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# Stratigraphy and Conodont Biostratigraphy of the Uppermost Carboniferous and Lower Permian from the North American Midcontinent

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PART A—General Sequence Stratigraphy and Conodont Biostratigraphy (including new species) of the Uppermost Carboniferous (upper Gzhelian) to Lower Permian (lower Artinskian) from the North American Midcontinent

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PART B—Conodont Distribution, Systematics, Biostratigraphy, and Sequence Stratigraphy of the Uppermost Carboniferous and Lower Permian (uppermost Wabaunsee, Admire, Council Grove, and lower Chase Groups) from the North American Midcontinent

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# Contents

## Part A



## Figures

## Plate



# Part B (on cd-rom in back pocket)

## Figures

## Plates

# Authors' Preface

This study was initiated in 1991, and originally was planned to be a summary of the sequence stratigraphy and naming of the new conodont species document that would be printed; the sometimes more detailed discourse about stratigraphic philosophy and observation to accompany the more detailed discussion and illustration of the conodont biostratigraphy was to be a digital supporting document. The research greatly evolved in scope in order to adequately deal with taxonomic, stratigraphic, and sequence stratigraphic issues.

Part A is largely a summary of the most essential elements of the conodont taxonomy, biostratigraphy, and sequence stratigraphy and is a printed document. Part B contains detailed conodont biostratigraphy, including an in-depth analysis of the problems of stratigraphic misplacement of species, clarification of types, and more complete discussion of the sequence stratigraphic concepts and is included on a cd-rom in the back envelope of this volume. Some redundancy exists between Part A and Part B, but we felt the basic concepts are better served in this format.

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**This entire Bulletin also is available on the Kansas Geological Survey web site at http://www.kgs.ku.edu/Publications/Bulletins/255/index.html.**

# PART A—General Sequence Stratigraphy and Conodont Biostratigraphy (including new species) of the Uppermost Carboniferous (upper Gzhelian) to Lower Permian (lower Artinskian) from the North American Midcontinent

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## Abstract

The uppermost Wabaunsee, Admire, Council Grove, and lower Chase Groups of Kansas, Oklahoma, and Nebraska are placed into three third-order depositional sequences: a Gzhelian late-highstand sequence set, a Council Grove transgressive and highstand sequence set, and a Chase transgressive sequence set. Sequences are defined by bounding maximum-exposure surfaces and are placed within the zone of exposure surfaces (typically, stacked paleosols). Conodonts are abundant in open-marine deposits and most marine units have a differing and characteristic faunal make-up. Eleven species are described as new: *Streptognathodus binodosus, S. denticulatus, S. elongianus, S. florensis, S. lineatus, S. nevaensis, S. postconstrictus, S. postelongatus, S. robustus, S. translinearis,* and *S. trimilus*.

# Introduction

This study focuses on upper Carboniferous and Lower Permian (Brownville Limestone Member through Fort Riley Limestone Member, upper Wabaunsee Group to middle Chase Group) strata that crop out from the North American midcontinent region from southern Nebraska through northern Oklahoma (figs. 1, 2). Conodont distribution and range data presented are based on over 1,000 in situ samples from 57 measured sections. The sequence stratigraphic framework is presented herein for the uppermost Wabaunsee, Admire, and Council Grove Groups, and lower Chase Group. Sections from northern and southern outcrop regions are utilized in order to test for the possible effects of different lithofacies on the distribution of conodont species. Marine Wabaunsee, Admire, Council Grove, and Chase strata from southern Kansas and northernmost Oklahoma are generally more carbonate-rich as compared to coeval strata from northern Kansas and Nebraska, which have a much higher percentage of open-marine as well as marginal-marine siliciclastics.

This report is an outgrowth of our long-standing research programs that include high-resolution multitaxial biostratigraphic, chronostratigraphic, and sequence stratigraphic analysis of Carboniferous and Permian strata. Much of the conodont-range data presented in this paper were generated as a direct result of conodont-biofacies analysis used for delineating Late Carboniferous–Early Permian depositional sequences and generating relative sea-level fluctuation curves (Boardman and Nestell, 1993). Open-marine shelfal Late Carboniferous and Early Permian strata contain abundant representatives of the evolutionary clades of the conodont *Streptognathodus*. Apparently, many species of *Streptognathodus* are cosmopolitan in distribution, thus making them reliable fossils for global correlation. Additionally, species of *Sweetognathus* have also been employed for correlating Lower Permian strata throughout the world. *Sweetognathus expansus* has been proposed as a basal Permian indicator, *Sw. merrilli* a basal Sakmarian index (Chuvashov et al., 2002a), and *Sw. whitei* as a basal Artinskian taxon (Chuvashov et al., 2002b).

Worldwide upper Carboniferous to Lower Permian strata are marked by cyclothems that resulted from numerous episodes of sea-level advances and retreats associated with waxing and

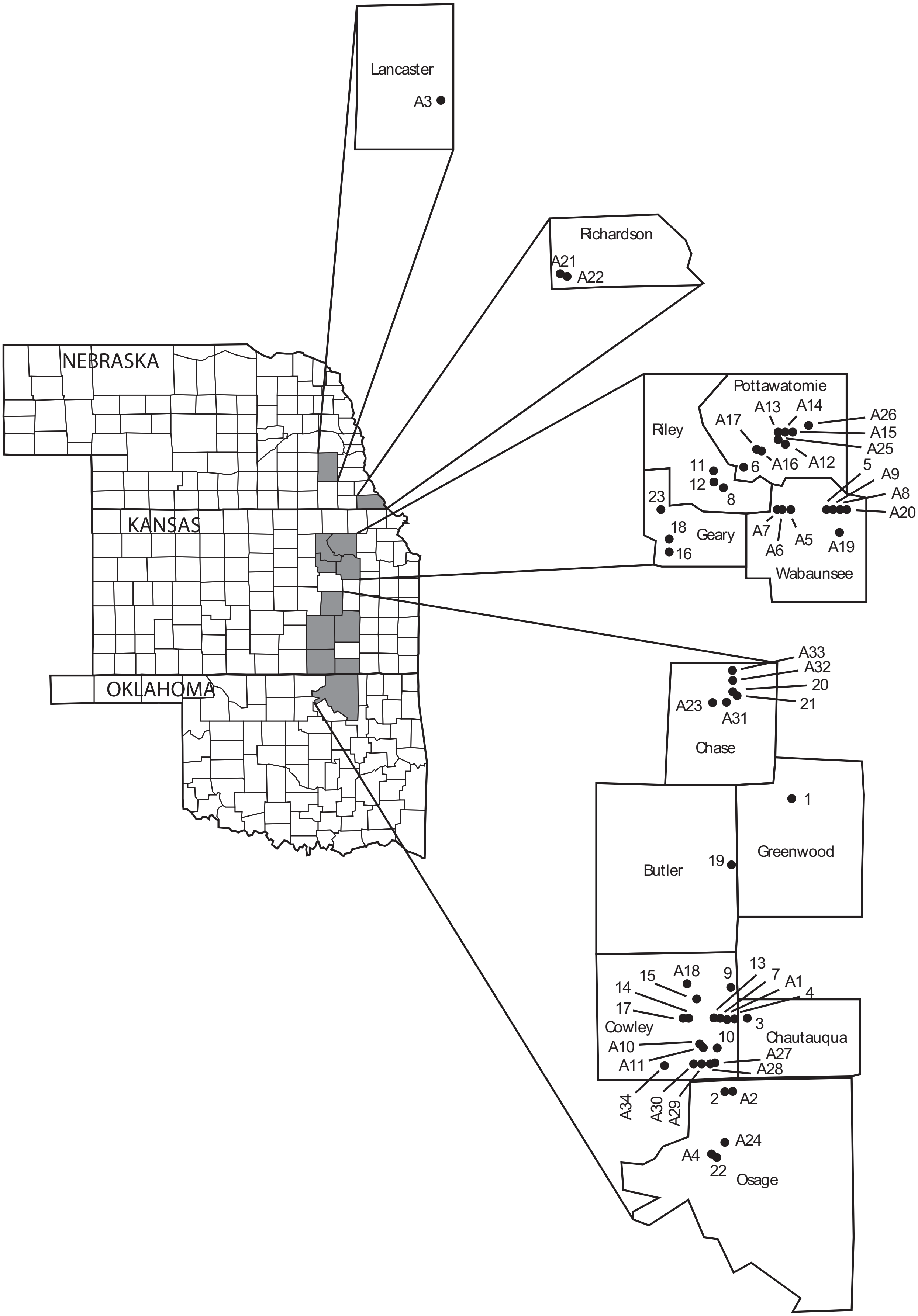



FIGURE 1—Location of measured sections.

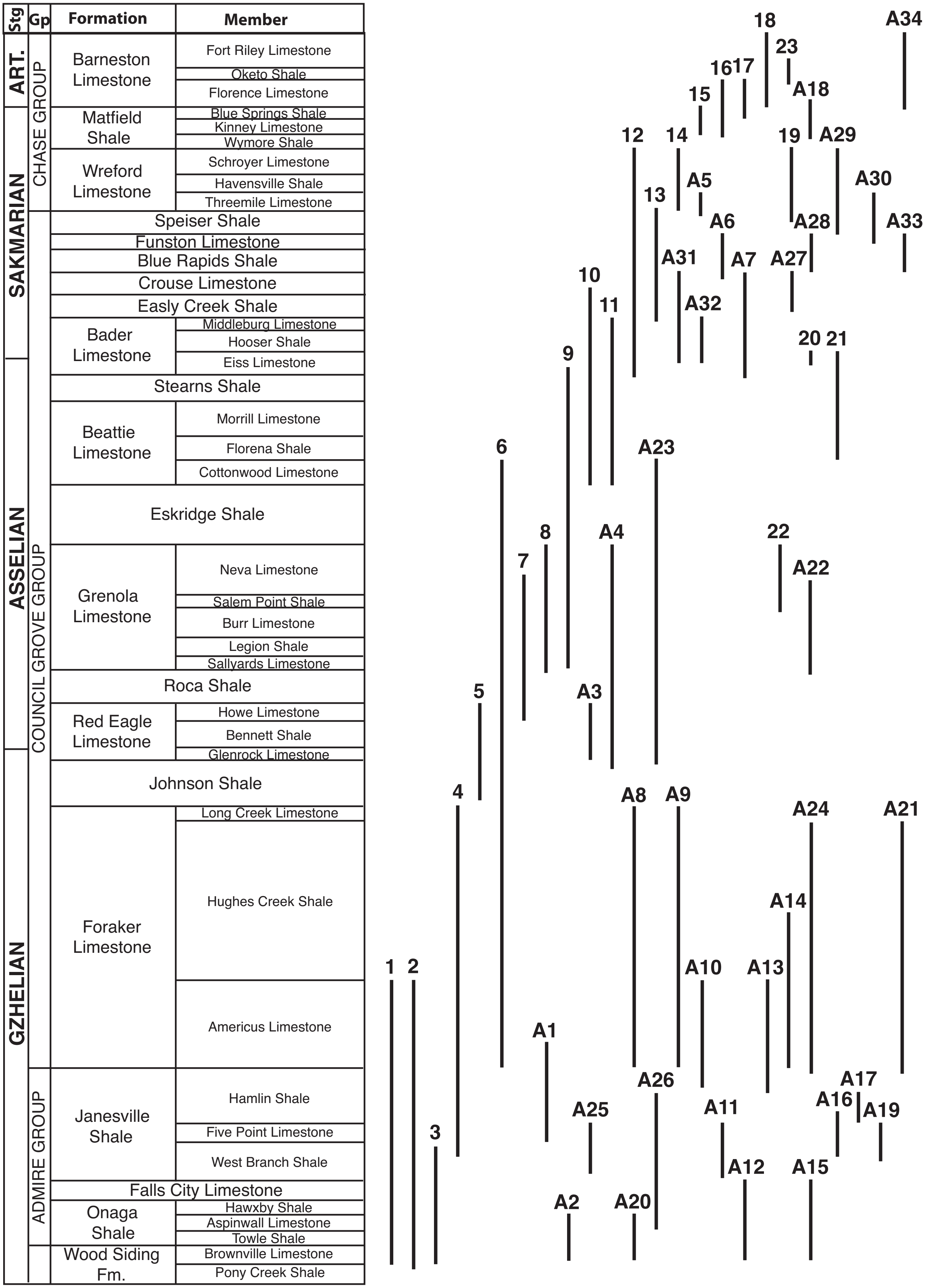



FIGURE 2—Stratigraphic coverage of localities included in this study.

waning of continental glaciers in Gondwanaland (Boardman, 1999; Boardman et al., 1984; Boardman and Heckel, 1989; Crowell, 1978; Crowell and Frakes, 1975; Crowley and Baum, 1991; Heckel, 1977, 1986; Schenk, 1967; Veevers and Powell, 1987; Wanless and Shepard, 1936; Yang, 1996). Magnitudes of sea-level rise and fall associated with glaciation and deglaciation apparently fall within the similar ranges (50–100 m) commonly associated with Pleistocene glacial episodes (Aldis et al., 1988; Crowley and Baum, 1991). The pattern of introduction of new species at or near maximum-flooding surfaces suggests that the species evolved elsewhere and migrated in during maximum flooding. This pattern fits the hypothesis that periodic major sea-level drops of about 50–100 m would likely have isolated many of the intracratonic basins, thereby creating the potential for the evolution of new species through allopatric speciation. New species evolving as peripheral isolates during lowstand could then migrate to other basins during the next major sea-level rise that would have reconnected many of the basins. Major sea-level rises should be associated with the introduction of new species, without a plethora of intermediate or transitional morphotypes, on a global basis if this theoretical pattern is correct. Likewise in the basin of new species origin, intermediate or transitional forms might be present. Sea-level curves that indicate the relative change in rise and fall of sea-level could give an independent test of the migration of new species from one region or province into another. At least for the midcontinent, new species of conodonts are introduced with most of the major maximum-flooding surfaces (fig. 3).

The late Carboniferous–Early Permian sequence stratigraphic model for the North American midcontinent can best be described as a complex succession of fifth-order transgressive-regressive cycles that are terminated by subaerial exposure (exposure cycles) or shallow-water deposition (subtidal cycles) following the terminology of Goldhammer et al. (1991). Fourth-order sequence sets are terminated by a major exposure surface evidenced by a well-developed paleosol or set of paleosols at the top of an exposure cycle. All the fifth-order cycles in the uppermost Wabaunsee and Admire Groups are exposure cycles. The Council Grove and lower Chase Groups are composed of mixed subtidal and exposure cycles. Essentially, subtidal cycles are typified by carbonate-dominated deposition (or carbonate hemicycle of Wardlaw et al., 2004), and exposure cycles are composed of siliciclastic-dominated deposition (or siliciclastic hemicycle of Wardlaw et al., 2004).

# Lithofacies

Lithofacies within the subtidal cycle for the Council Grove Group have been described by Puckette et al. (1995). Additionally, Mazzullo et al. (1995, 1997) discuss lithofacies comprising the carbonate subtidal cycles of the Chase Group. For purposes of this report, we follow Puckette et al. (1995) and Mazzullo et al. (1995, 1997) for interpretations of the carbonate-dominated part of each depositional sequence.

The following lithofacies are currently recognized from the Wabaunsee, Admire, Council Grove, and Chase Groups:

## Facies: Offshore

**1) Black, fissile to blocky, commonly silty, highly fossiliferous shales and mudstones with abundant *Streptognathodus* conodonts, *Ammodiscus* foraminifers, inarticulate brachiopods, abundant fish debris, and ammonoids.**

This facies is restricted to the lower Council Grove Group including the upper part of the Americus Limestone Member, middle part of the Hughes Creek Shale Member, upper part of the Hughes Creek Shale Member, Bennett Shale Member, and in a shale parting within the lower part of the Neva Limestone Member. These black shales are best developed in northern Kansas and Nebraska and have been documented in the Hugoton embayment (Puckette et al., 1995; Amador, 2000). This facies contains the conodont *Streptognathodus* biofacies and *Ammodiscus* foraminifer biofacies, along with locally abundant ammonoids and inarticulate brachiopods. Furthermore, this facies shows condensed sedimentation as evidenced by high conodont abundance (100–1,000 platform conodonts/kilogram).

**2) Gray, fissile to blocky, commonly silty, highly fossiliferous shales and mudstones with abundant *Streptognathodus* conodonts, diverse foraminifers, abundant brachiopods, crinoids, bryozoans.**

This facies is restricted to the lower Council Grove Group including the upper part of the Americus Limestone Member, middle part of the Hughes Creek Shale Member, upper part of the Hughes Creek Shale Member, Bennett Shale Member, and in a shale parting within the lower part of the Neva Limestone Member. It is usually associated with the black-shale facies (1) and immediately overlies or underlies it.

**3) Gray, fissile to blocky, highly fossiliferous calcareous and commonly siliceous shales and mudstones with abundant *Streptognathodus* conodonts, diverse foraminifers, abundant brachiopods, crinoids, bryozoans, and abundant siliceous sponge spicules.**

This facies is common in the lower Chase Group and represents the maximum-transgressive facies in the Florence Limestone Member, Threemile Limestone Member, and Schroyer Limestone Member.

**4) Highly fossiliferous, shaly, glauconitic wackestone with *Streptognathodus* conodonts, abundant and diverse foraminifers, brachiopods, bryozoans, crinoids, and locally ammonoids with evidence of condensed sedimentation along with phosphatized mollusks.**

This facies is very common in lower Council Grove strata cropping out in southern Kansas and northern Oklahoma. It is characterized by highly fossiliferous, shaly, glauconitic wackestones with the *Streptognathodus* conodont biofacies and phosphatized mollusks. It is deposited in slightly shallower water than the black and gray offshore shales at or near the euphotic zone and is common when the offshore black and gray shales change facies over inferred paleotopographic highs.

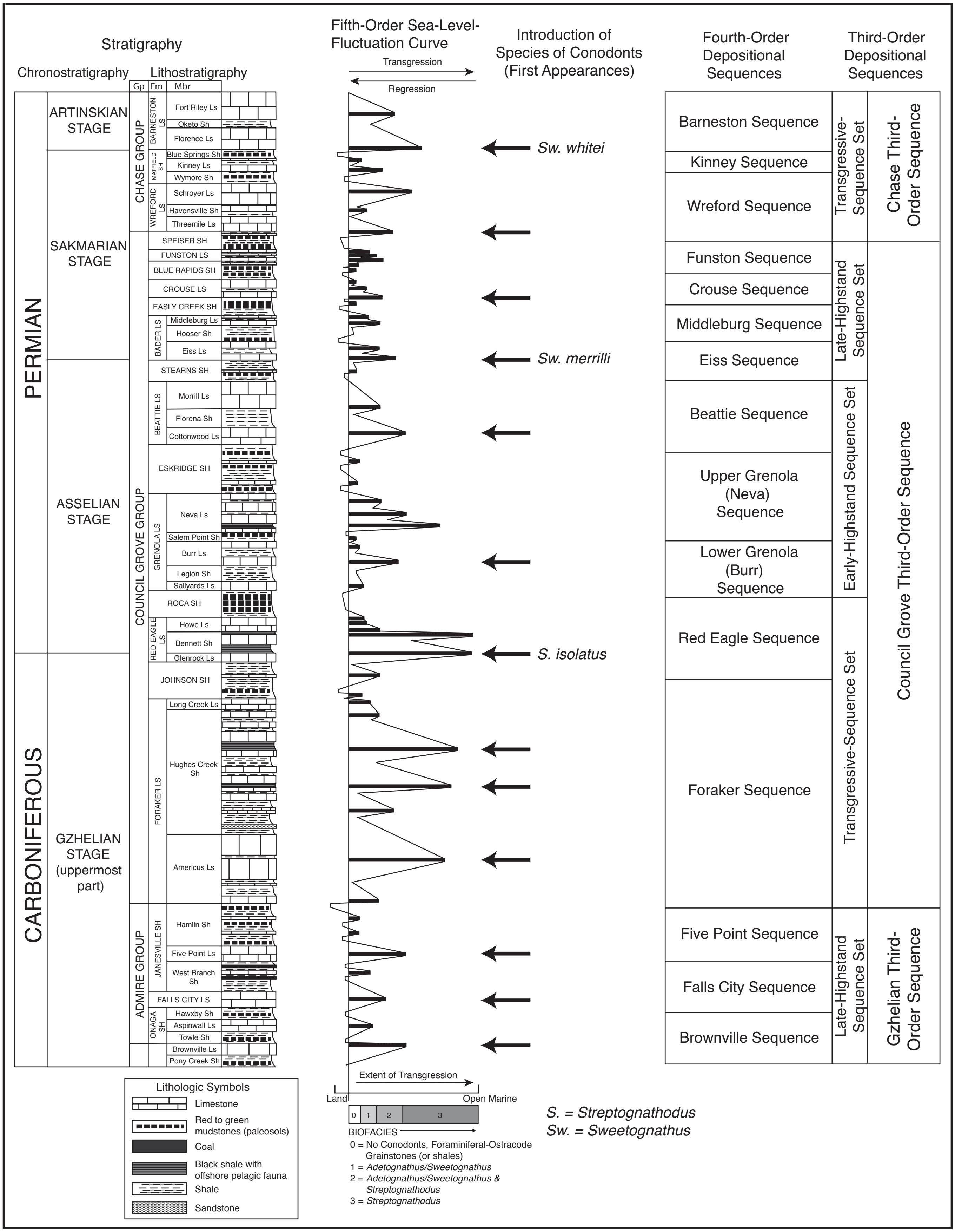



FIGURE 3—Stratigraphy, sea-level curve, conodont species FAD's, and depositional sequences for the interval from the Pony Creek Shale Member of the Wood Siding Formation to the Fort Riley Limestone Member of the Barneston Limestone. Arrows indicate introduction of new species (FAD's). Introduction of important species proposed as international stage-boundary definitions are named.

## Facies: Normal Marine, Shelf

**5) Highly fossiliferous wackestones to packstones with *Streptognathodus* conodonts, abundant and diverse foraminifers with locally abundant fusulinaceans, brachiopods, bryozoans, corals, crinoids.**

This facies is abundant throughout the Wabaunsee, Admire, and Council Grove Groups and represents normal-marine subtidal carbonates deposited below fair-weather wave base.

**6) Highly fossiliferous wackestones to packstones with mixed conodont fauna of *Streptognathodus–Adetognathus* (*Sweetognathus* above Red Eagle), foraminifers with mixed fauna of mollusks, brachiopods, bryozoans, corals, crinoids.**

This facies is a shoaling facies represented by a mixture of offshore and nearshore conodonts.

**7) Highly fossiliferous packstones to grainstones with rare conodonts, abundant fusulinaceans.**

This facies is abundant throughout the lower Council Grove Group, is a shoaling facies, and represents normal-marine subtidal carbonates deposited in moderate to high energy within wave base.

**8) Crossbedded ooid grainstones with rare abraded fossil fragments.**

This facies is rare in Wabaunsee-lower Chase Groups that crop out but is locally common in the subsurface Council Grove Group strata of the Hugoton embayment (Dubois et al., 2003). It represents very shallow marine high-wave-energy environments.

**9) Grapestone packstone to grainstone.**

This facies is common only in the subsurface Council Grove Group of the Hugoton embayment (Dubois et al., 2003) and was inferred to occur in a shoaling environment that had alternations of quiescence and turbulence. Additionally, the cement for this facies is anhydrite suggesting the rock was saturated with sulfate-enriched brines.

**10) Molluscan packstones to grainstones.**

This facies occurs in shallow moderate-wave-energy environments and contains abundant gastropods and bivalves with little evidence of stenohaline taxa. The upper part of the Eiss Limestone Member of central Kansas that contains *Sweetognathus merrilli* is an excellent example of this facies. The Hamlin Shale Member in northern Oklahoma near Foraker contains a molluscan coquina that is made up completely of *Myalina* shells.

**11) Phylloid-algal boundstones.**

This facies is restricted to the lower Council Grove Group in outcrop; in particular, the Red Eagle Limestone of northern Oklahoma and the Neva Limestone Member of northern and central Kansas. It is also reported in the Panoma field of the Hugoton embayment (Dubois et al., 2003).

**12) Gray shales to silty mudstones with normal-marine faunas.**

This facies is surprisingly rare within the study interval and is locally abundant in northern Kansas and southern Nebraska within lower Council Grove Group strata (especially the Foraker Limestone). The rarity of this facies is attributed to a lack of high-stand deltaic sedimentation. The common silt content within this facies suggests possible eolian derivation from a northern midcontinent source. This facies contains brachiopods, bryozoans, and locally abundant fusulinaceans. It was also noted within the Hugoton embayment by Dubois et al. (2003).

## Facies: Marginal Marine, Nearshore

**13) Stromatolitic boundstones.**

This facies is rare but occurs in the Houchen Creek limestone bed of the Admire Group, basal Americus Limestone Member, and the top of the Howe Limestone Member, all of which are restricted to northern Kansas.

**14) *Ottonosia* stromatolitic wackestones to packstones.**

This facies is common within the Crouse Limestone of southern and central Kansas. Commonly, *Composita* brachiopods are the nucleus for the growth of the *Ottonosia* colonies. Generally, the brachiopods within this facies are silicified. It is interpreted to form in shallow, moderately high energy environments with moderately hypersaline waters.

**15) Silty, locally dolomitic ostracode and bivalve carbonate mudstones to wackestones.**

This facies is very common in the late regressive deposits of numerous Council Grove and Chase Group cycles and represents brackish to hypersaline lagoonal carbonates. It contains very little evidence of normal-marine salinities as evidenced by the virtual absence of stenohaline organisms. Locally, evaporitic minerals are abundantly present in this facies.

**16) Thinly laminated carbonate mudstones with locally abundant mudcracks.**

This facies is locally present in Council Grove Group late-regressive deposits such as in the Foraker Limestone and represents tidal-flat sedimentation.

**17) Marginal-marine black-shale facies**

This facies occurs immediately above maximum-marine flooding levels in a number of minor-scale Council Grove Group depositional sequences including above the lower part of the Americus Limestone Member, upper part of the Johnson Shale, basal Legion Shale Member above the Sallyards Limestone Member, above the lower part of the Burr Limestone Member, above a limestone in the Salem Point Shale Member, above an unnamed limestone in the middle of the Stearns Shale, above the lower part of the Middleburg Limestone Member, above the lower part of the Crouse Limestone, above the lower part of the Funston Limestone, and in the upper part of the Fort Riley Limestone Member. These shales contain a limited ostracode and bivalve fauna with no conodonts. Additionally, evaporite minerals including gypsum and anhydrite (largely replaced by silica) are locally present in this lithofacies. This facies typically grades laterally into poorly fossiliferous silty carbonates with shallow-water indicators such as low-diversity ostracode and bivalve assemblages. We view this facies as representing a marginal-marine, perhaps lagoonal environment created by extremely rapid sea-level fall coupled with a dramatic increase in the influx of siliciclastic sediments immediately following maximum-marine flooding. This sea-level fall created localized low oxygen and perhaps variable salinity conditions on the proximal or high shelf. This facies was not distinguished by Olszewski and Patzkowsky (2003), who lumped it in with the offshore black-shale facies.

**18) Marginal-marine light-gray, green, or tan, blocky to fissile, poorly fossiliferous silty mudstones and shales.**

This facies occurs in numerous carbonate-dominated subtidal cycles within the Admire Group to Chase Group interval. This lithofacies commonly overlies the previous lithofacies or may directly overlie and separate carbonates within the hemicycle. This lithofacies is poorly fossiliferous, usually containing a low-diversity ostracode and foraminifer assemblage, may contain silica-replaced evaporite nodules, and grades laterally into poorly fossiliferous shallow- to restricted-marine carbonates. This facies is interpreted to represent a marginal-marine condition created by rapid forced regression accompanied by an increase in siliciclastic sedimentation on the shelf. The facies commonly separates high-frequency fifth-order cycles within the overall thicker carbonate subtidal cycles.

## Facies: Terrestrial

**19) Green blocky silty mudstones to shaly siltstones.**

This facies is also noted to contain abundant pedogenic features such as columnar peds, angular to subangular peds, and slickensides. This facies has been interpreted to represent paleosols.

**20) Red blocky silty mudstones to shaly siltstones.**

This facies is also noted to contain abundant pedogenic features such as columnar peds, angular to subangular peds, and slickensides, and has been interpreted to represent paleosols.

**21) Coals.**

This facies is restricted to the Wabaunsee and Admire Groups. A changeover from wetter to dry environments is thought to mark the end of coal formation at the base of the Council Grove Group.

**22) Boxwork carbonates.**

This facies is associated with well-developed paleosols and is thought to represent secondary calcification of shrinkage cracks. It is very common in the top of the Admire Group immediately below the Americus Limestone Member. McCahon and Miller (1997) noted boxwork structures in carbonates related to Carboniferous–Permian paleosols, and Olszewski and Patzkowsky (2003) recognized “boxwork” carbonates as a subaerial lithology.

# Biofacies

The distribution of ostracodes, conodonts, and foraminifers can characterize nearshore to offshore biofacies in the Wabaunsee, Admire, Council Grove and lower Chase Groups and is summarized by Boardman et al. (1996). Nearshore marginal-marine strata are characterized by a low-diversity microfossil assemblage dominated by *Geisina* ostracodes, no conodonts, and rare *Thurammina* foraminifers. Nearshore normal-marine strata contain a *Cavellina* ostracode assemblage (see Knox et al., 1995), an *Adetognathus/Sweetognathus* conodont fauna, and encrusting foraminifers along with *Ammodiscus*. Intermediate-depth (offshore) shelf strata contain an *Amphissites* ostracode assemblage, *Streptognathodus* conodont fauna, and diverse foraminifers including *Tetrataxis*, *Globivalvulina*, large paleotextularids, endothyranellids, and fusulinaceans. Deeper-shelf, more offshore deposits are characterized by a reduced-diversity benthic assemblage including inarticulate brachiopods (*Orbiculoidea*), the *Ammodiscus* foraminifer assemblage with a pelagic component of rare ammonoids, fish debris, and the *Streptognathodus* conodont fauna. Within our study interval, no stratified water column or very high productivity facies, exemplified by the conodont *Gondolella* (Stamm and Wardlaw, 2003) were observed. However, it appears that the number of species of *Streptognathodus* increases with increasing depth and more open-marine offshore depositional environments. We will refer to the four biofacies recognized in our study area as 1) Nearshore marginal marine, 2) Nearshore normal marine, 3) Offshore intermediate shelf, and 4) Offshore deeper shelf.

# Sequence Stratigraphy

## General

Uppermost Wabaunsee, Admire, Council Grove, and Chase Group strata are characterized by a complex shelfwide mixed siliciclastic-carbonate system that records a hierarchy of stratigraphic forcing similar to that described by Goldhammer et al. (1991) for the carbonate-dominated Desmoinesian cyclothemic strata of the Paradox basin. Cyclothemic-scale depositional sequences from the Wabaunsee and Admire Groups consist of thick exposure cycles of marginal-marine and nonmarine clastics separated by thin carbonate-dominated highstand deposits. In contrast, cyclothemic-scale depositional sequences from the Council Grove and Chase Groups are composed of a two-component system, one being carbonate-dominated subtidal cycles and the other siliciclastic-dominated exposure cycles. The carbonate-dominated hemicycle of the depositional sequences generally is thick (1–25 m) and generally represents more dominantly marine conditions. The thick carbonates are overlain by a relatively thick (5–15 m) red and green caliche-bearing blocky silty mudstones and siltstones hemicycle that commonly contains well-defined pedogenic features (Miller and West, 1993; Miller et al., 1996; Olszewski and Patzkowsky, 2003). These red and green deposits are generally thought to have formed during late stages of sea-level fall, lowstand, and perhaps earliest transgression. Close examination of both the dominantly marine carbonate hemicycle as well as the dominantly nonmarine siliciclastic hemicycle reveal a much more complicated scenario for their origin.

The fossil assemblages are critical in deciphering the depositional succession. Green, gray to black, clayey to silty mudstones contain the nearshore marginal-marine biofacies and represent nearshore to lagoonal deposition. Carbonates as well as siliciclastic-dominated facies commonly contain the nearshore, normal-marine biofacies and represent shallow-water, nearshore deposition. The moderate-depth open-shelf microfaunal assemblage of the offshore intermediate-shelf biofacies is usually found in wackestones, but also occurs in shales that are in close stratigraphic proximity to the fossiliferous wackestones. Deeper shelf marine deposits with the offshore, deeper-shelf biofacies occur in the offshore black shale and equivalent shaly, glauconitic, and fossiliferous wackestones. This deep-shelf assemblage is well represented in maximum-marine-flooding marine-condensed sections of the offshore black-shale facies common to the lower Council Grove Group.

Documentation of the vertical succession of conodont faunas allows correlation of the shallow shelfal cycles of the midcontinent to slope or basinal cycles of the Type Permian region of the southern Urals (Aidaralash Creek in Kazakhstan or Usolka in Russia). Late Carboniferous and Early Permian fourth-order depositional sequences demonstrate a plexus of superimposed orders of cyclicity (frequency) as well as amplitudes. Similar hierarchies with superposed cycles have been described in carbonate Pennsylvanian strata of the Paradox basin (Goldhammer et al., 1991), carbonate Triassic strata of northern Italy (Goldhammer et al., 1987, 1990), and in Cenozoic siliciclastic strata of the Gulf Coast of Mexico (Mitchum and van Wagoner, 1991). Documentation for various orders of cyclicity within the midcontinent cyclothemic succession has been illustrated by Busch and West (1987), Miller et al. (1992), Miller and West (1993), Boardman and Nestell (1993), and Youle et al. (1994).

Based on observed stacking patterns, fourth-order sequences can be objectively grouped into composite third-order depositional sequences following Mitchum and van Wagoner (1991). A similar methodology was utilized by Youle et al. (1994), who proposed composite third-order sequences for Middle Pennsylvanian strata of the Anadarko basin based on stacking patterns of fourth-order cyclothemic-scale depositional sequences. In contrast to the derivation of third-order cyclicity based on stacking patterns, Ross and Ross (1985, 1987) presented charts demonstrating coastal-onlap curves and defining third-order depositional sequences for Carboniferous and Lower Permian strata of the North American midcontinent based largely on faunal criteria. For the purposes of this report, we follow the methodology of Youle et al. (1994). Depositional sequences from the upper Wabaunsee and Admire Groups comprise the late-highstand sequence sets in a third-order composite depositional sequence that includes most of the Virgilian (Gzhelian) strata. The Council Grove Group comprises one third-order sequence (Council Grove Third Order Sequence) with the base of the Americus Limestone Member representing the transgressive surface. The Bennett Shale Member of the Red Eagle Limestone contains the most widespread maximum-marine-flooding condensed section of the Council Grove Group, and thus corresponds also to the maximum transgression of the composite third-order sequence. Additionally, the Red Eagle Limestone extends further paleo-landward into Oklahoma than any other unit of the Council Grove Group (Branson, 1964, p. 61). The Foraker and Red Eagle sequences form a retrogradational stacking pattern of sequences, which comprises the transgressive-systems tract of the third-order sequence. The highstand-systems tract includes sequences that stack into aggradational (Lower and Upper Grenola Sequences) and progradational stacking pattern (Beattie through Funston Sequences) with a very major Type 1 unconformity being developed in the Speiser Shale at the top of the Council Grove Group. The Wreford and Barneston Sequences of the overlying Chase Group belong to the retrogradational transgressive systems tract to the Chase Third Order Sequence. The Barneston Limestone also has been demonstrated to extend further paleo-landward into Oklahoma (Branson, 1964, p. 61).

In addition to the cyclothemic-scale fourth-order sequences, many high-frequency fifth-order sequences are evident within the fourth-order packages. Within the dominantly marine part of many latest Carboniferous and Early Permian midcontinent cyclothemic depositional sequences (e.g., Foraker and Grenola sequences), widely correlatable, subsequence-scale divisions (higher-order sequences) on the order of 1–5 m in thickness are present. These higher-order sequences form the parasequences and parasequence sets that clearly stack into the systems tracts that subdivide the fourth-order depositional sequences. Clear evidence of a basinward shift in facies is present in cases where the fifth-order sequences are not terminated by subaerial exposure. In addition to the fifth-order cyclicity in the dominantly marine part of the fourth-order depositional sequence, the minor transgressive-regressive marine bands with distinctive transgressive and highstand systems tracts that are commonly present within the thick siliciclastic-dominated intervals that overly the thick carbonate-dominated part of the sequence (Miller and West, 1993) also represent high-frequency fifth-order depositional sequences. These higher-order sequences are referred to as fifth-order transgressive-regressive cycles following the terminology of Goldhammer et al. (1991). The fifth-order cycles that are terminated by subaerial exposure are referred to as exposure cycles, whereas fifth-order cycles that are terminated without subaerial exposure are referred to as subtidal cycles (Goldhammer et al., 1991).

Type 1 depositional sequences (as defined by van Wagoner et al., 1988), such as those in this study, have been subdivided into the lowstand-systems tract, transgressive-systems tract, highstand-systems tract, and the forced-regressive-systems tract (Posamentier et al., 1992; Hunt and Tucker, 1992, 1995; and the equivalent falling-sea-level systems tract of Nummedal, 1992, and Nummedal and Molenaar, 1995). Historically, the lowstand-systems tract comprises the basin-floor fans, slope fans, and prograding coastal wedges. Lowstand deposits on the shelf form the prograding wedge deposited during late sea-level fall or early sea-level rise. The shelfal expression of the prograding wedge consists largely of incised-valley-fill deposits formed during late sea-level fall or earliest eustatic rise. Incised-valley fills are rare in the Admire strata and have not been documented in the Council Grove and lower Chase strata of the midcontinent. During the time interval in which these rocks were deposited, progressively more arid conditions predominated, and sea-level fall resulted in subaerial exposure of the majority of the shelf resulting in meteoric diagenesis of the highstand/forced-regressive carbonates. A small number of the tops of the highstand/forced-regressive carbonates (Five Point Limestone, Long Creek Limestone, Howe Limestone, Eiss Limestone, Middleburg Limestone, Schroyer Limestone, Kinney Limestone Members) demonstrate direct subaerial exposure as evidenced by red internal sediment infilling solution vugs and brecciation associated with regolith development, whereas the rest are evidently capped by nearshore- to marginal-marine siliciclastics. Therefore, sequence boundaries generally lie within the thick (5–15-m) red to green mudstone intervals in the siliciclastic deposits that separate the dominantly carbonate facies. Thick siliciclastic intervals contain zones that exhibit an array of pedogenic structures indicative of extensive paleosol development (Miller and West, 1993). The thick siliciclastic packages dramatically thicken to the south of Osage County, Oklahoma. The predominant percentage of the thick package is composed of fluvial depositional systems with fewer paleosols.

Because minor marine bands (higher-order cycles) punctuate the complex of paleosols, several unconformities are typically present within each thick siliciclastic section. This makes identification of the shelfal expression of the fourth-order master-depositional-sequence boundary difficult to identify. Theoretically, the best option is to place the sequence boundary at the unconformity surface that corresponds to the maximum lowstand, following Hunt and Tucker (1995). However, this procedure also presents a serious challenge in identifying which part of the paleosol interval corresponds to maximum lowstand. The unconformity surface that extends furthermost basinward corresponds to this master-sequence boundary. In order to delineate master-sequence boundaries for these late Carboniferous–Early Permian depositional sequences, a number of dip cores would have to be analyzed from the proximal shelf to the distal shelf and into the Anadarko basin. Unfortunately, availability of cores from this stratigraphic interval is largely restricted to the proximal-shelf region and the Hugoton embayment. We, therefore, in the absence of this crucial data, recognize a master-sequence-boundary zone that includes the true master-sequence boundary. This sequence-boundary zone is bounded at the base by the first evidence of subaerial exposure and the top by the highest subaerial exposure surface, which is also coincident with the transgressive surface of the succeeding depositional sequence. Based on the glacial-eustatic model for sea-level fluctuation, it is likely that the master-sequence boundary lies near the top of the paleosol interval. As a result of our utilization of a sequence-boundary zone, we do not recognize a lowstand-systems tract, but include the sequence-boundary zone within the forced-regressive-systems tract. If and when the precise position of the master-sequence boundary is picked, then a lowstand-systems tract could be recognized that would include strata above the sequence boundary and below the transgressive-systems tract. Because the initial surface of forced regression lies immediately above the marine-condensed section, and the marine-condensed section represents the latest transgressive-systems tract and the highstand-systems tract, the stratigraphic thickness of the highstand-systems tract as utilized in this study is limited to the upper part of the marine-condensed section. The transgressive-systems tract includes strata from the base of the transgressive surface to the marine-condensed section (downlap surface). These deposits form a retrogradational parasequence-set stacking pattern. The highstand-systems tract historically encompasses the upper part of the marine-condensed section along with the thick dominantly marine part of the depositional sequence that includes aggradational to progradational parasequence sets formed during late stages of sea-level rise, eustatic stillstand, and early sea-level fall (van Wagoner et al., 1988). Sinusoidal-shaped sea-level-fluctuation curves such as presented by Jervey (1988) and Posamentier et al. (1988) have served as the paradigm for modeling depositional sequences. This model has been used to demonstrate that the majority of the highstand-systems tract is associated with aggradation and progradation occurring during maximum eustatic stillstand and early sea-level fall.

Because the late Carboniferous and Early Permian global chronostratigraphic framework is not formally established, we provisionally use the marine-cyclothem names as names for the fourth-order depositional sequences. Additionally, there is a paucity of reliable absolute dates for this time interval. Therefore, we recognize different orders of depositional sequences, but do not attempt to correlate a particular order to an absolute time duration, nor do we attempt to relate a particular Milankovitch frequency to an observed sequence.

## Summary of the Sequence Stratigraphic Section

### Gzhelian Third-Order Sequence—Late-Highstand-Sequence Set

This sequence set is characterized by a series of composite fourth-order sequences composed of two to three fifth-order sequences that are all exposure cycles defined from soil to soil and characterized by a maximum-flooding surface represented by limestone.

### Brownville Composite Fourth-Order Sequence (figs. 3, 4)

This fourth-order sequence is composed of two fifth-order sequences.

**Fifth-Order Sequence A, Brownville** is composed of the upper meter of the Pony Creek Shale Member, the Brownville Limestone Member, and a majority of the Towle Shale Member and ranges from the transgressive surface in the uppermost part of the Pony Creek to the top of the red mudstones (paleosols) in the Towle Shale Member. The maximum-flooding surface is in the top of the Brownville Limestone Member (northern Oklahoma-central Kansas) or the fossiliferous base of the Towle Shale Member (northern Kansas).

**Fifth-Order Sequence B, Aspinwall** is composed of the upper Towle Shale, Aspinwall Limestone, and lower part Hawxby Shale Members and ranges from the top of the red mudstone, marked by a thin limestone, to the blocky mudstones (paleosols) near the base of the Hawxby Shale Member. The maximum-flooding surface occurs within the Aspinwall Limestone Member, in the lower part in southern Kansas and Oklahoma, and in the upper part in northern Kansas.

### Falls City Composite Fourth-Order Sequence (figs. 3, 5)

This fourth-order sequence is composed of three fifth-order sequences.

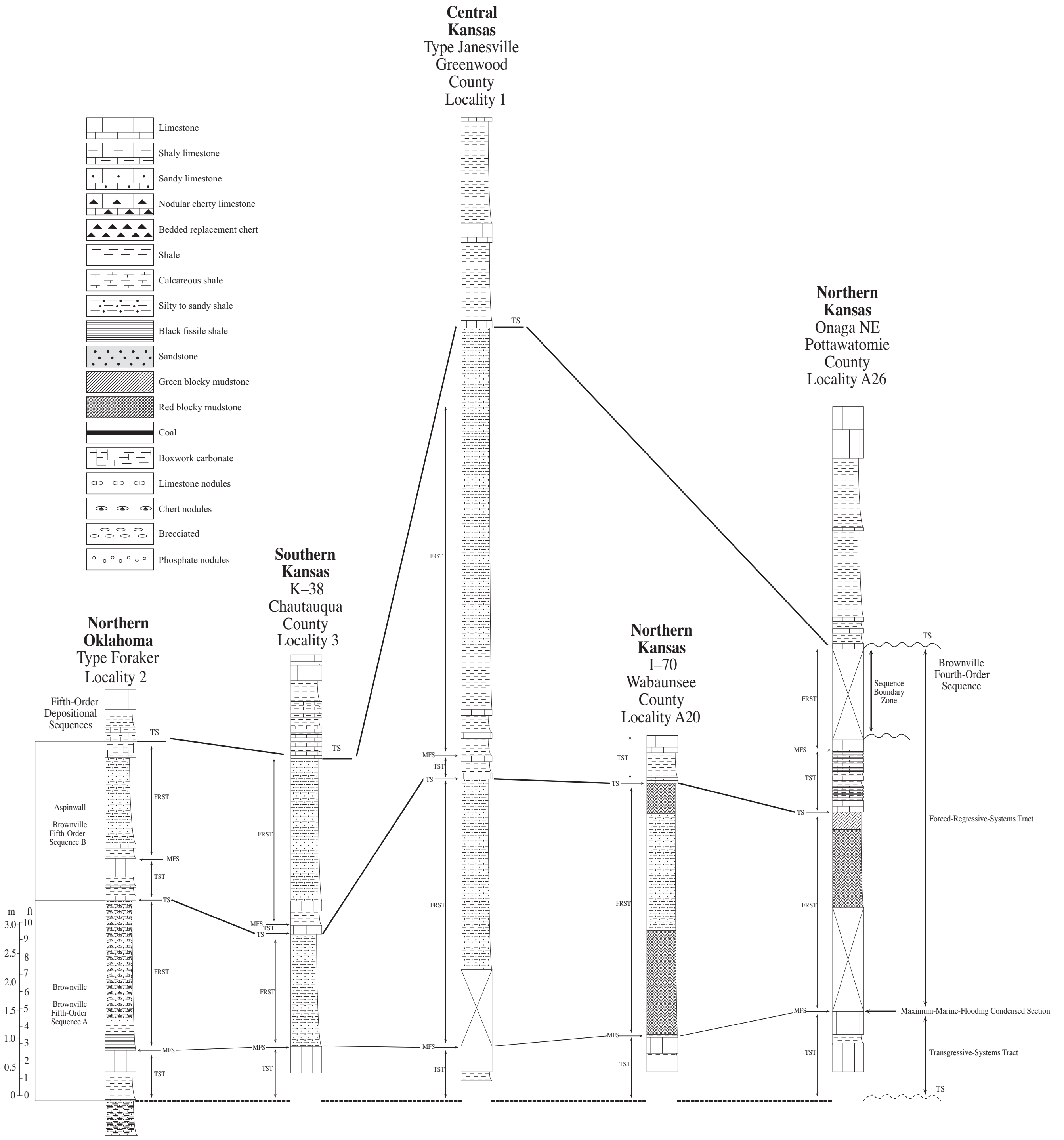



FIGURE 4—North-south sequence stratigraphic cross section of the Brownville Composite Fourth-Order Sequence; localities 2, 3, 1, A20, and A26. Some stratigraphic data for this cross section were provided by Boyd (1999).

**Fifth-Order Sequence A, lower Falls City** is composed of the upper Hawxby Shale Member and the lower Falls City Limestone and starts with a transgressive surface in the Hawxby Shale Member and ends within the poorly fossiliferous shale below the top limestone bed of the Falls City Limestone. Maximum flooding is represented by a highly fossiliferous wackestone in the middle of the Falls City Limestone (southern and central Kansas), and in the basal part of Falls City Limestone (northern Oklahoma and northern Kansas).

**Fifth-Order Sequence B, upper Falls City** is composed of the uppermost Falls City Limestone and the majority of the West Branch Shale Member and starts with the transgressive surface at the base of the uppermost limestone bed of the Falls City and extends to the top of the paleosol below the well-developed coal in the upper West Branch Shale Member. Maximum flooding is within the uppermost limestone bed of the Falls City Limestone.

**Fifth-Order Sequence C, Keene** is wholly contained within the upper West Branch Shale Member from the transgressive

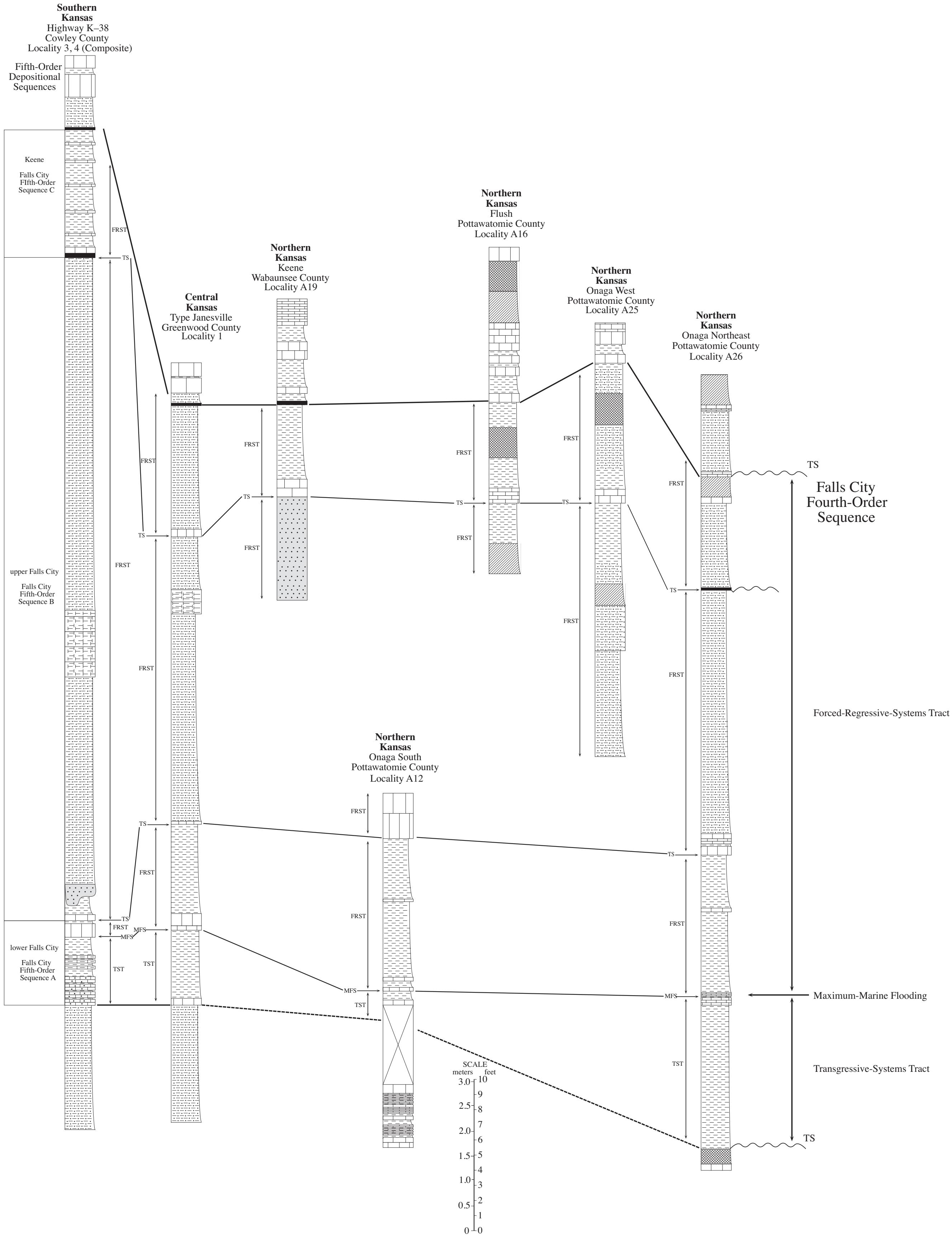



FIGURE 5—North-south sequence stratigraphic cross section of the Falls City Composite Fourth-Order Sequence; localities 3–4 (composite), 1, A19, A12, A16, A25, and A26. Some stratigraphic data for this cross section were provided by Vann (1994).

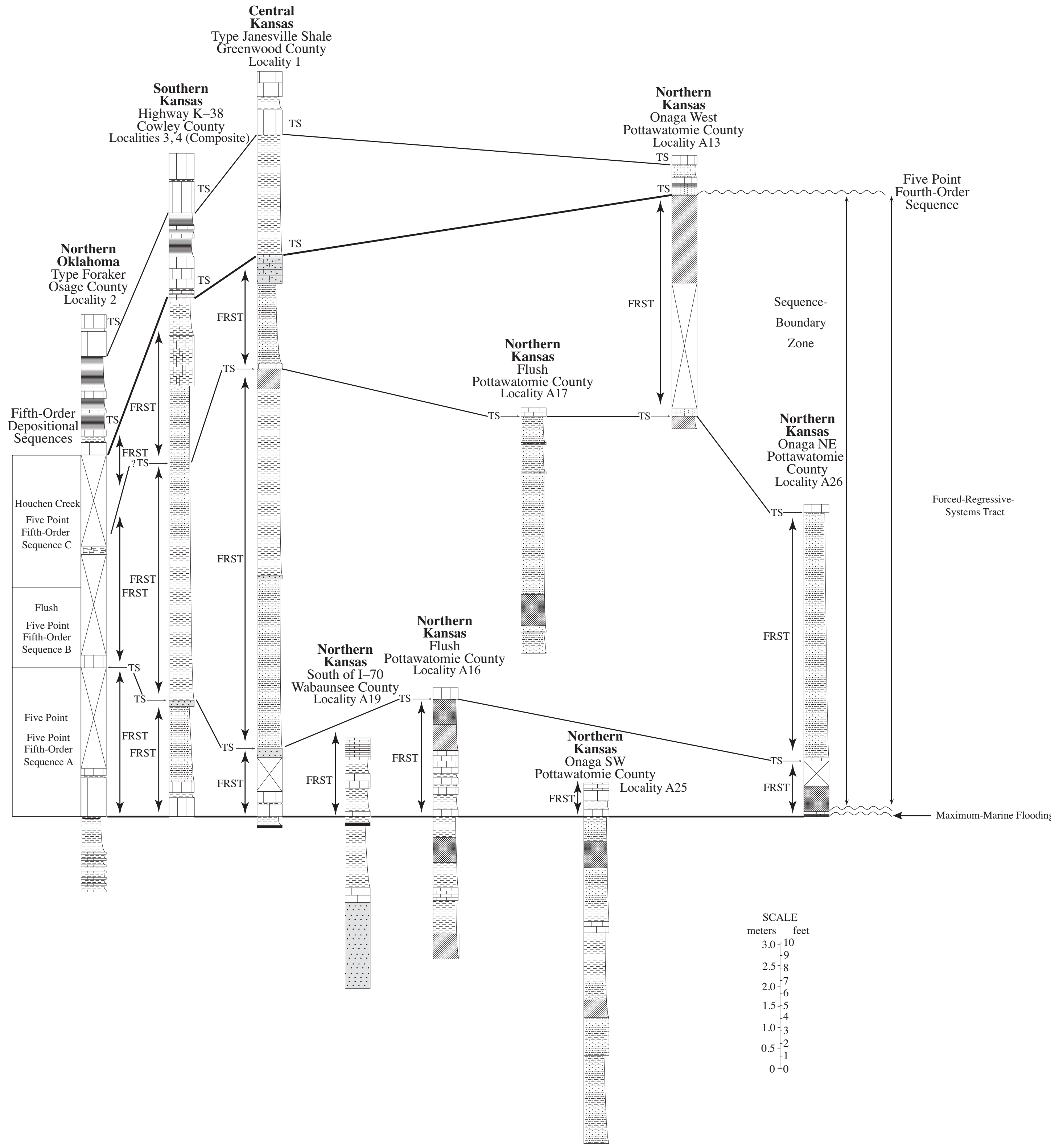



FIGURE 6—North-south sequence stratigraphic cross section of the Five Point Composite Fourth-Order Sequence; localities 2, 3–4 (composite), 1, A19, A16, A25, A17, A13, and A26. Some stratigraphic data for this cross section were provided by Vann (1994).

coal overlying a paleosol to the top of a following paleosol, which is followed by a coaly shale or coal deposit of the next sequence. The maximum-flooding surface occurs within a highly fossiliferous wackestone (northern Kansas), fossiliferous wackestone (central Kansas), and fossiliferous thin-bedded foraminiferal packstones and wackestones (southern Kansas and northern Oklahoma).

### Five Point Composite Fourth-Order Sequence (figs. 3, 6)

This fourth-order sequence is composed of three fifth-order sequences.

**Fifth-Order Sequence A, Five Point** is composed of the uppermost West Branch Shale, the Five Point Limestone, and the lower Hamlin Shale Members and starts with the transgressive surface represented by coal or coaly shale. The top of the sequence is represented by the paleosol at the base of the Hamlin Shale Member developed on top of the Five Point Limestone Member. Maximum flooding is represented by the highly fossiliferous glauconitic wackestone at the base of the Five Point Limestone Member.

**Fifth-Order Sequence B, Flush** is composed of the lower and middle Hamlin Shale Member and starts above the paleosol at the base of the Hamlin and ends at the top of the paleosol in the middle Hamlin. Maximum flooding is represented by fossiliferous units: foraminiferal-crinoid packstone in northern Kansas, fossiliferous shale in southern Kansas, and *Myalina*-bearing packstone/grainstone in northern Oklahoma.

**Fifth-Order Sequence C, Houchen Creek** is composed of upper Hamlin Shale Member, the Houchen Creek limestone bed, and the Oaks shale. This sequence is manifested by a stromatolitic carbonate (Houchen Creek limestone bed) in Nebraska and northern Kansas and an unnamed fossiliferous limestone in central and southern Kansas that are both underlain and overlain by red and green blocky mudstones that represent paleosols. The maximum-flooding surface lies within the limestone, and the sequence ranges from the top of the underlying paleosol to the top of the overlying paleosol.

### Council Grove Third-Order Sequence—Transgressive-Sequence Set

This sequence set is characterized by two marine-dominated composite fourth-order sequences that are composed of multiple fifth-order sequences that are mostly subtidal cycles; exposure cycles occurred in the upper part of each composite sequence, setting it apart from the ensuing composite sequence.

### Foraker Composite Fourth-Order Depositional Sequence (figs. 3, 7)

This fourth-order sequence is composed of eight fifth-order sequences; the lower six fifth-order sequences are capped by nearshore-marine to marginal-marine deposits consisting of poorly fossiliferous silty shales (representing subtidal cycles), and the upper two are capped by green to red blocky caliche-bearing mudstones indicative of paleosols (representing exposure cycles). The base of each fifth-order sequence is defined by a major flooding surface characterized by a highly fossiliferous wackestone with *Thalassinoides* traces and abundant open-marine fauna. Three of the fifth-order sequences contain condensed sections: upper Americus, middle Hughes Creek, and upper Hughes Creek, representing sedimentation during major sea-level rises. The upper Hughes Creek contains the most extensive and thickest condensed interval and represents maximum flooding during the Foraker and divides the Foraker composite depositional sequence into a transgressive-sequence tract leading to this maximum flooding and a forced-regressive-system tract represented by progressively shallower flooding surfaces above and soil development in the Johnson Shale. The transgressive surface of the Foraker sequence occurs at the base of the Americus Limestone Member and consists of a regionally extensive, transgressive lag-and-ravinement surface characterized by an ostracode-rich conglomeratic shale or carbonate.

**Fifth-Order Sequence A, lower Americus** is composed of the lower Americus Limestone Member, starts the transgressive base of the Americus, and includes the poorly fossiliferous shales that separate the lower and upper Americus Limestone Member beds. The maximum-flooding surface is represented by highly fossiliferous wackestone near the top of the lower Americus Limestone Member.

**Fifth-Order Sequence B, upper Americus** is composed of the upper Americus Limestone and lower Hughes Creek Shale Members, starts with the transgressive base of the upper Americus Limestone Member, and ends below the transgressive limestone in the lower Hughes Creek Shale Member. The maximum-flooding surface is represented by a thin condensed highly fossiliferous shale and shaly and phosphatic wackestone in southern Kansas and by shaly glauconitic and phosphatic wackestone in northern Kansas.

**Fifth-Order Sequence C, lower Hughes Creek** is composed of the lower Hughes Creek Shale Member, starts at the base of the first prominent limestone bed in the lower Hughes Creek Shale Member, and extends to the top of the shales below the base of the second prominent limestone bed in the lower Hughes Creek Shale Member. The maximum-flooding surface is within the first prominent limestone bed.

**Fifth-Order Sequence D, middle Hughes Creek** is composed of the middle Hughes Creek Shale Member, starts with the transgressive surface at the base of the second prominent limestone bed in the Hughes Creek, is dominated by limestone in southern Kansas, and has several limestone beds in northern Kansas, many representing multiple flooding surfaces. Maximum flooding is represented by a condensed highly fossiliferous black shale and shaly glauconitic and phosphatic wackestone throughout Kansas.

**Fifth-Order Sequence E, upper Hughes Creek** is composed of part of the upper Hughes Creek Shale Member and contains the major condensed black-shale maximum-flooding section of the Foraker fourth-order sequence. It begins with the transgressive surface at the base of the limestone immediately below the condensed black-shale interval and ends below the base of the Long Creek Limestone Member in northern Kansas and below the base of the prominent limestone in the upper part of the Hughes Creek Shale Member in southern Kansas.

**Fifth-Order Sequence F, top Hughes Creek** is composed of the top of the Hughes Creek Shale Member in southern and parts of northern Kansas and the lower part of the Long Creek Limestone Member in parts of northern Kansas. It begins with the transgressive surface at the base of the prominent limestone in the upper Hughes Creek or base of

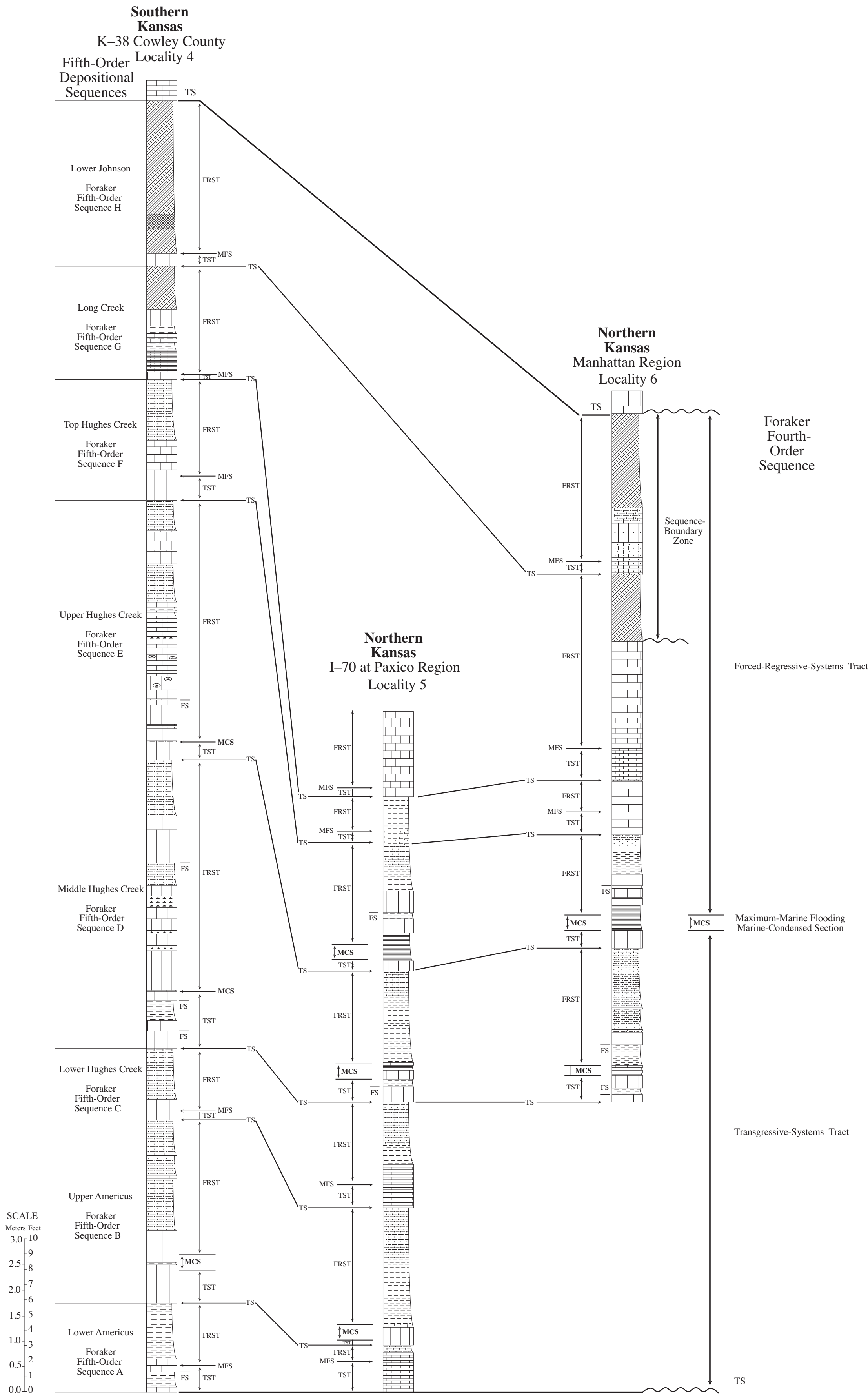



FIGURE 7—North-south sequence stratigraphic cross section of the Foraker Composite Fourth-Order Sequence; localities 4, 5, and 6. Some stratigraphic data for this cross section were provided by Keairns (1995).

the Long Creek and the maximum flooding surface occurs within that basal limestone. Poorly fossiliferous shales characterize the top of the sequence.

**Fifth-Order Sequence G, Long Creek** is composed of the Long Creek Limestone Member in southern Kansas, the upper part of the Long Creek Limestone Member in northern Kansas, and the thick soil profile that represents the lower Johnson Shale. It starts with the transgressive surface at the base of the limestone that forms the base of the Long Creek in southern Kansas and the base of the upper Long Creek in northern Kansas. The maximum flooding surface is just above the transgressive base, and the sequence extends to the top of the paleosols that comprise the lower Johnson Shale.

**Fifth-Order Sequence H, lower Johnson** is composed of the poorly fossiliferous limestone and overlying paleosols and shales of the lower and middle part of the Johnson Shale. The maximum-flooding surface is within the limestone, which contains a sparse assemblage of ostracodes and encrusting foraminifers and no conodonts.

## Red Eagle Composite Fourth-Order Depositional Sequence (figs. 3, 8)

This sequence is composed of six fifth-order sequences; the bottom three are subtidal cycles and the upper three are exposure cycles. The upper two subtidal cycles (lower Bennett and upper Bennett) contain condensed sections. The three subtidal cycles represent transgressive-system tracts up to maximum flooding and forced-regressive-system tracts following maximum flooding until the transgressive surface of the next cycle. The three exposure cycles represent an initial transgressive surface (and maximum flooding) followed by a forced-regressive-systems tract for each cycle. Only the uppermost exposure cycle is represented by an exposure surface everywhere. The lower two transition from exposure cycles in northern Kansas to subtidal cycles in southern Kansas.

**Fifth-Order Sequence A, top Johnson** is developed entirely in the upper part of the Johnson Shale and is represented typically by a thin intraclastic packstone developed as a transgressive lag and ravinement. Maximum flooding is represented by a fauna of abundant ostracodes, rare conodonts, and locally abundant mollusks and brachiopods generally in silty limestones and limy siltstones. The sequence terminates with silty dark mudstones and shales locally exhibiting silty rhythmites indicating tidally influenced deposition.

**Fifth-Order Sequence B, Top Glenrock-basal Bennett** is composed of the Glenrock Limestone Member and lower Bennett Shale Member in northern Kansas and Nebraska, and is within the lower Red Eagle (undifferentiated) in southern Kansas and Oklahoma. Maximum flooding occurs at the base of the Bennett Shale Member and is represented by abundant conodonts, orbiculoid brachiopods, ammonoids, and fish debris. In northern Kansas through Nebraska, this condensed section occurs in the base of black fissile shale of the Bennett Shale Member contrasted to central Kansas to Oklahoma where this condensed section occurs as highly fossiliferous, shaly, glauconitic, phosphatic wackestone. The cycle is terminated by poorly fossiliferous siltstone within the Bennett Shale Member in Nebraska, upper black-shale facies with no evidence of condensation of the Bennett in northern Kansas, and a phylloid-algal brachiopod-rich wackestone in central Kansas to northern Oklahoma. In northern Kansas the top of the Glenrock is represented by a burrowed surface infilled by Bennett Shale Member indicating a burrowed non-deposition surface before maximum flooding of the base of the Bennett. The sequence begins with the transgressive surface of the base of the Glenrock Limestone Member or its equivalent and ends below the transgressive surface of the upper Bennett.

**Fifth-Order Sequence C, upper Bennett** is composed of the upper Bennett Shale Member in northern Kansas and Nebraska and the middle Red Eagle undifferentiated in southern Kansas and Oklahoma. The maximum-flooding condensed section is represented by black fissile shale in Nebraska; by a calcite-cemented, black mudstone with *Thalassinoides* traces, orbiculoid brachiopods, and abundant fish debris and conodonts in the upper Bennett Shale Member in northern Kansas; and by either a highly fossiliferous shaly, glauconitic, phosphatic wackestone or a thin, gray, highly fossiliferous, phosphatic shale parting (<3cm) in central Kansas to northern Oklahoma. The sequence begins with transgressive surface of the upper Bennett and ends below the transgressive surface of the Howe Limestone Member or its equivalent.

**Fifth-Order Sequence D, Howe-lower Roca** is composed of the Howe Limestone Member or its equivalents in the Red Eagle undifferentiated, the paleosols of the lower Roca Shale in northern Kansas, and thin shales and silty limestone in the Red Eagle undifferentiated in southern Kansas and Oklahoma. Apparently the sequence is represented by an exposure cycle in northern Kansas and a subtidal cycle in southern Kansas and Oklahoma. Rankey and Farr (1997) recognize the lower Roca Shale that is part of this sequence as a single protosol at Tuttle Creek Reservoir spillway.

**Fifth-Order Sequence E, middle Roca** is composed of the middle Roca Shale in northern Kansas and limestone and limy shales in the Red Eagle undifferentiated in southern Kansas and Oklahoma. In northern Kansas it starts with a transgressive surface and thin marginal-marine limestone followed by paleosols. Rankey and Farr (1997) recognize this interval as an argillic calcisol at Tuttle Creek Reservoir spillway.

**Fifth-Order Sequence F, upper Roca** is composed of the upper Roca Shale in northern Kansas and the upper Red Eagle undifferentiated and entire Roca Shale in southern Kansas and Oklahoma. It is initiated by a transgressive surface and marginal-marine limestone in northern Kansas and limestones of the upper Red Eagle undifferentiated in southern Kansas and Oklahoma. Thick red paleosols mark the upper part of this exposure cycle. Rankey and Farr (1997) recognize this interval as two soils, a calcic argillisol followed by a calcic vertisol, at Tuttle Creek Reservoir spillway.

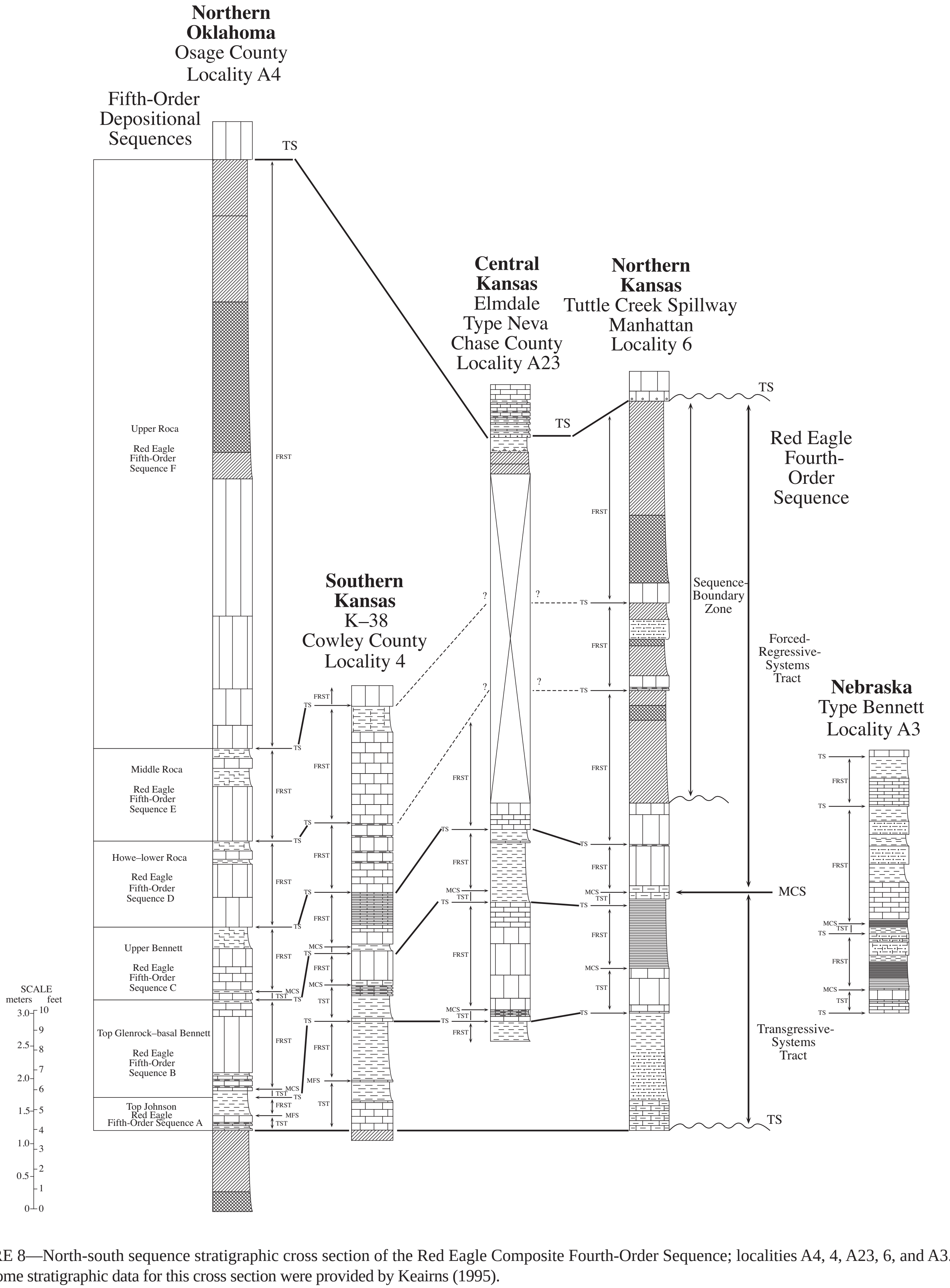



FIGURE 8—North-south sequence stratigraphic cross section of the Red Eagle Composite Fourth-Order Sequence; localities A4, 4, A23, 6, and A3. Some stratigraphic data for this cross section were provided by Keairns (1995).

## Council Grove Third-Order Sequence—Early-Highstand-Sequence Set

### Lower Grenola Composite Fourth-Order Depositional Sequence (figs. 3, 9)

This sequence is composed of four fifth-order depositional sequences. A transgressive lag (ravinement surface) marks the base of the Grenola sequence. This lag generally coincides with the basal bed of the Sallyards Limestone Member except in central Kansas where it occurs in the top of the Roca Shale. The transgressive-systems tract of the Lower Grenola sequence includes the interval from the base of the Sallyards Limestone Member to the maximum-marine-flooding surface at the top of the lower Burr Limestone Member. The forced-regressive system tract includes the interval from the maximum-marine-flooding surface to the Neva Limestone Member that marks the base of the Upper Grenola sequence. The lower three fifth-order sequences represent subtidal cycles, but barely so, representing very marginal marine environments during lowstand. The uppermost sequence, the Salem Point Shale Member, represents an exposure cycle with good paleosol development.

**Fifth-Order Sequence A, Sallyards** includes the Sallyards Limestone and the Legion Shale Members. Maximum flooding occurs at the top of the Sallyards Limestone Member and is characterized by abundant pectinid and myalinid clams locally and no conodonts. The lower part of the Legion Shale Member is typically gray to black silty mudstone with an abundant low-diversity ostracode assemblage of a possible lagoonal marginal-marine environment. The abrupt contact between the maximum-flooding surface at the top of the Sallyards Limestone Member and the base of the Legion Shale Member with no transitional lithofacies or biofacies suggests a basinward shift of facies associated with rapidly falling sea level.

**Fifth-Order Sequence B, lower Burr** includes the top of the Legion Shale Member and the lower Burr Limestone Member. The transgressive surface is usually in the base of the lower Burr Limestone Member except in northern Kansas where a thin conglomeratic ostracode-bearing carbonate is present near the top of the Legion Shale Member that represents the surface. The top of the lower Burr Limestone Member is locally developed as a hard ground with abundant brachiopods, a variety of mollusks, crinoids, and abundant phosphatic skeletal debris including fish and conodonts, and indicates minor condensation and maximum flooding. Like the sequence below, a sharp contact exists between the limestone representing maximum flooding and overlying marginal-marine shales and wackestones indicating basinward shift in facies and forced regression.

**Fifth-Order Sequence C, upper Burr** includes the upper Burr Limestone Member and the lower Salem Point Shale Member. The upper Burr Limestone Member contains a transgressive lag with locally abundant skeletal-fish debris at its base. The upper part of the upper Burr contains abundant clams and locally abundant evaporite molds and is interpreted to represent a sabkha environment. In this case the transgressive surface also represents maximum flooding.

**Fifth-Order Sequence D, Salem Point** includes the upper Salem Point Shale Member. In the middle of the Salem Point Shale Member is a thin pectinid- and myalinid-bearing carbonate, the base of which represents the transgressive surface of the fifth-order sequence. The bed is overlain by gray to black silty mudstones and shales with a low-diversity ostracode assemblage which, in turn, is overlain by a well-developed paleosol. Maximum flooding is interpreted to be at the top of the basal limestone unit.

### Upper Grenola Composite Fourth-Order Depositional Sequence (figs. 3, 9)

Five fifth-order sequences comprise this sequence; the basal two have maximum-marine flooding condensed sections. The base of the sequences is characterized by a regional transgressive lag that marks the base of the Neva Limestone Member and represents initial marine flooding. Maximum-marine-flooding surface of the Upper Grenola sequence occurs with the lower Neva marine-condensed section; therefore, the very thin interval from transgressive lag to first condensed section represents the transgressive-systems tract. The forced-regressive-systems tract includes the interval from the lower condensed section to the base of the Cottonwood Limestone Member that marks the base of the Beattie sequence.

**Fifth-Order Sequence A, lower Neva** composes the lower Neva Limestone Member. Maximum-marine flooding occurs in a tan, dark-gray, or black mudstone with ubiquitous skeletal phosphate composed of conodonts, orbiculoid brachiopods, and fish debris that overlie the basal bed of the Neva Limestone Member. The sequence terminates in a phylloid-algal-rich wackestone to packstone.

**Fifth-Order Sequence B, upper Neva** is composed of the upper Neva Limestone Member and consists of a thin transgressive interval that sharply overlies the top unit of the sequence below and is followed by a maximum-flooding marine-condensed section. Like the lower Neva sequence, the upper Neva terminates in a phylloid-algal-rich wackestone to packstone.

**Fifth-Order Sequence C, top Neva** is composed of the top of the Neva Limestone Member and lowermost Eskridge Shale. It starts with a thin transgressive limestone followed by shallow-water carbonates of the top of the Neva Limestone Member and paleosols of the lower Eskridge Shale. Maximum flooding occurs at or near the transgressive surface at the base of the sequence.

**Fifth-Order Sequence D, lower Eskridge** is wholly within the lower part of the Eskridge Shale. It is marked by a thin marginally marine limestone at its base, with maximum flooding occurring within the limestone. The limestone is followed by a paleosol.

**Fifth-Order Sequence E, upper Eskridge** comprises the upper Eskridge and is marked by a thin transgressive limestone at its base followed by shale and limestone deposition in both southern and northern Kansas, missing in central Kansas, and followed by a paleosol. Maximum flooding occurs within the shale, where it is developed, or within the limestone where there is no shale (central Kansas).

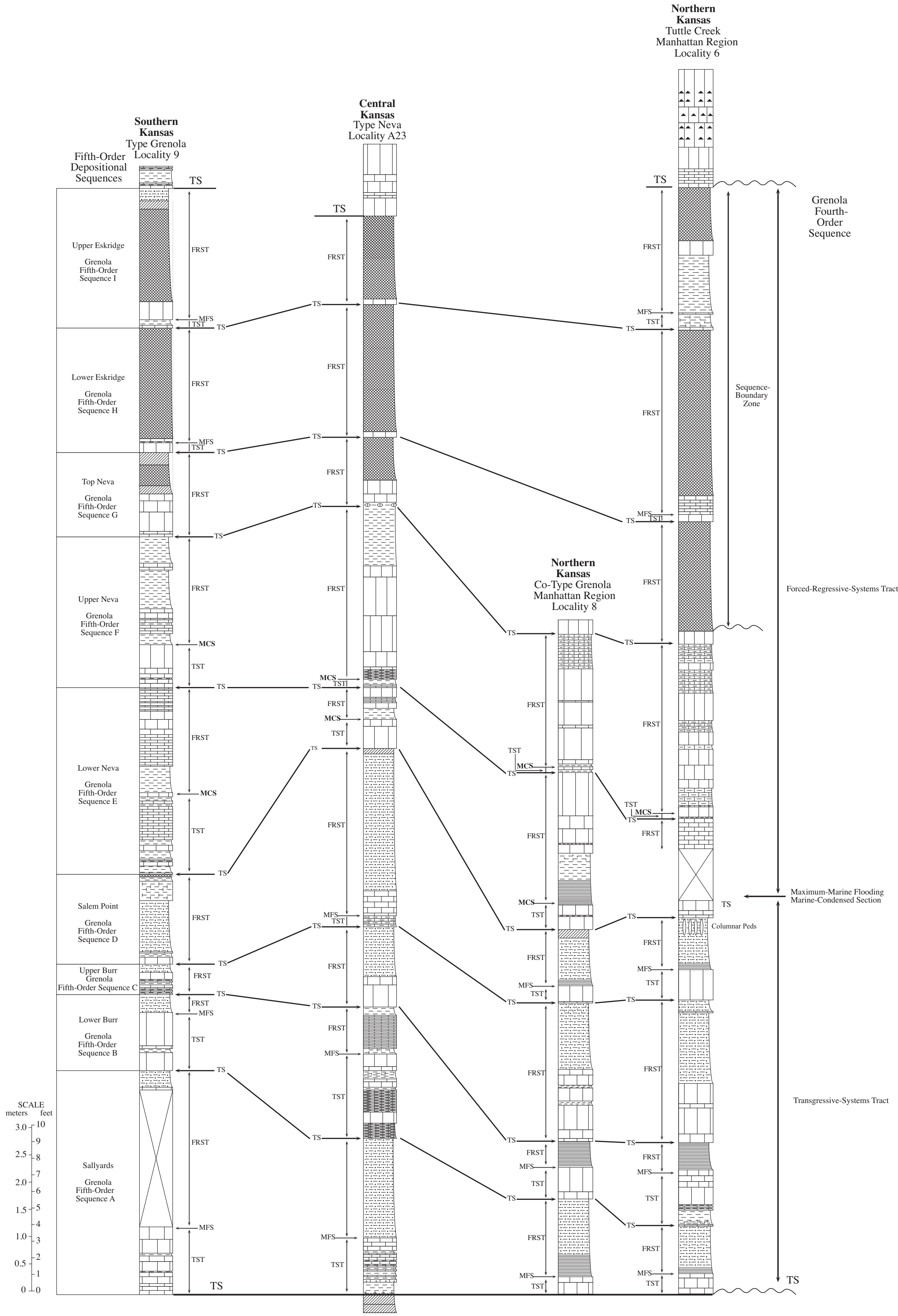



FIGURE 9—North-south sequence stratigraphic cross section of the Lower Grenola and Upper Grenola Composite Fourth-Order sequences; localities 9, A23, 8, and 6.

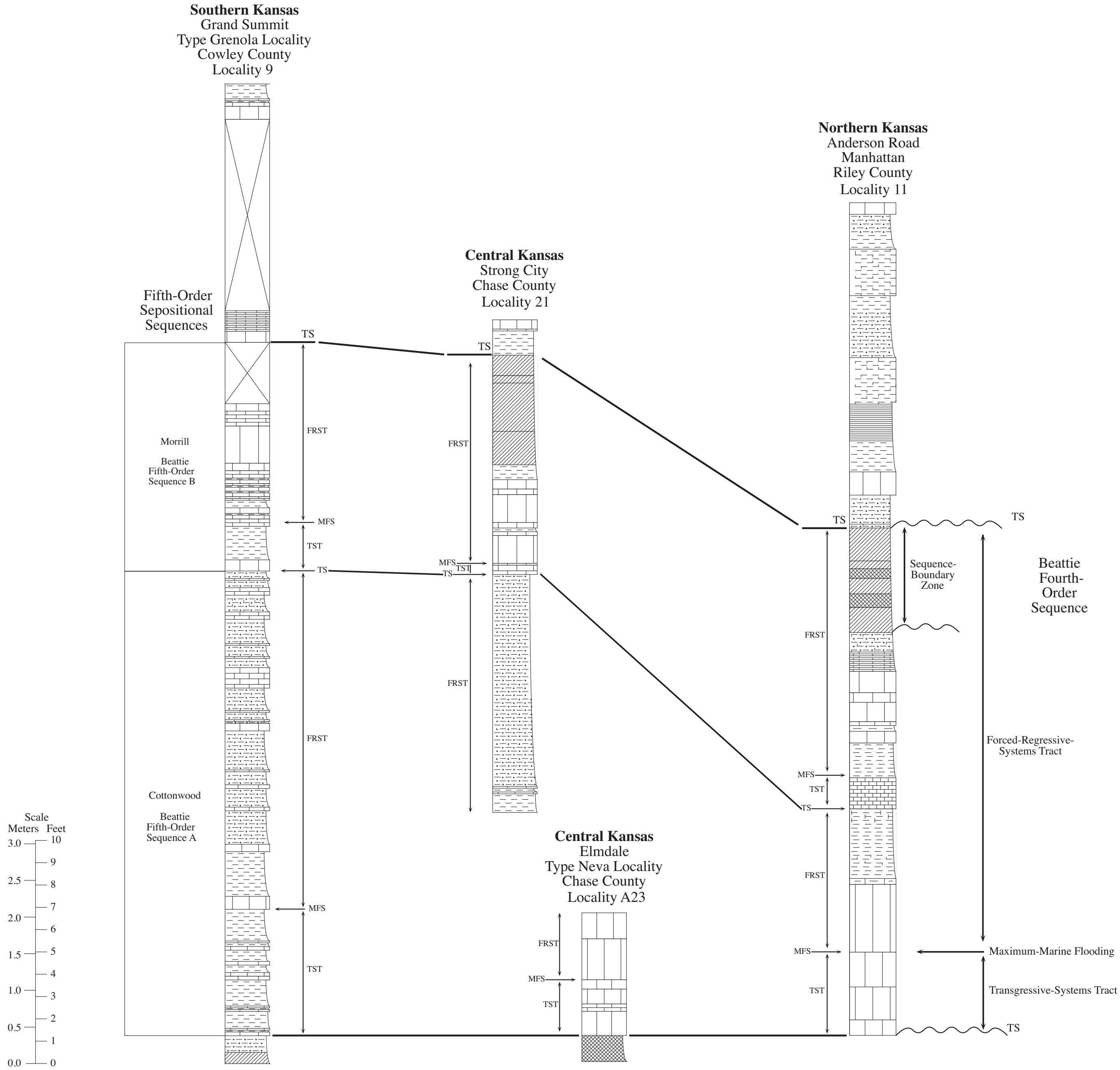



FIGURE 10—North-south sequence stratigraphic cross section of the Beattie Composite Fourth-Order Sequence; localities 9, 21, A23, and 11.

## Beattie Composite Fourth-Order Depositional Sequence (figs. 3, 10)

This sequence is composed of two fifth-order depositional sequences; the lower one represents a subtidal cycle, the upper one represents an exposure cycle. The base of the Cottonwood Limestone Member consists of a well-developed transgressive-lag deposit with abundant ostracodes in Nebraska through central Kansas. In southern Kansas, the lower Cottonwood Limestone Member changes facies from a massive cherty highly fossiliferous wackestone to packstone into highly fossiliferous shales and interbedded shaly wackestones, and the transgressive surface occurs as a transgressive lag in the first fossiliferous thin carbonate bed, which has been mapped previously with the Eskridge Shale.

**Fifth-Order Sequence A, Cottonwood** is composed of the Cottonwood Limestone and Florena Shale Member. Maximum flooding occurs near the center of the Cottonwood Limestone Member in Nebraska through central Kansas and is associated with fusulinaceans, a diverse brachiopod assemblage, corals, and some conodonts. In southern Kansas, the Cottonwood Limestone and Florena Shale Members have a gradational contact, and maximum flooding occurs in a highly fossiliferous glauconitic wackestone about 0.5 m below the top of the limestone that has been mapped as the top of the Cottonwood Limestone Member. This flooding surface is characterized by a rich brachiopod assemblage, bryozoans, corals, trilobites, a rich and diverse foraminifer and ostracode assemblage, and a moderate abundance of

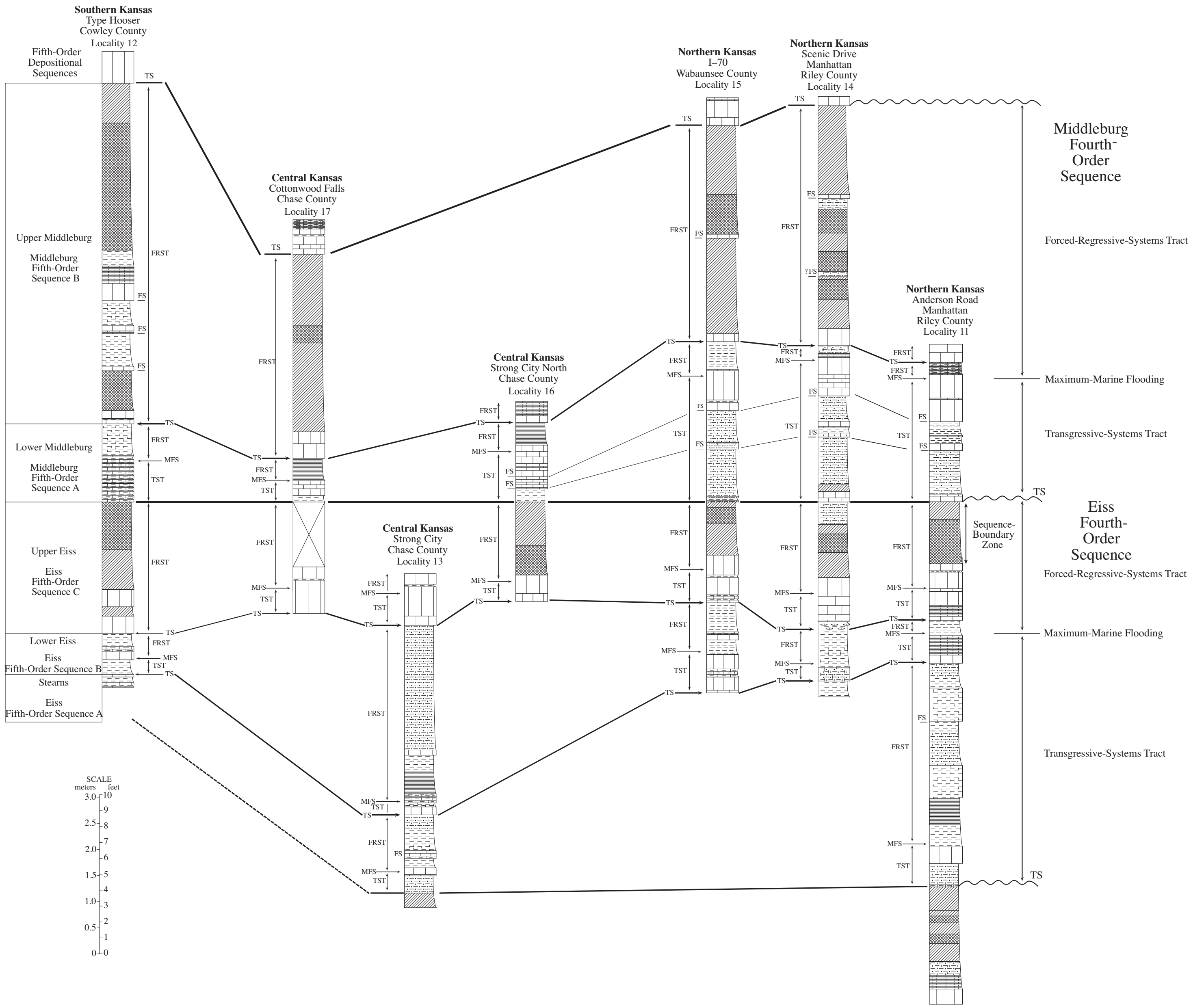



FIGURE 11—North-south sequence stratigraphic cross section of the Eiss and Middleburg Composite Fourth-Order sequences; localities 12, 17, 13, 16, 15, 14, and 11. Some stratigraphic data for this cross section were provided by Yang (1998).

conodonts. The sequence terminates in poorly fossiliferous, silty, locally dolomitic, shale and mudstones of the upper Florena Shale Member.

**Fifth-Order Sequence B, Morrill** is composed of the Morrill Limestone Member and lower Stearns Shale and is marked by a flooding surface at the base of the Morrill Limestone Member throughout the outcrop belt. Maximum flooding occurs in a *Derbyia*-rich brachiopod interval in northern exposures and fusulinacean-rich fossiliferous shaly wackestone in central and southern exposures. The sequence ends at the top of a paleosol developed in the lower part of the Stearns Shale.

## Eiss Composite Fourth-Order Depositional Sequence (figs. 3, 11)

This sequence is characterized by three fifth-order sequences. The transgressive surface occurs in slightly fossiliferous silty mudstones that overlie the paleosol interval at the top of the Morrill fifth-order sequence. Maximum-marine flooding occurs within the lower Eiss sequence so that the Stearns and lower part of the lower Eiss sequence represent a transgressive-system tract. The interval above the maximum-flooding surface including the upper part of the lower Eiss sequence and the upper Eiss sequence represents a forced-regressive-system tract. Both the Stearns and lower Eiss sequences represent subtidal cycles, but barely so, and the upper Eiss sequence represents an exposure cycle.

**Fifth-Order Sequence A, Stearns** is in the upper Stearns Shale. Maximum flooding occurs in a gray shale above a thin fossiliferous wackestone in northern Kansas and in a thin fossiliferous carbonate in central and southern Kansas. This shale contains an abundant fauna of ostracodes, foraminifers, and a low-diversity brachiopod and molluscan fauna, but no conodonts. The sequence terminates with poorly fossiliferous silty shales and mudstones of the uppermost Stearns Shale.

**Fifth-Order Sequence B, lower Eiss** is represented by the lower Eiss Limestone Member. In southern and central Kansas, the base of the Eiss Limestone Member marks the base of the sequence and consists of a lower algal-rich carbonate with *Aviculopinna* clams and *Meekella* brachiopods that represent initial marine flooding, whereas in northern Kansas a slightly fossiliferous silty shale denotes initial transgression of the sequence. Maximum flooding throughout the outcrop area occurs in an abundantly and diversely fossiliferous shale or shaly wackestone within the lower Eiss. This sequence is terminated by poorly fossiliferous marginal-marine silty mudstones.

**Fifth-Order Sequence C, upper Eiss** is composed of the upper Eiss Limestone and lower Hooser Shale Members. The base of the upper Eiss Limestone Member represents a transgressive surface, and the limestone is characterized by locally abundant gastropods and bivalves and *Sweetognathus* conodonts. The top of the Eiss Limestone Member shows direct evidence of subaerial exposure with a regolith developed on top of the unit. The base of the Hooser Shale Member is a thick paleosol, and the termination of the sequence is at the top of the paleosol.

## Middleburg Composite Fourth-Order Depositional Sequence (figs. 3, 11)

This sequence is composed of two fifth-order sequences, the lower Middleburg representing a subtidal cycle and the upper Middleburg representing an exposure cycle. Maximum flooding occurs in the brachiopod-rich interval of the lower Middleburg sequence. The strata from the transgressive surface to the maximum flooding within the lower Middleburg sequence represent a transgressive-system tract, and the strata above the flooding surface in the lower Middleburg and in the upper Middleburg sequence represent a forced-regressive-system tract.

**Fifth-Order Sequence A, lower Middleburg** is composed of the upper Hooser Shale and lower Middleburg Limestone Members. The transgressive surface that forms the base of the sequence occurs at the base of a limestone in the middle of the Hooser Shale Member in northern Kansas, occurs in shale near the top of the Hooser Shale Member in central Kansas and at the base of the Middleburg Limestone Member in southern Kansas. The sequence includes strata from the transgressive surface to the base of the upper Middleburg ledge. In northern Kansas the lower Middleburg contains abundant gastropods near the base and sparse brachiopods and crinoids near the center of the unit with sparse conodonts. In central and southern Kansas, the lower part of the lower Middleburg Limestone Member contains abundant pectinid bivalves, local phylloid algae, and gastropods. The upper part of the lower Middleburg Limestone Member contains an abundant and diverse open-marine fauna, dominated by brachiopods, and indicates maximum flooding. Above the lower Middleburg Limestone Member is a thin-bedded, shaly, dark-gray, poorly fossiliferous mudstone to wackestone in northern Kansas; a black fissile, somewhat silty, poorly fossiliferous shale in central Kansas; and a poorly fossiliferous, calcareous, and silty shale in southern Kansas.

**Fifth-Order Sequence B, upper Middleburg** is composed of the upper Middleburg Limestone and Easly Creek Shale Members. The base of the sequence is sharp with the poorly fossiliferous mudstones and shales of the lower Middleburg below and the prominent limestone ledge of the upper Middleburg Limestone Member. The limestone is a fossiliferous wackestone to packstone with gastropods, encrusting foraminifers, algal-coated grains, and no conodonts; the basal transgressive-flooding surface also marks the maximum flooding of the upper Middleburg sequence. The upper Middleburg Limestone Member ledge is followed by a series of green and red blocky silty mudstones of the Easly Creek Shale Member that represent paleosols. Local limestones and rarely shales separate the paleosols, which mark local flooding surfaces, but none appears to be regionally correlatable, nor appears to represent within-cycle fluctuations (sixth-order).

## Crouse Composite Fourth-Order Depositional Sequence (figs. 3, 12)

This sequence is composed of four fifth-order sequences. The base of the Crouse Limestone throughout the outcrop area constitutes the transgressive surface of the sequence and locally exhibits a well-developed transgressive lag. Maximum flooding occurs in the lower Crouse sequence dividing a transgressive-system tract below and forced-regressive-system tract above. The lower two fifth-order sequences are represented by subtidal cycles, the upper two by exposure cycles.

**Fifth-Order Sequence A, lower Crouse** comprises the lower Crouse Limestone. The lower Crouse sequence contains a moderately diverse fauna of brachiopods, bryozoans, and crinoids and includes abundant *Ottonosia* algal colonies in central and southern Kansas. Maximum flooding in northern and central Kansas occurs at the top of the lower Crouse Limestone ledge in a fossiliferous shaly wackestone with bryozoans, crinoids, and *Neochonetes* brachiopods. In southern Kansas, only one limestone ledge is present in the Crouse, and maximum flooding occurs in a fossiliferous wackestone above the *Ottonosia*-bearing interval. In central and northern Kansas, the sequence is terminated by black, poorly fossiliferous shales that become siltier upward. In southern Kansas, the cycle is capped by a poorly fossiliferous packstone and a small shale break.

**Fifth-Order Sequence B, upper Crouse** is composed of the upper Crouse Limestone. The base of this sequence is at the base of the middle limestone ledge of the Crouse Limestone in northern Kansas. Maximum flooding of that cycle occurs near the top of the middle ledge represented by ostracodes

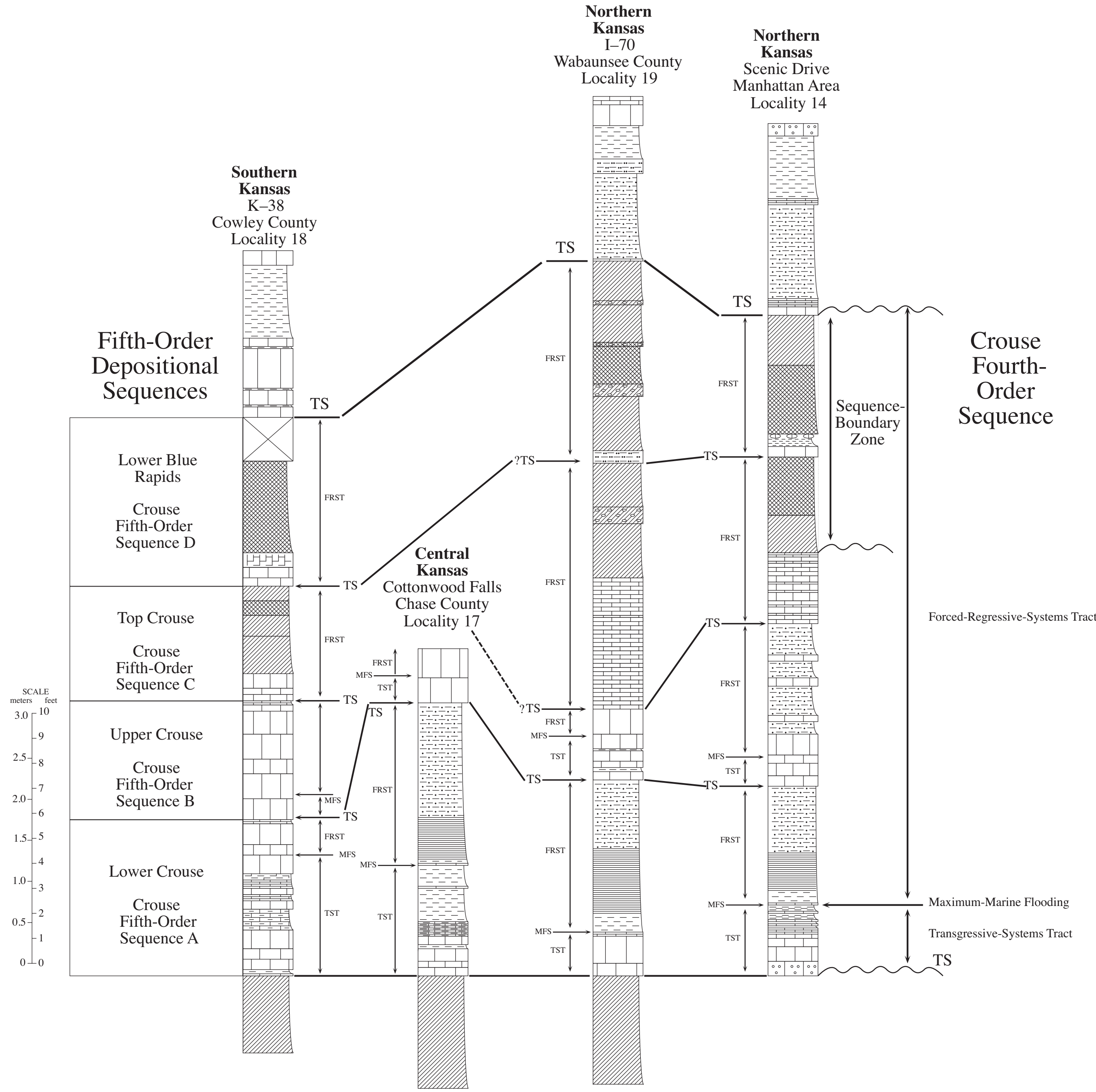



FIGURE 12—North-south sequence stratigraphic cross section of the Crouse Composite Fourth-Order Sequence; localities 18, 17, 19, and 14. Some stratigraphic data for this cross section were provided by Yang (1998).

and bivalves with a moderate number of the conodont *Sweetognathus*. In central Kansas the base of the sequence and maximum flooding are similar to northern Kansas, occurring with the second limestone ledge of the Crouse; no third ledge is developed. In southern Kansas, the upper Crouse occurs just above a small shale break at the top of the underlying sequence. Here it contains a more open-marine fauna including brachiopods, bryozoans, bivalves, and rare conodonts. This sequence terminates with a small shale break.

**Fifth-Order Sequence C, top Crouse** comprises the uppermost Crouse Limestone and lower Blue Rapids Shale. The uppermost Crouse Limestone contains a shallow-water ostracode assemblage and encrusting foraminifers. The lower Blue Rapids Shale is a paleosol. Maximum flooding is at or near the transgressive surface at the base of the sequence.

**Fifth-Order Sequence D, lower Blue Rapids** comprises the middle Blue Rapids Shale and is represented by a limestone or shale with shallow-water ostracodes and encrusting foraminifers followed by a paleosol. Maximum flooding is at or near the transgressive surface at the base of the sequence.

## Funston Composite Fourth-Order Depositional Sequence (figs. 3, 13)

This sequence is composed of four fifth-order sequences; the lower three represent subtidal cycles and the upper one represents an exposure cycle. Maximum flooding is in the

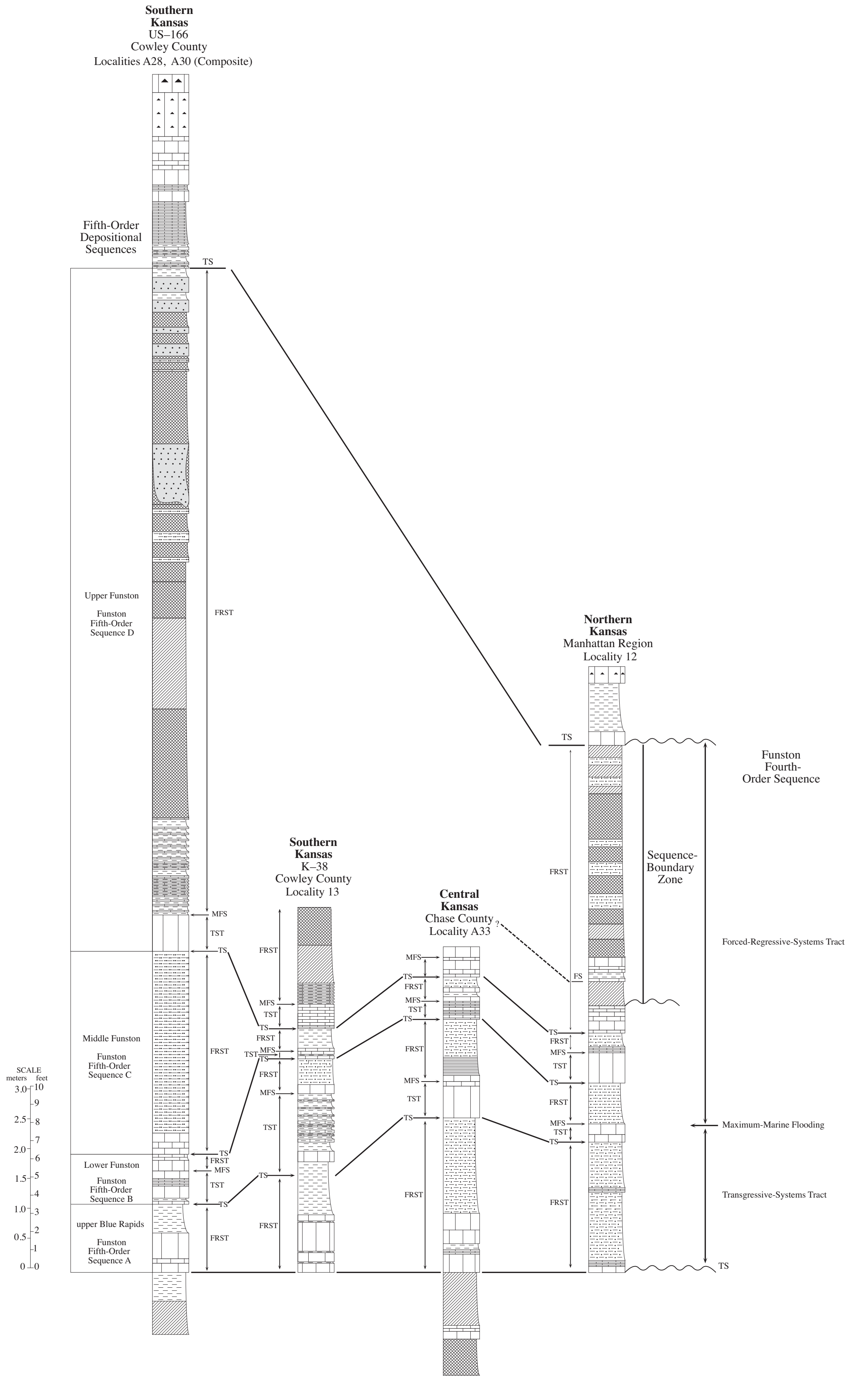



FIGURE 13—North-south sequence stratigraphic cross section of the Funston Composite Fourth-Order Sequence; localities A28–A30 (composite), 13, A33, and 12. Some stratigraphic data for this cross section were provided by Yang (1998).

lower Funston sequence, dividing the interval below into a transgressive-system tract and the interval above into a forced-regressive-system tract.

**Fifth-Order Sequence A, upper Blue Rapids** comprises the upper Blue Rapids Shale. The transgressive surface occurs at the base of a regionally correlative limestone in the upper Blue Rapids Shale. This limestone is best developed in southern Kansas. It then gradually thins into central and northern Kansas. In southern and central Kansas, this carbonate contains algae, bivalves, and encrusting foraminifers at its base that also represents the maximum-flooding surface. In northern Kansas it contains mainly ostracodes and encrusting foraminifers. Conodonts are restricted to the southern Kansas sections. The cycle is terminated by silty, poorly fossiliferous mudstones in central and northern Kansas and by poorly fossiliferous dark-gray shales in southern Kansas.

**Fifth-Order Sequence B, lower Funston** comprises the lower Funston Limestone. The base coincides with the base of the Funston Limestone except in southern Kansas on highway K–38, where it occurs a few centimeters below the base of the limestone. Maximum flooding occurs in the upper part of the cycle where a moderately diverse assemblage of crinoids, bryozoans, bivalves, and brachiopods occurs. The cycle is terminated by silty poorly fossiliferous shales and shaly, poorly fossiliferous carbonate in southernmost Kansas.

**Fifth-Order Sequence C, middle Funston** comprises the middle Funston Limestone. The transgressive surface is the base of the middle limestone; the limestone is poorly fossiliferous, featuring a low-diversity bivalve and gastropod assemblage with rare conodonts near the top of the limestone, marking maximum flooding. Poorly fossiliferous shales and siltstone terminate the cycle in central and northern Kansas, and only siltstones terminate it in southern Kansas.

**Fifth-Order Sequence D, upper Funston** comprises the upper Funston Limestone and Speiser Shale. The base of the upper Funston Limestone marks the transgressive surface; the maximum-flooding surface is represented near the top of the limestone just like the middle Funston with a low-diversity mollusk assemblage with rare conodonts. Poorly fossiliferous shales and siltstones overlie the limestone in southern Kansas. The cycle terminates in a series of stacked paleosols that represent most of the Speiser Shale. The paleosols are divided by sands and siltstones and in southern Kansas, at least one sandstone bed is channeliform, suggesting a return to fluvial deposition during lowstand in a group that has been dominated by exposure and soil formation during lowstand.

## Chase Third Order Sequence—Transgressive-Sequence Set

## Wreford Composite Fourth-Order Depositional Sequence (figs. 3, 14)

This sequence is composed of three fifth-order sequences, the lower two represented by subtidal cycles, and the upper one represented by an exposure cycle. Maximum-marine flooding occurs in the lower part of the Threemile Limestone Member, dividing the interval below into a transgressive-system tract and the interval above into a forced-regressive-system tract.

**Fifth-Order Sequence A, Threemile** is composed of the uppermost Speiser Shale, the Threemile Limestone Member, and the lower Havensville Shale Member. The transgressive surface of the Threemile occurs throughout the outcrop belt as a fossiliferous wackestone-packstone in the upper 1–5 m of the Speiser Shale. Maximum flooding occurs in a highly fossiliferous, shaly, slightly glauconitic, and siliceous wackestone that occurs near the base of the Threemile Limestone Member. This interval contains abundant silicified brachiopods, bryozoans, corals, and conodonts. The sequence is terminated by poorly fossiliferous silty shales and blocky mudstones of the middle Havensville Shale Member.

**Fifth-Order Sequence B, Havensville** comprises the upper Havensville Shale Member. The transgressive surface occurs at the base of a fossiliferous wackestone-packstone that occurs in the upper Havensville Shale Member. Maximum flooding occurs a short stratigraphic distance above the transgressive surface and is characterized by a low-diversity brachiopod assemblage with abundant echinoids and a moderate abundance of conodonts. The sequence is terminated by poorly fossiliferous silty shales of the topmost Havensville Shale Member.

**Fifth-Order Sequence C, Schroyer** is composed of the Schroyer Limestone Member and the Wymore Shale Member. The transgressive surface occurs either immediately beneath or coincident with the base of the Schroyer Limestone Member. Maximum flooding occurs in a highly fossiliferous wackestone in southern Kansas and a highly fossiliferous calcareous shale with abundant brachiopods, bryozoans, and conodonts in central and northern Kansas. The limestone is capped by a foraminiferal grainstone that has been subaerially exposed. A well-developed paleosol of the Wymore Shale Member terminates the sequence.

## Kinney Composite Fourth-Order Depositional Sequence (figs. 3, 15)

This sequence is composed of three fifth-order sequences; the first sequence represents a subtidal cycle, the upper two sequences represent exposure cycles. Maximum flooding occurs in the lower Kinney sequence dividing the strata into a very short transgressive-system tract below and a long forced-regressive-system tract above.

**Fifth-Order Sequence A, lower Kinney** comprises the lower Kinney Limestone Member. The transgressive surface is the base of the lower Kinney Limestone Member. Maximum flooding is characterized by fossiliferous wackestones and packstones with an abundant brachiopod fauna and a fairly abundant conodont fauna that occurs right at the transition from limestone to shale in the lower Kinney sequence. Above the brachiopod interval are poorly fossiliferous silty mudstones and shale that terminate the sequence.

**Fifth-Order Sequence B, upper Kinney** is composed of the upper Kinney Limestone and basal Blue Springs Shale Members. The transgressive surface is the base of the upper Kinney Limestone Member. Maximum flooding is characterized by fossiliferous packstones with brachiopods, crinoids, and echinoids with reduced numbers of conodonts

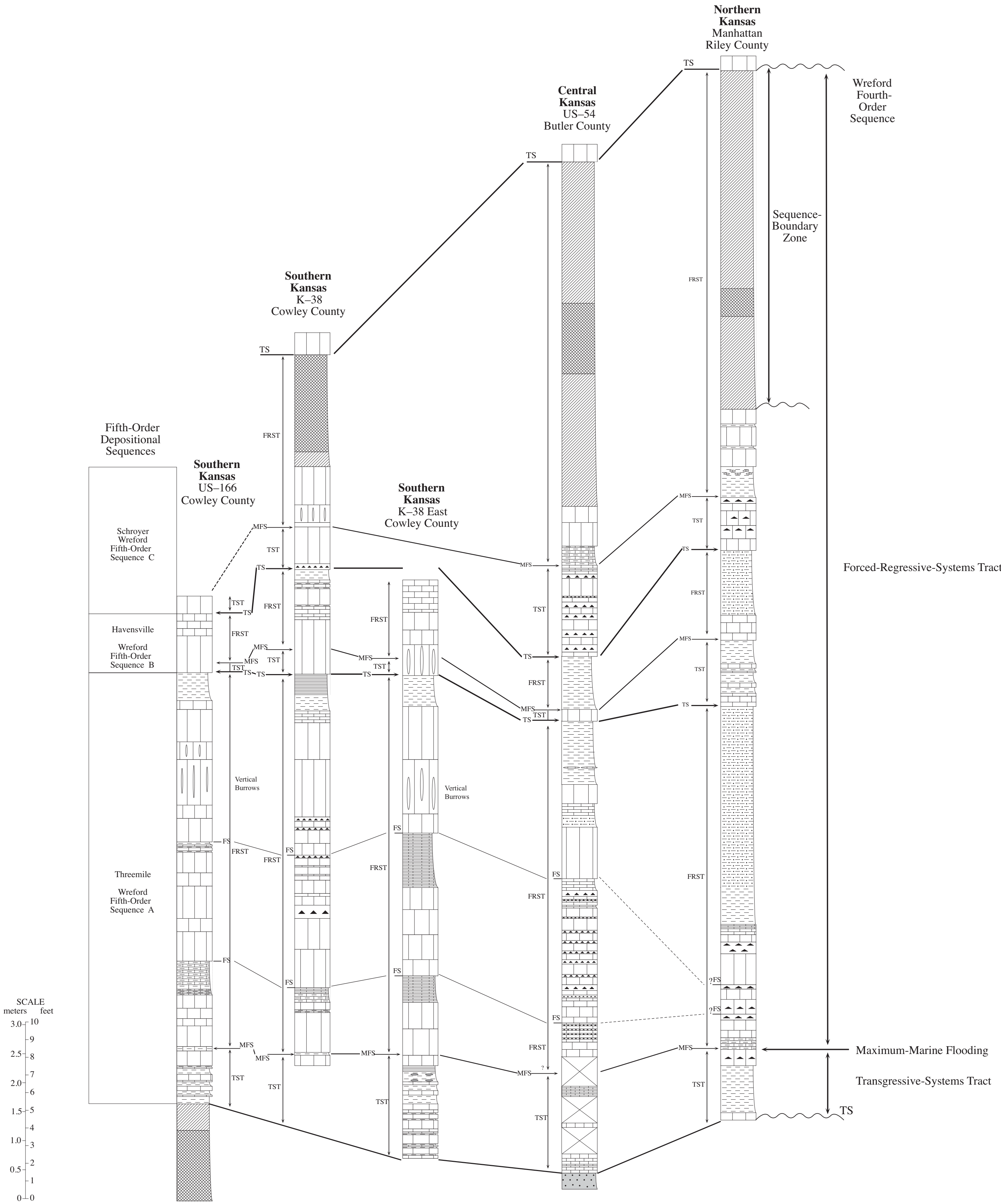



FIGURE 14—North-south sequence stratigraphic cross section of the Wreford Composite Fourth-Order Sequence; localities A29, 14, 13, 19, and 12.

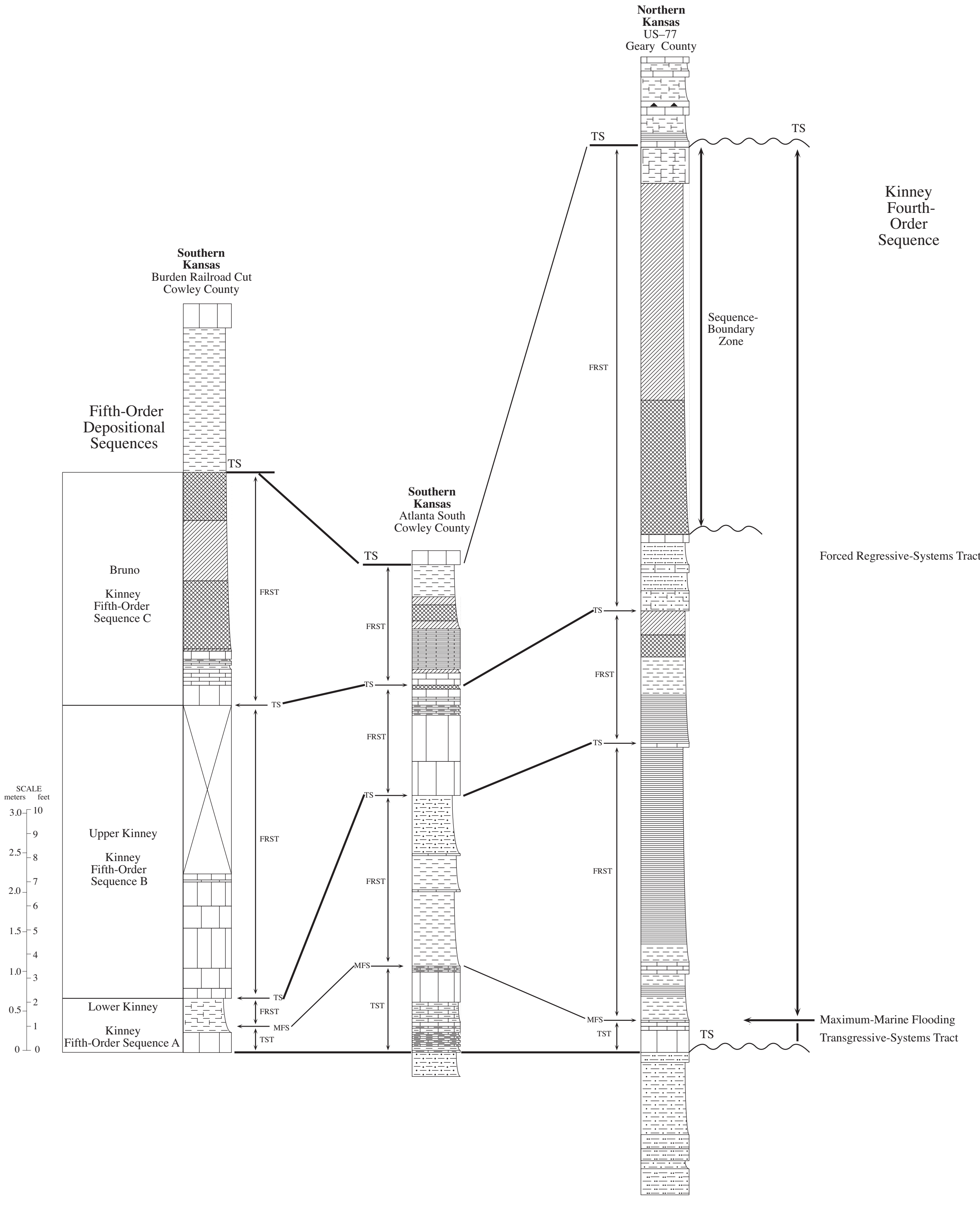



FIGURE 15—North-south sequence stratigraphic cross section of the Kinney Composite Fourth-Order Sequence; localities 15, A18, and 16.

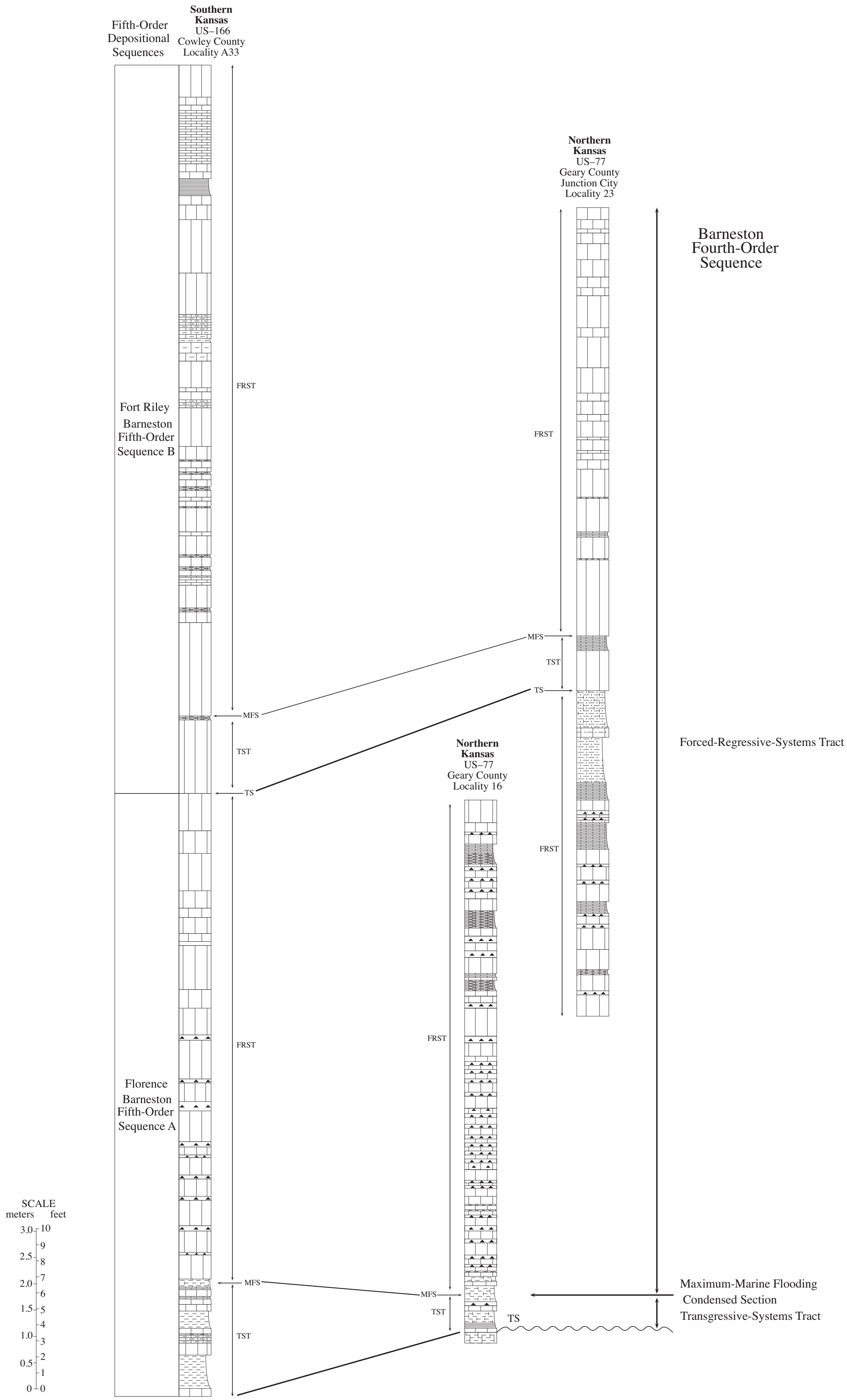



FIGURE 16—North-south sequence stratigraphic cross section of the Barneston Composite Fourth-Order Sequence, localities A33, 16, and 23.

in southern outcrops and by thin, shaly wackestones bearing some brachiopods in northern outcrops. In northern Kansas this sequence is capped by paleosols. In southern exposures the Kinney shows direct evidence of subaerial exposure.

**Fifth-Order Sequence C, Bruno** is composed of the Bruno limestone bed and upper Blue Springs Shale Member. The Bruno limestone bed marks the base of this sequence. This unit typically consists of a foraminiferal grainstone with few macrofossils and an absence of conodonts. The sequence is terminated by well-developed paleosols of the upper Blue Springs Shale Member. Commonly, post-Bruno erosion has locally removed this thin marine bed resulting in a sporadic distribution across the outcrop belt.

### Barneston Composite Fourth-Order Depositional Sequence (figs. 3, 16)

This sequence is composed of three fifth-order sequences; the lower is represented by a subtidal cycle with a condensed section of maximum-marine flooding and the upper two are represented by exposure cycles. Maximum flooding is in the lower Florence Limestone Member and divides the interval below into a transgressive-system tract and the interval above into a forced-regressive-system tract.

**Fifth-Order Sequence A, Florence** comprises the uppermost Blue Springs Shale, Florence Limestone, and Oketo Shale Members. The transgressive surface of the Florence sequence occurs in fossiliferous wackestones and mudstones of the uppermost Blue Springs Shale Member. These deposits contain locally abundant bivalves along with a low-diversity brachiopod fauna. Maximum flooding occurs in a highly fossiliferous shaly glauconitic wackestone or calcareous shale near the base of the Florence Limestone Member. This interval is dominated by a high abundance of conodonts and represents a marine-condensed section. It also contains a diverse assemblage of silicified brachiopods along with bryozoans, crinoids, and sponges. Immediately above this interval is dominated by fusulinaceans. The sequence terminates with the Oketo Shale Member in northern outcrops or with shallow grainstones and packstones with an abundance of algal-coated grains in central and southern Kansas and Oklahoma.

**Fifth-Order Sequence B, Fort Riley** comprises the Fort Riley Limestone and Holmesville Shale Members. The transgressive base is coincident with the base of the Fort Riley Limestone Member. Maximum flooding occurs at the base of the second limestone ledge above the base and is marked by an open-marine fauna of brachiopods, bryozoans, crinoids, and conodonts. The sequence is terminated by a paleosol of the Holmesville Shale Member.

**Fifth-Order Sequence C, Towanda** is composed of the Towanda Limestone Member and lower Gage Shale Member. Maximum flooding occurs near the base of the Towanda Limestone Member and is characterized by a fauna of gastropods and bivalves. No conodonts have been recovered from this interval. The sequence is terminated by paleosols of the lower Gage Shale Member.

# Conodont Biostratigraphy

Conodonts are common to abundant within the subtidal (carbonate-dominated) cycles and are dominated by *Streptognathodus* species and to a lesser extent *Sweetognathus, Hindeodus, Diplognathodus, Sweetina,* and *Adetognathus*. The changes in species of *Streptognathodus* and *Sweetognathus* can distinguish each marine-dominated hemicycle. The most widespread maximum-flooding surface of the Bennett Shale Member of the Red Eagle Limestone contains a series of first appearances of species that also marks the Carboniferous/Permian boundary in the southern Urals and the boundary stratotype at Aidaralash and the reference section at Usolka. These species include *Streptognathodus isolatus, S. nodulinearis, S. fuchengensis, S. minacutus, S. invaginatus,* and *Sweetognathus expansus* (fig. 17).

Currently, internationally proposed or accepted boundaries for the Lower Permian are defined by conodont species. The base of the Permian and the Asselian Stage is accepted as the first appearance datum of *Streptognathodus isolatus.* The base of the Sakmarian Stage is proposed as the first appearance datum of *Sweetognathus merrilli*. The base of the Artinskian Stage is the first appearance datum of *Sweetognathus whitei.* All three species occur in Kansas and allow placement of the stadial boundaries for the Lower Permian.

The *Streptognathodus* species are very common and allow further division of the sequence into range zones based on the succession of species (fig. 18). The succession of *Streptognathodus* species can be envisioned as successive species in three lineages. These are a lineage of very closely related robust forms that are characterized by no to few accessory nodes (denticles) exemplified by *S. barskovi*, a lineage of moderate to robust forms that are characterized by common accessory nodes (denticles) and lobes exemplified by *S. wabaunsensis* and *S. farmeri*, and a lineage of elongate forms that are characterized by few accessory nodes (denticles) exemplified by *S. elongatus* (fig. 19). All three lineages appear to derive from *Streptognathodus bellus*. The zones recognized are *Streptognathodus bellus, S. flexuosus, S. farmeri, S. binodosus, S. isolatus, S. nevaensis, S. fusus, S. barskovi, S. postconstrictus, S. trimilus,* and *S. florensis.*

## Conodont Systematics (New Species)

### Genus *Streptognathodus*

Type Species: *Streptognathodus excelsus* Stauffer and Plummer.

Morphological features of *Streptognathodus* species used to describe and distinguish species are shown in fig. 19. More information on the difficulty in identifying species from the upper Carboniferous and Lower Permian of the midcontinent can be found in the text of Part B of this publication.

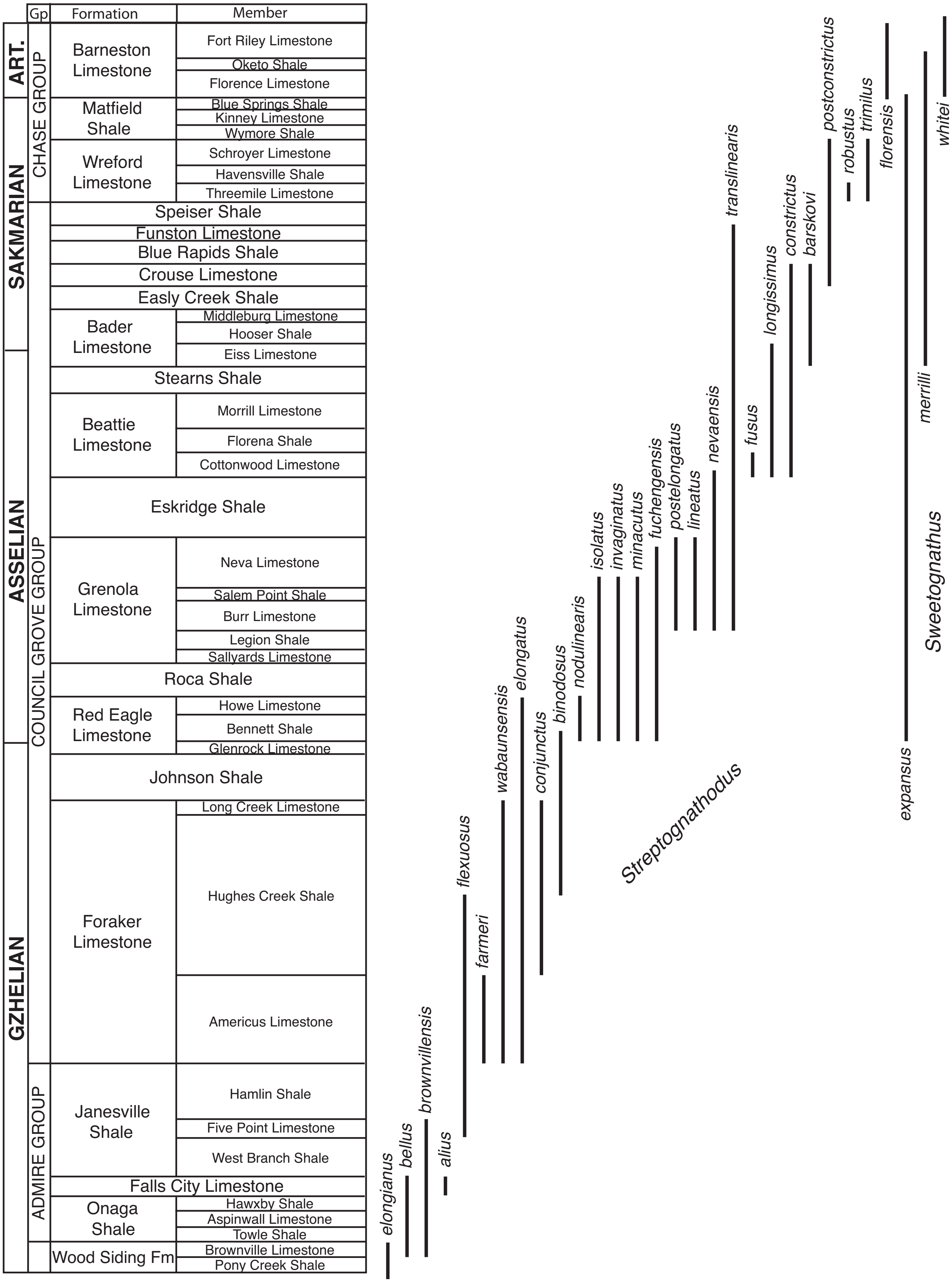



FIGURE 17—Conodont ranges for the interval from the Pony Creek Shale Member of the Wood Siding Formation to the Fort Riley Limestone Member of the Barneston Limestone.

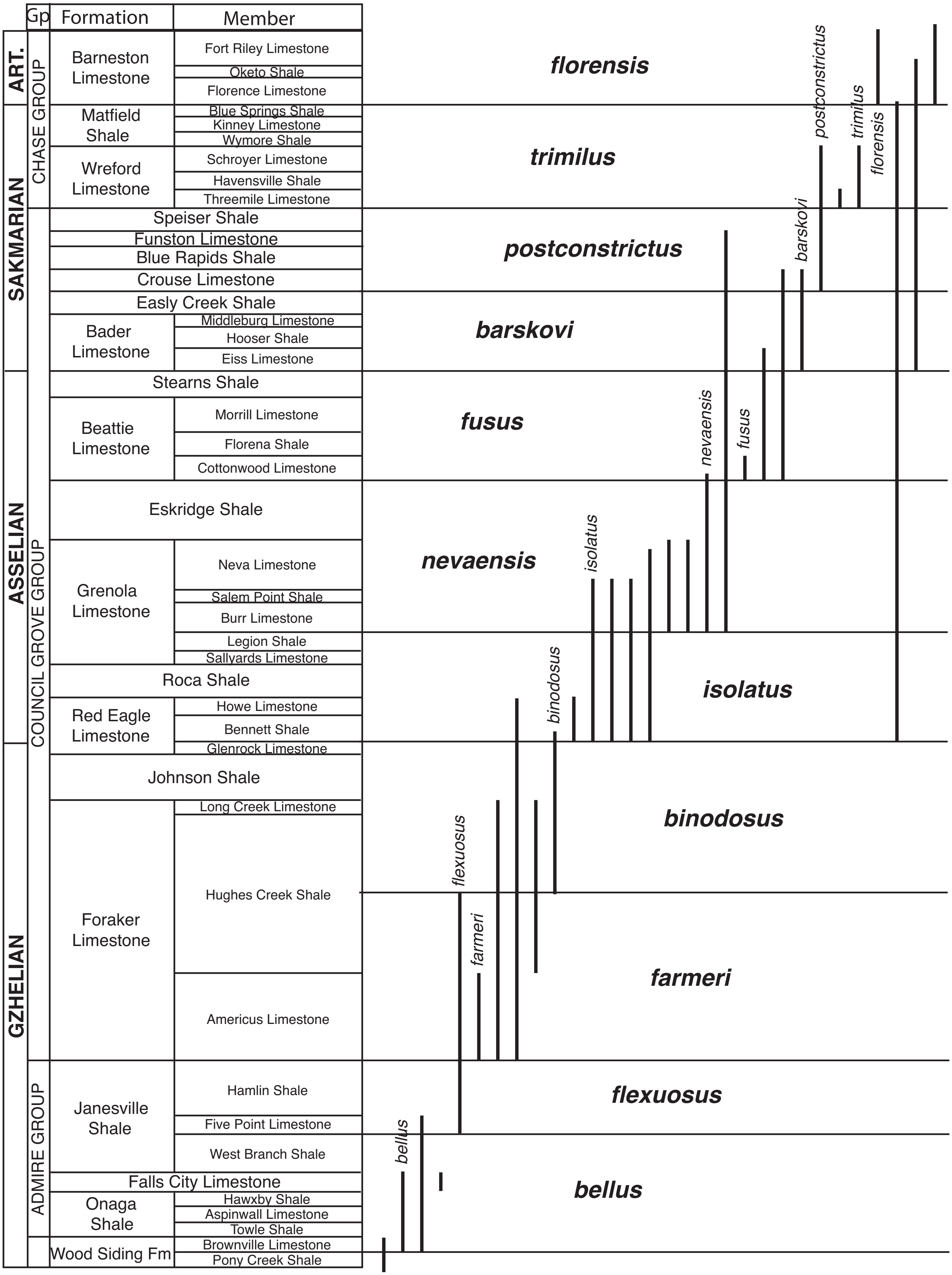



FIGURE 18—Conodont range zones based on *Streptognathodus* species ranges for the interval from the Pony Creek Shale Member of the Wood Siding Formation to the Fort Riley Limestone Member of the Barneston Limestone.

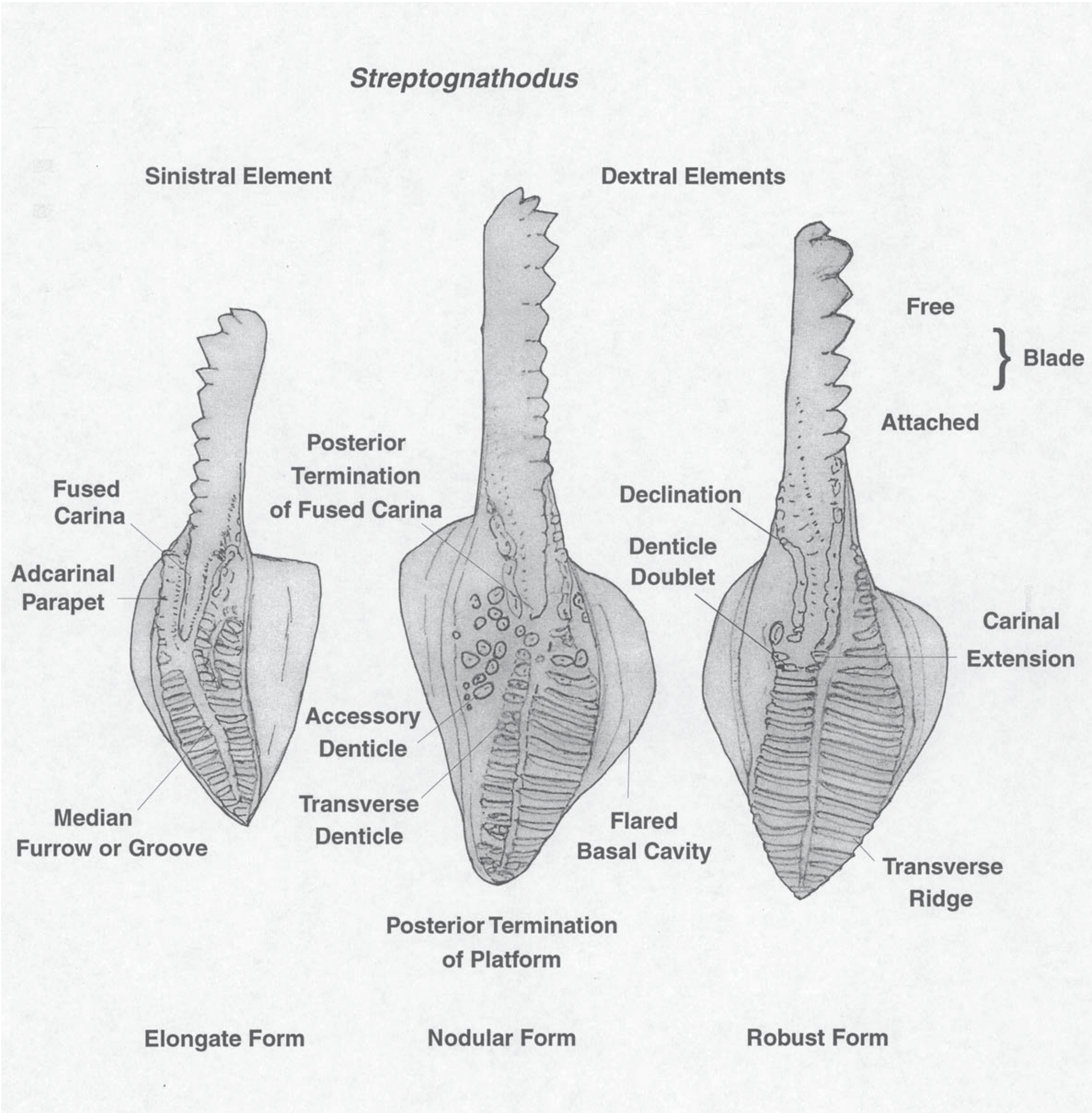



FIGURE 19—Morphological terms for the Pa element of *Streptognathodus.*

***Streptognathodus binodosus***
**Wardlaw, Boardman, and Nestell, new species**
Plate 1, fig. 1.

*Streptognathodus binodosus* Wardlaw, Boardman, and Nestell; Boardman, Nestell, and Wardlaw, *this volume*, Part B, p. 125, Plate 10, figs. 2–6, 8–11; Plate 11, figs. 1, 3–5, 7, 10, 12; Plate 13, fig. 3; Plate 18, fig. 11.
*Streptognathodus bellus* Chernykh and Ritter, 1997 (part), p. 464, fig. 4.9.

Diagnosis: A species of *Streptognathodus* characterized by a Pa element that has at least one pair of denticles in a transverse row on the inner side immediately posterior to the posterior termination of the carina.

Description.—Pa element moderate to long, widest in posterior one-fourth of element, near middle of platform, somewhat elongate, platform bowed, free blade makes up one-third to nearly one-half of the element, denticles on blade partly fused, compressed, increasing in size anteriorly except anteriormost one or two, denticles become fused as blade joins platform, typically as fused nodose carina, rarely anterior part of carina completely fused, posteriormost denticle on fused carina more discrete, no or one denticle in groove posterior to fused carina, posterior termination slightly curved toward outer side in dextral forms and inner side in sinistral forms nearly aligning with a pair of denticles or transverse ridge to form a 'J', posterior termination of platform pointed, but not acutely, typically termination with a single denticle, parapets ornamented by transverse ridges posteriorly becoming denticles anteriorly in back of posterior termination of carina, transverse ridges forming a broad oblique angle with each other near posterior end, angle becoming lesser anteriorly so that opposing transverse ridges nearly form a straight line, high parapets terminate at about the same point anteriorly where inner parapet sharply declines as denticulate rib, the outer parapet declines more sharply or terminates and is smooth, median groove generally deep anteriorly becoming well-expressed narrow groove posteriorly, rarely do one or two transverse ridges merge and cross the groove, groove is laterally placed toward inner side and generally extends to posteriormost denticle, but not always, basal cavity flared.

Dextral and sinistral elements differ in that the 'J' pattern of the carinal extension to the parapet is on the outer side in dextral forms and on the inner side in sinistral forms.

Holotype: USNM 484061, pl. 1, fig. 1; Part B, pl. 10, fig. 6.

Remarks.—The specimen illustrated (pl. 10, fig. 10, Part B) is transitional to *S. nodulinearis* from the upper Hughes Creek Shale Member, strongly suggesting that *S. binodosus* gave rise to *S. nodulinearis* and that this may occur slightly before level 7 as it may also occur in the Urals of Russia. The deep anterior groove and 'J' pattern of the carinal extension to the parapet suggest that *S. binodosus* derived from *S. farmeri* but differs in aligned accessory nodes forming denticle pairs.

### *Streptognathodus denticulatus* Wardlaw, Boardman, and Nestell, new species

Plate 1, fig. 2.

*Streptognathodus denticulatus* Wardlaw, Boardman, and Nestell; Boardman, Nestell, and Wardlaw, *this volume*, Part B, p. 127, Plate 25, fig. 20; Plate 31, figs. 1–6; Plate 32, figs. 3–5.

Diagnosis: A species of *Streptognathodus* characterized by a Pa element with a short posterior platform ornamented by numerous denticles and a long free blade with the largest denticle the anteriormost.

Description.—Pa element long, widest in middle of posterior platform, platform short, free blade makes up two-thirds of the element, denticles on blade with three compressed, smaller denticles in middle of blade breaking pattern of decreasing size posteriorly, anteriormost denticle is the largest, as blade joins platform becomes nodose fused ridge, nodes and carina decreasing in size posteriorly, in large specimens carina extends for two-thirds length of short platform, posterior carinal termination is abrupt, posterior platform termination is very rounded, in small specimens two lateral parapets are ornamented by partly fused transverse denticles partially ornamented by reticulate micro-ornamentation, partially overgrown, large specimens are completely overgrown with little reticulate micro-ornamentation remaining, only traces on the sides of outside denticles, larger specimens develop a micro-pustulose ornament on top of each denticle and along the crest of the carina, anterior declination of the parapets abrupt, declining a short distance and narrowing rapidly over a short distance to disappear anteriorly, secondary denticles added in a haphazard fashion all around the posterior platform outside the initial denticles on the lateral parapets, adcarinal grooves become infilled and parapets become overgrown to become indistinct with growth, a short groove or furrow in small specimens divides the lateral parapets as a short gap in back of the carina becomes overgrown and filled in with secondary denticles in larger specimens so that no median groove is present, moderately flared basal cavity with consistent posterior flare forming a lip at the bottom of the element throughout growth.

Dextral and sinistral elements appear to be very similar.

Holotype: USNM 487562, pl. 1, fig. 2; Part B, pl. 25, fig. 20, pl. 31, figs. 4–6, pl. 32, figs. 4–5.

Remarks.—This species represents a rare morphotype for which we can demonstrate a growth sequence, which we feel qualifies it for specific identification. It is known only from the Neva Limestone Member in our material. It shows reticulate micro-ornament in small specimens and relict reticulate micro-ornament in large specimens. Reticulate micro-ornament is common to well-preserved specimens of *Streptognathodus* (see Plate 31, figs. 1–2, Part B, *Streptognathodus nevaensis*, for an example) and not known in *Sweetognathus*, confirming that this rare morphotype belongs to *Streptognathodus*. The presence of a long blade is also common to *Streptognathodus* and not known in *Sweetognathus*. No species in our Kansas material is similar to this short-platformed denticulate form.

### *Streptognathodus elongianus* Wardlaw, Boardman, and Nestell, new species

Plate 1, fig. 3.

*Streptognathodus elongianus* Wardlaw, Boardman, and Nestell; Boardman, Nestell, and Wardlaw, *this volume*, Part B, p. 128, Plate 2, figs. 8–9.

Diagnosis: A species of *Streptognathodus* characterized by an elongate Pa element with relatively high fused to partially fused parapets and carina in the middle of the element, irregular transverse ridges, an irregular median furrow, and the carina extends for less than half of the platform with generally only one discrete posterior denticle.

Description.—Pa element moderate to long, narrow and elongate, upper surface slightly wider just posterior to carinal termination, platform is relatively straight with a slight curve inward toward posterior end and a slight constriction in width at the posterior end of the fused carina and parapets, free blade approximately one-fourth of element, denticles on blade compressed and partly fused, increasing in size anteriorly except anteriormost one or two, as blade joins platform becomes fused ridge, with denticles barely expressed, carina has one isolated denticle posterior to fused ridge, generally situated close to outer transverse ridge and nearly merging with it, carina extends for about one-half of the platform length when measured against the inner (longer) parapet, posterior termination of platform pointed, parapets ornamented by transverse ridges posteriorly, forming a partially nodose fused ridge in middle portion of element adjacent to fused carina with two or more relatively more discrete nodules anterior to highly fused portion, inner transverse ridges nearly perpendicular to median line of element, except for posteriormost one or two, outer transverse ridges at slight oblique angle to median line, one or two transverse ridges on either side of platform generally at angle to general plan or spaced closer to neighboring ridge and even partially merging with it to form diagnostic irregular ridge ornament, transverse ridges of irregular size, varying in length and size adding to the irregular ornamentation, inner parapet extends further to the anterior than outer parapet, both parapets gradually decline down fixed blade, median groove narrow, deep, roughly centrally placed, and very irregular, partially disrupted by irregular transverse ridges, generally still expressed as a narrow slit between the posteriormost few transverse ridges, ends at terminal posterior transverse denticle, basal cavity flared.

Dextral and sinistral elements are very similar; sinistral elements with more equal inner and outer anterior terminations than dextral elements.

Holotype.—USNM 483981, pl. 1, fig. 3; Part B, pl. 2, fig. 8.

Remarks.—This species is easily recognizable from other forms that occur with it in the Brownville Limestone Member by its narrow, elongate shape, fused parapets, relatively deep and irregular groove, and lack of many posterior carinal denticles.

### ***Streptognathodus florensis*** **Wardlaw, Boardman, and Nestell, new species**

Plate 1, fig. 4.

*Streptognathodus florensis* Wardlaw, Boardman, and Nestell; Boardman, Nestell, and Wardlaw, *this volume*, Part B, p. 130, Plate 23, figs. 1–12; Plate 24, figs. 9–13.

Diagnosis: A species of *Streptognathodus* characterized by asymmetric paired Pa elements with commonly two to three accessory denticles on the inner side, a dextral element with an anteriorly deep but narrow groove, a posterior carinal termination that aligns with an outer parapet transverse ridge, a flared inner adcarinal parapet, a sinistral element that is narrower, with a wider groove and an abrupt posterior carinal termination, transverse ridges, at least for some portion of the posterior platform, appear shingled.

Description.—Pa element of moderate length, widest in middle of posterior platform in dextral forms, but of only modest width, widest at the posterior carinal termination in sinistral forms, but sinistral forms narrow and of nearly equal width, bowed, free blade one-fourth to one-third length of element, denticles on blade partly fused, compressed increasing in size anteriorly except for anteriormost two which decrease, as blade joins platform becomes fused ridge, with denticles barely expressed, generally decreasing in size posteriorly but with one or two gaps (larger space between denticles) and one or two denticles typically just anterior to gap that are slightly larger and posteriormost denticle on carina which is also slightly larger, fused carina ends abruptly posteriorly, in dextral forms carina slightly curves to outer edge and aligns with a transverse ridge forming a vague backward ‘J’, in sinistral forms carina terminates posteriorly in middle of platform showing no curving or alignment, posterior termination of platform pointed except in very large forms which may be rounded, parapets ornamented by transverse ridges posteriorly becoming transverse denticles along adcarinal parapets, transverse ridges at a very slight angle to one another forming a nearly straight line from side to side, on both dextral and sinistral forms at least some ridges appear shingled with a sloping posterior and sharp ledge-like anterior in succession, dextral forms show almost all ridges to be shingled, the outer adcarinal parapet gradually declines along carina from posterior carinal termination, in sinistral forms vaguely denticulate, with partly fused denticles before becoming a short smooth rib along lower side of blade, in dextral forms denticulated for almost entire length, inner adcarinal parapet on dextral forms slightly raised and flared posteriorly before gradually declining, denticulate for almost entire length, anteriorly ending as a short smooth rib along lower side of blade, inner adcarinal parapet on sinistral forms gradually declining anteriorly but with an abrupt drop downwards at or about the carina-blade transition, then continuing a short distance anteriorly as a generally smooth rib along lower side of blade, rarely vaguely denticulate in large forms (pl. 22, fig. 9); one to three accessory denticles common on inner side at or near the posterior carinal termination situated in the inner curve of the bowed element, less well developed in dextral forms, median groove in dextral forms narrow but deep, placed toward inner side, becoming variously disrupted by transverse ridges posteriorly, commonly with one or two ridges merging across the groove, extends to near the posterior end. Groove in sinistral forms narrow, generally deep anteriorly, wider than in dextral forms, placed toward inner side, rarely disrupted by a ridge near posterior termination of carina, commonly disrupted by transverse ridges posteriorly, though rarely merging across the groove except for posteriormost one or two, basal cavity moderately to greatly flared.

Dextral and sinistral elements are very different as described above with sinistral elements narrower with a wider groove, less shingled transverse ridges, better developed and typically larger (per size) accessory denticles, and less clearly denticulate adcarinal parapets.

Holotype.—USNM 487527, pl. 1, fig. 4; Part B, pl. 23, fig. 10.

Remarks.—*S. florensis* is the youngest *Streptognathodus* in our collections from Kansas. The section above the Florence Limestone Member appears to be deposited in an inhospitable environment for *Streptognathodus* species with only *Sweetognathus* and *Rabeignathus* present. The immediate predecessor to *S. florensis*, *S. trimilus* is most similar to it and the differences are discussed under that species. *S. florensis* appears to start (at least in dextral forms) the long gradually declining denticulate adcarinal and anterior parapets that are continued and better developed in *S. artinskiensis*, but *S. florensis* differs in having a much shorter carina and well-developed groove.

### ***Streptognathodus lineatus*** **Wardlaw, Boardman, and Nestell, new species**

Plate 1, fig. 5.

*Streptognathodus lineatus* Wardlaw, Boardman, and Nestell; Boardman, Nestell, and Wardlaw, *this volume*, Part B, p. 133–134, Plate 15, figs. 1, 14; Plate 19, fig. 1.

PLATE 1—Holotypes of new species. All specimens are Pa elements, x100.

**Figure 1.** *Streptognathodus binodosus* Wardlaw, Boardman, and Nestell, new species, USNM 484061, from sample 21, upper part of the Hughes Creek Shale Member, Tuttle Creek (Locality 6).

**Figure 2.** *Streptognathodus denticulatus* Wardlaw, Boardman, and Nestell, new species, USNM 487562, from upper part Neva Limestone Member, Grenola Limestone, sample 6, intersection of US–60 and OK–18 roadcut (Locality 22).

**Figure 3.** *Streptognathodus elongianus* Wardlaw, Boardman, and Nestell, new species, USNM 483981, from base Brownville Limestone Member, K–38 roadcut (Locality 3).

**Figure 4.** *Streptognathodus florensis* Wardlaw, Boardman, and Nestell, new species, USNM 487527, from the Florence Limestone Member, Barneston Limestone, bed 1, K–38 roadcut (Locality 17).

**Figure 5.** *Streptognathodus lineatus* Wardlaw, Boardman, and Nestell, new species, USNM 484112, from basal phosphatic lag in the lower part of the Neva Limestone Member, Fort Riley Boulevard (Locality 8).

**Figure 6.** *Streptognathodus nevaensis* Wardlaw, Boardman, and Nestell, new species, USNM 484133, from upper phosphatic lag, upper part of the Neva Limestone Member, Fort Riley Boulevard (Locality 8).

**Figure 7.** *Streptognathodus postconstrictus* Wardlaw, Boardman, and Nestell, new species, USNM 487517, from Schroyer Limestone Member, Wreford Limestone, base of bed 3, Scenic Drive roadcut (Locality 12).

**Figure 8.** *Streptognathodus postelongatus* Wardlaw, Boardman, and Nestell, new species, USNM 484101, from top of the lower limestone ledge of the Burr Limestone Member, Grenola Formation, Tuttle Creek (Locality 6).

**Figure 9.** *Streptognathodus robustus* Wardlaw, Boardman, and Nestell, new species, USNM 487497, from Threemile Limestone Member, Wreford Limestone, base of ledge 3, Scenic Drive roadcut (Locality 12).

**Figure 10.** *Streptognathodus translinearis* Wardlaw, Boardman, and Nestell, new species, USNM 484107, from top of the lower limestone ledge of the Burr Limestone Member, Tuttle Creek (Locality 6).

**Figure 11.** *Streptognathodus trimilus* Wardlaw, Boardman, and Nestell, new species, USNM 487491, from Threemile Limestone Member, Wreford Limestone, base shaly limestone, Scenic Drive roadcut (Locality 12).

***Localities***

Locality 3—Roadcut on K–38, SW SW sec. 22, T. 32 S., R. 8 E., Dexter NE 7.5-minute quadrangle, Chautauqua County, Kansas. [Brownville Limestone through West Branch Shale Members]

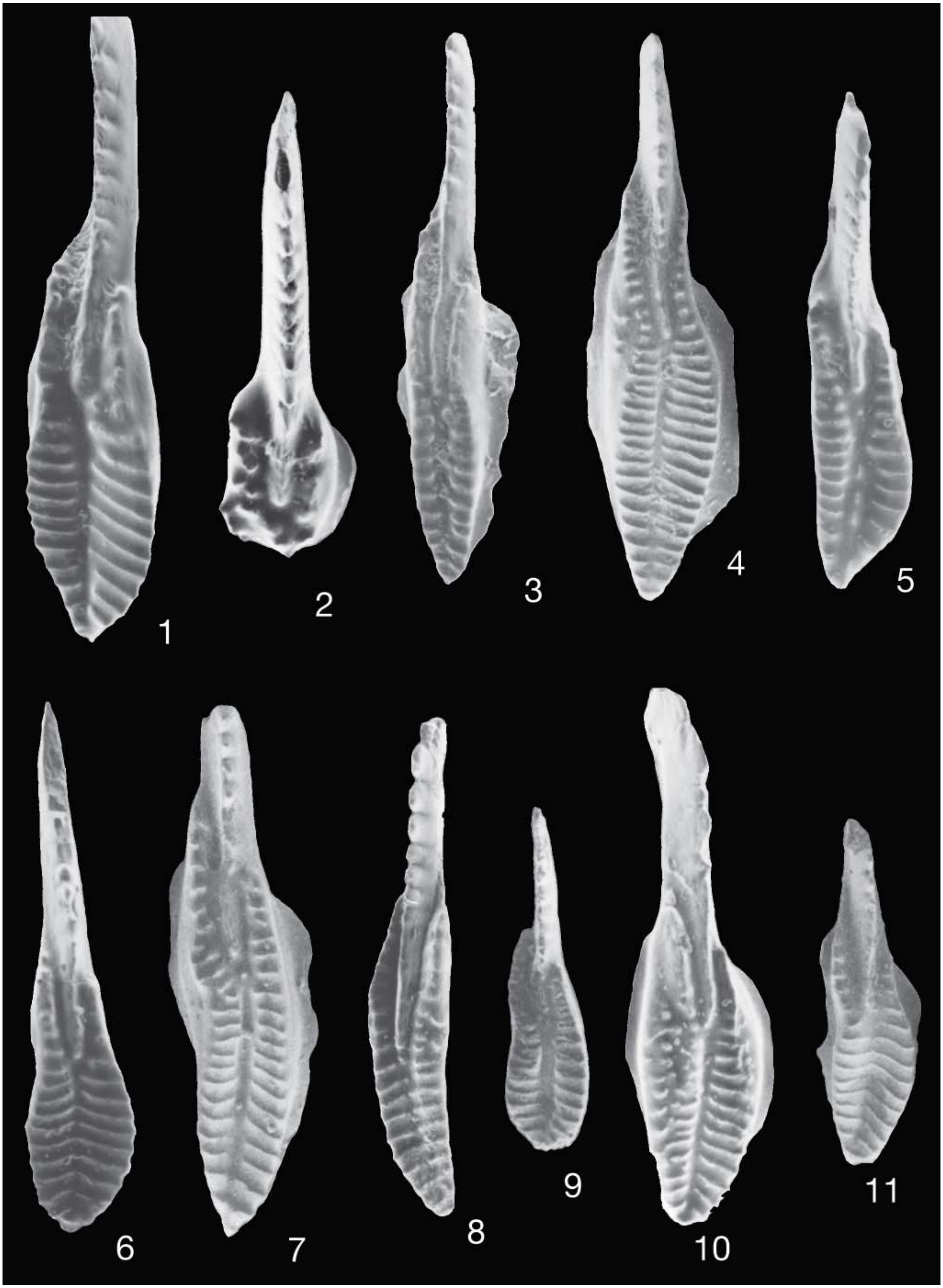
Locality 6—Spillway cut for Tuttle Creek Dam, NE sec. 19, SE sec. 18, T. 9 S., R. 8 E., Tuttle Creek Dam 7.5-minute quadrangle, Pottawatomie County, Kansas. [Foraker Limestone through Beattie Limestone]

Locality 8—Roadcut on north side of K–18 (Fort Riley Boulevard) west of Manhattan, SW sec. 23, T. 10 S., R. 7 E., Manhattan 7.5-minute quadrangle, Riley County, Kansas (co-type locality for Grenola Limestone). [Grenola Limestone through Cottonwood Limestone Member]

Locality 12—Roadcut on both west and east sides of Anderson Road in Manhattan, Kansas, W/2 sec. 10, T. 10 S., R. 7 E., Keats 7.5-minute quadrangle, Riley County, Kansas. [Eskridge Shale through Middleburg Limestone Member]

Locality 17—Roadcut on K–38, NW NW NW sec. 30, T. 32 S., R. 7 E., Cowley County, Kansas. [Blue Springs Shale through Florence Limestone Members]

Locality 22—Roadcut at intersection of US–60 and OK–18, due southeast of Burbank, Oklahoma, center WL sec. 32, T. 26 N., R. 6 E., Burbank 7.5-minute quadrangle, Osage County, Oklahoma. [Salem Point Shale through Neva Limestone Members]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Diagnosis: A species of *Streptognathodus* characterized by a Pa element with a marked gap in the carina in the anterior part of the posterior platform and concomitant pinching of the groove, one to seven accessory denticles align in rows representing the break-up of what is posteriorly transverse ridges.

Description.—Pa element short to moderate in length, bowed, widest in middle of posterior platform, nearly as wide at or near the posterior end of the fused carina where most accessory denticles have developed, free blade short, approximately one-fourth the element length, longer in small specimens, denticles on blade partly fused, compressed, increasing in size anteriorly, except for anteriormost, which is smaller, as blade joins platform becomes a fused ridge, denticles barely discernable, generally denticles or ridge decrease in size (height and width) posteriorly except for posteriormost which is slightly larger, carina continues as one or two discrete denticles, then there is a gap with no denticles and a constriction of the groove before carina posteriorly continues as small discrete denticles (generally about five) in the middle of the groove, posterior termination of platform pointed, parapets ornamented posteriorly by transverse ridges becoming denticles anteriorly, transverse ridges form a slight obtuse angle with one another, outer parapet continues ornamented by transverse ridges along fused carina gradually becoming transverse denticles decreasing in size anteriorly, rarely one transverse ridge breaks up into two aligned transverse denticles (pl. 14, fig. 1, Part B) at the anterior end of the narrowing of the groove and of the gap in denticulation of the carina, anterior part of high adcarinal parapet is fused, outer parapet declines abruptly down attached blade as a smooth rib, inner parapet declines at about the same point or slightly anterior to the outer parapet, inner parapet becomes ornamented by several rows of transverse denticles (the break-up of transverse ridges) just anterior to the narrowing of the groove, number of rows depends on size of specimens, in small specimens there is one (pl. 18, fig. 1, Part B, barely noticeable) to as many as four or five in large specimens (pl. 14, fig. 1, Part B), denticles on adcarinal parapet decline in size anteriorly and become partly fused just behind the anterior declination of the parapet, the inner parapet declination is sharp, but not as sharp as the outer parapet, the declining parapet bears two to four denticles, partly fused, rarely (as in the holotype) the anterior two are fused into a ridge, median groove wide with a marked narrowing or constriction in the anterior part of the posterior platform corresponding to the gap in the carina apparently caused by lengthening of lateral transverse ridges, groove widens posteriorly, bears several denticles, and extends nearly to the posterior end of the element, basal cavity moderately flared.

Dextral and sinistral elements are very similar.

Holotype.—USNM 484112, pl. 1, fig. 5; Part B, pl. 15, fig. 14.

Remarks.—The constriction of the groove and gap in carinal denticulation is only shown in this species in our material. The denticle doublets on the inner side near the posterior end of the fused carina are similar to those found in *S. postelongatus*, suggesting that these two species developed from the same common stock *S. elongatus*.

***Streptognathodus nevaensis***
**Wardlaw, Boardman, and Nestell, new species**
Plate 1, fig. 6.

*Streptognathodus nevaensis* Wardlaw, Boardman, and Nestell; Boardman, Nestell, and Wardlaw, *this volume*, Part B, p. 135, Plate 14, figs. 6–7; Plate 16, figs. 1–3, 5–8, 11; Plate 17, fig. 12; Plate 19, fig. 2; Plate 32, figs. 1–2.

Diagnosis: A species of *Streptognathodus* characterized by asymmetrically paired Pa elements with robust dextral element, short fused carina, high inner adcarinal parapet, and one to two accessory denticles on the inner side.

Description.—Pa element moderate to long, slightly bowed, widest in middle of posterior platform, free blade one-third or more of the element length, denticles on blade partly fused, compressed, increasing in size anteriorly except for anterior one or two, which may be smaller, as blade joins platform becomes fused ridge, carina pinches and swells in width indicating fused denticles of alternating size, typically with one small discrete denticle posterior to fused ridge showing a marked decrease in carina height and width at the posterior end, posterior platform termination bluntly pointed, parapets ornamented by transverse ridges that become transverse denticles anteriorly, transverse ridges at low to moderate obtuse angle to one another generally slightly curving anteriorward along median groove, outer parapet ornamentation gradually changes from shortening transverse ridges to transverse denticles, decreasing in size along carina, except anteriormost at declination of parapet which may be larger, outer parapet declines very sharply down the attached blade and is smooth or bears one or two denticles and is very short, inner parapet changes more abruptly to transverse denticles at or near the posterior carina termination, decrease in size anteriorly except anteriormost before declination of parapet which is larger, inner parapet gradually declines down attached blade bearing one to four denticles, rarely two or more may be fused to form small ridge before lowered parapet continues anteriorly for a short distance as a smooth rib, one or two accessory denticles develop in larger specimens on inner lateral side of platform at or near posterior carina termination, in larger specimens transverse ridges near the posterior carina termination may break up into aligned transverse denticles appearing as additional accessory denticles, but on top of platform not on its side, median groove generally narrow, nearly straight, extends a variable distance posteriorly generally extending to near the posterior end with the posteriormost two to three transverse ridges merging across it, but in rare specimens several transverse ridges merge across groove (pl. 15, fig. 7), basal cavity moderately flared.

Dextral and sinistral elements are dissimilar in that dextral forms are robust and sinistral forms are elongate but all of the descriptive features are the same.

Holotype.—USNM 484134, pl. 1, fig. 6; Part B, pl. 16, fig. 7.

Remarks.—*S. nevaensis* is similar to *S. fuchengensis* but differs in having a higher, longer inner parapet, presaging the development of a flared parapet in *S. fusus*, has more aligned platform ornamentation, and is more asymmetrically paired, the sinistral element not having a good counterpart in *S. fuchengensis*.

### *Streptognathodus postconstrictus* Wardlaw, Boardman, and Nestell, new species

Plate 1, fig. 7.

*Streptognathodus postconstrictus* Wardlaw, Boardman, and Nestell; Boardman, Nestell, and Wardlaw, *this volume*, Part B, p. 136–137, Plate 21, figs. 2–5, 13; Plate 22, fig. 8.

*Streptognathodus constrictus* Chernykh and Reshetkova, Chernykh and Ritter, 1997 (part), p. 464, fig. 8.10–8.13, 8.16.

Diagnosis: A species of *Streptognathodus* characterized by a Pa element that is elongate with a slight constriction posteriorly, becoming more pronounced with increasing size, a narrow but well-developed and deep groove posteriorly, and commonly has one to three accessory denticles.

Description.—Pa element elongate, widest near posterior and nearly as wide near posterior termination of the carina, slightly sigmoidal in outline, free blade approximately one-fourth or less of the element, denticles on blade partly fused, compressed, increasing in size anteriorly except anteriormost, as blade joins platform becomes nodose fused ridge, generally decreasing in size posteriorly, except posteriormost denticle which is more discrete and slightly larger than those anterior to it, fused carina short, carina continues posteriorly as a single discrete denticle, developing in larger specimens, posterior termination of the platform pointed generally as a single denticle, parapets ornamented by transverse ridges posteriorly becoming transverse denticles anteriorly, at slightly greater than 90º angle to median line, inner parapet on dextral forms extends much further to the anterior, outer parapet in sinistral forms extends slightly further to the anterior, inner parapet shows a slight to marked constriction just posterior to the posterior termination of the carina, one to three accessory denticles develop anterior to constriction on inner side align with transverse denticles to form “double” ridges or denticle doublet in larger forms, one to five transverse denticles on outer parapet along the carina or posterior to it also break up to form a “double” ridge or denticle doublet, inner parapet is slightly flared adjacent to the posterior part of the carina, outer parapet anterior termination generally abrupt with sharp decline down fixed blade continuing anteriorly for a short distance as a thin rib near the lower margin of the blade, inner parapet declines slightly along anterior part of the carina, descends moderately sharply to gradually on the fixed blade and continues anteriorly as a rib along lower margin of the blade for much of the blade length, descending parapet and anterior rib generally smooth on both inner and outer sides, median groove narrow, well developed, and deep, extending most of the length of the posterior platform to the posteriormost or next posterior denticle or transverse ridge, basal cavity slightly to moderately flared.

Dextral and sinistral elements differ in anterior parapet termination (discussed above) but are similar in that both are narrow, elongate forms.

Holotype.—USNM 487517, plate 1, fig. 7; Part B, plate 22, fig. 8.

Remarks.—*S. postconstrictus* differs from *S. constrictus* in that it commonly has accessory denticles forming doublets with parapet denticles and the inner parapet extends much further anteriorly.

### *Streptognathodus postelongatus* Wardlaw, Boardman, and Nestell, new species

Plate 1, fig. 8.

*Streptognathodus postelongatus* Wardlaw, Boardman, and Nestell; Boardman, Nestell, and Wardlaw, *this volume*, Part B, p. 137, Plate 14, figs. 1–2, 8; Plate 15, figs. 2–5, 10, 13, 15–17; Plate 16, figs. 9–10; Plate 20, figs. 9, 11–12.

Diagnosis: A species of *Streptognathodus* characterized by an elongate Pa element that has at least one double set of transversely aligned denticles.

Description.—Pa element narrow, of moderate length (elongate), bowed, generally widest near posterior end of carina, rare specimens wider on anterior to middle of posterior platform, free blade variable in length from nearly one-half to almost one-fourth the length of the element, the carina/blade length to posterior platform length ratio is relatively constant but the length of the high adcarinal parapets is quite variable, the high posterior parapets apparently decline down the side of the carina/blade from the middle of the posterior fused portion (carina) to the partly fused denticulate blade in different specimens, the fused to denticulate portions of the carina/blade remain at a relatively constant ratio of 1:2, carina is fused ridge, rarely extends posteriorly as one small discrete denticle, commonly that small posteriormost denticle is partially fused to fused carinal ridge, posterior platform termination is pointed, parapets are posteriorly ornamented by transverse ridges becoming denticles anteriorly at or about the posterior carina termination, transverse ridges at slight to moderate obtuse angle to each other, typically a higher angle in more bowed specimens, outer parapet gradually changes anteriorly from transverse ridges to transverse denticles, rarely in large specimens a transverse double set of denticles develops from the break-up of one transverse ridge just posterior to the posterior carina termination, denticles roughly decrease in size anteriorly, declination of the parapet is mildly sharp to gradual with no to three denticles before becoming a short smooth rib, inner parapet changes abruptly from ornamented by transverse ridges posteriorly to a transverse double set of denticles (denticle doublet) at or near the posterior carina termination, up to four double sets develop on the inner parapet, sets increasing with the size of the specimen, adcarinal parapet variously fused, generally in the anterior part from partly fused to overgrown, generally decreasing in size anteriorly in front of double sets of denticles except anteriormost before parapet declination which may be larger, double sets commonly of unequal size, anterior declination of parapet mildly sharp bearing one to three denticles, before becoming a short smooth rib, both parapets decline at about the same point, median groove narrow, long, generally extending nearly to posterior end, in rare specimens and very large specimens several transverse ridges at various points along the posterior platform merge across the groove, basal cavity moderately flared.

Dextral and sinistral elements are very similar.

Holotype.—USNM 484101, plate 1, fig. 8, Part B, plate 14, fig. 1.

Remarks.—*S. postelongatus* differs from *S. elongatus* by possessing at least one denticle doublet in almost any sized specimen. Its descendants differ by *S. constrictus* developing a constriction and *S. longissimus* developing a long clear groove.

### *Streptognathodus robustus* Wardlaw, Boardman, and Nestell, new species

Plate 1, fig. 9.

*Streptognathodus robustus* Wardlaw, Boardman, and Nestell; Boardman, Nestell, and Wardlaw, *this volume*, Part B, p. 137, Plate 21, figs. 6, 10–11.

Diagnosis: A species of *Streptognathodus* characterized by robust Pa element with a deep and wide furrow, rounded posterior platform termination, flared inner adcarinal parapet, no to few accessory denticles, and a short free blade.

Description.—Pa element short to moderate in length widest near posterior end of platform, slightly sigmoidal in outline shown by subtle inflections or curves in the carina and a slight invagination of the inner side of the platform, free blade short, one-third to one-fourth of the length of the element, denticles on blade partly fused, compressed, increasing in size anteriorly except for anteriormost, as blade joins platform becomes nodose fused carina, typically at or just anterior to outer parapet anterior declination is one larger denticle on the blade/carina, carina inflects at this denticle, denticles decreasing in size posteriorly, becoming more discrete posteriorly generally one small discrete denticle posterior to posterior fused carinal termination, fused carina short, posterior termination of platform bluntly rounded, parapets ornamented by transverse ridges posteriorly becoming transverse denticles along carina, ridges and denticles at slightly greater than 90° angle to median line except posteriormost two to three which are at a much greater angle and merging or nearly merging across furrow to form broad inverted 'V's , inner adcarinal parapet with one or two larger and(or) more elevated denticles than adjacent ones giving a flare to the inner parapet, outer parapet declines abruptly from anteriormost very transverse denticle which is larger and more elevated than the few posterior to it which forms a slight invagination on the outer side, anterior continuation of parapet after the abrupt declination obscure or as a smooth or slightly denticulate rib for a short distance, inner parapet anterior declination sharp with a few denticles, decreasing in size anteriorly before becoming a short smooth rib, inner high parapet extends further anteriorly than outer high parapet, median furrow wide and deep, extending nearly to the posterior end of the platform where the posteriormost one to three transverse ridges may join, basal cavity only slightly flared.

Dextral and sinistral elements are similar.

Holotype.—USNM 487497 pl. 1, fig. 9; Part B, pl. 21, fig. 6.

Remarks.—This species appears to be the last robust morphotype in our material and differs from its predecessor *S. barskovi* by its much wider furrow, rounded posterior platform termination, shorter free blade, sigmoidal outline, and carina with a larger denticle near where the blade joins the platform.

### *Streptognathodus translinearis* Wardlaw, Boardman, and Nestell, new species

Plate 1, fig. 10.

*Streptognathodus translinearis* Wardlaw, Boardman, and Nestell; Boardman, Nestell, and Wardlaw, *this volume*, Part B, p. 138, Plate 14, figs. 3–5, 9; Plate 21, figs. 7, 14, 16.

Diagnosis: A species of *Streptognathodus* characterized by a Pa element with a relatively straight fused to partially fused inner adcarinal parapet that parallels the carina or posteriorly slightly converges toward the carina, a sharp anterior declination of the inner parapet, and generally a few to several accessory denticles on the inner side.

Description.—Pa element moderate to long, widest on anterior of posterior platform, generally just beyond posterior termination of the carina, free blade approximately one-third of the element, denticles on blade partly fused, compressed, generally increasing in size anteriorly, but with one distinctly smaller denticle three to four from the anteriormost and the anteriormost which decreases in size as blade joins platform becomes short fused ridge, denticles barely expressed, generally decreasing in size posteriorly except for posteriormost which may be slightly larger than adjacent few denticles, no posterior extension of the fused carina with discrete denticles, posterior termination of the platform bluntly pointed, parapets ornamented by transverse ridges posteriorly, fused to partially fused denticles anteriorly, ridges at slightly greater than 90° angle to midline forming a broad oblique angle with each other except at posteriormost end in some specimens where marked inverted 'V' is formed, angle becoming lesser anteriorly so that opposing transverse ridges nearly form a straight line, ridges variable in large specimens, broken-up into several short ridges (typically on inner side), or short allowing for a large median sulcus to form, or several merging across median so that groove is obscure, adcarinal parapets fused, inner adcarinal parapet a little less fused, becoming less so posteriorly so that there is one discrete to partially fused denticle opposite the posterior carinal termination, inner adcarinal denticles of subequal size with one slightly larger denticle in middle of adcarinal ridge, outer adcarinal ridge generally decreasing in size anteriorly, inner high parapet extends further anteriorly than outer high parapet, inner adcarinal parapet anterior declination sharp, with zero to three small denticles, decreasing in size anteriorly, before becoming short smooth rib along lower side of blade, outer adcarinal parapet anterior declination sharp, but less so than inner declination, with zero to three small denticles before becoming short smooth rib along lower side of blade, median groove, furrow, or sulcus variously developed, generally in all but large specimens as a narrow, moderate-depth groove extending for most of the posterior platform, generally zero to three small accessory denticles developed on inner lateral wall of platform, opposite posterior termination of carina, in large specimens several accessory denticles on inner side with most in rough linear alignment, paralleling midline, and on outer lateral wall of platform, basal cavity moderately flared.

Dextral and sinistral elements are very similar.

Holotype.—USNM 484106, pl. 1, fig. 10; Part B, pl. 14, fig. 9.

Remarks.—This species suggests a close affinity to *S. nodulinearis* by its roughly aligned accessory denticles in larger specimens and the highly fused inner adcarinal parapet; it differs in lacking the well-developed line of nodes developed in large specimens, in having the variable groove to sulcus, and in having the more or less discrete denticle at the posterior end of the inner fused adcarinal parapet.

***Streptognathodus trimilus***
**Wardlaw, Boardman, and Nestell, new species**
Plate 1, fig. 11.

*Streptognathodus trimilus* Wardlaw, Boardman, and Nestell; Boardman, Nestell, and Wardlaw, *this volume*, Part B, p. 138–139, Plate 21, figs. 1, 8–9, Plate 22, figs 1–7, 9-13.
*Streptognathodus elongatus* Gunnell, Ritter, 1986 (part), p. 154, pl. 4, fig. 16.

Diagnosis: A species of *Streptognathodus* characterized by asymmetric paired Pa elements with a narrow median groove, one to many transverse ridges that merge across the middle of the platform, a posterior carinal termination that aligns with an inner parapet transverse ridge, a sinistral element that is narrower, with a wider groove, transverse ridges at least for some portion of the posterior platform appear shingled.

Description.—Pa element moderate in length, widest near middle of platform in dextral forms, sinistral forms are elongate with platform of near equal width, generally widest just posterior to posterior carinal termination, free blade one-fourth to one-third length of element, denticles on blade partly fused, compressed, increasing in size anteriorly except anteriormost one, as blade joins platform becomes fused ridge, with denticles barely expressed, decreasing in size posteriorly except of posteriormost denticle which is partially discrete and larger than those anterior to it, carinas on dextral forms terminate at this partially discrete denticle, sinistral forms as often as not have one additional discrete carinal denticle, carinal termination aligns with and sometimes merges with curving transverse ridge generally to the inner side, but ridges from both sides curve to the carinal termination, posterior platform termination pointed, parapets ornamented by transverse ridges at slightly greater than 90º angle to greater angle to median line, generally curving, in dextral forms, several merge across the platform, in sinistral forms one to several merge across the platform, adcarinal parapets with transverse denticles, gradually lowering down side of carina anteriorly, anterior declination generally not pronounced, in rare large specimens (pl. 21, fig. 13, Part B) declination is mildly abrupt, in dextral forms inner parapet extends further anteriorly than outer parapet, in sinistral forms roughly of equal length, the inner parapet in dextral forms is denticulate for more of its length, denticles decreasing in size anteriorly, before becoming a smooth rib along side of the blade, in sinistral forms the opposite is true the outer parapet is more denticulate, zero to three accessory denticles occur on the inner side near the posterior carinal termination, more common on sinistral forms than on dextral forms, median groove more pronounced in sinistral forms and only partially disrupted by merging transverse ridges, disrupted to almost not present in dextral forms, basal cavity moderately flared.

Dextral and sinistral elements are very dissimilar with sinistral elements being elongate with a moderately developed median groove, common accessory denticles and subequal anterior parapet terminations and dextral elements of moderate size with a disrupted median groove, rare accessory denticles, and inner parapet longer than the outer parapet.

Holotype.—USNM 487491, pl. 1, fig. 11; Part B, pl. 21, fig. 9.

Remarks.—This species is most like its daughter species, *S. florensis*, but is less asymmetrical. The sinistral elements are most alike between the two species but differ in that those of *S. florensis* have a wider groove and more accessory denticles generally for a given size. The dextral elements differ in that *S. trimilus* specimens have a much less developed groove, common transverse ridges merging across the middle of the platform, the inner adcarinal parapet that is not noticeably flared, a carina that aligns with a inner transverse ridge as opposed to an outer one in *S. florensis*, and typically it has fewer and less well developed accessory denticles. It differs from *S. translinearis* by the inner adcarinal parapet being less fused, more denticulated, not paralleling, or nearly so, the carina, and by having less broken-up and more curving transverse ridges.

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