1) Ancestral Rocky Mountain (ARM) basins extending from New Mexico into Colorado and Utah (e.g. Kluth & Coney 1981; Leary *et al.* 2017); 2) strata deposited on the broad, west-facing Bird Spring-Ely-Snaky Canyon carbonate ramp that occupied the western interior (e.g. Ritter 1991; Ritter & Robinson 2006) and western Canada (e.g. Richards *et al.* 1994); and 3) deformed and eroded tectonostratigraphic units associated with the collisional western margin of Pangea (e.g. Jones *et al.*, 1981; Trexler *et al.* 2004; Zubin-Statopoulo *et al.* 2012).

ARM basins. The oldest Pennsylvanian conodont faunas from basins in New Mexico have been obtained from isolated samples from the base of the Gobbler Formation in the Sacramento Mountains (Lane 1974) and at the base of the Horquilla Formation in the Big Hatchet Mountains (Lucas *et al*. 2017), where *Rhachistognathus primus* is present. Later Morrowan and early Atokan faunas are poorly known. Middle to late Atokan conodonts (*Neognathodus atokaensis* to *N. colombiensis* zones) appear in the oldest marine beds of the Sandia Formation in northern New Mexico (Moore 2017), and in the Red House Formation in central New Mexico (Barrick *et al.* 2013*b*; Lucas *et al*. 2016), the Gobbler Formation (Lucas *et al.* 2020), and the Horquilla Formation (Lucas *et al*. 2017). Latest Atokan and early Desmoinesian conodont faunas become widespread with the dominance of carbonate strata across New Mexico (Gray Mesa Formation, Barrick *et al.* 2013*b*; Lucas *et al.* 2016; Porvenir Formation, Treat 2014), Horquilla Formation, Lucas *et al*. 2017). The New Mexico successions strongly support the utility of the Midcontinent early Desmoinesian zones, and a conodont-based level for the base of the Desmoinesian could be easily be placed in one of the New Mexico sections, possibly in the Mud Springs Mountains (Lucas *et al.* 2016). Tectonic events of the ARM interrupt the cyclothemic pattern of the Middle and Late Pennsylvanian Midcontinent zonation, but many zones can be reproduced in different mountain ranges. Late Desmoinesian conodont faunas are poorly known. The most widely distributed late Desmoinesian conodont zone is the *Swadelina neoshoeneis* Zone, which occurs from southwestern New Mexico (Hoquillla Formation) as far north as the Manzanita Mountains near Albuquerque (Bartolino Member; Atrasado Formation) and in the Las Vegas region (Porvenir Formation) and eastward to the Sacramento Mountains (Gobbler Formation, Lucas *et al.* 2020).

The oldest widespread Missourian conodont interval is the *Idiognathodus cancellosus* Zone, which occurs in the widely distributed Amado Limestone Member of the Atrasado

Formation (Lucas *et al.* 2009, 2016), a similar thin limestone at the top of the Gobbler Formation (Lucas *et al.* 2020), and in the Horquilla Formation to the southwest. Diverse younger Missourian and Midcontinent conodont faunas are less widely distributed, but have been identified in one or more mountain ranges. Where present, the faunas can be assigned to the Midcontinent zones (e.g. Barrick *et al*. 2013*b*; Lucas *et al.* 2020), but when studied in detail are shown differ to some degree in the common morphotypes present (Hogancamp *et al.* 2017; Hogancamp & Barrick 2018). Latest Virgilian to earliest Asselian (Permian) conodont faunas occur in the Horquilla Formation (Lucas *et al.* 2017), the Sacramento Mountains (Frederick *et al*. 2018), and at Carrizo Arroyo in central New Mexico (Lucas *et al.* 2009).

The Hermosa Group in SE Utah and western Colorado was deposited in the northwest-southeast oriented Paradox Basin during Pennsylvanian time. Stacked depositional sequences accumulated in three parallel facies belts: the northeastern clastic wedge derived from the Uncompaghre uplift, the basin center evaporite belt, and southwestern carbonate ramp. The latter is exposed on the steep walls of the San Juan River in southeastern Utah and is characterized by asymmetrical, carbonate-dominated shallowing upward cycles that compose the Desmoinesian through early Virgilian Paradox and Honaker Trail formations. Ritter *et al.* (2002, fig. 1) subdivided these strata into a succession of 12 contiguous zones composed of one or a few low-order depositional cycles. These are (in ascending order) the *Idiognathodus obliquus*, *I*. n. sp A, *I*. n. sp. B, *I*. n. sp. C, *I. expansus*, *Swadelina neoshoensis*, *Sw. nodocarinata, I. eccentricus, Streptognathodus cancellosus, St. confragus, St. gracilis*, and *St. firmus* zones. The *I. obliquus* Zone is early Desmoinesian in age and correlates with the *I. amplificus/I. obliquus* Zone of the Midcontinent zonation. Additional work is needed to clarify the species composition of the *I*. sp. A through *I* sp. C zones before they can be correlated to the Midcontinent zonation. Selected cycles composing the *I. expansus* through *St. firmus* zones were correlated by Ritter *et al.* (2002) to coeval cyclothems of the *I. delicatus* through *I. eudoraensis* zones of the Midcontinent succession.

Western carbonate ramps: During the Pennsylvanian, a west-facing carbonate ramp extended from southern Nevada through western Utah and into eastern Idaho, bounded on the east by ARM uplifts and on the west by the Antler-Sonoma flysch trough. Cyclic carbonates deposited on this ramp include the Keeler Canyon, Bird Springs, Ely, and Snaky Canyon lithostratigraphic units. Morrowan through early Atokan strata were zoned by several workers focused on locating and defining the Mid-Carboniferous boundary (e.g. Webster 1969; Davis & Webster 1985; Morrow & Webster 1991). The most comprehensive Morrowan through lower Atokan zonation was developed in southern Nevada, now the site of the Mid-Carboniferous Global Section Stratotype and Point, by Baesemann & Lane (1985), Lane *et al.* (1999), and Lane *et al.* (2019). The *Declinognathus noduliferus* through *Idiognathoides convexus* zones of these authors mirror those of the Midcontinent zonation. Post-Atokan Pennsylvanian condont faunas from the Ely Limestone were described in the context of depositional sequences by Ritter & Robinson (2009), but Desmoinesian through Virgilian faunas were not divided into zones.

An informal zonation for the deep-water Keeler Canyon Formation was developed by Stevens *et al.* (2001). Desmoinesian through Virgilian strata were subdivided into seven zones, designated C1 through C7. C1 was correlated with the Desmoinesian *Idiognathodus amplificus/I. obliquus* through *I. expansus* zones, C2 with the upper Desmoineisan *Swadelina nodocarinatus* Zone, C3 with the lower Missourian *I. eccentricus* Zone, C4 with the middle Missourian *I. cancellosus* and *I. confragus* zones, C5 with the upper Missourian *Streptognathodus gracilis* and *St. firmus* (now *I. eudoraensis*) zones, C6 with the lower Virgilian zones characterized by the presence of trough-bearing *St. pawhuskaensis* and *St. virgilicus*, and C7 characterized by the presence of nodose upper Virgilian forms assigned to *St. wabaunsensis*.

In the Western Canada Sedimentary Basin, the Pennsylvanian Subsystem is incomplete, both regionally and stratigraphically (Higgins *et al.* 1991; Richards *et al.* 1994), and has been grouped into tectostratigraphic sequences (e.g. Zubin-Stathipoulos *et al*. 2012). The Mid-Carboniferous boundary is represented by a regional unconformity. The Pennsylvanian Spray Lakes Group is composed of the Tyrwhitt, Storelk, Tobermory, and Kananaskis formations. The Tyrwhitt/Storelk formations are assigned to the *Rhachistognathus websteri to Rh. minutus* zones (Henderson *et al.* 1994, figure 15.2; Zubin-Stathipoulos *et al*. 2012). The Tobermory and lower Kananaskis formations range from the Atokan through the Desmoisesian (*Declinognathodus. marginodosus* to *Neognathodus roundyi* zones). The upper Kananaskis is Missourian in age (*Streptognathodus oppletus* and *St. elegantulus* zones). The Tyalor and Belcourt formations in eastern British Colombia and the pericratonic Kootneay terrane in British Colombia contain similar tectnostratigraphic and conodont successions (Zubin-Stathipoulos *et al.* 2012)

Western and northern margins of North America. Western British Colombia and Alaska comprise a complex series of Paleozoic terranes that originated away from Pangea and were later fused with it during Mesozoic orogenic events (e.g. Torsvik & Cocks 2017). Orchard (1984) and Orchard *et al.* (2001) reported four conodont faunal intervals from the Cache Creek terrane in southern British Colombia oldest three of which are Early to Middle Pennsylvanian in age and the fourth is Late Pennsylvanian. Many of the Midcontinent conodont zones can be identified in the

Cache Creek faunas (Golding & Orchard 2019). Orchard & Struik (1985) recovered Middle to Late Pennsylvanian conodonts from the Alex Alan Formation in the Caribbo terrane in central British Colombia. Middle Pennsylvanian conodonts occur in the upper part of the Sicker Group in the Wrangellia terrane on Vancouver Island (Brandon *et al.* 1986). Pennsylvanian conodonts have been recovered from cherts in the Slide Mountain terrane in central British Colombia (Orchard 1986). Sparse Early and Middle Pennsylvanian conodonts have been reported from the Alexander terrane in southeastern Alaska (Savage & Barkeley 1985; Frederick & Barrick 2018).

Morrowan through lowest Atokan zones were reported from the Wahoo Limestone Member of the Lisburne Group in northeastern Alaska (Arctic-Alaska terrane) by Krumhardt *et al.* (1996). The base of the Pennsylvanian System was located 56 meters above the base of the Wahoo Limestone, overlain by the 28 m-thick *Declinognathodus noduliferus–Rhachistognathus. primus* Zone. The overlying 206 meters were subdivided into two stratigraphic intervals that they referred to as the *Rh. minutus* and the *Idiognathodus* faunas. Krumhardt *et al.* (1996) drew broad equivalence between the Alaskan *Rh. minutus* fauna and the *Rh. minutus–Idiognathoides sinuatus*, *Neognathodus symmetricus*, and *N. bassleri* zones. Similarly, they suggested correlation of their *Idiognathodus* fauna with the *I. sinuosus*, *I. klapperi*, *Id. convexus*, and *Id. ouachitensis* zones of the Midcontinent. Middle Atokan through Virgilian strata are absent in the region.

In northern Pangaea, the Sverdrup Basin in Arctic Canada has yielded Middle to Late Pennsylvanian conodonts. Bender (1980) described faunas dominated by *Idiognathoides* species from Axel Heiberg and Ellesmere islands that now appear to be Atokan in age when compared with the Midcontinent zonation. In the same area, Henderson *et al.* (1995) recognized faunas of Desmoinesian (*Neognathodus* spp. Zone), Missourian (*Streptognathodus* zones), and Virgilian (*I. simulator* Zone) ages.

Western Europe

The Mississippian conodont zonation for Western Europe was developed from the southern margin of Laurentia and from the terranes accreted to it, such as the British Isles (Rhodes *et al*. 1969; Higgins 1975; Metcalfe 1981; Varker & Sevastopulo; 1985), the Rhenish Mountains (Bischoff 1957; Voges 1959, 1960; Meischner 1970), and the Belgian Namur-Dinant basin (Groessens 1976). These areas include marginal marine sequences where Mississippian zonal schemes were based on shallow-water conodont faunas, although some deep-water conodont faunas were also included (Varker & Sevastopulo 1985; Somerville 2008). More recently, studies have focused in the Moravia-Silesian Basin and areas adjacent to the margin of the East European Platform (Bełka 1985; Kalvoda *et al*. 2002; Matyja 2008).

The German Mississippian zonation described by Voges (1959) and Meischner (1970) was based on deeper water conodont faunas. Sandberg *et al.* (1978) and Lane *et al.* (1980) integrated the German zonation with information from North America and Spain into a proposed worldwide standard scheme. This zonation was applied to the German and Polish conodont sequences, and in the peri-Gondwanan areas for the Mississippian Subsystem, such as Pyrenees, Cantabrian Mountains, Betics, Montagne Noire, Alps, Sardinia, and the Balkan Peninsula (Perret 1993; Schönlaub & Kreutzer 1993; Perret & Delvolve 1995; Perri & Spalletta, 1998; Sanz-López & Blanco-Ferrera 2012*a*; Sudar *et al*. 2018), which include terranes that were being added to northern Europe during closure of the Rheic Ocean and tectonic shortening of the Variscan Orogeny. Deep water conodont zonations based on *Siphonodella*, *Gnathodus* and *Lochriea* species maybe correlated with platform settings in the British Isles and the Namur-Dinant Basin and with other local zonations, based on *Polygnathus*/*Pseudopolygnathus*, *Mestognathus* and *Cavusgnathus* faunas (Fig. 4).

For the Pennsylvanian, a well established lower Bashkirian zonation, derived mainly from the British Islands and Ireland, contrasts with the poorly developed conodont faunas in the deltaic to continental environments of the Westphalian and Stephanian successions of other parts of Europe.

Mississippian

Tournaisian. The conodont zones for the lower-middle Tournaisian were based on the phylogeny of deep-water species of *Siphonodella* (Sandberg *et al.* 1978). It was accepted as the standard zonation for deep-water settings and applied in the southern European sections of the Montagne Noire, Cantabrian Mountains, Pyrenees, Sardinia, Carnic Alps, as well as in the Rhenish Mountains, the Czech Moravian Karst, the Polish Sudetes and Pomerania Basin (Perret 1993; Korn *et al*. 1994; Dzik 1997; Sanz-López *et al.* 1999; Matyja *et al*. 2000; Kaiser *et al*. 2008, 2009; Malec 2014; Kalvoda *el at*. 2015; Mossoni *et al.* 2015). The basal zones of the *Siphonodella* zonation were revised in Becker *et al.* (2016). The correlation of the Devonian/Carboniferous boundary is under discussion, and two datums have been proposed, the first occurrence of *Protognathodus kockeli* or that of *Pr. kuehni* in a section yet to be selected (Corradini *et al*. 2017; Spalletta *et al*. 2017; Aretz & Task Group 2019). The oldest traditional Carboniferous conodont zone, the *Siphonodella sulcata* Zone, corresponds to the revised *S.*

(*Eosiphonodella*) *sulcata-Pr. kuehni* Zone (Becker *et al*. 2016), the lower boundary of which is defined by the FAD of these two species. The Lower *S. duplicata* Zone of Sandberg *et al*. (1978) was divided into two zones, a lower *S.* (*Eo.*) *bransoni* Zone and an upper *S.* (*S.*) *duplicata* Zone. The original Upper *S. duplicata* Zone was revised as the *S.* (*S.*) *jii* Zone. The *S. sandbergi* Zone was subdivided into two zones, the lower *S.* (*S.*) *sandbergi* Zone and the upper *S.* (*S.*) *quadruplicata* Zone. The succeeding traditional *S. crenulata* Zone was retained. Kaiser *et al*. (2017) described additional unornamented species of *Siphonodella* (*S. belkai* and *S. kalvodai*) from Germany and the Czech Republic that support correlation with East European Platform and the South Urals.

In carbonate shelf facies, lower Tournaisian strata with siphonodellids correspond to the *Siphonodella* Acrozone of the Dinant-Namur Basin and Ireland (Groessens 1976), or to the *Polygnathus spicatus* and the *P. inornatus*-*Siphonodella* Assemblage zones in the British Isles (Varker & Sevastopulo 1985; Sevastopulo & Wyse Jackson 2009). The *P. spicatus Zone* is approximately equivalent to the *Patrognathus variabilis-Bispathodus plumulus* of Austin & Hill (1973), where *Clydagnathus gilwernensis* and *Cl. unicornis* occur. The first occurrence of *Gnathodus delicatus* close to that of *Gn. punctatus*, and the first occurrence of *Pseudopolygnathus multistriatus* were locally reported in the upper part of the *Siphonodella* Zone in Belgium (*Gnathodus* Subzone of Groessens 1976) and used by Bełka (1985) in the Moravia-Silesia Basin. The *Ps. multistriatus* Lineage Zone was defined for Ireland by the first occurrence of the eponymous taxon. This species evolved into *Polygnathus mehli*, the marker index of the overlying *P. mehli* Zone (Johnston & Higgins 1981; Sevastopulo & Nudds 1987).

The upper Tournaisian (Ivorian Substage) was subdivided into the *Polygnathus communis carinus* and the *Scaliognathus anchoralis* zones by Groessens (1976) and applied in southern Laurentia (British Isles and Namur-Dinant Basin). The first zone is nearly equivalent to the Lower and Upper *typicus* of the standard zonation of Lane *et al.* (1980). The *P. c. carinus* Zone was subdivided into the *Dollymae hassi*, *Eotaphrus* cf. *bultyncki*, *E. bultyncki* and *Dol. bouckaerti* subzones. The two first subzones are approximately equivalent to the *Prioniodina oweni* Subzone in the British Isles and Ireland (Varker & Sevastopulo 1985). The uppermost beds of the *Pri. oweni* Subzone were correlated with the beds assigned to the *P. mehli* Zone in Ireland (Sevastopulo & Nudds 1987). The subzones of the *Ne. c. carinus* Zone were also recognized locally in the margin of some South European basins, such as the Pyrenees and the Cantabrian Mountains (Menéndez-Álvarez 1991; Perret 1993). The *Gnathodus delicatus* Zone of Bełka (1985) in the Polish Moravia-Silesian Basin ranged from the first occurrence of *Gn. delicatus*, but includes occurrences of *Gn. punctatus*, *Gn. typicus*, *Protognathodus praedelicatus*, *Mestognathus* *groessensi*, *E.* cf. *bultyncki*, and *Ps. multistriatus*. The *Gn. cuneiformis* Zone ranged from the first occurrence of *Gn. cuneiformis* to that of *Scaliognathus anchoralis europensis* or *Doliognathus latus*. *Dolymae bouckaerti*, *Sc. praeanchoralis*, *Pr. cordiformis*, *Pseudopolygnathus oxypageus*, *Ps. pinnatus*, and *M. groessensi* are present, and may be correlated with the Upper *Gn. typicus* Zone of Lane *et al*. (1980).

The *Scaliognathus anchoralis-Doliognathus latus* Zone of Lane *et al.* (1980) replaced the *Sc. anchoralis* Zone proposed by Bischoff (1957). It was subdivided into the *Do. latus*, *Eothaphrus burlingtonensi*s, and *Sc. anchoralis* subzones in Belgium by Groessens (1976). In the British Isles, the third subzone was renamed as the *Sc. anchoralis-Polygnathus bischoffi* Zone (Varker & Sevastopulo 1985). Riley (1993) differentiated a fourth subzone, the *Mestognathus praebeckmanni* Zone. However, this latter subzone seems to correspond to local range of *M. praebeckamnni*, because this species ranges into beds of the Upper *Gn. typicus* Zone in other basins according to von Bitter *et al.* (1986). *Eotaphrus burlingtonensis* and *P. bischoffi* were reported also from Poland (Bełka 1985).

Viséan. Austin (1974) defined Viséan zones for the northern part of Western Europe that were updated later by Somerville (2008). The lower Viséan corresponds to the *Pseudognathodus homopunctatus-Mestognathus beckmanni* Zone of Austin (1974) that Metcalfe (1981) used as a local range zone in the Craven Lowlands (North England), and later was applied by Varker & Sevastopulo (1985). The *Pd. homopunctatus* Zone has been recognized in deep-water carbonate facies of Alps, the Pyrenees and Cantabrian Mountains (Perret & Weyant 1994; Perri & Spalletta 1998; Sanz-López & Blanco-Ferrera 2018). *Pseudognathodus homopunctatus* first occurs in beds included in the *Sc. anchoralis* Zone in Poland (after Bełka 1985) and in the *Gnathodus texanus* Zone in the Rhenish Mountains (Park 1983). The first occurrence of *M. beckmanni* is often used when *Pd. homopunctatus* is absent. The lower boundary of the Viséan is located between the first appearance of *M. beckmanni* and that of *Pd. homopunctatus* in China, Belgium and Rhenish Mountains. In the absence of both species, the first occurrence of *Taphrognathus varians* above *P. bischoffi* and the first occurrence of *M. beckmanni*, may serve as the datum close to the base of the Viséan. This event defines the *Taphrognathus* Zone in Cumbria and the Northumberland Trough (northern England) according to Higgins &Varker (1982) and Armstrong & Purnell (1987), or the *T. varians* Zone (Purnell 1992). *Taphrognathus varians* does occur in Ireland with *M. beckmanni* (Varker & Sevastopulo 1987), indicating proximity to the base of the Viséan.

Austin (1974) proposed the *Lochriea commutata* Zone for the Viséan in Western Europe. It was subsequently identified in the United Kingdom (Metcalfe 1981; Riley 1993; Somerville

2008) and the northwest Serbia (Sudar *et al*. 2018). However, a detailed study is necessary to verify the occurrences of the earliest *Lochriea* species, *L. saharae*, which is usually included in the range of variation of *L. commutata*, such as the specimens illustrated by Stone (1991) from Arundian beds. Alternatively, other zonal schemes used the first occurrence of *Gnathodus praebilineatus*, first in the Cantabrian Mountains (Menéndez-Álvarez 1991; García-López & Sanz-López 2002), and later recognized in the Rhenish Mountains (Meischner & Nemyrovska 1999), Pyrenees (Sanz-López 2002). It correlates with the *Gn. austini* Zone of Bełka (1985) in Poland where *Gn. praebilineatus* was first described. It is not equivalent to the *Gnathodus* sp. A Zone defined by Ebner (1977) in the Alps, because many of specimens included in this species correspond to *Gn. joseramoni* according to Sanz-López *et al.* (2004).

The *Gnathodus bilineatus* Zone was first defined in the Rhenish Mountains by Voges (1959), and later recognized by Higgins & Bouckaert (1968) in the Namur-Dinant Basin. Rhodes *et al*. (1969) recognized this zone in beds from the upper Asbian to the lower Brigantian in the British Isles. Later, Meischner & Nemyrovska (1999) recommended that the base of the *Gn. bilineatus* Zone begin at the first occurrence of *Gn. bilineatus romulus* in the uppermost *Entogonites nasutus* Ammonoid Zone. In contrast, Korn (2008) differentiated the *Gn. b. romulus* Zone, below the *Gn. bilineatus* Zone in the Rhenish Mountains. Sanz-López & Blanco-Ferrera (2012*a*) recognized the *Gn. romulus* Zone below the *Gn. bilineatus* Zone in the Cantabrian Mountains. A revision of the *Gn. bilineatus* group is necessary to better resolve the different sub- or species in the lineage of *Gn. bilineatus* and update the biostratigraphy of Asbian or equivalent rocks in European basins.

The *Lochriea nodosa* Zone was first defined as the *Gnathodus bilineatus-L. nodosa* Zone by van Adrichem Boogaert (1967) in the Cantabrian Mountains, and Higgins & Bouckaert (1968) in the late Viséan of the Namur-Dinant Basin. Rhodes *et al.* (1969) established the *L. mononodosa* Assemblage Zone in England, which Austin (1974) revised to *L. nodosa* Zone, based on the close first occurrences of both species. It has been widely used in different parts of Europe (Skompski *et al.* 1995; Sudar *et al.* 2018).

Skompski *et al.* (1995) recognized the *Lochriea ziegleri* Zone in the upper part of the older *L. nodosa* Zone. The *L. multinodosa* Zone was differentiated by Higgins (in Higgins & Wagner-Gentis 1982) in the Cantabrian Mountains. It is common in southern Europe and rare in northern Europe. The first appearance of *L. multinodosa* is close to that of *L. ziegleri*, or just below it, but occurrences of *L. multinodosa* seem to be sporadic in many basins, and its potential for correlation must be proved. The *Gn. girtyi collinsoni* Zone is in part equivalent to the *L. ziegleri*

Zone in the British Isles, where species of the *Gn. girtyi* group are used to define biostratigraphic units.

Serpukhovian. The *Kladognathus-Gnathodus girtyi simplex* Zone was differentiated in the Pendleian Substage (lower Namurian), although the specimens illustrated as *Gn. g. simplex* are different than typical forms from North America. It is a very rare taxon and is not usable for correlation. *Cavugnathus naviculus* occurs in beds with Pendleian (Namurian) foraminifers in the Guadiato area (South Spain) according to Medina-Varea *et al.* (2005). However, *C. naviculus* was reported from the Brigantian *Gn. girtyi collinsoni* Zone in the British Isles and Belgium (Higgins & Bouckaert 1968; Higgins 1985). It seems to occur in shallow-water settings equivalent to the deep-water beds of the *L. ziegleri* Zone. However, the lowermost occurrence of *C. naviculus* is known in the *Gn. bilineatus* Zone in Ireland (Somerville & Somerville 1999; Barham *et al.* 2015). Skompski (1996) recovered conodonts from thin limestones in deep boreholes that pierced the upper Viséan to lower Westphalian succession in the northeastern part of the Lublin Basin and the eastern border of Poland. He recognized the *L. nodosa* Zone, including beds with *C. naviculus* in the upper part. Above, Skompski (1996) defined a *L. cruciformis* Zone that included the first occurrences of *L. ziegleri* and *L. senckenbergica*. These occurrences of species of *Lochriea* are younger than in other basins, because these conodonts occur with upper Serpukhovian ammonoids.

The *Gnathodus bollandensis-C. naviculus* Zone was defined from Arnsbergian beds (upper Serpukhovian) in northern England (Higgins 1975). Meischner (1970) had defined previously the *Gn. bilineatus schmidti nomen nudum* (= *Gn. bollandensis*) Zone for the upper Serpukhovian in Germany. Later, Ebner (1977) and Higgins (1985) renamed it as the *Gn. bollandensis* Zone in the Alps and the British Isles. The zone was recognized in the Tramaka Limestone in the Namur-Dinant Basin, where it includes specimens of *Adetognathus unicornis* (Groessens 1983). In the Cantabrian Mountains, Sanz-López *et al.* (2007) found many of the identifications of *Gn. bollandensis* questionable, and defined the *Gn. truyolsi* Zone. The latter zone was correlated with middle-upper Arnsbergian based on ammonoids, and seems to correspond to the *Gn. bilineatus bollandensis* beds described by Ebner (1977) from the Alps.

The *Gnathodus postbilineatus Zone* was recognized in the upper Arnsbergian of the Cantabrian Mountains (Nemyrovska *et al*. 2011; Sanz-López *et al.* 2013) and West Ireland (Fallon & Murray 2015). The index species was reported in the upper Arnsbergian in the British Islands, E2c3 and E2c4 ammonoid horizons (Riley *et al*. 1987, 1994; Varker *et al*. 1990; Varker 1994). The lowest occurrence of *Declinognathodus bernesgae* is indicative of the *Dec. bernesgae*

Zone in the uppermost Serpukhovian of the Cantabrian Mountains (Sanz-López *et al*. 2006). The uppermost beds assigned to this zone also yielded *Dec. tuberculosus* and *Rhachistognathus minutus*.

Pennsylvanian

Bashkirian. The base of the Bashkirian was correlated with the lower boundary of the *Declinognathodus inaequalis* Zone in the Cantabrian Mountains (Sanz-López *et al*. 2006, 2013; Sanz-López & Blanco-Ferrera 2013). A strong correlation was also established with the base of the Bashkirian in the English Stonehead Beck section (H1a2 ammonoid Horizon) where the first occurrence of *Dec. inaequalis* occurs in the range of *Rhachistognathus minutus,* at the lower boundary of the *Dec. noduliferus-Dec. lateralis* Zone (Higgins 1975). The lowermost beds of this zone, without *Dec. inaequalis,* were excluded from the *Dec. noduliferus* Zone as defined by Higgins (1985; upper *Gnathodus b. bollandensis* or *Rh. minutus* Subzone). The *Dec. noduliferus-Dec. lateralis* Zone ranges through the greater part of the Chokierian and Alportian Substages in the Dinant-Namur Basin and the British Isles (Higgins & Bouchkaert 1968). Sanz-López & Blanco-Ferrera (2013) differentiated the *Dec. lateralis* Zone, from the first occurrence of the eponymous taxon, in the Cantabrian Mountains. In other instances, the first occurrence of any one of these *Declinognathodus* species has been used for the correlation of the *Dec. noduliferus sensu lato* Zone in the Cantabrian Mountains (Menéndez-Álvarez 1991; Nemyrovska *et al.* 2011) and the Pyrenees (Perret 1993; Sanz-López & Blanco-Ferrera 2012*b*). Meischner (1970) differentiated the lower *Gnathodus tricarinatus deflectens* Zone in the Rhenish Mountains based on species that were never formally described. The specimens of *Gn. tricarinatus* correspond to several species of the *Dec. noduliferus* group and some of *Neognathodus*.

The *Idiognathoides corrugatus-Id. sulcatus* Zone was first proposed by Higgins (1975, 1985) to represent the R1 ammonoid Zone (Kinderscoutian Substage) of Britain and is based on the first occurrence of *Id. corrugatus*. The zone is recognized by the occurrence of *Id. macer*, *Id. sinuatus, Lochriea glaber* and *Neognathodus symmetricus* in the Pyrenees (Marks & Wensink 1970; Perret 1993; Sanz-López & Blanco-Ferrera 2012), the Catalonian Coastal Ranges (Sanz-López *et al.* 2000), Ireland (Fallon & Murray 2015), and the Alps (Ebner 1977). *Neognathodus symmetricus* occurs in beds with reticuloceratid ammonoids in the Pyrenees and the British Isles (part of *N. bassleri* Zone in Higgins 1975), apparently older than the occurrence of this species in North America (Sanz-López *et al.* 2013). An older occurrence for *Id. corrugatus* together with *Id. asiaticus* was reported from the Cantabrian Mountains (Chokierian) and correlated with the oldest ranges of these species in the South Urals (Nemyrovska *et al*. 2011; Sanz-López *et al.* 2013). The zone corresponds to the upper *Gn. tricarinatus deflectens* Zone of Meischner (1970) characterized by species of *Idiognathoides* grouped as *Gnathodus dioskuroi nomen nudum.*

The *Idiognathoides sinuatus-Idiognathodus primulus* Zone was defined for the Marsdenian Substage to the lower Langsettian Stage (ex Westphalian A) Regional Stage, *Reticuloceras superbilingue* Ammonoid Zone. *Id. sinuatus* is the left element of several species, among them *Id. corrugatus*, and its biostratigraphic range is too broadly defined. *Idiognathoides attenuatus* has its first occurrence in this zone in Britain and the Namur-Dinant Basin (Higgins & Bouckaert 1968), but it occurred with conodonts of the *Id. corrugatus* Zone in the Pyrenees (Sanz-López & Blanco-Ferrera 2012*b*). There, probable fragments of *I. primulus* (*Idiognathodus* sp.) were correlated with the Marsdenian.

The *Idiognathoides sulcatus parvus* Zone of Higgins (1975) was defined for beds of the *Gastrioceras listeri* Horizon (Langsettian) in the British Isles and described form the Dinant-Namur Basin (Higgins & Bouckaert 1968). It was recognized in the Pyrenees by Perret (1993), although in older beds containing Kinderscoutian ammonoids. These occurrences should be confirmed, because samples yielded only few specimens of small size.

Meischner (1970) defined the upper boundary of the *Gnathodus tricarinatus deflectens* Zone by the first occurrence of *Gn. fiebigi nomen nudum* in the lower part of the *Gastrioceras subcrenatum* ammonoid Zone (basal Langsettian) in the Rhenish Mountains. Some specimens of *Gn. fiebigi* are similar to the mid-Bashkirian species *Idiognathodus sinuosus*. *Idiognathoides corrugatus* and “*Streptognathodus*” sp. are common in the *Katharina* marine Band (basal Duckmantian).

The Bashkirian of the Lublin Basin in Poland was not zoned, but the species characteristic for the lower Bashkirian to the Langsettian were present in the Bands M-S of the Demblin and Lublin formations (Skomspki 1996): *Declinognathodus inaequalis, Idiognathoides sinuatus, Id. lanei, Neognathodus symmetricus, Idiognathodus sinuosus* and *Id. tuberculatus*.

In the Cantabrian Mountains, Park (1983) included some beds of the carbonate platform in his *Idiognathodus delicatus* Zone. A revision of these occurrences of *I. delicatus* is neccesary, because it included several species. Besides *Idiognathodus*, they yielded upper Bashkirian "*Streptognathodus" suberectus* and "*St." expansus*. Later, Menéndez-Álvarez (1991) restricted this zone for the beds between the first occurrence of *Idiognathodus* and that of *Id. parvus*. In this interval, van den Boogaard & Bless (1985) described the occurrence of *Diplognathodus coloradoensis*, *D. orphanus* and *I. delicatus*, indicating that it should be correlated with the upper Bashkirian.The *Idiognathoides parvus* Zone of Menéndez-Álvarez (1991) included the presence of *St. suberectus* and *Id. tuberculatu*s in the carbonate platform facies of the Valdeteja Formation. However, rare specimens of *Id. tuberculatus* were recovered from the *Id. corrugatus-Id. sulcatus* Zone in the Pyrenees (Sanz-López & Blanco-Ferrera 2012*b*). One fauna from siliciclastic basin facies in the Pyrenees yielded upper Bashkirian *St. suberectus* and *Id. tuberculatus* (Sanz-López & Blanco-Ferrera 2012*b*). Upper Bashkirian beds with *I. incurvus* and different morphotypes of *Neognathodus* and *Declinognathodus marginodosus* and upper Bashkirian-lower Moscovian *I. incurvus* were reported from the Cantabrian Mountains (Blanco-Ferrera *et al.* 2005, 2009).

Moscovian. The Bashkirian–Moscovian boundary was correlated on basis of the occurrence of *Declinognathodus donetzianus* above *Dec. marginodosus*, *Idiognathoides postsulcatus* and *Neognathodus atokaensis* in carbonate platform facies of the Cantabrian Mountains (Blanco-Ferrera *et al.* 2009; Méndez 2012). *Diplognathodus ellesmerensis* was illustrated by van den Boogaard (1983). Some associations close to the base of the Bolsovian European Stage (correlated with the base of the Moscovian) were studied from the Aegiranum Band in the Bristish Isles, Belgium, the Netherlands and Germany subsurface. The associations illustrated by van den Boogaard (1983), van den Boogaard & Bless (1985), and Riley *et al.* (1985) include *Dec. donetzianus*, *I. aljutovensis*, *Id. ouachitensis*, *Id. tuberculatus*, *D. coloradoensis* and *D. orphanus*.

Moscovian beds of the Picos de Europa Formation in the Cantabrian Mountains yielded *Mesogondolella clarki*, *Gondolella laevis*, *G. pohli*, *G. magna*, *Idiognathodus incurvus*, and *I. podolskensis* (Méndez *et al*. 1998; Méndez 2002, 2012; Blanco-Ferrera & García-López 2005). Beds correlated with the upper Moscovian (Myachkhovian) to lower Kasimovian (Krevyakinian according Villa *et al*. 2009) yielded *Idiognathodus expansus*, *I. covadongae*, *I. harkeyi*, *I. sulciferus*, and *I. neverovensis* (Méndez 2006; Sanz-López *et al.* 2018).

Kasimovian. Beds of the Picos de Europa Formation (Cantabrian Mountains) correlated with the upper Moscovian (Myachkovian) yielded *Idiognathodus expansus*, *I. covadongae*, *I.* sp. D, together with late species of *Gondolella* (Méndez 2006; Sanz-López *et al.* 2018). However, these beds could correspond to the lower Kasimovian (Krevyakinian Substage). Younger beds yielded *I. harkeyi*, *I. sulciferus*, and *I. neverovensis*. Higher beds with *I. eccentricus*, *I. harkeyi*, *I. sulciferus*, *I. neverovensis*, *Idiognathodus* sp. 1 Goreva and *I. sagittalis* were correlated with the Khamovnikian (Méndez 2006; Villa *et al.* 2009b; Sanz-López *et al*. 2018). Forke *et al.* (2001) described some Kasimovian species from the Carnic Alps, among them *Swadelina makhlinae*, *I. toretzianus* and *I. neverovensis*.

Ukraine, Donets Basin

The study of the Carboniferous conodonts in Ukraine dates back to the 1970s, the most significant publication of which is Kossitzkaya *et al.* (1978) on the Donets Basin. The Carboniferous conodont zones were established mostly in the Donets Basin. Many of the zones can also be recognized in the Dnieper-Donets Depression and some of them, mostly upper Mississippian, in the L'viv-Volhyn Basin (Fig. 5).

Mississippian

Tournaisian and Viséan. The first attempt to subdivide the Tournaisian and Viséan stages in the Donets Basin using conodonts was by O. Lipnjagov (1978, 1979). Based on faunas from the Donets Basin type horizons and a number of boreholes of the Dnieper-Donets Depression he distinguished six conodont units, which he later designated as zones (Lipnjagov 1978, 1985). Lipnjagov (1979) proposed a more comprehensive zonation in the abstract of his dissertation. Three assemblage zones were defined for the Tournaisian Stage and three in the Viséan Stage of the Donets Basin. In the lower Tournaisian he distinguished the *Patrognathus andersoni–Siphonodella* spp. Zone (C$_1^t$b), in the middle Tournaisian the *Polygnathus* (*=Neopolygnathus*) *communis communis–Spathognathodus curvatus* Zone (C$_1^t$c), and in the upper Tournaisian - the *CavusgnathusPolygnathus kalmiussi* Zone (C$_1^t$d). He distinguished intervals of so-called "intrazones" where conodonts were not found.

Lipnjagov (1979) distinguished three assemblage zones within the Viséan Stage: the *Gnathodus texanus–Paragnathodus (=Lochriea)* aff. *commutatus;* probably **=***L. cracoviensis)* Zone (C$_1^v$e), *Gn. girtyi girtyi–P. (=L.) commutatus* Zone (C$_1^v$f$_1$), followed by the *Gn. girtyi girtyi-–P. (=L.) mononodosus* Zone (C$_1^v$f$_2$–g$_1$) and the latest Viséan *P. (=L.) nodosus* Zone (C$_1^v$g$_2$). The lower boundaries of the assemblage zones were defined by the first occurrences of stratigraphically important species that were the name-bearers of the zones. Lack of sufficient number of conodonts in the Donets Basin Tournaisian and Viséan strata and their absence in the boundary beds as well as the inability now to collect additional samples has prevented attempts to update this conodont succession.

Serpukhovian. Conodont zones for the Serpukhovian and lower Bashkirian, including the mid-Carboniferous boundary interval, were proposed by Nemirovskaya (1982, 1987) and Nemyrovska

(1999). Nemyrovska (2017) updated the conodont zonation for the Serpukhovian of the Donets Basin and the Dniper-Donets Depression. The earliest Serpukhovian *Lochriea ziegleri* Zone, based on the FAD of *L. ziegleri*, occurs in the deeper water sections of the Dnieper-Donets Depression (the base of the IX Microfaunal Horizon) and in the Lviv-Volhyn Basin lies at the base of the Serpukhovian Stage (Nemirovskaya 1983; Skompski *et al.* 1995). The lower beds of the Serpukhovian in the Donets Basin are represented by the coal-bearing units barren of conodonts. The first Serpukhovian zone in the Donets Basin, the *Cavusgnathus naviculus* Zone, characterizes the Prokhorivkian Horizon, which overlaps the interval of the section from limestone C_5 (= limestone C_1 of older nomenclature) of the upper part of the C_1^3 Formation up to limestone D_1^3 (= limestone C_5 of older nomenclature) of the lowest beds of the C_1^4 (D) Formation and corresponds roughly to the *L. ziegleri* Zone of the Dnieper-Donets Depression, Lviv-Volhyn Basin, Western Europe and Urals. Conodonts are common and are mostly shallow water forms. The FOD of *L. ziegleri* in the Donets Basin is confined to the lowest beds of the Kalmiuss Formation C_1^4 (D). For the Dnieper-Donets Depression, the *L. ziegleri–C. naviculus* Zone is defined by the first occurrence of either *L. ziegleri* or *C. naviculus*. The characteristic species are *Gnathodus bilineatus bilineatus*, *L. commutata*, *L. nodosa*, *L. ziegleri*, *C. naviculus*, and *C. unicornis*.

The FADs of *Gnathodus bollandensis* and *Adetognathus unicornis* define the base of the second Serpukhovian conodont Zone, the *Gn. bollandensis–A. unicornis* Zone, which comprises the Novolyubovkian Horizon of the middle part of the Starobeshevian Regiostage The *Gn. postbilineatus* Zone was established in the Donets Basin (Nemyrovska 1999) after recognition of the species in the deep-water sections in South Tien-Shan, Uzbekistan (Nigmadganov & Nemirovskaya 1992; Nemirovskaya & Nigmadganov 1993). It encompasses the Zapaltyubean Horizon, between the limestones D_5^6 and D_5^8 lower (Fig. 5). This zone in the Donets Basin contains the last Mississippian conodont association, where the characteristic species are *Gn. postbilineatus*, *Gn. bollandensis*, *Lochriea commutata*, and *L. ziegleri*.

Pennsylvanian

Bashkirian Stage. The conodont zonation for the Bashkirian and the lowermost Moscovian was published by Nemyrovska (1999) and updated by Nemyrovska (2017) and Nemyrovska & Hu (2018), who discussed correlations to other regions. In the Donets Basin and the Dnieper-Donets Depression, the base of the Bashkirian is determined by the FAD of *Declinognathodus noduliferus inaequalis* (Nemirovskaya 1987; Nemirovskaya *et al.* 1991; Nemyrovska 1999). It is placed at the base of the Voznessenkian Horizon in the Donets Basin and at the base of Microfaunal Horizon V in the Dnieper-Donets Depression (Nemirovskaya 1983; Nemyrovska 1999). The zone is called the *Dec. noduliferus* Zone to avoid confusion in the sections, where *Dec. noduliferus inaequalis* is not specified or the identification of *Dec. inaequalis* is problematic (Nemyrovska 2017). Other species characteristic of this zone are *Dec. lateralis*, and *Dec. japonicus*. The scope of the zone corresponds to that of the *Homoceras* ammonoid zone of the Donets Basin (Nemyrovska 1999).

The first occurrence of the oldest species of *Idiognathoides* in Ukraine marks the base of the *Id. sinuatus–Id. sulcatus sulcatus* Zone, which spans the interval between the limestones D_7^6–D_7^7 of the upper part of the Olmezovian Regiostage to limestone F_1 of the lower part of the Mandrykinian Regiostage. In the Donets Basin, as well as in the other sections in shelf settings, the appearances of these species correspond to the beginning of the *Reticuloceras* ammonoid Genozone (Nemyrovska, 1999; Kulagina *et al*. 2000)**.** *Declinognathodus* species are still common and *Neognathodus symmetricus* first appears.

The oldest species of *Idiognathodus* in the Donets Basin, *I. sinuosus*, marks the base of the *I. sinuosus* Zone and appears close to the base of the Mandrykinian (the lower part of the Blagodatnean Horison, Lms F_1^1). *Idiognathoides* species dominate and *Id. sulcatus parvus* appears. *Declinognathodus noduliferus*, *Dec. lateralis*, and *Neognathodus symmetricus* occur at some levels.

The appearance of “*Streptognathodus*” *expansus* is recorded in Donets Basin in the middle of the Bashkirian, marking the base of the “*St.*”*expansus* Zone. It spans the interval between limestones G_1 and H_3 of the lower part of the Kayalian Regiostage in the Donets Basin. “*St.*” *expansus/”St." suberectus* has never been found above this zone in the Donets Basin. The lower boundary of the *Idiognathoides tuberculatus–Id. fossatus* Zone is defined by FADs of name-bearers. This zone corresponds to the middle part of the Kayalian Regiostage and spans the interval from limestone H_3 through I_2 in the Donets Basin. The entry of both species is at the same level (limestone H_3) in the Donets Basin (Kozitskaya *et al.* 1978). Species of *Idiognathoides* dominate the faunas. The *Declinognathodus marginodosus* Zone encompasses the upper part of the Kayalian Regiostage (limestones I_2 through K_1) of the upper Bashkirian. Its lower boundary is defined by the FAD of *Dec. marginodosus*. The LAD of *Dec. noduliferus* is just above the base of this zone. *Idiognathoides* species continue to dominate. Several species of *Idiognathodus*, including *I. aljutovensis* are common.

Moscovian. The conodont zonation for the Moscovian Stage of the Donets Basin was constructed by Nemyrovska (1999), Nemyrovska *et al.* (1999), Nemyrovska (2011), and updated by Nemyrovska (2017). The appearance of *Declinognathodus donetzianus,* the third member of the *Dec. noduliferus noduliferus–Dec. marginodosus–Dec. donetzianus* lineage defines the base of the *Dec. donetzianus* Zone. This zone embraces the greater part of the Kam'iankian Horizon of the Lozovian Regiostage of the global Moscovian Stage and the uppermost part of the Krasnodonian Horizon of the uppermost Kayalian Regiostage (text-fig. 2). Characteristic species of this zone are *Dec. marginodosus, Dec. donetzianus, Idiognathoides sinuatus* (*Id. corrugatus*), *Id. fossatus, Id. postsulcatus,* and *Id. tuberculatus. Neognathodus* aff. *bothrops* and *Idiognathodus aljutovensis* are common. The last occurences of *Diplognathodus ellesmerensis*, *D. coloradoensis*, and *Mesogondolella donbassica* are recorded in this zone (Kossenko 1975, 1979; Nemyrovska 1999).

The "*Streptognathodus*" *transitivus–Neognathodus atokaensis* Zone corresponds to the upper part of the Kam'iankian Horizon and the lower part of the Mar'ivkian Horizon of the Lozovian Regiostage (limestones K_6–L_5) of the lower Moscovian. The lower boundary of the zone is defined by the FOD of "*St.*" *transitivus.* Characteristic species for the lower part of the zone are *Idiognathoides sinuatus, Id. fossatus, Id. tuberculatus*, "*St.*" *transitivus, N. atokaensis,* and *I. aljutovensis*. Other stratigraphically important taxa such as *Diplognathodus ellesmerensis*, *D. coloradoensis, N. bothrops*, and *I. volgensis* are common through the entire zone. *Declinognathodus donetzianus*, *Dec. marginodosus*, and *Id. postsulcatus* occur in the basal part of the zone (limestone K_6). The *Idiognathodus izvaricus* Zone corresponds to the uppermost part of the Lozovian Regiostage (limestones L_5–M_1) (Fig. 5). The lower boundary of the zone is defined by the FOD of *I. izvaricus,* and its upper boundary coincides with the entry of *Swadelina* species.

The conodont zonation of the upper Moscovian of the Donets Basin is based mostly on the evolution of the *Swadelina* species (Nemyrovska, 2011, 2017). The *Sw. dissecta* Zone corresponds to the lower part of the Lomovatkian Regiostage and it embraces almost the entire C_2^7(M) Formation between limestones M_1 and M_9, except for the uppermost part of the suite. The lower boundary of the zone is defined by the FAD of *Sw. dissecta*. The characteristic species of the *Sw. dissecta* Zone are *Sw. dissecta*, *Idiognathodus obliquus*, *Neognathodus colombiensis*, *Mesogondolella donbassica*, and *Diplognathodus coloradoensis*. The appearance of *Sw. gurkovaensis* marks the base of the *Sw. gurkovaeansis* Zone, which includes the short interval between limestones M_9 and M_{10}^1 of the C_2^7 (M) Formation. Its lower boundary is defined by the FADs of *Sw. gurkovaensis* and *Sw. concinna*. *Swadelina gurkovaensis, Sw. concinna, I. obliquus, M. laevis, M. clarki, N. colombiensis*, and *N. inaequalis* are characteristic species for this zone.

Kasimovian. The boundary between the Moscovian and Kasimovian stages in the Donets Basin is currently placed at the level of limestone N_4, according to the Ukrainian Carboniferous General Stratigraphic Scale (Poletaev *et al.* 2013). It is a sequence boundary drawn at the level of "limestone" N_4 (in fact, a laterite), the most regressive part of the sequence. The first Late Pennsylvanian conodont zonation of the Donets Basin was proposed by Kozitskaya (1983; Shchogolev & Kozitskaya 1984). She subdivided the Kasimovian and Gzhelian stages into six conodont zones. The proposed zonation was based on the principle of "faunistic and floristic developmental stages" and the beginning of a new "stage" represented the appearance of a new assemblage of characteristic forms. The lower boundaries of the zones were confined to the main limestones, probably using the distribution chart of the conodonts given in Kozitskaya *et al.* (1978). These zones are provisionally updated here, although more taxonomic work needs to be done.

The *Swadelina subexcelsa–Neognathodus inaequalis* Zone overlaps the upper part of the Lomovatkian Regiostage (limestones N_1–N_3^3) of the uppermost Moscovian in the Donets Basin. Its lower boundary is defined by the FAD of *Sw. subexcelsa.* The characteristic species are *Sw. subexcelsa*, and *Idiognathodus robustus*. *N. inaequalis*, *N. roundyi,* and *I. obliquus* occur in this zone for the last time in the Donets Basin. The *I. sagittalis – Streptognathodus* (=*I.*) *neverovensis* Zone characterizes a new stage in the conodont evolution. The zone embraces the lowermost part of the Toretzian Regiostage, Kartamyshian Horizon, limestones N_5^1–O_4. Its lower boundary is defined by the FOD of *I. sagittalis* and *I. neverovensis* at limestone N_5^1. The characteristic species are the name-bearers and several new species of *Idiognathodus,* yet to be described. The base of the succeeding *I. toretzianus* Zone is the FAD of *I. toretzianus*. This zone comprises the interval from limestone O_2 to limestone O_4. The base of the next zone, the *St. firmus–I. kalitvensis* Zone, is defined by the FAD of *St. firmus,* The zone includes approximately the interval from limestone O_4^1 up to limestone O_7.

Gzhelian. The appearance of members of the *Idiognathodus simulator* group in limestone O_7 indicates the base of the Gzhelian (*I. simulator, I auritus, I. lateris, I. luganicus, I. praenunitus*; see Hogancamp *et al.* 2017). The *I. luganicus* Zone ranges from the FAD of *I. luganicus* in limestone O_7 up through the disappearance of the *I. simulator* group in limestone P_2. *Idiognathodus lobulatus* and *I.* aff. *tersus* occur in this zone, but are not restricted to it. The higher Gzhelian strata are unzoned.

Russia and adjacent countries

The international stratigraphic scale of the Carboniferous System with its division into subsystems, series and stages was ratified by the International Union of Geological Sciences in 2004. Five Russian stages are used in the global scale of the Carboniferous. The central regions of the East European (Russian) Platform served as the basis for distinguishing the Serpukhovian, Moscovian, Kasimovian and Gzhelian stages. It is here their type regions are located, regional substages were distinguished, and division into foraminiferal zones was effected. The conodont zonation for the Moscovian and Kasimovian stages was based primarily on the detailed study of the reference sections on the East European Platform. The second important region for creating the conodont zonation was the South Urals. On the western slope of the South Urals (Bashkiria), the Bashkirian Stage was distinguished. In addition, sections of the South Urals, unlike the Moscow Basin, represent deeper-water environments and contain conodont taxa that are more widespread and allow interregional correlation, especially for the Mississippian. The first general conodont zonation for Carboniferous in the Soviet Union was proposed by Barskov *et al.* (1984*a*) for the East European Platform, which included the western slope of the Urals for the Mississippian.

Mississippian

The Mississippian corresponds to three stages - Tournaisian, Viséan and Serpukhovian, all divided into regional substages in each large geological region. The central regions of the East European Platform, where shallow-water Lower Carboniferous deposits are widely developed, are undesirable areas for the zonation by conodonts. The standard conodont zonal scale, which was developed for relatively deep-water facies and based on the evolution of the genera *Siphonodella* (lower and middle Tournaisian) and *Gnathodus* (upper Tournaisian-Serpukhovian) (Sandberg *et al.* 1978; Lane *et al.* 1980) can be applied in sections of the South Urals, the Caspian Depression and North-East Russia, and were included in the standard Russian conodont scale (Kagarmanov & Kossovaya 2003). For the shallow-water facies of the lower Tournaisian in the central part of the East European Platform (Moscow Basin), Timan-Pechora Province, Kazakhstan, certain regions of the North Caucasus and Transcaucasia, the evolutionary sequences of species of the genera *Patrognathus* (Barskov *et al.* 1984; Zhuravlev 2007) or *Polygnathus* are used. The Viséan and Serpukhovian are divided into the zones generally accepted for this interval. The standard conodont scheme of Russia contains eight zones in the Tournaisian, five zones in the Viséan and two zones in the Serpukhovian were established in the Lower Carboniferous (Kagarmanov & Kossovaya 2003) (Fig. 6).

*Tournaisian***.** The *Siphonodella sulcata* Zone is a partial range zone first identified in North America (Sandberg *et al.* 1978). The lower limit is the FAD of the index species. In the South Urals, the zonal assemblage includes *Siphonodella praesulcata*, *Polygnathus inornatus*, *P. symmetricus*, *P. purus purus*, *P. longiposticus*, *P. parapetus*, *Pseudopolygnathus conili*, *Ps. primus*, *Bispathodus aculeatus aculeatus*, *B. aculeatus anteposicornis*, *Neopolygnathus communis* and others. The zone has been recognized in the Peri-Caspian Basin (Akhmetshina *et al*. 2007), Pay Khoy (Zhuravlev 2003; Zhuravlev *et al*. 1999), the Kolyma-Omolon Region (Koren & Kotlyar 2009) and the South Tien Shan (Neevin 2005; Nigmadzhanov 1987; Bardasheva 1997) (Figs. 7, 8, 9).

In shallow-water strata, where siphonodellids are not found or are extremely rare, the evolutionary sequence of species of *Patrognathus* is used. The *Patrognathus crassus* Zone is a total range zone proposed by Barskov *et al.* (1984*b*) in the Moscow Basin (Fig. 6). The lower boundary is the FAD of *Pa. crassus*. The assemblage is represented by *Bispathodus aculeatus aculeatus*, *B. aculeatus anteposicornis*, *B. aculeatus plumulus*, and *Neopolygnathus communis*. The zone with the same name was also used for the shallow sediments in the North Urals (Zhuravlev 2007). In Kazakhstan, the regional *Polygnathus parapetus* Zone is distinguished at this level (Vorontsova 1986). The *Bispathodus costatus* Zone was used in the North Caucasus and Transcaucasia (Grechishnikova *et al*. 1984, 1988; Chegodaev 1988) and the local *P. lobulatus* Zone corresponds to this interval in sections of the Kolyma-Omolon Region (Gagiev & Kononova 1990) (Figs. 6, 8, 9).

The *Siphonodella duplicata* Zone is a partial range zone established in North America (Sandberg *et al.* 1978). The lower boundary is the FAD of *S. duplicata* and *S. sulcata*, *S. semichatovae*, *Polygnathus purus purus*, *P. longiposticus*, *P. corrugatus*, *Pseudopolygnathus fusiformis,* and *Ps. inaequalis* occur in this zone. The zone is widespread in deep water sections of the Urals, in the Caspian Sea Region and in the South Tien Shan (Figs. 6, 7). In shallow water successions, the *Patrognathus variabilis* Zone is used in the Moscow Basin and the Timan-Pechora Province, and the *P. inornatus rostratus* Zone in Kazakhstan and in the Kolyma-Omolon Region (Figs. 6, 8, 9.

The *Siphonodella belkai* Zone is a partial range zone first established by Pazukhin (Kulagina *et al*. 2003) in the South Urals. The lower boundary is the FAD of *S. belkai*. The zone is characterized by *S. duplicata*, *S. cooperi*, *S. kononovae*, *S. obsoleta*, *S. sandbergi*, *S.*

semichatovae, *Polygnathus purus purus*, *P. longiposticus*, *Pseudopolygnathus fusiformis*, and *Ps. inaequalis*. Besides the Southern Urals, the zone of this name was reported in the Caspian Region (Akhmetshina *et al.* 2007). The equivalent North American *S. sandbergi* Zone (Sandberg *et al.* 1978) has been recognized in the western and eastern slopes of the North Urals, in the Kolyma-Omolon Region, and also in sections of the South Tien Shan (Figs. 7–9). In shallow-water facies, regional zones have been established: *Patrognathus andersoni* Zone in the Moscow Basin (Barskov *et al.* 1984*b*), *Neopolygnathus communis* Zone in Kazakhstan (Vorontsova 1986), and *S. semichatovae* Zone in the Timan-Pechora Province (Zhuravlev 2003).

The *Siphonodella quadruplicata* Zone is a partial range zone established in North America (Sandberg *et al.* 1978) and defined by the FAD of *S. quadruplicata*. The zonal assemblage includes *S. cooperi*, *S. crenulata*, *S. obsoleta*, *S. sandbergi*, *Polygnathus inornatus rostratus*, *P. longiposticus*, and *Pseudopolygnathus triangulus*. The zone corresponds to the upper part of the Lower Tournaisian and has a wide geographical distribution. It can be traced into the central part of the East European Platform (Makhlina *et al.* 1993), the Urals (Kulagina *et al.* 2013), and the Caspian Sea Region (Akhmetshina *et al.* 2007).

The *Siphonodella isosticha* Zone is a total range zone first established by Sandberg *et al.* (1978). Its lower boundary is the FAD of *S. isosticha*. The zonal assemblage includes *S. crenulata*, *S. obsoleta*, *Gnathodus delicatus*, *Gn. punctatus*, *Pseudopolygnathus multistriatus*, and *Mestognathus groessensi*. This zone has been traced into the western and eastern slopes of the South Urals (Kulagina *et al.* 2003, 2013) and into the central part of the Southern Tien Shan in Kyrgizstan (Neevin 2005). It corresponds to the *S. crenulata* Zone established in sections of Tajikistan (Bardasheva 1997) and Uzbekistan (Nigmadzhanov 1987).

The *Gnathodus typicus* Zone is a partial range zone. The lower boundary is the FAD of the index species (Lane *et al.* 1980). The zonal assemblage contains *Bactrognathus hamatus*, *Dollymae hassi*, *Gn. delicatus*, *Gn. punctatus*, *Gn. semiglaber*, *Pseudopolygnathus multistriatus*, *Ps. pinnatus*, *Neopolygnatus carinus*, *Ne. communis*, and *Mestognathus groessensi*. The zone can be recognized in the Urals, Kazakhstan, the South Tien Shan (Kyrgyzstan) and the Kolyma-Omolon Region (Figs. 7–9). In the eastern margin of the Caspian Depression, index species and representatives of the *Bactrognathus* and *Dollymae* are absent, and the regional *Ne. carinus* Zone is identified, which corresponds to the *Gn. typicus* Zone and the overlying *Dollymae bouckaerti* Zone (Akhmetshina *et al*. 2007).

The *Dollymae bouckaerti* Zone is a total range zone that was first established in the South Urals (Kulagina *et al.* 2003) by the FAD of the index species. The assemblage includes *Bactrognathus angularis*, *Dollymae bouckaerti*, *Gnathodus delicatus*, *Protognathodus* *cordiformis*, *Neopolygnatus carinus*, and *Pseudopolygnathus pinnatus pinnatus*. Although the *Dollymae bouckaerti* Zone is included into the standard Russian conodont zonation (Kagarmanov & Kossovaya 2003), so far the zone has been established only in the South Urals (Kulagina *et al.* 2013).

The *Scaliognathus anchoralis* Zone is a total range zone. It was first established by Lane *et al.* (1980) by the FAD of the index species. The zonal assemblage is characterized by *Scaliognathus anchoralis europensis*, *Doliognathus latus*, *Gnathodus delicatus*, *Protognathodus cordiformis*, *Pseudopolygnathus pinnatus*, and *Ps. oxypageus*. The zone has a wide geographical distribution and has been reported from the Urals (Kulagina *et al.* 2003), the Caspian Basin (Akhmetshina *et al.* 2007), Novaya Zemlya (Sobolev & Nakrem 1996), and the South Tien Shan (Neevin 2005; Bardasheva 1997). In all these areas, the top of the zone marks the boundary of the Tournaisian and Viséan stages. In Kazakhstan, this interval corresponds to the *Gn. semiglaber* and *Gn. pseudosemiglaber* zones (Martynova & Vorontsova 1988), and in the northeast of Russia to the *Gn. punctatus* − *Do. latus* Zone (Koren & Kotlyar 2009).

Viséan. The *Gnathodus texanus* Zone is a partial range zone based on the FAD of the index species (Lane *et al.* 1980). The assemblage includes *Gnathodus texanus*, *Gn. semiglaber*, *Gn. pseudosemiglaber*, *Gn. cuneiformis*, *Gn. praebilineatus*, *Gn. meischneri*, *Pseudognathodus homopunctatus*, *Mestognathus beckmanni*, and *Polygnathus bischoffi*. The zone corresponds to the lower Viséan and is well represented in Kazakhstan, the South Tien Shan, Novaya Zemlya and the Kolyma-Omolon Region. In the central part of the East European Platform, there was a break in sedimentation in this interval, and for the Caspian Depression and the North Caucasus data on conodonts are not available. In shallow-water facies, the *Mestognathus bipluti* Zone is distinguished at this level (Figs. 7–9).

The *Gnathodus bilineatus bilineatus* Zone is a partial range zone. The lower boundary is determined by the FAD of *Gn. bilineatus bilineatus*. The zonal assemblage is poor and represented by *Gn. girtyi girtyi*, *Gn. girtyi collinsoni*, *Pseudognathodus homopunctatus*, and *Lochriea commutata*. The zone is well known in the central part of the East European Platform, the Urals, the Caspian Region, the Kolyma-Omolon Region and in the sections of the South Tien Shan. However, the stratigraphic position of this zone varies in these different regions (Figs. 6–9).

The *Lochriea nodosa* Zone is a partial range zone. The zone was first established under the name the *Gnathodus bilineatus* - *Gn. commutatus nodosus* Zone in Japan (Koike 1967). In Russia, the *L. nodosa* Zone was first established in the Moscow Basin as the *Paragnathodus nodosus* Zone (Barskov *et al.* 1984*a*) and its lower boundary was determined by the FAD of *Pa*.

nodosus (= *L. nodosa*). The zonal assemblage includes *Lochriea commutata*, *L. costata*, *L. monocostata*, *L. mononodosa*, as well as *Gn. bilineatus bilineatus*, *Gn. girtyi girtyi*, *Gn. girtyi collinsoni*, and *Pseudognathodus homopunctatus*. The lowest occurrence of *L. nodosa* in the Moscow Basin is in the Mikhailovian Regional Substage (Kabanov *et al*. 2016), but recently this species was found in the middle Aleksinian Regional Substage of the Polotnyany Zavod section (unpublished data of Alekseev 2019) This interval in the South Urals and the Caspian Region is occupied by the *L. nodosa* and *L. mononodosa* zones (Nikolaeva *et al.* 2001) (Figs. 6, 7). In the upper part of the zone, in the central part of the East European Platform and sections of the South Urals, *L. ziegleri* appears. Currently, this species is being considered by the international task group to establish the lower boundary of the Serpukhovian Stage as a potential marker of its lower boundary (Nikolaeva *et al.* 2019).

Serpukhovian. The *Lochriea cruciformis* Zone is a partial range zone that was first identified in sections of the eastern slope of the South Urals by the FAD of *L. cruciformis* (Pazukhin *et al.* 2009). The assemblage is characterized by *L. ziegleri*, *L. multinodosa*, *L. costata*, *L. monocostata*, *L. mononodosa*, *Gnathodus bilineatus bilineatus*, *Gn. girtyi girtyi*, and *Gn. girtyi simplex*. *Lochriea cruciformis* is widespread in sections of Eurasia (Skompski *et al.* 1995) and in many regions this species appears simultaneously with *L. ziegleri* at the base of the Serpukhovian. Because of the increased attention given to *L. ziegleri* as a potential index species for the lower zone of the Serpukhovian, an analogue of the *L. cruciformis*—the *L. ziegleri* Zone (Figs. 6-9) is universally distinguished. In the type area of the Serpukhovian, *L. ziegleri* appears almost in the middle of the Venevian Regional Substage (Kabanov *et al.* 2016), below the traditional lower boundary of the Serpukhovian.

The *Gnathodus bilineatus bollandensis* Zone is a total range zone. The zone is identified by the FAD of *Gn. bilineatus bollandensis*. The assemblage also includes *Gn. girtyi simplex*, *Lochriea cruciformis*, *L. ziegleri*, *L. costata*, *L. senckenbergica*, and *L. monocostata*. The zone of the same name corresponds to this level in the South Tien Shan (Neevin 2005; Nigmadzhanov 1987; Bardasheva *et al.* 2004), the Caspian Sea Region (Akhmetshina *et al.* 2007), and the Urals (Kulagina *et al.* 2013). In the shallow-water facies of the upper part of the Serpukhovian strata with *Cavusgnathus* or *Adetognathus unicornis* are known (Alekseev *et al*, 1984), which correspond to Protvian Regional Substage (Fig. 6).

Lower and Middle Pennsylvanian

In the general stratigraphic scale of Russia, the Pennsylvanian Subsystem corresponds to four stages, the Bashkirian and Moscovian (Middle Carboniferous) and the Kasimovian and Gzhelian stages (Upper Carboniferous), which are subdivided into regional substages. Bashkirian sediments are almost completely absent in the central part of the East European Platform. Therefore, the development of the conodont zonation was carried out partially along the sections east of the Russian Plate (Sungatullina 2002), but mainly in more complete sections of the western slope of the South Urals (Nemirovskay & Alekseev 1993; 1995). Conodont faunas of the latter part of the Carboniferous Period are characterized by a high degree of provincialism, which complicates the creation of a standard zonation and limits the possibility of its usage mainly to the European part of Russia and South Urals, as well as some adjacent regions (Alekseev *et al.* 2008). In the Pennsylvanian of Russia, 24 conodont zones have been identified (Alekseev 2008). The correlation of the standard Russian conodont zones with zonations of the central part of the East European Platform, the Caspian Sea Region, North Timan, Novaya Zemlya and the South Urals is shown in Figure 10. However, east of the Urals, conodonts are extremely rare in Pennsylvanian strata and only the *Declinognathodus noduliferus* Zone assemblage has been reported, but not illustrated, from Central Kazakhstan (Litvinovich *et al.* 1985). The Pennsylvanian conodont succession developed in Russia has been used as a major basis for a standard worldwide (Davydov *et al.* 2012) or European zonation (Ogg *et al*. 2016).

Bashkirian. The first information on Bashkirian conodonts was obtained by Furduy (1979) in the South Urals. In subsequent years, Nemirovskaya & Alekseev (1993, 1995) described new species and constructed a conodont zonal scheme for the Bashkirian and lower parts of the Moscovian along the Askyn River section (hypostratotype of the Bashkirian Stage) in the South Urals. Based on the study of numerous sections, Pazukhin developed a more detailed conodont zonation for the Bashkirian of the South Urals (Kulagina *et al.* 1992, 2001; Nikolaeva *et al*. 2017). Seven conodont zones were proposed, five of which were included in the standard conodont zonation of Russia (Kagarmanov & Kossovaya 2003).

The *Declinognathodus noduliferus* Zone is a partial range zone, proposed originally in North America by Dunn (1970). The lower boundary is identifed in Russian sections by the FAD of *Dec. inaequalis* and *Dec. noduliferus* and the assemblage contains *Dec. japonicus* and *Dec. lateralis*. The zone corresponds to the lower part of the Syuranian Regional Substage in the South Urals. The zone can be recognized in the South Urals and in the subsurface of the eastern areas of the East European Platform. However, according to Sungatullina (2002), the FAD of *Dec. noduliferus* apparently occurs at different levels.

The *Idiognathoides sinuatus* Zone is a partial range zone proposed by Higgins & Bouckaert (1968) in Belgium. The lower boundary of the zone coincides with the FAD of the index species and the upper boundary is marked by the first occurences of species of *Neognathodus* and *Idiognathodus*. The assemblage is dominated by *Declinognathodus inaequalis*, *Dec. noduliferus*, *Dec. lateralis*, and rare *Idiognathoides sulcatus* occur. A corresponding zone was established in Japan as the *Neolochriea nagatoensis* Zone (Mizuno 1997). The *Id. sinuatus* Zone corresponds to the upper part of the Syuranian and lower part of the Akavasian regional substages.

The *Neognathodus askynensis* Zone is a partial range zone established by Nemirovskaya & Alekseev (1993, 1995) in the South Urals on the FAD of the index species. The assemblage includes *Declinognathodus noduliferus*, *Dec. lateralis*, *N. symmetricus*, *Idiognathoides sulcatus*, *Id. sinuatus*, and a single *Neolochriea hisaharui*. The zone corresponds to the upper part of the Akavasian Regional Substage.

The *Idiognathodus sinuosus* Zone is a partial range zone. The lower boundary is defined by the FAD of the index species and *I. primitivus*. The assemblage includes *Declinognathodus noduliferus, Dec. lateralis*, *Neognathodus symmetricus*, *Idiognathoides sulcatus*, and *Swadelina bashkirica*. It is the equivalent of Askynbashian Regional Substage.

The *Declinognathodus marginodosus* Zone is a partial range zone. It was first porposed by Grayson (1984) in the middle part of the Atokan as a stratigraphic interval from the FAD of the index species to the FAD of *Neognathodus atokaensis*. The zonal assemblage is poor*:* *Idiognathoides lanei*, *Id. corrugatus, Id. ouachitensis, Id. sinuatus*, and *Swadelina bashkirica.* In the general stratigraphic scale of Russia, the zone corresponds to the Arkhangelskian Regional Substage (Kagarmanov & Kossovaya 2003; Alekseev 2008). In the Volga-Urals Region, this interval is divided into two zones, a lower *Id. tuberculatus–Id. fossatus* (= *Id. ouachitensis*) Zone and an upper *Dec. marginodosus* Zone, corresponding to two regional substages of the East European Platform, the Cheremshanian and Melekessian, respectively (Sungatullina 2002). In the South Urals two zones were identified, the *Dec. marginodosus* Zone, corresponding to the Tashastian Regional Substage (analogue of the Cheremshanian), and the *N. atokaensis* Zone in the Asatauian Regional Substage (Kulagina *et al.* 2001). A *Dec. marginodosus* Zone corresponding to the Arkhangelskian was proposed later (Nikolaeva *et al*. 2017).

Moscovian. The first conodont zonation of the Moscovian Stage was developed in the Moscow Basin by Barskov & Alekseev (1975), who proposed four concurrent range zones for the Moscovian. The scheme from the Kashirian to Myachkovian interval was based on the principle of joint occurrence of two characteristic species, one from the phyletic lineage of *Neognathodus* and second from *Declinognathodus*, *Idiognathodus* or *Streptognathodus*. Further changes in the scheme mainly reflected a change in ideas about the systematic position of zonal forms and zones were split into several subzones (Makhlina *et al*. 2001a,b). The most recent version of the Moscovian zonation contains eight zones (Fig. 10) (Kagarmanov & Kossovaya 2003; Alekseev 2008). Because *Neognathodus* is a relatively shallow-water genus, this zonation could be applied only with difficulty in deeper-water successions, such as the Donets Basin.

Similar conodont zonations, often only for an incomplete Moscovian interval, were also established in the South Urals (Nemirovskya & Alekseev 1993, 1995; Alekseev *et al*. 2002; Kulagina *et al.* 2009), Northern Timan (Goreva & Kossovaya 1997; Goreva *et al.* 1997), in the Middle Volga Region (Sungatullina 2002), the Caspian Basin Region (Akhmetshina 1984; Akhmetshina *et al.* 2007) and Novaya Zemlya (Sobolev & Nakrem 1996). (Fig. 10).

The *Declinognathodus donetzianus–Idiognathoides postsulcatus* Zone is a concurrent range zone first established by Nemyrovska (1999) in the Donets Basin, Ukraine. The assemblage of this zone includes *Dec. marginodosus, Idiognathoides ouachitensis*, *Id. tuberculatus*, *Id. sinuatus*, rare *Id. postsulcatus*, *Neognathodus atokaensis, Diplognathodus coloradoensis*, *D. ellesmerensis*, *Idiognathodus volgensis*, *I. aljutovensis*, and *I. parvus*. The interval corresponds to the lower part of the Vereian Regional Substage. The zone is also established in the Middle Volga Region (Sungatullina 2002) and the Caspian Sea Region (Akhmetshina *et al.* 2007). In the South Urals it corresponds to the upper part of the *N. atokaensis* Zone and the lower part of the Solontsian Regional Substage (Nemirovskaya & Alekseev 1993, 1995).

The *Streptognathodus transitivus* Zone is a total range zone that was proposed by Barskov *et al.* (1984*a*) in the “parallel” scale established by the sequence of species of the genus *Streptognathodus*. The range of the index species does not extend beyond the boundaries of this zone. The zonal assemblage includes rare *Declinognathodus marginodosus, Idiognathoides ouachitensis*, and *Id. sinuatus*, as well as the more common *Idiognathodus aljutovensis* and *Neognathodus nataliae*. The youngest species of *Idiognathoides* and *Declinognathodus* disappear at the upper boundary of this zone in the Moscow Basin, but a few *Idiognathoides* elements occur on the Oka-Tsna Swell in the overlying *N. bothrops* Zone. Species of *Idiognathoides,* however, continue to be found in the overlying Kashirian and Podolskian deposits of North Timan and the Urals (Goreva & Kossovaya 1997; Kulagina *et al*. 2013). The zone corresponds to the upper part of the Vereian Regional Substage.

The *Neognathodus bothrops* Zone is a partial range zone originally introduced by Barskov *et al.* (1979) as the *N. bothrops–Idiognathodus delicatus* Zone or *N. bothrops* Zone (Barskov *et al.* 1984*a*). An additional characteristic taxon of the zone is *N. tsnensis*. The zonal assemblage includes *I. praeobliquus*, *I. izvaricus*, *N. nataliae*, and *Swadelina dissecta*. *Idiognathodus obliquus* is excluded from this zone. The zone corresponds to the lower part of the Kashirian Regional Substage (Alekseev & Goreva 2013).

The *Neognathodus medadultimus* Zone is a partial range zone. It was originally proposed by Barskov *et al.* (1979) as the *N. medadultimus–Idiognathodus delicatus* Zone and was later renamed by the same authors (Barskov *et al.* 1984*a*) as the *N. medadultimus* Zone without changing its definition. In the zonal assemblage, there are numerous *Swadelina dissecta* and *I. obliquus*, the presence of rare *N. bothrops*, as well as *Diplognathodus coloradoensis*, and *N. colombiensis*. The zone corresponds to the middle part of the Kashirian Regional Substage.

The *Swadelina concinna–Idiognathodus robustus* Zone is a concurrent range zone. The zone was first identified based on material from sections near Moscow (Alekseev & Gerletselsteg 1996). In addition to the index species, the zonal assemblage includes *Neognathodus kashiriensis* and numerous forms from the *I. delicatus* Group. The zone is known only in the Moscow Basin.

The *Neognathodus medexultimus–Idiognathodus podolskensis* Zone is a partial range zone that was first established by Goreva (1984) in the Podolskian Regional Substage. The lower boundary of the zone is determined by the FAD of *N. medexultimus*. This species is a direct descendant of *N. medadultimus,* which occurs up to the middle of the substage (Barskov *et al*. 1982; Barskov & Goreva 1983). The ubiquitous species *I. delicatus* is constantly present together with *I. podolskensis*. Rare *N. colombiensis* and *Swadelina concinna* are also found. The zone corresponds to the lower part of the Podolskian Regional Substage.

The *Neognathodus inaequalis* Zone is a partial range zone that was first identified by Goreva (1984) as the lower subzone of the *N. roundyi–Streptognathodus cancellosus* Zone. The lower boundary is determined by the FAD of the index species and the disappearance of *N. medadultimus*. *Idiognathodus podolskensis, N. medexultimus, N. colombiensis, Diplognathodus coloradoensis* continue to be found. *Idiognathodus delicatus* is represented by morphologically typical forms. This zone corresponds to the upper part of the Podolskian Regional Substage and the lower Myachkovian Regional Substage.

The *Neognathodus roundyi* Zone is a total range zone. The zone was first proposed by Goreva (1984) in the Moscow Basin as the upper subzone of the *N. roundyi–Streptognathodus cancellosus* Zone in the Peski Formation. The lower boundary of the zone coincides with the FAD of the index species. In addition, the assemblage includes rare *N. inaequalis*, *N. dilatus*, and typical *Idiognathodus delicatus* and *Diplognathodus coloradoensis* continue to occur. The zone corresponds to the upper Myachkovian Regional Substage.

Upper Pennsylvanian

The first zonal scale for the Russian Upper Carboniferous (= Upper Pennsylvanian) was proposed by Barskov & Alekseev (1975) for the Moscow Basin. In this scale, the Kasimovian Stage corresponded to the *Streptognathodus oppletus–St. cancellosus* Zone, and the Gzhelian Stage was divided into three zones (from bottom to top): the *St. elegantulus–St. oppletus*, *St. gracilis–St. elegantulus*, and *St. elongatus–St. gracilis* zones. Later Barskov *et al.* (1982) modified the scheme. The Kasimovian in the new scale corresponded to the *St. oppletus–St. excelsus* Zone, which was divided into four subzones (from bottom to top): *Idiognathodus arendti* (Krevyakinian Regional Substage), *I. sagittalis* (Khamovnikian Regional Substage), *I. toretzianus* (Doromilovian Regional Substage) and *I. lobulatus* subzones (Yauzian Regional Substage). Most of the Gzhelian (Dobryatinian and Pavlovoposadian regional substages) was included in the *St. alekseevi* Zone, which was divided into two subzones, the *St. simulator* Zone (below) and *St. ruzhencevi* Zone (above). The Noginskian Regional Substage corresponded to the *St. elongatus* Zone. The Asselian Stage of Permian System began with the *St. wabaunsensis* Zone at that time. The same zonal scale was published in a more detailed form (Barskov *et al.* 1984*a*) and was used in the general scheme of the Carboniferous System of the Russian (East European) Platform (Kagarmanov & Donakova 1990). Later, as a result of additional detailed study of the sections of the Kasimovian in the Moscow Basin (the type region of the Upper Pennsylvanian regional substages) the scheme was refined (Alekseev *et al.* 1998). Part of this zonation has been applied to Novaya Zemlya (Sobolev & Nakrem 1996), Northern Timan (Goreva & Kossovaya 1997; Goreva 2019), in the Middle Volga Region (Sungatullina 2002), and the Caspian Basin (Akhmetshina 1984; Akhmetshina *et al.* 2007).

An updated version of the zonation was published by Alekseev & Goreva (2000). The Kasimovian of the Moscow Basin was divided into four zones: *Streptognathodus subexcelsus*, *St. makhlinae*, *Idiognathodus* aff. *sagittalis* and *I. toretzianus* zones. The Gzhelian was subdivided into five zones: *St. zethus*, *St. simulator*, *St. ruzhencevi*, *St. elongatus* and *St. simplex* zones. In recent years, sections of the Kasimovian and lower Gzhelian in the type localities have been re-studied in detail, which allowed a more detailed zonation to be produced (Goreva *et al.* 2007; Alekseev & Goreva 2007; Goreva *et al*. 2009; Alekseev *et al*. 2009). In the South Urals, the most attention was paid to deep-water sections of Bashkiria and the Orenburg Region (Chernykh 2002, 2012; Alekseev *et al.* 2002; Sungatullina *et al*. 2015). In the Moscow Basin, the Gzhelian was well characterized by conodonts only in the lower part, and for it the South Urals zonation proposed by Chernykh (2000, 2012) was accepted. The applicability of this scale in the eastern part of the East European Platform was shown by Sungatullina (2002). A zonal scale with the characteristics of conodont zones, selected based on the materials of the Moscow Basin and forming the basis of the standard scheme, was published together with illustrations of zonal species (Goreva & Alekseev 2010) (Fig. 10). Especially complete illustrations of youngest Kasimovian and Gzhelian conodonts from the South Urals were published by Chernykh (2012). In the South Urals scheme, eight zones comprise the Kasimovian: *Swadelina subexcelsa*, *Sw. makhlinae*, *I. sagittalis*, *St. cancellosus*, *I. mestsherensis*, *I. toretzianus*, *St. firmus*, and *St. zethus*. Five zones comrprise the Gzhelian: *I. simulator*, *St. vitali*, *St. virgilicus*, *St. bellus* and *St. wabaunsensis*. This zonation became the basis of the Carboniferous standard Russia zonation (Kagarmanov & Kossovaya 2003; Alekseev 2008), which comprises six zones for the Kasimovian and five zones for the Gzhelian.

Kasimovian. The *Swadelina subexcelsa* Zone is a partial range zone proposed by Alekseev & Goreva (2000; Makhlina *et al.* 2001b). The lower boundary is FAD of *Sw. subexcelsa*. At the base of the Kasimovian, a significant change of the taxonomic composition of the conodont assemblage took place. The genus *Neognathodus,* characteristic of the Bashkirian and Moscovian, became extinct in most areas. Species of *Neognathodus* continue to be found at this stratigraphic level only in the South Urals. In the Moscow Basin in the middle part of the zone, *Idiognathodus fischeri* appears. In the central regions of the East European Platform, where the distribution of conodonts in this interval has been studied in more detail, the *Sw. subexcelsa* zone can potentially be divided into several smaller units. This zone corresponds to the lower part of the Krevyakinian Regional Substage.

The *Swadelina makhlinae* Zone is a total range zone proposed by Alekseev & Goreva (2000; Makhlina *et al.* 2001b). The lower boundary is FAD of *Sw. makhlinae*. The assemblage of the *Sw. makhlinae* Zone is devoid of typical Moscovian forms, although *Sw. subexcelsa* is still occasionally found at the base of this zone. In the Moscow Basin and the South Urals, the assemblage of the *Sw. makhlinae* Zone is complemented by *Idiognathodus trigonolobatus* and *I. arendti,* both characteristic of this interval. In the Moscow Basin, the *Sw. makhlinae* Zone corresponds to the upper part of the Krevyakinian Regional Substage (Voskresensk Formation) and to the base of the Khamovnikian Regional Substage (Ratmirovo Formation). The *Sw. makhlinae* Zone is confidently distinguished in the central regions of the East European Platform (Makhlina *et al*. 2001b), in the Middle Volga Region (Sungatullina 2002), as well as in the South Urals (Alekseev *et al.* 2002; Sungatullina *et al.* 2015), and on Novaya Zemlya (Sobolev & Nakrem 1996).

The *Idiognathodus sagittalis* Zone is a partial range zone. The *I. sagittalis* Zone was established as a subzone by Barskov *et al.* (1982, 1984*a*) within the Khamovnikian Regional Substage in the Moscow Basin. The lower boundary is defined by FAD of *I. sagittalis*. *Idiognathodus neverovensis* is present in the lower part of the zone along with *I. sagittalis* in the central regions of the East European Platform (Alekseev & Goreva 2006, 2007; Goreva & Alekseev 2010). The index species has a wide geographical distribution and occurs not only in the Donets Basin, from where it was first described, but also in the South Urals (Alekseev *et al.* 2002; Sungatullina *et al.* 2015) and Timan (Goreva & Kossovaya 1997; Goreva *et al.* 1997). The interval of the *I. sagittalis* Zone corresponds to the lower and middle parts of the Khamovnikian Regional Substage of the Moscow Basin (Goreva *et al.* 2009).

The *Streptognathodu cancellosus* Zone is a total range zone that was originally included in the scale as the uppermost zone of the Moscovian Stage (Myachkovian Regional Substage) by Barskov *et al.* (1984*a*) and Barskov (1984). However, the identification of some morphotypes as belonging to the *S. cancellosus* proved to be erroneous (Makhlina *et al.* 2001b). Reillustration of the holotype of *S. cancellosus* permited this species to be identified at a higher level in the Kasimovian of the Moscow Basin. The *St. cancellosus* Zone was established in the lower part of the Missourian of the North America Midcontinent (Barrick & Heckel 2000). This zone is characterized by the presence of advanced forms of *Idiognathodus sagittalis*. In the central regions of the East European Platform, the *St. cancellosus* Zone corresponds to the upper part of the Khamovnikian and the lower part of the Dorogomilovian regional substages.

The *Idiognathodus toretzianus* Zone is a partial range zone that was first proposed as the *I. toretzianus* Subzone in the Dorogomilovian Regional Substage of the Moscow Basin (Barskov *et al*. 1982, 1984*a*). The lower boundary is marked by FAD of *I. toretzianus*. Another species, *I. mestsherensis*, is found in the lower part of the zone. The zonal assemblage also contains *Streptognathodus isakovae* and *I. magnificus* in the Moscow Basin. An important species, *I. eudoraensis*, is found in the upper part of the zone. The *I. toretzianus* Zone encompasses most of the Dorogomilovian Regional Substage. This conodont zone, in addition to the central regions of the East European Platform, is recognized in the Donets Basin, the Middle Volga Region, on the Don Bend in the Volgograd Region (Goreva *et al.* 2009) and the South Urals.

The *Streptognathodus firmus* Zone is a partial range zone proposed by Chernykh (2000) as the topmost zone in the Kasimovian in the South Urals. The lower boundary is the FAD of *St. firmus*. The assemblage contains *Idiognathodus toretzianus* and *St. zethus*, and the latter is more common in the upper part of the zone. In the Moscow Basin, the interval with *St. zethus* was assigned to the local *St. zethus* Zone (Alekseev & Goreva 2000, 2007). The *St. firmus* Zone was originally considered to be the basal Gzhelian zone in the Moscow Basin, but is now the uppermost Kasimovian zone (Alekseev 2008). *Streptognathodus zethus* was described from sections in the South Urals, where Chernykh (2000) distinguished the *St. gracilis* (*zethus*) Zone below the *St. firmus* Zone. Later, the same author renamed the zones as the *St. zethus–St. gracilis* (Chernykh 2002) and *St. firmus* zones (Chernykh 2012).

Gzhelian. The SCCS decided to position the lower boundary of the Gzhelian at the FAD of the conodont *Idiognathodus simulator* (Heckel *et al.* 2008) and this decision is considered as valid in the Russia. In the Russia, the Gzhelian succession of the conodont zones is accepted according that proposed by Chernykh (2000, 2012) based on two South Urals sections, the Usolka and Nikolsky sections.

The *Idiognathodus simulator* Zone is a partial range zone that was first distinguished by Barskov *et al.* (1981, 1984*a*). The zone is characterized by one of the most distinctive conodont assemblages, including, in addition to the index species *I. simulator*, species such as *I. luganicus*, *Streptognathodus pawhuskaensis* (= *St. alekseevi*), *I. tersus* and several others. The *I. simulator* Zone is extremely widespread and recognized in the central and eastern parts of the East European Platform, Donets Basin, and the South Urals.

The *Streptognathodus vitali* Zone is a partial range zone that was first distinguished by Chernykh (2002). The lower boundary is the FAD of *St. vitali*. The assemblage includes *St. pawhuskaensis*, *St. ruzhencevi*, and *Idiognathodus simulator*. Previously, this interval (upper Dobryatinian Regional Substage in the Moscow Basin) and the overlying Pavlovoposadian Regional Substage was named as the *St. ruzhencevi* Zone. Currently, the *St. vitali* Zone is recognized only in the northern and in the central part of the East European Platform and in the South Urals.

The *Streptognathodu virgilicus* Zone is a partial range zone. The zone of this name was first proposed by Ritter (1995) in the Virgilian of the North America Midcontinent. Barrick & Heckel (2000) divided it into two separate zones: a Lower *St. virgilicus* Zone and Upper *St. virgilicus* Zone with a boundary at the FAD of *S. holtensis*. Barrick *et al.* (2004) combined two zones into a single *St. virgilicus s.l.* Zone. In a more restricted sense, the *St. virgilicus* Zone is accepted by Chernykh (2002), since it is bounded above by the appearance of *St. simplex*. Here, the extent of the *virgilicus* Zone is somewhat expanded due to the inclusion of the *St. simplex* Zone by Chernykh (2012) in a revised *St. virgilicus* Zone. In the Moscow Basin, the presence of *St. virgilicus* was recorded in the lower part of the Pavlovoposadian Regional Substage on the eastern slope of the Oka-Tsna Swell (Goreva & Alekseev 2010). Currently, the *St. virgilicus* Zone is confidently recognized in the South Urals and in the central regions of the East European Platform.

The *Streptognathodus bellus* Zone is a partial range zone that was first proposed by Chernykh (2000). The lower boundary of the zone coincides with the FAD of the index species *St. bellus*. The zonal assemblage in the South Urals also includes *St. longilatus*, *St. costaeflabellus*, *St. tenuialveus* and others. In the Moscow Basin the index species was found on the Oka-Tsna Swell in the Noginskian Regional Substage. The *St. bellus* Zone can be traced in the central regions of the East European Platform and in the South Urals (Fig. 10).

The *Streptognathodus wabaunsensis* Zone is a partial range zone that was first proposed by Barskov *et al.* (1984*a*) as the lower zone of the Asselian Stage. Currently, this interval is included in the Gzhelian (Davydov *et al.* 1998).The zone is named for *St. wabaunsensis*, whose FAD is the lower boundary of the zone. In addition to the index species, *St. elongatus*, *St. simplex*, and a number of other species of *Streptognathodus* are present. Davydov *et al.* (2012) shows this zone as the *St. wabausensis–St. fissus* Zone after Chernykh (2002), but Chernykh (2012) used the name, the *St. wabausensis* Zone. The *St. wabaunsensis* Zone is very widespread and is distinguished in the central regions of the East European Platform, in the South Urals, Caspian Sea Region, Novaya Zemlya, and in the west of Kazakhstan (Davydov *et. al.* 1998).

East and Southeast Asia

China

Carboniferous deposits of China are recognized in four major stratigraphic provinces, Junggar-Hinggan, Tarim-North China, Qiangtang-South China and Tibet-West Yunnan (Jin *et al.* 2000; Wang & Jin 2003). The faunas of Qiangtang-South China and Tarim-North China have Tethyan affinities, while the fauna of Junggar-Hinggan belongs to the Boreal Realm. The fauna of Tibet-West Yunnan has Gondwana affinities. The best record of Carboniferous conodonts is in the carbonate rocks of South China. Conodonts are less common in Tarim-North China and relatively rare in Junggar-Hinggan and Tibet-West Yunnan. As a result, the Chinese conodont zonation is based largely on South China material. Although endemic species exist, the faunas of other provinces can be correlated to South China.

The first conodont investigation in China was that of Jin (1960), based on Permian material from Nanjing, Jiangsu. Much later, several Carboniferous ramiform conodonts from shales were described by Wang (1974). Wang & Wang (1978) published a paper related with Upper

Devonian–Lower Carboniferous conodonts from carbonate strata in Guizhou. Preliminary zonal research and more systematic conodont studies were started in 1980's in South China (Xiong & Zhai 1985; Wang *et al.* 1987*a,b*), Tarim-North China (Wang & Wang 1983; Wan *et al.* 1983), Tibet-West Yunnan (Qiu 1984; Lin 1989) and Junggar-Hinggan (Li 1986; Zhao 1986). During that time, zonation studies concentrated mainly on the lower Tangbagouan regional stage and especially on the Devonian-Carboniferous (D-C) boundary interval in South China (e.g. Wang & Yin 1984, 1988; Ji & Xiong 1985; Ji *et al*. 1988, 1990). The *Siphonodella*-based lower Tournaisian (=Tangbagouan) standard zonation of Sandberg *et al.* (1978) was followed by almost all Chinese researchers. Ji (1985) studied in detail the phylogeny and taxonomy of *Siphonodella* species and introduced the new subgenus *Eosiphonodella* from Hunan and Guizhou. He proposed a refined *Siphonodella*-based zonation that has been accepted by some European and Chinese researchers (Kaiser *et al*. 2009, 2017; Becker *et al.* 2016; Corradini *et al.* 2017; Hu *et al.* 2020*a*). Dong & Ji (1988) later reported a conodont zonation for upper Tangbagouan through the Permian from Yunnan. Wang (1990) synthesized some previous works and provided a scheme for the Lower Carboniferous, but did not adopt the *Siphonodella* zones of Ji (1985). Tian & Coen (2004, 2005) studied upper Tangbagouan–lower Jiusian conodonts from Guangxi and Yunnan and established a zonation that could be applied to both shallow- and deep-water facies. Based on the carbonate slope succession at the Naqing section, Guizhou, Wang *et al.* (1987*a*) and Wang & Higgins (1989) established a conodont zonation for the upper Jiusian through the lower Permian, which has been gradually revised and refined during the last past 30 years (e.g. Wang 1996; Wang & Qi 2003*a*; Wang *et al.* 2008; Wang *et al.* 2019). An integrated Carboniferous time scale of China and correlation with global stages was introduced by Jin *et al.* (2000) and Wang & Jin (2003) and has been recently refined (Wang *et al.* 2019). The latest Carboniferous zonation, consisting of forty-one zones was recently proposed by Hu *et al.* (2020*a*) and Qi *et al*. (2020). For more detailed information about each zone, such as history, definitions, stratigraphic ranges, correlation and associated species, is given in Hu *et al*. (2020*a*) and Qi *et al*. (2020). A detailed chart showing litho-, bio- and chronostratigraphic correlations among Chinese stratigraphic provinces, Korea, Japan and Southeast Asia is provided (Fig. 11).

Mississippian, Tangbagouan regional stage. The base of the Chinese Carboniferous, the base of the Tangbagouan, coincides with the global D–C boundary. The lower Tangbagouan comprises the seven *Siphonodella* zones of Ji (1985) with one minor alteration. In South China, those zones can be recognized in Guangxi (Ji *et al.* 1987; Wang & Yin 1988; Cheng *et al.* 2015; Li *et al.* 2015), Guizhou (Ji & Xiong 1985; Ji *et al.* 1988) and East Yunnan (Dong & Ji 1988; Dong &

Wang 2006). Qiu (1984) and Lin (1989) reported the *S. sulcata*, *S. bransoni* (=*S. duplicata* M1), *S. quadraplicata*–*S. crenulata*, *S. isosticha* and *Gnathodus semiglaber* zones from the Himalaya area in the Tibet-West Yunnan Province. In West Yunnan, the *S. crenulata* and *S. isosticha* zones are missing (Dong & Wang 2006). The *S. isosticha* Zone was also reported from Jiangsu (Ying 1987) and Hainan (Zhang *et al.* 2001) of South China. Lower Tangbagouan conodonts are generally absent in other stratigraphic provinces. The upper two *Siphonodella* zones were reported from Shaanxi, Qinling Mountains, which was a small terrane located between South China and North China during Carboniferous time (Wang & Wang 2005). In the Tarim Subprovince of the Tarim-North China Province, the *S. isosticha*–*S. obsoleta* Zone was recognized (Zhao *et al.* 2000; Ruan *et al*. 2001) and could be correlated with the *S. isosticha* Zone of South China. The older conodont faunas in Tarim are mainly represented by shallow-water *Polygnathus*, *Bispathodus*, *Clydagnathus* and *Pseudopolygnathus* species (Li 1996; Zhao *et al.* 2000). The *P. inornatus*–*P. purus purus*–*Ps. fusiformis* Assemblage Zone was also found in Tarim and northwest margin of the Junggar Basin (Zhao *et al.* 2000).

The upper Tangbagouan consists of four *Gnathodus* zones (Ji 1985; Tian & Coen 2004). These zones or equivalents can be recognized from East Yunnan (Dong & Wang 2006) and Guangxi (Li *et al.* 2015; Cheng *et al.* 2015) of South China and Shaanxi of Qinling Mountains (Wang & Wang 2005). In Guangdong, Hunan, and Guangxi provinces of South China, shallow-water *Siphonodella* zones, which are correlated with *S. sulcata* through *Gn. punctatus* zones, were also recognized (Ji *et al.* 1990; Ji & Ziegler 1992; Qie *et al.* 2014, 2016).

Jiusian regional stage. The Jiusian conodont succession of China has not been studied in detail. Only the *Pseudognathodus homopunctatus* and *Lochriea commutata* zones are included in the Jiusian. These zones can be recognized in East Yunnan (Dong *et al.* 1987; Dong & Ji 1988; Dong & Wang 2006) and Guangxi (Devuyst *et al.* 2003; Hou *et al.* 2011). In the Pengchong section, Guangxi, the GSSP section for the Viséan Stage, *Ps. homopunctatus* was recorded slightly higher than the boundary marker *Eoparastafella simplex* and is regarded as an auxiliary boundary marker for the basal Viséan (Devuyst *et al.* 2003). The base of the Jiusian is regarded as the base of the Viséan. Outside of South China, the *Mestognathus* cf. *beckmanni* Zone, which was reported from Tarim (Zhao *et al*. 2000), probably represents the lower Jiusian.

Shangsian regional stage. Only two zones, the *Gnathodus bilineatus* Zone and the *Lochriea nodosa* Zone, are recognized in the Shangsian. The base of the *Gn. bilineatus* Zone is tentatively regarded as the base of Shangsian (Wang & Jin 2003). The two zones were identified in East

Yunnan (Dong & Ji 1988; Dong & Wang 2006) and Guizhou (Qi & Wang 2005; Qi *et al.* 2014*a*, b). The *Gn. b. bilineatus* Zone and *L. nodosa* Zone were also reported from Tarim-North China, Gansu and Ningxia of the Qilian-Helan Mountains (Wang & Qi 2003*b*) and the southwest margin of the Tarim Basin (Zhao *et al.* 2000), and can be roughly correlated with the Shangsian. In other stratigraphic provinces, Shangsian conodonts are not recorded.

Dewuan regional stage. The Dewuan comprises three zones, the *Lochriea ziegleri*, *Gnathodus bollandensis* and *Gn. postbilineatus* zones. The *L. ziegleri* Zone is currently only recognized from slope sections in Guizhou, South China (Qi & Wang 2005; Wang *et al.* 2014; Qi *et al.* 2014*a*, 2016), as is the *Gn. postbilineatus* Zone (Hu *et al*. 2017, 2019). The *Gn. bollandensis* Zone, in which the *Gn. postbilineatus* Zone may be included, has been reported from East Yunnan, South China (Dong *et al.* 1987; Dong & Wang 2006) and from Gansu and Ningxia in the Qilian-Helan Mountains, Tarim-North China (Wang & Qi 2003*b*). In the Middle-Tianshan, Xinjiang of the Junggar-Hinggan stratigraphic province, the *Rhachistognathus muricatus* Zone was recognized by Zhao *et al*. (2000), which could represent the upper Dewuan. The *Gn. girtyi collinsoni–Gn. g. simplex* assemblage Zone was reported by Lin (1983) from the Tibet subprovince, which may correlate with part of the Dewuan. A younger fauna consisting of *Rh. muricatus*, *Gn. girtyi simplex*, *Declinognathodus noduliferus s. s.* and *Neognathodus* species, which could represent the upper Dewuan through Luosuan, were recovered from the same study area in the Tibet subprovince (Lin 1989; Zheng *et al.* 2005; Ji *et al.* 2007). Detailed foraminiferal studies from some type localities (Wu, 2008) suggest that the Dewuan can be correlated with the Serpukhovian, but the *Lochriea ziegleri* Zone has not been found there.

Pennsylvanian, Luosuan regional stage. The base of the Luosuan was defined by conodont *Declinognathodus noduliferus s. l.* and is easily correlated with the base of the Bashkirian (Rui *et al.* 1987*a*,*b*). The Luosuan consists of two zones, the *Dec. noduliferus s. l.* and *Idiognathoides sinuatus* zones. The two Luosuan zones or equivalents are widely recognized from Guizhou (e.g. Wang *et al.* 1987*a*; Wang & Qi 2003*a*), East Yunnan (Dong *et al.* 1987; Dong & Ji 1988; Dong & Wang 2006), Guangxi (Cheng *et al.* 2015), Hunan (Tan 1990) and Jiangsu (Ying 1987) of South China, Gansu and Ningxia (Wang *et al*. 1987*b*; Wang & Qi 2003*b*), Southwest Tarim (Zhao *et al*. 2000) and North and West Qinling Mountains, Gansu (Guo *et al*. 2010; Fang *et al.* 2014) of Tarim-North China, Mid-Tianshan (Zhao *et al.* 2000) and Liaoning and Jilin of Junggar-Hinggan (Ding *et al.* 1991; Li *et al.* 2012), and Tibet (Ji *et al.* 2007).

Huashibanian regional stage. The base of the Huashibanian is correlated with the base of the *Neognathodus symmetricus* Zone (Zhang *et al*. 2004). Three zones, the *N. symmetricus*, *Idiognathodus primulus* and "*Streptognathodus*" *expansus* M1 zones, are included in the Huashibanian. The *I. primulus* Zone was first recognized in the Naqing section of Guizhou and can be subdivided into the two subzones by the occurrences of *I. primulus* and "*St*." *expansus*, respectively (Wang *et al.* 1987*a*). Later, this zone was revised to the *I. primulus*–*Idiognathoides sinuatus* Zone (Wang & Higgins 1989), and then split into the *I. primulus*–*N. symmetricus* and *I. primulus*–*N. bassleri* zones (Wang & Qi 2002). The new results of Hu *et al.* (2019) show ed that *I. primulus* is stratigraphically younger than *N. symmetricus*. Consequently, the *I. primulus* Zone is now considered to follow the *N. symmetricus* Zone. The zonal species of the "*St*." *expansus* M1 Zone were found only in deep-water sections in Guizhou (Qi *et al.* 2014*b*, 2016; Hu *et al*. 2017). In East Yunnan, the *N. symmetricus*–*Id. corrugatus* and *N. bassleri* zones (Dong & Ji 1988) or the *I. primulus* and *Id. sulcatus paruvs*–*I. sinuosus* zones (Dong & Wang 2006) probably represent the Huashibanian. In the Tarim-North China, the *Id. corrugatus*–*I. delicatus*–*N. bassleri* assemblage Zone from southeast Tarim (Zhang *et al.* 2000), the *I. delicatus*–*N. bothrops* Zone from North China (Wang & Qi 2003*b*) and the *I. delicatus*–*I. sinuosus* Zone from West Qinling Mountains, Gansu (Guo *et al.* 2010) also could represent part of the Huashibanian.

Dalaun regional stage. The base of the Dalaun was defined by the fusulinid *Profusulinella priscoidea*–*P. parva* Zone, which is older than the traditional Bashkirian–Moscovian boundary marked by *P. aljutovica* (Zhang *et al.* 2008; Zhang *et al.* 2010). However, the conodont data are not sufficient to resolve this level. The Dalaun comprises six zones. The "*Streptognathodus*" *expansus* M2 Zone or the "*St*." *expansus* Zone has been recognized from Guizhou (Qi *et al.* 2014*a*, 2016; Hu *et al.* 2017), Yunnan (Dong & Wang 2006), South China, and Mid-Tianshan (Zhao 1988). A fauna containing "*St*." *suberectus*, *Swadelina einori* and *Idiognathodus sinuosus* was reported from Jilin of Junggar-Hinggan (Lang & Wang 2010) and probably corresponds with upper Huashibanian and lower Dalaun. In Tarim and Junggar, the "*St*." *parvus*– "*St*." *suberectus*–*Gondolella bella* assemblage Zone was recognized (Zhao *et al.* 2000), but it clearly spans a longer stratigraphic interval (likely to the upper *I. podolskensis* Zone) than the "*St*." *expansus* Zone of South China because the appearance of *Sw. concinna* and *G. bella* within this zone. The *Diplognathodus ellesmerensis* Zone has been only recognized from the Naqing section, Guizhou, South China (Wang *et al.* 2008). Outside of Guizhou, the zonal species of the *Mesogondolella donbassica*–*M. clarki* Zone have been found in Yunnan (Dong *et al.* 1987; Dong & Ji 1988; Dong & Wang 2006) and South Tarim (Li 1996). The Chinese species *I. shanxiensis* is very similar to *I.*

podolskensis and *I. obliquus* in both morphology and stratigraphic range. This species group has been found in Liaoning (Ding *et al.* 1991; Lang & Wang 2007) and Jilin (Ding *et al.* 1991), Shanxi (Wan *et al.* 1983), West Qinling Mountains and North Qilian Mountains of Gansu (Guo *et al.* 2010; Fang *et al.* 2014) of Tarim-North China and Guizhou of South China (Wang & Qi 2003*b*). Aside of South China, the *I. podolskensis*/*I. shanxiensis* Zone only represents part of the *I. podolskensis* Zone of South China because the upper two *Swadelina* zones are missing elsewhere.

Xiaodushanian regional stage: The base of the Xiaodushanian was originally defined by the fusulinid *Protriticites subschwagerinoides* Zone (Zhou *et al.* 1987). The *Triticites montiparus* Zone, which can be correlated with the conodont *Idiognathodus turbatus*/*I. sagittalis* Zone in the Moscow Basin (Alekseev 2008), is the second zone of the Xiaodushanian (Zhou *et al.* 1987). However, the base of the Xiaodushanian is tentatively correlated with the *I. turbatus* Zone to fit the provisional Moscovian–Kasimovian boundary (Wang *et al.* 2019). Eleven *Idiognathodus* and *Streptognathodus* zones are included in Xiaodushanian based on the zonation of Hu *et al.* (2020*a*) and the detailed taxonomic revision of Qi *et al.* (2020). Most of these zones are only recognized from the Naqing and adjacent sections in Guizhou, South China (Hu *et al.* 2020*a*, Qi *et al.* 2020). In East Yunnan, Dong & Wang (2006) established a similar zonation for the Xiaodushanian and recognized the *I. guizhouensis* and *I. nashuiensis* zones. Conodont zones or assemblage zones named after *I. magnificus* have been reported frequently from Tarim-North China (e. g. Wan & Ding 1984; Wang & Qi 2003*b*; Su *et al.* 2006; Fang *et al.* 2014), but they are not identical with the *I. magnificus* Zone of South China because the taxonomy and range of *I. magnificus* has been revised (see Hogancamp *et al.* 2017). In Tarim-North China, some *Streptognathodus* zones were established (Wang & Qi 2003*b*; Zhao *et al.* 2000), they can only be roughly correlated with South China zones through the ranges of the zonal species, i.e., *St. elegantulus*, *St. gracilis*, *St. elongatus* and *St. wabaunsensis*.

Japan

Carboniferous conodonts have been recovered mostly from limestone blocks in the Inner Zone of Southwest Japan and span a stratigraphic interval from the upper Tournaisian to Moscovian according to Igo (1994). The first Carboniferous conodont study was that of Igo & Koike (1963, 1964) on Omi Limestone. Subsequent workers (e.g. Igo & Koike 1965; Koike 1967; Igo 1973*a*, 1974*a*; Watanabe 1975) studied the taxonomy of the Carboniferous conodonts in the Omi, Atetsu and Akiyoshi limestones. Koike (1967) studied the fauna from Atetsu Limestone and introduced a zonation consisting of seven zones from ~lower Viséan to ~upper Moscovian and was used as the standard zonation of Japan till the 1990's. Haikawa (1988) integrated previous studies of the Akiyoshi Limestone and established five *Gnathodus* and *Lochriea* zones for the Lower Carboniferous (~Viséan). All the studies before 1994 were summarized and partly revised by Igo (1994). Mizuno (1997) later studied the middle Carboniferous conodonts from the Hina Limestone and proposed a zonation based on *Declinognathodus* and *Neolochriea*. Ishida *et al*. (2013) recently studied the Ko-yama Limestone and presented a lower Viséan to lower Moscovian zonation in which they recognized the *L. ziegleri* Zone. They also summarized the zonations from different limestones in Japan. The youngest Carboniferous (~lower Kasimovian) conodonts, *Gondolella sublanceolata* and *Idiognathodus sulciferus*, were found by Maekawa *et al.* (2018) from limestone boulders in the Mizuboradani Valley, Fukuji district, central Japan. The Japanese zonation can be found in Figure 11, in which the zonations from different limestones are compared.

Southeast Asia

In Southeast Asia, Carboniferous carbonate rocks are widely distributed in Malaya Peninsula (Malaysia, Thailand and Myanmar), Sumatra of Indonesia, East Myanmar, North Vietnam and North Laos (see Metcalfe 1984, fig. 1).

Igo & Koike (1968) first reported Carboniferous conodonts from the Panching Limestone of Bukit Charas, Pahang, Malaysia. Metcalfe (1979) and Lane *et al.* (1979) briefly reported Devonian–Carboniferous conodonts from the Kanthan Limestone of the northern part of Gunong Kanthan, Perak, Malaysia. Metcalfe (1980a, b) presented new taxonomic work on the Panching Limestone and introduced an early Namurian (Bashkirian) zonation, *Declinognathodus inaequalis–Lochriea commutata* and *Dec. japonicus–Rhachistognathus* subzones of the *Dec. noduliferus–Dec. lateralis* Zone. Metcalfe (2002) provided a zonation from Devonian to middle Mississippian of the Kanthan Limestone in which the *Scaliognathus anchoralis*, *L. commutata* and *Gnathodus bilineatus* zones were established for the upper Tournaisian to ~upper Viséan. Metcalfe (2017) provides a recent summary. Tsegab *et al.* (2017) studied the Kinta Limestone (a massive Paleozoic succession that includes the Kanthan Limestone) and introduced an early Devonian to Early Pennsylvanian succession. They have found some key species, for example, *Siphonodella crenulata*, *S. obsoleta*, *Polygnathus bischoffi*, *P. inornatus inornatus*, *Pseudopolygnathus multistriatus* and *Gn. punctatus* and could potentially establish a zonation for lower Tournaisian. However, their illustrated specimens of *Dec. noduliferus* are morphologically closer to *Gn. girtyi simplex*.

Conodonts from the Alas Formation, Sumatra, Indonesia were studied and interpreted as Viséan in age (Metcalfe 1983, 1987), but a zonation was not established due to the limited data. In the east-central Myanmar, Carboniferous conodonts were recovered from the Taungnyo Group by Metcalfe & Aung (2014). They are represented by species belonging to the upper *Gnathodus typicus*–*Protognathodus cordiformis* Zone and lower part of the *Scaliognathus anchoralis* Zone of upper Tournaisian.

In Peninsular Thailand (South Thailand), Igo (1973*b*) described Mississippian (upper Tournaisian–lower Viséan) conodonts from the Ko Yo, Songkhla for the first time. Sashida *et al.* (1993) reproduced the results of Igo (1973*b*). In the North Thailand, Igo (1974*b*) reported lower Permian conodonts that were later interpreted as Upper Pennsylvanian species (Mei & Henderson 2002) because they are dominated by *Streptognathodus elegantulus*. Chairangsee *et al.* (1990) reported some Viséan conodonts, e.g. *Cavusgnathus naviculus*, *Lochriea commutata, Pseudognathodus homopunctatus* and *Mestognathus* sp., from Loei. Sashida *et al*. (1993) reported *L. commutata* from the Chiang Dao Chert sequence in Chiang Mai. Randon *et al*. (2006) studied conodonts from the Chiang Dao Chert sequence in more detail and recognized some key species of upper Tournaisian–lower Viséan species, e.g. *Scaliognathus anchoralis* ssp., *Ps. homopunctatus* and *Gn. bilineatus*. Metcalfe & Aung (2014) summarized the Carboniferous conodont zonation of Thailand as *Sc. anchoralis, Pd. homopunctatus, L. commutata* and *Gn. bilineatus* zones from upper Tournaisian to lower Viséan.

Korea

The Carboniferous lithostratigraphic succession of Korea (Fig. 11) is similar to that of North China, where clastic-dominated Pennsylvanian strata unconformablely overlie Ordovician units. Lee (1985) studied the conodonts from the Hongjeom Formation in Yeongwol Area, Gangwondo and introduced a zonation consisting of *Idiognathoides sinuatus, Id. sulcatus, Idiognathodus sinuosus* and *I. delicatus* subzones from Bashkirian to Moscovian. Park (1989) and Park & Sun (2001) introduced a Moscovian *Neognathodus bothrops* Zone for the Manghang Formation and the *N. roundyi* Zone for the Geumcheon Formation in the Taebaek area, Kangwondo. It is worth mentioning that some illustrated *I. delicatus* from Korea are close to *I. podolskensis* or *I. shanxiensis* (Park & Sun 2001, pl. 1, figs. 8, 9) and *I. magnificus* (Park & Sun 2001, pl. 1, fig. 12). Also, *Streptognathodus elegantulus* was identified and illustrated by Park & Sun (2001) from the

Geumcheon Formation. Lee *et al.* (1988) reported the *Id. opimus*, lower *I. delicatus*, upper *I. delicatus*, *I. tersus* and *St. elongatus* zones from the Mitan area, Gangwondo. Park (1993) established the *St. elegantulus* zone in the Bamchi Formation in the Yeongwol area, Gangwon and assigned the formation an Asselian to Sakmarian age. Wang *et al.* (2018) revised the conodonts of the Bamchi Formation and presented a zonation from the upper Gzhelian *St. bellus* to upper Asselian *St. barskovi* zones. The Carboniferous conodont zonation of Korea can be summarized as Bashkirian *Id. sinuatus* and *I. sinuosus* zones, Moscovian *N. bothrops*, *I. delicatus* (*I. podolskensis*) and *N. roundyi* zones, Kasimovian *I. tersus* Zone, and Gzhelian *S. bellus* Zone.

Gondwana and associated terranes

South America

A strong latitudinal temperature gradient was well established across South America during the Carboniferous and Permian (Iannuzzi & Rössler 2000). Conodonts are only known from Carboniferous marine rocks of the northern half of South America. Adverse climatic conditions are inferred from the continental and shallow-marine transitional settings with siliciclastic sedimentation, including diamictites and glacial deposits during the major glacial or icehouse stage, described by Limarino *et al.* (2014). The intense cold stage ended earlier in the Andean basins, the retro-arc area of Paganzo Basin, and the intraplate Amazonas-Solimões basin (Bashkirian–Moscovian boundary interval) than in the intraplate Paraná Basin (Permian). In South America, only a single Mississippian conodont fauna with the cosmopolitan species *Gnathodus bilineatus*, *Gn. girtyi* and *Lochriea mononodosa* is known from the Amazonas Basin (Lemos & Medeiros 1996*a*). It could represent a late Viséan or Serpukhovian warm marine water interval, perhaps the early Serpukhovian warm–temperate climate event related to the Paraca Floral Realm described in South America (Limarino *et al.* 2014). The drift of western Gondwana from Mississippian mid-latitudes to Pennsylvanian lower latitudes produced climatic conditions more favorable to conodonts. Conodont associations align approximately with Midcontinent North American faunas, in a similar way that other marine faunas correspond to the Midcontinent–Andean Realm of Ross (1967) based on foraminiferal biogeography. However, several Eurasian Pennsylvanian species also occur in the South American associations.

Lower–Middle Pennsylvanian conodonts (Fig. 12) have been only recovered from the Amazonas Basin (Cardoso *et al.* 2017*a*,*b*; and authors herein) and the Andean fold-and-thrust belt in Bolivia (Suárez Riglos *et al.* 1987). The Amazonas type succession includes transgressive marine (Monte Alegre and Itaituba formations) to restricted carbonates with evaporites (Nova Olinda Formation) and regressive continental red beds (Andirá Formation). The Monte Alegre Formation and the lower part of the Itaituba Formation yielded conodont faunas of the *Neognathodus symmetricus* Interval Zone in the zonal scheme of Cardoso *et al.* (2017*b*). This zone was defined as the first occurrence of *N. symmetricus* together with *Adetognathus lautus* and *Rhachistognathus muricatus* and correlates with middle Morrowan. The occurrences of *Idiognathodus incurvus* and *Neognathodus* sp. A of Grayson in beds of the lower part of the Itaituba Formation may be useful for the recognition of the Atokan Stage. The *Diplognathodus coloradoensis* Interval Zone was defined as ranging from the first occurrence of *D. coloradoensis* up to the first occurrence of *D. ellesmerensis*. The first occurrence of *D. coloradoensis* seems to be close to the first occurrence of *D. orphanus* in the Amazonas Basin, and to a widespread horizon related to a general transgressive pulse (shale marker 65 in Lemos & Medeiros 1996*b*). The *D. ellesmerensis* Interval Zone was defined from the first occurrence of *D. ellesmerensis* up to the first occurrence of *I. itaitubensis*. The lowest occurrence of *D. ellesmerensis* is close to that of *D.* aff. *D. orphanus* and the disappearance of "*Streptognathodus*" *expansus* and *N. symmetricus*. The presence of *I. izvaricus* suggests correlation of the upper part of the Itaituba Formation with the Kashirian Substage (late Atokan) in the Moscow Basin. The disappearance of *Idiognathoides* species and the first occurrence of *I. amplificus* with *N. bothrops* and *N. colombiensis* allowed correlation of the upper beds of the Itaituba Formation with the lower Desmoinesian. The occurrence of *N. asymmetricus* in the lower part of the Nova Olinda Formation was also correlated with the lower Desmoinesian. The presence of *I. izvaricus*, *I.* cf. *I. praeobliquus*, *I.* cf. *I. obliquus* and *I. podolskensis* probably indicate immigration of Eurasian taxa characteristic of the Palaeo-Tethys Ocean into the Amazonas Basin during the Desmoinesian, although the latter three species are also known in North America (Cardoso *et al*. 2017*a*). *Idiognathodus* cf. *ignisitus* and *I. rectus* support the correlation of the Nova Olinda Formation with the *I. rectus*/*I. iowensis* Zone of the upper lower Desmoinesian of the North American Midcontinent (Barrick *et al*. 2013*a*). An isolated conodont association of *N. inaequalis, D. iowensis, I. crassadens* and *I. ignisitus* also indicates this level. The presence of *D. iowensis* suggests a late Desmoinesian age (Swade 1985).

In northern Brazil, a similar succession of conodont faunas occurs in the western continuation of the Amazonas basin, the so-called Solimões Basin (Lemos 1992*a,b*). To the east, the Parnaíba Basin differs from the equivalent Amazonian formations in its predominantly terrigenous, littoral to continental sedimentary character, although the Piauí Formation has produced conodonts correlated with the Itaituba Formation (Campanha and Rocha-Campos 1979; Rocha-Campos & Archangelsky 1985).

Lower to Middle Pennsylvanian strata in the Subandean area have been best studied in the Bolivian part of the Andean fold-and-thrust belt. *Idiognathoides sinuatus* was reported in the Huarina fold-and-thrust belt (Grader *et al.* 2008), whereas *Diplognathodus ellesmerensis* and *D.* aff. *orphanus* were illustrated from the Copacabana Formation (Merino Redo & Blanco Rojas 1990). Atokan–Desmoinesian conodonts such as those from the Amazonas Basin, including *Neognathodus asymmetricus*, were reported from a few beds in the lower member of the Copacabana Formation (Dalenz Farjat & Merino Redo 1994; Sakagami & Mizuno 1994; Heckel, in Grader *et al*. 2008). Similar species associations (*Adetognathus lautus*, *D. orphanus*, *N. asymmetricus*, *N. bothrops*, *N. colombiensis*, and *Mesogondoelella clarki*) were described by Stibane (1967), Stibane & Forero (1969) and Rabe (1977) from the North Andean area (Perija Range and Colombian Andes).

Virgilian conodonts are known from only a few marine beds in the continental succession of the Amazonas (Cardoso *et al*. 2017*b*). They are low abundance and diversity associations consisting of *Streptognathodus firmus* and *Adetognathus flexus*. Suárez-Riglos *et al.* (1987) defined the *St. elongatus* Zone based on the range of the eponymous species in the middle Copacabana Formation in the Andean Basin and correlated it with the Virgilian Conemaugh Group of the Central Appalachians. The overlying *Idiognathodus ellisoni* Zone corresponds to the range of this species from the Virgilian into the early Permian.

North Africa

The conodont faunas in North Africa are mainly known from the Béchar Basin (Algeria), where Weyant & Pareyn (1975) and Weyant (1985) defined twelve interval zones between the Tournaisian and the Moscovian. Isolated faunas are known from strata of the Moroccan Meseta at North, and other basins at South, Illizi, Reggan, Ahnet, Mouydir, Timimoun and Tindouf, although detailed sequences are usually lacking.

Tournaisian. Conodonts of the *Protognathodus kockeli* Zone are locally known in the Djebel Anter and Gjebel Grouz (northwards the Béchar Basin) according to Alberti (1972) and Lemosquet *et al.* (1980) and the zone is also known from the Maider area, Anti-Atlas (Becker *et al.* 2012). Conodonts of the *Siphonodella sulcata* Zone were reported from the Saoura Valley (Béchar Basin, Algeria), and in the Tafilat and Dra Valley (Anti–Atlas). Illustrations are scarce and two pictures identified as specimens of *S. sulcata* (see Weyant 1985, pl. 5, figs. 1–2) from the Saoura Valley (Algeria) correspond to younger species, such as *S. bransoni* and *S. duplicata*. Other lower Tournaisian faunas consist of *S. quadruplicata* (Alberti 1972) and *Pseudopolygnathus dentilineatus* from the Taoudeni Basin (Lys 1964), the Saoura Valley (Conrad *et al.* 1970), and the Ahnet-Mouydir area (Conrad 1985). Middle to upper Tournaisian *S. crenulata* was described in the Saoura Valley (Weyant 1985) and *Dollymae bouckaerti* in the North of Djebel Antar (Lemosquet *et al.* 1980). The upper Tournaisian *Scaliognathus anchoralis* Zone is well represented at the top of the Hassi Sguilma Formation in the Saoura Valley (Conrad *et al.* 1970; Nemyrovska *et al*. 2006) with *Sc. anchoralis* and *Doliognathus latus*. It was usually correlated with the occurrence of *Pseudopolygnathus pinnatus* in the Timimoun Basin, the "Dalle des Iridet" in the Ahnet-Mouydir area (Conrad 1985), the Dejel Bega area of the eastern Anti-Atlas (Wendt *et al*. 2001) and the transgressive bed of the Teguentour Shale (Wendt *et al.* 2009).

Viséan. The early Viséan *Pseudognathodus homopunctatus* Zone occurs in the El Hariga Formation of the Saoura Valley (Nemyrovska *et al.* 2006). The index species is above the first occurrence of *Lochriea saharae*, although the potential for correlation of the latter species must be tested. Bełka (in Wendt *et al.* 2001, 2009) recognized the lower Viséan *Gnathodus texanus* Zone in low diversity associations of *Gn. pseudosemiglaber* and *Gn. semiglaber* in the eastern Anti-Atlas and the Ahnet-Mouydir area. Lemosquet *et al.* (1980) indicated a condensed succession at Teniet el Haidour (Djebel Grouz, north Béchar Basin) with a crinoidal limestone with conodonts of the *Scaliognathus anchoralis* and *Pd. homopunctatus* zones (Weyant & Pareyn 1975). Blocks of this limestone and older rocks are in the flysch facies of the early Viséan in Ben-Zireg. Beds assigned to the *Pd. homopunctatus* Zone above an unconformity on Devonian strata were recognized in the Antar-Horreit area and Djebel Anter, Anti-Atlas (Lemosquet *et al.* 1980). Lower Viséan flysch facies lie unconformably on older rocks in the Azrou Khénifra area of Central Morocco, where Rodríguez *et al.* (2020) found carbonate turbidites with *Mestognathus* cf. *beckmanni*.

The *Gnathodus praebilineatus* Zone was recognized in the Waulsortian mounds of the eastern Anti-Atlas area by Wendt *et al.* (2001). The first occurrence of *Gn. praebilineatus* coincides with the first occurrence of *Lochriea commutata* and *Gn. girtyi* aff. *intermedius* in the Béchar basin (Nemyrovska *et al.* 2006). The *Gn. bilineatus* Zone was described from the Béchar Basin (Lemosquet & Pareyn 1985; Weyant 1985; Nemyrovska *et al.* 2006), the Djebel Grouz (Weyant & Pareyn 1975), and the microbial mounds of the eastern Anti-Atlas (Wendt *et al.* 2001). The *L. nodosa* Zone was recognized in the Djebel Grouz and the Béchar Basin according to Weyant (1985), the Djebel Berga Limestone of the Ahnet-Mouydir area (Conrad 1985), and the eastern Anti-Atlas (Wendt *et al.* 2001). Neqqazi *et al.* (2014) reported *L. nodosa* from the Our Cherrat area (Northern Morocco, Moroccan Meseta) and *L. mononodosa* from the Azrou Khénifra area (Central Morocco).

Serpukhovian. The lower part of the Serpukhovian is not clearly recognized on the basis of conodont faunas, although the occurrences of uppermost Viséan to Serpukhovian *Lochriea multinodosa,* and particularly of *L. ziegleri* (Weyant 1985, pl. 6, fig. 25) were reported from the Béchar Basin. *Cavusgnathus naviculus* is known in the same basin and in the Anhnet Mouydir area (Weyant 1985; Wendt *et al.* 2009, 2010), but it was not used to subdivide the *L. nodosa* Zone. Upper Serpukhovian *Gnathodus bollandensis* was reported from the Adarouch area of Central Morocco (Cózar *et al.* 2011). Conrad *et al.* (1980) recognized the *Adetognathus unicornis* Zone from the Hassi-Taïbine Gypsum of the Reggan Basin, where the nominal species occurs with *C. naviculus* and *Gn. bollandensis*. The zone was also described by Weyant (1985) in the Béchar Basin, where it includes an unconformity with paleokarst between the Djenien and the Tagnana formations. The infilling of the cavities contain conodonts correlated with the Lower and Upper *Rhachistognathus muricatus* zones of North America (Weyant 1985; Manger *et al*. 1985). Shallow water species such as *A. lautus*, *A. unicornis*, *Rh. muricatus* and *Rh. minutus* are typical. Other shallow-water conodonts such as *Rh.* aff. *muricatus*, *Clydagnathus windsorensis* and *C. unicornis* together with *Gn. girtyi,* are known from probably upper Viséan to Serpukhovian beds interbedded with evaporites in the Rhadames and Mourzouk basins, Libya, (Weyant & Massa 1985).

Bashkirian and Moscovian. Declinognathodus noduliferus and *Dec. lateralis* are known in the Béchar Basin and were correlated with the lower Bashkirian (Weyant 1985). Both of these Bashkirian species and *Dec. japonicus* were also illustrated in the Rhadames and Mourzouk basins (Weyant & Massa 1985). *Declinognathodus noduliferus* was also reported from the Central Morocco and correlated with the *Dec. noduliferus* Zone (Cózar *et al.* 2011). The identification of conodonts of the *Dec. noduliferus* Zone from the Djebel Berga Limestone (Wendt *et al.* 2009, 2010) is controversial, and the occurrence of *Idiognathoides sulcatus sulcatus*? in the Tindouf Basin by Cózar *et al.* (2014) is also debatable based on the illustrated material. Conodonts assigned to the *Idiognathodus delicatus* Zone require revision. They were described from the upper Bashkirian beds of the Béchar Basin and upward to upper Moscovian units northwards this basin (van den Boogaard 1983; Weyant 1985; Manger *et al.* 1985). They are also known from the Reggan, Illizi Basin Rhadames and Mourzouk basins (Conrad *et al.* 1980; Weyant 1985; Weyant & Massa 1985).

Turkey

Thick and almost complete Devonian and Carboniferous sequences are represented in Taurides, which are interpreted to have been a peri-Gondwana terrane (Torsvik & Cocks 2017). Atakul-Özdemir (2012) gave a listing of previous Carboniferous conodont work in the Taurides. Devonian–Carboniferous boundary beds dominated by shale and calcareous limestone intercalations are well exposed near Naltaş in the eastern Taurides **(**Atakul-Özdemir 2019). The revised D–C boundary zonation of Corradini *et al*. (2017) was used. The base of the Carboniferous was placed at the base of the *Protognathodus kockeli* Zone, which included the *Siphonodella sulcata* Zone of previous workers. The *S. bransoni*, *S. duplicata,* and *S. hassi* zones were recognized in higher strata. Younger Mississippian conodont faunas were described from shallow-water strata in the eastern Taurides by Atakul-Özdemir (2015). Although lacking *Siphonodella*, the *Polygnathus inornatus* Zone was correlated to the *S. isosticha*–Upper *S. crenulata* Zone of Sandberg *et al.* (1978). The overlying *Gnathodus cuneiformis–P. communis communis* Zone was correlated with the lower *Gn. typicus* Zone of Lane *et al.* (1980) and comparable zones in Europe. Sparse late Viséan and Serpukhovian conodonts from the Central Taurides (Atakul-Özdemir *et al.* 2019) were assigned to the *Gn. girty girtyi* and *Gn. girtyi simplex* zones. The Mid-Carboniferous boundary in the Central Taurides (Atakul-Özdemir *et al.* 2012) was recognized by the uppermost Serpukhovian *Rhachistognathus muricatus* Zone and the lowermost Bashkirian *Declinognathodus inaequalis–Dec. noduliferus* Zone. Ekmekçi & Kozur (1999) reported Moscovian species of *Idiognathodus* and *Neognathodus* from the Central Taurides.

Other terranes of Turkey apparently formed away from Gondwana, perhaps more closely to Bohemia (Torsvik & Cocks 2017). Conodonts recovered from the Griotte-type nodular pelagic limestone of the Istanbul terrane, northwestern Turkey, were assigned to the upper part of the *Siphonodella sandbergi* Zone through the *S. isosticha*–Upper *S. crenulata* Zone by Göncüoğlu *et al.* (2004). Radiolarian cherts from the Mersin Melange, southern Turkey yielded conodonts of the *Gnathodus typicus* to the *Scaliognathus anchoralis–Doliognathus latus* Zone (Okuyucu *et al.* 2018). Çapkinoğlu (2003) recovered what are likely Late Pennsylvanian *Idiognathodus, Streptognathodus,* and *Gondolella* species from the Eastern Pontides, in northeastern Turkey.

Iran

Carboniferous conodonts have been reported from three areas in Iran, the Tabas area (Shotori Range) on the central-east Iran microplate, the Alborz Mountains in northern Iran, and in the Shahreza-Abadeh-Hambast belt in the southwest central Iran. Yazdi (1999) described a series of faunas ranging from the late Devonian to the early Pennsylvanian in the Tabas area. The oldest Mississippian fauna belongs to the Lower *Siphonodella crenulata* Zone. Faunas of the *S. isosticha*–Upper *S. crenulata*, *Gnathodus typicus (Neopolygnathus communis carina)*, and *Scaliognathus anchoralis–Doliognathus latus* zones extend to the top of the Shistu Formation. The base of the overlying Sardar Formation yielded sparse faunas that were tentatively assigned to the *Gn. texanus* Zone. The Viséan lower *Gn. bilineatus* Zone occurs above, but is was uncertain if the upper *Gn. bilineatus* Zone is present. In the upper part of the Sardar Formation, early Pennsylvanian conodont faunas were assigned to their Bashkirian *Idiognathoides sinuatus–Id. corrugatus–Id. sulcatus* Zone and the uppermost levels produced *Mesogondolella clarki*. Bahrami *et al.* (2011) demonstrated the presence of the Lower *S. praesulcata* through the *S. sandbergi* zones in a condensed interval (2 m) at the base of the Mush Horizon, and Lower S. *crenulata* through *Sc. anchoralis–Do. latus* zone faunas in the thicker overlying section of the Shishtu-2 subformation.

Habbibi *et al.* (2008) reviewed previous conodont work in the Alborz Mountains of northern Iran. The conodont succession at the Shahmirzad section extends from the lower *Siphonodella praesulcata* through the *S. sandbergi* zones into the lower *S. crenulata* Zone. An undifferentiated Lower *Gnathodus typicus* to *Scaliognathus anchoralis–Doliognathus latus* faunal interval lies higher in the section.

In the southwest central Iran region, near Isfahan, Iran, Boncheva *et al.* (2007) reported conodonts from the Asadabad section in the Shahreza-Abadeh-Hambast belt, which they described as the most complete Carboniferous section in Iran. Although no *Siphonodella* species were recovered, in the lower Shishtu Formation they recognized the Lower *S. duplicata*–Lower *S. crenulata* zones based on the range of *Bispathodus* and *Pseudopolygnathus* species. *Gnathodus* species allowed the recognition of the *Gn. typicus* and *Scaliognathus anchoralis–Doliognathus latus* zones, but the youngerst Mississippian strata did not yield age-diagnostic conodonts. The Mississippian–Pennsylvanian boundary was identified in the Sardar Formation by the occurrence of *Rhachistognathus muricatus* followed by that of *Declinognathodus noduliferus noduliferus.*

Bahrami *et al.* (2014) studied the conodont succession across the Mid-Carboniferous boundary at four sections, two in the Tabas area and two in the Sanadaj-Sirjan Northwest Trend zone near Isfahan, one of which was the Asadabad section. Above Serpukovian faunas with *Lochriea ziegleri* and *L. nodosa,* they recovered, conodonts of the *Rhachistognathus muricatus, Declinognathodus noduliferus, Idiognathodies sinuatus–Rh. minutus,* and *Idiognathodus sinuosus* zones.

Pakistan and India

Pogue *et al.* (1992) reported Carboniferous conodonts from the Jafar Kandao Formation in the Peshawar Basin, Pakistan. The fauna of *Gnathodus semiglaber, Gn. pseudosemiglaber* and *Eotaphrus* sp. from the middle of the formation is late Tournaisian in age. The uppermost sample contained a *Rhachistognathus* species and a possible example of *Mesogondolella donbasica*, which suggested an early Pennsylvanian age. Molloy *et al.* (1997) recovered Late Devonian to middle Tournaisian conodonts from the Ali Masjid Formation in the Khyber region, northwest Pakistan. Faunas assigned to the Lower *Siphonodella duplicata* and Lower *S. crenulata* zones rest unconformably above upper Famennian strata. In the same region, Khan *et al.* (2004) reported a fauna from the Tabai Limestone that included *Gnathodus semiglaber* and *Pseudopolygnathus multistriatus*, which was interpreted to represent a *Scaliognathus anchoralis–Doliognathus latus* Zone fauna that is late Tournaisian in age.

Vannay (1993) illustrated conodonts from the Lipak Formation in upper Lahual, India, that included *Pseudopolygnathus primus,* which indicated an age of late Famennian (Upper *Polygnathus expansa* Zone) to middle Tournasian (Lower *Siphonodella crenulata* zone), according to Draganits *et al.* (2002). Draganits *et al.* (2002) reported a series of faunas from Lipak Formation the Pin Valley of Spiti (India), the younger faunas of which are dominated by *Clydagnathus* species occurring with species of *Bispathodus* and *Pseudognathodus*, and which interpreted to be as young as the middle Tournaisian Lower *S. crenulata* Zone. The other reports of Carboniferous conodonts from the Himalaya region by V. J. Gupta were considered to be unreliable by Webster *et al.* (1993).

Australia

In eastern Australia, faunas of the *Siphonodella sandbergi* to *S. crenulata* zones are widespread because of a major transgressive event (New South Wales, Jenkins 1974; Queensland, Mawson & Talent 1987, 1999). The reports of older *Siphonodella* faunas in eastern Australia (e.g. Pickett 1981; Mory & Crane 1982) were reinterpreted by Mawson & Talent (1999) to be most likely *S.*

crenulata Zone faunas. Druce (1969) reported Tournaisian faunas from the Bonaparte Gulf Basin in western Australia, which range in age from the *S. sulcata* Zone into the *Scaliognathus anchoralis–Doliognathus latus* Zone. Nicoll & Druce (1979) reported similar early to middle Tournaisian conodont faunas from the Fairfield Group in the Canning Basin, but precise zonal correlations were difficult because of the endemic nature of the fauna.

Druce (1970) described small faunas of early Tournaisan (*Siphonodella*), late Tournaisian (*Scaliognathus anchoralis–Doliognathus latus* Zone), and Viséan age (*Gnathodus texanus* and *Gn. girtyi*) from the Yarrol Basin, Queensland. Conodont faunas equivalent to North America Midcontinent FU 2 (*Gn. punctatus*) to FU 6 (*Gn. bulbosus* and *Taphrognathus*) were reported by Jenkins (1974) from New South Wales. Viséan faunas from Queensland and New South Wales were described further by Jenkins (1993), who erected four zones above the range of *Scaliognathus anchoralis*. The lower three were defined on the FADs of species of the *Patrognathus–Montognathus* lineage. The youngest Viséan zone was based on the co-occurrence of *Gn. texanus* and *Gn. bilineatus*. Druce (1973), Nicoll & Gorter (1995), and Nicoll (in Mory & Haig 2011) reported rare Viséan conodonts in the Bonaparte Gulf, Canning, and Carnarvon basins in western Australia.

The rare occurrences of Pennsylvanian conodonts in eastern Australia (Palmieri 1969; Jones & Roberts 1975) and from South Island of New Zealand (Jenkins & Jenkins 1971; Forsyth *et al.* 2006) appear to be restricted to exotic terranes of uncertain origin (Nicoll & Metcalfe 2001).

Summary

Carboniferous conodont biostratigraphy comprises a series of regional zonations that reflect the changing paleogeographic distribution of taxa during the series of orogenies that led to the formation of Pangaea. Biostratigraphic correlation is further complicated by the presence of distinct shallow-water conodont biofacies that evolved in partially isolated basins that lacked free interchange with offshore and deep-water conodont biofacies. The rise of the Late Paleozoic ice ages and the corresponding multiple short-lived eustatic events that produced cyclical depositional sequences also makes reliable determination of species ranges problematic. Fortunately, sufficient species have a global distribution and can effect high quality global correlations at some levels, and for this reason conodont taxa have been incorporated into the definitions of global Carboniferous chronostratigraphic units. A single standard Carboniferous conodont zonation could be constructed, but it would fall to the regional zonations to effect high-resolution correlation between major chronostratigraphic boundaries within each region.

The lowermost Mississippian is zoned by well-known *Siphonodella* species, except in shallow-water facies, where other polygnathids are used. The extinction of siphonodellids was followed by a middle Tournaisian radiation of *Gnathodus* species, which are used to define many zones to the end of the Mississippian, although the species-level taxonomy of *Gnathodus* is still unsettled. A short late Tournaisian maximum in diversity, characterized by several distinct short-lived genera such as *Scaliognathus*, allows for easy correlation of this interval. It was followed by the lower diversity faunas of *Gnathodus* species and carminate genera through the Viséan and Serpukhovian. In the late Viséan and Serpukhovian, a burst of diversification in *Lochriea* provides additional biostratigraphic resolution. Shallow-water zonations based on genera like *Cavusgnathus* and *Mestognathus* are more difficult to correlate.

Near the base of the Pennsylvanian, the extinction of typical Mississippian taxa was followed by a major radiation of new gnathodid genera. A number of genera characterize Bashkirian and early Moscovian faunas and are incorporated into the zonations: *Rhachistognathus, Declinognathodus, Neognathodus, Idiognathoides,* and *Idiognathodus*. By the middle of the Moscovian, fewer genera remained to be used in zonations: *Idiognathodus, Neognathodus* and *Swadelina,* although species diversity was high. In the middle Kasimovian and Gzhelian, only two genera are commonly used, *Idiognathodus* and *Streptognathodus,* within which peaks of high species diversity were followed by lower diversity intervals, especially during the Gzhelian. The distribution of species first and last appearances reflect the cyclicity imposed by eustatic events. Near the very end of the Gzhelian, a rapid rediversification of *Streptognathodus* species extended into the early Cisuralian.

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Fig. 1. North American Mississippian conodont zonations. Left two columns are the Midcontinent Mississippian zonation of Lane & Brenckle (2005) with faunal units (FU). Right column is the Mississippian zonation commonly used in the western United States, as compiled from sources discussed in the text. SERPUK. = Serpukhovian. L = Lower; Up = Upper. Genus abbreviations: *A-Adetognathus; "Ap."-"Apatognathus"* (see text); *B-Bactrognathus; C-Cavusgnathus; Do-Doliognathus; E-Eotaphrus; Gn-Gnathodus; "H."-"Hindeodus"* (see text); *Ne-Neopolygnathus; P-Polygnathus; Pd-Pseudognathodus; Pr-Protognathodus; Ps-Pseudopolygnathus; Rh-Rhachistognathus; S-Siphonodella; Sc-Scaliognathus.*

Fig. 2. North American Early-Middle Pennsylvanian conodont zonation. Modified from Barrick et al. (2013). Major cyclothems are in capitals. Genus abbreviations: *Dec-Declinognathodus; I-Idiognathodus; Id-Idiognathoides; N-Neognathodus; Sw-Swadelina.*

Fig. 3. North America Late Pennsylvanian conodont zonation. Modified from Barrick et al. (2013). Major cyclothems are in capitals. Genus abbreviations: *I-Idiognathodus; St-Streptognathodus.*

Fig. 4. Correlation of global stages of the Mississippian and part of the Lower Pennsylvanian and regional substages in the Western Europe with the conodont zones differentiated in deep-water settings, shallow-water platforms of North-central Europe and zones based on shallow-water *Polygnathus*/*Pseudopolygnathus*, *Mestognathus* and *Cavusgnathus* species. Arnsb.=Arnsbergian, Chokier.=Chokierian, Kinders.=Kinderscoutian, Marsd.=Marsdenian, Yeadon=Yeadonian. Genus abbreviations: *Dol-Dollymae; L-Lochriea*; *M-Mestognathus; T- Taphrognathus;* other abbreviations are given in captions to Figs. 1-3.

Fig. 5. Conodont zonation for the Donets Basin, Ukraine, and correlations to regional and global chronostratigraphic units. Slightly modifed from Nemyrovska (2017). Genus abbreviations are given in captions to Figs. 1-4.

Fig. 6. Mississippian **(**Lower Carboniferous) conodont zonations for the East European Platform, Timan-Pechora Province and Pericaspian Depression. Genus abbreviations are given in captions to Figs. 1-4.

Fig. 7. Mississippian (Lower Carboniferous) conodont zonations for the Urals. Genus abbreviation: *Emb-Embsaygnathus*; other abbreviations are given in captions to Figs. 1-4.

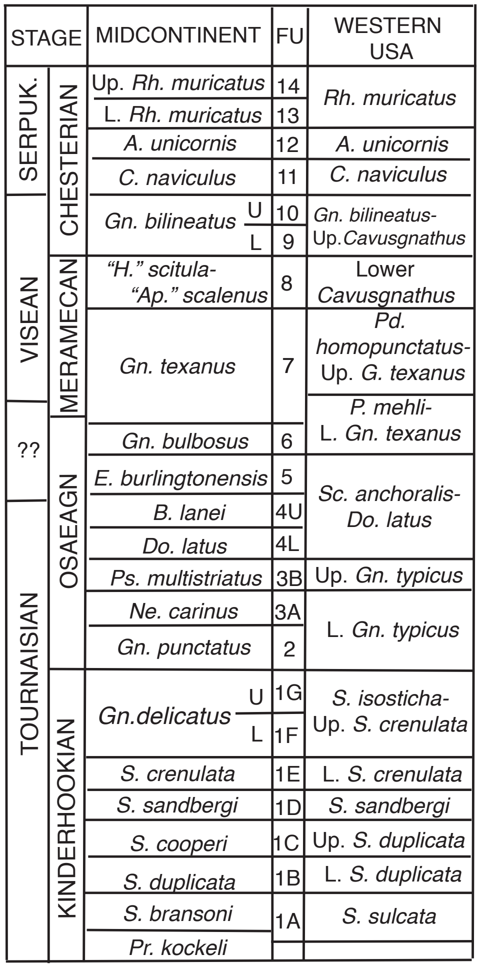
Fig. 8. Mississippian (Lower Carboniferous) conodont zonations for the Transcaucasus, North Caucasus, Kazakhstan and South Tian Shan. Abbreviations: Sar.=Sargardonian Substage, Bais.=Baisaian Substage, It.=Itelgiuinian Substage, Ak.=Aksarsian Substage. Genus abbreviations are given in captions to Figs. 1-4.

Fig. 9. Mississippian (Lower Carboniferous) Mississippian conodont zonations for the Novaya Zemlya and Kolyma-Omolon Region. Genus abbreviations are given in captions to Figs. 1-4.

Fig. 10. Pennsylvanian (Middle and Upper Carboniferous) conodont zonations for the East European Platform, Timan-Pechora Province and Pericaspian Depression. Genus abbreviations are given in captions to Figs. 1-4.

Fig. 11. Summary of Carboniferous conodont zonations of East and Southeast Asia. Most of the formations and litho-units are not completely shown in the figure due to biostratigraphic overlap, unless they are marked with the same background shading in succession. Formation or litho-unit suffixed by a "*" indicates the zonation was not established by the original author(s) but summarized by the authors here. For Qiangtang-South China, Nbc. = Nanbiancun. Genus abbreviations: *D-Diplognathodus; Mg-Mesogondolella*; other abbreviations are given in captions to Figs. 1-4.

Fig. 12. Pennsylvanian conodont zones described in the northern part of South America according to Suárez Riglos *et al*. (1987) and Cardoso *et al*. (2017*b*), and correlation with the global stages, and North American and Western European regional stages. Duckmant. =Duckmantian; Kas.=Kasimovian.



STAGE		MIDCONTINENT	FU	WESTERN USA
SERPUK.	CHESTERIAN	Up. *Rh. muricatus*	14	*Rh. muricatus*
		L. *Rh. muricatus*	13	
		A. unicornis	12	*A. unicornis*
		C. naviculus	11	*C. naviculus*
VISEAN		*Gn. bilineatus* U	10	*Gn. bilineatus*-Up. *Cavusgnathus*
		Gn. bilineatus L	9	
	MERAMECAN	*"H." scitula*-*"Ap." scalenus*	8	Lower *Cavusgnathus*
		Gn. texanus	7	*Pd. homopunctatus*-Up. *G. texanus*
				P. mehli-L. *Gn. texanus*
??	OSAEAGN	*Gn. bulbosus*	6	
		E. burlingtonensis	5	*Sc. anchoralis*-*Do. latus*
TOURNAISIAN		*B. lanei*	4U	
		Do. latus	4L	
		Ps. multistriatus	3B	Up. *Gn. typicus*
		Ne. carinus	3A	L. *Gn. typicus*
		Gn. punctatus	2	
	KINDERHOOKIAN	*Gn.delicatus* U	1G	*S. isosticha*-Up. *S. crenulata*
		Gn.delicatus L	1F	
		S. crenulata	1E	L. *S. crenulata*
		S. sandbergi	1D	*S. sandbergi*
		S. cooperi	1C	Up. *S. duplicata*
		S. duplicata	1B	L. *S. duplicata*
		S. bransoni	1A	*S. sulcata*
		Pr. kockeli		

Fig. 1

STAGE		ZONATIONS			CYCLOTHEM
KASIMOVIAN	DESMOINESIAN		I. sulciferus		Checkerboard
		N. roundyi	Sw. nodocarinatus		LOST BRANCH Norfleet
			Sw. neoshoensis		ALTAMONT Farlington
??			I. delicatus		Coal City Pawnee U. FORT SCOTT
MOSCOVIAN			I. acutus		L. FORT SCOTT
		N. asymmetricus	I. rectus/ I. iowaensis		Bevier VERDIGRIS Fleming Russell Creek UPPER TIAWAH Wainwright
		N. caudatus	I. amplificus/ I. obliquus		INOLA DONELEY Sam Creek McCURTIN
		N. bothrops	unzoned		SEVILLE (ILL.)
	ATOKAN	N. colombiensis			cyclothems generally not recognized below Desmoinesian
		N. atokaensis			
BASHKIRIAN		N. nataliae	Id. convexus	Baesemann & Lane 1985	
	MORROWAN	N. bassleri	I. klapperi		
			I. sinuosus		
			N. bassleri		
		N. symmetricus	N. symmetricus		
		N. higginsi	Id. sinuatus		
			Dec. noduliferus		

Fig. 2

STAGE		ZONE	CYCLOTHEM
GZHELIANN	VIRGILIAN	*St. binodosus*	U. HUGHES CREEK
		St. farmeri	L. HUGHES CREEK AMERICUS
		St. flexuosus	Five Point
		St. bellus	Falls City Brownville
		St. virgilicus (sensu stricto)	Grandhaven Dover Elmont Reading Wakarusa Burlingame Winzler HOWARD TOPEKA Curzon Hartford DEER CREEK Avoca
		St. vitali	LECOMPTON
		I. simulator	Spring Branch Clay Creek OREAD
KASIMOVIANN		*St. zethus*	Toronto CASS
	MISSOURIAN	*I. eudoraensis*	Iatan South Bend STANTON
		St. gracilis	Plattsburg Wyandotte IOLA DEWEY Cherryvale Hogshooter
		I. confragus	DENNIS
		I. cancellosus	SWOPE
		I. turbatus	HERTHA
		I. eccentricus	Exline

Fig. 3

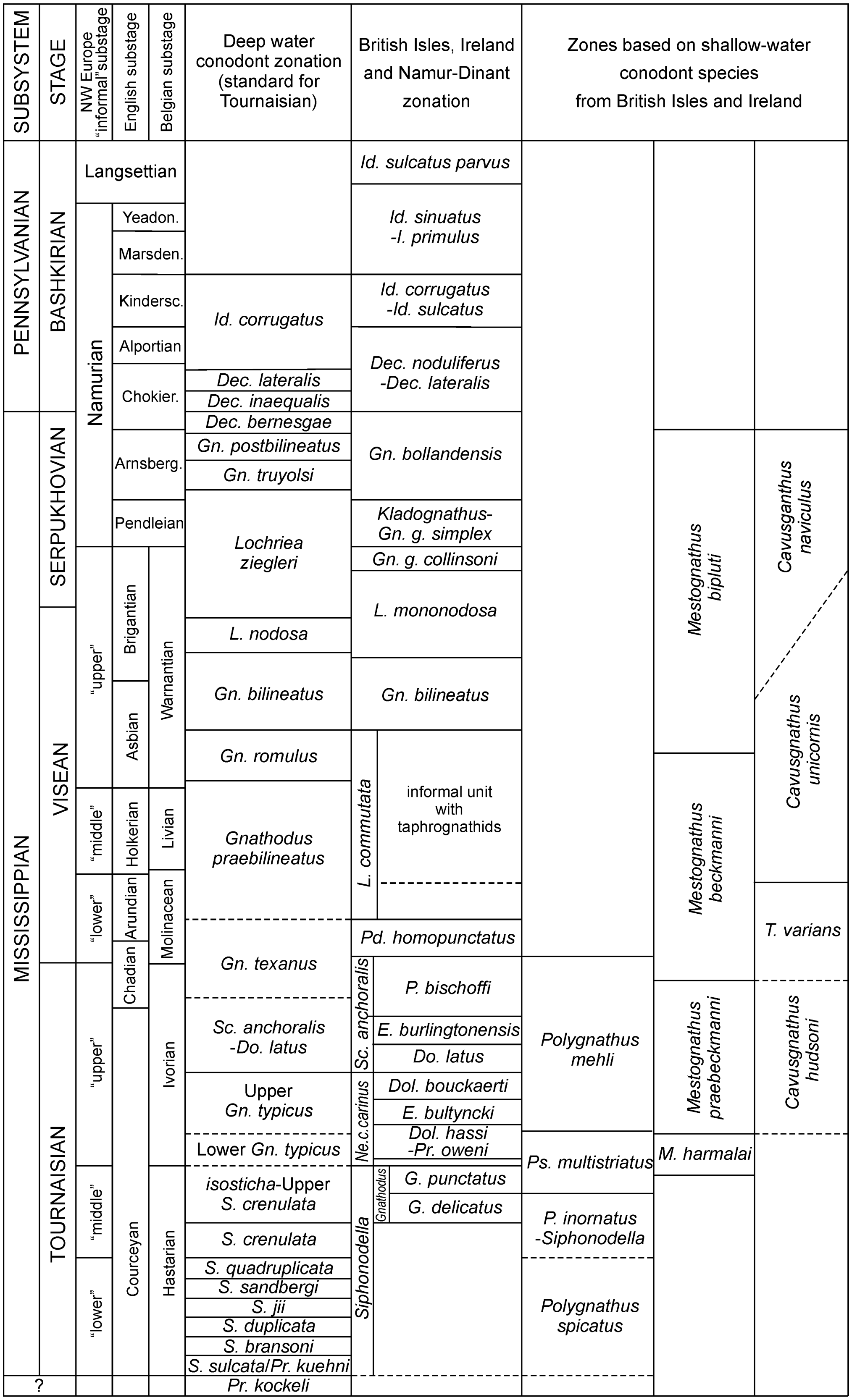
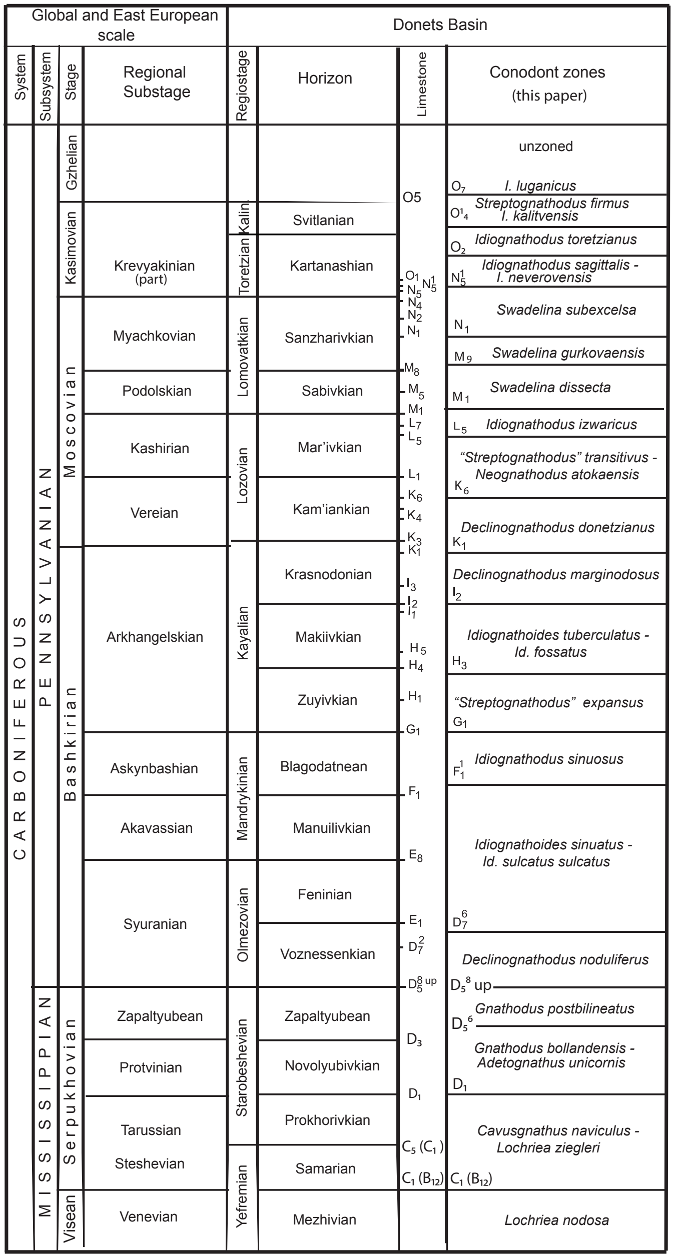
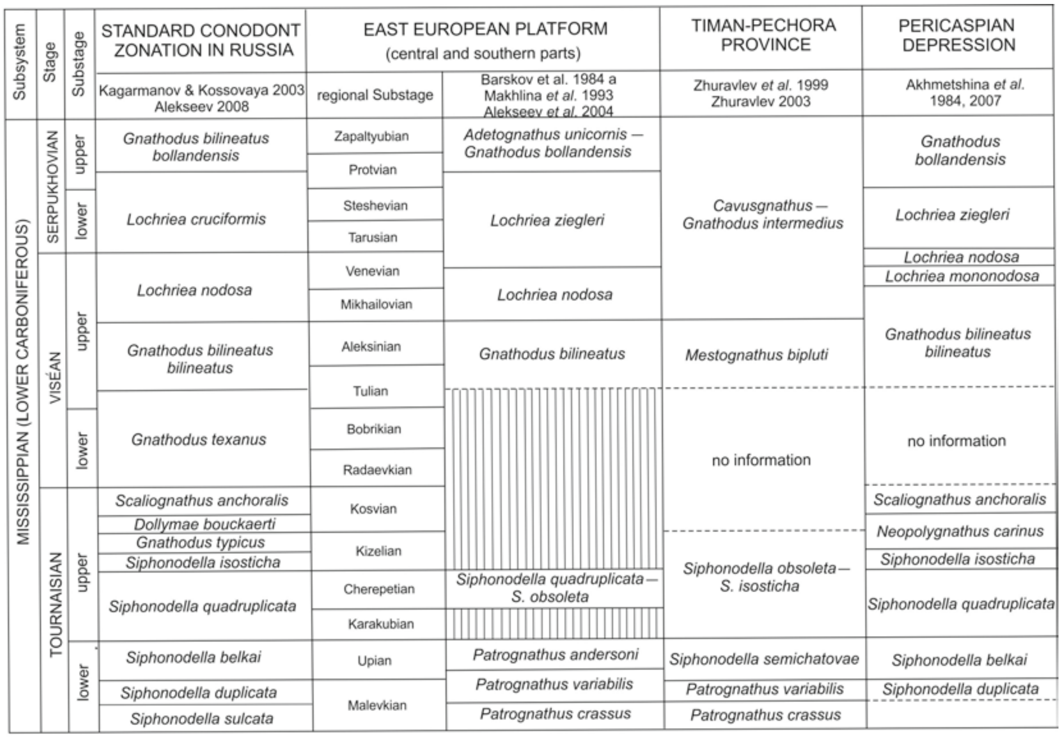

SUBSYSTEM
STAGE
NW Europe "informal" substage
English substage
Belgian substage
Deep water conodont zonation (standard for Tournaisian)
British Isles, Ireland and Namur-Dinant zonation
Zones based on shallow-water conodont species from British Isles and Ireland
PENNSYLVANIAN
MISSISSIPPIAN
?
BASHKIRIAN
SERPUKHOVIAN
VISEAN
TOURNAISIAN
Langsettian
Namurian
"upper"
"middle"
"lower"
"upper"
"middle"
"lower"
Yeadon.
Marsden.
Kindersc.
Alportian
Chokier.
Arnsberg.
Pendleian
Brigantian
Asbian
Holkerian
Arundian
Chadian
Courceyan
Warnantian
Livian
Molinacean
Ivorian
Hastarian
Id. corrugatus
Dec. lateralis
Dec. inaequalis
Dec. bernesgae
Gn. postbilineatus
Gn. truyolsi
Lochriea ziegleri
L. nodosa
Gn. bilineatus
Gn. romulus
Gnathodus praebilineatus
Gn. texanus
Sc. anchoralis -Do. latus
Upper Gn. typicus
Lower Gn. typicus
isosticha-Upper S. crenulata
S. crenulata
S. quadruplicata
S. sandbergi
S. jii
S. duplicata
S. bransoni
S. sulcata/Pr. kuehni
Pr. kockeli
Id. sulcatus parvus
Id. sinuatus -I. primulus
Id. corrugatus -Id. sulcatus
Dec. noduliferus -Dec. lateralis
Gn. bollandensis
Kladognathus- Gn. g. simplex
Gn. g. collinsoni
L. mononodosa
Gn. bilineatus
L. commutata
informal unit with taphrognathids
Pd. homopunctatus
Sc. anchoralis
P. bischoffi
E. burlingtonensis
Do. latus
Ne.c.carinus
Dol. bouckaerti
E. bultyncki
Dol. hassi -Pr. oweni
Siphonodella
Gnathodus
G. punctatus
G. delicatus
Polygnathus mehli
Ps. multistriatus
P. inornatus -Siphonodella
Polygnathus spicatus
Mestognathus bipluti
Mestognathus beckmanni
Mestognathus praebeckmanni
M. harmalai
Cavusganthus naviculus
Cavusgnathus unicornis
T. varians
Cavusgnathus hudsoni

Fig. 4.



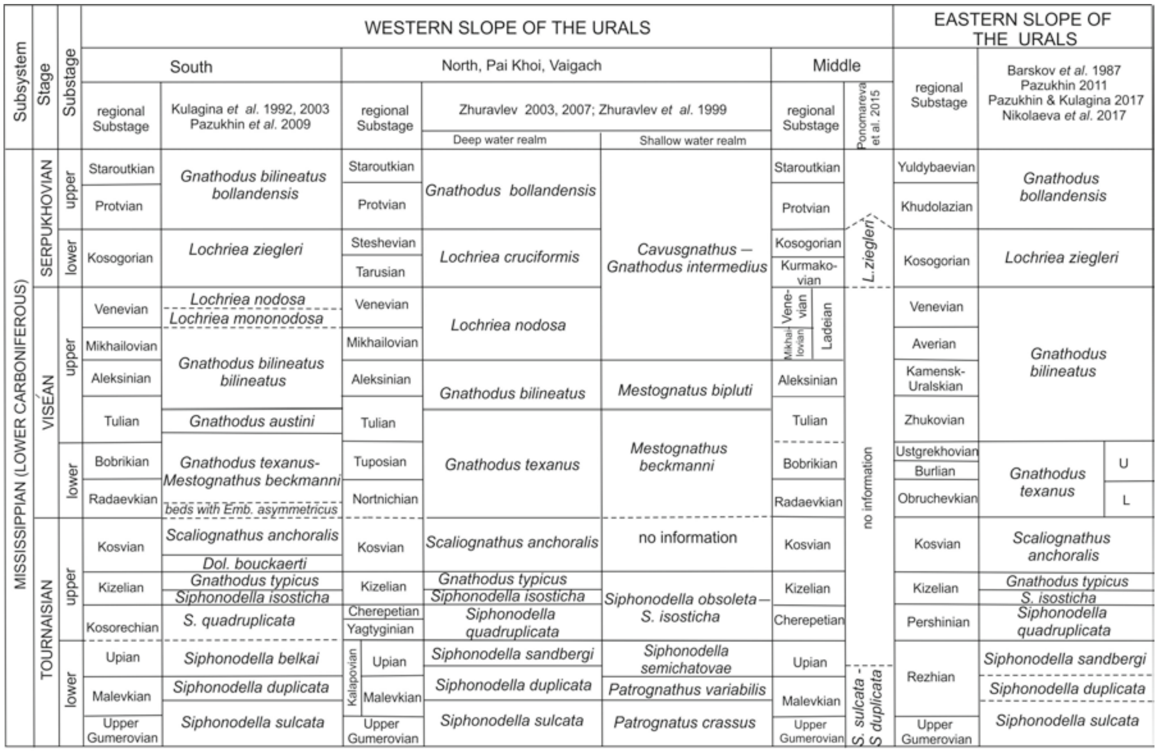
Global and East European scale				Donets Basin			
System	Subsystem	Stage	Regional Substage	Regiostage	Horizon	Limestone	Conodont zones (this paper)
CARBONIFEROUS	PENNSYLVANIAN	Gzhelian					unzoned O_7 *I. luganicus*
		Kasimovian	Krevyakinian (part)	Kalin.	Svitlanian	O5	O^1_4 *Streptognathodus firmus I. kalitvensis*
				Toretzian	Kartanashian	O_1 N_5^1 N_5	O_2 *Idiognathodus toretzianus* N_5^1 *Idiognathodus sagittalis - I. neverovensis*
		Moscovian	Myachkovian	Lomovatkian	Sanzharivkian	N_4 N_2 N_1 M_8	N_1 *Swadelina subexcelsa* M_9 *Swadelina gurkovaensis*
			Podolskian		Sabivkian	M_5 M_1	M_1 *Swadelina dissecta*
			Kashirian	Lozovian	Mar'ivkian	L_7 L_5 L_1	L_5 *Idiognathodus izwaricus* K_6 *"Streptognathodus" transitivus - Neognathodus atokaensis*
			Vereian		Kam'iankian	K_6 K_4 K_3	K_1 *Declinognathodus donetzianus*
		Bashkirian	Arkhangelskian	Kayalian	Krasnodonian	K_1 I_3 I_2	I_2 *Declinognathodus marginodosus*
					Makiivkian	I_1 H_5 H_4	H_3 *Idiognathoides tuberculatus - Id. fossatus*
					Zuyivkian	H_1 G_1	G_1 *"Streptognathodus" expansus*
			Askynbashian	Mandrykinian	Blagodatnean	F_1	F_1^1 *Idiognathodus sinuosus*
			Akavassian		Manuilivkian	E_8	*Idiognathoides sinuatus - Id. sulcatus sulcatus*
			Syuranian	Olmezovian	Feninian	E_1	D_7^6
					Voznessenkian	D_7^2 $D_5^{8\ up}$	*Declinognathodus noduliferus* D_5^8 up
	MISSISSIPPIAN	Serpukhovian	Zapaltyubean	Starobeshevian	Zapaltyubean	D_3	*Gnathodus postbilineatus* D_5^6
			Protvinian		Novolyubivkian	D_1	*Gnathodus bollandensis - Adetognathus unicornis* D_1
			Tarussian		Prokhorivkian	C_5 (C_1)	*Cavusgnathus naviculus - Lochriea ziegleri*
			Steshevian	Yefremian	Samarian	C_1 (B_{12})	C_1 (B_{12})
		Visean	Venevian		Mezhivian		*Lochriea nodosa*

Fig. 5



Subsystem	Stage	Substage	STANDARD CONODONT ZONATION IN RUSSIA	EAST EUROPEAN PLATFORM (central and southern parts)		TIMAN-PECHORA PROVINCE	PERICASPIAN DEPRESSION
			Kagarmanov & Kossovaya 2003 Alekseev 2008	regional Substage	Barskov et al. 1984 a Makhlina *et al.* 1993 Alekseev *et al.* 2004	Zhuravlev *et al.* 1999 Zhuravlev 2003	Akhmetshina *et al.* 1984, 2007
MISSISSIPPIAN (LOWER CARBONIFEROUS)	SERPUKHOVIAN	upper	*Gnathodus bilineatus bollandensis*	Zapaltyubian	*Adetognathus unicornis — Gnathodus bollandensis*	*Cavusgnathus — Gnathodus intermedius*	*Gnathodus bollandensis*
				Protvian			
		lower	*Lochriea cruciformis*	Steshevian	*Lochriea ziegleri*		*Lochriea ziegleri*
				Tarusian			
	VISÉAN	upper	*Lochriea nodosa*	Venevian	*Lochriea nodosa*		*Lochriea nodosa* *Lochriea mononodosa*
				Mikhailovian			
			Gnathodus bilineatus bilineatus	Aleksinian	*Gnathodus bilineatus*	*Mestognathus bipluti*	*Gnathodus bilineatus bilineatus*
				Tulian		no information	no information
		lower	*Gnathodus texanus*	Bobrikian			
				Radaevkian			
	TOURNAISIAN	upper	*Scaliognathus anchoralis* *Dollymae bouckaerti*	Kosvian			*Scaliognathus anchoralis* *Neopolygnathus carinus*
			Gnathodus typicus *Siphonodella isosticha*	Kizelian		*Siphonodella obsoleta — S. isosticha*	*Siphonodella isosticha*
			Siphonodella quadruplicata	Cherepetian	*Siphonodella quadruplicata — S. obsoleta*		*Siphonodella quadruplicata*
				Karakubian			
		lower	*Siphonodella belkai*	Upian	*Patrognathus andersoni*	*Siphonodella semichatovae*	*Siphonodella belkai*
			Siphonodella duplicata *Siphonodella sulcata*	Malevkian	*Patrognathus variabilis* *Patrognathus crassus*	*Patrognathus variabilis* *Patrognathus crassus*	*Siphonodella duplicata*

Fig. 6



Subsystem	Stage	Substage	WESTERN SLOPE OF THE URALS							EASTERN SLOPE OF THE URALS		
			South		North, Pai Khoi, Vaigach			Middle				
			regional Substage	Kulagina *et al.* 1992, 2003 Pazukhin *et al.* 2009	regional Substage	Zhuravlev 2003, 2007; Zhuravlev *et al.* 1999		regional Substage	Ponomareva et al. 2015	regional Substage	Barskov *et al.* 1987 Pazukhin 2011 Pazukhin & Kulagina 2017 Nikolaeva *et al.* 2017	
						Deep water realm	Shallow water realm					
MISSISSIPPIAN (LOWER CARBONIFEROUS)	SERPUKHOVIAN	upper	Staroutkian	*Gnathodus bilineatus bollandensis*	Staroutkian	*Gnathodus bollandensis*	*Cavusgnathus — Gnathodus intermedius*	Staroutkian		Yuldybaevian	*Gnathodus bollandensis*	
			Protvian		Protvian			Protvian		Khudolazian		
		lower	Kosogorian	*Lochriea ziegleri*	Steshevian Tarusian	*Lochriea cruciformis*		Kosogorian Kurmakovian	*L. ziegleri*	Kosogorian	*Lochriea ziegleri*	
	VISÉAN	upper	Venevian	*Lochriea nodosa* *Lochriea mononodosa*	Venevian	*Lochriea nodosa*		Venevian Mikhailovian Ladeian	no information	Venevian	*Gnathodus bilineatus*	
			Mikhailovian	*Gnathodus bilineatus bilineatus*	Mikhailovian					Averian		
			Aleksinian		Aleksinian	*Gnathodus bilineatus*	*Mestognatus bipluti*	Aleksinian		Kamensk-Uralskian		
			Tulian	*Gnathodus austini*	Tulian	*Gnathodus texanus*	*Mestognathus beckmanni*	Tulian		Zhukovian		
		lower	Bobrikian	*Gnathodus texanus-Mestognathus beckmanni*	Tuposian			Bobrikian		Ustgrekhovian Burlian	*Gnathodus texanus*	U
			Radaevkian	*beds with Emb. asymmetricus*	Nortnichian			Radaevkian		Obruchevkian		L
	TOURNAISIAN	upper	Kosvian	*Scaliognathus anchoralis* *Dol. bouckaerti*	Kosvian	*Scaliognathus anchoralis*	no information	Kosvian		Kosvian	*Scaliognathus anchoralis*	
			Kizelian	*Gnathodus typicus* *Siphonodella isosticha*	Kizelian	*Gnathodus typicus* *Siphonodella isosticha*	*Siphonodella obsoleta — S. isosticha*	Kizelian		Kizelian	*Gnathodus typicus* *S. isosticha*	
			Kosorechian	*S. quadruplicata*	Cherepetian Yagtyginian	*Siphonodella quadruplicata*		Cherepetian		Pershinian	*Siphonodella quadruplicata*	
		lower	Upian	*Siphonodella belkai*	Kalapovian Upian	*Siphonodella sandbergi*	*Siphonodella semichatovae*	Upian	*S. sulcata - S duplicata*	Rezhian	*Siphonodella sandbergi*	
			Malevkian	*Siphonodella duplicata*	Malevkian	*Siphonodella duplicata*	*Patrognathus variabilis*	Malevkian			*Siphonodella duplicata*	
			Upper Gumerovian	*Siphonodella sulcata*	Upper Gumerovian	*Siphonodella sulcata*	*Patrognatus crassus*	Upper Gumerovian		Upper Gumerovian	*Siphonodella sulcata*	

Fig. 7

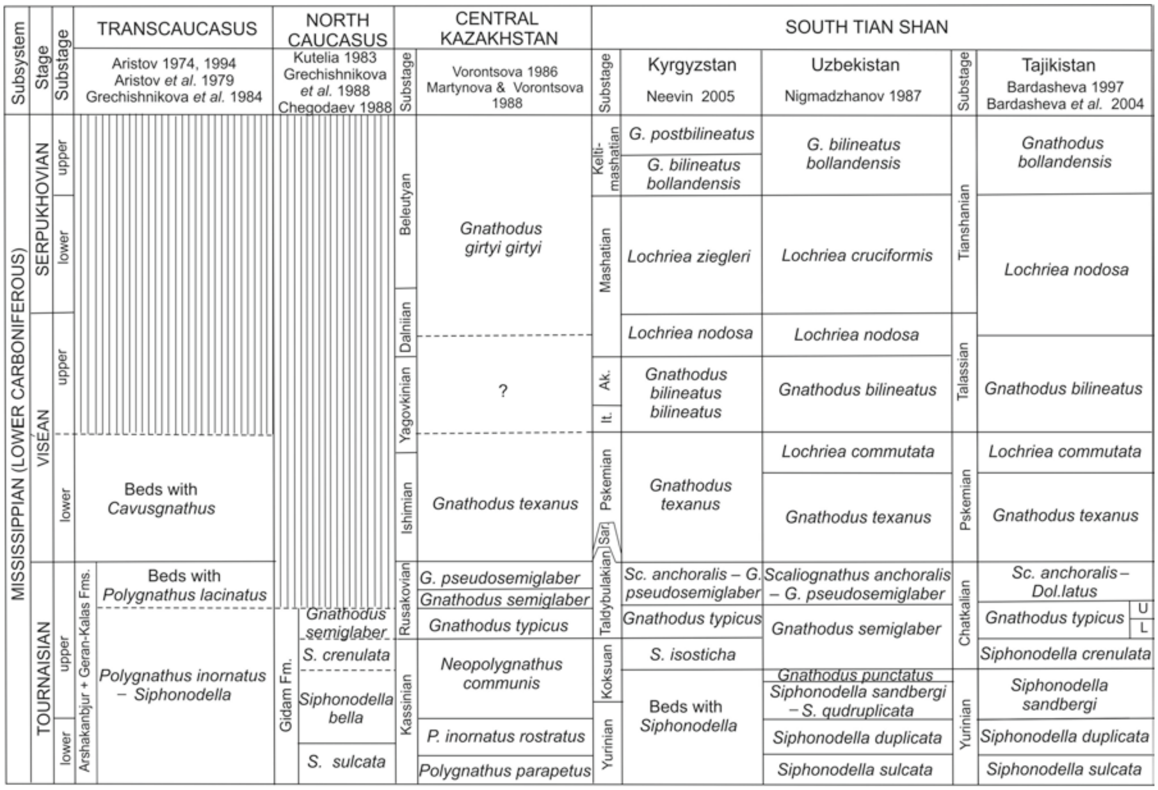

Subsystem
Stage
Substage
TRANSCAUCASUS
Aristov 1974, 1994
Aristov et al. 1979
Grechishnikova et al. 1984
NORTH CAUCASUS
Kutelia 1983
Grechishnikova et al. 1988
Chegodaev 1988
CENTRAL KAZAKHSTAN
Substage
Vorontsova 1986
Martynova & Vorontsova 1988
SOUTH TIAN SHAN
Substage
Kyrgyzstan
Neevin 2005
Uzbekistan
Nigmadzhanov 1987
Substage
Tajikistan
Bardasheva 1997
Bardasheva et al. 2004
MISSISSIPPIAN (LOWER CARBONIFEROUS)
SERPUKHOVIAN
upper
lower
VISEAN
upper
lower
TOURNAISIAN
upper
lower
Beds with Cavusgnathus
Arshakanbjur + Geran-Kalas Fms.
Beds with Polygnathus lacinatus
Polygnathus inornatus – Siphonodella
Gidam Fm.
Gnathodus semiglaber
S. crenulata
Siphonodella bella
S. sulcata
Beleutyan
Dalniian
Yagovkinian
Ishimian
Rusakovian
Kassinian
Gnathodus girtyi girtyi
?
Gnathodus texanus
G. pseudosemiglaber
Gnathodus semiglaber
Gnathodus typicus
Neopolygnathus communis
P. inornatus rostratus
Polygnathus parapetus
Kelti-mashatian
Mashatian
Ak.
It.
Pskemian
Sar.
Taldybulakian
Koksuan
Yurinian
G. postbilineatus
G. bilineatus bollandensis
Lochriea ziegleri
Lochriea nodosa
Gnathodus bilineatus bilineatus
Gnathodus texanus
Sc. anchoralis – G. pseudosemiglaber
Gnathodus typicus
S. isosticha
Beds with Siphonodella
G. bilineatus bollandensis
Lochriea cruciformis
Lochriea nodosa
Gnathodus bilineatus
Lochriea commutata
Gnathodus texanus
Scaliognathus anchoralis – G. pseudosemiglaber
Gnathodus semiglaber
Gnathodus punctatus
Siphonodella sandbergi – S. qudruplicata
Siphonodella duplicata
Siphonodella sulcata
Tianshanian
Talassian
Pskemian
Chatkalian
Yurinian
Gnathodus bollandensis
Lochriea nodosa
Gnathodus bilineatus
Lochriea commutata
Gnathodus texanus
Sc. anchoralis – Dol.latus
Gnathodus typicus
U
L
Siphonodella crenulata
Siphonodella sandbergi
Siphonodella duplicata
Siphonodella sulcata

Fig. 8

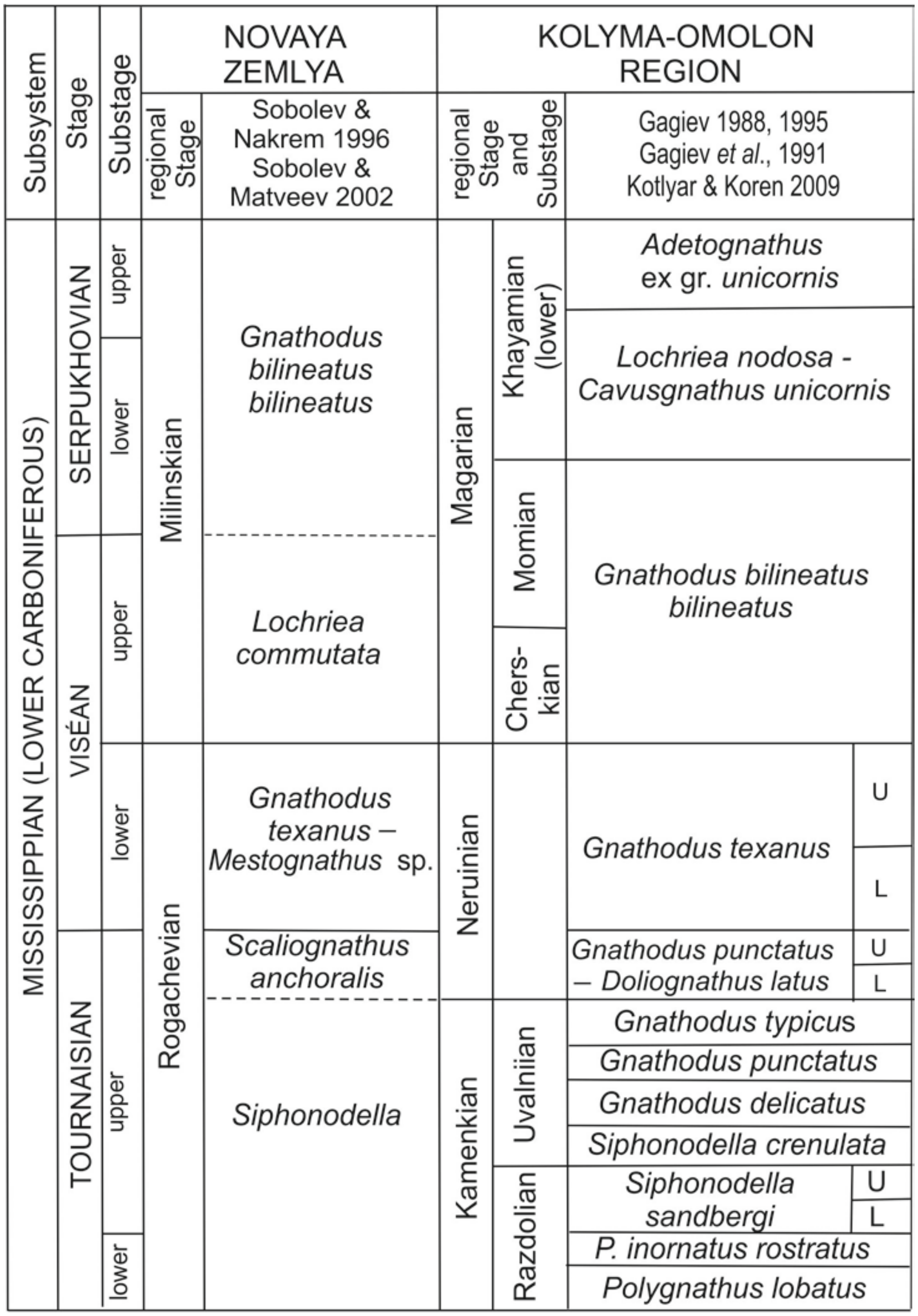
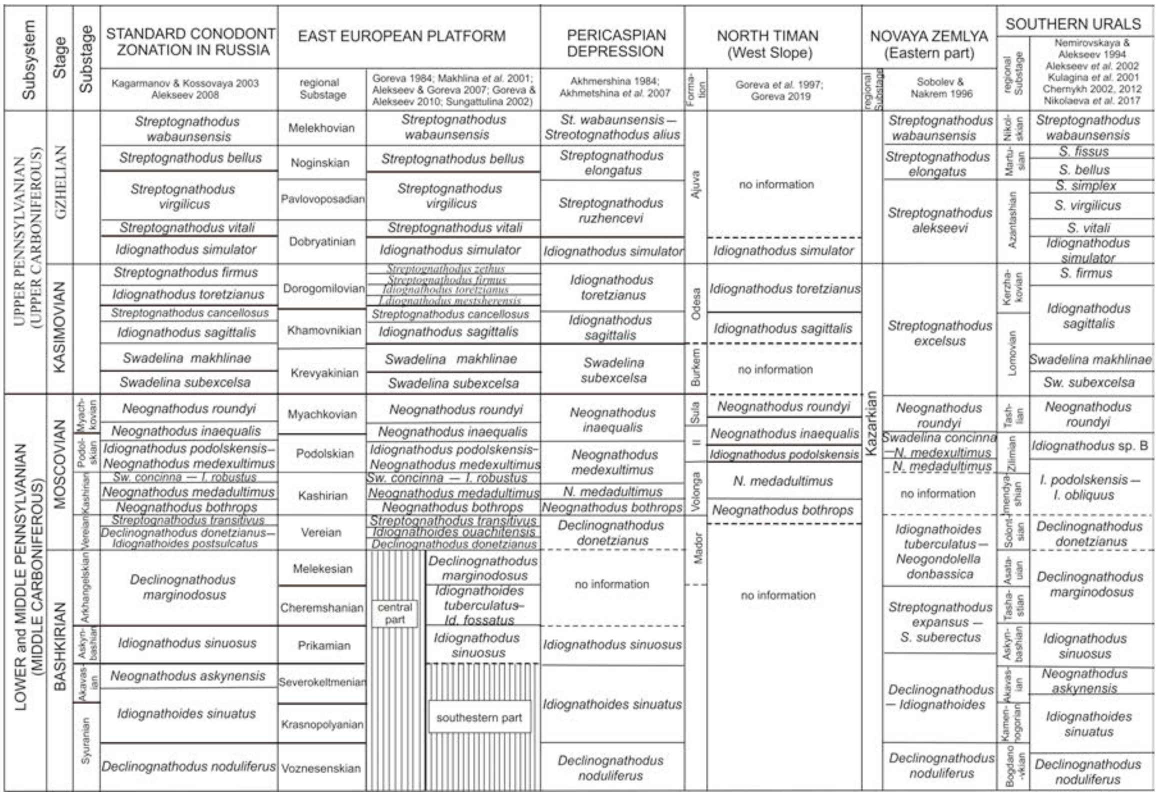

Subsystem
Stage
Substage
NOVAYA ZEMLYA
regional Stage
Sobolev & Nakrem 1996 Sobolev & Matveev 2002
KOLYMA-OMOLON REGION
regional Stage and Substage
Gagiev 1988, 1995 Gagiev et al., 1991 Kotlyar & Koren 2009
MISSISSIPPIAN (LOWER CARBONIFEROUS)
SERPUKHOVIAN
VISÉAN
TOURNAISIAN
upper
lower
upper
lower
upper
lower
Milinskian
Rogachevian
Gnathodus bilineatus bilineatus
Lochriea commutata
Gnathodus texanus – Mestognathus sp.
Scaliognathus anchoralis
Siphonodella
Magarian
Neruinian
Kamenkian
Khayamian (lower)
Momian
Chers-kian
Uvalniian
Razdolian
Adetognathus ex gr. unicornis
Lochriea nodosa - Cavusgnathus unicornis
Gnathodus bilineatus bilineatus
Gnathodus texanus
U
L
Gnathodus punctatus – Doliognathus latus
U
L
Gnathodus typicus
Gnathodus punctatus
Gnathodus delicatus
Siphonodella crenulata
Siphonodella sandbergi
U
L
P. inornatus rostratus
Polygnathus lobatus

Fig. 9



Subsystem	Stage	Substage	STANDARD CONODONT ZONATION IN RUSSIA	EAST EUROPEAN PLATFORM		PERICASPIAN DEPRESSION	NORTH TIMAN (West Slope)		NOVAYA ZEMLYA (Eastern part)		SOUTHERN URALS	
			Kagarmanov & Kossovaya 2003 Alekseev 2008	regional Substage	Goreva 1984; Makhlina *et al.* 2001; Alekseev & Goreva 2007; Goreva & Alekseev 2010; Sungattulina 2002)	Akhmershina 1984; Akhmetshina *et al.* 2007	Formation	Goreva *et al.* 1997; Goreva 2019	regional Substage	Sobolev & Nakrem 1996	regional Substage	Nemirovskaya & Alekseev 1994 Alekseev *et al.* 2002 Kulagina *et al.* 2001 Chernykh 2002, 2012 Nikolaeva *et al.* 2017
UPPER PENNSYLVANIAN (UPPER CARBONIFEROUS)	GZHELIAN		*Streptognathodus wabaunsensis*	Melekhovian	*Streptognathodus wabaunsensis*	*St. wabaunsensis — Streotognathodus alius*	Ajuva	no information		*Streptognathodus wabaunsensis*	Nikolskian	*Streptognathodus wabaunsensis*
			Streptognathodus bellus	Noginskian	*Streptognathodus bellus*	*Streptognathodus elongatus*				*Streptognathodus elongatus*	Martusian	*S. fissus* *S. bellus*
			Streptognathodus virgilicus	Pavlovoposadian	*Streptognathodus virgilicus*	*Streptognathodus ruzhencevi*				*Streptognathodus alekseevi*	Azantashian	*S. simplex* *S. virgilicus*
			Streptognathodus vitali	Dobryatinian	*Streptognathodus vitali*							*S. vitali*
			Idiognathodus simulator		*Idiognathodus simulator*	*Idiognathodus simulator*		*Idiognathodus simulator*				*Idiognathodus simulator*
	KASIMOVIAN		*Streptognathodus firmus*	Dorogomilovian	*Streptognathodus zethus* *Streptognathodus firmus* *Idiognathodus toretzianus* *I. diognathodus mestsherensis*	*Idiognathodus toretzianus*	Odesa	*Idiognathodus toretzianus*		*Streptognathodus excelsus*	Kerzhakovian	*S. firmus*
			Idiognathodus toretzianus									*Idiognathodus sagittalis*
			Streptognathodus cancellosus	Khamovnikian	*Streptognathodus cancellosus*	*Idiognathodus sagittalis*		*Idiognathodus sagittalis*			Lomovian	
			Idiognathodus sagittalis		*Idiognathodus sagittalis*							
			Swadelina makhlinae	Krevyakinian	*Swadelina makhlinae*	*Swadelina subexcelsa*	Burkem	no information				*Swadelina makhlinae*
			Swadelina subexcelsa		*Swadelina subexcelsa*							*Sw. subexcelsa*
LOWER and MIDDLE PENNSYLVANIAN (MIDDLE CARBONIFEROUS)	MOSCOVIAN	Myachkovian	*Neognathodus roundyi*	Myachkovian	*Neognathodus roundyi*	*Neognathodus inaequalis*	Sula	*Neognathodus roundyi*	Kazarkian	*Neognathodus roundyi*	Tashlian	*Neognathodus roundyi*
			Neognathodus inaequalis		*Neognathodus inaequalis*		II	*Neognathodus inaequalis*		*Swadelina concinna —N. medexultimus*	Zilimian	*Idiognathodus* sp. B
		Podolskian	*Idiognathodus podolskensis– Neognathodus medexultimus*	Podolskian	*Idiognathodus podolskensis- Neognathodus medexultimus*	*Neognathodus medexultimus*		*Idiognathodus podolskensis*				
		Kashirian	*Sw. concinna — I. robustus*	Kashirian	*Sw. concinna — I. robustus*		Volonga	*N. medadultimus*		*N. medadultimus*	Imendyashian	*I. podolskensis — I. obliquus*
			Neognathodus medadultimus		*Neognathodus medadultimus*	*N. medadultimus*				no information		
			Neognathodus bothrops		*Neognathodus bothrops*	*Neognathodus bothrops*		*Neognathodus bothrops*				
		Vereian	*Streptognathodus transitivus*	Vereian	*Streptognathodus transitivus*	*Declinognathodus donetzianus*	Mador	no information		*Idiognathoides tuberculatus — Neogondolella donbassica*	Solontsian	*Declinognathodus donetzianus*
			Declinognathodus donetzianus– Idiognathoides postsulcatus		*Idiognathoides ouachitensis* *Declinognathodus donetzianus*							
	BASHKIRIAN	Arkhangelskian	*Declinognathodus marginodosus*	Melekesian	*Declinognathodus marginodosus*	no information					Asatauian	*Declinognathodus marginodosus*
				Cheremshanian	central part *Idiognathoides tuberculatus– Id. fossatus*					*Streptognathodus expansus — S. suberectus*	Tashastian	
		Askynbashian	*Idiognathodus sinuosus*	Prikamian	*Idiognathodus sinuosus*	*Idiognathodus sinuosus*					Askynbashian	*Idiognathodus sinuosus*
		Akavasian	*Neognathodus askynensis*	Severokeltmenian	southestern part	*Idiognathoides sinuatus*				*Declinognathodus — Idiognathoides*	Akavasian	*Neognathodus askynensis*
		Syuranian	*Idiognathoides sinuatus*	Krasnopolyanian							Kamenogorian	*Idiognathoides sinuatus*
			Declinognathodus noduliferus	Voznesenskian		*Declinognathodus noduliferus*				*Declinognathodus noduliferus*	Bogdanovkian	*Declinognathodus noduliferus*

Fig. 10

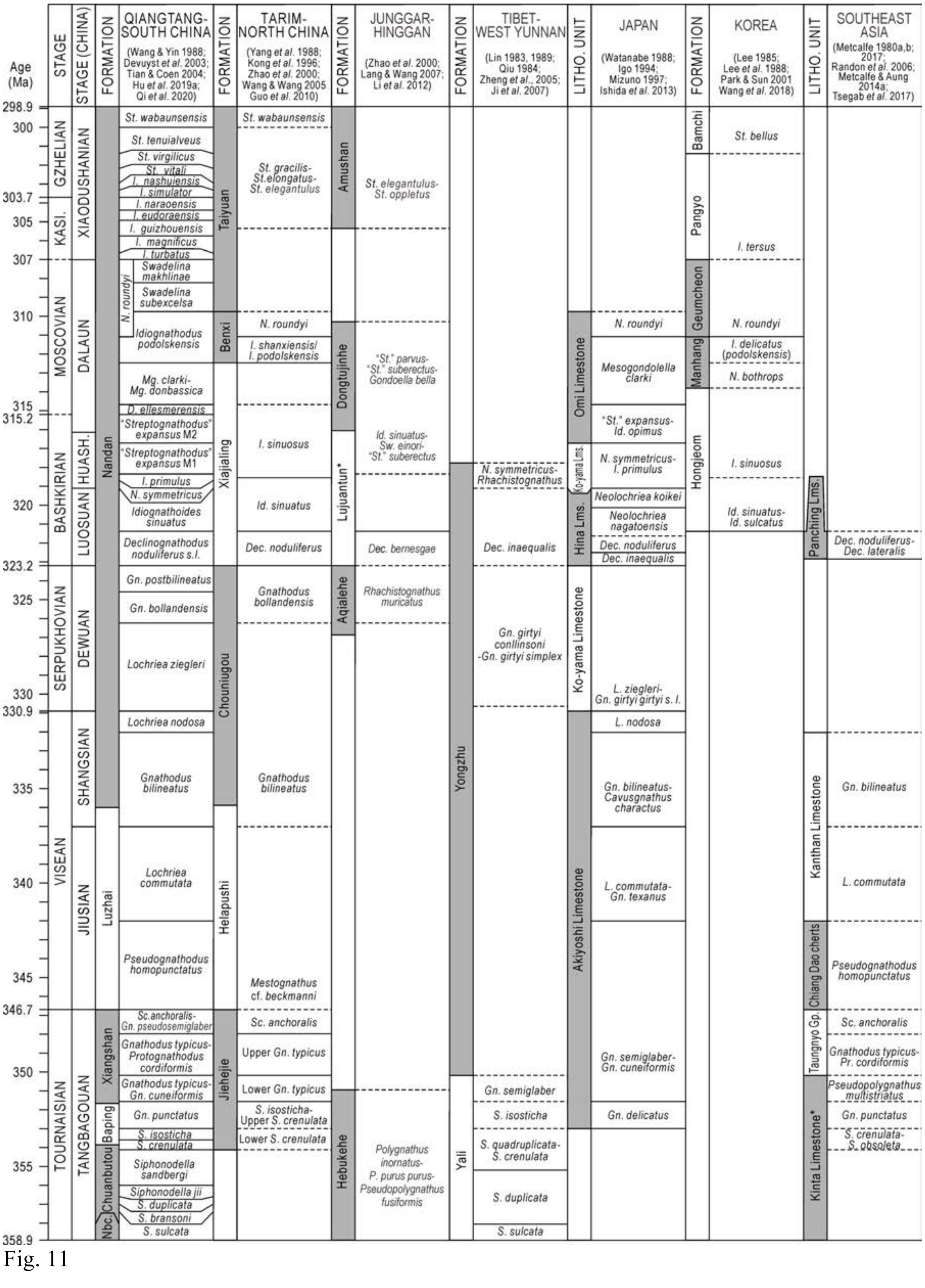

Age (Ma)
STAGE
STAGE (CHINA)
FORMATION
QIANGTANG-SOUTH CHINA
(Wang & Yin 1988; Devuyst et al. 2003; Tian & Coen 2004; Hu et al. 2019a; Qi et al. 2020)
FORMATION
TARIM-NORTH CHINA
(Yang et al. 1988; Kong et al. 1996; Zhao et al. 2000; Wang & Wang 2005 Guo et al. 2010)
FORMATION
JUNGGAR-HINGGAN
(Zhao et al. 2000; Lang & Wang 2007; Li et al. 2012)
FORMATION
TIBET-WEST YUNNAN
(Lin 1983, 1989; Qiu 1984; Zheng et al., 2005; Ji et al. 2007)
LITHO. UNIT
JAPAN
(Watanabe 1988; Igo 1994; Mizuno 1997; Ishida et al. 2013)
FORMATION
KOREA
(Lee 1985; Lee et al. 1988; Park & Sun 2001 Wang et al. 2018)
LITHO. UNIT
SOUTHEAST ASIA
(Metcalfe 1980a,b; 2017; Randon et al. 2006; Metcalfe & Aung 2014a; Tsegab et al. 2017)
298.9
300
303.7
305
307
310
315
315.2
320
323.2
325
330
330.9
335
340
345
346.7
350
355
358.9
GZHELIAN
KASI.
MOSCOVIAN
BASHKIRIAN
SERPUKHOVIAN
VISEAN
TOURNAISIAN
XIAODUSHANIAN
DALAUN
HUASH.
LUOSUAN
DEWUAN
SHANGSIAN
JIUSIAN
TANGBAGOUAN
Nandan
Luzhai
Xiangshan
Baping
Chuanbutou
Nbc.
N. roundyi
St. wabaunsensis
St. tenuialveus
St. virgilicus
St. vitali
I. nashuiensis
I. simulator
I. naraoensis
I. eudoraensis
I. guizhouensis
I. magnificus
I. turbatus
Swadelina makhlinae
Swadelina subexcelsa
Idiognathodus podolskensis
Mg. clarki-Mg. donbassica
D. ellesmerensis
"Streptognathodus" expansus M2
"Streptognathodus" expansus M1
I. primulus
N. symmetricus
Idiognathoides sinuatus
Declinognathodus noduliferus s.l.
Gn. postbilineatus
Gn. bollandensis
Lochriea ziegleri
Lochriea nodosa
Gnathodus bilineatus
Lochriea commutata
Pseudognathodus homopunctatus
Sc.anchoralis-Gn. pseudosemiglaber
Gnathodus typicus-Protognathodus cordiformis
Gnathodus typicus-Gn. cuneiformis
Gn. punctatus
S. isosticha
S. crenulata
Siphonodella sandbergi
Siphonodella jii
S. duplicata
S. bransoni
S. sulcata
Taiyuan
Benxi
Xiajialing
Chouniugou
Helapushi
Jiehejie
St. wabaunsensis
St. gracilis-St.elongatus-St. elegantulus
N. roundyi
I. shanxiensis/I. podolskensis
I. sinuosus
Id. sinuatus
Dec. noduliferus
Gnathodus bollandensis
Gnathodus bilineatus
Mestognathus cf. beckmanni
Sc. anchoralis
Upper Gn. typicus
Lower Gn. typicus
S. isosticha-Upper S. crenulata
Lower S. crenulata
Amushan
Dongtujinhe
Lujuantun*
Aqialehe
Hebukehe
St. elegantulus-St. oppletus
"St." parvus-"St." suberectus-Gondoella bella
Id. sinuatus-Sw. einori-"St." suberectus
Dec. bernesgae
Rhachistognathus muricatus
Polygnathus inornatus-P. purus purus-Pseudopolygnathus fusiformis
Yongzhu
Yali
N. symmetricus-Rhachistognathus
Dec. inaequalis
Gn. girtyi conllinsoni-Gn. girtyi simplex
Gn. semiglaber
S. isosticha
S. quadruplicata-S. crenulata
S. duplicata
S. sulcata
Omi Limestone
Ko-yama Lms.
Hina Lms.
Ko-yama Limestone
Akiyoshi Limestone
N. roundyi
Mesogondolella clarki
"St." expansus-Id. opimus
N. symmetricus-I. primulus
Neolochriea koikei
Neolochriea nagatoensis
Dec. noduliferus
Dec. inaequalis
L. ziegleri-Gn. girtyi girtyi s. l.
L. nodosa
Gn. bilineatus-Cavusgnathus charactus
L. commutata-Gn. texanus
Gn. semiglaber-Gn. cuneiformis
Gn. delicatus
Bamchi
Pangyo
Geumcheon
Manhang
Hongjeom
St. bellus
I. tersus
N. roundyi
I. delicatus (podolskensis)
N. bothrops
I. sinuosus
Id. sinuatus-Id. sulcatus
Panching Lms.
Kanthan Limestone
Chiang Dao cherts
Taungnyo Gp.
Kinta Limestone*
Dec. noduliferus-Dec. lateralis
Gn. bilineatus
L. commutata
Pseudognathodus homopunctatus
Sc. anchoralis
Gnathodus typicus-Pr. cordiformis
Pseudopolygnathus multistriatus
Gn. punctatus
S. crenulata-S. obsoleta

Fig. 11

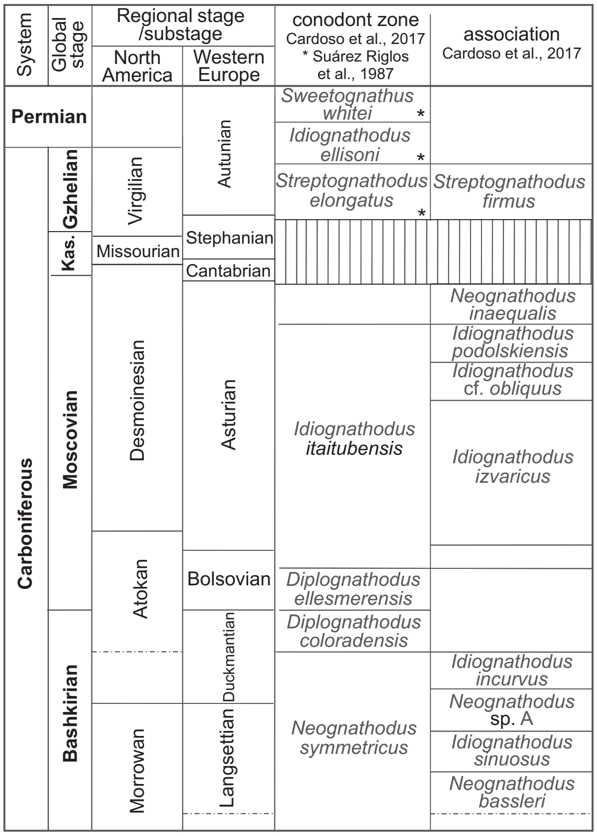

System
Global stage
Regional stage /substage
North America
Western Europe
conodont zone
Cardoso et al., 2017
* Suárez Riglos et al., 1987
association
Cardoso et al., 2017
Permian
Carboniferous
Gzhelian
Kas.
Moscovian
Bashkirian
Virgilian
Missourian
Desmoinesian
Atokan
Morrowan
Autunian
Stephanian
Cantabrian
Asturian
Bolsovian
Duckmantian
Langsettian
Sweetognathus whitei *
Idiognathodus ellisoni *
Streptognathodus elongatus *
Streptognathodus firmus
Neognathodus inaequalis
Idiognathodus podolskiensis
Idiognathodus cf. obliquus
Idiognathodus itaitubensis
Idiognathodus izvaricus
Diplognathodus ellesmerensis
Diplognathodus coloradensis
Idiognathodus incurvus
Neognathodus sp. A
Idiognathodus sinuosus
Neognathodus symmetricus
Neognathodus bassleri

Fig. 12