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UPPERMOST CARBONIFEROUS AND LOWERMOST PERMIAN DEPOSITION AND CONODONT BIOSTRATIGRAPHY OF KANSAS, USA

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Abstract: The Kansas section of upper Gzhelian-Asselian rocks is composed of a series of major and minor order cyclothems consisting mostly of shales and limestones with some sand, commonly as channels. The rocks represent terrestrial soil, marginal marine estuarine and swamp, and shallow marine deposition. Flooding surfaces are distinguished by normal marine faunas and the increase of conodont diversity. Maximum flooding surfaces within each cycle contain a dominance of offshore normal marine conodont faunas, especially species of *Streptognathodus*. Four major and six minor changeovers in *Streptognathodus* species mark the stratigraphic succession and provide a refined biostratigraphy to correlate the section. The current favored boundary for the Carboniferous-Permian in the southern Urals can be confidently correlated to the base of the Bennett Shale Member of the Red Eagle Limestone.

Keywords: conodont, biostratigraphy, Kansas

INTRODUCTION

The uppermost Carboniferous (Gzhelian) and lowermost Permian (Asselian) rocks are composed of a series of major and minor order cyclothems in a shallow shelf setting distinguished by the opposing interplay of terrestrial and normal marine environments. The section studied comprises the uppermost Wabaunsee, Admire, and Council Grove Groups located in Kansas and northern Oklahoma (Fig. 1). Sections were chosen for stratigraphic continuity to avoid mistakes in correlating individual limestone units. 11 sections containing several units in stratigraphic succession were utilized (Fig. 2). The sections were microsampled in detail for conodonts to determine overall distribution and abundant yielding samples in each cycle were sampled in bulk to determine taxonomic variability and validity. The overall stratigraphic column, flooding surfaces, and levels of conodont changeovers are shown in Fig. 3.

STRATIGRAPHY

Wabaunsee Group

The lowest stratigraphic unit in this study is the Brownville Limestone Member, Woodsiding Formation, uppermost Wabaunsee Group (Fig. 1). The base of the sedimentary sequence associated with the Brownville Limestone occurs in the upper Pony Creek Shale Member, Woodsiding

Formation (Localities 1, 2, 3; Figs. 1, 2, 3). The middle Pony Creek contains local, fluvial channels and overbank deposits that are overlain by thin underclays and coals. The coal is, in turn, overlain by thin carbonate and fossiliferous gray shale that contains abundant *Myalina* clams, and bryozoans. The initial marine flooding surface commonly is located within a meter of the top of the Pony Creek Shale and marks the base of the sedimentary sequence. The base of the Brownville Limestone is marked by a local transgressive lag and contains a more offshore marine fauna of brachiopods, crinoids, fusulinids, and *Streptognathodus* conodonts. Maximum flooding of the Brownville Limestone cyclothem (sequence) occurs at or near the top of the unit. The maximum flooding interval is characterized by a hard ground (locally), abundant glauconite, phosphatized molluscs, abundant *Streptognathodus* conodonts as well as an open marine fauna similar to that of the base. The base of the overlying Towle Shale represents the final stages of sea-level lowering and maximum lowstand for this cyclothem.

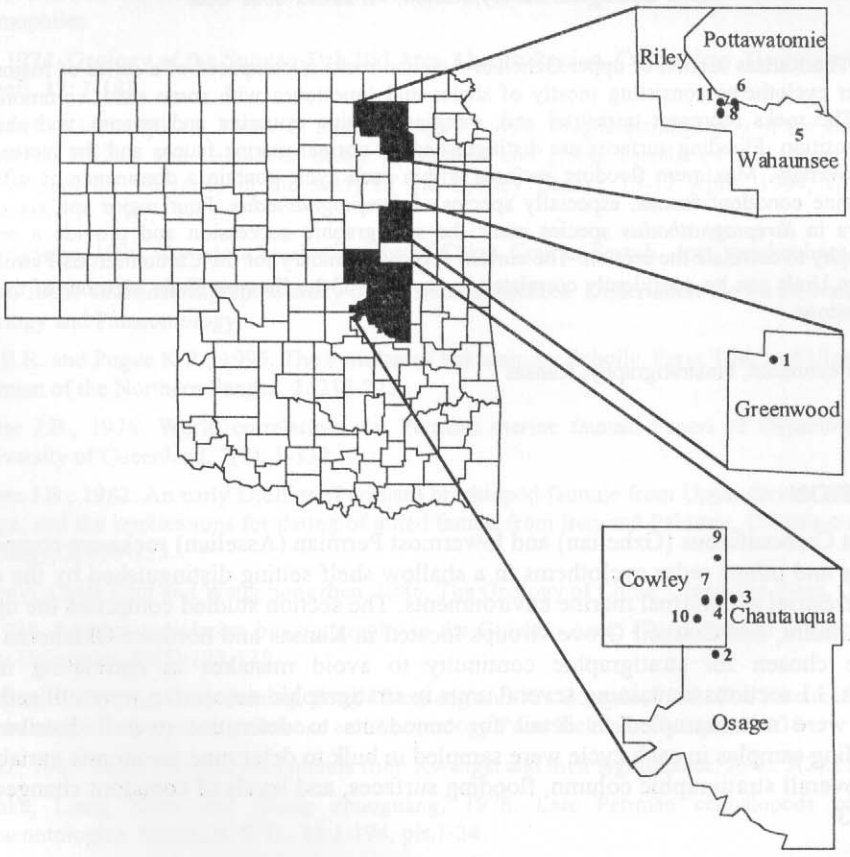

Fig. 1 County map of Kansas and Oklahoma showing location of numbered measured sections referred to in text in Cowley, Chautauqua, Greenwood, Pottawatomie, Riley, and Wabaunsee Counties, Kansas and Osage County, Oklahoma.

Admire Group

Comprehensive summaries on the cyclic stratigraphy of the Admire Group are presented by Mudge and Yochelson (1963) and Vann (1994). The Onaga Shale (Fig. 1) is comprised of the Towle Shale,

Aspinwall Limestone, and the Hawxby Shale, in ascending order. As previously mentioned, the base of the Towle Shale is marine and is genetically associated with the Brownville Limestone. In northern Oklahoma (Locality 2; Fig. 2), the entire Towle Shale may be marine. Exposures in northern Kansas and Nebraska show clear evidence of red blocky caliche-bearing mudstones indicative of paleosol development along with local incised valley fills (Indian Cave Sandstone) in the middle of the unit. In northern Oklahoma, the Towle Shale contains *Adetognathus* at the base and is barren in the silty middle part of the unit. In Kansas and Oklahoma, however, clear evidence of marine flooding is present in the upper part of the shale that mark the beginning of the Aspinwall Cyclothem (sequence). In northern Oklahoma (Locality 2; Fig. 2), this interval is marked by bryozoans, crinoids, and rare brachiopods along with an increased abundance in *Adetognathus*, whereas in northern Kansas, this interval contains a low diversity bivalve assemblage along with ostracodes and an absence of conodonts. The Aspinwall Limestone proper contains two highly fossiliferous limestones with an intervening fossiliferous gray shale in northern Oklahoma and southern Kansas. In central Kansas (Locality 1; Fig. 2), the Aspinwall interval contains numerous thin fossiliferous limestones interbedded with fossiliferous silty shales, whereas in northern Kansas it is represented by a relatively thick bed of poorly fossiliferous hematitic mudcracked limestone with sand infilling the cracks. This unit is overlain by a crinoidal-rich packstone that contains *Adetognathus*. Throughout the outcrop belt, maximum flooding of the Aspinwall is marked by *Adetognathus*. The Hawxby Shale contains green to gray silty shales at the base with rare ostracodes. This interval is interpreted to represent the shoaling stages of the Aspinwall Cyclothem. The middle and upper part of the Hawxby Shale contains boxwork carbonates and blocky mudstones that are interpreted as paleosols. The uppermost part of the Hawxby Shale is a gray highly fossiliferous shale that contains bryozoans, crinoids, brachiopods and *Adetognathus* conodonts (Localities 2, 3; Fig. 2). This unit is interpreted as representing the initial stages of marine flooding associated with the Falls City Limestone with which it is genetically related.

The Falls City Limestone (Fig. 1) consists of thin-bedded carbonates and fossiliferous gray shales throughout the outcrop area. The Falls City Limestone contains a mixed megafauna of bryozoans, brachiopods, crinoids, and clams along with a mixed *Adetognathus-Streptognathodus* conodont assemblage (Localities 1, 2, 3; Fig. 2).

No evidence of condensation is present in the Falls City Limestone. The basal part of the overlying West Branch Shale marks the marginal marine phase of the cyclothem.

The Janesville Shale (Fig. 1) consists of the West Branch Shale, Five Point Limestone, and Hamlin Shale in ascending order. The basal part of the West Branch Shale consists of green-gray silty shales that contain only sparse ostracodes and are genetically related to the Falls City Limestone (Localities 1, 2, 3; Fig. 2). Lenticular, channel sandstones commonly are also present in the lower West Branch Shale. The middle West Branch Shale contains blocky mudstones with unfossiliferous boxwork limestones that are interpreted to represent paleosol horizons. The boxwork carbonates are overlain by a widespread underclay and prominent coal bed that, in turn, is overlain by fossiliferous interbedded shales and limestones that contain *Myalina* clams, bryozoans, productid brachiopods, abundant encrusting foraminifers and no conodonts. This marine interval, which is overlain by another underclay and thin coal is considered to represent a minor cyclothem within the West Branch Shale. The Five Point Limestone directly overlies the upper coal and is the most prominent limestone and marine band within the Admire Group and the only cyclothem to contain a fully open marine fauna including brachiopods, bryozoans, corals, crinoids, fusulinids, as well as a *Streptognathodus*-dominated conodont assemblage. The base of the Five Point Limestone represents the initial flooding surface as well as the maximum flooding interval within the cyclothem. The upper Five Point Limestone commonly contains vugs filled with red internal sediment (Vann, 1994) that represents subaerial exposure. In northern Kansas a well-developed paleosol overlies the Five Point Limestone. A short distance above the Five Point Limestone in Kansas through northern Oklahoma is

a *Myalina*-bearing marine carbonate that is devoid of conodonts and represents a minor flooding event in the lower Hamlin Shale. The Hamlin Shale contains a red blocky mudstones with abundant boxwork carbonates in the upper part that is interpreted to represent stacked paleosols. North of the study area in northernmost Kansas and Nebraska is the lenticular Houchen Creek Limestone. It is unclear as to where this unit fits stratigraphically with sections south of central Pottawatomie County, Kansas (Mudge and Yochelson, 1963).

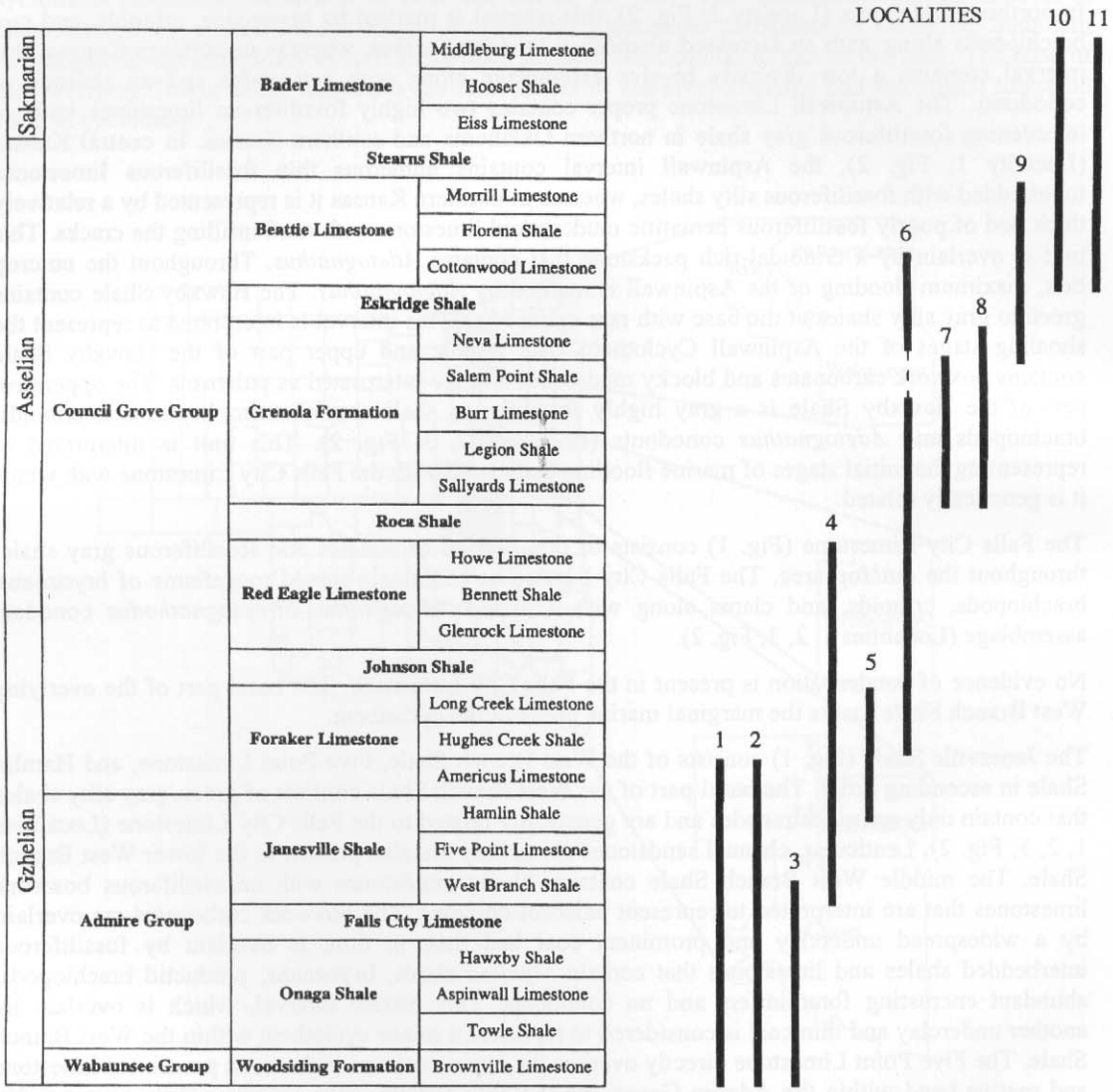

Fig. 2 Stratigraphic interval of each numbered measured section. Numbers the same as those in Fig. 1.

Council Grove Group

In ascending order, the Americus Limestone Member, Hughes Creek Shale Member, and the Long

Creek Limestone Member comprise the Foraker Limestone (Fig. 1). The Foraker Limestone represents a single sedimentary sequence and is bounded at the base and top by red blocky mudstones (paleosols). The Foraker Cyclothem (Sequence) is subdivided into six subcyclothems (subsequences) that are each capped by either nearshore silty shales or carbonates (Fig. 3). The base of each subcyclothem is defined by a flooding surface which is represented by carbonates containing open marine faunas (including brachiopods and fusulinids). Maximum flooding surfaces are represented by open marine carbonates without evidence of condensed sedimentation in cases of minor sea-level rises or open marine carbonates or dark shales with evidence of condensed sedimentation for more major sea-level rises. The nearshore silty shales either contain reduced numbers of *Adetognathus* or are completely barren of conodonts in contrast to the more offshore normal marine carbonates and dark shales that contain either mixed *Adetognathus-Streptognathodus* fauna or a *Streptognathodus*-dominated fauna. Each of these subcyclothems can be correlated across the outcrop belt from southernmost Kansas to northern Kansas. The maximum flooding surfaces of the lower Americus (Subcyclothem A, lower Hughes Creek (Subcyclothem C) and uppermost Hughes Creek (Subcyclothem F) contain a mixed *Adetognathus-Streptognathodus* Biofacies (Fig. 3) with no evidence of condensed sedimentation, and are interpreted to represent minor marine flooding events. In contrast, the upper Americus Limestone (Subcyclothem B), lower Hughes Creek (Subcyclothem D) and the middle Hughes Creek (Subcyclothem E) contains an abundant *Streptognathodus*-dominated fauna (Fig. 3) with evidence of condensed sedimentation in all of these subcyclothems including abundant glauconite, and phosphatized molluscs in addition to the conodonts that may exceed 1,000 platforms/kilogram. These are interpreted to represent more major sea-level rises. Importantly, this report demonstrates that each of the major subcyclothems within the Foraker Limestone contains a similar but distinctive conodont fauna that can be correlated across the Kansas outcrop belt. Little (1965) in his unpublished masters thesis documented the occurrence of these three conodont abundant intervals within the Foraker Limestone.

The lower part of the Johnson Shale (Fig. 1) in the northern Kansas area (Tuttle Creek Spillway-Locality 6) consists of interbedded silty carbonates and red to variegated mudstone with numerous paleosol textures (Miller, 1994). Similar observations of the lower Johnson Shale in southern Kansas and northern Oklahoma have been made by the authors, but have yet to be adequately documented. No marine fossils have been recovered from the lower Johnson Shale. Throughout the outcrop belt, the upper part of the Johnson Shale (Fig. 3) contains gray marginal marine mudstones and thin carbonates with abundant ostracodes that represent the earliest stages of marine transgression (Miller, 1994). Unit 4 of the Johnson Shale (Locality 6b; Fig. 3) contains a few small unidentifiable specimens of *Streptognathodus*. This part of the Johnson Shale is therefore genetically related to the Red Eagle Limestone and is the base of the same cyclothem (sequence).

The Red Eagle Limestone consists of the Glenrock Limestone, Bennett Shale, Howe Limestone, in ascending order (Fig. 1). McCrone (1963) presented a comprehensive lithologic and stratigraphic summary of the Red Eagle Limestone from Nebraska to northern Oklahoma. In the Tuttle Creek section (Locality 6b; Fig. 1, lower stratigraphic section) the base of the Glenrock Limestone is characterized by a 2cm transgressive lag bed that marks the third flooding surface of the cyclothem. Only a single abraded specimen of *Streptognathodus* has been recovered from this section (Locality 6b). The majority of the Glenrock is a poorly fossiliferous intraclastic packstone to grainstone. The top of the Glenrock is a richly fossiliferous wackestone to packstone and is characterized by fusulinids and large burrows that contain black shale from the overlying Bennett Shale. The contact at the Glenrock-Bennett Shale marks a major flooding surface with a possible hard ground being developed in the top of the Glenrock Limestone. The uppermost Glenrock contains abundant *Streptognathodus* but it is unclear as to whether they are from the Glenrock Limestone or from the Bennett Shale inclusions in the burrow systems. The Glenrock Limestone is well developed in northern Kansas and Nebraska but is not traceable as a lithologic entity in southern Kansas and

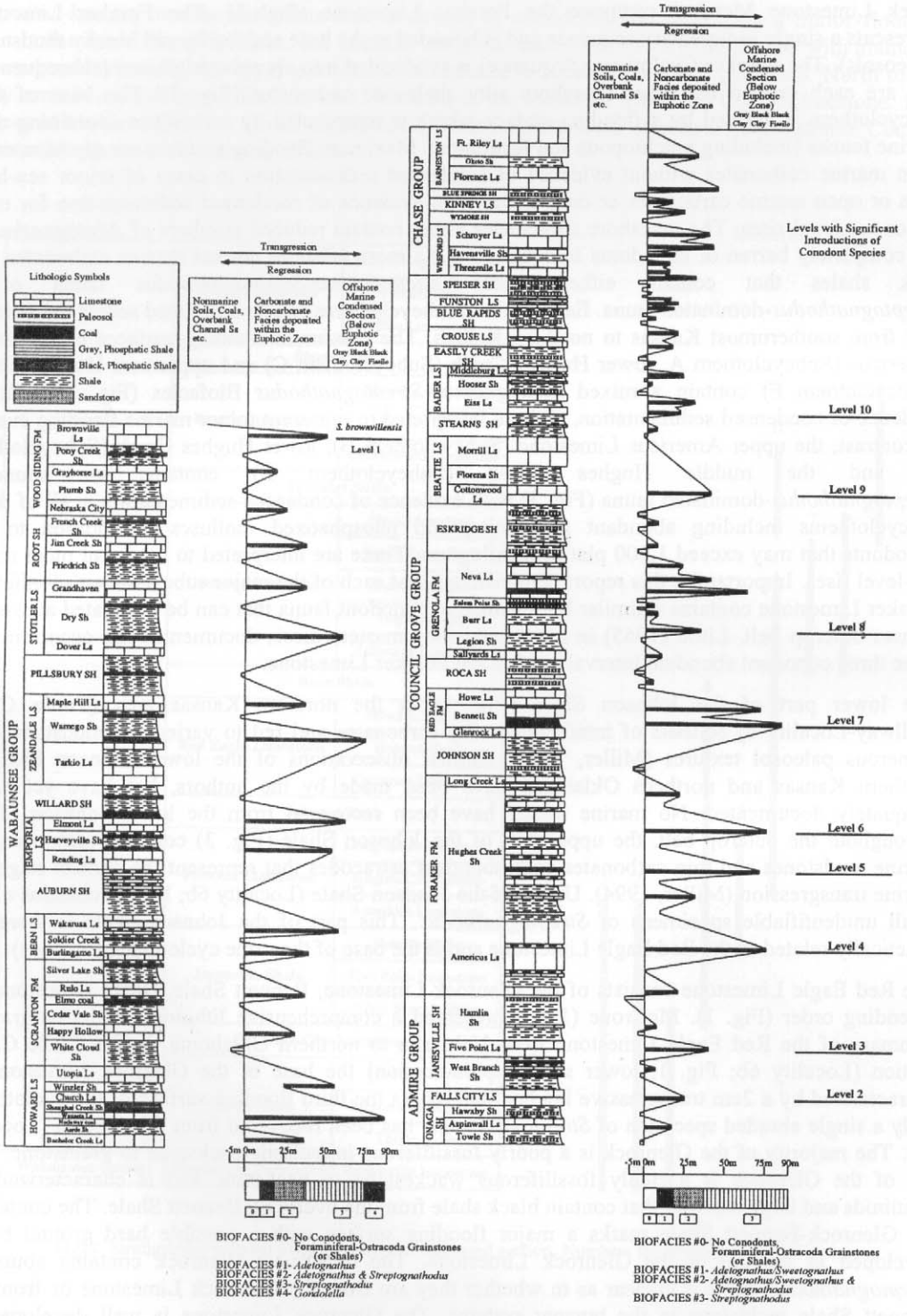

Fig. 3 General lithology, biofacies, sedimentation curve showing flooding surfaces and significant levels of changeover in *Streptognathodus* species.

northern Oklahoma. In northern Kansas and Nebraska the Bennett Shale is a gray to black (occasionally tan) shale commonly with a gray shaly bioturbated limestone in the upper part of the member. Faunally, the Bennett is characterized by orbiculoid brachiopods, locally abundant *Streptognathodus* conodonts, and fish debris. The base of the Bennett Shale shows condensation as evidenced by the abundance of conodonts, as well as the upper carbonate bed. The upper carbonate bed exposed at Tuttle Creek contains over 1,000 elements of *Streptognathodus*/kilogram and has abundant remains of fish teeth, and orbiculoid brachiopods. In southern Kansas the Bennett has changed facies from dark shales to dominantly fossiliferous carbonates. The two condensed intervals are however, present at all sampled localities. At locality 4 (Fig. 2) the lower marine condensed section is represented by a thin shaly, glauconitic fossiliferous wackestone with abundant phosphatized molluscs and abundant conodonts (500 platforms/kilogram). At the same section the upper marine condensed section is a thin highly fossiliferous shale with abundant conodonts (500 platforms/kilogram). In northern Kansas, the Howe Limestone is easily separated from the Bennett Shale and represents a shoaling upwards carbonate and is locally capped by stromatolites. In southern Kansas and northern Oklahoma, the contact between the carbonates of the Bennett and the Howe are not easily separated.

The Roca Shale (Fig. 1) consists largely of red to variegated, blocky, carbonate concretion-rich mudstones punctuated with flooding surfaces overlain by thin marginal marine carbonates. Although this pattern was observed at localities throughout the study area, only the Tuttle Creek Locality (Locality 6) has been adequately documented. Miller (1994) has interpreted this unit to represent stacked paleosols with periodic minor marine flooding surfaces. All of these marginal marine carbonates were sampled in this study but no conodonts were recovered (Miller 1994, p. 6, 10-12 for detailed measured section).

The Grenola Formation consists of the Sallyards Limestone, Legion Shale, Burr Limestone, Salem Point Shale, and the Neva Limestone, in ascending order (Fig. 1). The Grenola Formation actually comprises four sedimentary sequences each bounded by paleosols. However, due to the limited thickness of each sequence, we view each of these to represent subcyclothems (subsequences) similar in concept to those of the Foraker Limestone. Within two of these subcyclothems additional flooding surfaces are also apparent. The Sallyards Limestone (base of Subcyclothem A) is a relatively thin carbonate with pectinid and myalinid clams that are locally abundant at the top of the unit. The limestone has not yielded conodonts from any of the sampled localities (Localities 6c, 7, 8; Fig. 2). The lower part of the Legion Shale is typically gray to black shale with an abundant, low diversity ostracode assemblage that is devoid of conodonts. This unit is interpreted to be a marginal marine shale associated with the upwards shoaling of the Sallyards Limestone. At the Tuttle Creek Locality (6c), the upper part of Unit 4 of the Legion Shale (Locality 6c; Fig. 3) is represented by calcareous mudstones with columnar ped structures interpreted by Miller (1994) to be a paleosol horizon. The lateral extent of this paleosol horizon has not been documented in other sections, but our sampling has demonstrated barren intervals that might represent a paleosol. This, in turn, is overlain by a thin marginal marine ostracode-bearing carbonate that represents the initial stages of marine flooding (Fig. 3, Unit 5) that marks the base of Subcyclothem B. The marginal marine nature of the uppermost Legion Shale has been observed at localities throughout the outcrop belt. The base of the Burr Limestone consists locally of a transgressive lag with a moderate number of *Streptognathodus* conodonts (Locality 7; Fig. 2). The top of the lower Burr Limestone is locally developed as a hard ground with abundant brachiopods, and crinoids with abundant phosphatic skeletal debris from fish remains as well as conodonts (Localities 6c, 8; Fig. 2) and is interpreted to represent condensed sedimentation and maximum flooding. The gray to black, locally silty, gypsiferous middle Burr Shale is characterized by a very sparse fauna of *Promytilus* clams and is interpreted to represent a marginal marine possibly hypersaline environment associated with rapid shallowing. The base of the upper Burr that is present across the entire study area is characterized by a transgressive lag with locally abundant skeletal fish debris (Localities 6c, 8; Fig. 2). This is interpreted to represent a minor

flooding event due to the absence of any conodonts or other normal marine faunal indicators. The upper part of the Burr Limestone contains abundant molds of clams and evaporite molds and is interpreted to represent a shoal sabkha environment. In northern Kansas, the lower part of the overlying Salem Point Shale consists of blocky mudstones with ped structures interpreted by Miller and West (1993) to represent a paleosol (Localities 6c, 8; Fig.s 10, 14). The basal Salem Point Shale in southern Kansas and northern Oklahoma consists of red blocky mudstones that may also represent paleosols. Within the middle part of the Salem Point Shale, a thin pectinid and myalinid-bearing carbonate is present from southern Nebraska to northern Oklahoma. This bed is interpreted to represent the base of Subcyclothem C (Localities 6c, 7, 8; Figs. 10, 13, 14). Due to the lack of any conodonts or other indications of open marine conditions, we view this as a minor flooding event. This carbonate is overlain by gray to black, silty, ostracode-bearing, marginal marine shale. The top of the Salem Point Shale consists of red to variegated mudstone with locally well developed ped structures interpreted to represent a paleosol (Localities 6c, 7, 8; Figs. 10, 13, 14). The base of the Neva Limestone is characterized by a transgressive lag and represents a flooding event that marks the base of Subcyclothem D (Localities 6c, 7, 8; Figs. 10, 13, 14). Maximum flooding of the Neva Limestone occurs in a tan to dark gray shale with a prominent phosphatic skeletal lag that occurs above the basal limestone in both northern and southern Kansas. Significant evidence of condensation includes locally over 1,000 *Streptognathodus* conodonts/kilogram in the unit in northern Kansas (Localities 6c, 8; Fig. 2). In southern Kansas the skeletal lag occurs in a glauconitic and phosphatic carbonate at the base of the black shale bed (Locality 9; Fig. 2). The upper, thicker Neva Limestone contains at least two additional flooding events that is characterized in northern Kansas by phosphatic, glauconitic shaly carbonates and shales with orbiculoid brachiopods, fish debris, and abundant conodonts (Localities 6c, 9, Fig. 2). In southern Kansas, less direct evidence of flooding is available except for a moderate increase in conodonts, along with more open marine macrofauna including fusulinids and brachiopods.

The Eskridge Shale (Fig. 1) consists of red to variegated, blocky, ped-bearing mudstones with two prominent molluscan-rich, dominantly carbonate, marine units separated by red variegated mudstones within the unit (Localities 6d, 9; Fig. 2). The two prominent marine bands are present from southern Nebraska to northern Oklahoma and are interpreted as minor marine flooding events that interrupt a dominantly paleosol unit (Bogina, 1986; Joeckel, 1989; and Miller and West, 1993). No conodonts have been recovered from either of the marine units.

The Beattie Limestone (Fig. 1) comprises the Cottonwood Limestone, Florena Shale, and Morrill Limestone in ascending order. The Beattie Limestone marks a single sedimentary sequence bounded by paleosols. The base of the Cottonwood Limestone consists of a transgressive lag deposit with abundant ostracodes in both northern and southern Kansas (Localities 9, 10, 11a; Fig. 2). Maximum flooding occurs near the center of the Cottonwood Limestone in northern Kansas and is associated with fusulinids, brachiopods, corals, and relatively abundant *Streptognathodus* conodonts (Locality 11a; Fig. 2). Shoaling towards the top of the Cottonwood Limestone includes a reduction in diversity of open marine organisms including brachiopods and corals and the introduction of abundant echinoids. The abundance of conodonts is also dramatically reduced. In southern Kansas, the Cottonwood Limestone shales out into thin interbedded highly fossiliferous shales and carbonates and the maximum flooding surface occurring near the top of the Cottonwood Limestone as evidenced by the abundance of conodonts along with some glauconite and phosphatized molluscs (Localities 9, 10; Fig. 2). The Florena Shale is typically gray to black, locally calcareous and silty shale that carries a moderately diverse fauna of chonetid brachiopods and trilobites. In both northern and southern Kansas thin carbonates are present in the middle of the shale (Localities 9, 10, 11a; Fig. 2). In northern Kansas the contact with the underlying Cottonwood Limestone is sharp whereas in southern Kansas, the contact is highly gradational. The Florena Shale contains only sparse conodonts. The Morrill Limestone in northern Kansas is quite thin, poorly fossiliferous, and commonly contains extensive quartz lined vugs as well as abundant celestite in the insoluble residue and is devoid of

conodonts (Locality 11a; Fig. 2). In southern Kansas, the Morrill is highly fossiliferous in the lower part of the unit with abundant fusulinids and echinoids at the base, followed by corals and brachiopods. However, no conodonts have been recovered from the unit (Localities 9, 10; Fig. 2).

The Stearns Shale (Fig. 1) is dominantly a complex of blocky mudstones interpreted to represent a series of stacked paleosols with one significant marine flooding unit of thin carbonate and overlying dark shale in the middle of the shale (Miller and West, 1993). This marine flooding unit contains a sparse fauna of productid brachiopods and molluscs with abundant ostracodes. However, this unit contains no conodonts.

The Bader Limestone (Fig. 1) consists of the Eiss Limestone, Hooser Shale, and the Middleburg Limestone, in ascending order. The Eiss Limestone is remarkably consistent from northern Kansas to southern Kansas (Localities 10, 11b; Fig. 2). The basal Eiss Limestone consists of a lower algal-rich carbonate with *Aviculopinna* clams and *Meekella* brachiopods that represents the initial marine flooding and contains dominantly *Sweetognathus* conodonts. This interval is overlain by an abundantly and diversely fossiliferous shale with crinoids, brachiopods, and trilobites with small numbers of *Streptognathodus* conodonts. This is overlain by a shaly carbonate with a similar fauna with an increased number of *Streptognathodus*. This interval is interpreted to represent an additional flooding event and corresponds with maximum flooding. The upper Eiss is characterized by decreasing fossil content and local regolith and internal sediment developed at the top of the unit.

The Hooser Shale (Fig. 1) contains a well developed red to variegated blocky mudstone at the base of the unit (Localities 10, 11b; Fig. 2) that has been interpreted to be a paleosol by Miller and West (1993). The upper part of the Hooser Shale contains a marine flooding surface indicated by ostracode bearing silty carbonates in northern Kansas and by brachiopod-bearing calcareous shales in southern Kansas (Localities 10, 11b; Fig. 2). No conodonts have been recovered from this unit. The upper flooding surface of the Hooser Shale marks the beginning of a sedimentary sequence that includes the overlying Middleburg Limestone.

The Middleburg Limestone (Fig. 1) contains sparse brachiopods and crinoids near the center of the unit that contains sparse *Streptognathodus* conodonts in northern Kansas (Locality 11b; Fig. 2). In southern Kansas, no conodonts have been recovered from the unit (Locality 10; Fig. 2).

CONODONT BIOSTRATIGRAPHY

The succession of conodonts is represented by ten minor and major faunal introductions (Fig. 4). Four major and six minor changeovers in *Streptognathodus* species are marked in stratigraphic succession by the introduction of: (**1**) *S. brownvillensis* (Ritter, 1994) in the Brownville Limestone Member of the Woodsiding Formation (minor), (**2**) *S. alius* in the Falls City Limestone (minor), (**3**) *S. barskovi* in the Five Point Limestone Member of the Janesville Shale (minor), (**4**) *S. elongatus, S. farmeri,* and *S. wabaunsensis* in the upper bed of the Americus Limestone Member of the Foraker Limestone (major), (**5**) *S. conjunctus* in the lower part of the Hughes Creek Shale Member of the Foraker Limestone (minor), (**6**) *S.* n. sp. C in the upper part of the Hughes Creek Shale Member of the Foraker Limestone (minor), (**7**) *S. fuchengensis, S. invaginatus, S. nodulinearis,* and *S.* n. sp. D in the Bennett Shale Member of the Red Eagle Limestone (major), (**8**) *S.* n. sp. E, *S.* n. sp. F, *S.* n. sp. G, and *S.* n. sp. H in the Burr Limestone Member of the Grenola Limestone (major), (**9**) *S. constrictus, S. fusus,* and *S. longissimus* in the Cottonwood Limestone Member of the Beattie Limestone (major), and, (**10**) *S. postfusus* in the Eiss Limestone Member of the Bader Limestone (minor). This succession is very similar to that in the Usolka section in the southern Urals, Russia (Chuvashov *et al.*, 1991), and ties the faunal introduction **4** in Kansas to bed 16/1 at Usolka, **7** to bed 16/3, **8** to bed 16/5, and **9** to bed 17/2. The first appearance of our *Streptognathodus* n. sp. D is the same as the isolated nodular morphotype of Chernykh and Ritter (1994). Though conodont taxonomy through

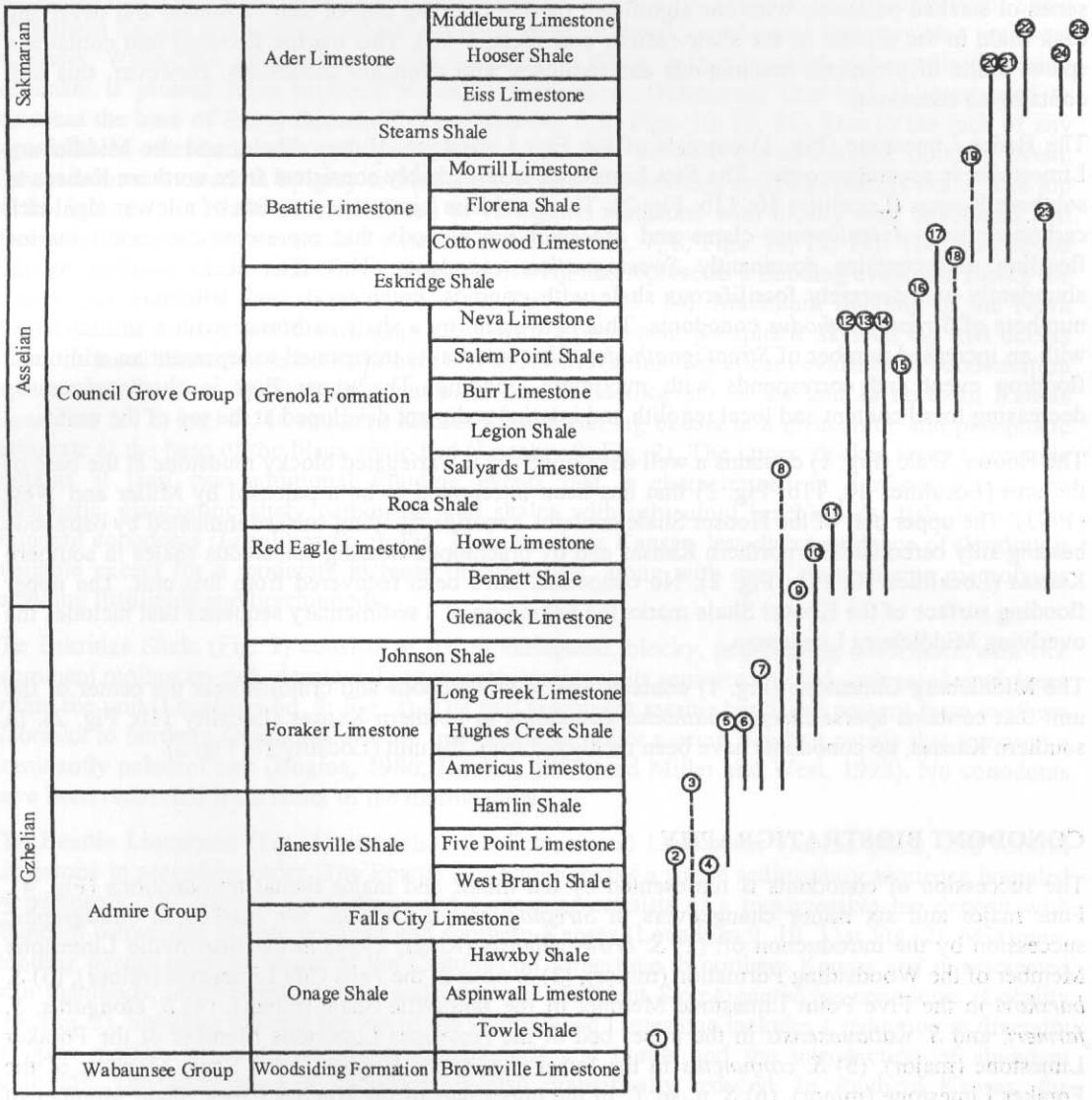

Fig. 4 Range of conodont species. 1, *Streptognathodus* n. sp. A, 2, *S. brownvillensis*, 3, *S.* n. sp. B, 4, *S. alius*, 5, *S. barskovi*, 6, *S. farmeri*, 7, *S. wabaunsensis*, 8, *S. elongatus*, 9, *S. conjunctus*, 10, *S.* n. sp. C, 11, *S. nodulinearis*, 12, *S. fuchengensis*, 13, *S. invaginatus*, 14, *S.* n. sp. D, 15, *S.* n. sp. E, 16, *S.* n. sp. F, 17, *S.* n. sp. G, 18, *S.* n. sp. H, 19, *S. fusus*, 20, *S. constrictus*, 21, *S. longissimus*, 22, *S. postfusus*, 23, *Sweetognathus adenticulatus*, 24, *Sw. "inornatus"*, 25, *Sw. merrilli*.

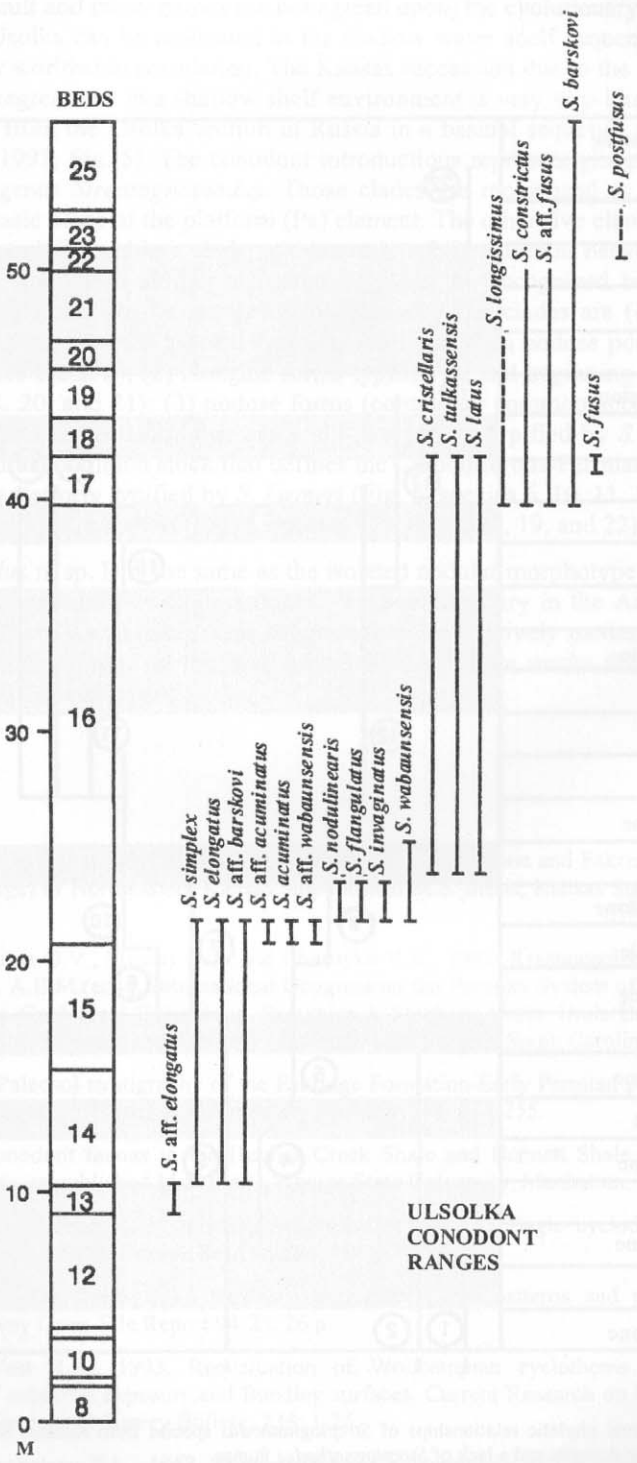

Fig. 5 Ranges of preliminarily identified species at Usolka section (Chuvashov *et al.*, 1991) showing a similar pattern of changeover of species to that in Kansas (Fig. 4).

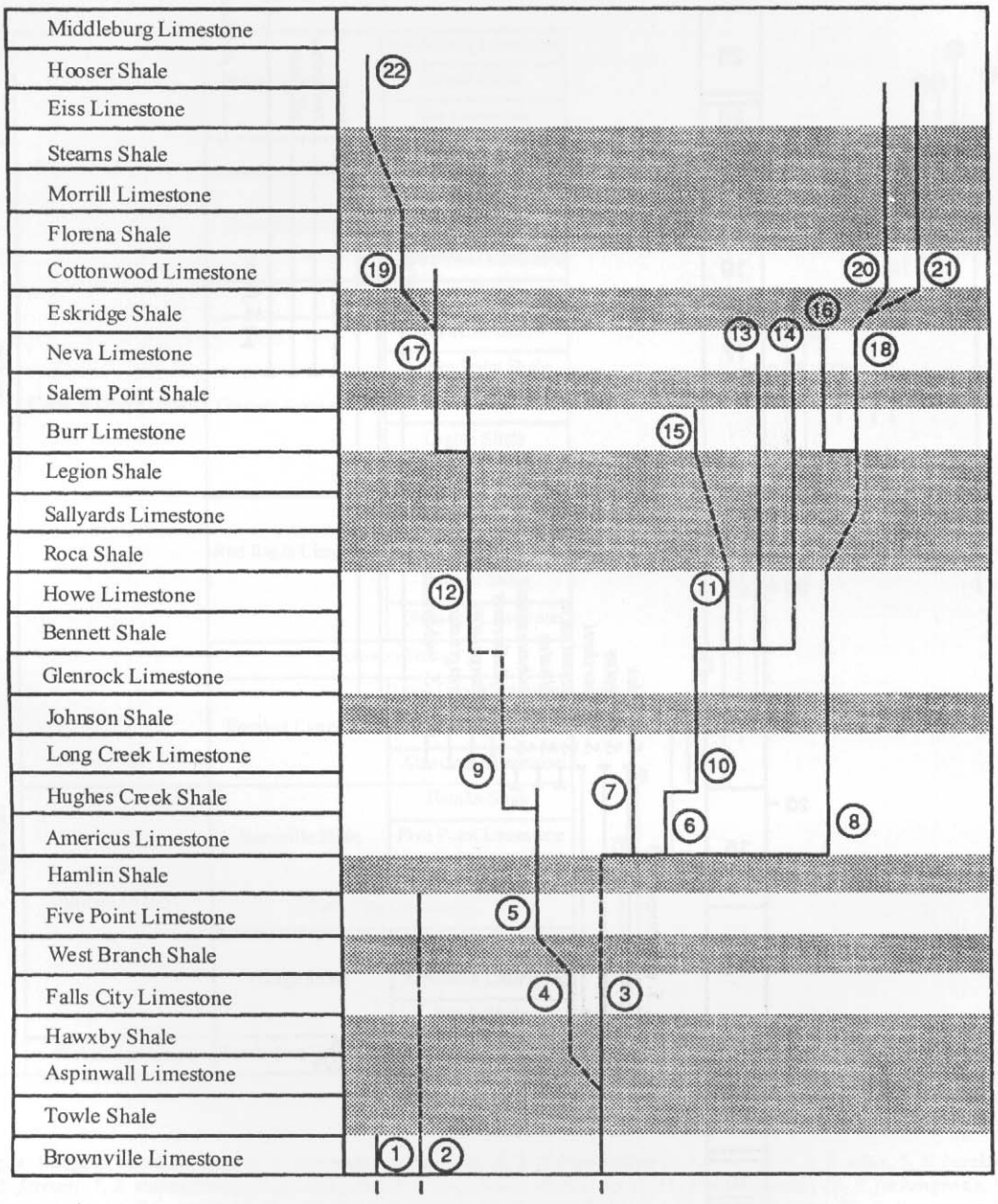

Fig. 6 Hypothesized and real phyletic relationships of *Streptognathodus* species from Kansas. Shaded intervals represent terrestrial to marginal marine deposits and a lack of *Streptognathodus* faunas.

this interval is difficult and many names are not agreed upon, the evolutionary clines displayed at the basinal section at Usolka can be replicated in the shallow water shelf sequence in Kansas, showing their importance for worldwide correlation. The Kansas succession due to the cyclic nature of marine transgressions and regressions in a shallow shelf environment is very step-like and matches the step-like pattern known from the Usolka section in Russia in a basinal sequence due to coarse sampling (Chuvashov *et al.*, 1991; Fig. 5). The conodont introductions represent glimpses of the evolution of four clades of the genus *Streptognathodus*. Those clades are recognized as a succession of minor variations on four basic plans of the platform (Pa) element. The other five elements of the apparatuses are very similar, especially within a clade, and are only subtly different between clades. The clades, or succession of species with similar architectural plans are recognized because the species are stratigraphically useful and can be recognized worldwide. The clades are (1) Virgillian holdovers characterized by a long and wide groove, typically with a median nodose posterior extension of the carina (Fig. 6, species 1 and 2); (2) elongate forms typified by and beginning with *S. elongatus* (Fig. 6, species 8, 16, 18, 20, and 21); (3) nodose forms (containing common accessory denticles) which can be subdivided into a root stock that has a slit-like furrow typified by *S. wabaunsensis* (Fig. 6, species 3 and 4) and the common stock that defines the Carboniferous-Permian boundary which has a trough-like furrow anteriorly typified by *S. farmeri* (Fig. 6, species 6, 10, 11, 13, 14, and 15); and (4) robust forms typified by *S. barskovi* (Fig. 6, species 4, 5, 9, 12, 17, 19, and 22).

Our *Streptognathodus* n. sp. D is the same as the isolated nodular morphotype proposed by Chernykh and Ritter (1994) as defining the Carboniferous-Permian boundary in the Aidaralash section in the southern Urals, northern Kazakhstan. This suggests that the relatively moderate species radiation in the nodose species clade found in the base of the Bennett Shale marks the same horizon and the Carboniferous-Permian boundary.

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