Genetic stratigraphy of the Fort Scott Limestone (Pennsylvanian, Desmoinesian), southeastern Kansas

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Abstract The punctuated aggradational cycle (PAC) approach of Anderson and Goodwin (1980) and transgressive-regressive units of Busch and Rollins (1984) were used to differentiate small-scale [1–3 m (3.3–10 ft) thick] genetic units in strata of the 9+-m-thick (30+-ft-thick) Fort Scott Limestone (Marmaton Group, Desmoinesian Stage, Middle Pennsylvanian Series) of southeastern Kansas, northeastern Oklahoma, and west-central Missouri. Nine outcrop exposures were observed directly, and information from 20 stratigraphic sections was taken from the literature. The lithologic sequence of the Marmaton Group is similar to cyclothems of the Illinois basin, and thus the genesis of coal is important. Many recent studies have interpreted midcontinent sedimentary strata using Heckel's (1977) model of the basic Kansas cyclothem, which emphasizes a lithostratigraphic approach. The PAC hypothesis is a genetic approach that provides a chronostratigraphic framework for interpreting the strata, reveals a more detailed sea-level history compared to the cyclothem approach, and provides more details for inferring the paleotopography, structural controls, paleogeography and paleoclimatology of the interval. We have identified four (possibly five) sixth-order cycles (Brett et al., 1990) or PACs (Goodwin and Anderson, 1985), which include as many flooding surfaces, in an interval previously interpreted as one cyclothem [the upper Fort Scott cyclothem of Knight (1985)]. These PACs can be traced and correlated throughout the outcrop area, a distance of over 300 km (190 mi), and are similar to small-scale cycles recognized by others in the Triassic of Italy and in the Silurian–Devonian sequence of New York. Recognition and correlation of sixth-order cycles (Brett et al., 1990) or PACs is of value to sedimentary modelers because the more detailed relative sea-level curves and finer scale stratigraphic details will result in better defined parameters, such as sedimentation rates, magnitudes of sea-level changes, and climatic perturbations.

Stratified rocks of the midcontinent have been studied using numerous different approaches, most of which have highlighted the alternating mudstone-limestone lithologies of the strata [e.g., Wanless and Weller (1932), Moore (1936), and Heckel (1977)]. In this article we examine part of the Pennsylvanian Marmaton Group (fig. 1) from southeastern Kansas, northeastern Oklahoma, and west-central Missouri using the punctuated aggradational cycle (PAC) approach of Anderson and Goodwin (1980) and discuss how small-scale genetic units are recognized and correlated.

Interpretive perspective

Heckel's (1977) model of the Kansas cyclothem is the basis of recent popular approaches to the study of midcontinent sedimentary rocks. However, Heckel's model is based largely on studies of the Missourian rocks of Kansas and as such is less appropriate for explaining cyclicity in the Desmoinesian, Virgilian, or Wolfcampian (Lower Permian). The lithologic sequence recorded in the Marmaton rocks (upper Desmoinesian of Kansas), which are emphasized here, is more appropriately examined in light of the typical Illinois basin cyclothem, which was the original cyclothem model (Wanless and Weller, 1932).

The model used here traces small-scale genetic deepening-shallowing units across a depositional basin and uses these units for reconstructing basin history. This is the punctuated aggradational cycle (PAC) approach of Anderson and Goodwin (1980), and thus each small-scale unit is called a PAC. A PAC [sixth-order cycle of Brett et al. (1990)], as recognized and used here, is essentially the same as the ideal cyclothem that Moore (1936) recognized in the Wabaunsee Group. In that same paper, Moore (1936) introduced the megacyclothem concept, which can be considered analogous to a shallowing PAC sequence (Goodwin and Anderson, 1985).

We believe that these sixth-order cycles (PACs) result in part from eustatic sea-level fluctuations, and because the scale is appropriate, the units could be termed sixth-order transgressive-regressive units, as proposed by Busch and Rollins (1984). They are equivalent to Goldhammer's fifth-order units (Goldhammer et al., this volume). However, these cycles could also be responses to changes in climate (Cecil, 1990), in which case transgressive-regressive units are not appropriate; indeed these cycles are no doubt responses to both climate and sea-level change as well as to other factors. Although we do not believe that it is possible to infer the

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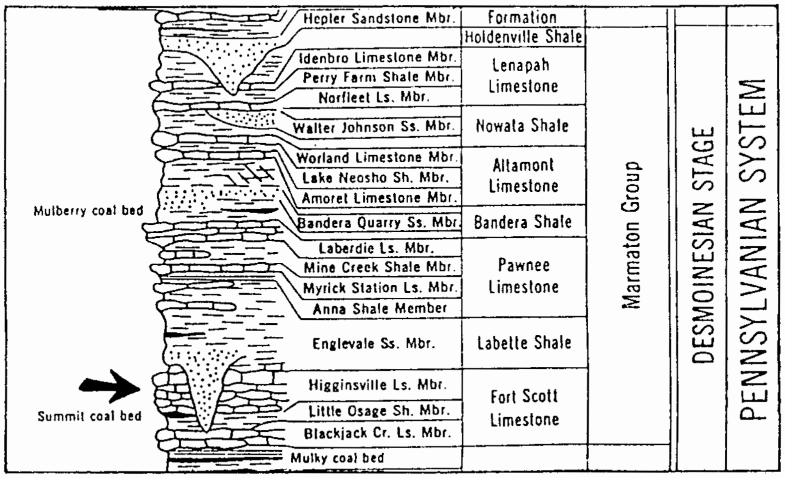

Figure 1. Stratigraphic column of the Marmaton Group [from Zeller (1968)]. Study interval is the upper part of the Fort Scott Limestone (arrow).

predominant cause of these cycles, eustasy appears to have been important, but we use sixth-order cycles or PACs rather than transgressive-regressive units.

PACs (sixth-order cycles) can be grouped into shallowing PAC sequences (Goodwin and Anderson, 1985), each of which, as a package, exhibits shallowing-upward characteristics. In the Busch and Rollins (1984) hierarchy, a shallowing PAC sequence is a fifth-order transgressive-regressive unit and is equivalent in scale to Heckel's (1977) Kansas cyclothem or to Goldhammer et al.'s (this volume) fourth-order unit. A sixth-order cycle (PAC) is usually 1–5 m (3.3–16 ft) thick and represents tens of thousands of years, whereas a fifth-order cycle represents hundreds of thousands of years (Busch and Rollins, 1984; Busch and West, 1987); both fit within the Milankovitch bands of orbital parameters.

Each sixth-order cycle (PAC) is normally bounded by a surface representing rapid marine transgression (flooding) and may or may not have a thin transgressive layer at its base. The remainder of the sixth-order cycle (PAC) represents aggradation and progradation of sediments during long periods of sea-level stasis or slow sea-level fall [see Goodwin and Anderson (1985) for further discussion]. Within carbonate rocks a sixth-order cycle (PAC) may show many of the characteristics described by James (1984) for his shallowing-upward sequences.

Changes in rock type from the top of one sixth-order cycle (PAC) to the base of the next overlying one may be a result of change from a terrestrial to a marine environment or from shallow to deeper marine conditions. Busch (1984) argued that a PAC may even be represented on land, for example, by a change from an arid terrestrial to a humid terrestrial climate, in which case the genetic surface would be a climate change surface.

We contend that our model closely approaches time stratigraphy, in which genetic units can be correlated across a depositional basin. The bounding genetic surfaces are assumed to be essentially geologically synchronous and thus define relatively isochronous rock slices. Correlation of these surfaces greatly improves our resolution of the rock record over methods that trace diachronous rock facies across a basin [see Goodwin et al. (1986)].

Setting

The rock units studied are from what has been known, until recently, as the Fort Scott Limestone and part of the overlying Labette Shale (fig. 1). They belong to the Marmaton Group and are Desmoinesian or Middle Pennsylvanian in age.

Knight (1985) reassigned rocks of the Fort Scott Limestone and the underlying Excello shale member, as shown in fig. 2. He grouped them into the lower Fort Scott cyclothem and the upper Fort Scott cyclothem. Here we are concerned with the rocks of Knight's upper Fort Scott cyclothem, from the top of the Morgan School shale member, through the Little Osage shale member and Houx–Higginsville limestone member of the Wolverine Creek formation and part of the overlying Labette Shale.

These rock units crop out in a belt trending from northeastern Oklahoma through southeastern Kansas and across western Missouri to Iowa (fig. 3). All the stratigraphic sections are illustrated and described by Suchy (1987, plate 1 and appendix A). In addition to these field data, over 100 petrographic thin sections and 70 acetate peels were studied and described [see Suchy (1987, appendix C)]. Localities of outcrops and descriptions are shown in fig. 3. Exposures in southeastern Kansas and westernmost Missouri, from locality SOS to locality BUT, were examined in detail. Information on other localities was taken from the literature (Knight, 1985; Jeffries, 1958; Schell, 1955).

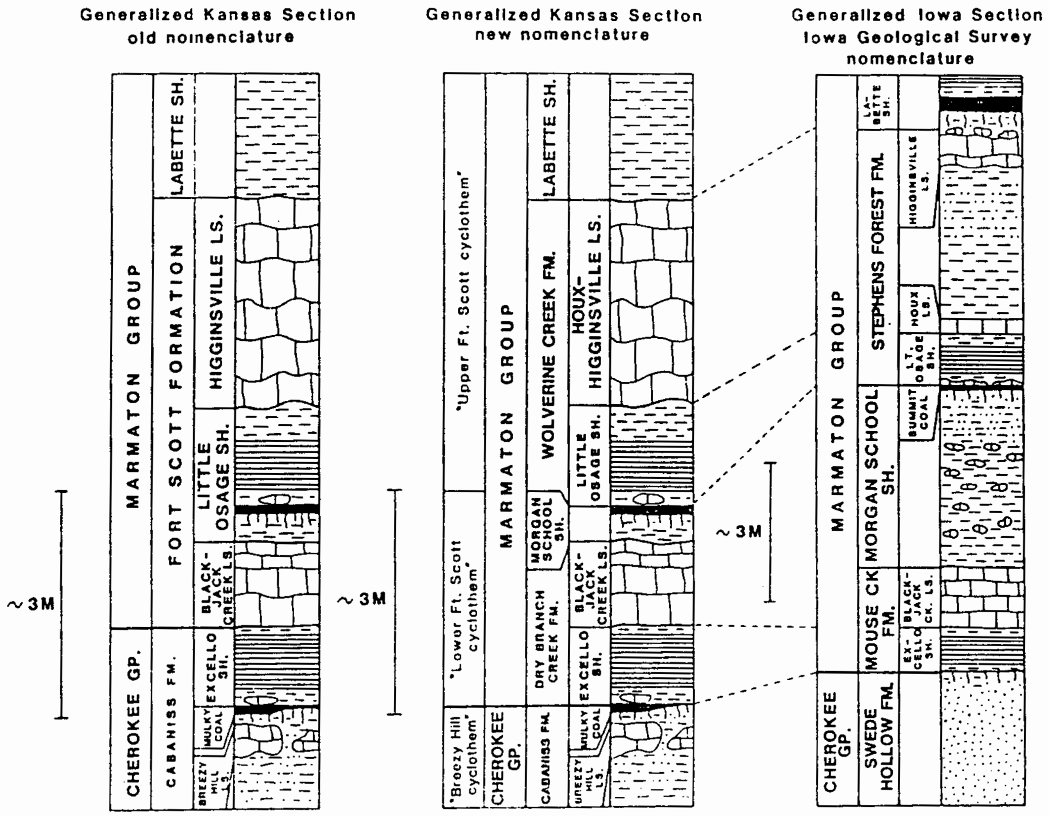

Figure 2. Generalized stratigraphic columns comparing old nomenclature in Kansas with new nomenclature in Kansas and Iowa [from Knight (1985, fig. 3; Iowa nomenclature from Ravn et al. (1984)]. Nomenclature used in this article is that of the middle column.

Coals, climate, and genetic stratigraphy

In this study we recognize the tops of coal beds as the upper boundaries of sixth-order cycles (PACs) because the boundary between the juxtaposed phosphatic carbonaceous shale and the coal is a significant genetic surface (see later discussion). In addition, an intimate relationship can exist between underclays and coals, with the coal being the organic-rich zone or A horizon of the underlying soil, the underclay. Thus similar climatic conditions would have produced both; they would be genetically related. Where several beds of coal are closely associated, as in the Anna–Labette interval (see later discussion), these coal splits are considered to belong to a single genetic unit. Although this interpretation considers the coal intervals to be more or less allocyclic, as suggested by Cecil and Englund (1989), the initiation of a single peat accumulation at any one locality can be largely an autocyclic process. Breyer and McCabe (1986) and Kvale and Archer (1990) have suggested that coals within tidally dominated sequences are the result of locally controlled vertical accretion with the subsequent establishment or reestablishment of a coal forest.

Cecil (1990, p. 533) attributed the types of sediments deposited during the Mississippian and Pennsylvanian directly to climate, saying that "perennially wet climates are conducive to coal formation, whereas dry climates produce carbonates and/or evaporites" and "in warm climates, siliciclastic input is greatest under highly seasonal rainfall." Therefore, as the US midcontinent drifted slowly from an equatorial position during the Mississippian to a few degrees north latitude in the Late Pennsylvanian to Permian (Scotese and McKerrow, 1990), it moved from the tropical rainy (nonseasonal) belt through a monsoonal belt toward more arid conditions. This is reflected in the rock record, with widespread thick coals occurring in the Middle Pennsylvanian section, decreasing in number and thickness up-section, and more limestones occurring in the Upper Pennsylvanian (Cecil, 1990).

In addition, Ziegler et al. (1987) attempted to explain why coals were sometimes deposited in the intertropical convergence zone of consistent rainfall (a zone approximately 10° wide, centered on the equator). They concluded that, during warmer climatic periods on the Earth, the intertropical convergence zone was less latitudinally confined because of "a

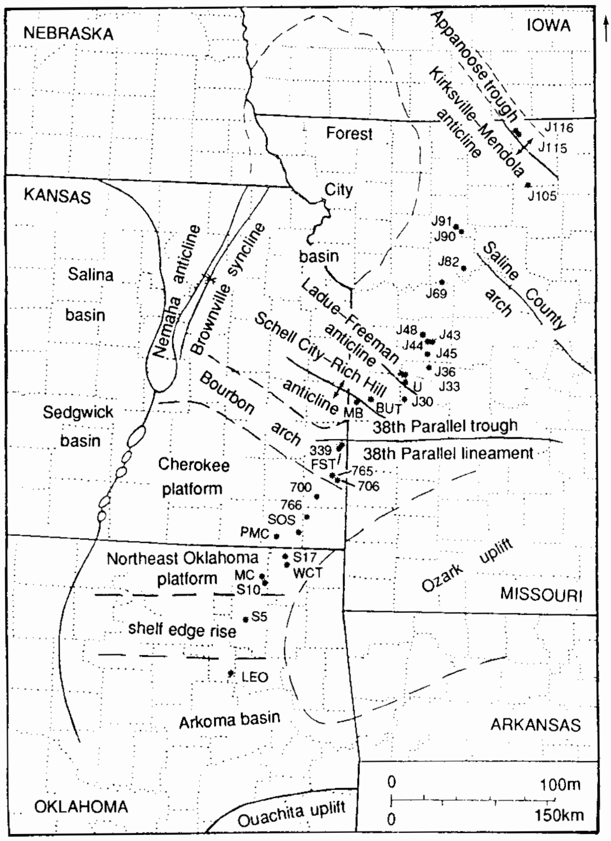

Figure 3. Pennsylvanian paleogeographic map with localities (stars) used in this study. [Base map modified from Knight (1985, fig. 7).]

reduction in the effect of the polar front that at present seems to confine the Hadley cells and thereby to channel the tropical rainy belt" and therefore that, during these warmer times, "there was no area in the tropics with year-round rainfall" (Ziegler et al., 1987, p. 43). They contended that "the cooler 'icehouse' periods exhibit simultaneously the driest and wettest climate indicators meaning, again, that precipitation is better channelled during glacial times" (p. 43).

Although Ziegler et al. (1987) and Cecil (1990) were considering broad geologic time scales, their conclusions are relevant to a discussion of the rocks of the Marmaton Group. Kansas and Missouri were approaching the northern edge of the intertropical convergence zone during the Desmoinesian, and so depositional environments would have been sensitive to climatic changes. During warmer climatic periods, major deglaciation would have raised sea level and the intertropical convergence zone would have been less confined, producing conditions in which year-round rainfall did not occur in the tropics and thus reducing the likelihood of coal formation. During these times, limestone was deposited. Of course, the midcontinent was covered by seawater and only marine sediments could be deposited there. However, during lowstands, such as the one represented by the top of the upper Fort Scott cyclothem, the climate was cooler, polar land-based glaciation was greater, and the intertropical convergence zone was more latitudinally confined. This created an equatorial zone of consistent year-round rainfall conducive to coal-swamp formation. The intervening times, between wet and dry periods, when seasonality of rainfall was high, resulted in deposition of siliciclastic units that overlie and underlie the coal beds (Cecil, 1990) (see later discussion).

Sixth-order cycles (PACs): Descriptions and interpretations

Southeast Kansas A number of sixth-order cycles (PACs) within Knight's upper Fort Scott cyclothem can be seen in single quarry sections. For example, four sixth-order cycles have been recognized at locality 700 (fig. 4), beginning just above the base of the Little Osage shale member and continuing upward to a boundary at the top of this unit; two boundaries within the Houx–Higginsville limestone member and one within the Labette Shale have also been recognized.

Rocks near Fort Scott, Kansas (localities 339 and FST; fig. 3), are similar to those at locality 700 and, although over 50 km (30 mi) away, they show a correlative response to genetic changes (fig. 5). The Houx–Higginsville limestone member here is approximately 5 m (16 ft) thick; PAC 3 is approximately 1 m (3.3 ft) thick. The Morgan School shale member is a terrestrial deposit representing the upper part of an earlier PAC underlying PAC 1. Wanless (1947) noted the extremely variability of cyclothems. This variability is illustrated by PAC 1, which extends from the top of a coal (the Summit) through a carbonaceous shale into a marginal marine mudstone, but at some localities a thin fossiliferous limestone occurs in the upper part of this PAC. Overall, PAC 1 is similar to some cyclothems of the Illinois basin.

PAC 1, consisting primarily of the Little Osage shale member [+1.75 m (+5.7 ft) thick], is interpreted to have been deposited in a low intertidal (possibly shallow subtidal) to nonmarine environment. In the sections we observed the carbonaceous shale is finely laminated and contains abundant phosphate nodules and conodonts, few detrital mineral grains, and sparse fish scales, all of which are features listed by Coveney et al. (1991) as indicative of an offshore black shale. However, these features are not limited to an offshore environment. Intertidal flat and coastal marsh muds can look similar, and A. Archer (personal communication, 1990) has observed laminations within carbonaceous shales of the Little Osage member that are similar to laminations described within tidal rhythmites from other localities (Kvale and Archer, 1990; Archer, this volume). The fact that the Summit coal bed occurs immediately below and in contact with this carbonaceous shale at more that one locality supports a more marginal marine to nonmarine interpretation.

Figure 4. Quarry face at locality 700 in Crawford County, Kansas, showing most of Knight's (1985) upper Fort Scott cyclothem. Hammer at base is at the top of the Little Osage shale member (which forms the floor of the quarry) at its contact with the Houx–Higginsville limestone member (which extends upward to where soil and vegetation occur). Elsewhere in the quarry the Labette Shale can be seen lying directly on top of the limestone shown here. The Houx–Higginsville limestone member here is over 5 m (16 ft) thick, with well-developed chaetetid colonies between 2 m and 4.5 m (6.6–15 ft) above the base of the limestone (arrow). Hammer is 31 cm (12 in.) long. Numbers on the right refer to sixth-order cycles (PACs).

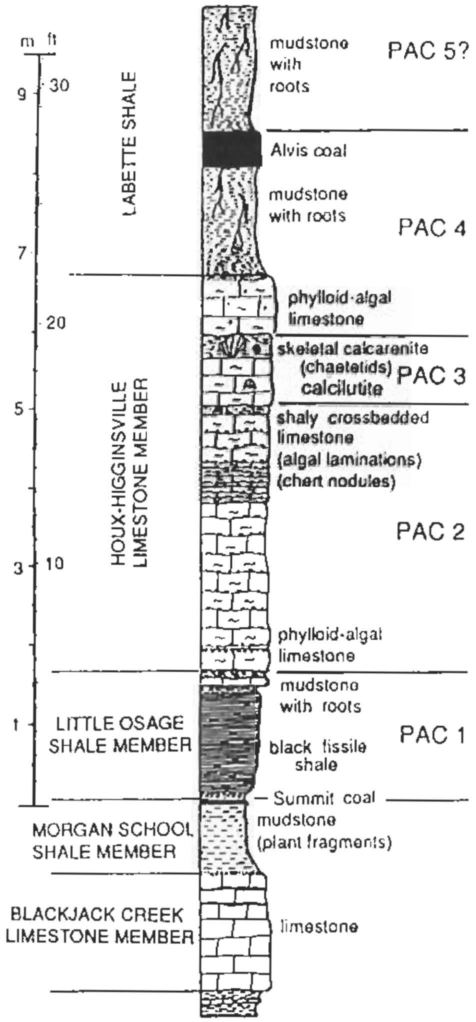

Figure 5. Composite stratigraphic column from Fort Scott, Kansas, showing sixth-order cycles (PACs) at localities 339 (from top of Little Osage shale member upward) and FST (from top of Little Osage member downward). See fig. 7 for legend.

This carbonaceous shale and associated Summit coal are traceable with little change in character over distances of hundreds of kilometers (as extrapolated from descriptions in the literature; Schell, 1955; Jeffries, 1958; Knight, 1985). Based on Heckel's (1977) model, such carbonaceous (black) shales were interpreted as the deepest water phase. Clearly, more work needs to be done.

Given the stratigraphic relationships observed in this study, it seems more reasonable to interpret the carbonaceous shales as related to shallow marine flooding of coastal coal swamps. Indeed, this interpretation is essentially the same as that proposed by Wenger and Baker (1986). Based on detailed study of the organic geochemistry of the Little Osage and Excello black shales, Wenger and Baker (1986) stated that "eustatic rise of sea level and rapid marine transgression over the continental craton, with subsequent flooding of adjacent extensive brackish-marine (peat) swamps and the resultant influx of a large supply of nutrients and humic detritus, appear to be the key geologic control of black-shale deposition" (p. 85).

Ice-sheet surges have been suggested by Hollin (1969) as a mechanism for rapid sea-level rise, 50 m (160 ft) in 50 years or less. Such sea-level rises would have created new coastal zones, covering tens of kilometers, where the settling out of reworked peat debris would produce allochthonous coals and carbonaceous black shales, such as the Excello (Hollin, 1979, p. 91). Thus the lower boundary of PAC 1 is placed at the top of the Summit coal or at the base of the carbonaceous shale.

Following deposition of the carbonaceous shale and a thin mudstone, a thin [6–12 cm (2.4–4.7 in.)] limestone was deposited near the top of PAC 1. This limestone contains brachiopods (*Orbiculoidea*, marginiferids, chonetids, *Crurithyris*) and small burrows and has conodonts at its base and root traces at the top (fig. 5). The limestone does not occur everywhere. The erratic occurrence and the taphonomic character of the marine fossils, burrows, and root traces suggest that it represents an intertidal skeletal accumulation. This was followed by deposition of a thin [8–10 cm (3.1–4.0 in.)] mudstone with abundant root casts, the trace fossil *Chondrites*, and the brachiopod *Crurithyris*. Root casts were observed only in this thin mudstone and the upper surface of the underlying limestone, not in the other overlying or underlying facies. Therefore, whether these root casts were contemporaneous with deposition of the mudstone or superimposed afterward, they represent a significant shallowing event at the end of PAC 1 time and before the beginning of PAC 2. This same mudstone facies occurs at the equivalent stratigraphic position in the exposures at localities 700 and BUT, and is interpreted as representing marginal marine to lagoonal to possibly even paralic mud-flat deposition. At other localities in southeast Kansas (SOS, 766, 765, and MB), a sparsely fossiliferous to nonfossiliferous grayish-orange claystone occurs at the top of PAC 1.

Following this, a rapid marine flooding (transgression; beginning of PAC 2) culminated in a long period of open marine conditions in which phylloid-algal limestone [up to 3 m (10 ft) thick] was deposited in relatively quiet waters (figs. 4 and 5). This facies extends, with some thickness variations, over a wide area in southeastern Kansas and western Missouri. The top of PAC 2 (fig. 5) at locality 339 is a shaly, crossbedded limestone with algal laminations and chert nodules. This is interpreted as representing a nearshore environment, probably within normal wave base to possibly intertidal. At locality 700 the top of PAC 2 is a strongly cross-laminated, shaly calcarenite with a nodular chert layer; this is interpreted to be shallow marine, well within normal wave base. At other localities (BUT and J33 through J48) the transition between PACs 2 and 3 may be more subtle, represented simply by a change in limestone facies separated by a bedding plane [see Suchy (1987, plate 2 and appendix A)].

PAC 3 (fig. 5) represents another deepening event, although not of as great a magnitude as the previous one. Fossiliferous limestone with chaetetids occurs at locality 339 (fig. 5). At localities 700 and 706 PAC 3 contains well-developed chaetetid colonies [referred to as a chaetetid reef by Heckel et al. (1979, p. 35) and by Knight (1985)] in a fusulinid packstone matrix. The chaetetid-bearing facies in southeastern Kansas varies from 1 m to 2.3 m (3.3–7.5 ft) thick.

The top of PAC 3 (fig. 5) at locality 339 is represented by a strongly cross-laminated, coarse-grained, shelly calcarenite with some toppled chaetetid colonies. At localities 700 and 706 the top of this PAC is represented by a thin [0–40 cm (0–16 in.)] paralic to terrestrial shale; this shale is light brownish gray and flaky and contains limestone lenses and broken and abraded shell fragments in the lower part, with only plant fragments in the upper part. At locality BUT the top of the Houx–Higginsville limestone member exhibits paleokarst features, suggesting subaerial exposure before deposition of PAC 4.

PAC 4 marks the return to more open marine conditions reflected by phylloid-algal limestone [up to 3.3 m (11 ft) thick] at most localities in southeastern Kansas and marginal marine shale (containing only limestone nodules rich in fusulinids) at locality BUT. At all localities the top of this PAC contains terrestrial mudstone [0.5–3.5 m (1.6–11 ft)], usually recorded as a soft gray mudstone containing only plant fragments and root traces.

The upper boundary of PAC 4 (fig. 5) at locality 339 is marked by the top of the Alvis coal. The top of PAC 4 and the beginning of an overlying PAC (PAC 5?) is more clearly shown at locality 700 by a pale-orange mudstone containing abundant bivalves (*Aviculopecten* and *Permophorus*). At several other localities (BUT, J30, J33, J36, J43, J44) the Alvis coal is overlain by a thin limestone or marginal marine shale overlain by a terrestrial mudstone with root traces; these thin limestones and marginal marine shales may represent another PAC (PAC 5?), but the relationships are unclear.

North-central Missouri Now that we have discussed the relationships among the sixth-order cycles (PACs) in southeastern Kansas and western Missouri, we can move 300 km (186 mi) northeast (localities 115 and 116; fig. 3) and examine exposures of Knight's upper Fort Scott cyclothem in north-central Missouri (fig. 6). Recall that we have not examined in the field the exposures in this area but have used the detailed descriptions of Jeffries (1958). As such, our sixth-order cycles (PACs) are more tenuous. Obviously, careful examination in the field is necessary to test our predictions.

PAC 1 at this locality is just under 1 m (3 ft) thick. It is similar to the southeastern Kansas localities in that a similar carbonaceous shale occurs at the base and is interpreted as representing tidal flat deposition. A thin skeletal calcarenite occurs at the top of this PAC, reminiscent of the thin, erratic limestone that occurs near the top of PAC 1 in southeastern Kansas (fig. 5). The upper boundary of PAC 1 in northwestern Missouri is at the top of this thin skeletal calcarenite.

PAC 2 at locality 116 is marked at its base by a fossiliferous marine shale [15 cm (6 in.)] followed by a thin [5 cm (2 in.)] skeletal calcarenite. This is overlain by a thick [5.6 m (18 ft)] nonfossiliferous siliciclastic unit called the Flint Hill sandstone member. The Flint Hill member is a siltstone and sandstone wedge that prograded from the north as far south as locality J69 during the time of PAC 2 deposition [fig. 7; see also Wanless (1964, fig. 9, p. 603)]. At many localities in Missouri the Houx limestone member contains thicker limestone beds, but it is consistently split in the middle by a shale parting (localities J91 and J82) or by a nonfossiliferous shale

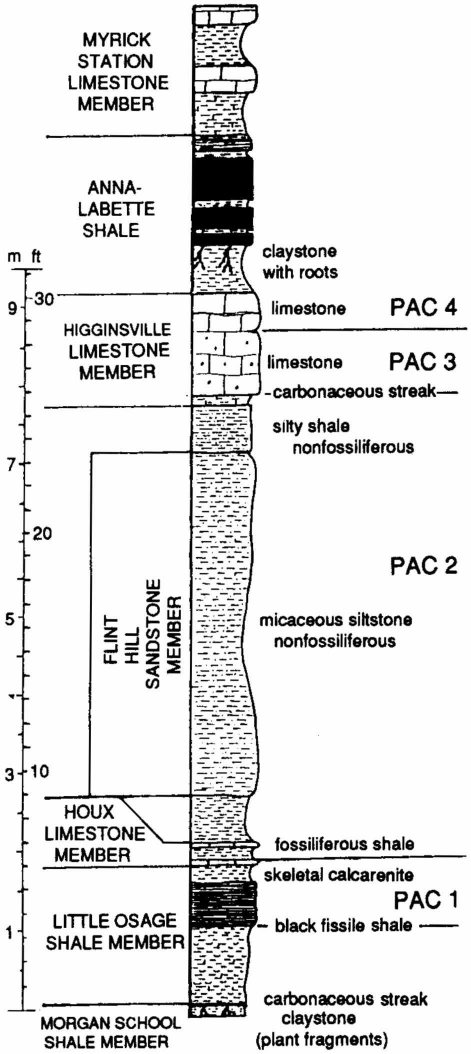

Figure 6. Composite stratigraphic column from northern Missouri showing sixth-order cycles (PACs) at localities 116 (from top of Higginsville limestone member downward) and 115 (from top of Higginsville member upward), which are 3.2 km (2 mi) apart. Named rock-stratigraphic units are from Ravn et al. (1984). [Drawn from descriptions by Jeffries (1958).] See fig. 7 for legend.

up to 2 m (6.6 ft) thick (J48) that in some outcrops (J44 and J45) is red-gray or iron stained, suggesting subaerial oxidation. These features, along with the great lateral persistence and consistent position of the shale and its possible correlation with thin, sometimes rooted mudstone between limestones at the top of the Little Osage shale member (localities BUT, MB, 339, and FST) suggest that the lower boundary of PAC 2 should be placed within this shale parting. The upper boundary of PAC 2 is recorded by a thin carbonaceous streak near the base of a limestone (fig. 6).

PAC 3 at locality 116 (fig. 6) consists of a blocky limestone [0.8 m (2.6 ft) thick] containing abundant brachiopods, crinoid fragments, and fusulinids. At many localities in Missouri (J91, J82, J48, BUT), as in exposures in southeast Kansas, this PAC contains chaetetids. The upper boundary of PAC 3 and the lower boundary of PAC 4 are marked by a change in carbonate lithology (fig. 6).

PAC 4 at locality 116 is represented in its lower part by a nodular, fossiliferous limestone [0.5 m (1.6 ft)] with shaly partings, especially at its base. The upper part [0.6 m (2.0 ft)] is a gray massive claystone containing carbonized fossil roots that may extend up through the several coals of the Anna–Labette interval. If a fifth PAC (PAC 5) exists in the southern localities (southeast Kansas), as we suspect, the Anna–Labette interval in the northern localities (Missouri) will need to be examined more carefully to establish its presence in north-central Missouri. Note that we have not indicated an upper boundary for PAC 4 because we have not examined the exposures and a boundary is not suggested by data from Jeffries (1958) (fig. 6).

Coals and sea level The relationship between the coals and sea-level changes is illustrated in fig. 8b. For PAC 1 (figs. 5 and 7) rapid marine flooding followed coal deposition, resulting in deposition of the carbonaceous shale across the entire basin. In the upper part of PAC 4 peat swamps covered much of the area but were subsequently inundated by marine waters in a few low-lying areas in southeastern Kansas (PAC 5?), never reaching the coal swamps of northern Missouri (fig. 7) [also see Wanless (1964, fig. 3, p. 597)].

Relative sea-level curves

The relative sea-level curve for Knight's (1985) upper Fort Scott cyclothem shows a strong sea-level change at the top of the Houx–Higginsville limestone member (fig. 8a); this is the position of the base of PAC 4 (fig. 8b). Also, Knight (1985) correlated the Flint Hill sandstone member with the middle part of the Houx–Higginsville member. Herein, we correlate it with the lower part.

By examining the rocks centimeter by centimeter and recording all facies changes, however minor, that may have resulted from relative sea-level fluctuations, we constructed a relative sea-level curve (fig. 8b) based on the sixth-order cycles (PACs) we identified in the same rocks described by Knight (1985). Although there is an initial flooding in the Little Osage shale member, it is not as pronounced as that shown by Knight (1985) because the geochemical and related data do not support a deep-water anoxic environment for this unit. There are also several other deepening-shallowing events, as evidenced by the data presented earlier. If the rocks had been examined only at the scale of shallowing PAC sequences (fifth-order cycles), the curve might have resembled Heckel's (1977) cyclothem curve.

Summary and regional implications

A review of the overall relationships among the sixth-order cycles (PACs) at the different localities studied can also be attained by examining fig. 7 [for further information see Suchy (1987)]. PAC 1 includes most of the Little Osage shale member at all localities but also includes the lower part of the Houx limestone member from locality J36 northward.

PAC 2 includes most of the lower part of the Houx–Higginsville limestone member from locality S10 in northeast Oklahoma (also see fig. 3) to locality J48 in west-central Missouri and includes the upper part of the Houx member and the Flint Hill sandstone wedge from locality J69 northward in Missouri (fig. 7). That part of the Houx–Higginsville member included in PAC 2 is primarily a wavy-bedded phylloid-algal limestone.

PAC 3, the chaetetid PAC, consists of the middle part of the Houx–Higginsville member from locality PMC in southeast Kansas to locality J48 in west-central Missouri. From there northward it consists primarily of the Higginsville limestone member. The chaetetid facies occurs sporadically within this PAC over most of the outcrop area, usually associated with paleotopographic highs (Suchy, 1987). At localities 700 and 706 (fig. 7), chaetetids, where they are well developed, occur in a fusulinid packstone matrix; at other chaetetid localities there are usually common to abundant fusulinids. At the non-chaetetid-bearing localities, this PAC contains fossiliferous limestone with or without fusulinids.

PAC 4 includes the upper part of the Houx–Higginsville limestone member and part of the Labette Shale from locality PMC in southeast Kansas all the way to northern Missouri (locality J115). Within this PAC the Alvis coal of southeastern Kansas and western Missouri (localities 339 to J44) is correlated with the Dutchman and Lexington coals in northern Missouri [J115; also see Wanless (1964, fig. 3, p. 597, and fig. 5, p. 598)]. At the top of PAC 4 at locality 700, a marginal marine shale containing abundant bivalves occurs, possibly marking the base of another PAC. At localities BUT to J44 the Alvis coal is overlain by a marginal marine gray shale or thin marine limestone, both containing brachiopods, which, in turn, is overlain by terrestrial mudstone, usually gray and flaky and sometimes rooted; these marine events mark the base of the next higher PAC (PAC 5?).

The pattern of small-scale cycles grouped into a single shallowing-upward package is similar to the patterns and scale seen in the Triassic Latemar massif of northern Italy, for which Goldhammer et al. (1990, p. 537) described a 400-m (1,300-ft) section exhibiting repetitive bundling of cycles into 5-part megacycles. Similar small-scale cycles also occur in the Silurian–Devonian section of New York (Brett and Baird, 1985, 1986), a part of the Paleozoic that is supposedly nonglacial (C. E. Brett, personal communication, 1990). This is apparently a recurring theme throughout the geologic record, and its recognition will provide a basic framework that will greatly enhance our resolution and reconstruction of earth history.

Conclusions

We have provided an example of the PAC approach to stratigraphic analysis, an approach in which genetic units are recognized and traced over a wide area. PAC analysis can form the basis for a refined and more detailed picture of the paleogeography, paleoclimatology, paleotopography, structural controls, and subtle, small-scale sea-level changes. It can also be used to make more detailed interpretations of depositional environments within the geologic record and to predict geographic areas of economic interest. This approach also provides some indication of how certain features, such as relative position of shoreline and topography, change over time.

The PAC approach results in subdivision of a Kansas cyclothem (as modeled by Heckel (1977)] into smaller scale units (sixth-order cycles) analogous to the cyclothems originally described by Wanless and Weller (1932) and used by Moore (1936). These smaller scale cyclothems bear many similarities to PACs, or sixth-order (approximately 50,000–130,000 years) cycles (Brett et al., 1990). Furthermore, Moore's original concept of a cyclothem of cyclothems, or megacyclothem, still seems appropriate and, when updated with current jargon, can be described as a shallowing PAC sequence or a fifth-order cycle. In addition, Moore's original interpretation of coal-related carbonaceous (black) shales, wherein he inferred a marginal marine environment, seems more appropriate for the Little Osage shale member than the deep-water interpretation required by Heckel's (1977) model.

Certainly the interpretations here will be refined, modified, or changed with future studies, but it is this approach, careful observations of the effects of small-scale events, that will point the way toward a better understanding and interpretation of the geologic past and will help to constrain and define more detailed geologic data that may be of use to sedimentary modelers.

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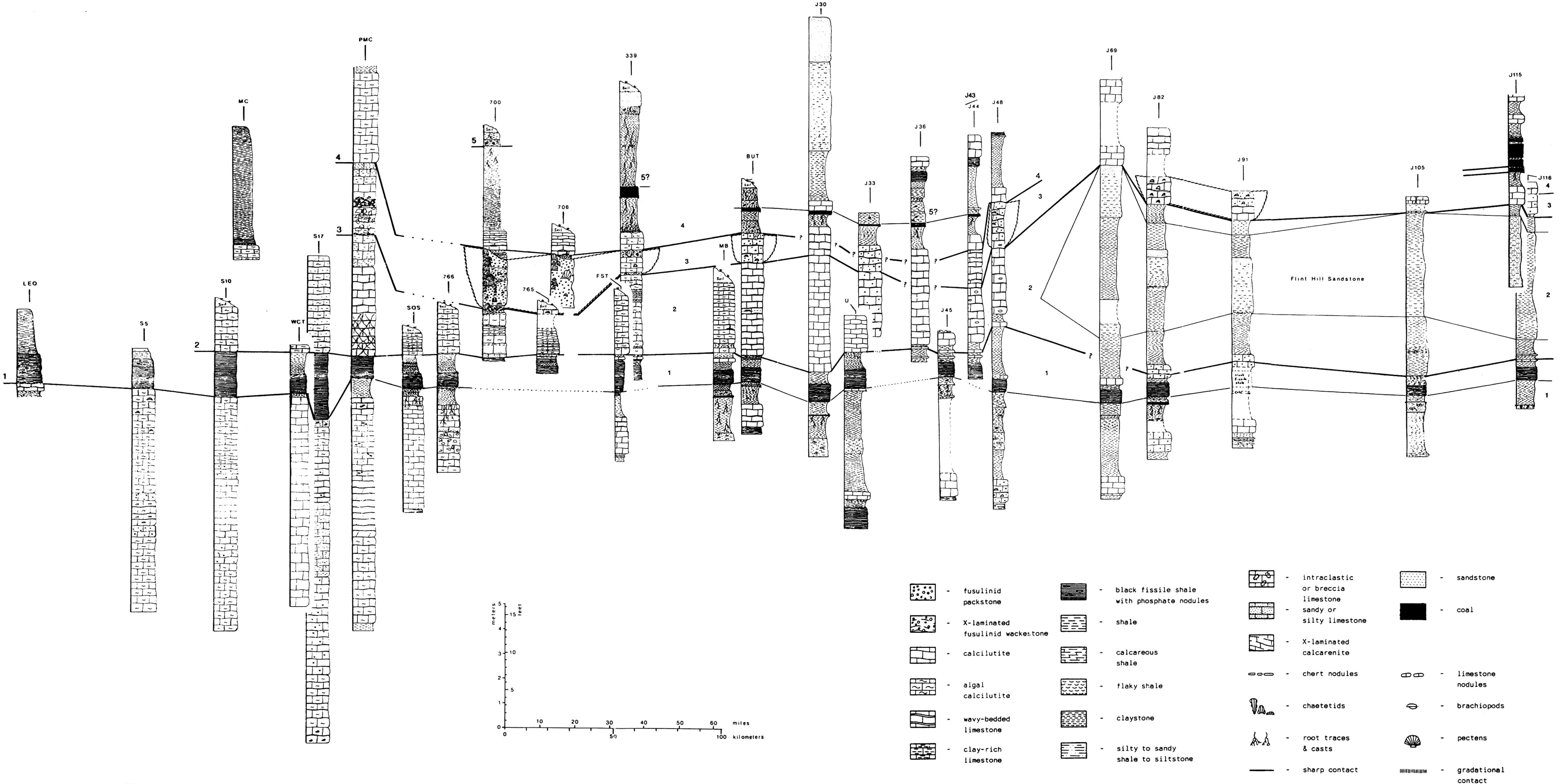

Figure 7. Correlation of sixth-order cycles (PACs) in Knight's (1985) upper Fort Scott cyclothem from northeastern Oklahoma to north-central Missouri. Sixth-order cycle (PAC) boundaries are shown by thick solid lines and are dotted where inferred. Thinner lines indicate member boundaries, and wavy lines indicate chaetetid facies boundaries. Sixth-order cycles (PACs) are indicated by boldface numbers.

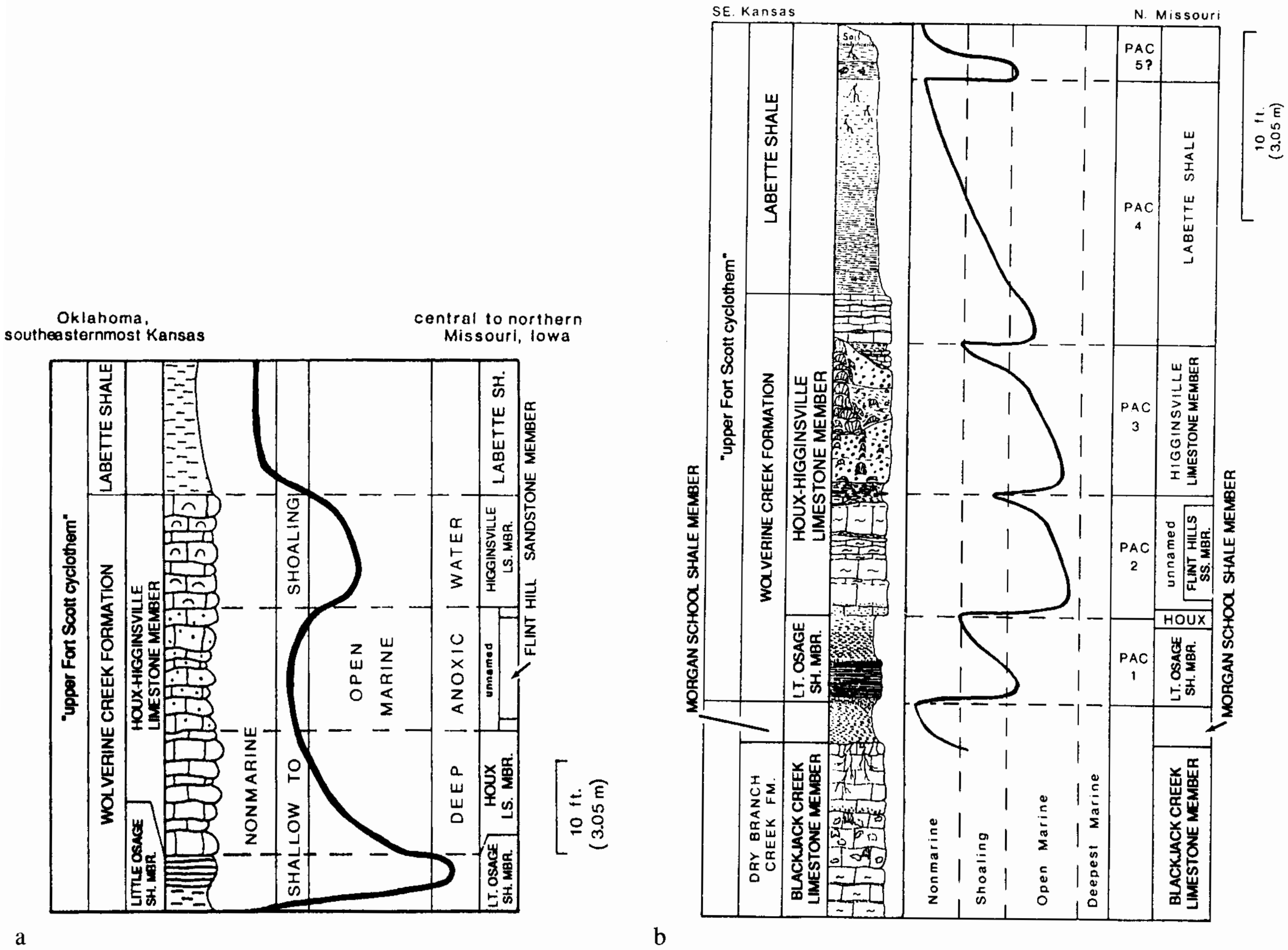

Figure 8. (a) Knight's (1985) relative sea-level curve developed by using the cyclothem approach [modified from Knight (1985, fig. 42)]. (b) Relative sea-level curve based on PACs recognized in this study. Stratigraphic column from the top of the Little Osage shale member upward is from locality 700; below that is from locality 766, 13.5 mi (21.7 km) apart. At other localities, noted on fig. 7, coal occurs just below the lower boundary of PAC 1 and at the top of PAC 4. Symbols are the same as those used in fig. 7.

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