STRATIGRAPHY AND CYCLIC SEDIMENTATION OF MIDDLE AND UPPER PENNSYLVANIAN STRATA AROUND WINTERSET, IOWA

GUIDEBOOK SERIES NO. 14

Iowa Department of Natural Resources
Larry J. Wilson, Director
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Iowa Department of Natural Resources
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OVERVIEW OF PENNSYLVANIAN CYCLOTHEMS IN SOUTHWESTERN IOWA

by

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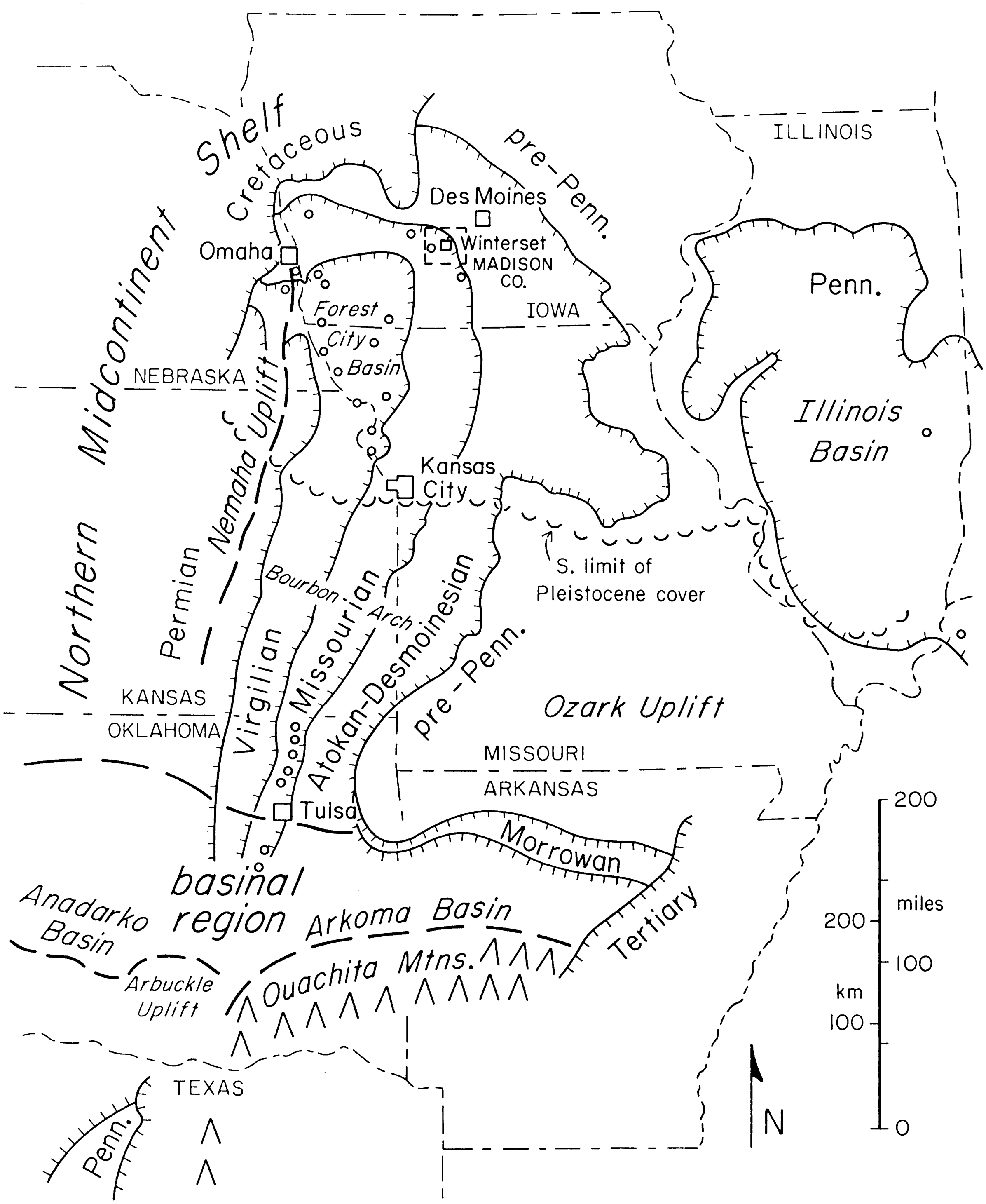


Figure 1. Midcontinent Pennsylvanian outcrop belt with hachures in direction of dip, showing Madison County, Iowa (location of field trip), and generalized Pennsylvanian structural features. Nemaha Uplift and Forest City Basin were formed during Early Pennsylvanian time; Forest City Basin became largely filled by end of Middle Pennsylvanian (Desmoinesian) time, and entire region north of basinal region of Oklahoma then acted as Northern Midcontinent Shelf. Circles denote locations of long cores in states other than Kansas.

GEOLOGIC SETTING

During Late Pennsylvanian time, Iowa lay toward the north end of the relatively stable Northern Midcontinent Shelf, which included Nebraska, Missouri and Kansas along the north side of the subsiding basinal region of central Oklahoma (Fig. 1). Middle and Upper Pennsylvanian bedrock geology of southwestern Iowa is characterized by an alternation of laterally persistent limestone formations from 6 to 30 ft thick and containing thin shale members and beds, with laterally persistent blocky to sandy shale formations from 5 to 30 ft thick and containing local sandstones and coals (Fig. 2). These rocks strike generally south-north near the Missouri border, and swing toward the northwest around Winterset to an east-west strike westward toward Council Bluffs and Omaha (Fig. 1). Regional dip is gentle, toward the southwestern corner of Iowa.

Several problems have complicated the understanding of Pennsylvanian stratigraphy and structure of southwestern Iowa: 1) Most exposures are so isolated from one another by thick Pleistocene cover that stratigraphic relations are difficult to determine without drilling to discover more of the local vertical sequence. 2) So many of the formations resemble one another closely enough in vertical lithic sequence that it is difficult to distinguish one from another in isolated exposures. 3) Local variations in dip and strike known for some time (e.g., in northeastern Adair County just west of the field trip area; see Welp and others, 1968, p. 4-1) have hindered attempts to correlate between nearby isolated exposures by means of projecting elevations. The combination of all these problems had led to a large number of questionable correlations, which are now becoming largely resolved through a combination of study of long cores obtained by the Iowa, Nebraska and Missouri Geological Surveys, and analysis of conodont faunas from both cores and outcrops by von Bitter and Heckel (1978), Swade (1985), Heckel (1991a), and ongoing work derived in part from student theses (e.g., Mitchell, 1981; Price, 1981; Schutter, 1983; Nielsen, 1987). As a result, in the 12 years since the last formal field trip to this area (Heckel, 1980a), several mid-Missourian formations have undergone significant recorrelation and revision of nomenclature, which are incorporated into Figures 2, 6 and 7, and will be indicated at field trip stops 3, 5, 6 and 7.

MIDCONTINENT PENNSYLVANIAN CYCLOTHEMS

The cyclic alternation of limestone and shale formations that dominates the Middle and Upper Pennsylvanian succession (Fig. 2) along the Midcontinent outcrop belt (Fig. 1) has intrigued geologists ever since Moore (1931) first described it, and Wanless and Weller (1932) applied the term cyclothem to the component unit of repeating rock types. Weller (1930) invoked a model of periodic tectonism to explain both the overall alternation and the individual cyclothem. In contrast, Wanless and Shepard (1936) related both these features to eustatic changes in sea level brought about by waxing and waning of Gondwanan ice caps. More recently, autocyclic models of delta-shifting have been applied to cyclic sequences in the Appalachians (Ferm, 1970) and Texas (Galloway and Brown, 1973). In the meantime, Wanless (1964, 1967) suggested that the glacial eustatic model readily accommodates delta shifting as a mechanism to explain otherwise anomalous clastic wedges in many of the cyclothems. This view has been more fully developed by Heckel (1977, 1980b, 1984a, 1990), who recognized the cyclothems as marine transgressive-regressive sequences, centered on the thin, nonsandy, black phosphatic ("core") shales, which represent maximum marine inundation of the shelf, and with most deltas forming during the succeeding regressive phases. The more recently proposed "sequence-stratigraphic" terminology (Van Wagoner et al., 1987) can be applied to the cyclothemic succession of the Midcontinent Pennsylvanian (e.g., Watney et al., 1989), although with some caution on the northern shelf because this terminology was developed for much thicker sedimentary units delineated by seismic stratigraphic methods in slope situations along continental margins.

BASIC CYCLOTHEM

The term cyclothem has been applied to a number of different (but related and quite specific) repeating lithic sequences in the Pennsylvanian (Moore, 1936, 1950; Weller, 1958; see review in Heckel, 1984b). Current work on the mid-Desmoinesian to mid-Virgilian Midcontinent succession has established the nature of the basic transgressive-regressive cyclothem that characterizes the succession across the northern Midcontinent shelf from Kansas to Iowa. This cyclothem is a "stratigraphic sequence" that resulted from a major rise and fall of sea level over the Northern Midcontinent

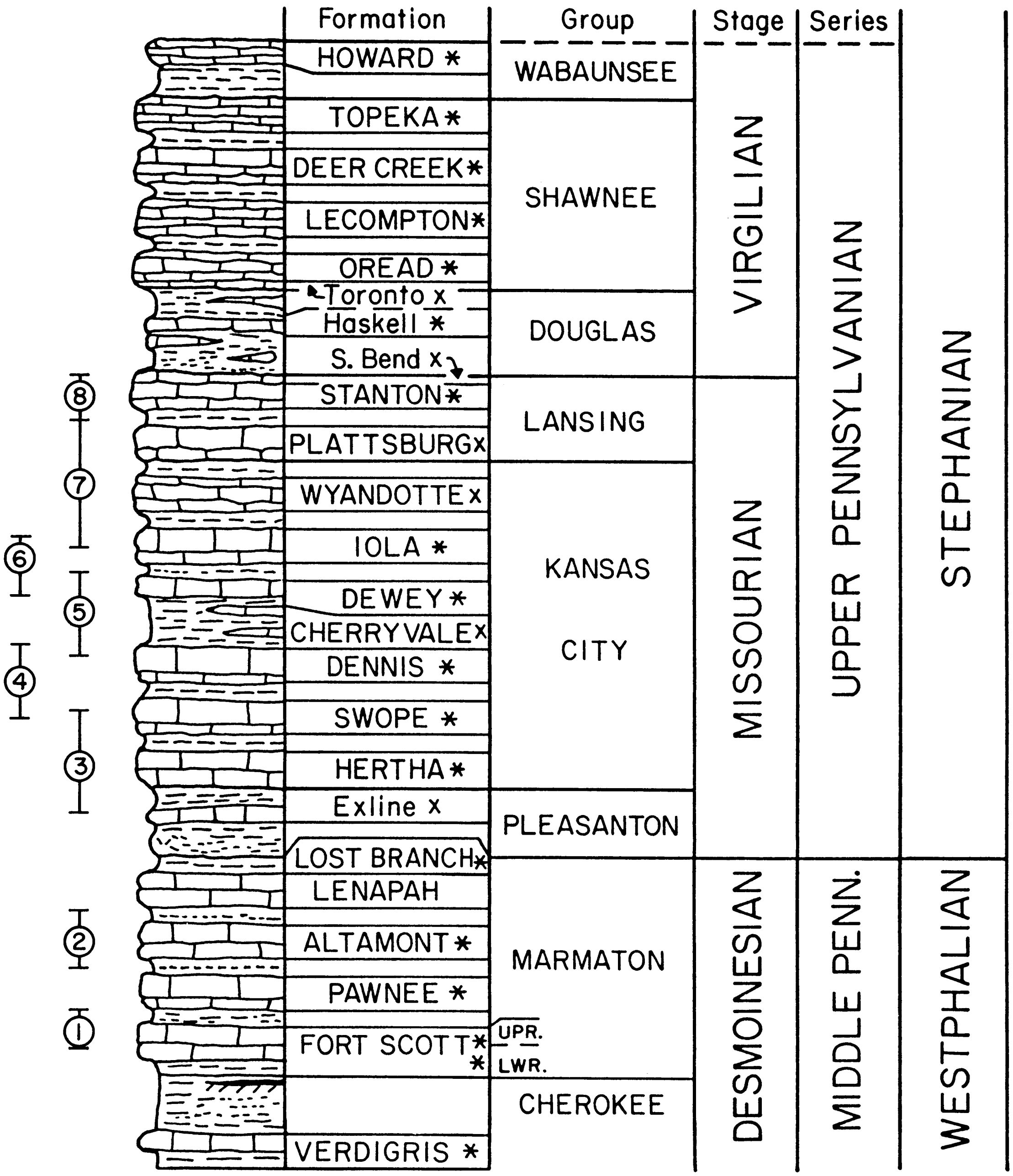


Figure 2. Part of Middle-Upper Pennsylvanian stratigraphic succession along outcrop belt of Northern Midcontinent Shelf from Iowa to Kansas, showing vertical extent of field trip stops (lines with numbered circles). Capital names in formation column denote marine, mostly limestone formations that include a major widespread cyclothem or intermediate transgressive-regressive cycle of deposition. Names in lower case denote members that represent mainly intermediate cycles of deposition (see Fig. 9 for all cycles). * denotes presence of conodont-rich black phosphatic facies in offshore shale across much of northern shelf; x denotes presence of gray conodont-rich shale. Names of nearshore to terrestrial shale formations that separate limestone formations are shown on Figure 9 and on diagrams for field trip stops.

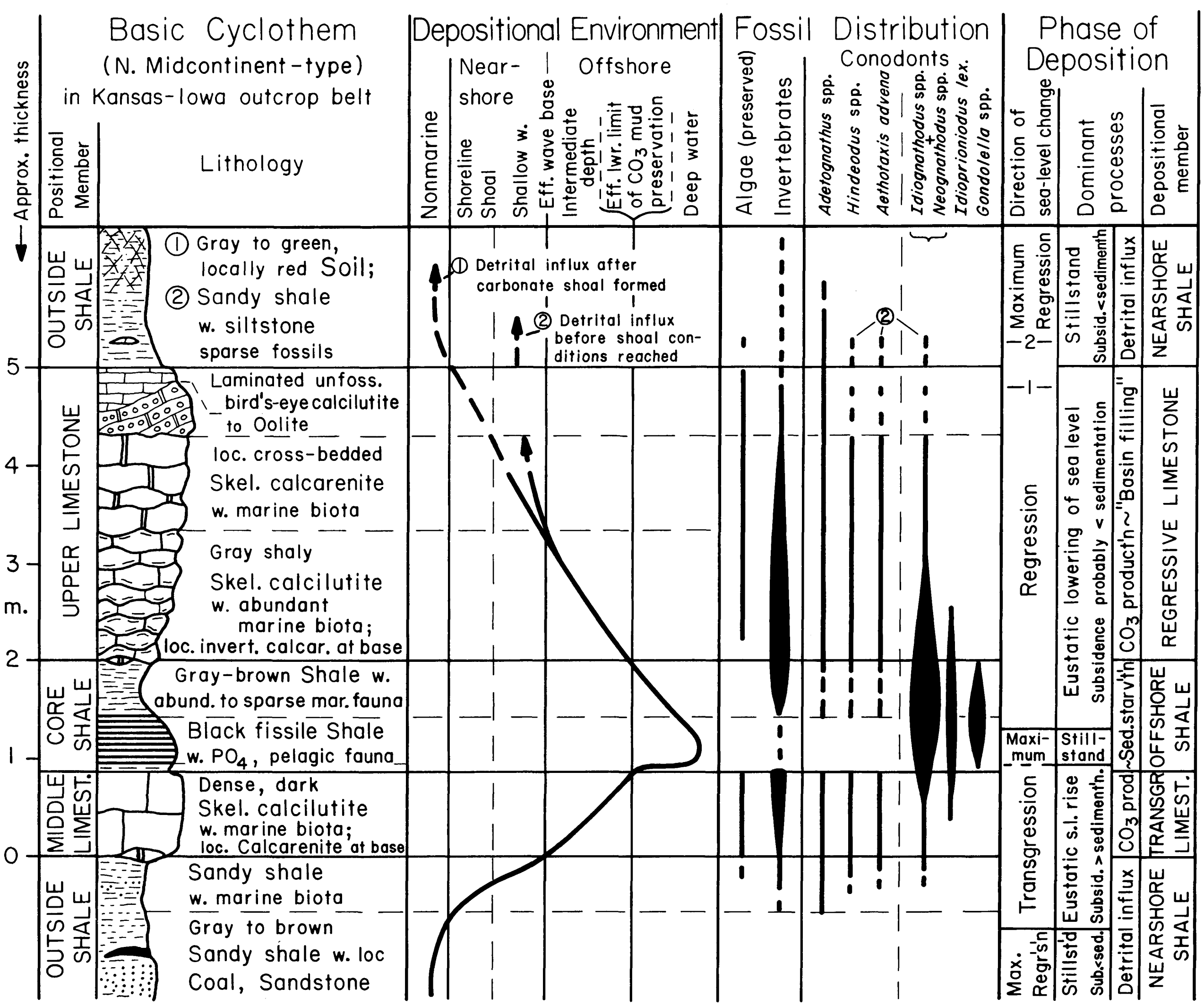


Figure 3. Basic Midcontinent cyclothem characterizing with minor modification all major and many intermediate marine cycles of deposition across Northern Midcontinent Shelf, and representing one sufficiently slow and extensive inundation and withdrawal of the sea to produce both transgressive and regressive limestones and intervening black phosphatic shale facies across most of shelf. Phases of deposition reflect ranges of sea-level stand. Conodont information derived from Heckel & Baesemann (1975) and Swade (1985) supplemented by thesis and other unpublished data.

Shelf, which extended from the north edge of the Arkoma-Anadarko basinal region of central Oklahoma across Kansas, Missouri, Nebraska and Iowa (Fig. 1). In ascending order, this cyclothem (Figs. 3-4) consists of the following members:

Transgressive limestone

The transgressive limestone, deposited in deepening water, is typically a thin (~1-2 ft), marine skeletal calcilutite deposited below effective wave base during later transgression, but it locally includes calcarenites at the base deposited in shallower water during earlier transgression. Because these limestones commonly overlie paleosols and terrestrial deposits (to nearshore deltaic complexes southward) they form much (or all) of the marine flooding deposits above a "sequence boundary". The calcilutites typically are dark, dense and nonpelleted, with neomorphosed aragonite grains, and the calcarenites typically are overpacked and lack evidence of early marine cementation or meteoric leaching and cementation. This is because both facies remained in the marine phreatic environment of deposition until buried by higher marine strata of the cyclothem, which acted as a barrier to meteoric diagenesis. Thus, they underwent slow compaction before cementation, often by ferroan carbonates in a decreasingly oxygenated burial environment (Heckel, 1983), in which much of the fine organic matter also became preserved in the rock.

Offshore ("core") shale

The offshore or "core" shale, which formed at maximum transgression, is typically a thin (~1-3 ft), nonsandy, gray to black phosphatic shale deposited under conditions of near sediment starvation. It is thus the condensed section of the "stratigraphic sequence" represented by the cyclothem. In most cyclothems the water became deep enough for a thermocline to develop over much of the Northern Midcontinent Shelf. The thermocline reduced bottom-oxygen replenishment over shallower areas just enough to produce the dark gray dysoxic facies with only low-oxygen tolerant benthic invertebrates, such as certain crinoids and brachiopods (e.g., *Crurithyris*, chonetids). It eliminated bottom oxygen over the deeper areas to produce the black anoxic facies with only pelagic fossil remains such as conodonts, fish debris, and under certain preservational conditions, radiolarians and ammonoids.

Sedimentation was so slow at this time in the northern Midcontinent that in the gray facies, aragonite fossils apparently were dissolved and calcite fossils were locally corroded (Malinky, 1984). Evidence for this lies in the appearance of great numbers of originally aragonitic molluscs (snails, clams, ammonoids: see Boardman et al., 1984) now preserved as siderite, pyrite, or phosphorite in thicker developments of these gray shales in southern Kansas and Oklahoma. Ammonoids also are preserved locally in early diagenetic carbonate nodules ("bullion") in the black facies in Kansas and Missouri. In the first case, early rapid burial and mineralization, and in the second case early matrix mineralization, prevented sea-floor dissolution of these fossils in the colder, undersaturated waters below the top of the thermocline.

Quasi-estuarine circulation and upwelling associated with the thermocline in this deeper phase of the shelf sea caused deposition in both the gray and black shale facies of nonskeletal phosphorite as peloids, laminae, and nodules. These are analogous to modern phosphorite nodules forming under similar conditions of periodic upwelling associated with a thermocline, in low-oxygen sediment on the offshore shelf along the coast of Peru (Kidder, 1985). The nonskeletal phosphorite, abundant conodonts, and stratigraphic position between the two limestone members serve to distinguish this offshore type of black shale from phosphate- and conodont-poor black shales that in some places overlie a coal or other exposure surface, often lie beneath a transgressive limestone (seen at Stops 5 and 8 on this trip), and were probably deposited under conditions of organic overload in a dysoxic environment during early transgression (Bisnett and Heckel, 1992).

Regressive limestone

The regressive limestone, deposited in shallowing water, is typically a thick (4-25 ft), marine skeletal calcilutite deposited below wave base, grading upward into cross-bedded skeletal calcarenite, with algae (including "osagia" coatings) and locally oolitic abraded grains, deposited above wave base in shallow water. Because the regressive limestone was deposited during a glacial-eustatic drop in sea level, indicated by the small vertical distance between the top of the black shale (top of the thermocline) and the exposure surface at the top of the regressive limestone, the sequence-stratigraphic term "highstand systems tract" should not be applied, as all of the regressive limestone was deposited at progressively lower stands of sea level in carbonate-producing to shoal-water and peritidal depths.

In some cyclothems a distinctly different calcarenite appears at the base, associated with the offshore shale. This calcarenite contains only invertebrates (crinoids, brachiopods, bryozoans and encrusting foraminifers), often shows evidence of grain corrosion, and lacks any evidence of algae, grain abrasion, or cross bedding. It therefore must have formed below effective wave base and probably below effective photic base for the algae in this sea. It represents proliferation of invertebrates in deeper water as the thermocline weakened and sufficient oxygen returned to the bottom. Its overcompacted nature resulted from relatively deep burial before cementation, as in the transgressive limestone (Heckel, 1983).

The tops of most regressive limestones, particularly northward in Iowa and Nebraska (Fig. 4), display sparsely fossiliferous, laminated to birdseye-bearing, lagoonal to peritidal carbonates that represent passage of the strandline toward the basin during later regres-

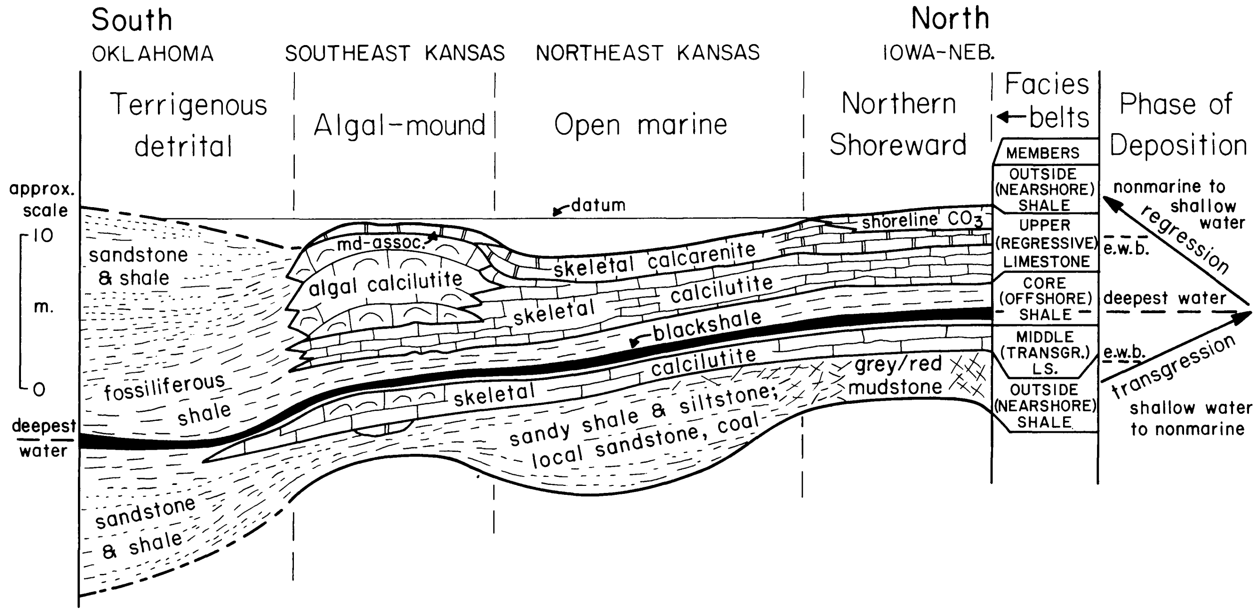


Figure 4. Generalized north-south cross-section of basic Midcontinent cyclothem along Midcontinent outcrop belt, from upper shelf (north) to basin (south). Datum is interpreted sea level at time when subaerial exposure (north) and increased detrital influx (central, south) began to terminate deposition of regressive limestone member during eustatic sea level fall.

sion. The tops of most regressive limestones also display subaerial exposure surfaces with such features as pitting, cracking, brecciation, "cryptokarst", and solution-tubes formed from plant rooting and infiltration of meteoric water, clay, and terrestrial organic matter. In local areas where meteoric water became saturated, laminar and pisolitic caliche formed on the surface of the limestone. Infiltration of oxygenating, undersaturated meteoric water farther down into the regressive limestone before much compaction took place also oxidized most of the original organic matter in the sediment, leached the aragonitic grains, and eventually became saturated enough to precipitate blocky calcite in both intergranular and moldic voids. This preserved original peloidal fabric, depositional packing of grains, and also porosity where cementation was incomplete. Thus the lighter-colored, more porous and more conspicuously sparry, upper regressive limestones stand in contrast with the darker, denser, overcompacted transgressive limestones and the lower, more offshore facies of the regressive limestones (Heckel, 1983).

Nearshore ("outside") shale

The nearshore ("outside") shales (which lie outside the limestone formations comprising the three previously described marine members of the cyclothem) encompass a great variety of nearshore marine and terrestrial deposits on the shelf, all deposited at lower stands of sea level. These are the shoreward deposits of the "lowstand systems tract" of sequence-stratigraphic terminology, and they typically contain the sequence boundary at or near the top. They include thick (up to 100 ft) sparsely fossiliferous prodeltaic shales, which prograded out over regressive limestones during later stages of sea-level fall, particularly from Kansas City southward. In places these grade upward into delta-front and delta-plain sandstones and coals.

Outside shales also include thinner blocky mudstones, which range from gray to red in color, from 2 to 10 ft in thickness, typically overlie exposure surfaces on regressive limestones, and dominate these units northward in Iowa and Nebraska. Some of those that have been studied in detail show upward decrease in crystallinity of illite and upward increase in mixed-layer and kaolinite proportions (Schutter and Heckel, 1985), which are characteristics that suggest a weathered soil profile. Others display a number of micromorphological features of paleosols such as neostrians, argillans, skeletans, and various plasmic fabrics (Goebel et al., 1989), and calcite glaebules, blocky spar crystallaria, peds, silt- and clay- or micrite-filled pedotubules (Joeckel, 1989) along with slickensides, mottling and horizonation. The blocky fabric of the paleosol mudstone that is conspicuous on outcrop is a result of disturbance of the normally flat-lying clay minerals by plant rooting, animal burrowing, and rain-water illuviation of clay minerals into holes formed by the organic agents and into cracks formed by periodic desiccation. In addition, these mudstones often contain irregular carbonate nodules, that show internal clotted, mottled, and cracked fabric characteristic of caliche (Prather, 1985). The origin of the detrital material in these mudstones probably included aeolian silt and clay (loess) from the Pennsylvanian desert areas to the present north and west (Goebel et al., 1989). In some shale units that are dominantly paleosols, marine fossils and fissile character appear at the top, below the succeeding transgressive limestones; in these cases the sequence boundary occurs at the top of the paleosol, within the outside shale unit, because the top of the shale is the lower part of the marine flooding deposit, which continues upward through the transgressive limestone.

The blocky mudstones at several horizons in the sequence are overlain by the most widespread and thickest coals in the Midcontinent Pennsylvanian. These coals apparently formed in response to the early stages of sea-level rise of the succeeding transgression, which ponded fresh-water runoff to form broad swamps on the surface of low relief. These swamps then migrated shelfward ahead of the transgression. Coals at this position are particularly characteristic of the Desmoinesian Stage (Middle Pennsylvanian: Stops 1-2) when the overall climate was wetter than during the Missourian Stage (Upper Pennsylvanian: Stops 3-8) (Schutter and Heckel, 1985).

CONODONT INFORMATION

The succession of conodont faunas reported at closely spaced intervals of all lithic units in outcrop and core sequences, by Heckel and Baesemann (1975), Swade (1985), various theses (some previously cited), and supplementary work established a distinctive vertical succession of conodont genera that characterizes all the major cyclothems (Fig. 3) from the northern limit of outcrop to the basinal region of Oklahoma. Both gray and black facies of the slowly deposited offshore shales are characterized by high abundance of conodonts, hundreds to thousands per kilogram. These faunas are strongly dominated by *Idiognathodus* (includes closely related *Streptognathodus*), with common *Neognathodus* (only in the Desmoinesian), *Idioprioniodus*, and, usually confined to the middle of the shale, *Gondolella*. In contrast, the rapidly deposited nearshore marine portions of the outside shales are characterized by low abundance of conodonts, from a few up to twenty or so per kilogram. These faunas are typically dominated by *Adetognathus*, sometimes subequally with *Idiognathodus* and *Hindeodus* (= *Anchignathodus* of previous work), but with *Idioprioniodus* and *Gondolella* conspicuously absent, and *Neognathodus* (Desmoinesian only) quite rare. The two limestone members contain faunas that are gradational and intermediate between those of the adjacent shale members, and these limestone faunas tend to be mirror images of one another, symmetrical about the "core" shale that separates them (Fig. 3).

The distinctive differences in conodont faunas between offshore and nearshore parts of the cyclothems appear related to characteristics of the water masses that covered the shelf at different sea-level stands (Swade, 1985). *Idiognathodus* and *Streptognathodus* (with *Neognathodus* in the Desmoinesian) apparently inhabited the normal, open marine, warm surface-water layer (Fig. 5), which covered most of the sea away from strong fresh-water influx, at all sea-level stands. *Idioprioniodus* probably occupied the lower, cooler water mass in the top of the thermocline, and therefore is found mainly in the offshore shale and adjacent deeper-water parts of the limestone members. *Gondolella* apparently lived in deeper, even cooler and possibly somewhat dysoxic water lower in the thermocline, and thus is more completely confined to the most offshore facies. These four genera probably were pelagic, as all are found in good numbers in the anoxic black shale facies, which lacks any definitely benthic fossils. At the other extreme, *Adetognathus* apparently inhabited the variable nearshore water mass, where it was tolerant of fluctuations in salinity and other conditions. *Hindeodus* probably occupied a slightly more offshore environment associated with carbonate sediment, as it is most commonly found in the limestone members. Both these latter genera may have been benthic, as they are not found in the anoxic black shales.

Because these distinctive patterns in abundance

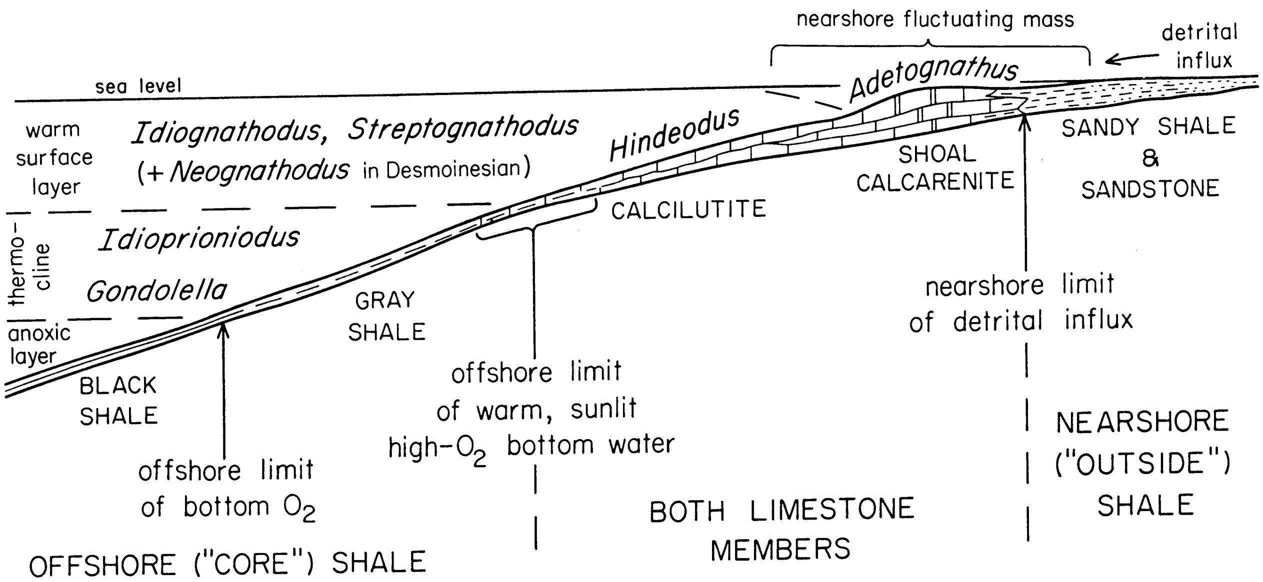


Figure 5. Inferred living distribution of seven major conodont genera in Midcontinent Pennsylvanian sea relative to major water masses developed at maximum transgression. Genus *Streptognathodus* evolved from *Idiognathodus* during early Missourian (Barrick and Boardman, 1989). Transgression and regression of sea caused laterally equivalent rock types and various settled conodonts to become superposed to produce basic cyclothem (Fig. 3). Modified from Heckel & Baesemann (1975, p. 499) and Swade (1985, p. 50).

and generic composition of conodont faunas are reasonably related to depositional environment and phase of deposition within the cyclothem, they can be used to identify the position of strata within the overall transgressive-regressive sequence where the lithic sequence is ambiguous (e.g., entirely skeletal calcilutite or marine shale). In this way, thin gray offshore shales can be distinguished from thin gray nearshore shales that resulted from a rapid pulse of sediment influx; transgressive limestones can be distinguished from regressive limestones in areas where adjacent shales are unexposed; black offshore shales can be distinguished from black nearshore lagoonal shales; and black offshore shales can be traced laterally into gray offshore shales. The lateral tracing of the conodont-rich, sediment-starved, condensed, offshore "core" horizons of the cyclothems has greatly helped to sort out the stratigraphy and environmental interpretation in areas of abrupt carbonate facies changes and thick enigmatic shale sequences, as is common in southern Kansas and Oklahoma.

More recently, the species composition of the faunas of the offshore shales are being worked out (Swade, 1985; Heckel, in press; Barrick and Boardman, 1989). Discrimination of species among the most abundant genus *Idiognathodus* (including closely related *Streptognathodus*), supplemented at certain horizons by distinctive species of *Gondolella*, is establishing a biostratigraphic succession of conodonts within the offshore biofacies. Combining this with the succession of ammonoid faunas in the thicker offshore shales and of fusulinid faunas in the limestones is facilitating the correlation of each individual cyclothem across the Midcontinent (Figs. 6-9) and with the successions in Texas (Boardman and Heckel, 1989: Fig. 10), Illinois (Heckel and Weibel, 1991: Fig. 11) and the Appalachians (P.H. Heckel and J.E. Barrick, in prep.).

OTHER CYCLES

Because most interest has been focused on the classic cyclothem sequences, the portions of the succession that do not fit readily into the basic pattern are only now receiving closer attention. In order for a cycle of transgression and regression of the sea to produce a classic Midcontinent cyclothem (Fig. 3), the inundation must have been slow enough to develop a transgressive limestone over most of the shelf, and sufficiently extensive onto the shelf to become deep enough for enough time to establish a thermocline and thus the conodont-rich black phosphatic facies of the core shale over much of the shelf; furthermore, the withdrawal must have been slow enough and sufficiently free of detrital influx to develop a regressive limestone over most of the shelf, and it must have extended far enough basinward for either soils to form or for terrigenous detrital rocks eventually to cover much of the shelf. A marine horizon that lacks one or more characteristics of the basic Midcontinent cyclothem would have resulted if: 1) the inundation were too fast to allow carbonate formation, or 2) the inundation were not far enough to become sufficiently deep to establish a thermocline for black shale formation, or 3) the withdrawal were too fast to allow carbonate formation, or 4) the withdrawal were not far enough to form a complete regressive sequence, or 5) the withdrawal occurred during a time of overwhelming detrital influx. These horizons can still be recognized as T-R cycles or stratigraphic sequences as well as incomplete cyclothems.

I have informally classified cycles into three categories for the purpose of further analysis, based largely on point 2 above, extent of transgression onto the shelf. Major cycles are those inundations far and deep enough onto the shelf to form a conodont-rich shale to the northern limit of outcrop in Nebraska and Iowa and generally develop enough of the other facies to be recognized as classic cyclothems over much of their extent. Intermediate cycles extend as marine horizons into Iowa and Nebraska, but carry conodont-rich horizons mainly on the lower shelf, and most have been recognized in some places as cyclothems or parts of them. Minor cycles typically extend as marine horizons only a short distance from the basinal region of Oklahoma into Kansas or Missouri, or represent a minor reversal within a more major cycle, and have not generally been recognized as cyclothems nor in some cases been named as separate units. This latter type of unit has been termed "parasequence" in sequence stratigraphic terminology. The recognition of minor eustatic cycles requires correlation of the horizon over a reasonable geographic area, because in any one section or small geographic area, autocyclic processes such as delta shifting can produce minor cycles of deposition. The above criteria provide the basis for construction of a sea-level curve for the Midcontinent outcrop belt (Fig. 9). Note that only the major cycles, several intermediate cycles and a few minor cycles extend as far northward on the shelf as Iowa.

POSSIBLE CONTROLLING FACTORS

The possible different factors that ultimately controlled formation of the Pennsylvanian cyclothems of Midcontinent North America have historically been recognized either as tectonic (Weller, 1930, 1956), glacial eustatic (Wanless and Shepard, 1936), or autocyclic, essentially delta shifting where marine deposits are involved (Ferm, 1970; Galloway and Brown, 1973). Delta shifting is a local process that requires the presence of deltas throughout the vertical and lateral extent of the cyclic sequence and results in stratigraphic units with limited lateral extent. Glacial eustasy is a global process that requires the presence of large ice sheets that wax and wane in the higher latitudes, and can result in distinct stratigraphic units of extremely widespread extent in stable cratonic areas and potential correlatability on a global scale. Tectonic controls either can be local variations in uplift or subsidence, which would result in units of lateral extent limited by tectonic features, or they can be the more widespread effects of large-scale movements in major orogenic belts (as has been more recently developed in the Appalachians by Tankard, 1986), which could result in units of more widespread extent and potential correlatability.

Delta-shifting as the basic control over the major Midcontinent cyclothems can be readily ruled out on several counts. First, the extremely widespread extent of each of these laterally continuous major marine transgressive-regressive horizons (Figs. 6-8) covers a minimum area of remaining outcrop today of roughly half of the states of Iowa, Missouri, Nebraska, and Oklahoma, and all of Kansas, totalling perhaps 500,000 km^2, compared to a generous estimate of perhaps 5,000 km^2 for the larger individual delta lobes (Gould, 1970, p. 9) in the Holocene deposits of the Mississippi River, one of the largest and most sediment-rich of modern delta systems. Second, as also illustrated by Figures 6 and 7, deltas are simply lacking over much of the shelf area north of Kansas City, where paleosols 2 to 10 ft thick separate nearly all the Missourian cyclothems over perhaps 200,000 km^2. Third, the phosphatic black shales that mark the maximum inundative phase in the major cyclothems over most of the present outcrop area require thermoclines in minimum water depths on the order of 100 m (Heckel, 1977, 1991b), which is highly unlikely above shifting delta lobes at a fixed sea-level stand. Fourth, the well developed paleosols require long-term withdrawal of the sea to form; soils on modern active delta lobes are typically very immature, and their foundering beneath the sea critical to the delta

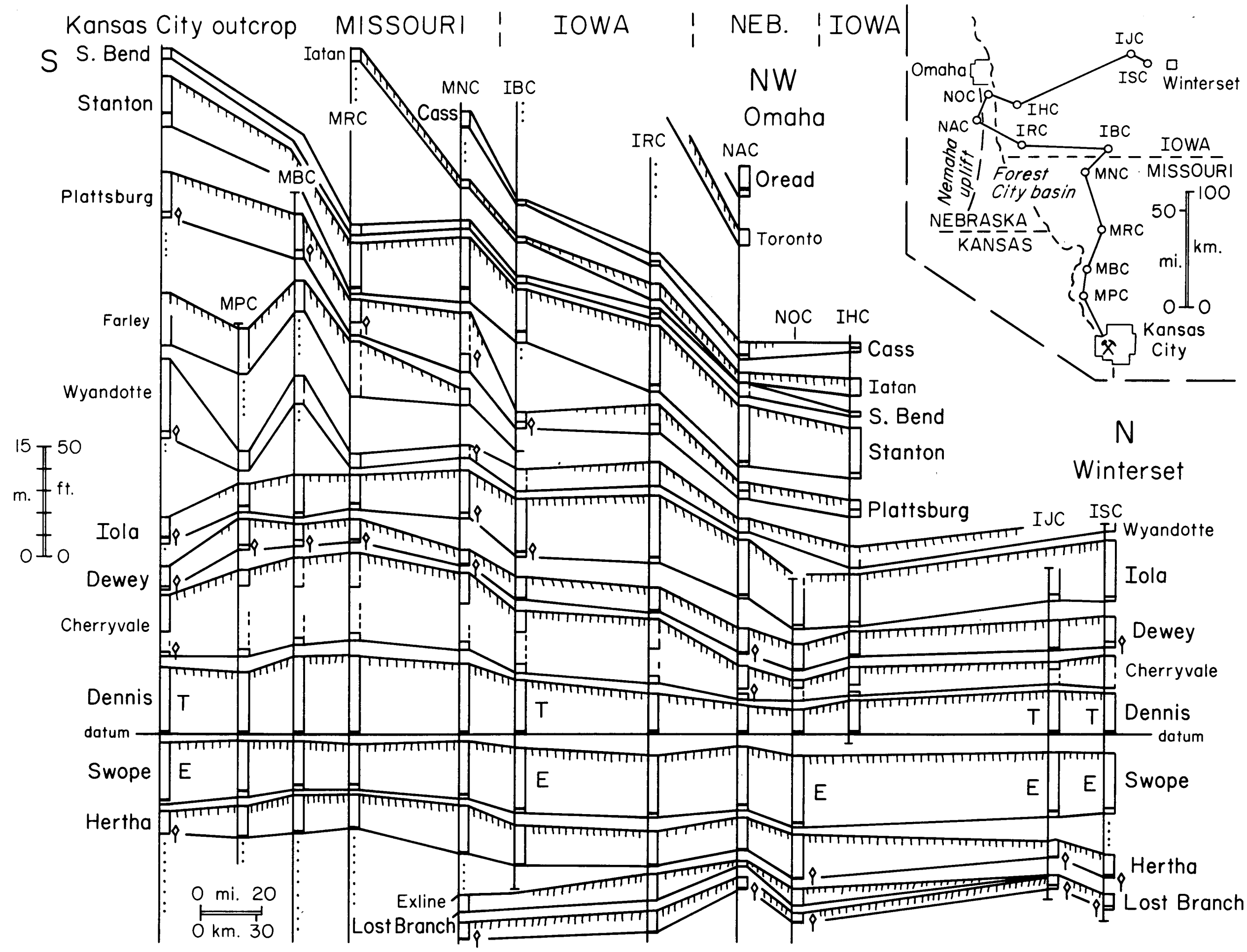


Figure 6. Correlation cross-section of lower part of Upper Pennsylvanian succession (Missourian Stage = Exline-Iatan) on northern Midcontinent shelf from Kansas City to central Iowa, based on long cores held by respective state geological surveys. Named units are limestone formations; those labeled with largest letters are major marine cyclothems (with black lines near base representing black phosphatic shale); those with smaller letters are intermediate or minor marine cycles. Limestones are separated by shale formations (left unlabeled), which are mostly paleosol mudstones where thin (exposure surfaces are shown by hachures on top of underlying regressive limestones). Shales contain rare deltas (dots show sandstones) only where thick (mainly below Hertha and above Iola cyclothems in northern Missouri). Tailed diamond symbols for conodont faunas and letters for fusulinids (E = *Eowaeringella ultimata*; T=lowest *Triticites*) show biostratigraphic control for correlation.

shifting model would inhibit much further soil development after abandonment. Therefore, considering the widespread lateral continuity of both the maximum transgressive phosphatic shales and the maximum regressive paleosols and exposure surfaces in close vertical alternation, the major Midcontinent cyclothems must have resulted from a significant rise of sea level, perhaps on the order of 150 m, with shoreline transgressing at times from the upper margin of the Anadarko-Arkoma basin of Oklahoma to well beyond the northern limit of outcrop in central Iowa, perhaps as much as 800 km, followed by a major drop in sea level with shoreline withdrawal a similar distance in the opposite direction. Even during the late Desmoinesian when the climate was more humid (Schutter and Heckel, 1985) and terrigenous detrital deposits, including deltas, were more common in the cyclic sequence on the shelf north of Kansas City (Fig. 8), the major marine cyclothems with their conodont-rich black shales are still laterally continu-

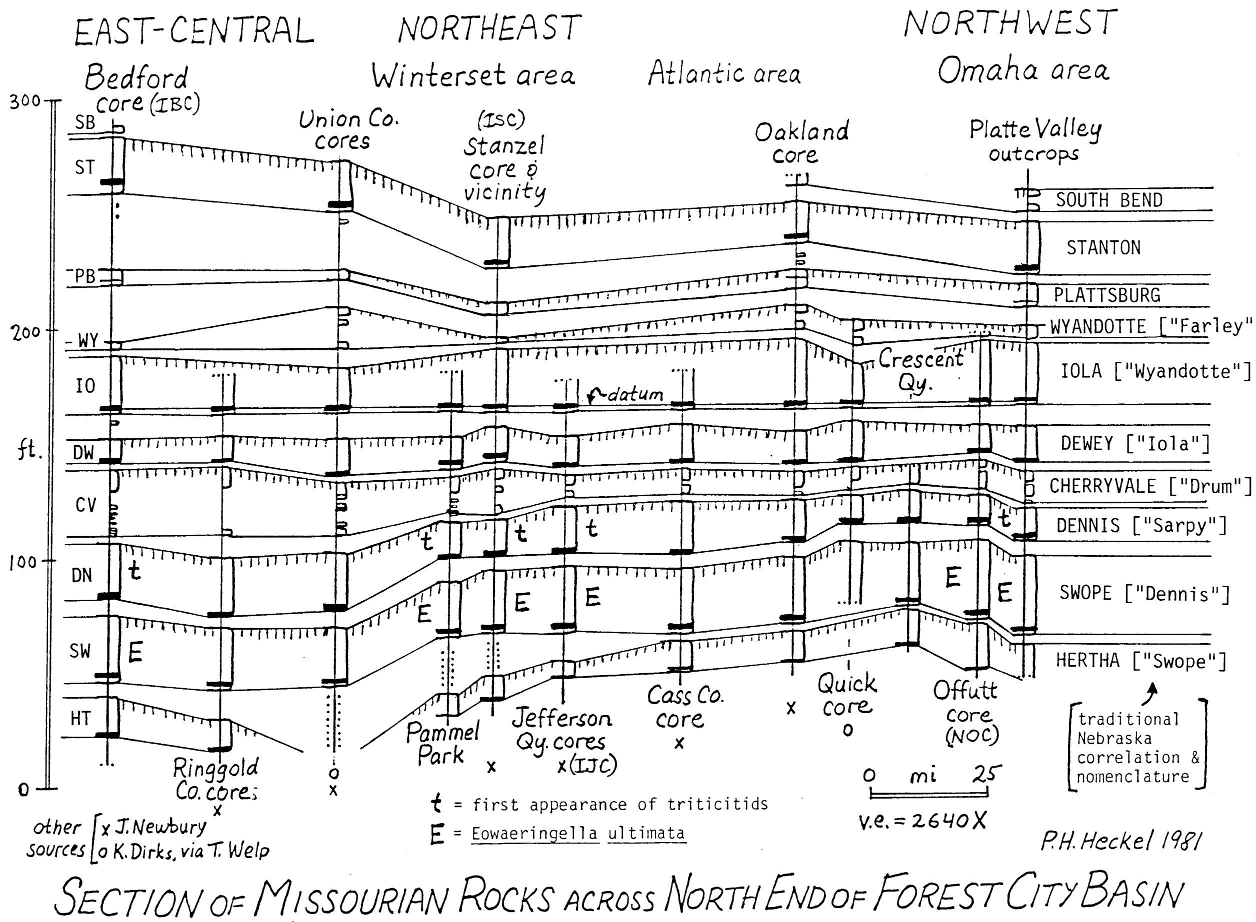


Figure 7. Correlation cross-section of most of Missourian succession around north end of Forest City basin, based mainly on long cores (or descriptions) made available from various sources (lettered cores located on Fig. 6). Named units are limestone formations, with thick black lines near base representing black phosphatic shale. Limestones are separated by shale formations (left unlabeled), which are mostly paleosol mudstones where thin, generally above exposure surfaces shown by hachures on top of underlying regressive limestones. Shales contain rare deltas only where thick (dots show sandstones). Biostratigraphic control shown by letters for fusulinids. Note essential lack of deltas from Swope through Wyandotte cyclothems in Iowa. Until recently, traditional Nebraska correlation (bracketed names in quotes) was shared by Iowa for Dewey-Iola-Wyandotte succession.

ous between the detrital units, and paleosols are well developed on the tops of most of them.

Local differential tectonic movements in which variable rates of down-dropping of a basin adjacent to a faulted uplift could cause periodic transgression in the basin, followed by apparent regression as the basin filled with detritus, can also be ruled out as the control over the major late Desmoinesian and Missourian cyclothems. The main tectonic features in the northern Midcontinent were the faulted Nemaha uplift and adjacent Forest City basin (Fig. 1), which formed early in the Pennsylvanian and strongly affected local sedimentation in the basin through about mid-Desmoinesian time. Minor differential effects on late Desmoinesian sedimentation is shown by thinning of these units over the Nemaha uplift (Fig. 8, core NAC), but each individual major cyclothem (identified by its distinctive conodont fauna) is found within the thinned sequence upon the uplift, indicating that these marine transgressions inundated the uplift as well as the basin. Therefore, the marine inundation must have been controlled by forces other than those that differentially controlled

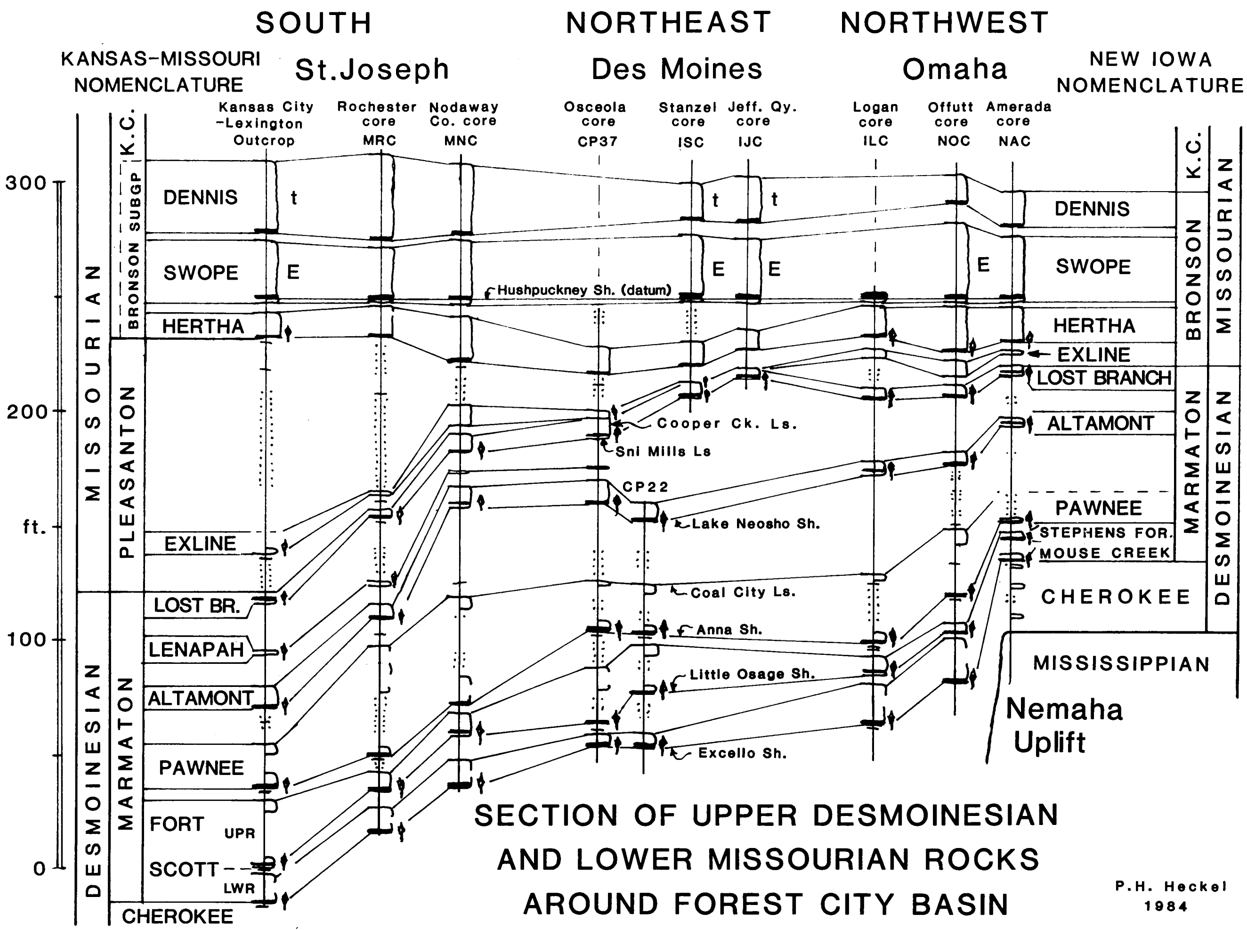


Figure 8. Correlation cross-section of upper Desmoinesian and lower Missourian sequence on Northern Midcontinent Shelf from Kansas City through Iowa to Nebraska, based on long cores (see Figs. 1,6) held by respective state geological surveys. Named units are limestone formations. Those with thick black lines at base (representing black phosphatic shales) are major marine cyclothems. Other units (e.g., top of upper Fort Scott; Coal City Ls.; Lenapah Ls.; Exline Ls.) are intermediate cycles. Fluvial and deltaic sandstones (shown by dots) are much more common in Desmoinesian and lowermost Missourian when climate was more humid than in rest of Missourian (Schutter and Heckel, 1985), but marine horizons maintain lateral continuity between them. Moreover, all major cyclothems extend across Nemaha uplift (core NAC), an early Pennsylvanian structure that persisted as a topographic feature throughout Desmoinesian, as shown by thickening of Desmoinesian units away from it, and by presence of gray instead of black phosphatic conodont-rich core shales in Desmoinesian cyclothems on top of it. Tailed diamond symbols for conodont faunas and letters for fusulinids (same as on Figs. 6,7) show biostratigraphic control for correlation.

the basin/uplift couplet. The presence of greater remaining topography during late Desmoinesian over the uplift is indicated by the lateral passage from black to gray phosphatic shales in the locality upon the uplift (Fig. 8, core NAC). The younger Missourian cyclothems, however, show little detectable lateral change as they pass over the uplift, which must have been essentially dormant by that time; Joeckel (1989) did recognize that the late Missourian Rock Lake (post-Stanton) paleosol reflects drier conditions on the Nemaha uplift than in the Forest City basin, however.

Thus we are left with a eustatic control. This classically has been considered glacial in origin (Wanless and Shepard, 1936), which is strongly supported by the long-known presence of Gondwanan glacial deposits, and particularly by the more recent dating of the greatest amount of Gondwanan glaciation during Middle to Late Pennsylvanian time (Veevers and Powell, 1987), when the Midcontinent cyclothems were best developed.

But eustatic changes in the Midcontinent could also be tectonic in origin, from periodic large movements in a more distant orogenic belt. The mechanism of episodic orogenic thrust loading causing repeated flexural subsidence in the foreland basin and resulting in transgression when the basin was down, followed by regression as it filled with sediment, has been applied to the Appalachian basin by Tankard (1986). It has been suggested to progressively combine with the dominant glacial-eustatic control recognized in the Midcontinent to account for progressive differences in the cyclothems through the Illinois basin to the Appalachian basin, by Klein and Willard (1989). This type of mechanism could have had various different effects in distant areas. For example, it could cause transgression if the downwarping were transmitted that far, or conversely, it could cause regression if the foreland downwarp diverted enough marine water into the foreland basin from more distant cratonic areas.

In order to discriminate between glacial and distant tectonic controls, the frequencies of the transgressive-regressive events provide important information. Analysis of the probable lengths of time during which each of the Midcontinent marine cycles of transgression and regression took place, based on sets of assumptions explained elsewhere (Heckel, 1986), estimated a range of lengths of 235,000 to 400,000 years for the major cyclothems, 120,000 to 220,000 years for the intermediate cycles, and 44,000 to 120,000 years for the minor cycles. Even if the lower ends of the ranges are halved to accommodate the shorter duration of the analyzed sequence suggested by more recent radiometric dating (Leeder, 1988; Klein, 1990), the estimated ranges for all types of cycles still fall within the entire range of periods of the earth's orbital cycles that constitute the Milankovitch insolation theory of control of the Pleistocene ice ages. These cyclic orbital parameters are: eccentricity, with two dominant periods, one about 413,000 years, and the other ranging from 95,000 to 136,000 years and averaging about 100,000 years; obliquity, with a dominant period near 41,000 years; and precession, with two dominant periods averaging 19,000 and 23,000 years (Imbrie and Imbrie, 1980). Their apparent control over the timing and duration of the Pleistocene ice ages suggests that they probably controlled that of the Pennsylvanian ice ages on Gondwanaland as well. Thus they were at least partly responsible for the frequent rise and fall of the North American Midcontinent Sea. Because the periods and amplitudes of particularly the 100,000-year eccentricity parameter are variable, they cause a somewhat irregular interference and amplification among all parameters throughout the succession of longer periods. Depending upon the exact nature of the linkage or mechanism of control over the waxing and waning of Gondwanan ice sheets, this interference probably gave rise to the range of variation observed in the intermediate and the major Midcontinent cyclothems, which represent the strongest, most conspicuous effects of sea-level change during the Pennsylvanian.

It is apparent that only if the frequencies of episodic tectonic flexuring were coincidently within the same range as the Milankovitch cycles, would tectonic controls have likely played a major role in the genesis of Midcontinent cyclothems, considering the fairly well constrained frequencies of the cyclothems within that range. However, the range of periodicities suggested for the earlier Pennsylvanian (late Morrowan to late Atokan) transgressions thought to have resulted from foreland downwarp in the Appalachians is on the order of 3 to 5 million years (F.R. Ettensohn *in* Tankard, 1986, p. 866). This is at least an order of magnitude less frequent than those of the Midcontinent cyclothems. Therefore distant orogenic movement of this sort is unlikely as an origin for the Midcontinent cyclothems, at this stage of our understanding, which is currently being updated by Heckel (manuscript in review-A).

Another line of evidence for glacial control of eustasy lies in the thinness of the algae-bearing transgressive limestone (Fig. 3) overlain by offshore deposits formed below the carbonate-producing warm sunlit surface water layer (Fig. 5). As developed by Heckel (1984a, p. 38; also ms. in review-A) modern maximum rates of shallow-water carbonate production of 0.5 to 3.0 mm/year would need to be consistently outstripped by sea level rise in order to produce such a thin unit consisting of the material (algal blades and mud of presumably algal origin) that typically is involved in optimal carbonate production. Estimated rates of post-Wisconsinan (Flandrian) sea level rise at times between 10,000 and 7,000 years B.P. range from 5 to 35 mm/year, which is sufficient to deepen the water fast enough to accomplish this. In contrast, even modern basinal subsidence rates of 0.3 to 2.5 mm/year could essentially be accommodated by carbonate production to produce a limestone as thick as the amount of subsidence. Rates of sea level rise resulting from distant tectonic movements are not known to be greater than rates of basinal subsidence, and would not likely achieve the potentially much higher rates of glacial-eustatic rise. (An updating of this discussion is

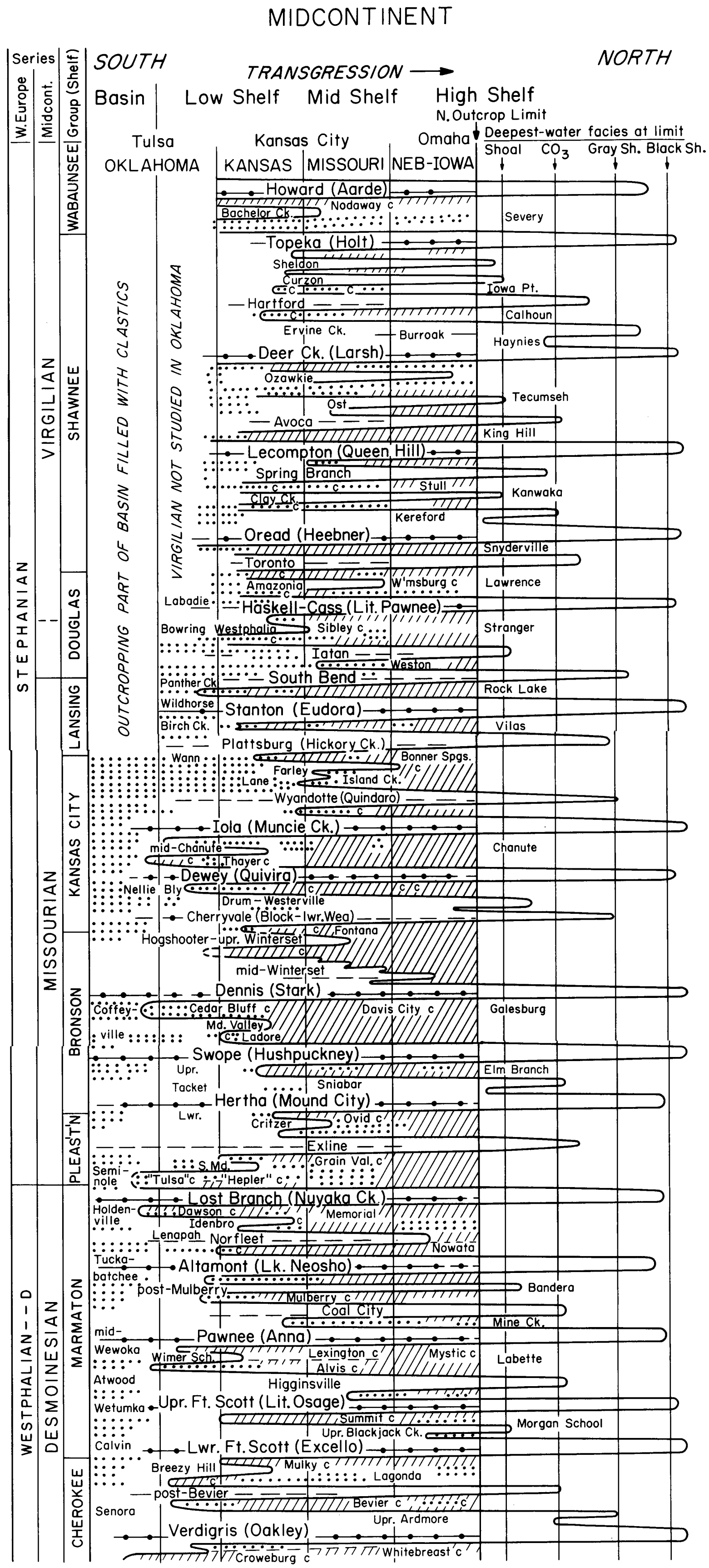


Figure 9. Sea-level curve for part of Middle-Upper Pennsylvanian succession along Midcontinent outcrop belt, based on shoreline positions estimated from (1) farthest basinward extent of exposure surfaces (///) and fluvial-deltaic complexes (...) for lowstand and (2) farthest shelfward extent of marine horizons or deepest-water facies at northern outcrop limit for highstand. Size of letters in names of marine cycles on left side of curve reflects classification as major, intermediate, or minor. Names in parentheses after cycle names denote conodont-rich offshore shales, both black (solid line with dots) and gray (dashes). Names on right of curve are nearshore to terrestrial shale and coal (c). Names on far left are basinal and southern shoreline facies. Data sources include outcrops and long cores (Figs. 6-8) for Desmoinesian to lower Shawnee, theses cited in Heckel (1977, 1984b), State Geological Survey publications and more recent analyses. Sequence ranges from 260 m in Iowa to 550 m in Kansas. (From Heckel, 1986, as modified by Heckel, in press, and later).

currently in review, A).

The other imputed characteristic of glacial-eustatic control, that of ready correlatability of the cyclothems, has recently received a strong positive test in an area that has implications for identifying tectonic control. Boardman and Heckel (1989) have biostratigraphically correlated all the major and intermediate cyclothems in a large segment of the Midcontinent succession analyzed by Heckel (1986) with transgressive-regressive cycles of similar magnitude in north-central Texas, which is 400 km distant from southern Kansas, across the Arbuckle uplift (Fig. 1) and close to the active Ouachita orogenic belt. In spite of the conspicuous delta shifting in the regressive phases of the eustatic Texas cycles and in spite of the potential larger scale modifications from any tectonic flexuring originating from the nearby Ouachita belt, an extremely close correlation (Fig. 10) was achieved, in which all but one of even the minor cycles currently recognized in Texas have previously recognized counterparts in stratigraphic position in the Midcontinent. The correlation was based mainly on a combination of first, last, sole, or acme occurrences of conodonts, ammonoids, and fusulinids. It provides such a close match of both faunas and cycle magnitude in the two areas that it shows not only that the primarily glacial-eustatic signal of the Midcontinent is strongly evident in the more detrital-rich Texas succession, but also that any tectonic movements in the Ouachitas at that time had little effect on the Texas cyclic succession other than possibly suppressing or enhancing cycle magnitude by one of the informal ranks in a few cases. More recently, analysis of conodont faunas in the offshore shales indicates direct correlation (Fig. 11) of all the major cycles of roughly the same succession with the major marine horizons in the Illinois basin (Heckel and Weibel, 1991). J.E. Barrick and I are currently analyzing conodont faunas from Conenaugh marine horizons in the Appalachians to determine if they can be correlated with the Midcontinent and Illinois successions.

CONCLUSIONS

All the different lines of evidence currently available strongly converge toward periodic glacial eustatic rise and fall of sea level as the principal cause for the distinctive marine cyclothems of Midcontinent North America. Their extreme lateral persistence, repeatedly superposing offshore marine sediment-starved phosphatic shales closely above paleosols and other exposure surfaces, for hundreds of miles across local tectonic features and largely in the absence of deltas, requires a periodic eustatic control. The presence of Gondwanan glacial deposits at this time, in conjunction with the estimates of the periodicity of the cyclothems within the range of those of the Earth's orbital cycles that are involved in Pleistocene glacial frequencies, and much shorter than those so far estimated for periodic tectonic movement, strongly point to glacial rather than distant tectonic control of the eustasy.

Because of its global nature, glacial eustasy must have been an underlying control over Pennsylvanian stratigraphy in all areas. This would be true in Texas and the Appalachians, where involvement in tectonic movements and proximity to resulting local detrital sources allowed structural complications and delta-shifting to mask the eustatic control by inhibiting the development of widespread limestone units. Both tectonic movement and glacial eustasy controlled the position of the shoreline in various places, and deltas dominated the areas near detrital sources when eustatic sea level was stable at lowstand or highstand, or falling during regression. Glacial eustasy is evident in the older mid-Carboniferous succession of Britain in the remarkable lateral persistence of the succession of transgressive dark marine shale horizons that have been correlated biostratigraphically among the complex tectonic elements there (e.g., Ramsbottom, 1979), and which also have a mean periodicity within the Milankovitch band according to recent British work (e.g., Leeder, 1988).

Recognizing the broad control of eustatic events, we now stand at a threshold of biostratigraphic correlation of major cycles around and among basins so that "event" correlation of the intermediate and minor cycles between them, can be tested as Boardman and Heckel (1989) and Heckel and Weibel (1991) have begun between the Midcontinent and Texas and Illinois (Figs. 10-11). From this we can document the relative extents of these eustatic events in other areas and evaluate the frequencies of other basic causes, such as tectonic movements, some of which at this early rudimentary stage of analysis appear to occur at significantly longer periods than glacial eustasy.

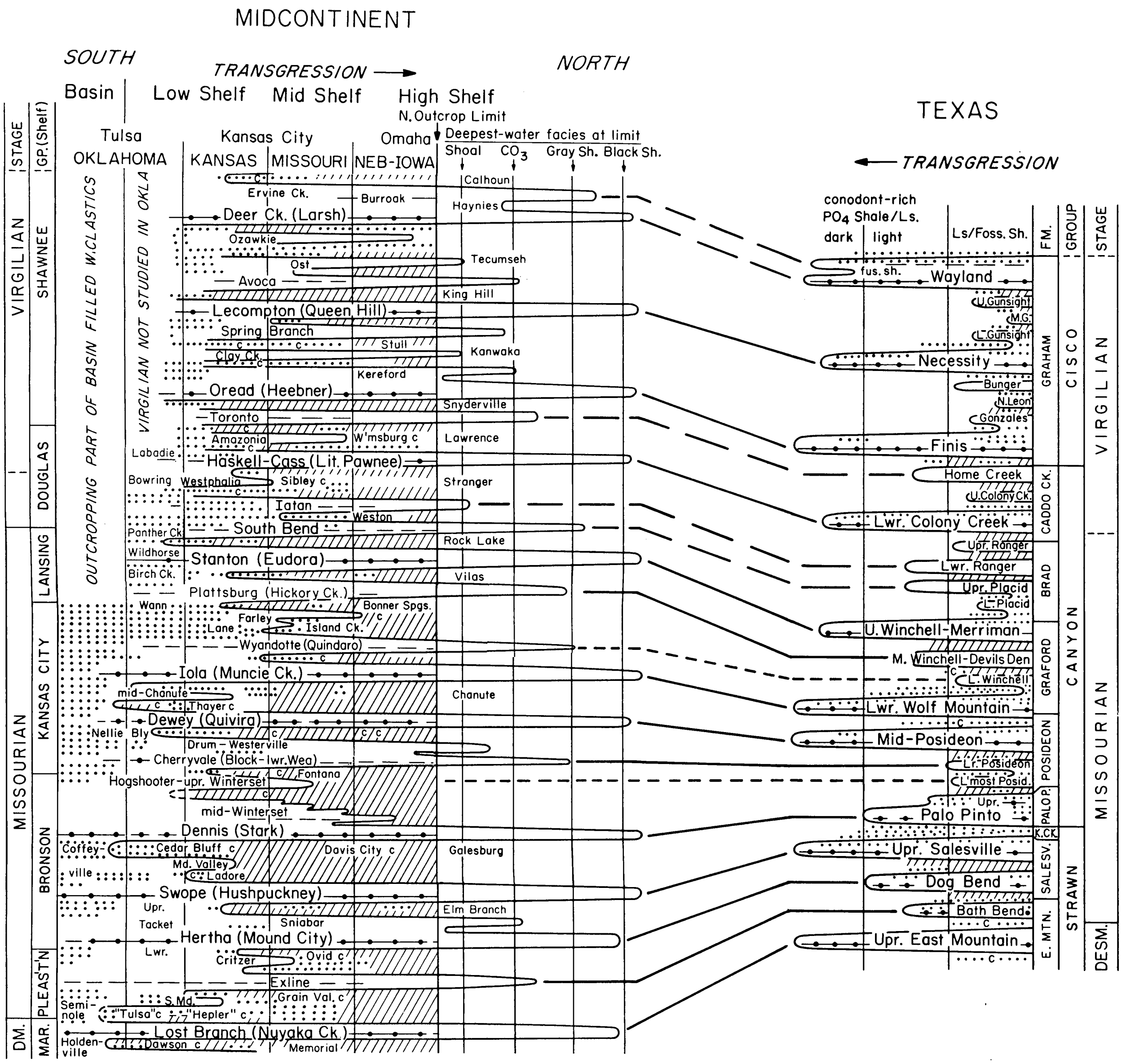


Figure 10. Eustatic sea-level curve for part of Pennsylvanian succession along Midcontinent outcrop (part of Fig. 9) and biostratigraphic correlation with curve for north-central Texas outcrop belt on other side of Arbuckle uplift (Fig. 1). Lowstand deposits (named on right of Midcontinent curve) include exposure surfaces and paleosols (///), fluvial-deltaic complexes (...) and coaly beds (c). Marine cycles (named on left side of Midcontinent curve and on right side of Texas curve) contain highstand deposits, which include conodont-rich shales (named in parentheses), both black (solid line) and gray (dashed) with phosphate nodules (large dots). Size of letters in names of marine cycles reflects informal rank classification as major, intermediate, or minor. Correlations reflect 1) diagnostic faunas (solid lines) with first, last, sole, or acme occurrence of certain taxa, 2) compatible faunas (long dashes), and 3) positional matches (short dashes in selected examples) (slightly modified from Boardman and Heckel, 1989).

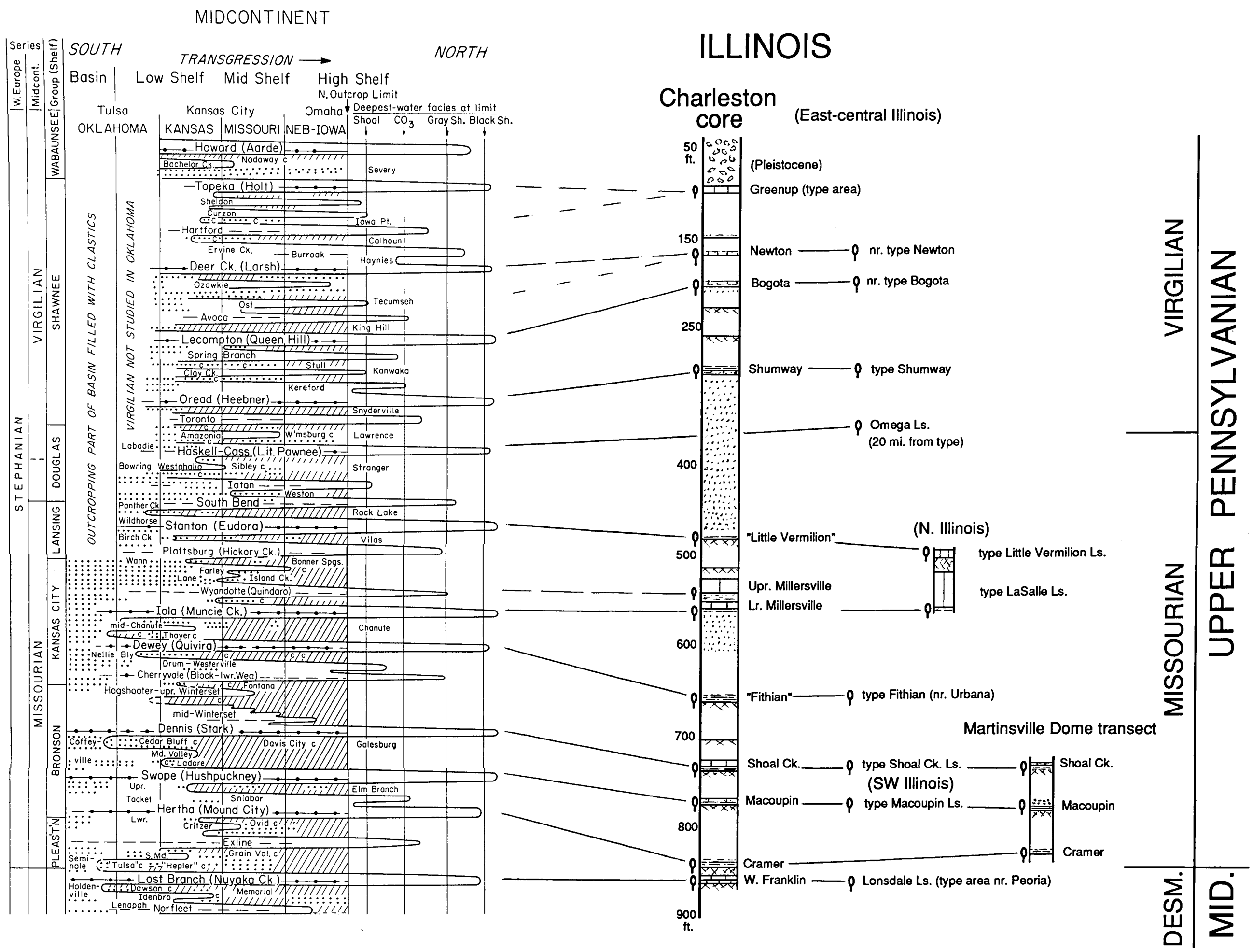
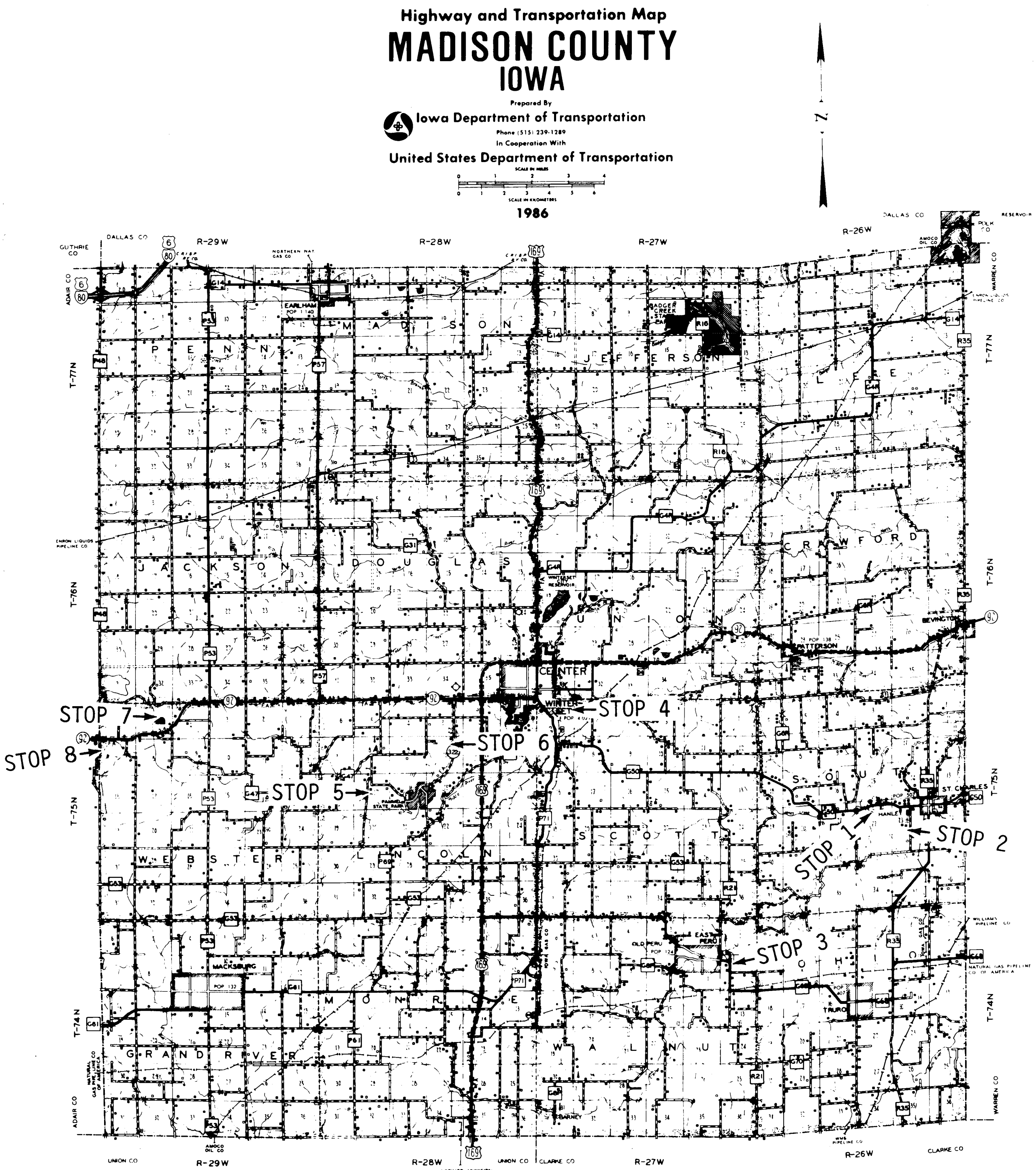


Figure 11. Correlation of part of eustatic Midcontinent Pennsylvanian sea level curve (part of Fig. 9) with major marine units in upper three quarters of Charleston, Illinois, core, and with outcrops in type areas of named marine units in Illinois, based on abundant conodont faunas (large tailed oval symbols) in black to gray, typically phosphatic shales. Solid lines indicate definite correlations; dashed lines indicate compatible correlations (usually with sparse faunas that are indicated by small symbols) and possible alternative correlations (slightly modified from Heckel and Weibel, 1991).

GUIDE TO FIELD TRIP STOPS

by

Philip H. Heckel and John P. Pope



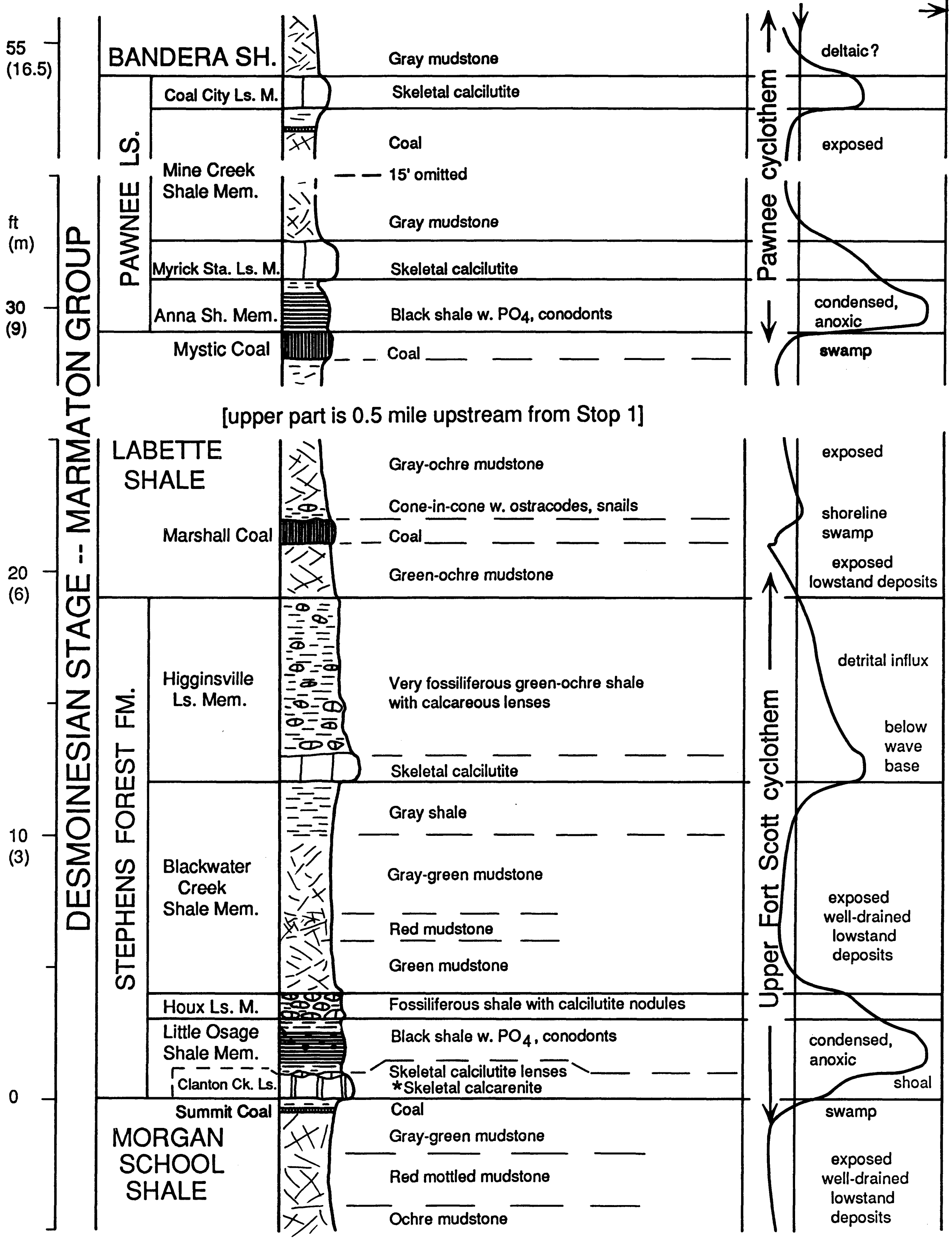
MAP OF FIELD TRIP AREA

SUMMARY OF SCHEDULE AND DRIVING DIRECTIONS

LEAVE Village View Motel at 6:00 AM	**# minutes/time**
Drive right (west) on Rte 92 to jct Rte 169; turn left (south) on John Wayne Drive to Winterset town square.	5 / 6:05
BREAKFAST at Oakwood Inn on east side of square; LEAVE at 7:00 AM	55 / 7:00
Drive 10.7 mi: South on John Wayne Drive to Rte P71; bear left (southeast) on P71, 1.6 mi; left (east) on Rte G50, 9.1 mi, across old railroad grade to first driveway on right (Alan Downs farm)	20 / 7:20
STOP 1: STREAMBANK AT HANLEY...(UPPER FORT SCOTT)	45 / 8:05
Drive 1.8 mi: Right (east) 1.1 mi; right (south) on gravel road at JCA Express Co., 0.7 mi to downgrade past Ray Johnston farm.	5 / 8:10
STOP 2: RAVINE SOUTHWEST OF ST. CHARLES...(ALTAMONT)	60 / 9:10
Drive 11.1 mi: Continue south 0.5 mi; turn left (east) 0.4 mi; turn right (south) on Rte R35, 3.4 mi to Rte G68; continue south on G68, then west through Truro to jct with Rte R21; right (north) 0.8 mi to roadcut	20 / 9:30
STOP 3: ROADCUT EAST OF EAST PERU...(HERTHA, SWOPE)	45 / 10:15
Drive 12.7 mi: Continue on G68 west through East Peru, 5.5 mi to jct with Rte P71; right (north) on P71, 6.2 mi into Winterset & north on John Wayne Drive to Court St. at city square; right on Court St. 1.0 mi to quarry entrance	25 / 10:40
STOP 4: MARTIN-MARIETTA QUARRY AT WINTERSET...(SWOPE, DENNIS)	80 / 12 noon
Drive 1.6 mi: left (west) on Court St, 1.0 mi to John Wayne Dr.; turn left (south) 0.3 mi to W. Summit Ave (P71); right (west) 0.1 mi to S. 2nd Ave; left (south) 0.2 mi to Madison Co. Historical Complex	5 / 12:05
LUNCH in Madison County Museum at historical complex	65 / 1:10
Drive 6.9 mi: return north to Summit Ave (P71); left (west) 1.3 mi to jct. Rtes 92 & 169; continue west on 92 for 2.6 mi; turn left (south) on Rte G47 for 1.4 mi; then right (west) 0.2 mi to State Park sign; then left (south) 0.6 mi to Y intersection and keep right for 0.5 mi to short of Middle River bridge.	15 / 1:25
STOP 5: MIDDLE RIVER CUT WEST OF PAMMEL PARK...(CHERRYVALE, DEWEY)	60 / 2:25
Drive 4.6 mi: Return 0.5 mi to Y intersection; turn right (south & east) 2.1 mi to Pammel State Park, continuing 0.6 mi to concrete ford over Middle River and Harmon Tunnel through Devil's Backbone; then 1.4 mi north on Rte 322 to culvert over creek	10 / 2:35
STOP 6: STREAMBANK NORTH OF PAMMEL PARK...(DEWEY, IOLA)	30 / 3:05
Drive 10.3 mi: continue north on Rte 322 to Rte 92; turn left (west) on 92 for 8.2 mi to quarry entrance on right; drive into quarry 0.7 mi to north end	15 / 3:20
STOP 7: SCHILDBERG'S STANZEL QUARRY...(IOLA, WYANDOTTE, PLATTSBURG)	80 / 4:40
Drive 2.6 mi; return to Rte 92, turn right (west) 1.5 mi to gravel road at county line; turn left (south) for 0.4 mi across culvert over creek	5 / 4:45
STOP 8: STREAMBANK NEAR MADISON-ADAIR COUNTY LINE...(STANTON)	30 / 5:15
Drive 13 mi: Return to Rte 92, turn right (east) and continue to jct with Rte 169; continue east on P71 into Winterset; then left on John Wayne Drive to town square	20 / 5:35

DINNER at North Side Cafe on north side of square.

STOP 1: STREAMBANK AT HANLEY



Measured by J. P. Pope, 1991 * = Fossil list in appendix

DESCRIPTION OF FIELD TRIP STOPS

Leave Oakwood Inn on east side of Winterset town square at 7:00 AM.

Drive 10.7 miles (see directions at front of guide) (20 min)

STOP 1: STREAMBANK AT HANLEY: UPPER FORT SCOTT CYCLOTHEM (45 min)
(Location: NE1/4 SE1/4 NW1/4 sec 22, T75N, R26W; on Alan Downs farm)

This stop shows the Upper Fort Scott cyclothem, a carbonate-poor cyclothem characteristic of the Desmoinesian when the climate was more humid; this cyclothem includes a second transgression of intermediate scale within the general phase of regression, a feature characteristic of the lower three cyclothems of the Marmaton Group (Fig. 9). The type Fort Scott Limestone in Kansas is dominantly marine carbonate away from either northern or southern detrital sources, but comprises two major cyclothems separated by the Summit coal and underclay. Because this terrestrial break in the Fort Scott succession is widespread, Ravn et al. (1984) named the upper part Stephens Forest Formation in Iowa to be more consistent with the classification of higher Marmaton units; this name has not been used elsewhere, and the cyclothem is referred to as Upper Fort Scott.

Morgan School Shale is a mudstone deposited at low sea-level stand when shoreline stood at the Kansas-Oklahoma border. The red mottling suggests subaerial exposure with oxidation and dehydration of iron minerals in a paleosol. The ***Summit coal*** at the top represents swamps formed when runoff was ponded ahead of the leading edge of the Upper Fort Scott transgression. The gray top of the mudstone probably reflects a combination of rising water table prior to coal swamp formation and later influence of organic-rich water from the peat, both of which would inhibit oxidation and dehydration of iron minerals.

Little Osage Shale Member comprises a black phosphatic shale (traceable into northern Oklahoma), and a basal transgressive limestone, which is local and named informally from this locality as ***Clanton Creek Limestone bed.*** The limestone consists of abraded skeletal calcarenite overlain by skeletal calcilutite, reflecting the deepening-upward trend of transgression. The phosphatic black shale represents the sediment-starved condensed section deposited below a pycnocline at sea-level highstand.

Houx Limestone Member (solid limestone where it was named in Missouri) records enough shallowing during early regression to break up the thermocline and return oxygen to the sea floor and support a benthic fauna.

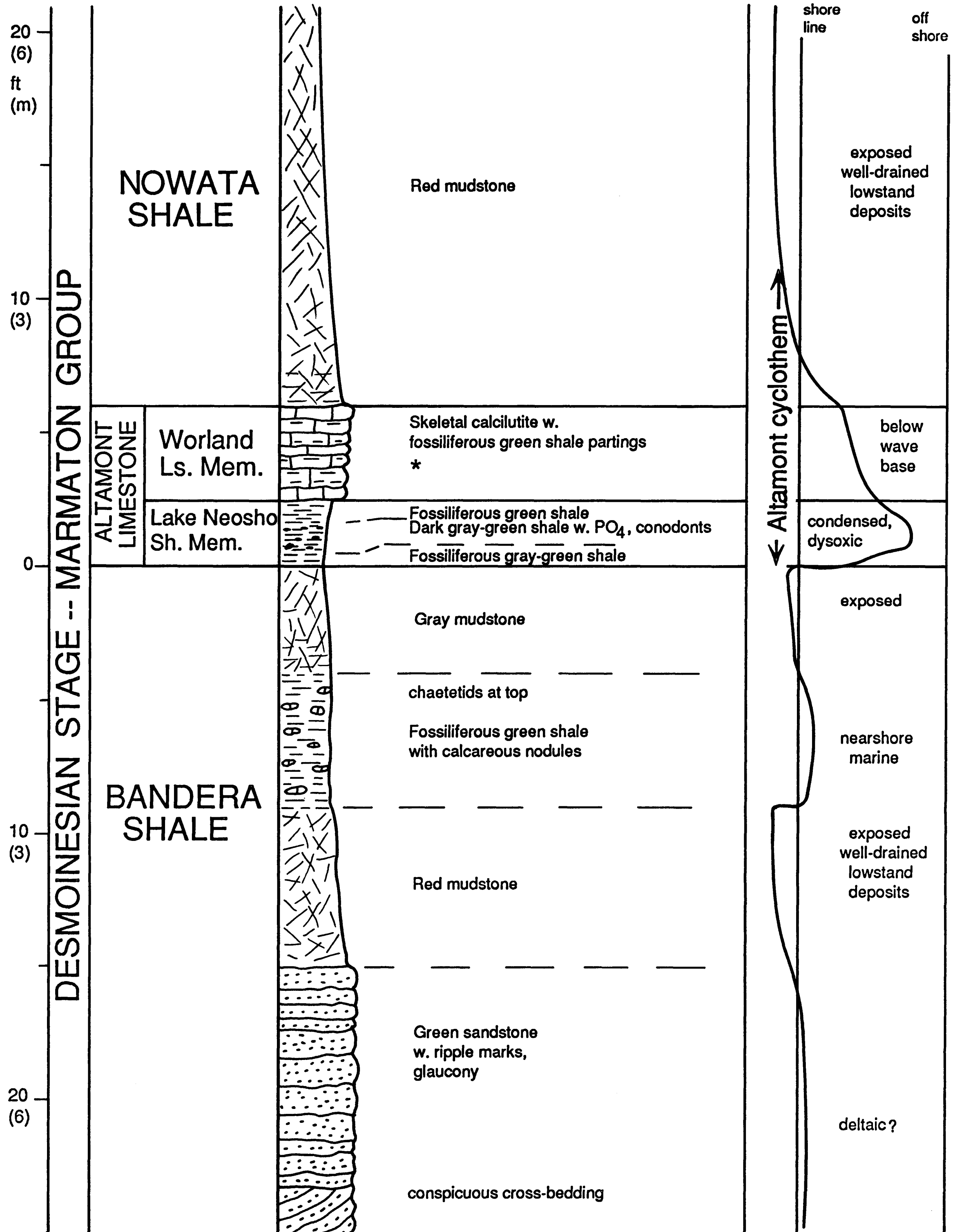
Blackwater Creek Shale (Greene and Searight, 1949) includes the Flint Hill sandstone of northern Missouri and represents progradation of detrital clastics during mid-regression, probably in a terrestrial environment here, but deltaic southward in Missouri where it penetrates the Houx-Higginsville carbonate sequence of Kansas.

Higginsville Limestone represents a transgression of intermediate scale within the general Upper Fort Scott regression. The basal limestone records enough sea level rise to strand detrital sediment some distance away, and the upper nodular shale records resumption of regression and advance of detrital clastics.

Basal ***Labette Shale*** is another probable paleosol formed at sea-level lowstand, overlain by the ***Marshall coal,*** which may represent ponding of water shoreward of one of the minor marine T-R cycles in the Labette Shale southward (Fig. 9). The ***Mystic coal*** at the top of the Labette and the basal beds of the overlying ***Pawnee cyclothem*** are present about 0.5 mile upstream.

Leave Stop 1 at 8:05 AM
Drive 1.8 miles (see directions at front of guide) (5 min)

STOP 2: RAVINE SW. OF ST. CHARLES



measured by J. P. Pope, 1991

* = fossil list in Appendix

STOP 2: RAVINE SOUTHWEST OF ST. CHARLES: ALTAMONT CYCLOTHEM (60 min)
(Location: SE1/4 SW1/4 sec 23, T75N, R26W; on Ray Johnston farm)

This stop shows the Altamont cyclothem, which was interpreted early by Schenk (1967) as a single transgressive-regressive sequence that reached greatest depth of water during deposition of the phosphatic shale.

Bandera Shale represents a complex sequence of lowstand deposits throughout most of the northern Midcontinent (Fig. 8), which are largely terrestrial to nearshore marine. The glaucony in the sandstones at the base of the succession here suggests marine influence; thus the sandstones may be deltaic, representing the regression closing the underlying Coal City cycle (Fig. 9) at the top of the Pawnee cyclothem, as Swade (1985) showed for this succession in the Osceola core (CP-37), 15 miles to the south. The unfossiliferous red mudstone above the sandstone is probably terrestrial, and represents well-drained conditions leading to oxidation and dehydration of iron minerals. The overlying fossiliferous green shale appears to represent the nearshore extent of a minor marine inundation, in view of the blocky nature of the gray mudstone above it, which may represent subaerial exposure and paleosol formation prior to the major Altamont transgression; if so, this shale probably is the post-Mulberry marine unit (Fig. 9), which overlies the Mulberry coal in the Bandera Shale of western Missouri and southeastern Kansas.

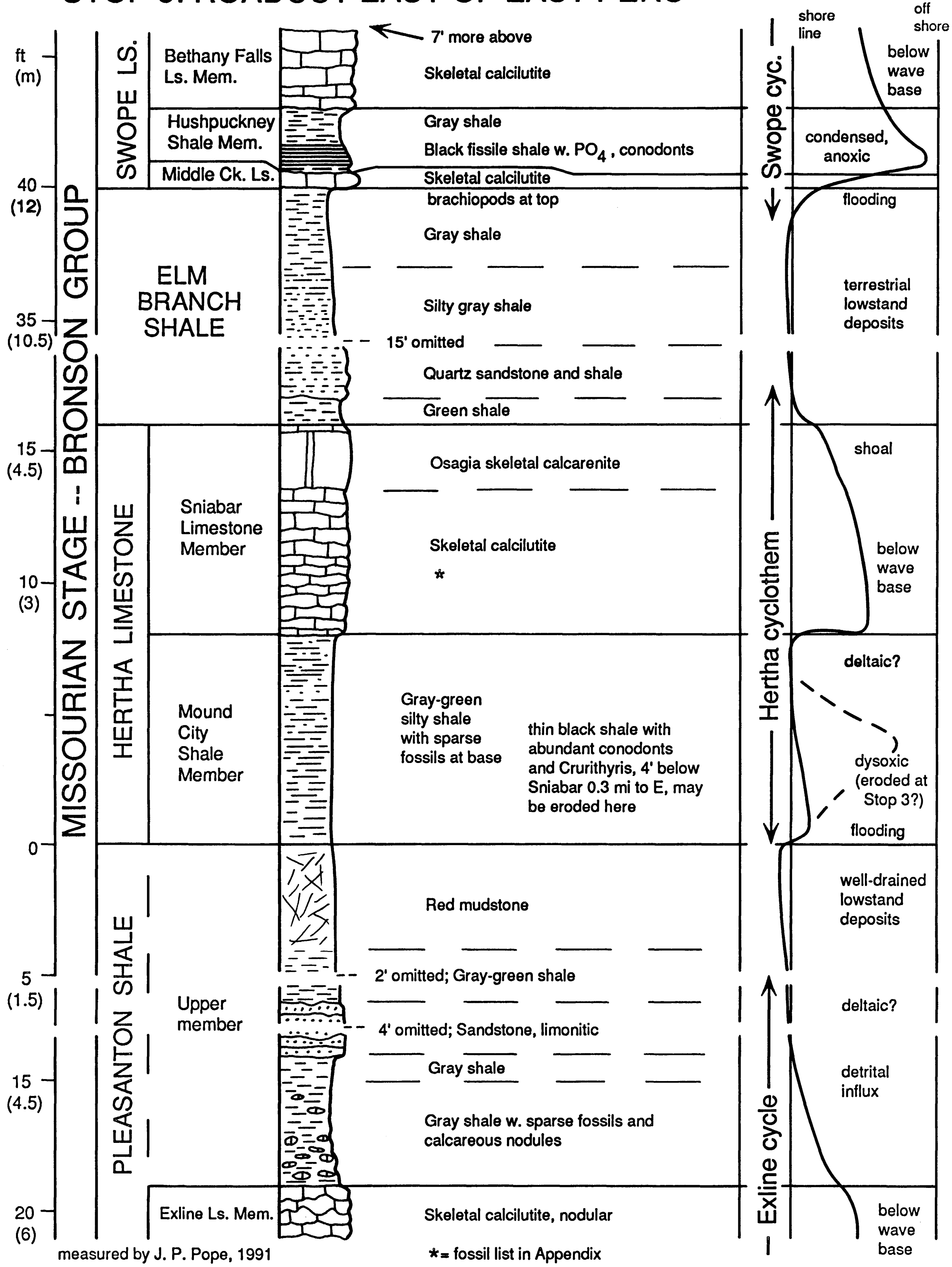
Lake Neosho Shale Member here includes the position of the transgressive Amoret Limestone Member, which is absent here. Therefore the Lake Neosho at this locality includes both the marine flooding deposits at the base and the condensed section of sea-level highstand represented by the dark phosphatic shale in the middle, as well as the initial early regressive lighter green shale with conspicuous benthic fossils at the top. The Lake Neosho Shale is traced into east-central Oklahoma by means of its distinctive conodont fauna (Heckel, 1991a). The general lack of a hard black fissile organically bound facies in this shale in Iowa reflects less organic matter preserved in the sediment. This may have resulted from less organic matter available to settle out below the thermocline (perhaps due to climatic conditions) or from less consistent development of the thermocline through time, which may possibly reflect slightly shallower water during sea-level highstand within this cycle of inundation, than within the others that have the hard black facies this far north.

Worland Limestone Member is the regressive limestone of the Altamont cyclothem, which at this locality is nearly all skeletal calcilutite (with fossiliferous shale partings) deposited in open marine water below effective wave base. About 15 miles south of here in the Osceola Core, Swade (1985) described several feet of shale-parted limestone at the top of the Worland, including abraded calcarenites overlain by barren laminated peloidal calcarenites and calcilutites, which reflects the upward-shoaling sequence to peritidal deposits typical of most regressive limestones on the northern shelf.

Nowata Shale is red blocky mudstone that is probably a well-drained paleosol, which represents the lowstand deposits that terminated the Altamont cyclothem.

Leave Stop 2 at 9:10 AM
Drive 11.1 miles (see directions at front of guide) (20 min)

STOP 3: ROADCUT EAST OF EAST PERU



measured by J. P. Pope, 1991

*= fossil list in Appendix

STOP 3: ROADCUT EAST OF EAST PERU: HERTHA & SWOPE CYCLOTHEMS (45 min)
(Location: W line E1/2 NW1/4 sec 12, T74N, R27W)

This stop shows the Hertha cyclothem, the lower part of the Swope cyclothem, one of the classic midcontinent cyclothems, and also (poorly exposed) the Exline Limestone, the oldest Missourian marine horizon in Iowa.

Exline Limestone is best known in northern Missouri as 1 to 2 feet of conodont-rich shaly limestone with an offshore molluscan fauna including *Trepospira* (see Boardman et al., 1984) extending up into the overlying prodeltaic shale. A dense transgressive limestone is known from northern Missouri into the type area of southern Iowa, and a regressive limestone is known in cores in western Iowa and adjacent Nebraska (Nielsen, 1987). The Exline is now traced as a conodont-rich shelly marine zone into east-central Oklahoma (mainly in cores) and is considered a T-R cycle of intermediate scale (Fig. 9).

Upper Pleasanton Shale is largely deltaic? to terrestrial clastics deposited during the regression and lowstand that closed the Exline cycle, and is capped by a red mudstone that probably represents a well-drained paleosol. Southward this unit becomes a thick deltaic complex in north-central Missouri, with prodeltaic shales extending into eastern Kansas.

Mound City Shale Member is the marine flooding unit of the Hertha cyclothem. It generally lacks a transgressive limestone, but typically contains a conodont-rich black or gray shale (the condensed section), and also an early regressive prodeltaic shale unit at the top in eastern Kansas (Heckel, ms. in review-B). The black phosphatic shale has been collected 0.3 mile to the east by John Pope, but as not even a gray condont-rich zone has yet been detected here at Stop 3, the condensed section may have been eroded here during the lower sea-level stand responsible for both the upper prodeltaic unit in Kansas and apparently the entire shale preserved here.

Sniabar Limestone Member is transgressive at the base above silty shale, but is essentially the regressive limestone of the Hertha cyclothem, shoaling upward from skeletal calcilutite to calcarenite. This relationship (Fig. 9) is more conspicuous in eastern Kansas where the Sniabar overlies the thick prodeltaic unit in the top of the Mound City Shale; a similar relationship is apparent also in other cyclothems in this region (e.g., Higginsville Limestone at Stop 1; Westerville Limestone at Stop 5).

Elm Branch Shale is a revived eastern Kansas name that replaces Ladore, a southeastern Kansas unit that had been miscorrelated (Heckel, ms. in review-B). The Elm Branch here comprises largely terrestrial lowstand deposits that terminated the Hertha cyclothem; the brachiopod-rich shale in the top foot represents the initial marine flooding deposits of the Swope cyclothem.

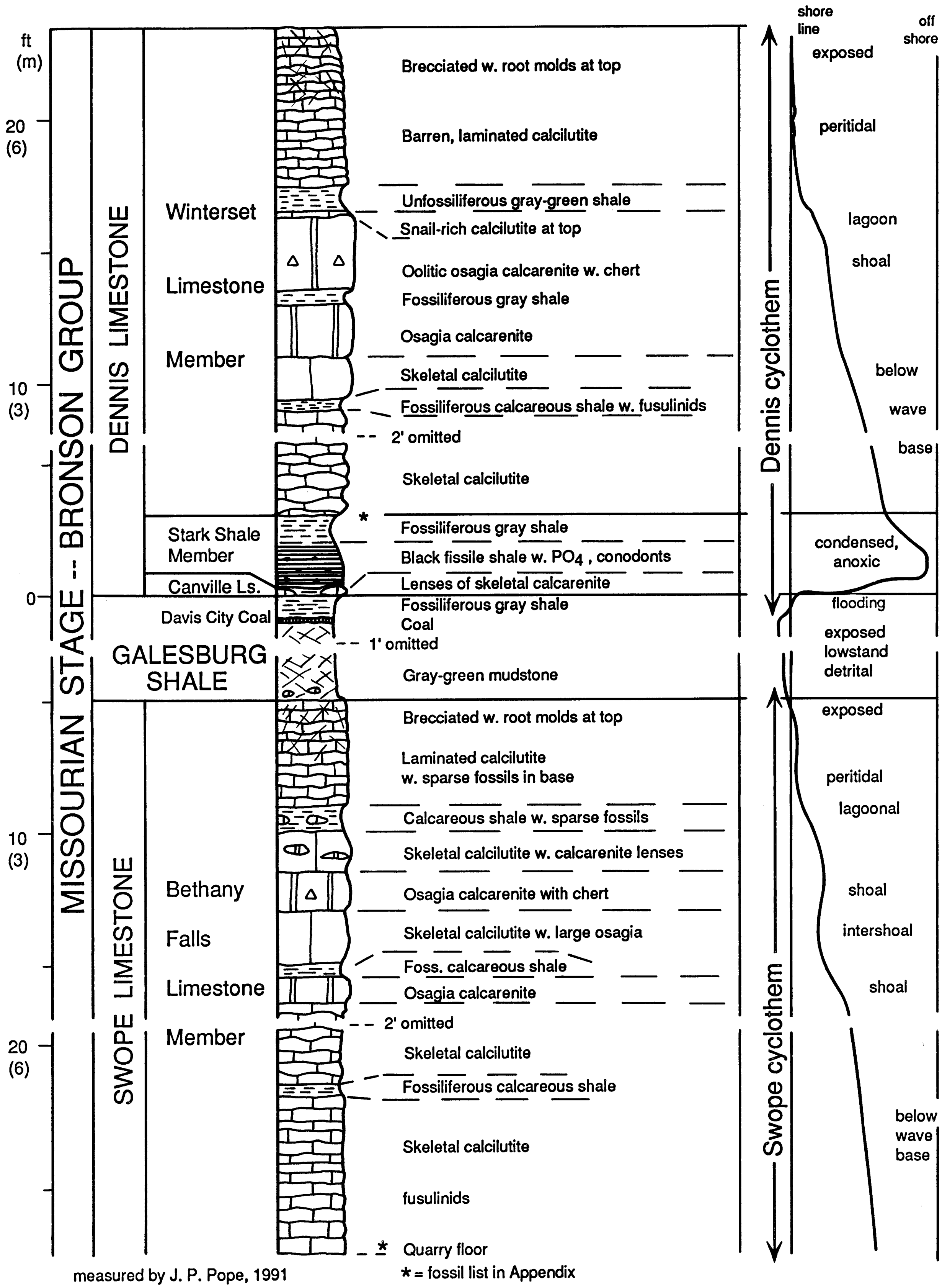
Middle Creek Limestone Member is the transgressive limestone of the Swope cyclothem, a skeletal calcilutite deposited below effective wave base.

Hushpuckney Shale Member is the core shale (condensed section) of the Swope cyclothem, a black phosphatic shale that is traced to the basinal region of central Oklahoma and correlated with prominent marine horizons in Texas (Fig. 10), Illinois (Fig. 11), and the Appalachians, based on its distinctive conodont fauna.

Bethany Falls Limestone is the regressive limestone of the Swope cyclothem. Only the base is exposed here; the top is exposed at Stop 4.

Leave Stop 3 at 10:15 AM
Drive 12.7 miles (see directions at front of guide) (25 min)

STOP 4: MARTIN-MARIETTA QUARRY AT WINTERSET



measured by J. P. Pope, 1991

* = fossil list in Appendix

STOP 4: MARTIN-MARIETTA QUARRY AT WINTERSET:
SWOPE & DENNIS CYCLOTHEMS (80 min)
(Location: S1/2 NE1/4 sec 6, T75N, R27W; old Penn-Dixie Quarry)

This stop shows the Swope and Dennis cyclothems, two classic carbonate-rich Midcontinent cyclothems separated by a paleosol (Galesburg Shale). Because both regressive limestones are thick and the shales between them are thin, this succession is the most quarried and thus the best known part of the Missourian Stage in the northern Midcontinent.

Bethany Falls Limestone Member is the regressive limestone of the Swope cyclothem, which displays well the classic shoaling-upward sequence. The lower part is skeletal calcilutite with a diverse biota representing deposition during earlier regression below effective wave base. The middle includes beds of osagia-coated skeletal calcarenite that record deposition in shoal water above wave base. (Osagia is essentially a small oncolite consisting of blue-green algae and encrusting forams coating a typically abraded skeletal grain.) The capping calcilutites with less diverse faunas in the base, and lamination, probable rootmolds and brecciation toward the top, record passage through lagoonal and peritidal environments to subaerial exposure as the sea withdrew southward. Fusulinids from the Bethany Falls Limestone in a roadcut just west of here and elsewhere (Thompson, 1957) are *Eowaeringella ultimata*, which is not found above the Swope in the Midcontinent.

Galesburg Shale is mostly blocky mudstone that is a paleosol (Schutter and Heckel, 1985) and represents lowstand deposits that terminated the Swope cyclothem. The fossiliferous shale above the coal at the top represents the initial marine flooding deposits of the Dennis transgression.

Canville Limestone Member is the transgressive limestone of the Dennis cyclothem. It consists only of nodules of skeletal calcilutite where present north of its type area in southeastern Kansas, perhaps because the transgression was rapid enough over the northern Midcontinent that only a limited amount of carbonate mud was produced (or preserved) in patches.

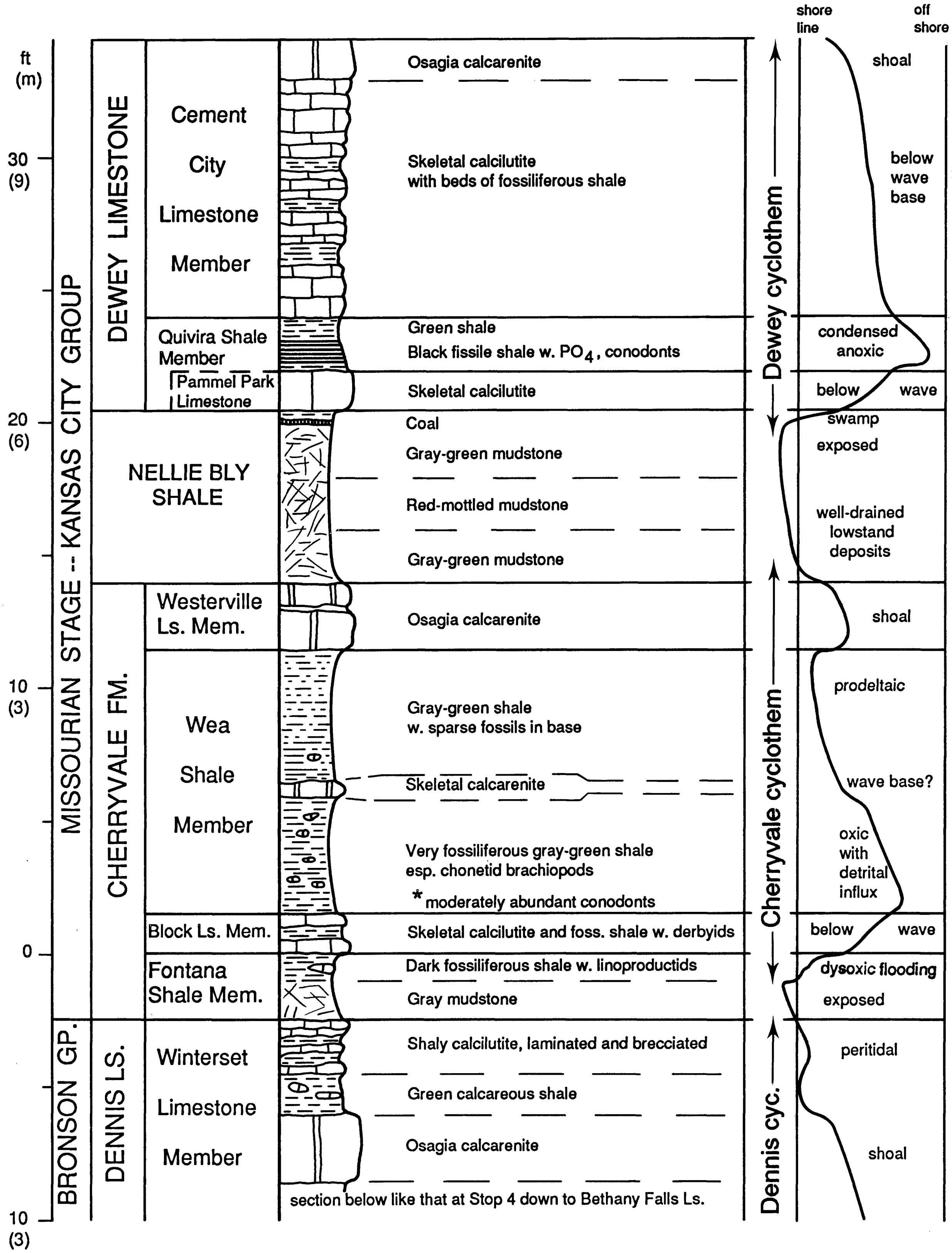
Stark Shale Member is the black phosphatic core shale (condensed section) of the Dennis cyclothem deposited largely below a thermocline at maximum highstand of sea level. It is correlated with conspicuous marine horizons in Texas (Fig. 10), Illinois (Fig. 11), and the Appalachians based on its distinctive conodont fauna.

Winterset Limestone Member (named from this area) is the regressive limestone of the Dennis cyclothem, which exhibits the classic shallowing-upward sequence like that of the homologous Bethany Falls below, with which it is easily confused in exposures of only one regressive limestone. The lower part is skeletal calcilutite deposited below effective wave base, the middle is largely osagia to oolitic calcarenite deposited in shoal water above wave base, and the top is mostly barren laminated calcilutite with probable rootmolds and brecciated appearance recording peritidal deposits followed by subaerial exposure. The fusulinids in the Winterset Limestone here and elsewhere (Thompson, 1957) are the lowest occurrence of triticitids in the Midcontinent, which along with the distinctly different fusulinids in the underlying Bethany Falls have resolved correlation problems (Fig. 7) between the Nebraska-Iowa outcrop and the Kansas City area (Heckel and Meacham, 1980).

Leave Stop 4 at 12 noon
Drive 1.6 miles (see front of guide) to Winterset Museum for LUNCH

Leave Museum at 1:10 PM
Drive 6.9 miles (see directions at front of guide) (15 min)

STOP 5: MIDDLE RIVER CUT WEST OF PAMMEL PARK



measured by J. P. Pope, 1991

* = fossil list in Appendix

STOP 5: MIDDLE RIVER CUT WEST OF PAMMEL PARK:
CHERRYVALE & DEWEY CYCLOTHEMS (60 min)
(Location: NE1/4 NE1/4 SW1/4 sec 17, T75N, R28W; on Paul Busch farm)

This stop shows the Cherryvale cyclothem, a less straightforwardly developed cycle of intermediate scale, and the overlying Dewey cyclothem, which until recently (Heckel, ms. in review-B) was misidentified as Iola (see explanation under Stop 6).

Top of ***Winterset Limestone*** here is shalier than at Stop 4, but contains laminated brecciated calcilutite recording exposure after peritidal deposition.

Fontana Shale Member is mostly blocky mudstone that probably represents a paleosol developed during the sea-level lowstand that closed the Dennis cyclothem. It is partly time equivalent to upper marine beds of the Winterset Limestone southward in Missouri and Kansas, which were deposited during minor inundations that did not extend this far north (Felton and Heckel, 1992). The top of the Fontana is marine fossiliferous shale that represents the initial flooding deposits of the succeeding Cherryvale cycle, as Reeves and Felton (1992) have recognized. Its dark color here probably reflects organic-matter overload in a nearshore dysoxic environment.

Block Limestone Member is the transgressive limestone of the Cherryvale cyclothem. It shows an upward trend in dominant brachiopods from linoproductids at the base (and below) through derbyids in the middle to a diverse fauna with chonetids in the shale above, which reflects an offshore progression of communities during deepening into oxygenated environments.

Wea Shale Member includes the highstand and early regressive deposits of the Cherryvale cyclothem. Its base is marked by only a moderately conodont-rich shale representing the condensed section of the cyclothem (which is not black on outcrop north of Oklahoma) overlain by diversely fossiliferous shale. This is because the Cherryvale cyclothem resulted from an inundation of less extent and water depth, and thus no permanent pycnocline formed above the deposits representing greatest water depth here, which were also more diluted by nearshore sediment in stable oxic environments than were most other core shales in this region. The type upper Wea Shale in eastern Kansas is conodont-poor, regressive and prodeltaic in places, and the top of the Wea Shale is similar here and nearby (Reeves and Felton, 1992).

Westerville Limestone Member, named from an Iowa locality about 30 miles south, is essentially the regressive limestone of the Cherryvale cyclothem. However, like older regressive limestones (Stops 1, 3), it resulted from a minor transgression (Fig. 9) that inundated the underlying deltaic deposits and allowed limestone to form in a shallowing-upward sequence (seen in nearby cores) as regression resumed. It is now correlated with the Drum Limestone of southeastern Kansas, which underwent a similar history of deposition above the Wea Shale (Heckel, ms. in review-B).

Nellie Bly Shale is mostly mudstone, probably a paleosol, that represents the sea-level lowstand that closed the Cherryvale cyclothem. Nellie Bly is an Oklahoma name extended northward as a result of recorrelation of mid-Missourian units (Heckel, ms. in review-B).

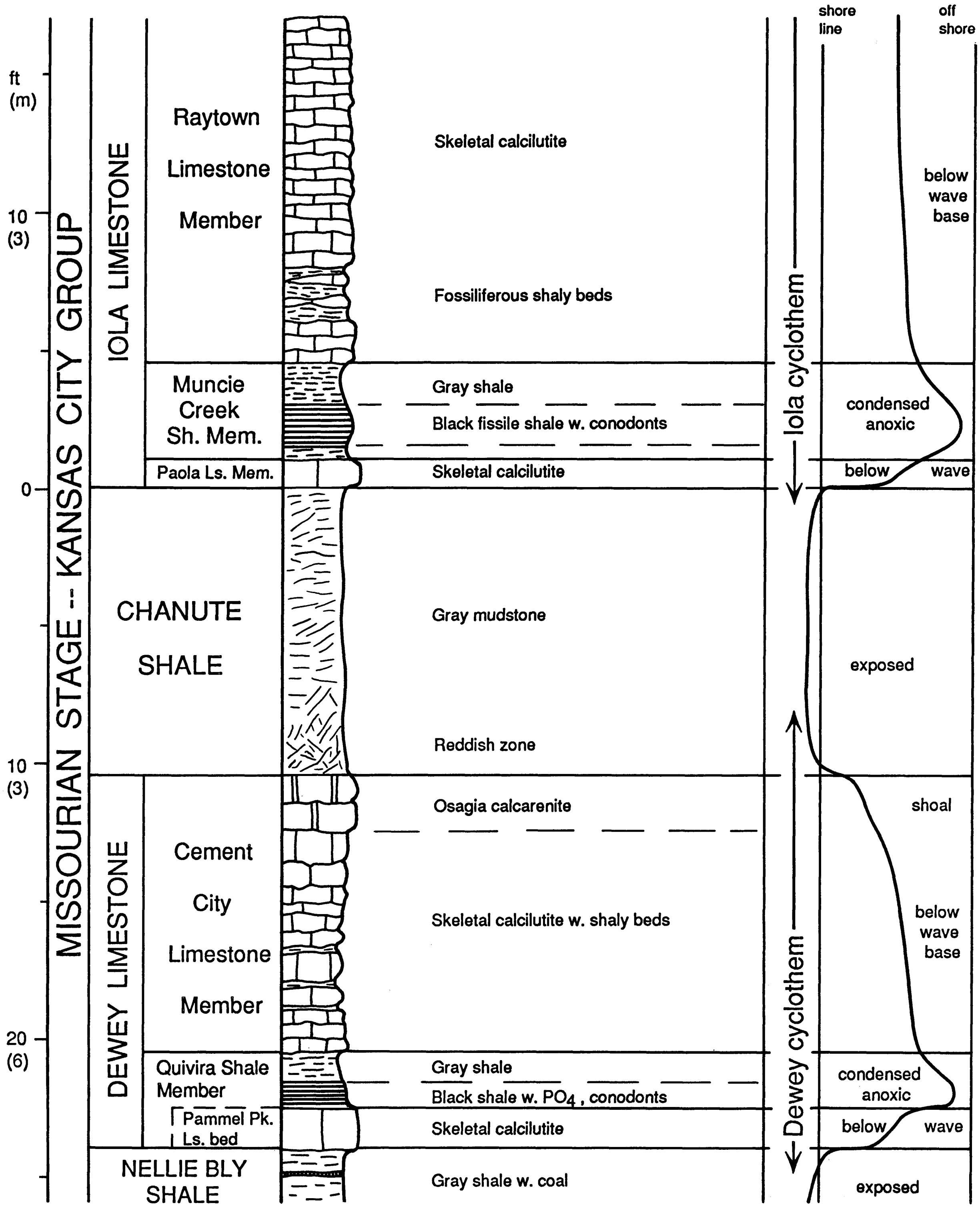
Pammel Park Limestone bed is a new name applied from this area to this local development of transgressive limestone in the Dewey cyclothem.

Quivira Shale Member is the dark phosphatic core shale of the Dewey cyclothem deposited below a thermocline during maximum inundation.

Cement City Limestone is the regressive limestone of the Dewey cyclothem and displays the typical shallowing-upward sequence of calcilutite to calcarenite.

Leave Stop 5 at 2:25 PM
Drive 4.6 miles (see directions at front of guide) (10 min)

STOP 6: STREAMBANK NORTH OF PAMMEL PARK



from Welp, et al., 1968; slightly modified by P. H. Heckel (Dewey) 1969, and J. P. Pope (Iola) 1991

STOP 6: STREAMBANK NORTH OF PAMMEL PARK:
DEWEY & IOLA CYCLOTHEMS (30 min)
(Location: NE1/4 SW1/4 NE1/4 sec 10, T75N, R28W; on Paul Bruett farm)

This stop shows both the Dewey and Iola cyclothems (lower part), which were once correlated with the Iola and Wyandotte formations, respectively, of the Kansas City area based largely on relative thicknesses of the regressive limestones. They are now recorrelated by tracing lithic units through long cores in Missouri and Iowa (Fig. 6) and confirmed by conodont faunas of the black shales. We will visit only the Iola here because the Dewey (east of the road) was seen at Stop 5.

Pammel Park Limestone Bed is a new name applied from this area to the transgressive limestone of the Dewey cyclothem. It is currently classified as a bed in the Quivira Shale Member because it is only locally developed, mainly in this area and in several cores in Missouri and Iowa. It was previously misidentified as the Paola Limestone Member of the Iola Limestone.

Quivira Shale Member is the black to gray phosphatic core shale that represents the condensed section of highstand deposits of the Dewey cyclothem. Previously thought to be the Muncie Creek Shale Member of the Iola Limestone, its conodont fauna (from a locality 2 miles southwest of here: Stop 3 of Heckel, 1980a) much more closely resembles that of the Quivira Shale in its type area in Kansas City, and also allows it to be correlated into Texas (Fig. 10) and Illinois (Fig. 11).

Cement City Limestone Member is the regressive limestone of the Dewey cyclothem, which displays the typical shallowing-upward sequence. It was previously misidentified as the Raytown Limestone Member of the Iola Limestone, which at Kansas City is closer in thickness (6-8 ft) to the Cement City Limestone here (9-10 feet) than to the Raytown in this area (about 22 feet at Stop 7).

Chanute Shale is the terrestrial lowstand deposit that closed the Dewey cyclothem, probably with paleosol development. It was previously misidentified as the Lane Shale (which at its type section in east-central Kansas is now known to lie above both the Iola and Wyandotte limestones: Heckel, ms. in review-B).

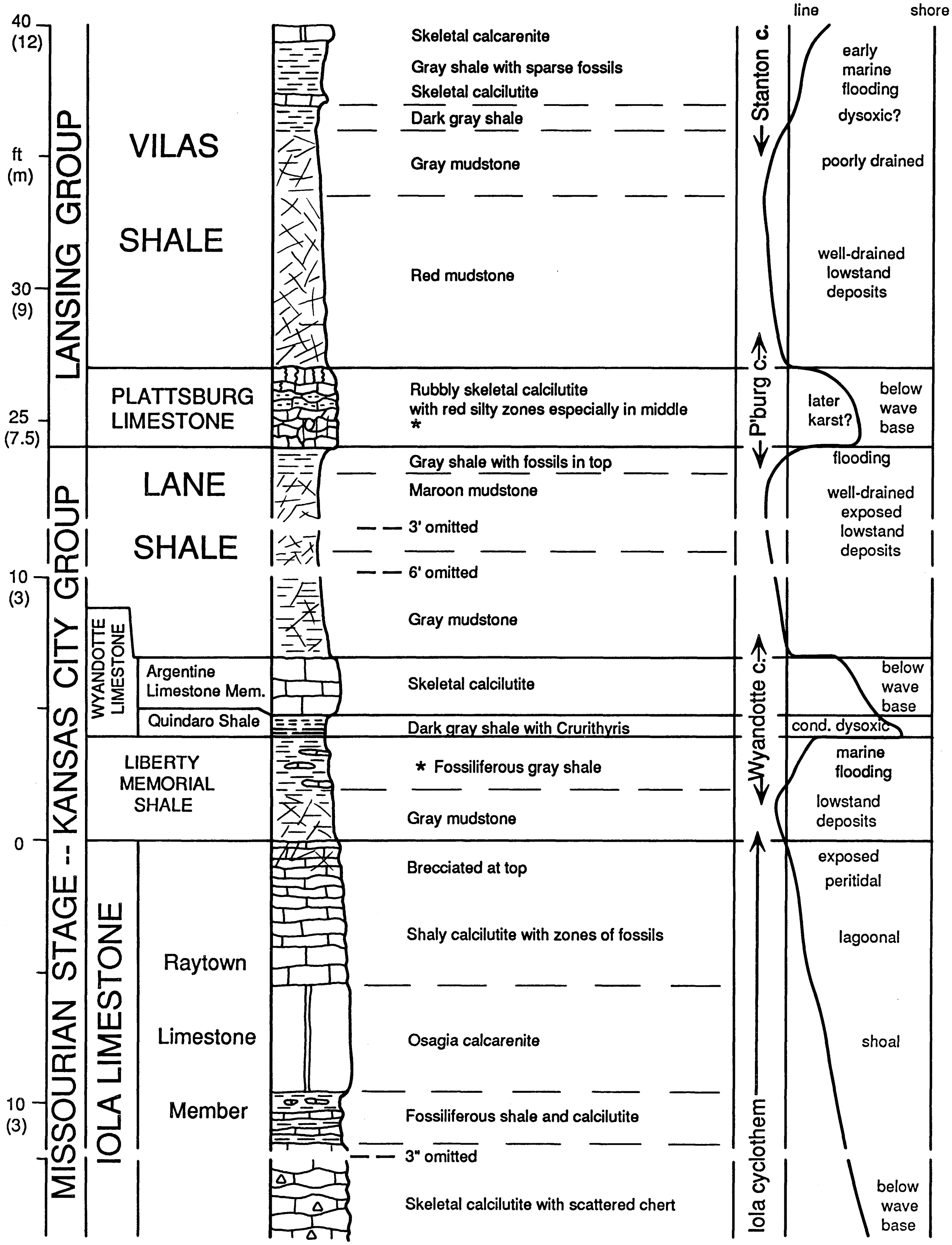
Paola Limestone Member is the transgressive limestone of the Iola cyclothem, a typical skeletal calcilutite deposited below effective wave base. It is exposed in the small cutbank on the first major meander northwest of the road culvert across the creek, and it was previously misidentified as the Frisbie Limestone Member of the Wyandotte Limestone.

Muncie Creek Shale Member (exposed above the Paola Limestone in the cutbank) is the black core shale of the Iola cyclothem, which represents condensed-section highstand deposition below a thermocline. The conodont fauna processed by J.W. Swade from this locality resembles that of the Muncie Creek Shale in its type area in Kansas City much more than that of the Quindaro Shale in its type area there, with which it had previously been miscorrelated.

Raytown Limestone Member (exposed upstream) is the regressive limestone of the Iola cyclothem. The lower part is skeletal calcilutite deposited below effective wave base during earlier regression. Apparently because of its much greater thickness in Iowa and Nebraska (20-25 feet) than in its type area at Kansas City (6-8 feet), the Raytown here was previously miscorrelated with the Argentine Limestone Member, a unit of similar great thickness in its type area at Kansas City.

Leave Stop 6 at 3:05 PM
Drive 10.3 miles (see directions at front of guide) (15 min)

STOP 7: SCHILDBERG'S STANZEL QUARRY



measured by J. P. Pope, 1991 * = fossil list in Appendix

STOP 7: SCHILDBERG'S STANZEL QUARRY NORTH OF RTE 92:
IOLA, WYANDOTTE & PLATTSBURG CYCLOTHEMS (80 min)
(Location: SW1/4 NE1/4 sec 5, T75N, R29W; land once owned by Stephen Pope)

This stop shows the upper part of the Iola cyclothem and attenuated developments of the Wyandotte and Plattsburg cyclothems, which are cycles of intermediate scale that are well developed mainly in the Kansas City area.

Raytown Limestone Member is the regressive limestone of the Iola cyclothem, another of the important quarried units along the Iowa outcrop (and previously misidentified as the Argentine Limestone Member of the Wyandotte because of its thickness, as explained at Stop 6). Like the Bethany Falls and Winterset regressive limestones seen at Stop 4, it displays the classic shallowing-upward sequence of skeletal calcilutite overlain by osagia-coated, abraded-grain calcarenite, and eventually capped by poorly fossiliferous brecciated beds recording subaerial exposure.

Liberty Memorial Shale is a revived Missouri name from Kansas City applied to the shale formerly called Lane between the Iola and Wyandotte Limestones there, which is not equivalent to type Lane Shale of east-central Kansas (Heckel, ms. in review-B). The Liberty Memorial here (previously misidentified as Island Creek Shale) is mudstone in the base representing lowstand deposits that closed the Iola cyclothem, with fossiliferous shale above representing the early marine flooding deposits of the Wyandotte cyclothem; around Kansas City the Liberty Memorial is mostly thick prodeltaic marine shale above thin Raytown skeletal calcilutite, and thus it is probably time equivalent to the shoal-water top of the Raytown here as well (see datum on Fig. 4 for generalized illustration of this relationship).

Quindaro Shale Member is dark fossiliferous shale with a conodont fauna similar to that of the type Quindaro Shale at Kansas City; it represents the condensed section of the Wyandotte cyclothem deposited in dysoxic water at maximum transgression. This bed was misidentified as a coal by previous workers.

Argentine Limestone Member is the regressive limestone of the Wyandotte cyclothem, previously misidentified here as Farley Limestone. Because of recent recognition of the underlying Quindaro Shale here, the Farley (which is younger than the Argentine in their type region) is now recognized to pinch out within the overlying Lane Shale at the Missouri-Iowa border, based on analysis of long cores (Fig. 6).

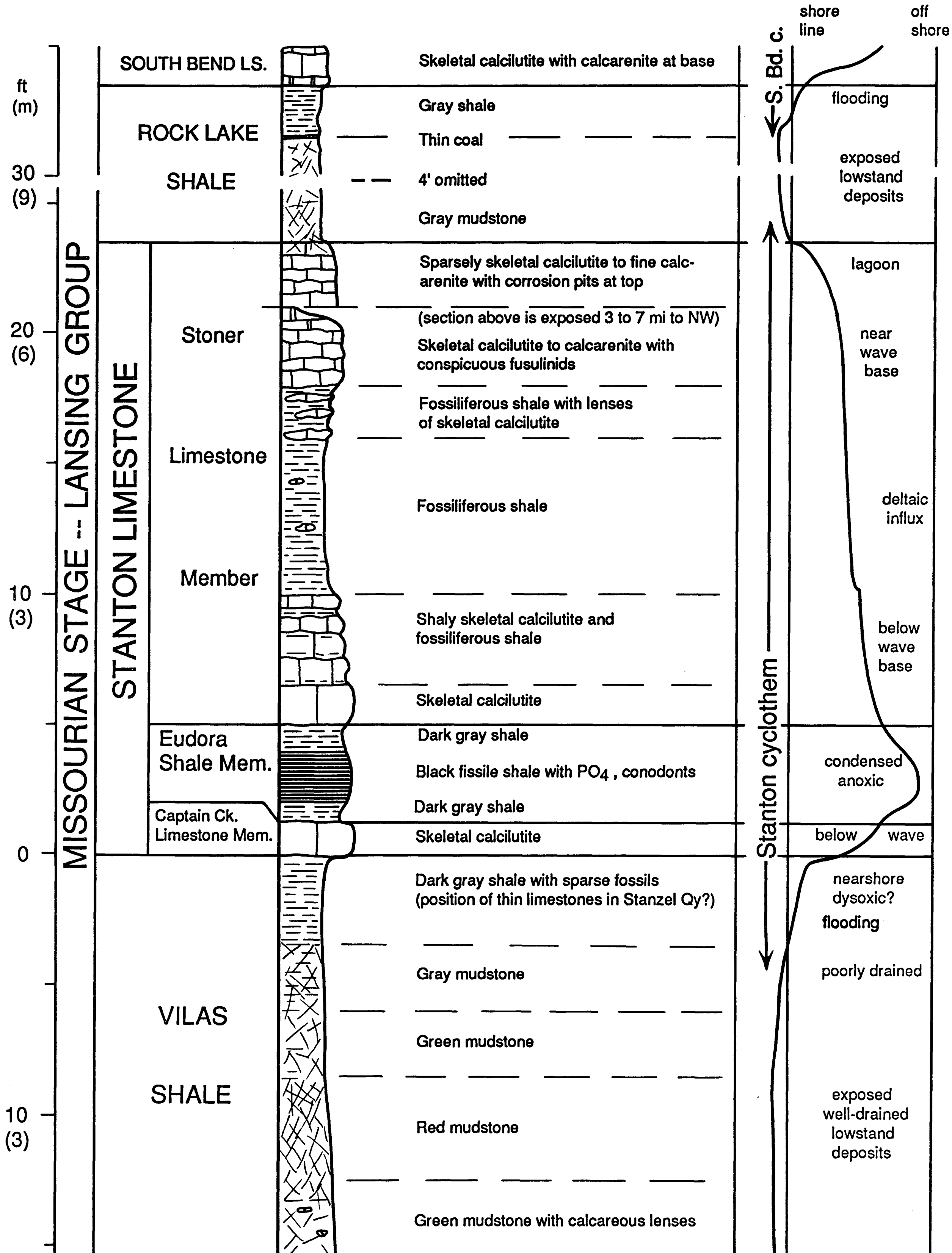
Lane Shale includes maroon mudstone that records well-drained terrestrial environments and represents the lowstand deposits that terminated the Wyandotte cyclothem. The Lane was previously termed Bonner Springs Shale here, a name that is now confined to the upper shale member of the Lane where the Farley Limestone (now regarded also as a member of the Lane) is present; the lower Lane is now the Island Creek Shale Member where the Farley Limestone is present to separate it from the Bonner Springs.

Plattsburg Limestone represents a marine incursion in which the more conodont-rich lower half here apparently represents the nearshore facies of the gray core shale that is well developed mainly from the Bedford core (IBC on Fig. 6) southward. This unit is particularly rubbly here because pedogenesis affecting the overlying red Vilas mudstone extended paleosol development down through probable shallow karst development in the limestone, as indicated by red muddy siltstone layers in the upper middle and by the vertical trend of reddish shaly zones within the entire unit.

Vilas Shale is red mudstone in the lower part, a well drained paleosol that represents the lowstand deposits that terminated the Plattsburg cyclothem. The fossiliferous upper part with thin limestones represents early marine flooding deposits of the Stanton cyclothem, to be seen at Stop 8.

Leave Stop 7 at 4:40 PM
Drive 2.6 miles (see directions at front of guide) (5 min)

STOP 8: STREAMBANK NEAR MADISON-ADAIR CO. LINE



measured by J. P. Pope (lower part) 1991, and P. H. Heckel (upper part) 1981

STOP 8: STREAMBANK NEAR MADISON-ADAIR COUNTY LINE:
STANTON CYCLOTHEM (30 min)
(Location: SW1/4 SW1/4 NW1/4 sec 7, T75N, R29W; on Eugene Drake farm)

This stop shows most of the Stanton cyclothem, the youngest classically developed cyclothem of Missourian age. For years this exposure had been misidentified as the much higher Oread cyclothem of early Virgilian age, but conodont faunas collected and identified by P.H. von Bitter from the black shale here necessitated recorrelation with the Stanton (von Bitter and Heckel, 1978).

Vilas Shale is mainly blocky mudstone that represents the terrestrial lowstand deposits that closed the Plattsburg cyclothem seen at Stop 7. The red mudstone represents a well-drained paleosol in which iron minerals were both oxidized and dehydrated to hematite. The overlying green and gray mudstones indicate hydration and reduction of iron minerals and probably reflect the raising of the water table that accompanied the earliest stages of transgression when both sea level was rising and the climate was becoming wetter because of the approaching sea; these conditions would have been further enhanced in the top of the paleosol by the eventual inundation by the sea. The capping dark gray shale represents the initial marine flooding deposits, probably in a dysoxic environment subject to organic-matter overload; this portion is thicker and contains thin marine limestones at Stop 7, 2 miles to the east-northeast, where the depositional topography may have been lower, thus accommodating more sediment during this time of early transgression.

Captain Creek Limestone Member is the transgressive limestone of the Stanton cyclothem, a skeletal calcilutite deposited below effective wave base during later transgression. It has been traced from southeastern Nebraska to northern Oklahoma through a thick algal mound complex in southeastern Kansas.

Eudora Shale Member is the phosphatic core shale (condensed section) of the Stanton cyclothem, in which the black facies in the middle was deposited below a thermocline during maximum sea-level highstand. The basal gray shale records deepening below the level of carbonate production/preservation before the permanent thermocline was reached, and the upper gray shale records earliest regression when initial shallowing of water destroyed the permanent thermocline but was not enough for preservation of any carbonate that may have been produced. The Eudora has been traced from Nebraska to northern Oklahoma on the basis of its stratigraphic position in conjunction with its distinctive conodont fauna, which has also allowed it to be correlated into Texas (Fig. 10) and Illinois (Fig. 11).

Stoner Limestone Member is the regressive limestone of the Stanton cyclothem, with skeletal calcilutite and fossiliferous shale throughout most of this exposure recording deposition below effective wave base. The detrital influx forming the shale probably reflects a nearby, perhaps deltaic source of clastics that shifted here for a while. The more calcarenitic fusulinid limestone at the top records shallowing to effective wave base. The poorly fossiliferous fine-grained muddy calcarenite with corrosion pits a few feet higher (projected from an exposure 3 miles to the northwest in SE• SW• sec 26, T76N, R30W) probably represents a restricted shoreline lagoon followed by subaerial exposure. The Stoner is overlain (7 miles to the northwest in NE• SE• sec 18, T76N, R30W) by the ***Rock Lake Shale***, which displays paleosol micromorphology described by Joeckel (1989) in Nebraska, and represents the lowstand deposits that closed the Stanton cyclothem.

Leave Stop 8 at 5:15 PM
Drive 13 miles back to Winterset for DINNER at North Side Cafe

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APPENDIX:

LISTS OF FOSSILS COLLECTED FROM SELECTED UNITS AT VARIOUS STOPS

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(*marks position of collections on stratigraphic column for each stop)

STOP 1: CLANTON CREEK LIMESTONE BED of LITTLE OSAGE SHALE MEMBER

Brachiopods
- *Derbyia crassa*
- *Composita subtilita*
- *Linoproductus echinatus*
- *Desmoinesia muricata*
- *Antiquatonia portlockianus*
- *Mesolobus mesolobus*
- *Neospirifer cameratus*
- *Punctospirifer kentuckyensis*
- *Neochonetes* sp.
- *Crurithyris planoconvexa*
- *Wellerella osagensis*
- *Juresania nebrascensis*

Bryozoans
- *Rhombopora* sp.
- *Cyclotrypa zonata*
- Fenestellidae

Corals
- *Stereostylus* sp.

Clams
- *Myalina (Orthomyalina)* sp.
- *Wilkingia terminale*
- *Edmondia*? sp.

Crinoids
- plates and stems

Plants
- carbonized fragments

STOP 2: WORLAND LIMESTONE MEMBER of ALTAMONT LIMESTONE (lower part)

Brachiopods
- *Phricodothyris perplexa*
- *Composita argentea*
- *Composita subtilita*
- *Neospirifer triplicatus*
- *Cleiothyridina orbicularis*
- *Neochonetes* sp.
- *Chonetinella flemingi crassiradiata*
- *Antiquatonia portlockianus*
- *Kozlowskia splendens*
- *Derbyia crassa*
- *Wellerella osagensis*
- *Hustedia mormoni*
- *Punctospirifer kentuckyensis*
- *Mesolobus mesolobus*
- *Linoproductus prattenianus*
- *Juresania nebrascensis*
- *Dielasma bovidens*
- *Cryptacanthia compacta*
- *Crania modesta*
- *Leptalosia ovalis*
- *Meekella striatocostata*
- *Planispina armata*
- *Orbiculoidea missouriensis*
- *Echinaria* sp.
- many juveniles

Crinoids
- *Apographiocrinus* sp.
- plates, stems

Snails
- *Naticopsis (Jedra)* sp.
- *Straparollus (Straparollus)* sp.
- *Straparollus (Amphiscapha)* sp.
- *Straparollus (Euomphalus)* sp.
- *Bellerophon (Bellerophon)* sp.
- *Trepospira* sp.
- *Goniasma* sp.
- many other unidentified genera

Forams
- *Climacammina* sp.
- *Polytaxis* sp.
- *Fusulina mysticensis*

Corals
- *Stereostylus sp.*
- *Sestrophyllum sp.*
- *Lophamplexus sp.*

Bryozoans
- *Rhombopora* sp.
- *Cyclotrypa* sp.
- Fenestellidae

Clams
- *Nuculopsis* sp.
- *Aviculopecten* sp.
- *Acanthopecten* sp.
- *Wilkingia* sp.

Trilobite
- *Ameura sangamonensis*

STOP 3: SNIABAR LIMESTONE MEMBER of HERTHA LIMESTONE (lower part)

Brachiopods
- *Planispina armata*
- *Composita subtilita*
- *Composita argentea*
- *Neospirifer triplicatus*
- *Derbyia crassa*
- *Kozlowskia splendens*
- *Phricodothyris perplexa*
- *Chonetinella flemingi*
- *Meekella striatocostata*
- *Cleiothyridina orbicularis*

Corals
- *Amandophyllum?* sp.
- *Stereostylus* sp.
- *Kionophyllum?*
- *Sestrophyllum?* sp.
- *Cladochonus?* sp.
- *Syringopora?* sp.

Bryozoans
- *Rhombopora* sp.
- *Cyclotrypa zonata*
- *Fenestrellina* sp.
- *Polypora* sp.
- *Septapora* sp.

Echinoids
- Aristotle Lantern pyramid plates
- interambulacral plates
- spines
- teeth

Crinoids
- pentagonal stems
- plates

Fish
- teeth

Foram
- *Climacammina* sp

Trilobite
- *Ameura sangamonensis*

Clams
- *Nuculopsis* sp.
- *Permophorus* sp.
- *Edmondia* sp.
- *Parallelodon* sp.
- *Wilkingia* sp.
- *Myalina (Orthomyalina)*

STOP 4: BETHANY FALLS LIMESTONE MEMBER (lower part: quarry floor)

Brachiopods
- *Juresania nebrascensis*
- *Antiquatonia portlockianus*
- *Wellerella osagensis*
- *Composita subtilita*
- *Composita argentea*
- *Neospirifer triplicatus*
- *Neospirifer triplicatus alatus*
- *Neospirifer latus*
- *Punctospirifer kentuckyensis*
- *Derbyia crassa*
- *Linoproductus prattenianus*
- *Meekella striatocostata*
- *Cleiothyridina orbicularis*
- *Chonetinella flemingi*
- *Dielasma bovidens*
- *Phricodothyris perplexa*
- *Echinaria semipunctatus*
- *Crurithyris planoconvexa*
- *Leptalosia ovalis*
- *Crania modesta*
- *Planispina armata*
- *Hustedia mormoni*
- *Kozlowskia splendens*
- *Hystriculina* sp. aff. *H. hystriculina*

Bryozoans
- *Rhombopora* sp. cf. *R. lepidodendroides*
- *Fenestrellina* sp.
- *Fenestella* sp.
- *Cyclotrypa* sp.
- *Septapora* sp.
- *Rhabdomeson* sp.
- *Megacanthopora* sp.
- *Tabulipora* sp.
- mitoclemid
- *Polypora* sp.

Trilobite
- *Ameura sangamonensis*

Foraminifers
- *Polytaxis* sp.
- *Climacammina* sp.
- fusulinid (probably *Eowaeringella ultimata*)

Corals
- *Stereostylus* sp.
- *Sestrophyllum* sp.
- *Cladochonus* sp.

Snails
- *Straparollus (Straparollus)* sp.
- *Straparollus (Amphiscapha)* sp.
- *Naticopsis (Jedra)* sp.
- *Naticopsis (Naticopsis)* sp.
- *Bellerophon (Bellerophon)* sp.
- *Platyceras* sp.
- *Discotropis*? sp.

Clams
- *Parallelodon* sp.
- *Acanthopecten* sp.
- *Aviculopecten* sp.
- *Clavicosta* sp.
- *Annuliconcha* sp.
- *Wilkingia terminale*
- *Myalina (Orthomyalina)* sp.
- *Septamyalina* sp.
- *Nuculopsis*? sp.
- *Pinna*? sp.
- *Schizodus*? sp.
- *Edmondia*? sp.
- *Streblopteria* sp.
- *Streblochondria* sp.

Cephalopods
- *Planetoceras tiltoni*
- *Metacoceras* sp.

STOP 4: STARK SHALE -- WINTERSET LIMESTONE MEMBER transition zone

Crinoids (mainly from basal inch of Winterset)
- *Laudonocrinus* sp.
- *Exocrinus* sp.
- *Plummericrinus nettingi* (variants)
- *Exoriocrinus rugosus*
- *Exoriocrinus* sp.
- *Ureocrinus*? sp.
- *Elibatocrinus* sp.
- *Erisocrinus typus*
- *Erisocrinus obovatus*
- *Aexitrophocrinus*? sp.
- *Euonychocrinus*? sp.
- *Stellarocrinus* sp.
- *Apographiocrinus typicalis*
- *Apographiocrinus angulatus*
- *Apographiocrinus arcuatus*
- *Apographiocrinus obtusus*
- *Apagraphiocrinus exculptus* (variant)
- *Agassizocrinus*? sp.
- *Delocrinus (Endelocrinus tumidus)*
- *Plaxocrinus* sp.
- *Probletocrinus*? sp.
- *Haeretocrinus wagneri* (variant)
- *Haeretocrinus washburni*
- undescribed genus
- *Hydriocrinus*? sp.
- *Metacromyocrinus*? sp.
- *Graffhamicrinus*? sp.
- *Moundocrinus*? sp.
- *Contocrinus*? sp.
- *Exactocrinus*? sp.
- *Plummericrinus* sp.

Brachiopods
- *Cancrinella boonensis*
- *Juresania nebrascensis*
- *Antiquatonia portlockianus*
- *Wellerella osagensis*
- *Rhynchopora illinoisensis*
- *Composita subtilita*
- *Composita ovata*
- *Composita argentea*
- *Neospirifer triplicatus*
- *Neospirifer triplicatus alatus*
- *Neospirifer latus*
- *Punctospirifer kentuckyensis*
- *Derbyia crassa*
- *Linoproductus prattenianus*
- *Meekella striatocostata*
- *Cleiothyridina orbicularis*
- *Chonetinella flemingi*
- *Dielasma bovidens*
- *Phricodothyris perplexa*
- *Echinaria semipunctatus*
- *Crurithyris planoconvexa*
- *Leptalosia ovalis*
- *Crania modesta*
- *Planispina armata*
- *Hustedia mormoni*
- *Kozlowskia splendens*
- *Hystriculina* sp. aff. *H. hystriculina*
- *Orbiculoidea missouriensis*

Bryozoans
- *Rhombopora* sp. cf. *R. lepidodendroides*
- *Fenestrellina* sp.
- *Fenestella* sp.
- *Cyclotrypa* sp.
- *Polypora* sp.
- *Septapora* sp.
- *Rhabdomeson* sp.
- *Megacanthopora* sp.
- *Tabulipora* sp.

Trilobite
- *Ameura sangamonensis*

Snails
- *Straparollus (Straparollus)* sp.
- *Straparollus (Amphiscapha)* sp.
- *Naticopsis (Jedra)* sp.
- *Naticopsis* sp.
- *Bellerophon (Bellerophon)* sp.
- *Baylea*? sp.

Forams
- *Polytaxis* sp.
- *Climacammina* sp.
- *Triticites* sp.

Corals
- *Stereostylus* sp.
- *Kionophyllum*? sp.
- *Amandophyllum*? sp.
- *Syringopora*? sp.
- *Michelinia* sp.
- *Sestrophyllum*? sp.
- *Cladochonus* sp.

Clams
- *Acanthopecten* sp.
- *Aviculopecten* sp.
- *Clavicosta* sp.
- *Wilkingia terminale*
- *Myalina (Orthomyalina)* sp.
- *Septamyalina* sp.
- *Nuculopsis*? sp.
- *Pinna*? sp.
- *Schizodus*? sp.
- *Edmondia*? sp.
- *Streblopteria* sp.
- *Parallelodon* sp.
- *Streblochondria* sp.

STOP 5: WEA SHALE MEMBER of CHERRYVALE FORMATION (lower part)

Brachiopods
- *Neospirifer triplicatus*
- *Neospirifer triplicatus alatus*
- *Neospirifer latus*
- *Composita trilobata*
- *Composita ovata*
- *Composita subtilita*
- *Neochonetes* sp.
- *Chonetinella flemingi*
- *Punctospirifer kentuckyensis*
- *Meekella striatocostata*
- *Cleiothyridina orbicularis*
- *Leptalosia ovalis*
- *Derbyia crassa*
- *Derbyia bennetti*
- *Derbyia* sp.
- *Linoproductus prattenianus*
- *Linoproductus missouriensis?*
- *Linoproductus platyumbonus*
- *Linoproductus* sp.
- *Dielasma bovidens*
- *Orbiculoidea capuliformis*
- *Orbiculoidea missouriensis*
- *Lingula carbonaria*
- *Juresania nebrascensis*
- *Pulchratia symmetrica*
- *Antiquatonia portlockianus*
- *Phricodothyris perplexa*
- *Crurithyris planoconvexa*
- *Echinaria semipunctatus*

Trilobite
- *Ameura sangamonensis*

Bryozoans
- *Megacanthopora* sp.
- *Rhabdomeson* sp.
- *Rhombopora lepidodendroides*
- *Cyclotrypa nebrascensis*
- *Fenestrellina*? sp.
- *Fenestella*? sp.
- *Polypora* sp.
- *Septapora* sp.
- *Tabulipora* sp.

Crinoids
- *Delocrinus* sp.
- *Aesiocrinus* sp.
- *Ethelocrinus* sp.
- *Vertigocrinus* sp.
- *Apographiocrinus* sp.
- *Erisocrinus* sp.
- *Stellarocrinus* sp.
- *Plaxocrinus* sp.
- many Pirasocrinidae, Cymbiocrinidae, and Ampelocrinidae, plates, stems, and partial cups.

Worms
- *Spirorbis* sp.
- *Serpulopsis* sp.

Forams
- *Triticites* sp.

Ostracodes
- several genera

Fish teeth
- cladodont type
- *Agassizodus*? sp.
- *Caseodus*? sp.
- *Petalodus allegheniensis*

Corals
- *Stereostylus* sp.
- *Kionophyllum*? sp.

Snails
- *Straparollus (Straparollus)* sp.
- *Straparollus (Amphiscapha)* sp.
- *Bellerophon (Bellerophon)* sp.
- *Bellerophon (Pharkidonotus)* sp.
- *Platyceras* sp.
- *Naticopsis (Naticopsis)* sp.
- *Naticopsis (Jedra)* sp.
- *Baylea*? sp.
- *Goniasma*? sp.
- *Donaldina*? sp.
- *Trepospira* sp.
- many other genera

Clams
- *Myalina (Orthomyalina)* sp.
- *Myalina (Myalinella)* sp.
- *Wilkingia terminale*
- *Septamyalina* sp.
- *Acanthopecten* sp.
- *Aviculopecten* sp.
- *Parallelodon* sp.
- *Monopteria* sp.
- *Streblopteria* sp.
- *Clavicosta* sp.
- *Clinopistha* sp.
- *Nuculopsis* sp.
- *Permophorus* sp.
- *Edmondia* sp.
- *Paleyoldia* sp.
- *Phestia* sp.
- *Solemya* sp.
- *Volsellina* sp.
- *Streblochondria* sp.
- *Pinna* sp.
- *Promytilus* sp.

STOP 7: STANZEL QUARRY: LIBERTY MEMORIAL SHALE (upper part)

Brachiopods

Enteletes hemplicatus plattsburgensis
Enteletes pugnoides
Meekella striatocostata
Neospirifer triplicatus
Neospirifer triplicatus alatus
Neospirifer latus
Composita argentea
Composita subtilita
Composita sp.
Punctospirifer kentuckyensis
Cleiothyridina orbicularis
Leptalosia ovalis
Derbyia crassa
Derbyia sp. cf. *D. wabaunseensis*
Derbyia sp. cf. *D. plattsmouthensis*
Derbyia sp.
Linoproductus prattenianus
Linoproductus magnispinus
Linoproductus missouriensis
Neochonetes granulifer
Dielasma bovidens
Chonetinella sp.
Chonetinella flemingi
Cancrinella boonensis
Orbiculoidea capuliformis
Orbiculoidea missouriensis
Orbiculoidea sp.
Lingula carbonaria
Streptorhynchus sp.
Juresania nebrascensis
Juresania ovalis
Pulchratia symmetrica
Antiquatonia portlockianus
Phricodothyris perplexa
Crurithyris planoconvexa
Echinaria sp. cf. *E. moorei*

Crinoids

Neocatacrinus protensus
Erisocrinus typus
Delocrinus hemisphericus
Endelocrinus kieri
Ethelocrinus sp.
Aglaocrinus pustulosus
Ulocrinus kansasensis
Ulocrinus buttsi
Exoriocrinus multirami
Vertigocrinus parilis
Plaxocrinus discus
Sciadiocrinus sp.
Stenopecrinus hexagonus
Glaukosocrinus sp.
Stellarocrinus exculptus
Plummericrinus nettingi (variant)
Schistocrinus sp.
Aatocrinus sp.
Parethelocrinus expansus
Metaperimestecrinus sp.
Aesiocrinus sp.
Oklahomacrinus? sp.
Parulocrinus? sp.
Hydriocrinus turbinatus
Laudonocrinus subsinuatus
Bathronocrinus madisonensis
Terpnocrinus ellipticus
Neoprotencrinus sp. cf. *N. subplanus*
Contocrinus kingi
Apographiocrinus typicalis
Isoallagecrinus sp.
many Pirasocrinidae, Cymbiocrinidae, and Ampelocrinidae, plates, stems, and partial cups.

Clams

Wilkingia terminale
Myalina (Orthomyalina) sp.
Septamyalina sp.
Nuculopsis sp.
Paleyoldia? sp.
Clinopistha? sp.
Promytilus? sp.
Pinna? sp.
Aviculopecten sp.
Acanthopecten sp.
Clavicosta sp.
Schizodus? sp.
Edmondia? sp.
Sanquinolites sp.
Streblopteria sp.
Permophorus sp.
Phestia sp.
Septimyalina sp.
Streblochondria sp.
several other genera

Snails

Straparollus (Straparollus) sp.
Straparollus (Amphiscapha) sp.
Bellerophon (Bellerophon) sp.
Bellerophon (Pharkidonotus) sp.
Euphemites sp.
Platyceras sp.
Baylea? sp.
Discotropis? sp.
Naticopsis (Naticopsis) sp.
several other genera

Forams

Polytaxis sp.
Climacammina

Fish teeth

cladodont type
Agassizodus? sp.
Caseodus? sp.
Petalodus alleghenienis
Janassa bituminosa
several other genera

Bryozoans

Megacanthopora sp.
Rhabdomeson sp.
Rhombopora sp. cf. *R. lepidodendroides*
Cyclotrypa carbonaria
Fenestrellina? sp.
Fenestella? sp.
Polypora? sp.
Septapora sp.

Cephalopods

Metacoceras sp.
Tainoceras sp.
Brachycycloceras sp.
several other genera

Trilobite

Ameura sangamonensis

Coral

Stereostylus sp.

Worms

Spirobis sp.
Serpulopis? sp.
Phosphannulus sp. on crinoid stems and brachiopods

Echinoids

Aristotle Lantern pyramid plates
interambulacral plates
spines
teeth

Ostracodes

several genera

Unknown borings in calcareous nodules, brachipods, bryozoans, and clams

STOP 7: STANZEL QUARRY: PLATTSBURG LIMESTONE (lower part)

Brachiopods
- *Juresania nebrascensis*
- *Pulchratia symmetrica*
- *Neospirifer triplicatus*
- *Neospirifer latus*
- *Punctospirifer kentuckyensis*
- *Composita subtilita*
- *Cleiothyridina orbicularis*
- *Chonetinella flemingi*
- *Linoproductus prattenianus*
- *Linoproductus missouriensis*
- *Leptalosia ovalis*
- *Meekella striatocostata*
- *Derbyia crassa*
- *Antiquatonia portlockianus*
- *Cancrinella boonensis*
- *Dielasma bovidens*

Bryozoans
- Fenestellidae
- *Polypora* sp.
- *Septapora* sp.
- *Rhombopora* sp.
- *Rhabdomeson* sp.
- *Megacanthopora* sp.
- *Cyclotrypa* sp.

Clams
- *Septimyalina* sp.
- *Myalina (Orthomyalina)* sp.

Fish
- *Petalodus* sp.
- cladodont type

Cephalopod
- *Pseudorthoceras* sp.

Crinoids
- stems
- plates

Worms
- *Spirorbis* sp.
- *Serpulopsis* sp.

Coral
- *Stereostylus* sp.

Echinoids
- Aristotle Lantern pyramid plates
- interambulacral plates
- spines
- teeth

Trilobite
- *Ameura sangamonensis*

Ostracodes
- several species

Snails
- *Bellerophon (Bellerophon)* sp.

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