1989

Late Pennsylvanian and Early Permian Cyclic Sedimentation, Paleogeography, Paleoecology, and Biostratigraphy in Kansas and Nebraska

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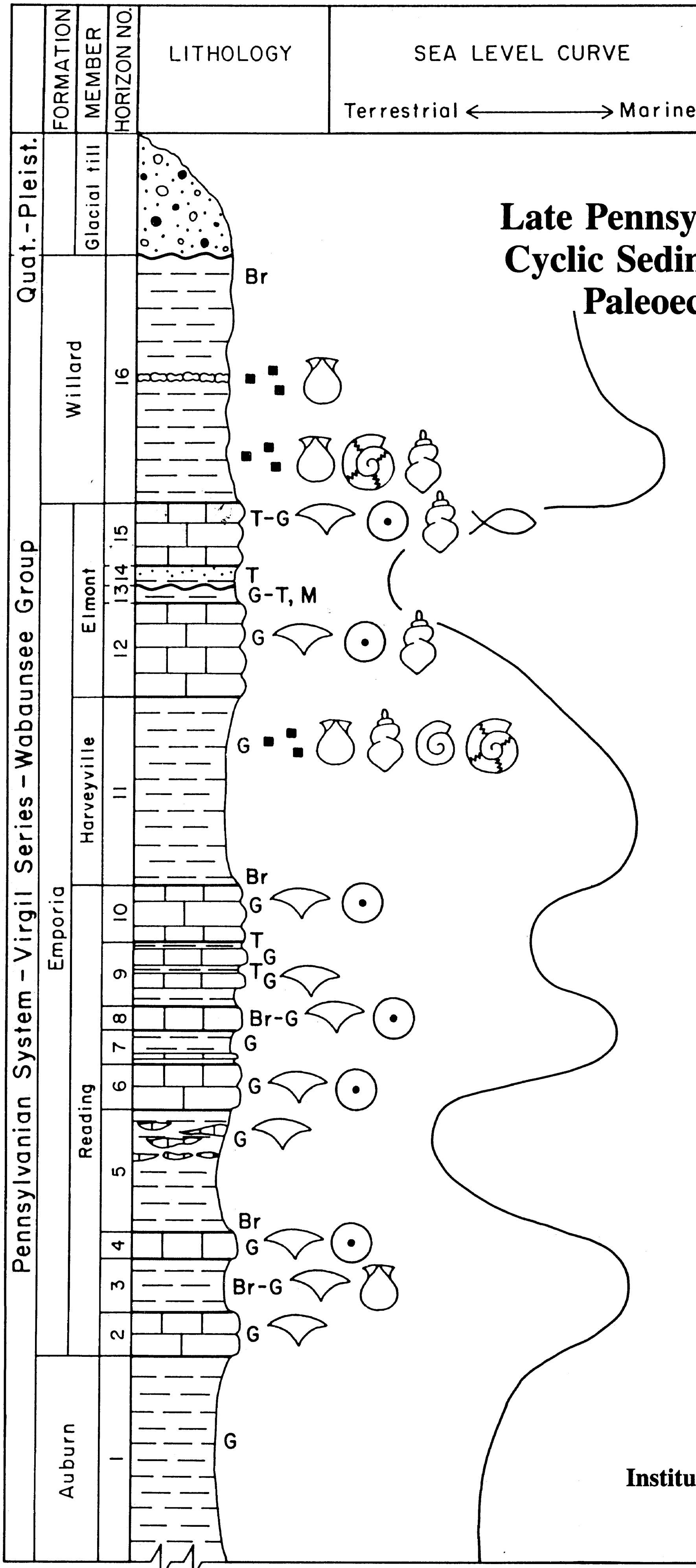

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Compiled by:
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Guidebook
for a pre-meeting field trip
in conjunction with the
1989 annual meeting
of the Geological Society of America,
St. Louis, Missouri,
November 6-9, 1989

Nebraska Geological Survey
Conservation and Survey Division
Institute of Agriculture and Natural Resources
University of Nebraska–Lincoln

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October 1989

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Overview of Upper Pennsylvanian Cyclic Sedimentation in Kansas and Nebraska

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Introduction

The cyclic alternation of limestone and shale formations in the Upper Pennsylvanian sequence (fig. 1) along the Midcontinent outcrop belt (fig. 2) 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 in Illinois. This term was adopted in the Midcontinent outcrop area by Moore (1936). Weller (1930) invoked a model of periodic tectonism to explain both the overall alternation and the individual cyclothem. 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 (e.g., Galloway and Brown, 1973), and these have been extended to Illinois (Merrill, 1975). 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 recently has been more fully developed by Heckel (1977, 1980), who recognized the cyclothems as basically marine transgressive-regressive sequences, centered on the thin, nonsandy, black phosphatic ("core") shales, which represent maximum inundation of the shelf, and with most deltas forming during the succeeding regressive phases. The eustatic model has been applied to the sequence in Texas by Boardman and Malinky (1985) and Boardman and Heckel (1989).

Basic Cyclothem

The term cyclothem has been applied to a number of different, but related and quite specific, repeating lithic successions in the Pennsylvanian (e.g., Moore, 1936, 1950; Weller, 1958; see review in Heckel, 1984a). Current work on the mid-Desmoinesian to mid-Virgilian sequence in the Midcontinent has established the nature of the basic transgressive-regressive ("Kansas") cyclothem (fig. 3). This cyclothem resulted from a major rise and fall of sea level over the northern Midcontinent shelf (fig. 2), extending from the Arkoma-Anadarko basinal region of central Oklahoma across the lower parts of the North American craton.

Positional members and lithologies of cyclothemic units have been described in great detail by Heckel (1977) and more recently have been reiterated (Heckel, 1985). These are briefly summarized in figure 3. Some variance may be observed in any of the positional members, and these are covered in detail at each of the stops on this trip.

Conodont Information

The successions of conodont faunas at closely spaced vertical intervals of all lithic units in a Missourian outcrop sequence and in two upper Desmoinesian cores have been presented by Heckel and Baesemann (1975) and Swade (1985). Since the original vertical sequence was established, further work by many students and myself has shown that the distinctive vertical successions of conodont faunas in the major Kansas cyclothems (fig. 3) maintain their integrity laterally from the northern limit of outcrop to the basinal region of Oklahoma.

Distinctive differences in conodont faunas between offshore and nearshore parts of the cyclothem appear related to characteristic water masses that covered the shelf at different sea-level stands (Swade, 1985), and these are summarized in figure 4.

The onshore-offshore trend in conodont distribution is paralleled by an onshore-offshore trend in other marine fossil groups (fig. 5), delineated by Boardman and others (1984).

Other Cycles

Because both the original and more recent focus of interest has been on the classic cyclothem sequences, the portions of the sequence 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 Kansas cyclothem (fig. 3), the inundation must have been slow enough to develop limestone

Note: Stratigraphic nomenclature used by authors outside Nebraska may not agree with that used by the Nebraska Geological Survey (Conservation and Survey Division, UNL). Additional copies may be obtained from the Conservation and Survey Division, 113 Nebraska Hall, University of Nebraska-Lincoln, Lincoln, NE 68588-0517.

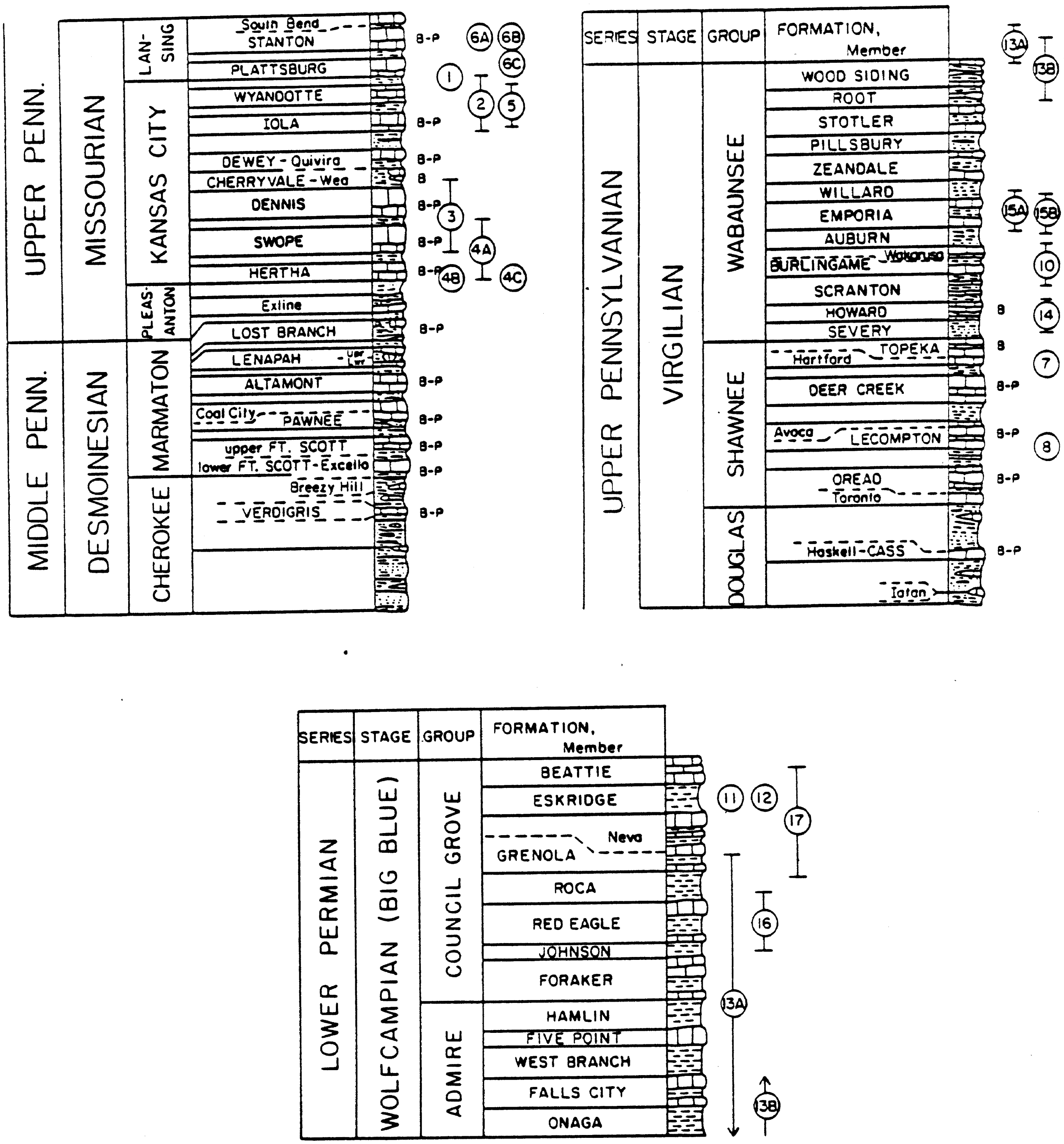


Fig. 1. Generalized Pennsylvanian and Permian stratigraphic sequence along outcrop belt from Kansas to Nebraska. Numbers indicate approximate stratigraphic intervals for stops.

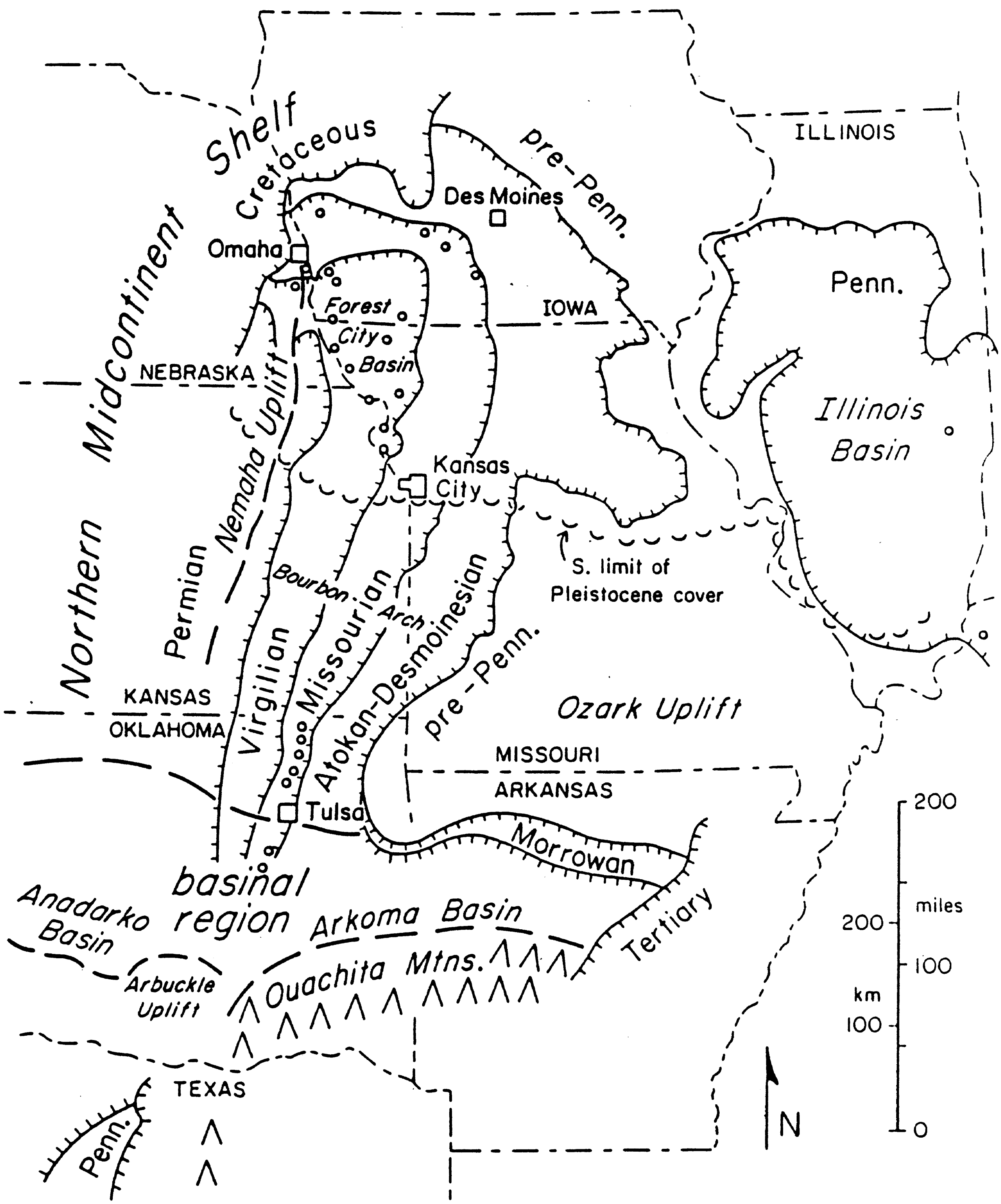


Fig. 2. Map of Midcontinent Pennsylvanian outcrop belt with hachures in direction of dip, showing relation to generalized Pennsylvanian-Permian structural features (after Moore, 1979).

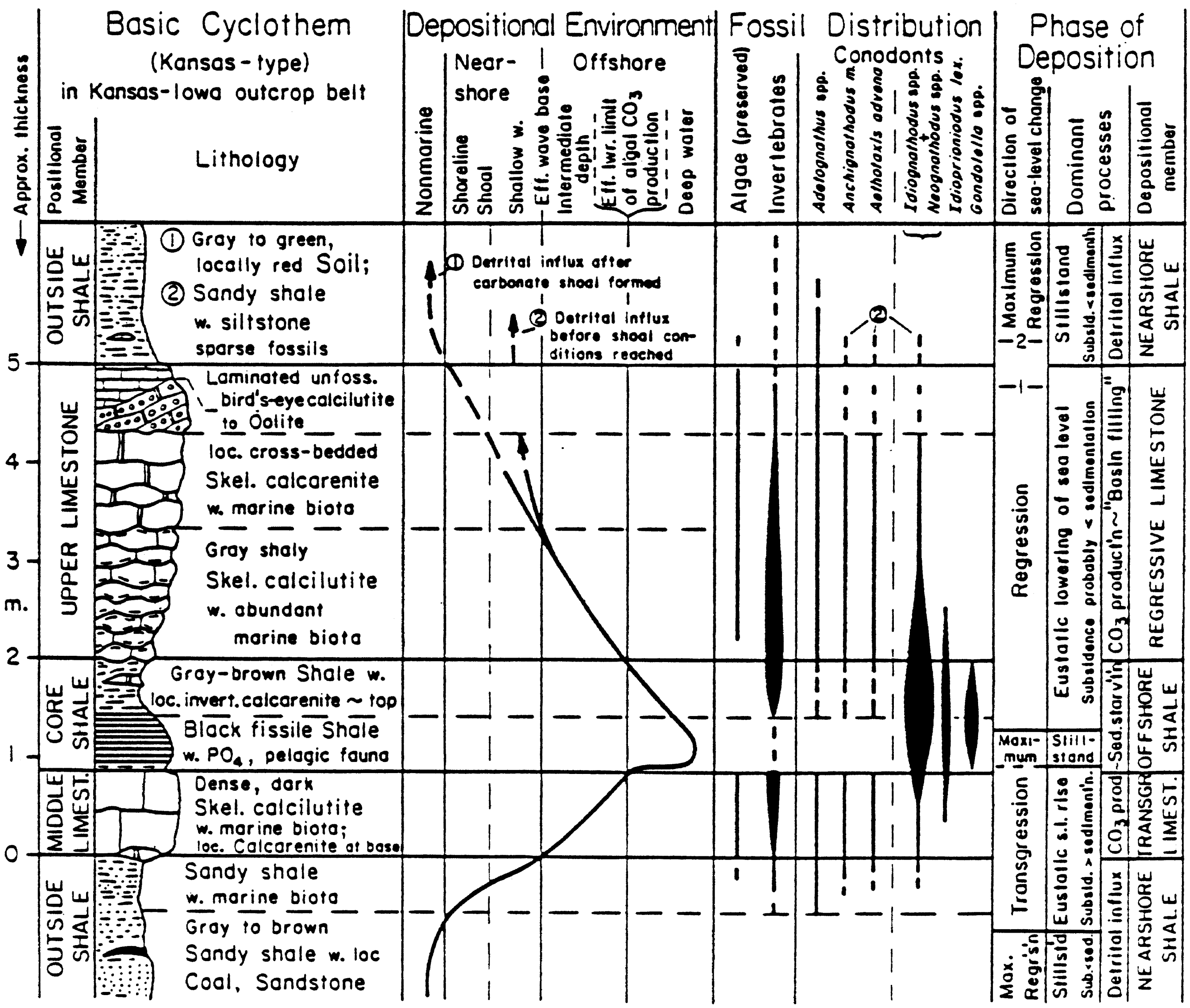


Fig. 3. Basic Kansas cyclothem characterizing (with minor modifications) all major and many intermediate cycles across the northern Midcontinent Shelf (modified from Heckel, 1984b).

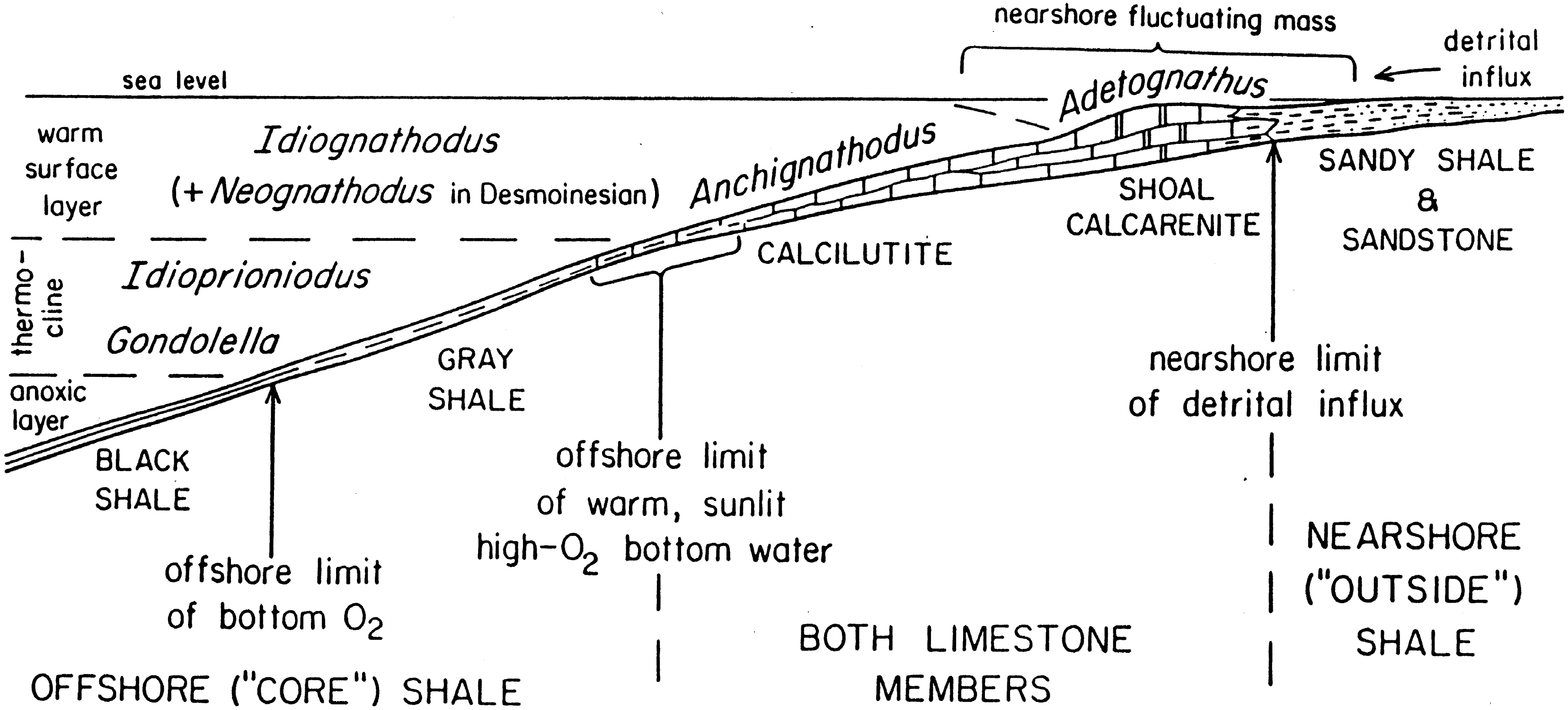


Fig. 4. Inferred living distribution of six major conodont genera in Midcontinent Pennsylvanian sea relative to major water masses developed at maximum transgression (modified from Heckel and Baesemann, 1975; and Swade, 1985).

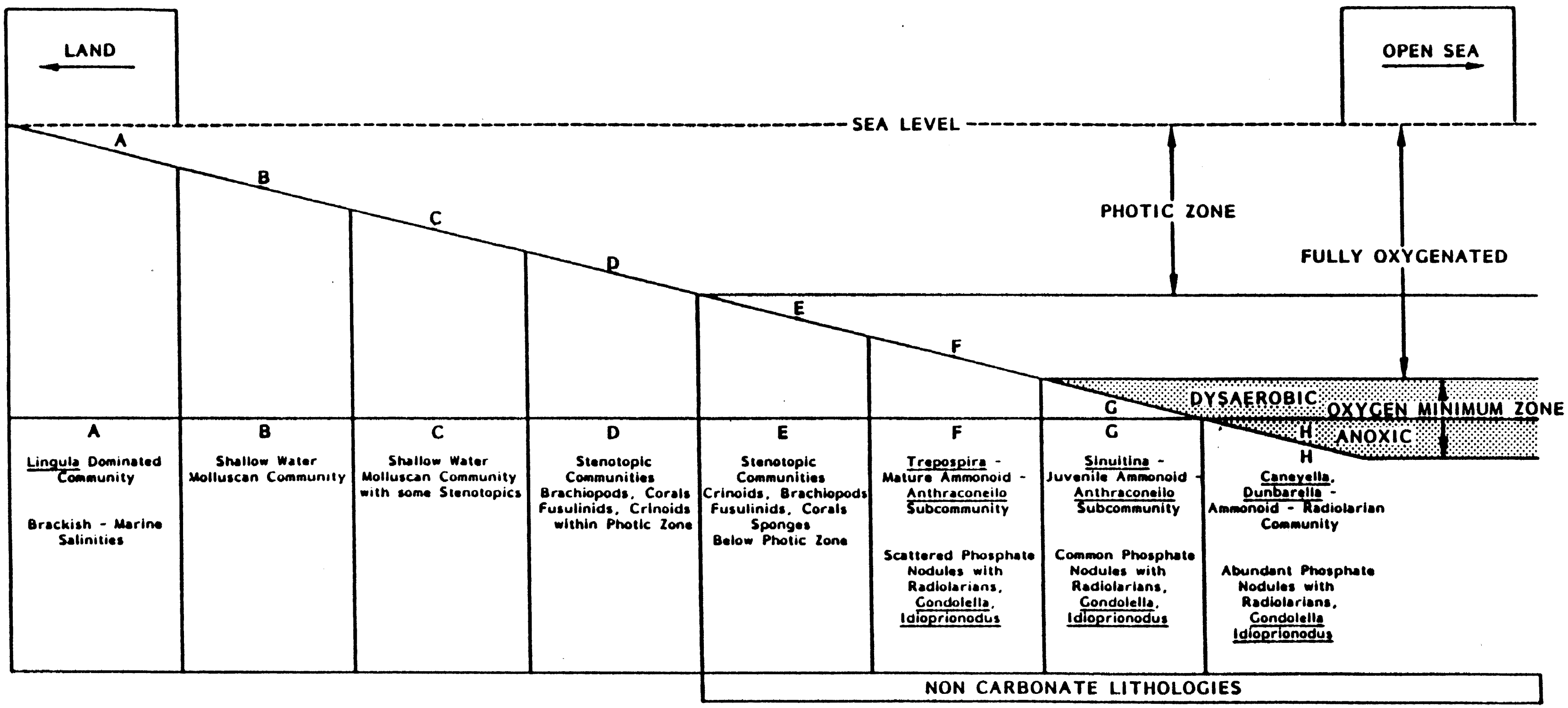


Fig. 5. Onshore-offshore model for Pennsylvanian community succession related to water depth and overlying water masses (from Boardman *et al.*, 1984, p. 171).

over most of the shelf and deep enough to establish a thermocline, and thus the black phosphatic facies over much of the shelf; furthermore, the withdrawal must have been slow enough and sufficiently free of detrital influx to develop 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 Kansas cyclothem would have resulted if: 1) the inundation was too fast to allow carbonate formation; or 2) the inundation was not far enough to become sufficiently deep to establish a thermocline for black shale formation; or 3) the withdrawal was too fast to allow carbonate formation; or 4) the withdrawal was not far enough to form a complete regressive sequence; or 5) the withdrawal occurred during a time of overwhelming detrital influx. Those horizons that lack a transgressive limestone have been termed "Illinois" cyclothems because of their common development in the Illinois basin. Lack of more characteristics leads progressively to both less distinctive sequences and more controversy as to their designation as cyclothems.

Several cyclothems in the Late Pennsylvanian Wabaunsee Group and Early Permian Admire Group of Nebraska also lack regressive limestones because of nearness of detrital influx at that time (Pabian, 1989). These will be covered at their respective stops.

Some units have been forced into older cyclothemic classifications only with difficulty, e. g., the Critzer Limestone(stop 4). In order to avoid both the controversy over whether or not to call these units cyclothems and the plethora of generally ignored cyclothem types that have been named to accommodate the incomplete sequences (e.g., Moore, 1950; Weller, 1958), I have generally used the term cyclothem for only the more complete sequences. However, because most traceable marine horizons on the shelf, however poorly developed as cyclothems, do represent a cycle of marine inundation and retreat, and thus need a term for easy reference, I use the term "cycle" for this record of marine inundation and withdrawal.

Furthermore, I have classified cycles into three categories for the purpose of further analysis, based partly on extent of transgression onto the shelf (Heckel, 1985).

Ultimate Controls

Analysis of the probable lengths of time for these types of marine cycles of transgression and regression has been based on sets of assumptions explained elsewhere (Heckel 1986) and has been estimated at a range of about 235,000 to 400,000 years for the major cyclothems, about 120,000 to 220,000 years for the intermediate cycles, and about 44,000 to 120,000 years for the minor cycles. The estimated ranges for all types of cycles fall within the 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). The thin, shallowing-upward depositional sequences observed within the regressive Winterset Limestone of the Dennis cycle in eastern Kansas (stop 3) are minor cycles that appear to be punctuated aggradational cycles (PACs of Goodwin and Anderson, 1985), which may reflect the shorter orbital periods. Examples of PACs will be observed at stop 3 (Heckel, 1985).

Conclusion

It appears that great strides have taken place in the last 20 years in understanding the significance of the cyclic stratigraphy of the Midcontinent Pennsylvanian. From my perspective, a number of milestones stand out:

1) More actualistic models of depositional environments than were available to the early workers have allowed recognition of the once enigmatic black phosphatic shales as offshore shelf deposits, that is, at the deep-water end of a large epicontinental shallow sea. This not only provided a rationale for their being widely traceable along outcrops and across large parts of the subsurface, but also obviated the old controversy between tectonically implausible oceanic depths and stratigraphically implausible shoreline lagoonal environments for the deposition of the widespread black shales.

2) The use of conodont abundance to identify these deposits as zones of sediment starvation and convergence and to help trace them into time-equivalent gray shales and invertebrate calcarenites, in conjunction with the use of conodont genera to supplement lithic characters in placing other carbonate and shale facies into paleoenvironmental perspective, has allowed much better definition of stratigraphic relations within the entire sequence. The delineation by Boardman and others (1984) of macrofossil biofacies that parallel the conodont distribution pattern has greatly strengthened our understanding of the paleoecology of the cyclic sequence. This has resulted in the recognition of major eustatic cycles in the Oklahoma and Texas sequences where nearby deltaic detrital sources locally overwhelmed carbonate production in enough places to render most limestones discontinuous and to obscure the dark offshore shales at the base of thick prodeltaic sequences. Detailed biostratigraphic study of the conodonts, ammonoids, fusulinids, and palynomorphs holds great promise for correlation of cycles into other regions. This is being realized with the correlation of all major, most intermediate, and several minor cycles between the Mid-

continent and Texas sequences (Boardman and Heckel, 1989).

3) The study of long cores (fig. 6) held by the Iowa, Nebraska, and Missouri geological surveys has revealed both that the major cycles do indeed maintain their lateral integrity across large parts of the outcrop that are obscured by Pleistocene cover, and that deltaic deposits are quite rare in the more northern areas (fig. 7). This insignificance of deltas in these areas, combined with the increasing recognition of widespread paleosols and subaerial exposure surfaces upon the regressive carbonates, alternating with widespread offshore deposits over the same broad region, indicates that eustatic events must have been paramount in the control over Midcontinent cyclic stratigraphy. This has helped put the delta-shifting model into its proper perspective as a minor cycle-producing mechanism at work only in areas adjacent to detrital influx during times of relative stillstand or regression, and pretty much at the mercy of eustatic events.

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, pioneered by Busch and Rollins (1984) in the Appalachians, can be tested. (See Boardman and Heckel, 1989.) From this we can document the significance and scale of these eustatic events and evaluate their relations to possible ultimate causes, which at this point seem to involve the waxing and waning of Gondwanan ice caps and associated climatic changes resulting from the variations in the earth's orbital parameters in its revolution around the sun, but could also involve the large-scale effects of tectonic movements if they occur with similar frequencies, a problem that seems well worth addressing.

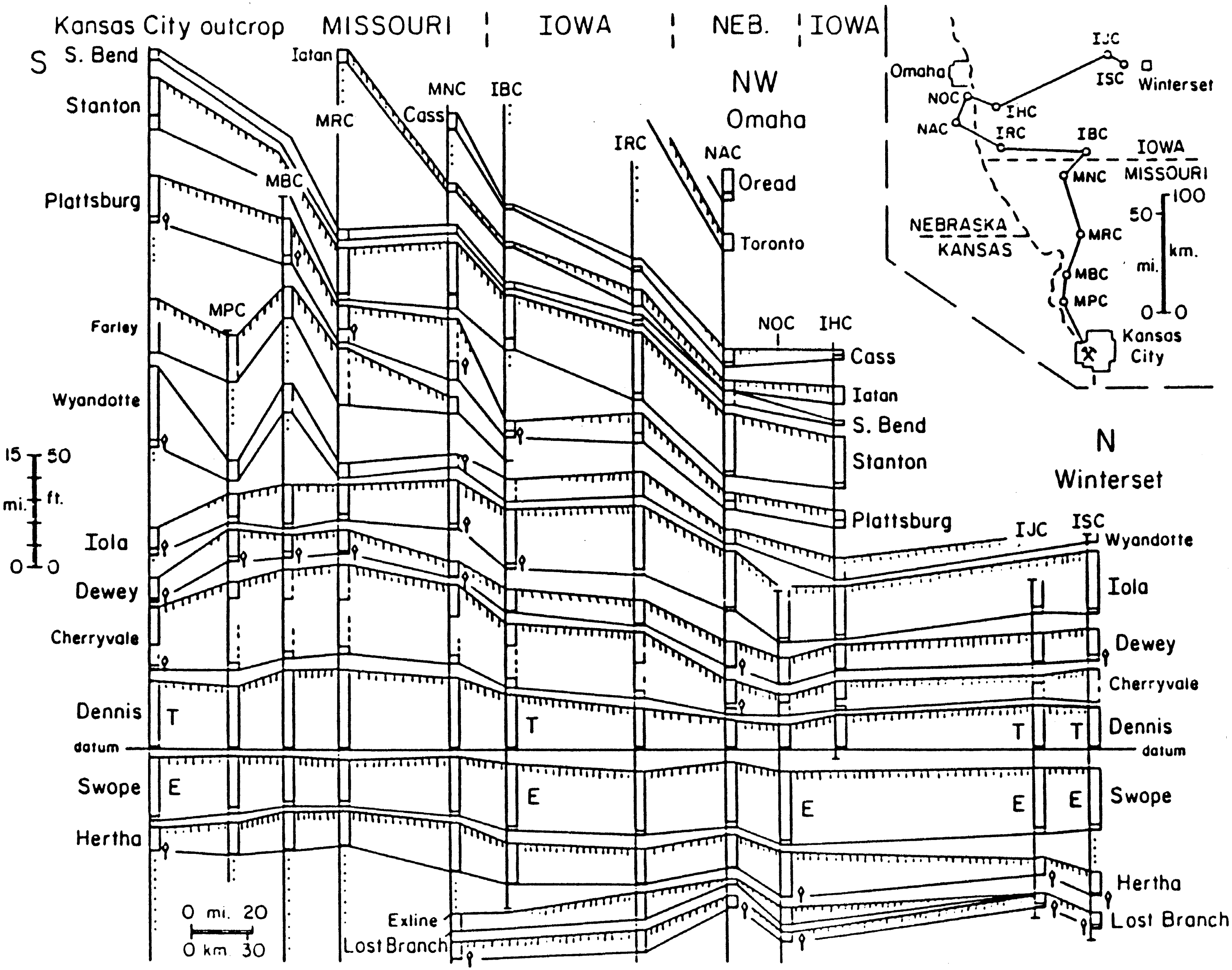


Fig. 6. Cross section of Missourian rocks across north end of Forest City Basin, from Omaha, Nebraska, eastward to Des Moines, Iowa, and southward to Bedford, Iowa, and Kansas City area.

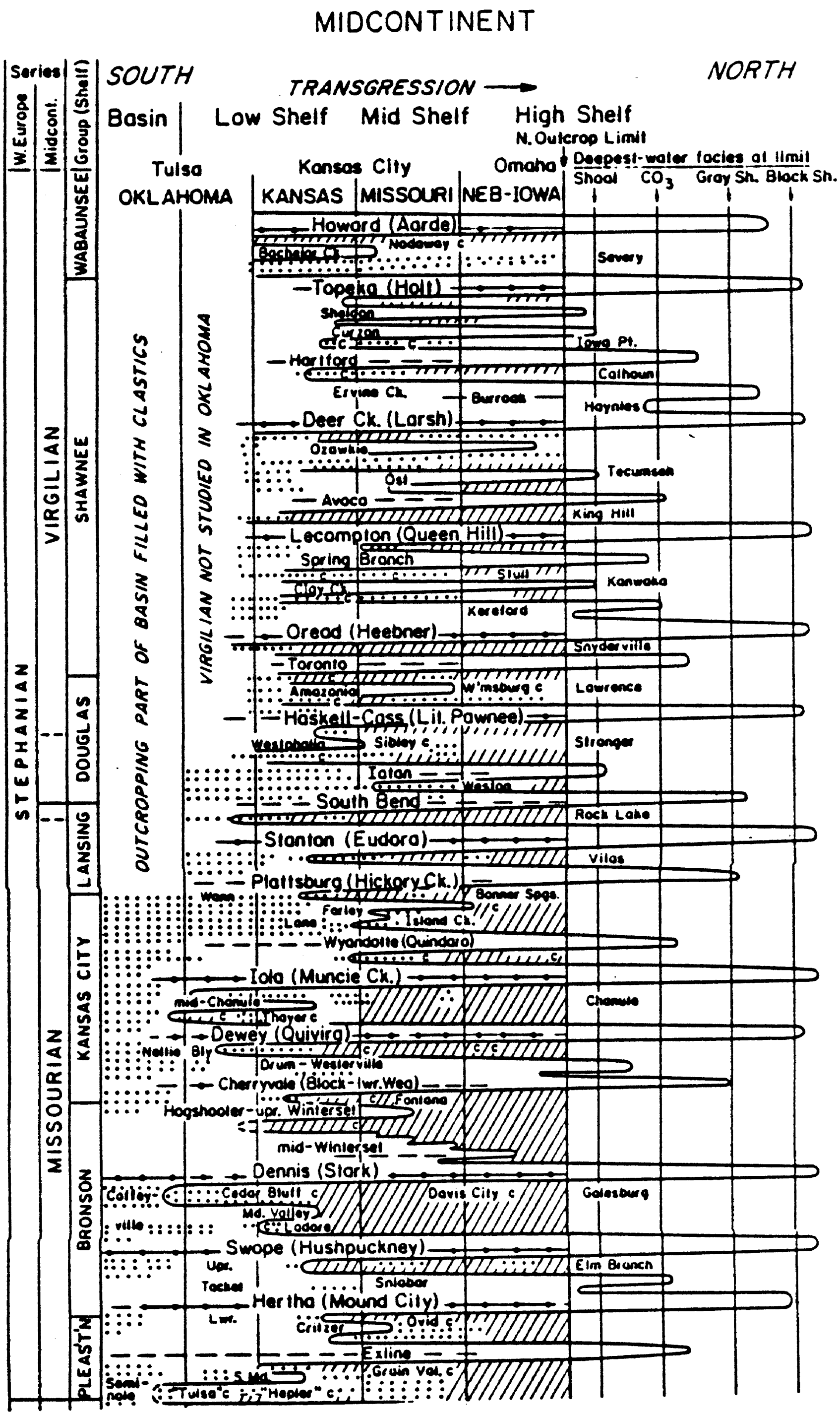


Fig. 7. Sea-level curve for part of Middle-Upper Pennsylvanian sequence along northern Midcontinent outcrop belt and near-subsurface, based on shoreline positions estimated from 1) farthest basinward extent of exposure surfaces (///) and fluvial-deltaic complexes (...) for low stand, and 2) farthest shelfward extent of marine horizons for minor cycles, and deepest water facies preserved at northern erosional outcrop limit for more major cycles. Size of letters reflects classification of cycles as major, intermediate, or minor.

Description of Field Trip Stops

FIRST DAY: Buses ready to load at 6:45 a.m. Leave motel at 7 a.m.

Drive about 20 miles southward on I-435 toward Kansas City, Kansas.

ROUTE: Kansas stops 1-9, see figure 8. Nebraska stops 10-17 are shown on figure 26.

STOP 1: NORTHEAST INTERCHANGE AROUND A SECTION OF A CLOVERLEAF AT THE INTERSECTION OF I-70 AND I-435, SW 1/4, SEC. 12, T. 11 S., R. 23 E., WEST OF KANSAS CITY, KANSAS (fig. 9) (40 minutes).

Leaders: John Harris and David Ball.

Things to see: Units examined at stop 1 include the upper Farley Limestone of the Wyandotte Formation, the Bonner Springs Shale, and the Merriam Limestone, Hickory Creek Shale, and Spring Hill Limestone members of the Plattsburg Formation. Emphasis will be on the dramatic thickness and facies variations of the Bonner Springs Shale and the overlying Merriam Limestone.

Approximately 1 m (3-4 ft) of the upper Farley Limestone is exposed at the base of the outcrop. The presence of cross-bedded grainstone near the top of the unit suggests deposition in very shallow water under shoaling conditions. Isolated rip-up clasts or mud-clast conglomerates capping the upper Farley indicate possible subaerial exposure or deposition by storm currents.

The Bonner Springs Shale ranges from 8.2 m (27 ft) thick on the south side of the road to less than 0.9 m (3 ft) thick at the northwest end of this exposure. The Bonner Springs consists of a medium-gray, silty-to-sandy shale with numerous isolated laminae and thin beds of sandstone with soft sediment deformation. Brachiopods are abundant near the northwest end of the outcrop as the shale grades laterally into sandstone. Small starfish have also been found on the upper bedding surfaces of sandstone lenses at this locality. A red iron-stained zone near the top of the Bonner Springs Shale seems to be laterally persistent in thicker exposures in the area. This red zone disappears as it is traced laterally across this outcrop. Sandy, fossiliferous lags, localized conglomerates, and mud cracks are also present at the top of the Bonner Springs. The slope of the upper surface of the Bonner Springs in this exposure maintains about a 5-degree angle as the unit thins to the northwest. If the shale was de-compacted 50 percent, the resulting dip would be 12 degrees. Depositional slopes on the modern Mississippi River delta average about 0.5 degree and reach a maximum of 2 degrees. The presence of mudcracks, sandy lags, and conglomerates near the top of the unit, the steep slope, and the truncation of the red zone that is present near the top suggest that the upper surface of the Bonner Springs Shale is the result of erosion. Most of the observed thickness variation is therefore due to truncation of the section from the top downward along an unconformity. (The lateral extent of the erosional surface present here and in other local outcrops is unknown and may be related to the development of localized structures. On a subregional scale, the widespread nature of marine shale and carbonate units suggests that very little erosion has occurred in the northern outcrop belt. Localized paleosols and subaerial exposure surfaces are present in both shale and carbonate units. However, erosion of these units is much more common to the south, towards the source of terrigenous influx.)

The Merriam Limestone Member of the Plattsburg Formation consists of four distinct units in this and nearby exposures. A sandy basal lag unit, with localized conglomerate ranging up to 0.6 m (2 ft) thick, is generally present on paleotopographic highs resulting from erosion of the underlying Bonner Springs. The sandy zone contains a diverse and abundant marine fauna including brachiopods, bryozoans, corals, bivalves, gastropods, and large myalinid clams.

The basal carbonate unit of the Merriam Limestone ranges in thickness from 2.7 m (9 ft) to less than 3 m (9.8 ft) in this exposure. This unit consists of low-angle, cross-bedded lime grainstone to packstone containing an abundant and diverse marine fauna, as well as sand, silt, oolites, and *Osagia*-coated grains. The diversity of carbonate-particle types and grain sizes suggests that large areas of the marine bottom were scoured in order to deposit these grains and create the varying thickness relationships. The lower unit of the Merriam resulted from infilling of paleotopographic lows, possibly during storms and floods, that were previously developed on the Bonner Springs Shale.

An unnamed shale unit overlies the lower Merriam carbonates at this location and ranges in thickness from 0.8 m (2.7 ft) to less than 3 cm (0.1 ft) thick across the outcrop. This shale represents low-energy terrigenous sedimentation in paleotopographic lows related to the Bonner Springs unconformity, with onlap and non-deposition of the shale on paleotopographic highs. The upper unit of the Merriam Limestone ranges in thickness from 0.64 to 0.67 m (2.1 to 2.2 ft). It undergoes very little thickness change across the outcrop. However, a lateral facies change from mudstone into high-energy coralline grainstone on the paleotopographic high records minor topographic and bathymetric relief that persisted during deposition of the upper Merriam. The upper surface of the Merriam Limestone in this and other areas consists of a burrowed or bored limonitic zone that has been described as

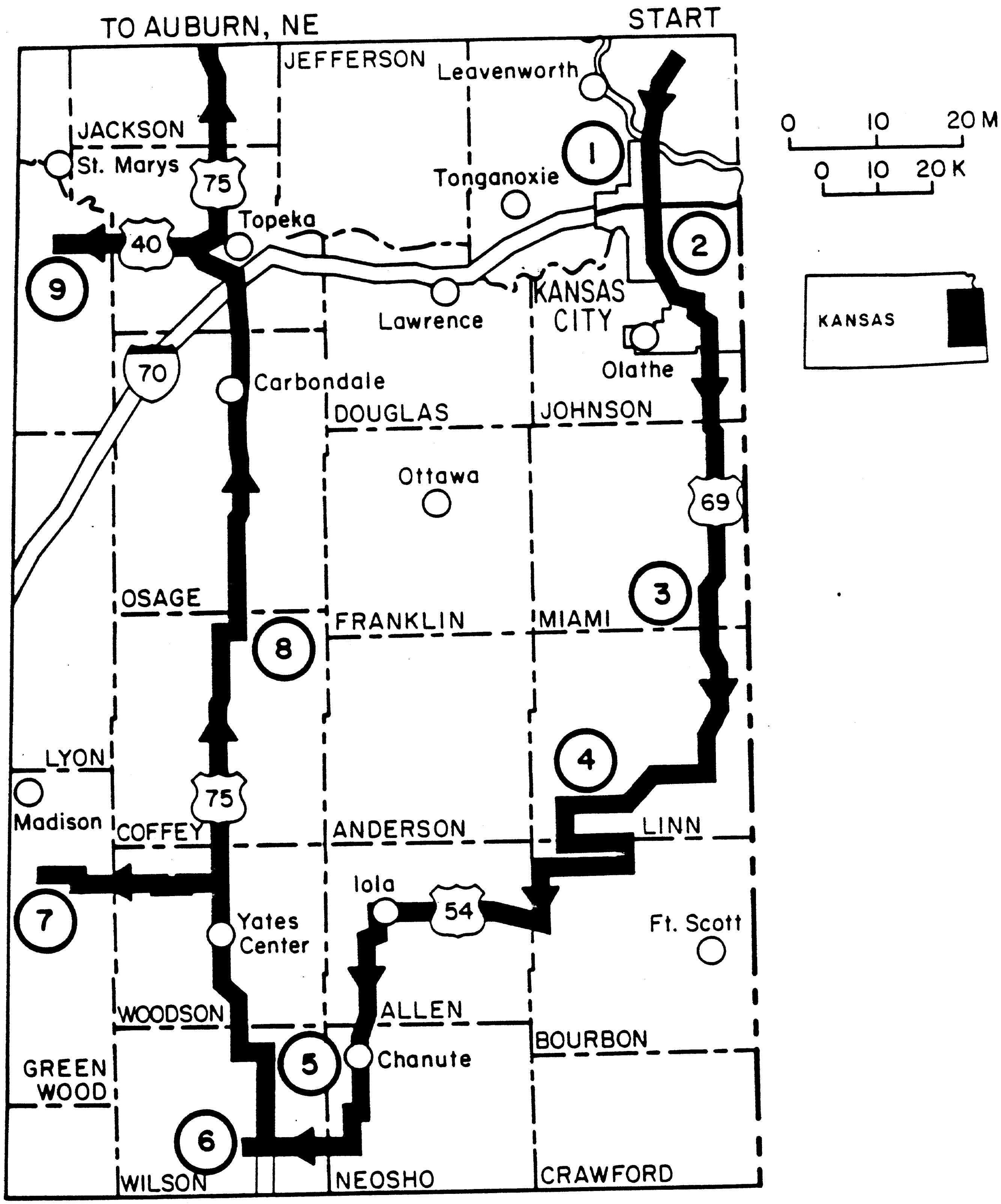


Fig. 8. Locations of field-trip stops in eastern Kansas.

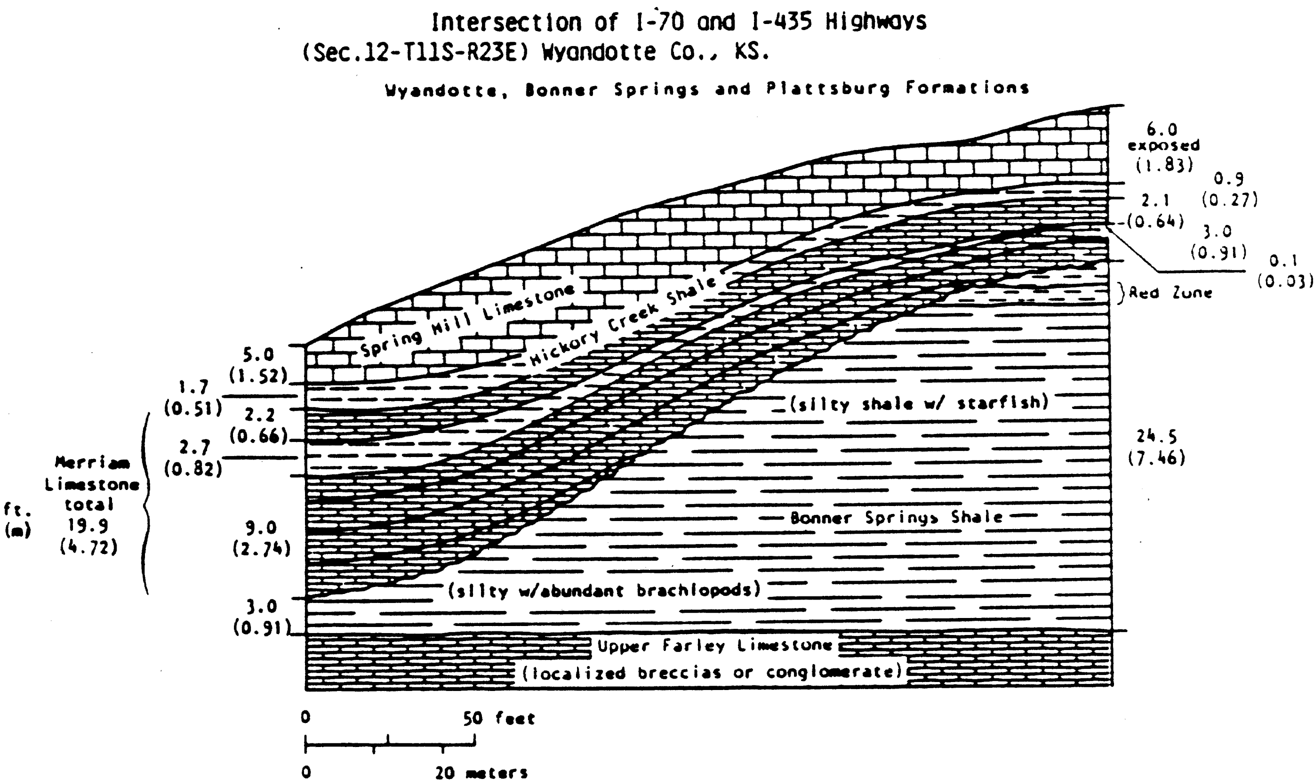


Fig. 9. Geologic section exposed at stop 1.

"wormy" by previous workers. This surface appears to be a weathered horizon, suggesting possible subaerial exposure prior to deposition of the overlying Hickory Creek Shale.

The Hickory Creek Shale consists of a medium-gray shale with dark streaks and ranges in thickness from about 0.3 to 0.5 m (1 to 1.7 ft). This subtle thickness variation suggests that slight bathymetric relief due to the unconformable surface of the Bonner Springs may have persisted at least until the time of deposition of the Hickory Creek.

The Spring Hill Limestone Member of the Plattsburg Formation consists of approximately 3.9 m (13 ft) of lime mudstone to wackestone containing numerous thin horizontally continuous shale partings. A packstone to grainstone facies at the top may represent minor progradation and shoaling-upwards conditions. The lack of thickness change or facies change, and the laterally continuous nature of the thin shale partings, suggests that little if any bathymetric relief persisted during deposition of the Spring Hill Limestone.

LEAVE STOP 1 AT 8 A.M.

Drive 5 mi, south on I-435, 1.5 mi across river and take exit around to right, pulling off before meeting Holliday Rd. (10 minutes).

STOP 2: I-435 EXIT AT HOLLIDAY RD: IOLA AND WYANDOTTE CYCLOTHEMS, NE 1/4 NW 1/4, SEC. 6, T. 12 N., R. 24 E. (fig. 10) (70 minutes).

Leader: P. H. Heckel

Things to see: the well-developed Iola Cyclothem (Mitchell, 1981) with a typical black phosphatic core shale, the prodeltaic Liberty Memorial Shale, the Wyandotte Cyclothem with a gray core shale and thicker development of algal-rich facies on a delta-lobe high (Crowley, 1969), and minor Farley cycles at the top.

The Chanute Shale records influx of prodeltaic clastics. Southward, thicker shale with sandstones and coal represent a delta-plain environment.

The Paola Limestone is a skeletal calcilutite with a diverse biota recording a major advance of the sea to quiet water below the effective wave base. Traced with little change from Iowa to Oklahoma, it is a typical transgressive limestone at the base of the Iola Cyclothem. Condonts are used to supplement paleoenvironmental interpretations of lithic sequences (Heckel, this volume, fig. 4). In the Paola, they number 10s/kg and are dominated by *Idiognathodus*, typical of the open shelf; with *Anchignathodus*, typical of shelf carbonates, throughout, *Adetognathus*, typical of nearshore environments, at the base, and *Idioprioniodus*, typical of more offshore environments, at the top (Mitchell, 1981).

The Muncie Creek Shale is the offshore ("core") shale of the Iola Cyclothem. The black shale facies with phosphorite nodules records anoxic, phosphate-rich bottom conditions that developed below a thermocline with quasi-estuarine circulation and upwelling during maximum transgression (Heckel, 1977). The gray shales above and below reflect low bottom-oxygen (dysaerobic) conditions, which developed as the thermocline was forming and as it was breaking up. Conodont abundance is the highest (100s/kg) in the entire cyclothem, and the fauna is strongly dominated by *Idiognathodus*, with *Idioprioniodus*, and also *Gondolella*, the most offshore genus, which probably was tolerant of low-oxygen water.

The Raytown Limestone is the regressive limestone of the Iola Cyclothem. The basal overpacked invertebrate calcarenite lacks cross-bedding, grain abrasion, algal grains, micrite envelopes, and early marine or meteoric cement. It records accumulation of invertebrates such as fusulinids, bryozoans, brachiopods, and crinoids in quiet water with little detrital influx but sufficient oxygen below both the effective wave base and the lower effective limit of algal activity. It was cemented very late with ferroan cements after deep burial compaction eliminated much of the original intergranular space (Heckel, 1983). It has a high conodont abundance with *Idiognathodus* dominating *Idioprioniodus*, like the underlying core shale. The upper Raytown is skeletal calcilutite, with conspicuous phylloid algae recording deposition in water shallow enough for algae, but still below the effective wave base. The thin lenticular skeletal calcarenite at the top may possibly record a storm event. Conodont faunas are again sparser, still generally dominated by *Idiognathodus*, with *Idioprioniodus* in the base and *Anchignathodus* and *Adetognathus* appearing in greater numbers toward the top. Thus, the pattern of conodont distribution in the regressive Raytown is a mirror image of that in the transgressive Paola, symmetrical about the offshore Muncie Creek Shale.

Liberty Memorial (formerly Lane) Shale records a major advance of prodeltaic clastics from the northeast that smothered accumulation of Raytown carbonates while in a quiet marine environment before regression reached the phase of shoal-water deposition. The fossiliferous zone in the base reflects the onset of terrigenous mud accumulation from the approaching delta as it began to smother the clear-water, open-marine, fossiliferous Raytown environment. Forty miles southwestward, the Liberty Memorial delta pinches out, and the overlying Wyandotte cycle sits directly upon the Iola, as can be seen at stop 5, 100 mi away, later.

The Frisbie Limestone is the transgressive limestone of the Wyandotte Cyclothem. It records a marine inundation strong enough both to swamp the detrital influx that formed the Liberty Memorial delta and to push the shoreline back northward past the Iowa outcrop. At the top are several small mounds where phylloid algae locally built up the sea bottom in the deepening water while becoming

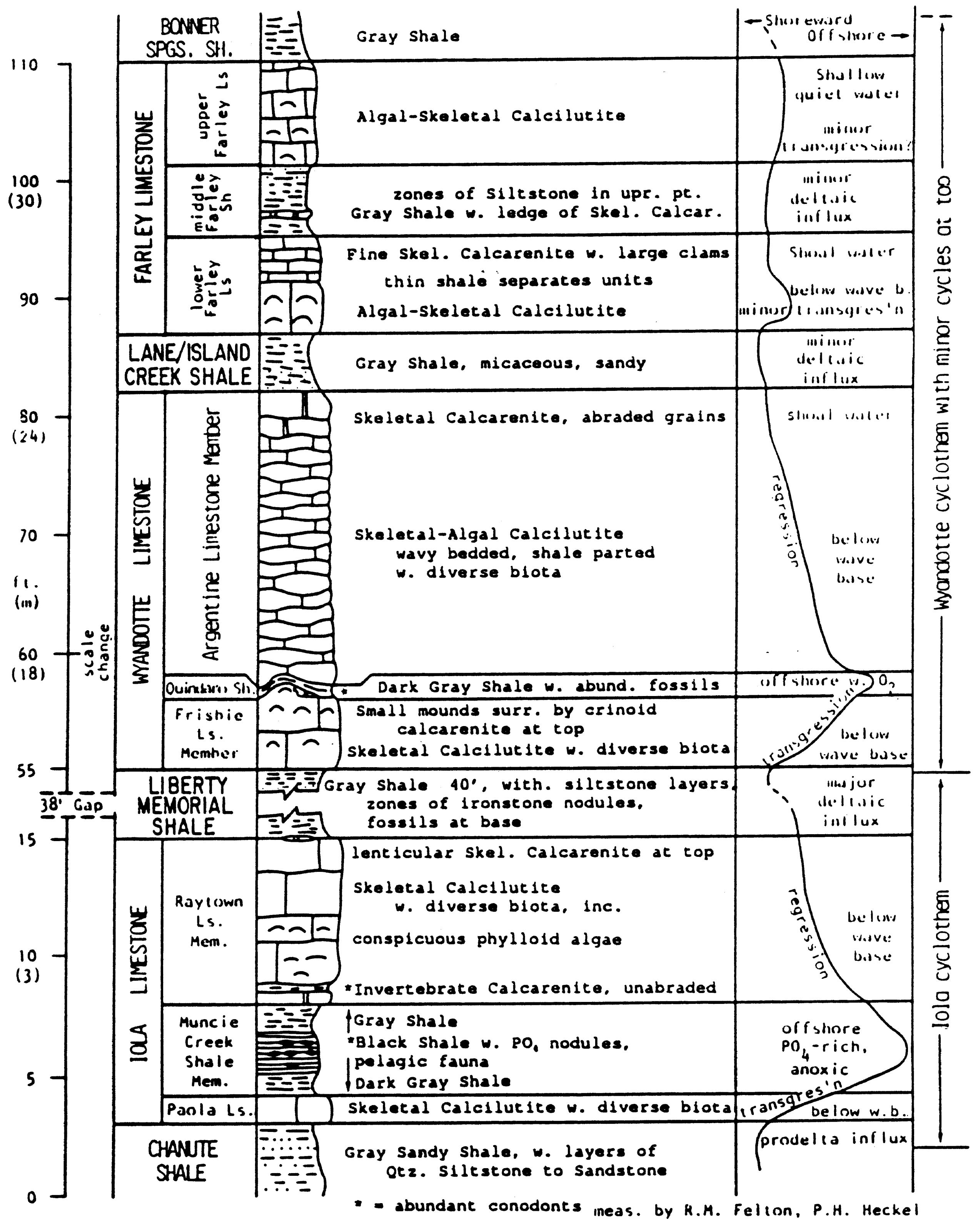


Fig. 10. Geologic section exposed at stop 2.

surrounded by crinoid thickets. The Frisbie carries a sparse *Idiognathodus* -dominated conodont fauna similar to that described for the homologous Paola (Heckel and Baesemann, 1975).

The Quindaro Shale is the core shale of the Wyandotte Cyclothem. It is gray and fossiliferous, reflecting deposition in oxygenated water even at maximum transgression. A lack of black phosphatic shale facies reflects a lack of water deep enough to develop a persistent thermocline and marks the Wyandotte as a marine cycle of intermediate scale. The abundant *Idiognathodus*-dominated conodont fauna includes *Idioprioniodus* and has been traced southward in beds formerly included in the upper Raytown at localities 40 mi southwest of here. This provides evidence for the southwestward pinchout of the Liberty Memorial delta between the Iola and Wyandotte cyclothems and indicates that the shoreline withdrew only to the Kansas City area during the regression separating the two cycles.

The Argentine Limestone is the regressive limestone of the Wyandotte Cyclothem. It consists of skeletal-to-algal calcilutite capped by skeletal calcarenite and was deposited in shallowing water to shoal conditions at the top. It forms the main part of the bedded algal bank complex described in the Kansas City area by Crowley (1969). It carries a sparse *Idiognathodus* -dominated conodont fauna, with *Anchignathodus* relatively abundant throughout (Heckel and Baesemann, 1975).

The Lane/Island Creek Shale records a minor deltaic influx from the north (Crowley, 1969). It carries a conodont fauna dominated by *Adetognathus*, the typical nearshore genus.

The Farley Limestone here comprises two carbonates (lower, upper) separated by the middle Farley Shale. Conodont faunas throughout are sparse and dominated by *Adetognathus*, with *Anchignathodus* but very few *Idiognathodus*, which suggests that the entire sequence was deposited in shallow nearshore environments. The lower Farley is a shallowing-upward sequence of algal-skeletal calcilutite deposited below the effective wave base, overlain by fine skeletal calcarenite deposited in shoal water. The middle Farley is a minor perhaps prodeltaic influx from the north (Crowley, 1969). The upper Farley is algal-skeletal calcilutite throughout, suggestinga shallow, but quiet off-shoal environment. Recorrelation of the Island Creek Shale with the type Lane Shale 50 mi to the south shows that the Farley represents one or two minor cycles of marine inundation separate from the Wyandotte below and extending only from east-central Kansas to the Missouri-Iowa border. It is so far not determined if the middle Farley Shale is persistent enough to suggest a regional regression or a local delta.

LEAVE STOP 2 AT 9:20 A.M.

Drive about 45 mi, south and east on I-435, south on US 69, to gravel road 13 mi south of K-68 (Kansas Hwy. 68), Louisburg exit. Many exposures of Wyandotte are seen along US 69. South of Louisburg, some dip to the southwest, apparently reflecting topography on the underlying thinning Liberty Memorial prodeltaic shale (60 minutes).

STOP 3: US-69 ROADCUT BY JINGO: SWOPE AND DENNIS CYCLES, SW 1/4 SE 1/4, SEC. 31, T. 18 N., R. 25 E. (fig. 11) (60 minutes).

Leader: P. H. Heckel

Things to see: well-developed Swope and Dennis cyclothems, both with black phosphatic core shales. It also shows evidence for subaerial exposure at the top of the Swope, and for minor cycles within the regressive phase of the Dennis, with subaerial exposure at the top of at least one.

The Middle Creek Limestone is the transgressive limestone of the Swope Cyclothem. Traced from Iowa to southern Kansas, it resembles the transgressive Paola Limestone seen at stop 2.

The Hushpuckney Shale is the offshore "core" shale of the Swope Cyclothem with a black phosphatic facies like that seen in the Muncie Creek Shale of the Iola Cyclothem at stop 2. It is traceable from Iowa to central Oklahoma with its characteristic abundant conodont fauna dominated by *Idiognathodus*, and including *Idioprioniodus* and *Gondolella.*

The Bethany Falls Limestone is the regressive limestone of the Swope Cyclothem. Although homologous with the regressive Raytown Limestone of the Iola Cyclothem and consisting of similar skeletal calcilutite in the lower two-thirds, it differs in having a cap of oolite and pelleted calcilutite with faint birdseye fabric, which record late-regressive shoaling before any detrital influx reached this area. Vertical, rusty, tube-like structures strongly suggest pathways of intense meteoric leaching that were later filled with ferroan dolomite during burial diagenesis. Recognition of widespread exposure surfaces and meteoric diagenesis in regressive carbonates is an important argument for the significance of eustatic drops of sea level as a major factor in the formation of Midcontinent cyclothems.

The Galesburg Shale is a gray blocky mudstone with upward-increasing amounts of mixed-layer clay relative to illite, accompanied by a decrease in crystallinity of the illite, and the appearance of some kaolinite, all of which strongly suggest formation as a paleosol (Schutter, 1983; Schutter and Heckel, 1985). These features characterize the Galesburg from east-central Kansas to the northern erosional limit of outcrop in Iowa and Nebraska. Southward,the Galesburg displays fluvial facies in southeastern Kansas and a large deltaic complex in northeastern Oklahoma, extending tens of miles south of Tulsa. This

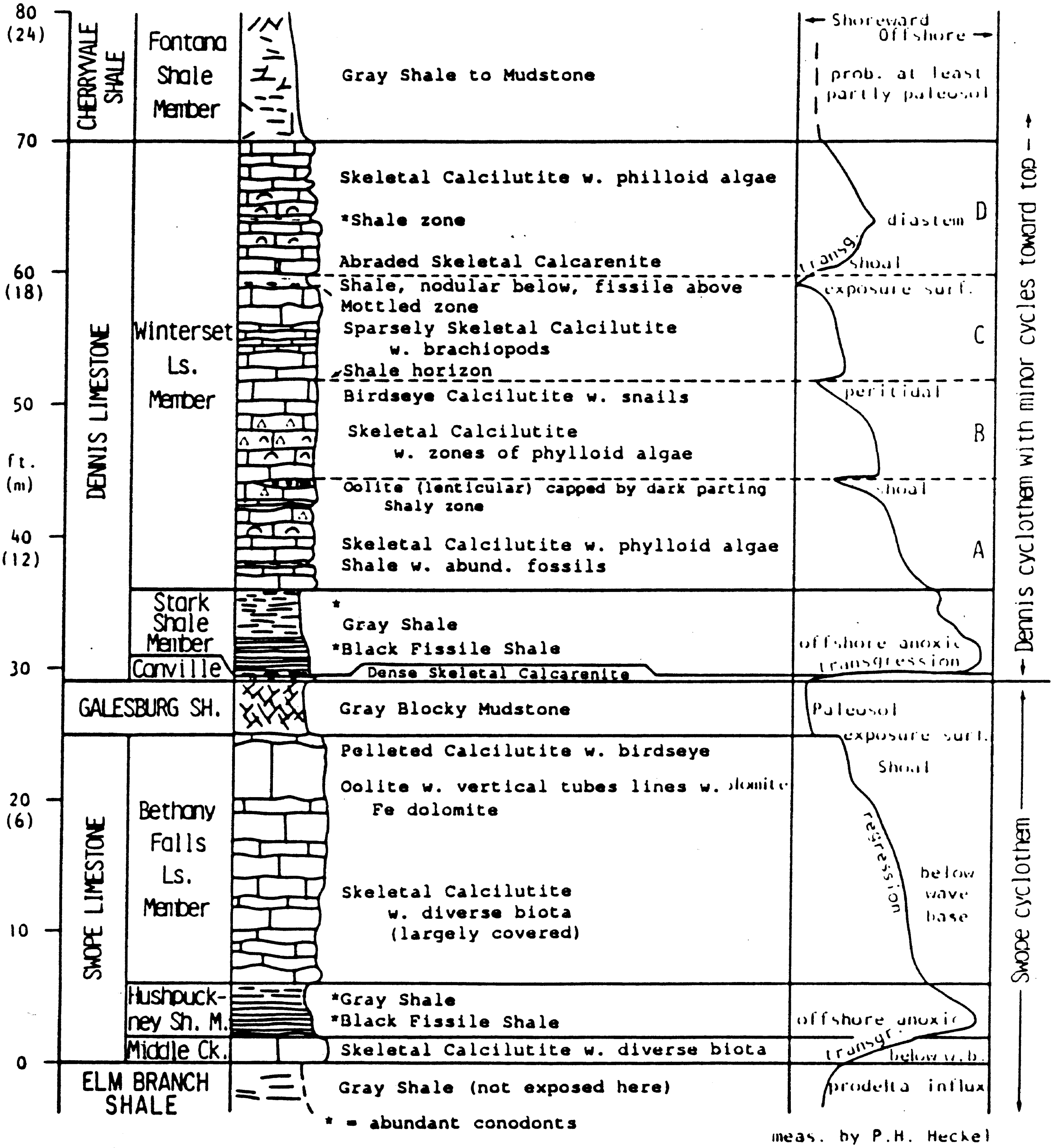


Fig. 11. Geologic section exposed at stop 3.

shows both the large amount of time during this regression (which is reflected in the generic change in fusulinid faunas from the underlying Swope to the overlying Dennis; see Heckel, this volume, fig. 7) and also the great distance of marine withdrawal between these two major marine cycles, at least into northern Oklahoma. Both of these cycles retain their offshore black phosphatic shale facies to the northern outcrop limit north of Omaha, Nebraska, about 400 mi from Tulsa, implying that the strandline of the transgression went much farther to the north.

The Canville Limestone is the transgressive limestone of the Dennis Cyclothem, here a very thin, dense, overpacked skeletal calcarenite, which suggests compaction before late burial cementation like transgressive calcilutites and offshore calcarenites. But, unlike the offshore calcarenite in the basal Raytown at stop 2, it has abraded grains suggesting deposition in shallow agitated water early during transgression. The Canville is not as continuous northward as are most transgressive limestones, which suggests a more rapid transgression with insufficient time for carbonate production, resulting in sediment starvation. The overlying offshore black shale rests directly on the Galesburg paleosol in most areas to the north (Schutter, 1983).

The Stark Shale is the offshore shale of the Dennis Cyclothem with characteristic black phosphatic facies. Both the black and overlying gray marine facies show well-crystallized illite dominating mixed-layer clays, and no kaolinite, features that are typical of marine shales and stand in contrast to the underlying Galesburg paleosol (Schutter, 1983). The Stark can be traced from Iowa to central Oklahoma, and the black facies carries an abundant conodont fauna with *Idiognathodus* dominating *Idioprioniodus* and *Gondolella*, just like the homologous Hushpuckney and Muncie Creek shales in the Swope and Iola cyclothems.

The Winterset Limestone is the regressive limestone of the Dennis Cyclothem. This has been corroborated by the evidence of infiltration of meteoric water from the top described by Railsback (1984). But unlike the rather simple regression displayed by the homologous Bethany Falls Limestone of the underlying Swope cycle, the Winterset displays several conspicuous minor cycles of shallowing-upward lithology. Because the transgressive surfaces are abrupt, with little or no deepening-upward deposits, three of these units appear to represent punctuated aggradational cycles (PACs) of Goodwin and Anderson (1985). If correlatable over significant distances (currently under doctoral study by R. M. Felton), these would be minor eustatic cycles and thus probably represent the glacial control of the shorter periods of the earth's orbital parameters. In the probably subsurface equivalent of the Winterset Limestone 400 mi to the northwest (in southwestern Nebraska), DuBois (1985) traced two minor shoaling-upward cycles in numerous cores across an entire county, which hints at the possibility of the extremely widespread extent of some of these minor cycles.

The lowest minor cycle in the Winterset (A) is open marine skeletal calcilutite capped with lenticular oolite, recording a minor shoal. The next cycle up (B) is similar skeletal calcilutite capped by birdseye-bearing calcilutite with snails, recording a peritidal environment. The next cycle up (C) is sparsely fossiliferous calcilutite grading up to a mottled zone that contains fitted-clasts of limestone separated by thin shale-filled fissures with small chips of limestone matrix. The carbonate apparently had been partially dissolved and infiltrated by shale. Some fissures may be root casts, and all the features support early, near-surface meteoric diagenesis. The mottled zone is capped by a shale, the lower one-third of which is blocky and contains irregular limestone clasts but no fossils, and appears to be a paleosol with erosional remnants of the underlying limestone. These lower three minor cycles each show progressive shallowing of the capping facies upward from shoal to tidal flat to soil, and therefore are easily accommodated within the regressive phase of the Dennis Cyclothem. The sparse conodont faunas collected at selected horizons corroborate this sequence, in that open-shelf *Idiognathodus* was found in low numbers only in minor cycle A and the base of minor cycle B, whereas nearshore *Adetognathus* was found only above this.

In contrast to the PAC-like lower three minor cycles, the topmost minor cycle (D) displays a deepening-upward or transgressive lithic sequence in the lower half. The dark shale at the base with extremely sparse conodonts probably represents a nearshore, perhaps lagoonal environment. It is overlain by an abraded-grain skeletal calcarenite suggesting a shoal environment, and this is followed upward by more offshore skeletal-algal calcilutites deposited below the effective wave base. This sequence culminates in a thin shale with relatively abundant conodonts (more than 100s/kg), which probably represents a slight diastem and would be analogous to a core shale of a more major cycle. However, all of the conodonts so far picked from this shale are *Adetognathus*, the nearshore genus, which shows that this cycle involved only shallow nearshore shelf environments in this region. The upper part of minor cycle D is regressive up into the overlying Fontana Shale, which represents another paleosol. The main difference between cycle D and the underlying PACs is that the transgression in cycle D was slow enough for a deepening-upward lithic sequence to be deposited. The possibility that cycle D is the nearshore end of an intermediate cycle represented in Oklahoma by the main part of the Hogshooter Limestone is currently under study.

Before we too quickly assume that the internal correlation of the Winterset will be readily accomplished by simply counting minor cycles at different sections, I hasten to point out that the shaly zone in the middle Winterset at Kansas City shown by Heckel and Baesemann

(1975) to carry abundant *Idiognathodus* and some deeper-water *Idioprioniodus* was not detected in the Winterset here. Rather, a conodont-rich horizon reported by Schutter (1983) 0.3 m (1 ft) down into the upper gray facies of the underlying Stark Shale (which is thicker here than in Kansas City) carries these conodonts and is separated by less conodont-rich gray shale from the black conodont-rich facies in the lower Stark. If this upper conodont-rich horizon in the Stark here correlates with the conodont-rich horizon in the middle Winterset in Kansas City (currently under study by R. M. Felton), then the entire 3.05-m (10-ft) thick lower Winterset there has graded southward in 40 mi into the top of the thicker Stark Shale here, and the minor depositional units within the Winterset are oriented gently obliquely downward toward the south in the basinward direction. Price (1981) found this pattern to be true with the more major units in the regressive part of the Pawnee cycle in the Desmoinesian, and our work is showing this pattern also in the Pleasanton-Hertha sequence, just below the Swope, which we shall see at stops 4A-C later today. This type of stratigraphic pattern is to be expected when minor cycles of lesser lateral strandline shift are superimposed onto major cycles of greater strandline shift.

LEAVE STOP 3 AT 11:30 A.M.

Drive 12 mi, south on US 69 to Trading Post, descending "Bronson" escarpment held up by Dennis, Swope, and Hertha limestones over Pleasanton prodeltaic shales (15 minutes).

Drive about 32 mi, south on US 69 through Pleasanton; west on K-52 through Mound City to Blue Mound, continuing south on county road at south side of town for 4 mi; then west at intersection on curve, 0.3 mi to roadcut. Prominent escarpment seen to west, ascended west of Mound City and visited at stops 4A-C is the same one held up by Dennis, Swope, and Hertha limestones over Pleasanton prodeltaic shales (40 minutes). Lunch at stop 4A (60 minutes).

STOP 4A: XENIA N.W.: SWOPE AND THIN HERTHA ON SHELF, CSL SE 1/4, SEC. 20, T. 23 N., R. 22 E. (fig. 12; cross sections are shown on fig. 15) (60 minutes).

Leader: P. H. Heckel

Things to see: Swope Cyclothem about 35 mi southwest of stop 3 and also the underlying Pleasanton-Hertha sequence. The Swope contains a distinctive mottled calcilutite facies within the regressive limestone that resulted from meteoric diagenesis. The thin Hertha sequence, once thought to be a straightforward transgressive-regressive Kansas cyclothem (Heckel and Baesemann, 1975), has been found to be more complex both in terms of cyclic sequence and local paleogeography in the Bourbon-Linn County area (Underwood, 1984). We shall first consider the Swope.

The Middle Creek Limestone, the gray transgressive limestone of the Swope cycle is a little thicker, but lithologically similar to that seen at stop 3.

The Hushpuckney Shale, the offshore shale with phosphatic black facies, also is similar to that seen at stop 3.

The Bethany Falls Limestone, the regressive limestone, is the same as at stop 3 in that it shows a shallowing-upward sequence from skeletal calcilutite at the base to oolite at the top. Conspicuous at this exposure, however, is the distinctive mottled zone in the upper part of the calcilutite. In this zone, smoothly outlined but irregularly shaped, resistant dark mottles stand in contrast with the lighter-colored, less resistant matrix. Detailed study by Nollsch (1983) using the SEM showed that the dark mottles are microspar, whereas the light matrix is micrite. (The coarser microspar allows light to be absorbed, and thus appears darker, while the finer micrite reflects more light and thus appears lighter; the colors are reversed in thin section because the microspar transmits more light than the micrite). Nollsch (1983) also showed that the darker microspar is isotopically lighter in both carbon and oxygen than the micrite and therefore resulted from meteoric neomorphism and cementation, which did not affect the matrix as strongly. These mottles have a modern analog in the aggrading microspar nodules interpreted by Steinen (1982) as resulting from meteoric phreatic diagenesis of lime mud on Andros Island in the Bahamas. The overlying oolite also shows strong signs of intense meteoric diagenesis in that all the originally aragonitic ooids have been leached and now appear as moldic voids or partly to completely calcite-spar-filled molds, as is the case also at stop 3. Local zones show collapse of oomoldic fabric to form cement-shard calcarenite (Nollsch, 1983). The contact between the oolite and underlying calcilutite is sharp here, suggesting cessation of calcilutite deposition and/or scour prior to oolite deposition. It is not yet determined if this might be a eustatic-event surface during the Swope regression. In the western Kansas subsurface 250 mi west of here, Watney (1985) described a similar sequence of mottled calcilutite overlain by oomoldic oolite capped by a laminar caliche crust in the Bethany Falls equivalent. This attests further to the extremely widespread extent of these well-defined cyclothems, which more strongly affirms the eustatic nature of their control.

We now will consider the Pleasanton-Hertha interval (below the Swope), for which stops 4A, B, and C show a shelf-to-basin transect (cross-sections: figs. 15A-B).

The Middle Pleasanton Shale is a very thick (more than 30 m [100 ft]) sequence here and to the northeast. The thin-bedded, calcareous, fine-grained sandstones within the upper part of the sequence here suggest the distal delta

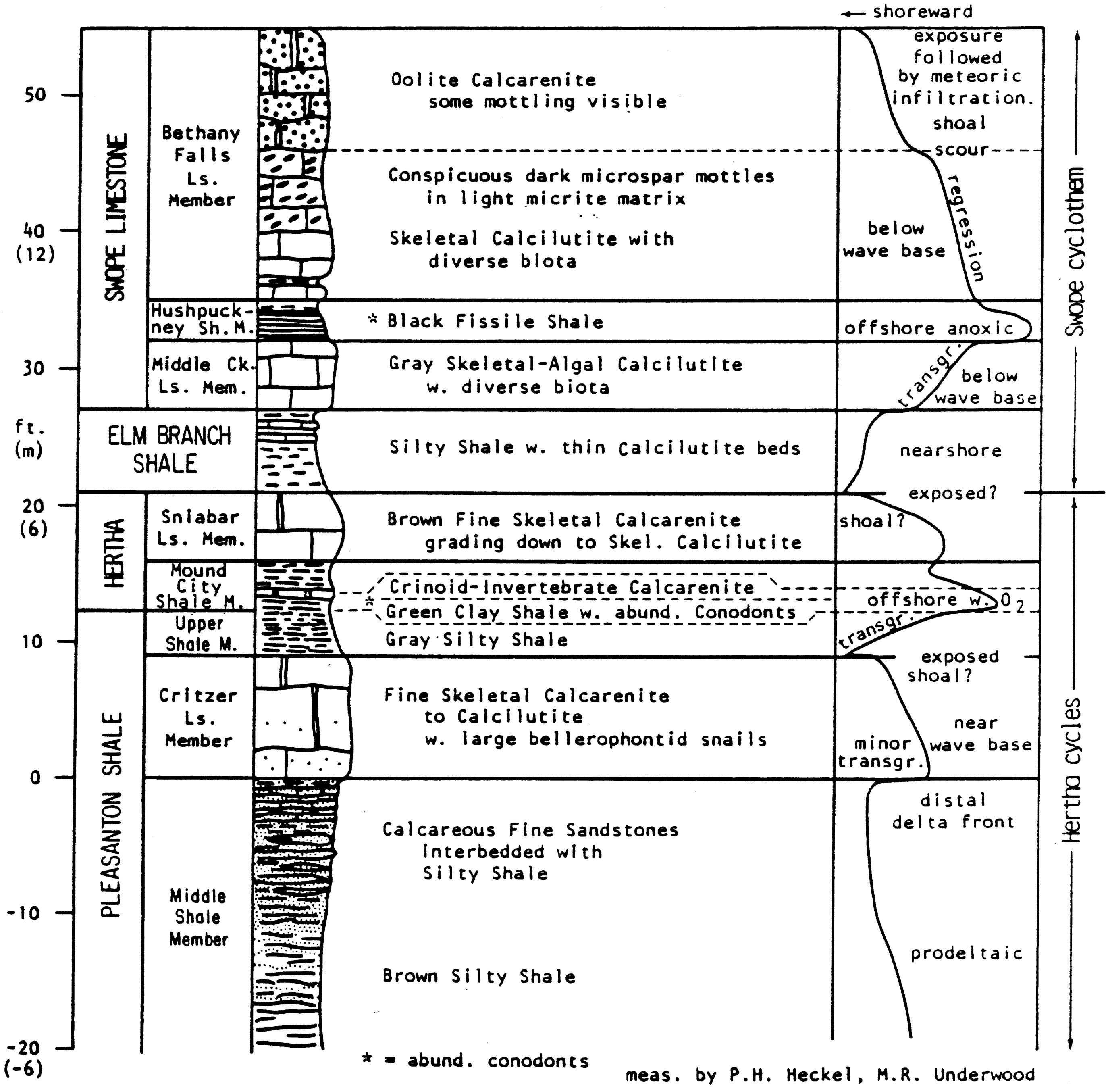


Fig. 12. Geologic section exposed at stop 4A.

front to upper slope of a large deltaic complex. The delta front is recorded in more massive noncalcareous sandstones several miles to the northeast around Mound City and Pleasanton. The thin shale at the very top carries sparse *Idiognathodus* here, and *Adetognathus* as well at other localities, which in the context of a deltaic complex, suggests a minor transgression from either lobe abandonment or slight sea-level rise.

The Critzer Limestone (now included as a member of the Pleasanton) consists of silty, fine, abraded-grain skeletal calcarenite to calcilutite with a sparse *Adetognathus-Anchignathodus* fauna. It was probably deposited between the effective wave base and a nearby shoal. Once thought to be the transgressive limestone of the Hertha Cyclothem, it is now interpreted as a regressive limestone of a minor cycle because 1) the most conodont-rich horizon (with *Idiognathodus*) is found in several localities at the base of the Critzer or in the very top of the underlying shale, 2) the Critzer contains blocky calcite-filled snails with dropped internal molds (Underwood, 1984), which suggests meteoric leaching and cementation, more typical of regressive than transgressive limestones, and 3) the stratigraphic and facies relations of the overlying shale seen at stops 4B & C.

The Upper Pleasanton Shale (formerly included as the base of the Mound City Shale) is essentially unfossiliferous shale that represents the distal margin of a thick prodeltaic influx seen again at stop 4C.

The Mound City Shale is a gray shale with a thin, crinoid-rich invertebrate calcarenite near the base. This calcarenite bed lacks any evidence of algae, cross-bedding, or grain abrasion, which suggests a deeper water origin like that of the similar basal Raytown bed at stop 2. This thin limestone and the underlying 0.15-m (0.5-ft), green, clayey fossiliferous shale carry extremely abundant conodonts dominated by *Idiognathodus*, with *Idioprioniodus* and *Gondolella*, the same three genera that characterize the black phosphatic shales in other cyclothems and the black shale facies in the Hertha to the north. This zone is the "core" of the major Hertha cycle here, which lay in this area above the anoxic water layer because of the topographic expression of the underlying Middle Pleasanton delta lobe. A transgressive limestone seems to be lacking, which suggests rapid transgression over the thin wedge of prodeltaic Upper Pleasanton Shale.

The Sniabar Limestone is a brown, rather massive, sparsely skeletal calcilutite, grading upward to fine skeletal calcarenite (Underwood, 1984), as expected in a regressive limestone. Shoaling-upward regressive sequences are better seen in the Sniabar northward (e.g., Heckel, 1978); and 10 mi northeast of here, a similar facies to that seen here displays small channel-like crevices with pebbly carbonate debris, suggesting an exposure surface at the top.

The Elm Branch (formerly Ladore) Shale is a sparsely fossiliferous gray silty shale, which in view of the probable subaerial exposure of the top of the Sniabar nearby, probably records mostly the early phase of the Swope transgression in this area.

LEAVE STOP 4A AT 2:15 P.M.

Drive 3 mi east on county road, bearing right at intersection at the foot of the hill (5 minutes).

STOP 4B: XENIA N.E.: CRITZER (BOURBON FLAGS) ON SLOPE, CSL, SEC. 23, T. 23 N., R. 22 E. (fig. 13; cross sections are shown on fig. 15) (20 minutes).

Leader: P. H. Heckel

Things to see: facies change of the Critzer Limestone, partly into a thick unit informally called the Bourbon flags.

The Middle Pleasanton Shale exposed low in the spillway just to the northeast appears shalier than at stop 4A; therefore, presumably this area was farther down the delta slope.

The Bourbon flags are a sequence of alternating argillaceous calcilutite and calcareous silty shale with very sparse marine fossils (brachiopods, crinoids, snails, conodonts--*Idiognathodus*) and well-preserved plant fragments. The flags represent relatively rapid deposition (to account for the sparsity of fossils and good preservation of the plant fragments) in an open marine environment of relatively stable salinity, as indicated by the presence of what are considered stenohaline organisms (crinoids, *Idiognathodus*). This rapid deposition took place on a slope, as indicated by the local eastward dip here, which is anomalous in this area of regional westward dip (see lower cross-section). This slope was that of the Middle Pleasanton delta after its normal progradation was stymied by a minor transgression that was just strong enough to inhibit further outbuilding, but not enough to totally submerge it in water deep enough to push the detrital source far away and deposit pure limestone (as happened to the Liberty Memorial delta at stop 2 where the intermediate Wyandotte transgression deposited the purer, transgressive Frisbie Limestone over its top). Here, deltaic influx was weakened by the minor transgression in an episodic mode of deposition, perhaps related to storm events or minor delta-lobe shifting. The more offshore marine carbonate sediment eventually prevailed through time to produce the thicker, more fossiliferous upper Bourbon flags, probably as the transgression slowly continued.

The Critzer Limestone has changed facies from stop 4A to coarser calcarenite overlain by phylloid algal calcilutite, with the addition of *Idiognathodus* down the slope to the *Adetognathus* -dominated fauna present at stop 4A. At stop 4B, the upward appearance of calcarenite and *Adetognathus* above the Bourbon flags provides evidence for shallowing of water for Critzer deposition, which,

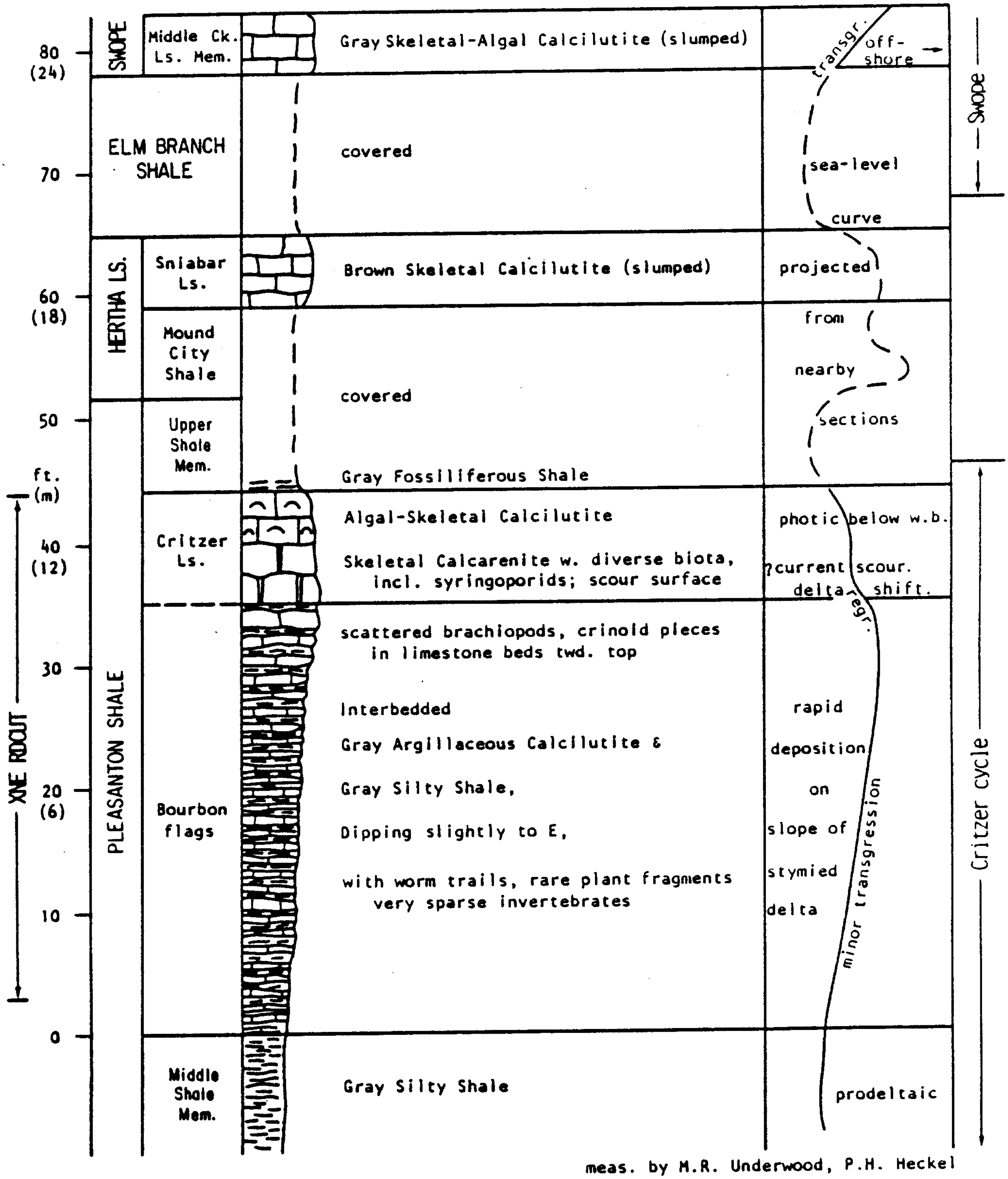


Fig. 13. Geologic section exposed at stop 4B.

taken with the loss of detrital influx, indicates that by this time the major delta lobe had shifted far away from this area. This sea-level drop was only enough to bring current (or wave) scour to stop 4B, whereas it exposed the Critzer higher on the delta-formed shelf at stop 4A to meteoric diagenesis.

The Upper Pleasanton and Mound City shales are mostly covered in the hillside above the spillway section just to the northeast, but their interval has thickened to 4.6 m (15 ft) from 2.1 m (7 ft) at stop 4A, 3 mi to the west, reflecting its position partway down the Middle Pleasanton delta slope in conjunction with the basin-filling tendency of the silty shale facies.

The Sniabar Limestone is mostly slumped in the same hillside, but its discovery there at the beginning of Underwood's (1984) thesis work helped resolve the problem of the Hertha-Pleasanton-Bourbon flags relations. Previous workers had regarded the Critzer in the roadcut as the entire Hertha, and I was puzzled by the lack of abundant conodonts in the calcarenite facies, which I had assumed was the crinoidal limestone of the Mound City Shale in an area where the shale facies was not deposited.

The Elm Branch Shale interval also has thickened to about 3.8 m (12 ft) from 2 m (6.5 ft) at stop 4A, reflecting its basin-filling tendency in this position down the delta slope.

The Middle Creek Limestone, although mostly slumped, more firmly established the recorrelation of the roadcut section with only the Critzer by showing that the brown limestone on the hillslope below is definitely the Sniabar.

LEAVE STOP 4B AT 2:40 P.M.

Drive 2.5 mi east on county road, passing Bethany Falls oolite over mottled calcilutite near top of first hill (5 minutes).

STOP 4C: MAPLETON N.W.: THICK BASINAL PLEASANTON-HERTHA INTERVAL, SL SW 1/4 SW 1/4, SEC. 20, T. 23 N., R. 23 E. (figs. 14, 15) (30 min-utes).

Leader: P. H. Heckel

Things to see: greatly thickened Pleasanton-Hertha interval farther down the Middle Pleasanton delta slope.

Bourbon flags, exposed in the lane to the south and along the creek to the north, have thinned to about 3 m (9.8 ft) here from about 9 m (29.5 ft) at stop 4B, 2.5 mi to the west. This is presumably due to a combination of 1) greater distance from the detrital influx from the stymied delta near stop 4A, 5.5 mi to the west, and 2) less carbonate influx from its area of production, presumably higher on the slope or shelf formed by the stymied delta. A dark conodont-rich shale with *Idiognathodus* and *Idioprioniodus* found at the base of the Bourbon flags in other basinal exposures marks the core horizon of the minor Critzer cycle in this region of sediment starvation. As this conodont-rich horizon is traced up the delta slope, conodont abundance decreases, *Idioprioniodus* disappears, and *Adetognathus* appears, reflecting passage into shallower, more sediment-laden water during the maximum phase of this minor transgression.

The Critzer Limestone thins to about 0.9 m (3 ft) of algal-skeletal calcilutite from about 2.8 m (9 ft) of this facies plus calcarenite higher on the slope at stop 4B. This reflects its basinal position here, below the current and wave base even during the lower stands of this minor regression, and lower in the photic zone where algal growth would have been less luxuriant than higher on the slope. The Upper Pleasanton Shale has thickened to 14 m (44 ft) here from 0.9 m (3 ft) at stop 4A. It is essentially a basin filling over the topographically low, basinal Critzer and Bourbon flags near the toe of the Middle Pleasanton delta slope. This fine detrital material may well be the prodeltaic influx from a new delta lobe that resulted from the shift to a more easterly direction of the source for the earlier Middle Pleasanton delta lobe during the time of Critzer deposition. The black shale and overlying earthy crinoidal limestone at the base of the Mound City Shale here carry the same abundant conodont fauna as do the clayey green shale and purer crinoidal limestone in the thin Mound City at stop 4A. They represent the same rapid and far-reaching transgression and early regression of the major Hertha (Mound City) cycle. The black color of the shale and the argillaceous nature of the limestone here reflect their basinal position, respectively, below the top of the anoxic water layer, which developed only in the lower areas below the delta shelf during maximum transgression, and below any zone of winnowing during early regression. The discovery of these beds here by Underwood (1984) and analysis for conodonts played a significant role in establishing understanding of Pleasanton-Hertha stratigraphic relations (see cross-sections). This greatly aided in applying the depositional model of transgression and regression in areas where regressions did not withdraw the sea off the broad Midcontinent shelf (as in the previously better-understood units) and where minor transgressions (such as the Critzer) did not establish water deep enough over the higher areas to achieve the black conodont-rich facies over a large area. It also shows the power of tracing the conodont-rich shales through different facies regions to establish correlations of the marine transgressions. This black shale at stop 4C is traced southward through the thinning Pleasanton sequence as the lower part of the black Tacket Shale sequence of southern Kansas and northern Oklahoma, which is an entirely offshore marine unit that contains the core horizons of at least four cycles (Swope, Hertha, Critzer, and a lower one, Exline). Between these four horizons, regressions only withdrew the sea to northeastern or east-central Kan-

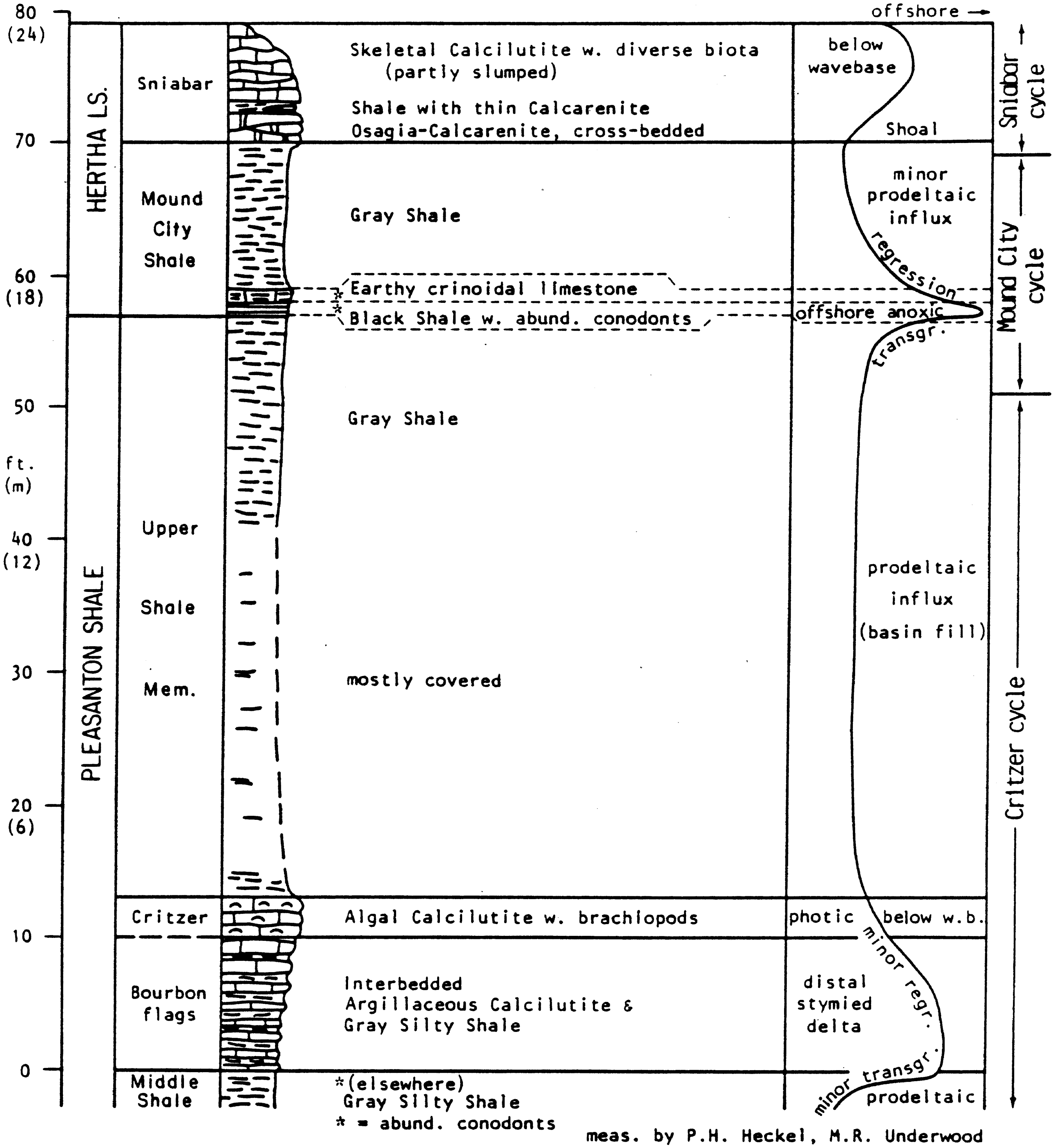


Fig. 14. Geologic section exposed at stop 4C.

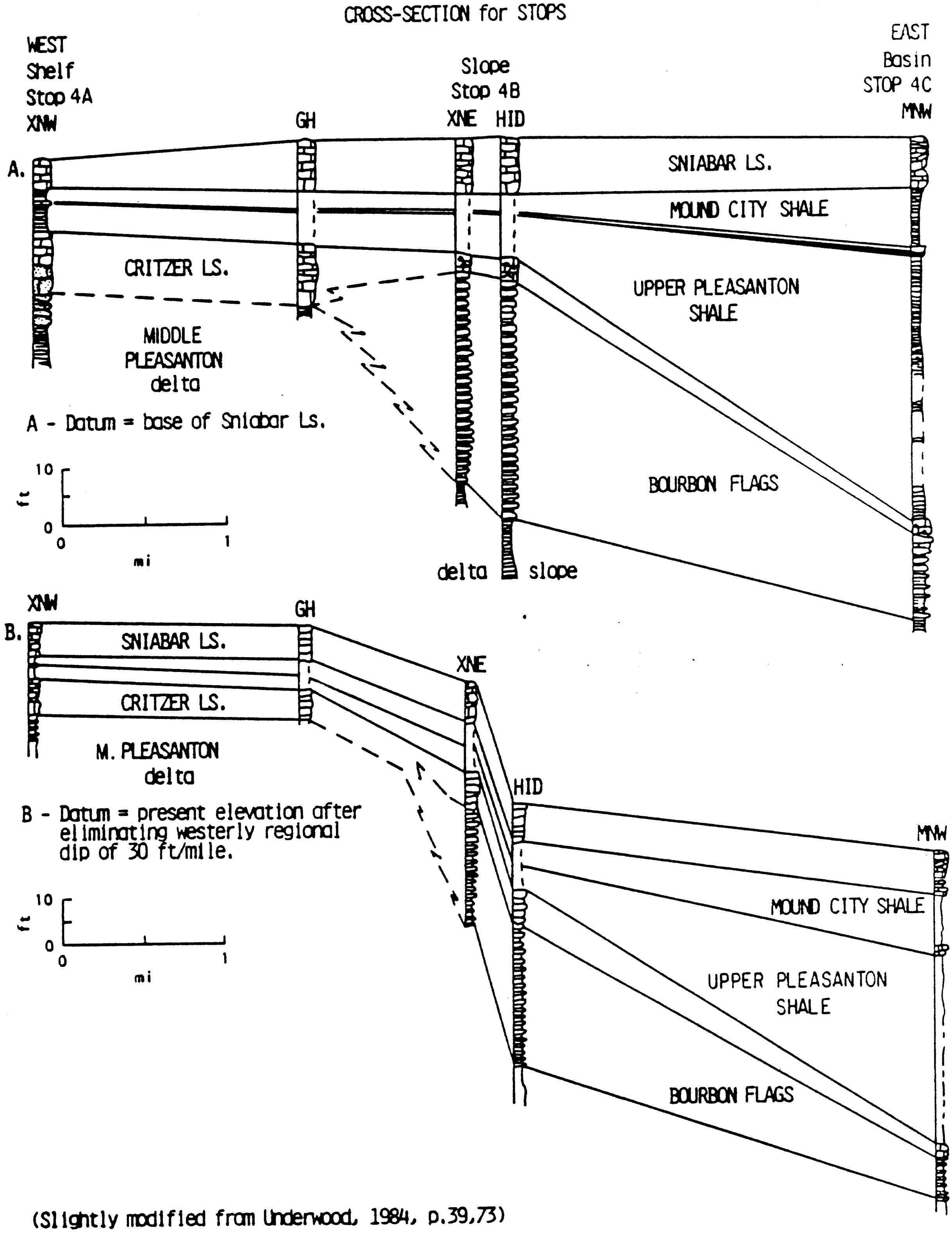


Fig. 15. Cross sections of rocks seen at stops 4A, 4B, and 4C.

sas, where thick deltaic sequences formed during the low stands, and decreasing amounts of only fine sediment were transported much farther south than this area here. Recognition of these relations has led to readjustment of nomenclature and classification of the lower Missourian sequence in Kansas (Heckel, in preparation).

The upper 3.1 m (11 ft) of the Mound City Shale here is not very fossiliferous, and rather than part of the normal regressive sequence leading up to the overlying limestone, it appears to be another prodeltaic influx. Its source is to the northeast, where, a few miles south of Pleasanton, the interval between the Mound City black shale and the Sniabar has thickened to 8 to 9 m (25 to 28 ft) of thin-bedded shaly sandstone. This deltaic influx is interpreted to have occurred during a minor regression above the crinoidal limestone prior to another minor transgression that terminated this delta and allowed initiation of Sniabar carbonate deposition.

The Sniabar Limestone here shows a cross-bedded skeletal calcarenite overlain by skeletal calcilutite, which supports its initiation by a transgression from shoal water to a quiet regime below the effective wave base. The rest of the Sniabar here and most all of the Sniabar at stop 4A and across the more northerly shelf areas of the Midcontinent were deposited as a shallowing-upward sequence during a regression that withdrew the sea much farther southward into southern Kansas than the previous regressions in the Pleasanton-Hertha Sequence. The thin shale with its lenticular calcarenite in the lower Sniabar here was thought by earlier workers (including myself) to be the Mound City Shale with its crinoidal limestone, as seen at stop 4A, and I was mystified by its sparse *Adetognathus*-dominated conodont fauna for some time before Underwood showed me the black shale more recently exposed down the ditch after a thunderstorm. This again shows the importance of the conodonts in working out Midcontinent Pennsylvanian stratigraphy.

LEAVE STOP 4C AT 3:15 P.M.

Drive 55 mi east to K-31 and south into Mapleton; west on K-65 through Xenia to K-3; south to Bronson; west on US 54 to Iola; south on US 169 to K-39 exit at Chanute; take exit ramp, cross K-39 and stop along ramp leading south back to US 169 (65 minutes).

STOP 5: US 169 ON-RAMP ROADCUT AT CHANUTE: IOLA ALGAL MOUND AND SKELETAL WYANDOTTE FACIES, E LINE AT NE COR., NW 1/4, SEC. 19, T..27 N., R. 18 E. (fig. 16) (40 minutes).

Leader: P. H. Heckel

Things to see: top of the thick phylloid algal mound complex in the regressive Raytown Limestone Member of the Iola, overlain by a thin but abundantly fossiliferous skeletal calcarenite facies of the Wyandotte Limestone about 60 mi south of the pinchout of the intervening Liberty Memorial Shale and 100 mi from stop 2.

The Raytown Limestone here is algal-skeletal calcilutite near the south end of its phylloid-algal mound complex (Heckel and Cocke, 1969), which is dipping southward along this roadcut. It is about 13 m (40 ft) thick here, and thins to about 1.1 m (4 ft) of off-mound, basinal, silty skeletal calcilutite detected in a core taken 6 mi south of here (Mitchell, 1981). Conspicuous here are large, upright, grossly vase-shaped masses of crinkly phylloid algae, which may represent original growth forms of this plant. Their preservation here may relate to the position of this exposure near the south end of the mound, which was prograding basinward in photic but quiet water below the wave base as sea level dropped during the Raytown regression. The mound was then stranded as the Wyandotte transgression raised sea level above the effective photic zone for these algae at a time when shoreline still had not migrated south of Kansas City, where the overlying Liberty Memorial delta is best developed. Thus the mound surface here never was subjected to the strong wave or current activity that probably broke up large algal plants into scattered blades in other mound complexes that are capped by shoal-water facies.

The abrupt contact at the top of the Raytown marks the position of the upper part of the Liberty Memorial deltaic complex of the Kansas City area seen at stop 2, which also was stranded by the Wyandotte transgression. The lower part of the Liberty Memorial at Kansas City is probably time-equivalent to the upper part of the Raytown mound here, which developed during the entire regressive phase of the Iola Cyclothem, far behind the distal limit of the Liberty Memorial deltaic influx that overwhelmed Raytown carbonate deposition somewhat earlier in the Kansas City area.

Wyandotte skeletal calcarenite (assigned to the Argentine member) is somewhat shaly and consists of unabraded brachiopods, bryozoans, encrusting forams, and echinoderms. It also contains abundant conodonts (mainly *Idiognathodus*), which allow correlation, in part, with the offshore shale (Quindaro) of the Wyandotte Cyclothem at stop 2. It lacks algae and cross-bedding or any other evidence of shallow-water deposition. The shaly matrix reflects quiet water deposition and lack of lime mud. All these characteristics point to slow deposition in relatively deep water, far south of the Liberty Memorial delta, over which the Argentine algal mound developed in the Kansas City area. Because the Wyandotte transgression responsible for this deposit was only of intermediate scale, the water never became deep enough for a thermocline to form and produce a black anoxic facies, so depths remained within the oxygenated zone, allowing proliferation of invertebrates, though still deep enough for elimination of lime-mud-producing algae.

Lane-Bonner Springs Shale (more than 30 m [100 ft]

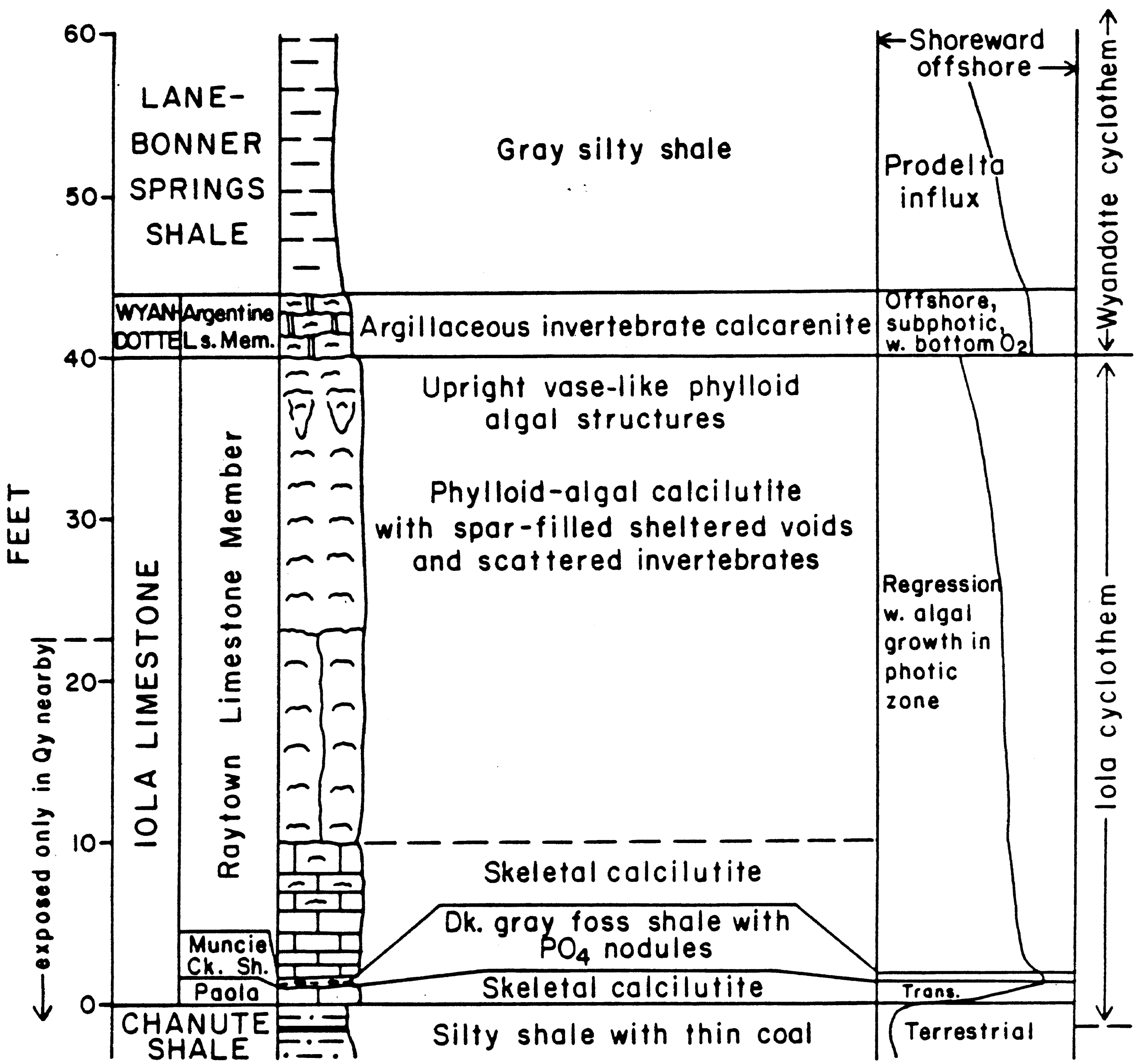


Fig. 16. Geologic section exposed at stop 5.

thick in this area) represents a large deltaic influx that overwhelmed the offshore Wyandotte skeletal beds later during the Argentine and Bonner Springs regressions, as shoreline migrated into southern Kansas.

LEAVE STOP 5 AT 5 P.M.

Drive about 4 mi, south on US 169 to first exit, then east into Chanute for dinner and overnight.

SECOND DAY: Buses ready to load at 6:45 a.m. Leave motel at 7 a.m. Drive 24 miles: south on US 169; west on K-47 through Altoona to gravel road 0.5 mi west of Verdigris River bridge; north 0.7 mi, west 1 mi; south up hill (30 minutes).

STOP 6A: NORTH ALTOONA ROADCUT: STANTON CHANNEL EDGE, WL NW 1/4 SW 1/4 SW 1/4, SEC. 7, T. 29 S., R. 16 E. (figs. 17A, 17B) (20 minutes).

Leader: P. H. Heckel

Things to see: facies change along the north side of a contemporaneous marine channel in the Stanton Cyclothem.

The Captain Creek Limestone is the transgressive limestone of the Stanton Cyclothem. Here its algal mound facies dips and thins southward to disappearance toward the channel axis while the basal skeletal calcilutite grades to mound-flank calcarenite, which thickens complementarily. As Captain Creek mound facies grew vertically in response to deepening water, it extended laterally very little into the channel. The mound-flank calcarenite contains calcilutite "clasts" derived from tops of algal blades in the mound facies.

The Stoner Limestone is the regressive limestone of the Stanton Cyclothem. Here its basal muddy calcarenite overlies a thin tongue of Captain Creek mound facies in the middle of the cut and also dips southward toward the channel axis. Offshore Eudora Shale, normally separating the Captain Creek and Stoner, was probably not deposited here because of slow currents in deep water impinging on the prominent edge of the mound. Conodonts characteristic of the Eudora (*Gondolella*) were recovered from the basal Stoner at this outcrop, attesting to the position of the Eudora.

The carbonate channel facies lies at least 24 m (80 ft) below equivalent mound facies on either side (see map). Averaging 0.6 mi wide, the channel is traced from linear outliers northeast of Altoona westward 22 mi, where it forms a topographic low in the main outcrop belt. Most channel fill is regressive Stoner calcarenite, but later regressive Reddish Rock Lake quartz sandstone (exposed on the way to stop 6B), gray South Bend fossiliferous quartz sandstone, and sandy calcilutite of the succeeding transgression overlie the Stoner along the channel axis.

LEAVE STOP 6A AT 7:50 A.M.

Drive 1 mi south, then east on K-47; park at quarry entrance on right. Reddish Rock Lake sandstone on left at junction (10 minutes).

STOP 6B: K-47 ALTOONA ROADCUT: STANTON CHANNEL AXIS, C NW 1/4 NE 1/4, SEC. 18, T. 29 S., R. 16 E. (fig. 17B) (50 minutes).

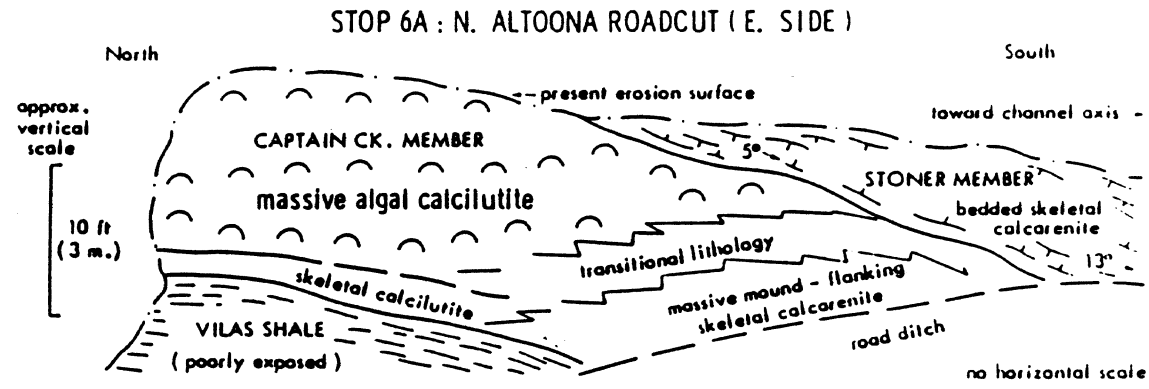
Leader: P. H. Heckel

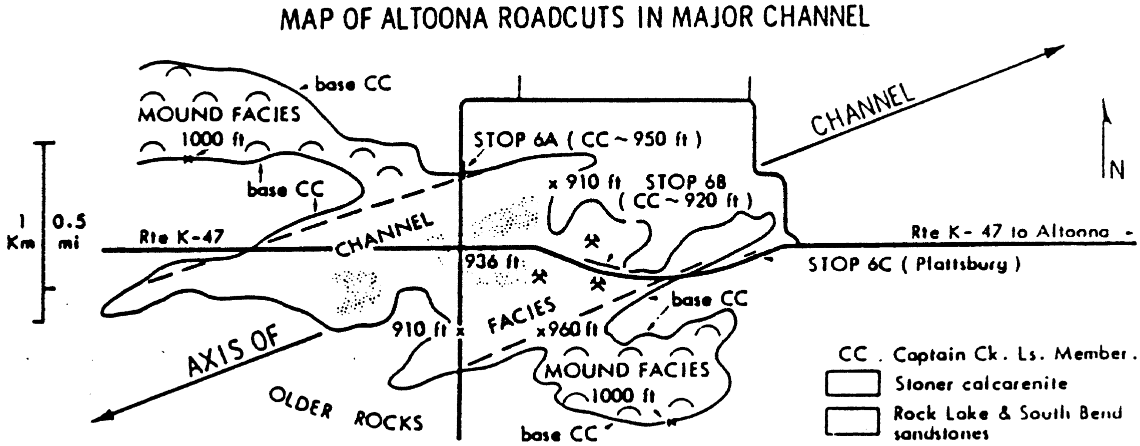
Things to see: Stanton channel facies near the axis of the channel.

The Captain Creek is a thin skeletal calcilutite (seen at east end of cut) in which diverse marine fauna and lack of clasts from underlying Vilas Shale record deposition in quiet water below the effective wave base. This suggests that the initial Stanton carbonate deposit merely conformed to pre-existing channelled topography on the prodeltaic Vilas surface, after transgression caused terrigenous influx to cease in a continually subaqueous environment as sea water encroached into a formerly freshwater or brackish channel.

Thin black Eudora Shale (seen at east end of cut) records greatly reduced deposition of the finest suspended material in an anoxic bottom environment developed below a thermocline in the deepest water of the channel axis at maximum transgression. The black color disappears as the shale rises 3 m (9.8 ft) across the highway toward the south side of the channel, which apparently remained continually above the anoxic water layer.

The Stoner Limestone, forming most of the channel fill, is shaly skeletal calcilutite at the base, recording resumption of carbonate deposition in relatively deep quiet water after anoxic bottom conditions disappeared during early regression. Phylloid algae appear a short distance above the base. The upper Stoner is spar-cemented, abraded-grain calcarenite, which records the increasingly well-washed environment developed in the channel as further shallowing caused currents to funnel along the channel and impinge upon the bottom. Many abraded grains have micrite envelopes, and some are coated. The brownish grains are ferroan dolomite, probably late-stage void-filling in a low-oxygen burial environment after grain dissolution during meteoric leaching following the Stoner regression. Distinctive large-scale cross-bedding, in which uparched beds coalesce laterally at the edges, probably represents cross sections of elongate lime-sand bars, parallel to the sides of the channel, which accreted upward through time with little movement toward the sides of the channel. Small-scale cross-bedding locally shows bidirectional transport of tidal currents. Many organisms present as whole fossils (certain brachiopods *[Schizophoria]*, bryozoans *[Meekoporella]*, snails, and corals) probably lived in the channel. Articulated crinoids stems suggest rapid





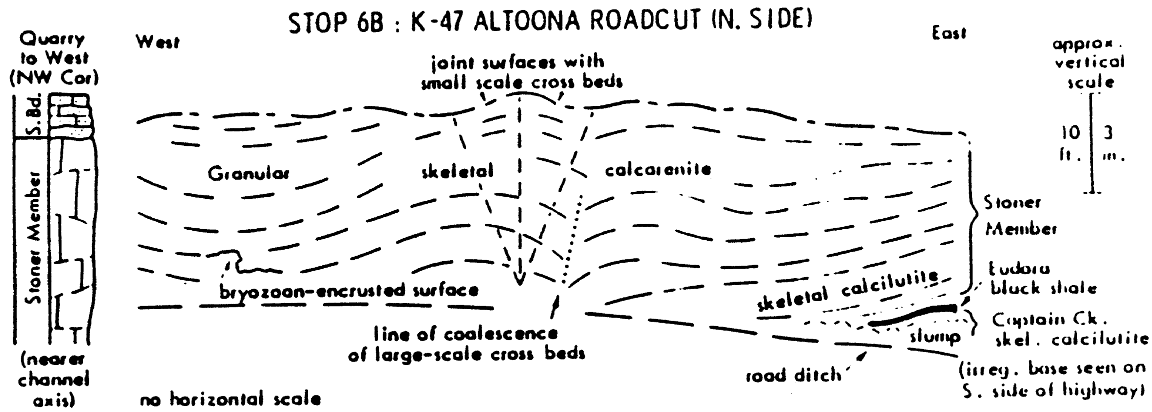


Fig. 17. Geologic sections at stops 6A and 6B and cross section and map of major Stanton channel in Altoona roadcuts.

burial by a thick layer of debris during storms. The bryozoan-encrusted irregular surface indicates intermittency of deposition with periods of erosion and reef-like growth as waves and currents impinged upon the channel bottom.

The quarry to the west exposes lenses of overlying late regressive Rock Lake sandstone and 15 m (4.9 ft) of transgressive South Bend interbedded fossiliferous quartz sandstone and sandy calcilutite. These record later channel fill that was reworked and augmented during the succeeding South Bend transgression.

LEAVE STOP 6B AT 8:50 A.M.

Walk 0.4 mi east along north side of K-47, partway down hill (10 minutes).

STOP 6C: K-47 ALTOONA LOWER ROADCUT: PLATTSBURG CYCLOTHEM, NE COR, SEC. 18, T. 29 S., R. 16 E. (fig. 18) (40 minutes).

Leader: P. H. Heckel

Things to see: offmound facies of the Plattsburg Cyclothem, which lacks black phosphatic facies in the core shale and contains shaly limestones and calcareous shales that yield abundant fossils.

The Lane-Bonner Springs Shale is an "outside" shale about 50 m (165 ft) thick, formed by coalescence of the Lane and Bonner Springs shales south of the disappearance of the Farley Limestone about 60 mi northeast. Here, the Lane-Bonner Springs records prodeltaic detrital influx during the sea-level lowstand prior to the Plattsburg transgression. This influx waned abruptly, perhaps through delta abandonment, sometime before the transgression, allowing accumulation of enough shells to form a regional zone of shaly limestone lenses in the upper part. The assemblage of clams, snails, and crinoid fragments probably represents a marine fauna dominated by organisms adapted to soft substrate and relatively turbid water. Above these lenses, later shift of prodeltaic influx back into this region formed the upper 4 m (13 ft) of this shale. Waning of this influx, as the Plattsburg transgression pushed the shoreline northward, established first the "turbid water" molluscan fauna, then a clear-water fauna at the top, containing bryozoans and more brachiopods and crinoids than below.

The Merriam Limestone is the transgressive limestone of the Plattsburg Cyclothem, deposited in clearer water when algae produced enough carbonate mud to form a shaly calcilutite. The Merriam is lenticular and appears developed on a mega-rippled surface, which suggests enough current activity to produce bedforms on the underlying shale surface and to prevent even distribution of lime mud, but not strong enough to winnow sufficient mud to form a calcarenite.

The Hickory Creek Shale is the core shale of the Plattsburg Cyclothem. It was deposited far enough offshore for stable marine salinity, but not in water deep enough for establishment of the thermocline and quasi-estuarine circulation cell that led to loss of bottom oxygen and phosphorite deposition in other cycles. Suppression of carbonate production probably was due to its position low in the photic zone; any fine detrital influx that may have helped subdue algal growth in water this deep was nonetheless low enough to allow establishment of good filter-feeding fauna of most of the major invertebrate phyla, including conspicuous calcisponges.

The Spring Hill Limestone is the regressive limestone of the Plattsburg. Its more pervasive shaliness than most other regressive limestones suggests a more persistent detrital source, which apparently remained closer to the present outcrop because less water depth was attained during the Plattsburg transgression. Local proliferation of encrusting phylloid algae in the upper part is the only indication here that the north end of one of the thickest (24 m [80 ft]) algal-mound complexes in the Kansas Pennsylvanian, equivalent to the upper half of the Spring Hill but extending up to the base of the Stanton, lies about 2 mi to the southwest (Harbaugh, 1959). Following a further increase in detrital influx, the calcarenite at the top of the Spring Hill records the impinging zone of wave agitation during regression.

The Vilas Shale records another prodeltaic detrital influx that ended Plattsburg deposition here and filled in around the north end of the Plattsburg mound.

LEAVE STOP 6C AT 9:40 A.M.

Drive 60 mi: east on K-47, into Altoona; north on US 75, through Yates Center to county road 7 mi beyond; west through Virgil (70 minutes).

STOP 7A: LATE PENNSYLVANIAN NONMARINE AND MARGINAL MARINE VERTEBRATE AND INVERTEBRATE FOSSILS (THE HAMILTON BEDS) (figs. 19, 20) (60 minutes).

Leaders: Royal H. Mapes, Christopher G. Maples, and Ron West.

Things to see: unusual lithologies and associations; diverse marine and brackish water biotas.

One of the important aspects of this stop is the ongoing debate over the stratigraphic sequence exposed. The Hamilton Beds have been interpreted to be Virgilian in age and part of the Deer Creek Limestone (Busch *et al.*, 1988), equivalent to various members of the Topeka Formation (Bridge, 1988; French *et al.*, 1988) and even Permian in age (Taggart and Ghavidel-Syooki, 1988). A coring program initiated in the summer of 1989 may clear up this picture.

The Hamilton Beds are unusual in their lithologies and lateral continuity. Present at the Hamilton quarries is a limestone conglomerate that is overlain by an algal-lami

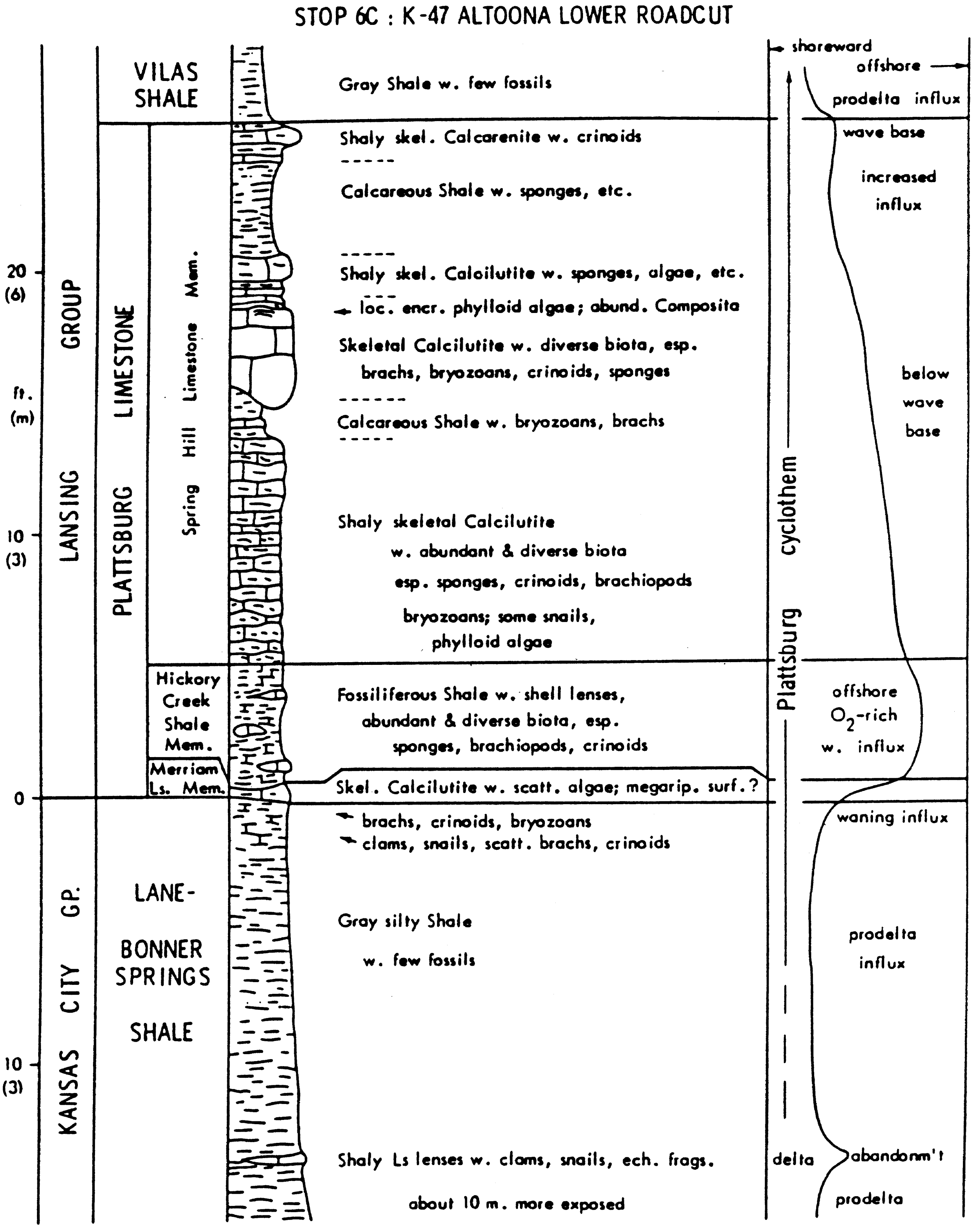


Fig. 18. Geologic section exposed at stop 6C.

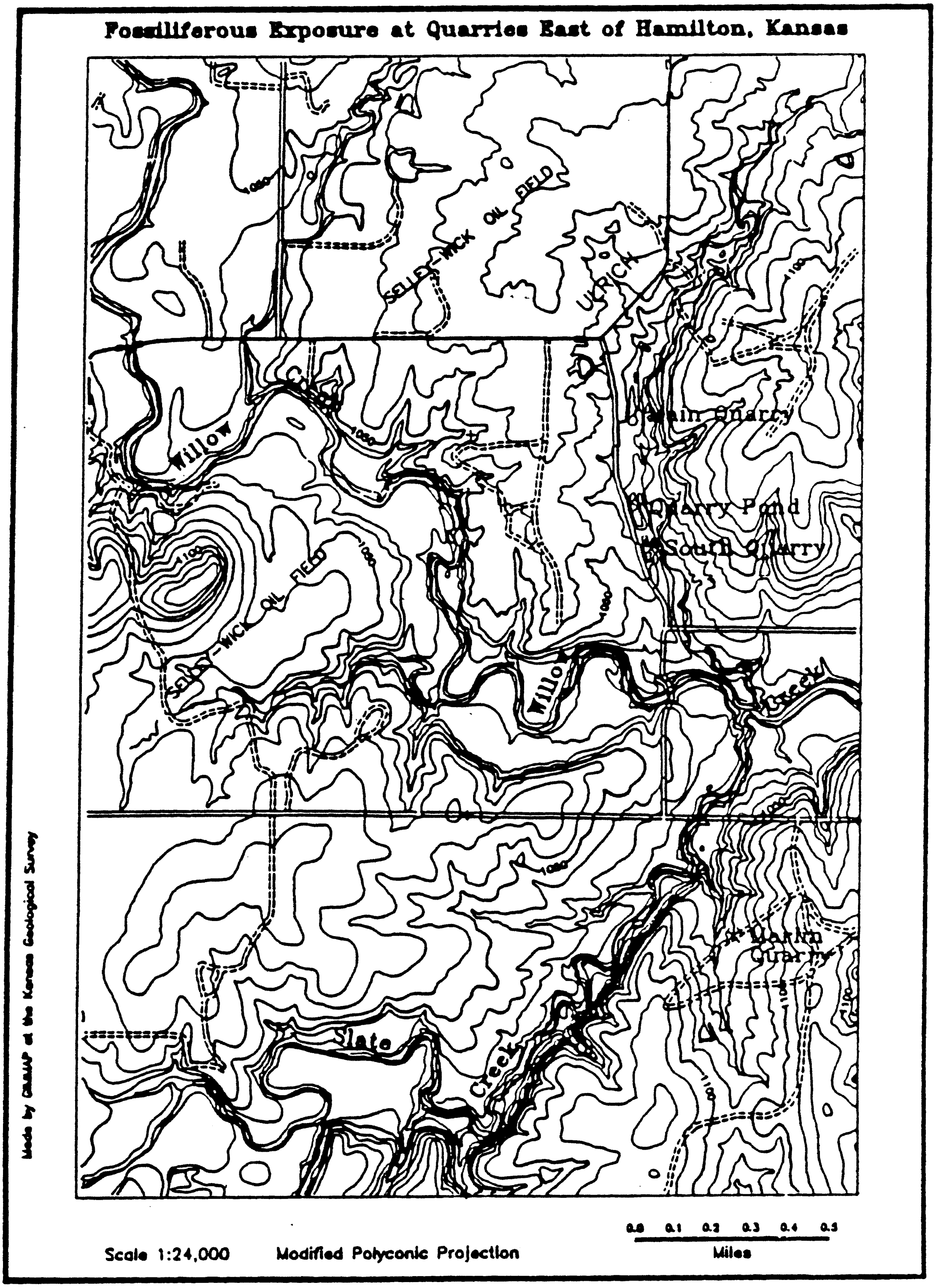


Fig. 19. Generalized geographic map showing the location of the major quarry areas where units of the Hamilton deposit have been observed.

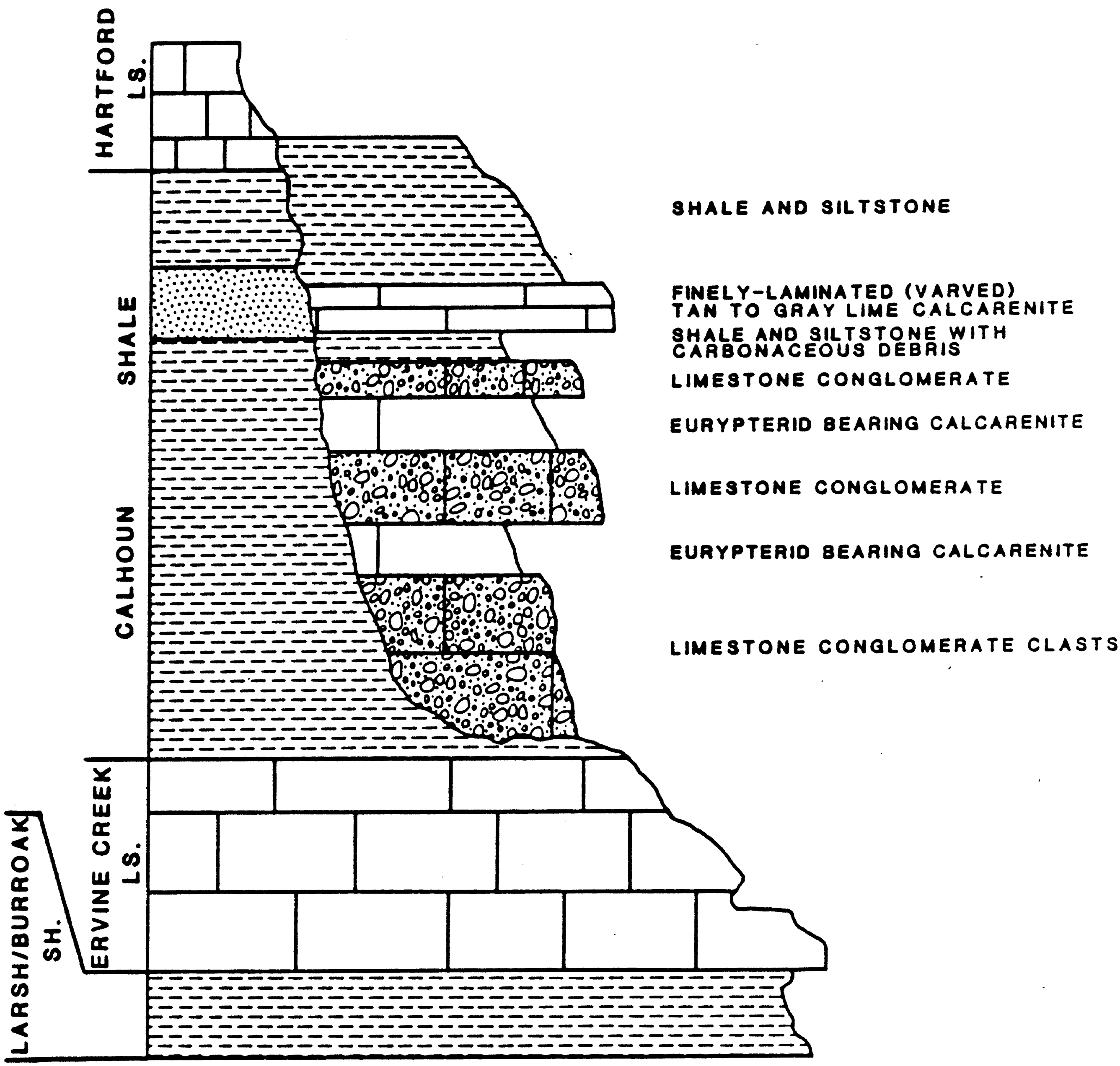


Fig. 20. The left side of the generalized stratigraphic diagram of the Hamilton deposits represents the normal stratigraphic succession in the vicinity of the Hamilton Quarries. On the right, the generalized stratigraphic succession of the Hamilton lagerstatte deposit is represented (modified from Mapes and Maples, 1988).

nated wackestone. Very thin beds of fossiliferous grainstone and conglomerate are interlaminated with the algal wackestone. The geometry of the deposit suggests channeling of channel-fill (this summer's drilling program will address this question as well); however, the timing of channel formation is unclear. The carbonate lithologies exposed are unusual, however. Even more interesting is their association at this locality.

The Hamilton Beds preserve a remarkable diversity of fossil nonmarine biota. Some of the nonmarine fossils recovered from the Hamilton quarries include reptiles, amphibians, fish, myriapods, shrimp, eurypterids, cockroaches, scorpions, nonmarine clams, nonmarine ostracods, and three-dimensionally preserved cones of conifers. This is a rich assemblage with some spectacular preservation.

Equally unusual in these remarkable beds is the presence of so-called marine and brackish-water fossils, including brachiopods, serpulid and spirorbid worms, clams, ostracods, and fusulinids. Some of these fossils are admixed on the same bedding planes as the nonmarine fossils, implying fluctuating salinity conditions.

STOP 7B: THE HAMILTON QUARRIES (fig. 20) (60 minutes).

Leaders: Royal H. Mapes, Christopher G. Maples, and Hans-Peter Schultze.

Things to see: fossil lagerstatte.

The Hamilton quarries contain a unique fossil lagerstatte discovered in 1964 by local oilman and amateur paleontologist Walter Lockard (Bridge and Mapes, 1988) (fig. 19). In 1969, Thomas Bridge and Gil Leisman of Emporia State University became involved in interpreting the geology and the fossil animals and plants in the main fossil-bearing deposits (specifically, the finely laminated, varved, tan-to-gray calcarenite unit on the generalized stratigraphic succession in fig. 20). Increasing interest resulted in a series of abstracts and studies and a symposium session at the 108th annual meeting (1976) of the Kansas Academy of Sciences at Emporia, Kansas. More recently, in 1988 (1989), the Kansas Geological Survey published a field trip guidebook from a second symposium with the 22nd annual meeting of the South-Central Geological Society of America at Lawrence, Kansas. This guidebook, edited and compiled by Gene Mapes and Royal H. Mapes, contains 30 research papers reporting geologic and paleontologic investigations of the Hamilton deposit. The following summary is a compilation from that report.

Since the summer of 1988, intensive field mapping and a short-hole coring program have been initiated by the Kansas Geological Survey because the overall geometry of the Hamilton deposit remains obscure. Overall, four major rock types with their characteristic faunas and floras make up the bulk of the exposed stratigraphic succession. The Hamilton deposit includes a set of massive carbonate conglomerate beds separated by fine-grained, finely laminated, white-to-cream calcarenite beds. Overlying these units are shale and siltstone beds that contain one or more finely laminated (varved) tan-to-gray calcarenites. These latter calcarenites contain the excellent lagerstatte preservation, whereas the shale and siltstone units mostly contain only carbonized plant debris (fig. 20).

Overall, this sequence of rock units appears to fill a cut incised into the Calhoun Shale and Hartford Limestone (fig. 20) that trends more or less north-south for at least several kilometers. Preliminary studies on the geology of the Hamilton deposit include those by Bridge (1988), French *et al.* (1988), and Busch *et al.* (1988).

The Hamilton deposit comprises a unique Midcontinent rock sequence. Associated with this unique rock sequence is one of the most important known paleontological assemblages in the Upper Paleozoic of North America and perhaps the world (Hannibal, 1988). The extensive variety and quality of the preserved plants and invertebrate and vertebrate animals is extraordinary and combines remains from several terrestrial, freshwater, brackish, and marine environments (Maples and Schultze, 1988).

The conglomeratic sequence in the lower part of the deposit contains isolated vertebrate teeth and bone fragments and plant charcoal. The invertebrate fauna includes brachiopods, bivalves, gastropods, trilobite fragments, crinoids (Pabian and Holterhoff, 1988), fusulinids (Douglass, 1988), bryozoans (West, 1988), and other groups that suggest a nearshore, marine environment.

The laminated, white-to-cream calcarenite beds interbedded with the conglomerates contain highly degraded carbon impressions of fern and seed-fern foliage and conifer remains in association with freshwater bivalves (Maples and Mapes, 1988), articulated eumalacostracan crustaceans (Schram, 1988), and both articulated and disarticulated eurypterids (Kues, 1988). The presence of freshwater bivalves and eurypterids suggests a freshwater to somewhat brackish-water phase in the Hamilton depositional system.

The vast majority of the paleontological research from the Hamilton quarries has focused on fossils from the finely laminated (varved), tan-to-gray calcarenite exposed in the northern part of the Hamilton deposit. To date, only some of the rich biota has been studied. Invertebrates include "freshwater" bivalves, brachiopods, gastropods, crinoid fragments and annelid worms (*Spirorbis* and *Serpula*) (Mapes and Maples, 1988), fusulinids (Douglass, 1988), eurypterids (Kues, 1988), ostracods (Kaesler, 1988), arachnids (Hansen *et al.*, 1988), millipeds (Hannibal and Feldman, 1988), and several insects (crickets, stick insects, dragon flies, and cockroaches) (Durden, 1988). Numerous articulated and disarticulated vertebrate specimens include acanthodians (Zidek, 1976a, 1976b; 1988a), palaeoniscoid fishes (Gottfried, 1988), chondrichthyans (Zidek, 1988b; Maisey, 1988); lungfish (Chorn and Schultze, 1988), osteolepidid rhipidistian fishes (Schultze, 1988), dissorophoid amphibians (Daly, 1988), reptiles (Reisz, 1988), and coprolites (McAllister, 1988).

Fossil plants from the Hamilton deposit occur in a variety of preservational states, including spores and pollen (Taggart and Ghavidel-Syooki, 1988). Probably the most significant material includes petrification grade permineralization of primitive walchian conifers (Mapes and Rothwell, 1984, 1988) and cordaites, as well as associated seed ferns that may represent part of the rarely preserved upland understory vegetation (Mapes and Gastaldo, 1986; Rothwell and Mapes, 1988). The compression plant assemblage reveals taphonomic influence with diverse fragmented and disarticulated remains that may represent more than one plant community (Leisman, Gillespie, and Mapes, 1988). By contrast the numerous excellently preserved conifer remains include large, leafy branching systems with woody branches, young buds, pollen cones, and seed cones. Some of the Hamilton conifer seed cones contain cotyledonary embryos (Mapes, Rothwell, and Haworth, 1989) that provide the first evidence for post-zygotic quiescence leading to seed dormancy. In addition, the presence of certain conifers and seed ferns preserved as charcoal suggests recurring forest fires may have been an important part of the Hamilton paleoenvironment.

Ongoing research on the Hamilton sequence currently includes American Chemical Society-Petroleum Research Fund support (PRF #20742-B8-C) to R.H.M.; National Science Foundation and National Geographic Society support to C.G.M. and H.P.S.; and continued long term support to G.M. and other researchers by the Kansas Geological Survey. Property access for the above research and this field trip has been carefully obtained. We would request that all interested workers please obtain the appropriate permission before entering any Hamilton properties and take special care not to litter, start fires, damage fences, or leave gates open.

STOP 8: WAVERLY, KANSAS, TRACE-FOSSIL LOCALITY: APPROXIMATELY 3 MI WEST-SOUTHWEST OF WAVERLY, KANSAS (figs. 21-23) (60 minutes). (KANSAS STATE UNIVERSITY PALEOECOLOGY SEMINAR: R. R. West, V. Voegeli, S. Roth, C. G. Maples, K. Leonard, H. R. Feldman, and C. Cunningham)--Streambank exposure, Coffey County, Kansas.

We will examine the exposure along the stream east of the section-line road. This locality is 10 minutes from the Waverly exit off of I-35 and is easily accessible by car or bus.

Things to see: tidal-flat deposits, sedimentary structures, trace fossils, trails, burrows, and lag accumulations.

Stratigraphic sequence exposed: Doniphan Shale Member of the Lecompton Limestone (Pennsylvanian: Virgilian).

An excellent trace-fossil assemblage in a siliciclastic sequence of the Virgilian (Pennsylvanian) Doniphan Shale Member (Lecompton Limestone) occurs in the streambanks near the road. Park along the east shoulder of the road, cross the barbed-wire fence carefully,and descend into stream valley. REMEMBER THAT WE ARE ON PRIVATE PROPERTY WITH THE OWNER'S PERMISSION. PLEASE BE CONSIDERATE OF THIS PROPERTY.

At this stop we can examine in detail one part of the large-scale transgressive-regressive cycles seen earlier in the field trip. As a dominantly nonmarine-to-marginal-marine mudrock unit, the Doniphan Shale Member would be considered an "outside shale" in the terminology of Heckel (1977). However, evidence of small-scale transgressive and regressive events and sedimentary processes can be identified within this stratigraphic interval at this locality using paleoecological and ichnological analyses (Maples and West, 1988b, fig. 1). Beautifully preserved trace fossils (*Uchirites, Lockeia, Asteriacites, Conostichus, Chevronichnus*, and others) and sedimentary structures indicative of tidal-flat sedimentation (flat-topped ripple marks, wrinkle marks, and others) can be seen on thin slabs of fine-grained sandstone lying loose in the stream bed (Maples and West, 1988a). Trace-fossil preservation is enhanced in the sandstone at this locality because of the fine grain size and because of the presence of thin, intercalated shale partings between the sandstone beds that lend an overall sedimentary heterogeneity to the unit. This sandstone unit is overlain by an intensely bioturbated and bored (?) surface in which open U-shaped burrows and borings (?) are preserved (surface "A" in fig. 21). As you walk upstream, note that this sandstone interval is quite thin relative to the overlying mudstone unit.

The overlying mudstone is very silty throughout and has a lens-shaped body of fine-grained, ripple-laminated sandstone within it. Fossils in this mudstone unit are very small, worn, and corroded fragments (most passed through a 0.5 mm sieve) and include mollusk fragments (bivalves, gastropods, and scaphopods), crinoid and echinoid fragments, broken ramose and fenestrate bryozoans, and productid brachiopod spines and shell fragments (Roth *et al.*, 1989). The uppermost surface of the lens-shaped sandstone is criss-crossed by large (up to 20 cm [7.87 in.] wide) *Diplichnites* trackways. These trackways probably were produced by an arthropleurid-like animal (a milliped several decimeters long) and have been reported from classical Paleozoic nonmarine and marginal-marine areas such as Joggins, Nova Scotia.

Above the sparsely fossiliferous mudstone that contains the lens-shaped *Diplichnites* sandstone is a thin,

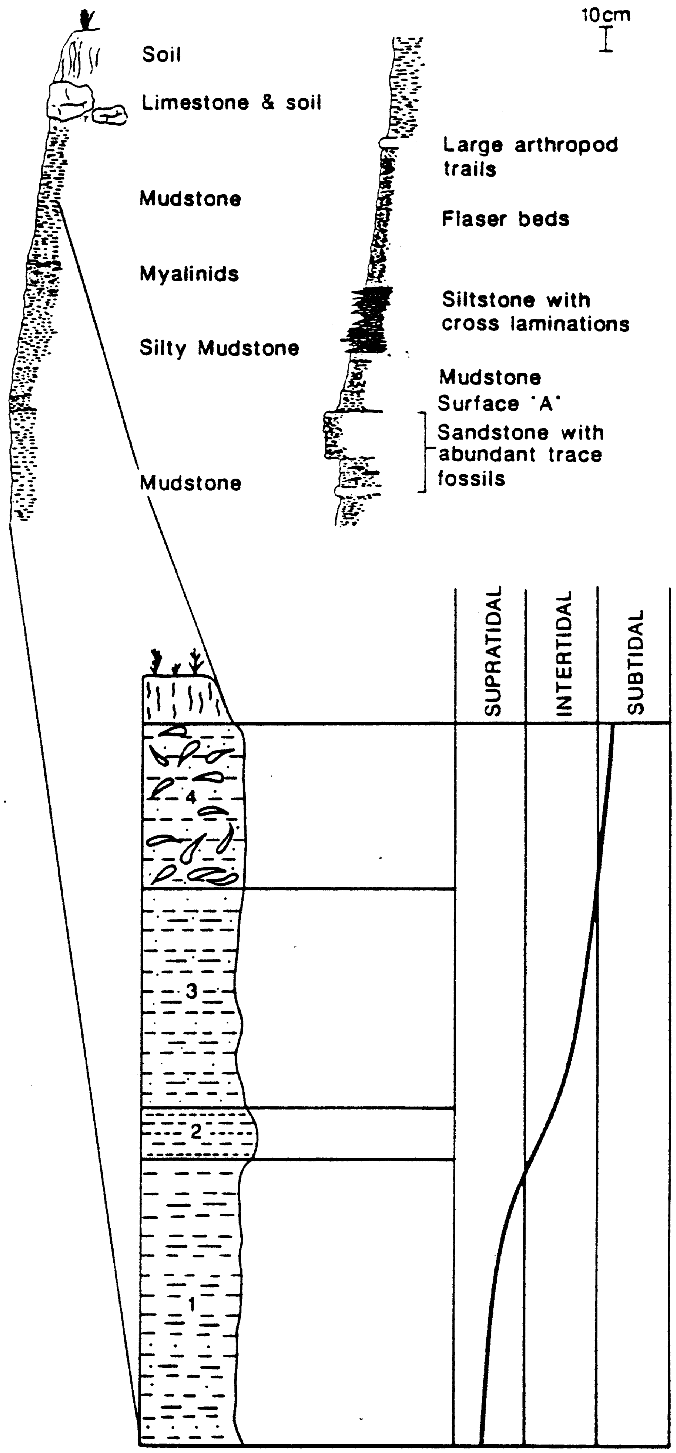


Fig. 21. Generalized stratigraphic section of the Doniphan Shale Member of the Lecompton Limestone at stop 8. Interval of study by the Kansas State University paleoecology seminar is shown in the foreground.

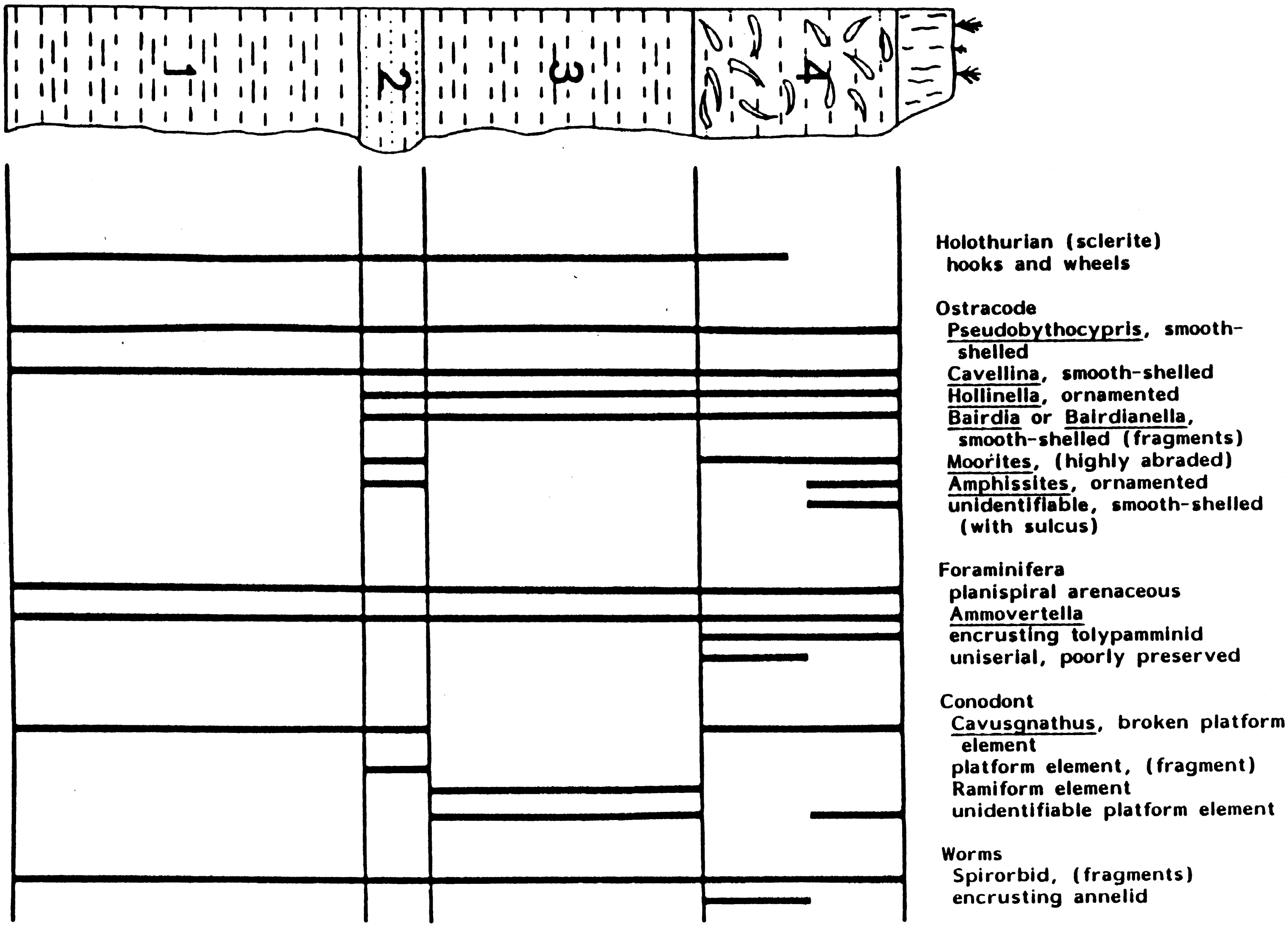


Fig. 22. Microfossil diversity of study interval (see fig. 21) based on bulk sample processing (data from Roth *et al.*,1989).

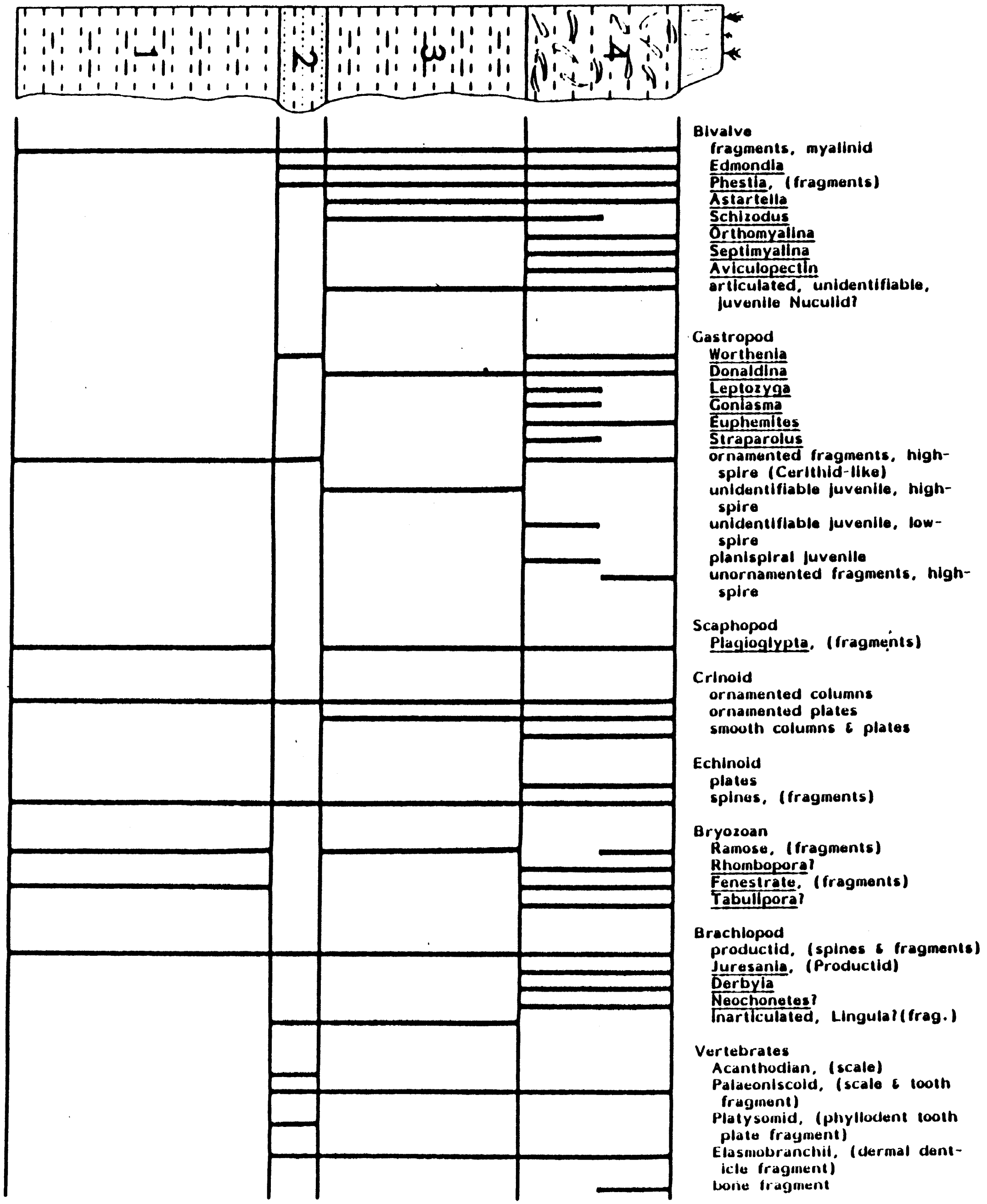


Fig. 23. Macrofossil diversity of study interval (see fig. 21) based on bulk sample processing (data from Roth *et al.*, 1989).

iron-stained bed in which Roth *et al.* (1989) noted a slight increase in both microfossil and macrofossil taxonomic diversity (figs. 22 and 23). This iron-stained bed appears to mark the beginning of a transition from the nonmarine to marginal-marine mudstone below to an environment of greater marine influence. Discontinuous layers (lenses) of packstone occur within the iron-stained unit and the grains in these packstones are mostly the bivalve *Edmondia* and the gastropod *Worthenia*. These packstone lenses could represent storm lags.

A greenish-gray mudstone overlies the iron-stained bed, and the contact is sharp. Taxonomic diversity of the fossil assemblage increases in this mudstone unit with bivalves (*Phestia, Astartella, Edmondia, Schizodus*) and gastropods (*Donaldina, Plagioglypta*) dominant and skeletal fragments of echinoderms, bryozoans, brachiopods, and vertebrates present (fig. 23). Some of the bivalve specimens are complete and articulated; however, most of the fossils are broken and abraded. Roth *et al.* (1989) interpreted this mudstone to represent low intertidal to very shallow subtidal deposition.

The highest diversity of marine body fossils is found in a 30-cm (11.8 in.) interval above the previously described greenish-gray mudstone (figs. 22 and 23). This 30-cm interval is essentially a myalinid shell bed in which *Orthomyalina* is the dominant taxon. Other conspicuous invertebrate fossils include other bivalves, gastropods, brachiopods, ramose and fenestrate bryozoans, echinoderm (crinoid and echinoid) debris, brachiopod fragments, and vertebrate pieces (fig. 23). Most bivalves show some disarticulation and abrasion. The heavier (myalinid) shells exhibit much less abrasion; however, a high degree of breakage from bioerosion is evident.

Using the morphometric study of myalinids by Hickey (1987), the dominant species present here probably is *Myalina* (*Orthomyalina*) *slocomi*. The general shape of this species, following Hickey (1987), suggests that it inhabited either tidal-flat or lagoonal environments. The life-orientation of these bivalves, as suggested by Seilacher (1984), is consistent with our field observations. The other myalinid species present is *Septimyalina perattenuata*. These myalinid species are rarely preserved articulated (five of 113 excavated *in-situ* specimens were articulated). In addition, there is almost no difference in numbers of right valves (57) and left valves (51). Most of the myalinid valves have been encrusted and bored. Borers (acrothoracican barnacles, ctenostomatid bryozoans, and probably polychaetes) occurred mostly on the external parts of the shells; however, encrusters (algae, polypamminid foraminiferans, and fistuliporoid bryozoans) occur both inside and outside the shells. Preliminary study of the broken margins of these myalinid valves strongly suggests that the action of the borers, especially the probable polychaetes (*Caulostrepsis*), was responsible for the majority of shell breakage. If this proves to be the case, then this is one of the earliest examples of extensive bioerosion (such as that in modern coastal areas) in the fossil record. Our interpretation of this myalinid interval is that it accumulated in a shallow subtidal environment and represents the transgressive event of the genetic sequence, which ends at the base of the overlying limestone (see fig. 21).

STOP 9: ROADCUTS NEAR MAPLE HILL, KANSAS, ALONG SOUTH LINE OF SEC. 26, T. 11 S., R. 12 E., WABAUNSEE COUNTY (figs. 24, 25) (60 minutes).

Leaders: R. R. West and and R. Matsumoto.

Things to see: Pennsylvanian-Permian boundary, lack of Kansas-type cyclothem, and facies mosaic in Pony Creek Shale.

The Pennsylvanian-Permian contact is exposed on both sides of I-70 at this locality. We will examine the exposure on the north side of the interstate. Please be sure to pull off the highway carefully and completely.

As shown in figure 24A, this exposure is located on the west flank of the Brownville Syncline, an asymmetrical structure in the Forest City Basin, and the east flank of the Nemaha Anticline. The depositional environment is marginal marine as determined by Bisby (1985) and shown in figure 24B. Dominantly terrestrial environments occur to the west along the Nemaha Anticline with dominantly marine environments eastward in the Brownville Syncline.

The stratigraphic sequence exposed here extends from the Grayhorse Limestone member of the Wood Siding Formation (Pennsylvanian), which crops out low in the road ditch at the west end of the exposure, to the Aspinwall Limestone Member of the Onaga Shale (Permian) at the top of the outcrop (fig. 24C). Besides the Grayhorse and Aspinwall, the other stratigraphic units exposed, in ascending order, are: Pony Creek Shale Member and Brownville Limestone Member, both of the Wood Siding Formation, and the Towle Shale Member of the Onaga Shale.

The three important aspects of this stop are: 1) the Pennsylvanian-Permian boundary is clearly visible, 2) the basic "Kansas" cyclothem seen in the Missourian earlier on this trip is not present here, and 3) the facies mosaic recorded by a very small (thin) and subtle, but important, genetic event within the Pony Creek Shale Member.

The systemic boundary between the Pennsylvanian and Permian is placed at the top of the Brownville Limestone Member (i.e., at the top of the Wood Siding Formation). Placement of the boundary at this position is based on what have been considered major changes in the "aspects" of the fossil assemblages in the rocks below this position and compared to fossil assemblages in the rocks above this position (Moore, 1940; Moore, 1949; and Mudge and Yochelson, 1962). The Brownville Lime-

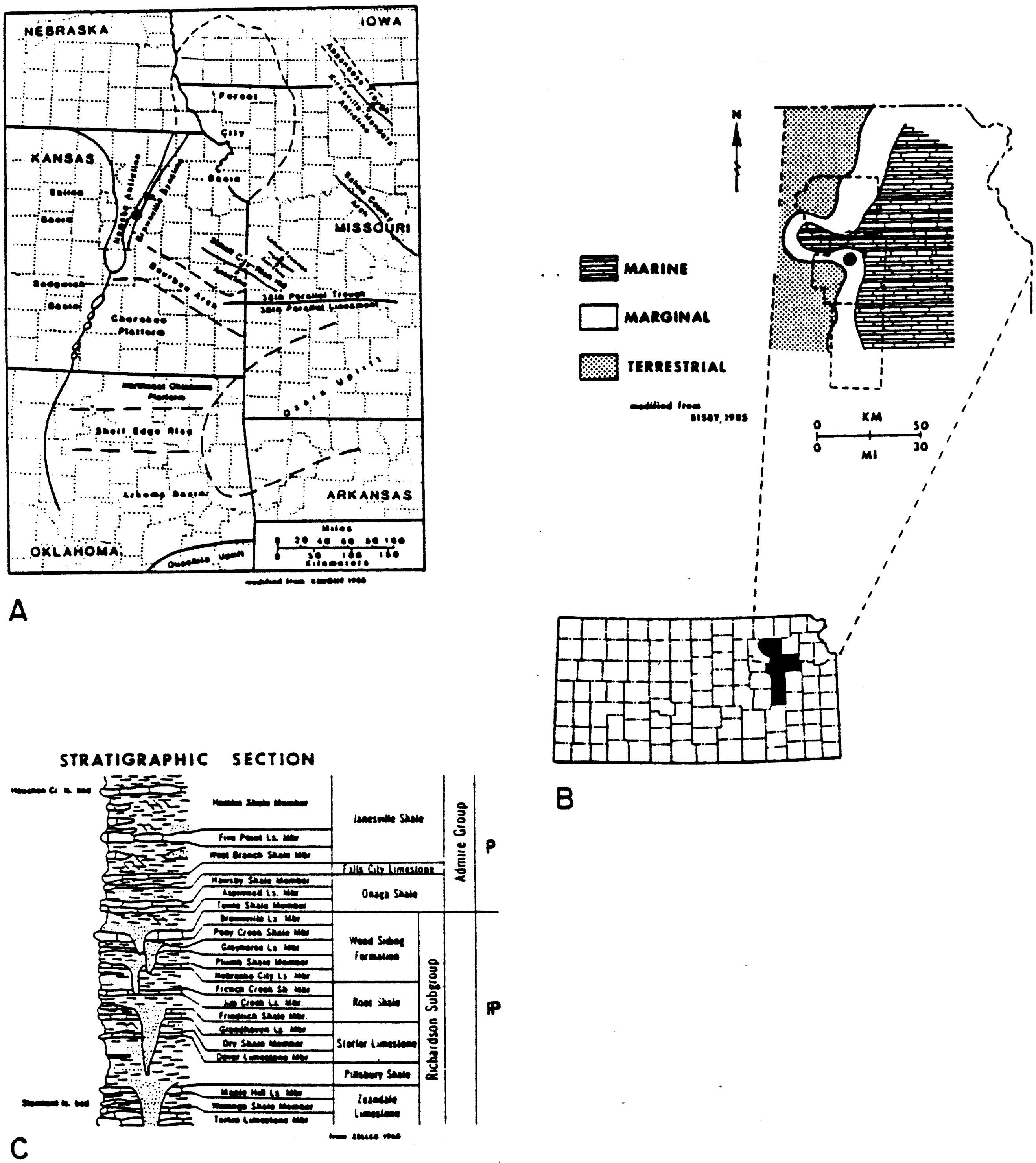


Fig. 24. Maple Hill, Kansas, stop 9; A) location of stop relative to structural features (modified from Knight, 1985); B) location of stop relative to inferred depositional environments (modified from Bisby, 1985); C) Stratigraphic sequence (from Zeller, 1968).

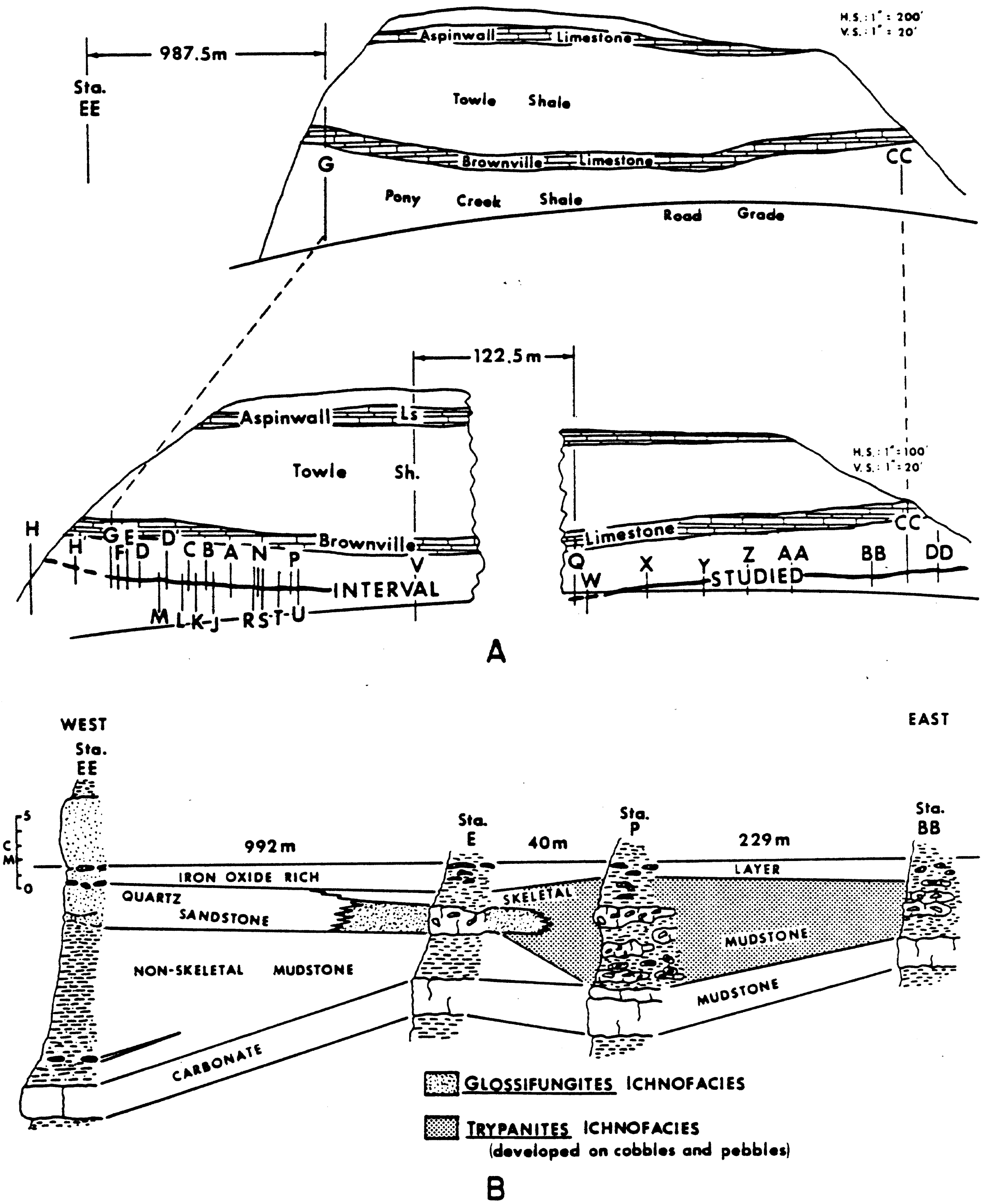


Fig. 25. A) Vertical profile of exposure at Maple Hill stop showing locations of stratigraphic sections; B) Stratigraphic cross section at Maple Hill stop (west to east) showing facies mosaic.

stone Member is a conspicuous lithostratigraphic unit and is easily recognized across Kansas, but the significance of the biotic change is debatable (Mudge and Yochelson, 1962).

In this part of the stratigraphic sequence (upper Wabaunsee and lower Admire groups), the typical "Kansas" cyclothem of Heckel (1977) is difficult, if not impossible, to recognize, and may not exist. The basic lithologies of these Upper Pennsylvanian and Lower Permian rocks, in this area, are siltstones, claystones, mudstones, and sandstones. Limestones are commonly thin and a minor part of the sequence. Close examination of these sequences reveals that they record numerous small-scale events (Bisby, 1985, 1986). In the area studied to date (north-central Kansas), some of these are allogenic events that record sea-level and/or climate change. Indeed, the paleogeography suggested by the correlation of these events is reflected in the differences in the biotic diversity of some of the dominantly marine units, such as the Brownville Limestone Member (Bisby, 1985, 1986).

One of the genetic events recorded by this sequence of rocks reveals an interesting facies mosaic at this locality. This genetic event occurs in an 8-to-11 cm (3.14-4.33 in.) interval, about 3 m (9.8 ft) below the top of the Brownville Limestone Member in this roadcut. A total of 30 stratigraphic sections were measured and described along a 300-m (984 ft) transect (fig. 25A, secs. H to DD). From the base to the top of the 8-to-11 cm interval, the environment of deposition is inferred to have changed from a nonmarine muddy environment to a marginal marine environment (low intertidal to very shallow subtidal) and higher intertidal to nonmarine environment. This uppermost depositional environment is represented by an interval of heavily oxidized ironstone nodules and crusts in a unfossiliferous mudstone (West and Matsumoto, 1986). The low intertidal to very shallow subtidal part of this thin sequence is represented by a 2-cm (0.78-in.) thick tempestite that overlies a 1-cm (0.39-in.) thick, clayey carbonate mudstone (West and Matsumoto, 1986). It is within this clayey carbonate mudstone that the facies mosaic is conspicuous. From west to east, along this 300-m roadcut exposure, this clayey carbonate mudstone records a *Glossifungites* ichnofacies (sec. E, fig. 25B) to a *Trypanites* ichnofacies (secs. P and BB, fig. 25B). Across the valley to the west (sec. EE, fig. 25B), a nonmarine-to-marginal-marine quartz sandstone correlates with this ichnofacies mosaic. This interpretation is reasonable in terms of the paleotopography at the time of deposition of these units (Bisby, 1985, 1986). Essentially, the clayey carbonate mudstone, as it dried and cracked, provided flat pebbles, cobbles, and shingles that were colonized by components of the *Trypanites* ichnofacies. The inferred sequence of events that led to this storm deposit and its hiatus pebbles and cobbles is, in general, similar to genetic sequence VIa described by Fursich (1979) for some Jurassic rocks and a pebbly to reworked morphological hardground described from the Ordovician of Ontario by Brett and Brookfield (1984). The lateral relationships described by Pemberton and Frey (1985) and West *et al.* (in press) between sands and *Glossifungites* and *Trypanites* ichnofacies along the offshore islands of the Georgia coast are a reasonable modern analog for this record within the Pony Creek Shale Member at this locality.

DAY THREE: NEBRASKA STOPS (figs. 26, 27)

STOP 10. ROADCUT ON COUNTY ROAD ABOUT 2.5 MI SOUTHEAST OF TABLE ROCK: WHITE CLOUD, CEDARVALE CHANNEL DEPOSITS; CEDARVALE "CORE" SHALE WITH REGRESSIVE RULO LIMESTONE; SILVER LAKE CHANNEL DEPOSITS, NEW "BURLINGAME" CYCLOTHEM, SE 1/4 SE 1/4, SEC. 3, T. 2 N., R. 12 E., PAWNEE COUNTY (fig. 28) (40 minutes).

Leaders: Roger K. Pabian, R. F. Diffendal, Jr.

Things to see: Minor and intermediate cycles; subaerially eroded Happy Hollow Limestone.

Here, there is evidence for several separate transgressions that are comparable to minor and intermediate cycles (cf. Heckel, 1985). There is an unfossiliferous shale in the White Cloud Shale Member of the Scranton Formation (unit 1, fig. 28); unit 2, however, is a limestone that is slabby near the base and becomes blockier in the upper 10 cm (4 in.). It contains algal-coated marine fossils and marks a short incursion in a nearshore sequence. Units 3, 4, and 5 are generally unfossiliferous.

The Happy Hollow Limestone member is an unfossiliferous, rotten, clayey limestone that is a dark yellow-orange on weathered surfaces. It may have been subaerially weathered and eroded; no fossils have yet been found in it.

The Cedarvale Shale Member of the Scranton Formation contains two units; the lower (unit 7, fig. 28) is an unfossiliferous shale with limonite concretions, some of which may contain plant remains. It appears to be a nearshore shale. Unit 8, however, is a dark olive-gray to dark gray shale that is fissile in some areas; it contains abundant ostracods (*Holinella* ?) and a few small bivalves (cf. *Dunbarella*). It may represent an offshore shale, the transgression having been sufficiently rapid to prevent the development of a transgressive limestone. The greatly reduced Rulo Limestone Member (unit 9, fig. 28) contains numerous large invertebrates, and it may represent a regressive limestone. The absence of a transgressive limestone facies and the greatly reduced regressive limestone facies suggest a rapid rise and a rapid fall of sea level and a minor incursion in shaly formations (cf. Heckel, 1985).

The Silver Lake Shale Member of the Scranton For-

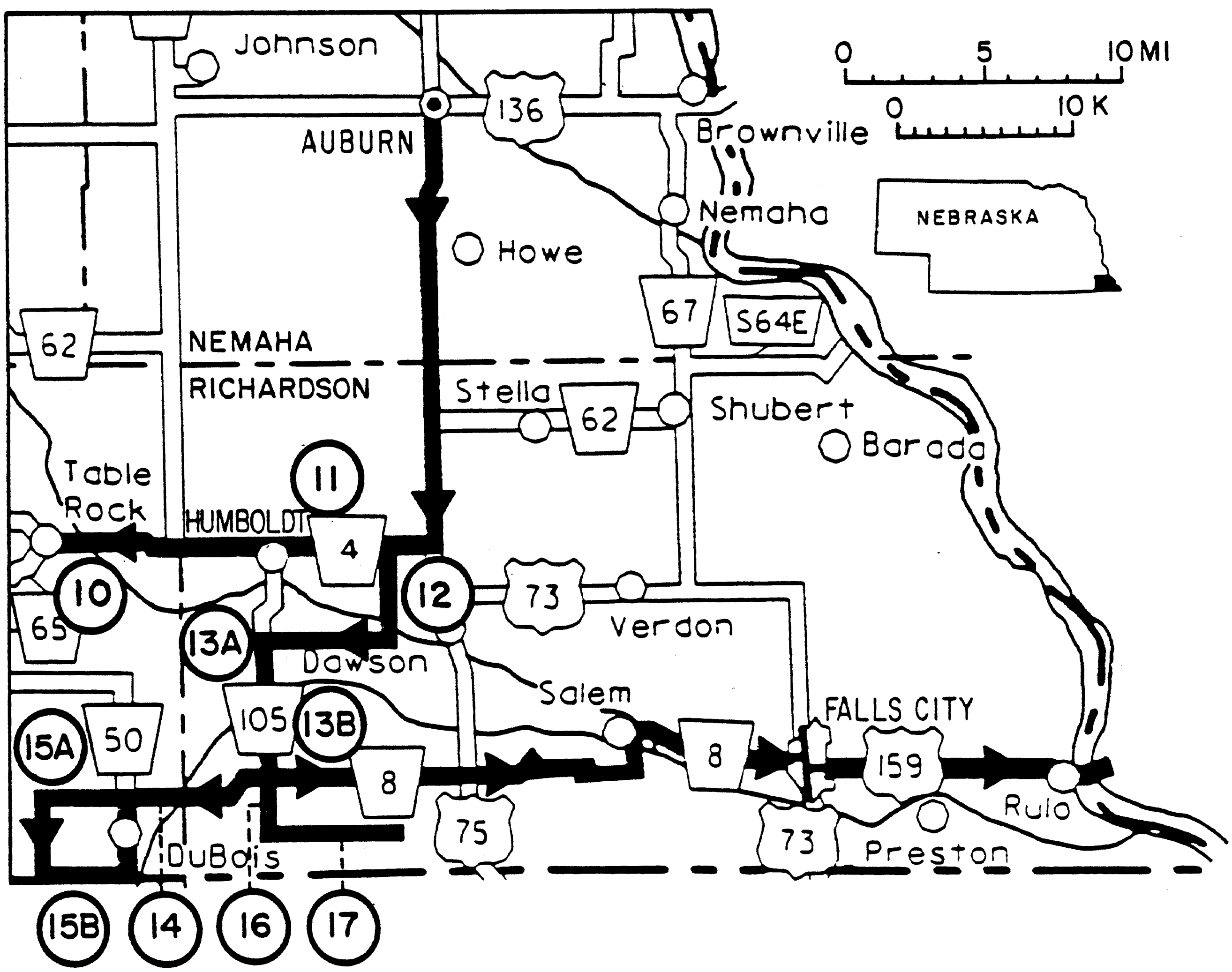


Fig. 26. Locations of field trip stops in southeastern Nebraska.

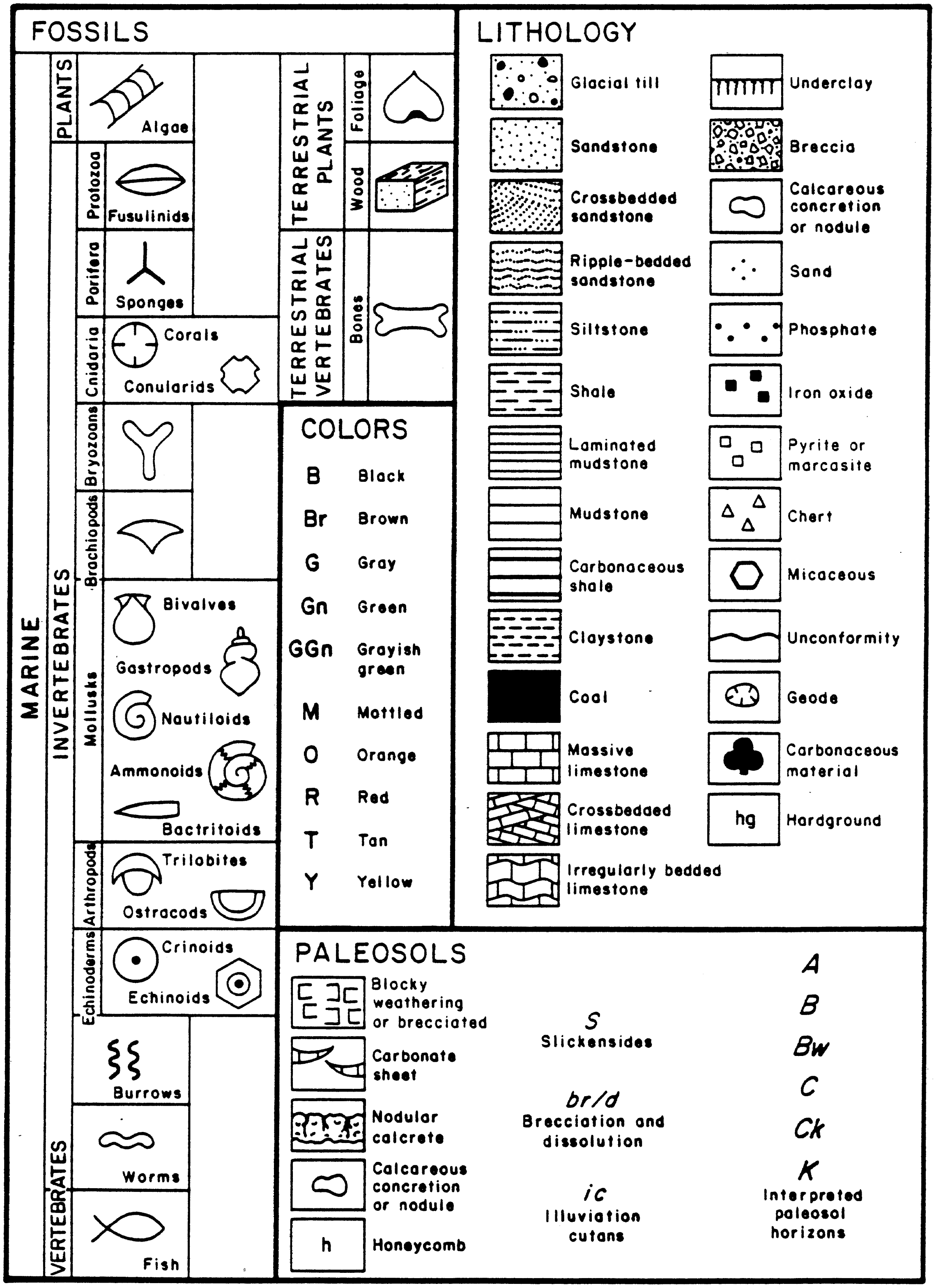


Fig. 27. Legend of symbols and letters used for Nebraska field trip stops.

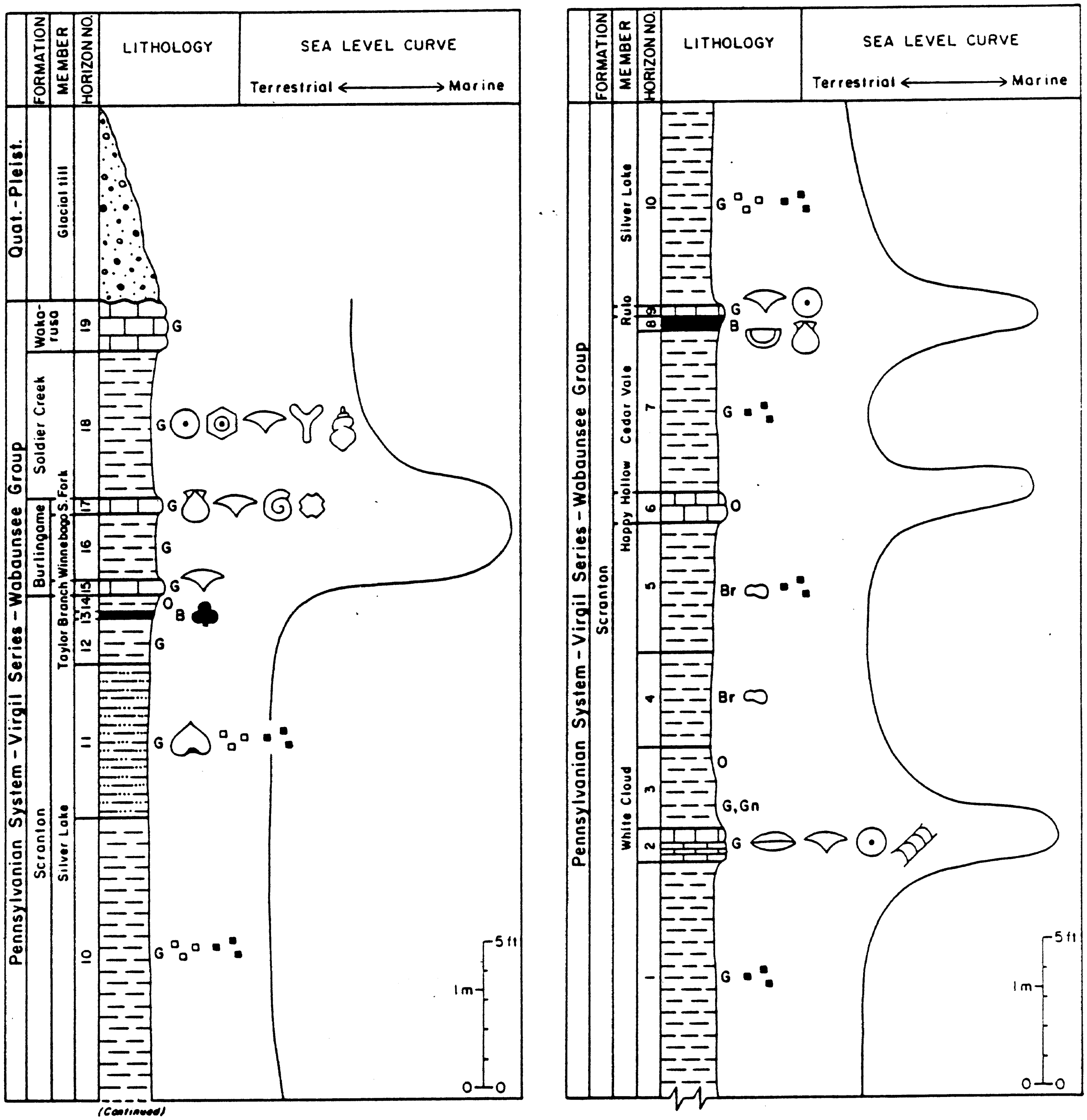


Fig. 28. Geologic section exposed at stop 10.

mation (units 10-14, fig. 28) may contain estuarine deposits; it contains marcasite concretions--some having plant remains--suggesting a nearby, low-lying source area. Nearshore conditions persisted through the deposition of unit 14. Unit 13, a black claystone, contains abundant plant matter and is a nearshore shale.

The Taylor Branch Limestone Member of the Burlingame Formation may be a transgressive limestone of a new cyclothem; it is a very dense, fossiliferous unit. The overlying Winnebago Shale Member (unit 16, fig. 28) may be the offshore shale. The nature of the included fossils suggests that the South Fork Limestone Member (unit 17) and the Soldier Creek Shale (unit 18) are regressive units. Sea level may have risen slowly and fallen rapidly to produce the reduced regressive limestone (Heckel, 1985). The Wakarusa Limestone (unit 19) is difficult to interpret because of the few, poorly-preserved fossils; it too may have been subaerially eroded.

STOP 11: BORROW PIT ON COUNTY ROAD ABOUT 2.5 MI EAST OF HUMBOLDT, C W 1/2 SW 1/4 NW 1/4 SW 1/4 SW 1/4, SEC. 36, T. 3 N., R. 13 E., RICHARDSON COUNTY (fig. 29) (40 minutes).

Leaders: R. M. Joeckel

Two noteworthy paleosol complexes occur in the Lower Permian of Richardson County, Nebraska. One of these paleosol complexes is in a mudstone unit tentatively identified as the uppermost part of the Eskridge Shale (stop 1: C W 1/2 NW 1/4 SW 1/4 SW 1/4, Sec. 36, T. 3 N., R. 13 E.) of the Council Grove Group. Burchett and Arrigo (1978) described a fault in the Beattie Formation in the area; therefore the mudstone unit--which underlies that faulted limestone--can be correlated with the Eskridge. However, this correlation is not yet fully resolved.

The paleosol complex here is thick (> 3 m [9.8 ft]) and has an upper surface (ancient land surface) that evolved into a marine transgressive surface with rising sea level. There are two color zones (not discrete soil horizons in themselves): 1) an upper, light gray to light olive-gray (5Y 7/2-6/2) massive zone that extends 145 cm (4.75 ft) downward from the terrestrial paleosurface and 2) a lower, reddish-brown (2.5 YR 5/4-4/4), breccia-like zone extending from 145 to 310 cm (10.16 ft) below the terrestrial paleosurface. A 4-cm (1.57 in.) gradation in color (pedologically, a clear boundary) separates these zones. Several 1-8 cm (0.39-3.15 in.) thick pod-to-sheet-like bodies of carbonate occur in both color zones. These pods or sheets are crudely wavy in geometry, pinch and swell every 20-50 cm (0.66-1.64 ft), and are 7-10 cm (0.22-0.33 ft) apart in vertical section.

The breccia-like appearance of the lower zone is due to the presence of carbonate-impregnated mudstone aggregates that are highly dissimilar in size and shape. These aggregates are probably not original soil peds in the strictest sense, but instead seem to have resulted from the displacive and disruptive effects of pedogenic calcite precipitation (in the form of abundant crystallites)--perhaps in the initial stages of soil nodule formation. In thin section, some of the vein-like areas between aggregates contain zones of weakly to moderately oriented clay analogous to stress argillans developed in some carbonate-containing modern soils (e.g., Sobecki and Wilding, 1983). Presumably these features formed as clayey soil material was laterally displaced and compressed between regions of carbonate precipitation. Subhorizontal (dipping up to 45 degrees), mudstone-filled fractures with associated weakly developed slickensides are further evidence for *in-situ* pedogenic disruption. Although there appears to be no specific modern analog to the breccia-like zone in the paleosol at stop 11, its features are generally analogous to slickensides, brecciation, and related features found in some modern and ancient carbonate-rich soils/calcretes (e.g., Watts, 1977, 1978; Klappa, 1980; Goldbery, 1982; Wright, 1982; Allen, 1986). Whether the profile at stop 11 represents a single thick paleosol or multiple, amalgamated paleosol horizons is unclear; in either case significant alteration of depositional fabrics by near-surface processes took place. Carbonate sheets within the paleosol lack the nodular, pisolitic, or laminar fabrics common in modern pedogenic (within-soil) calcretes (Goudie, 1983; Machette, 1985). Thus, the sheets are probably groundwater (subsoil) features precipitated near the water table, either during the terminal evolution of the ancient land surface or at a much later date.

STOP 12: BORROW PIT ON ROADCUT ABOUT 1 MI SOUTH AND 3.5 MI EAST OF HUMBOLDT, SW 1/4 SW 1/4, SEC. 8, T. 2 N., R. 14 E., RICHARDSON COUNTY (fig. 30) (25 minutes).

Leader: R. M. Joeckel

The second of these paleosols-calcretes also occurs in the Eskridge Shale (stop 12: SW 1/4 NW 1/4 SW 1/4 SW 1/4, Sec. 8, T. 2 N., R. 14 E.). Four distinct horizons of pedogenic carbonate enrichment are present in the section here. Three of these horizons are laterally continuous, well-indurated, and thick (up to 80 cm [2.62 ft]) horizons of intergrown carbonate nodules with small amounts of interstitial, calcareous silty clay (paleosol host) filling large, irregular, vertical voids. The carbonate phase is micritic and is light gray (2.5Y 7/2) to pale yellow (2.5Y 7/4) in color; the paleosol host material is light greenish-gray (5GY 7/1) with a few reddish-gray (10R 6/1) patches. As with the breccia-like zone at locality 11, the soil host within the nodular horizons shows zones of weak to moderate clay orientation in thin section, indicating *in-situ*, displacive precipitation of carbonate. Coarse, blocky spar-filled planar voids and vugs are common in the micritic carbonate phase. The uppermost of

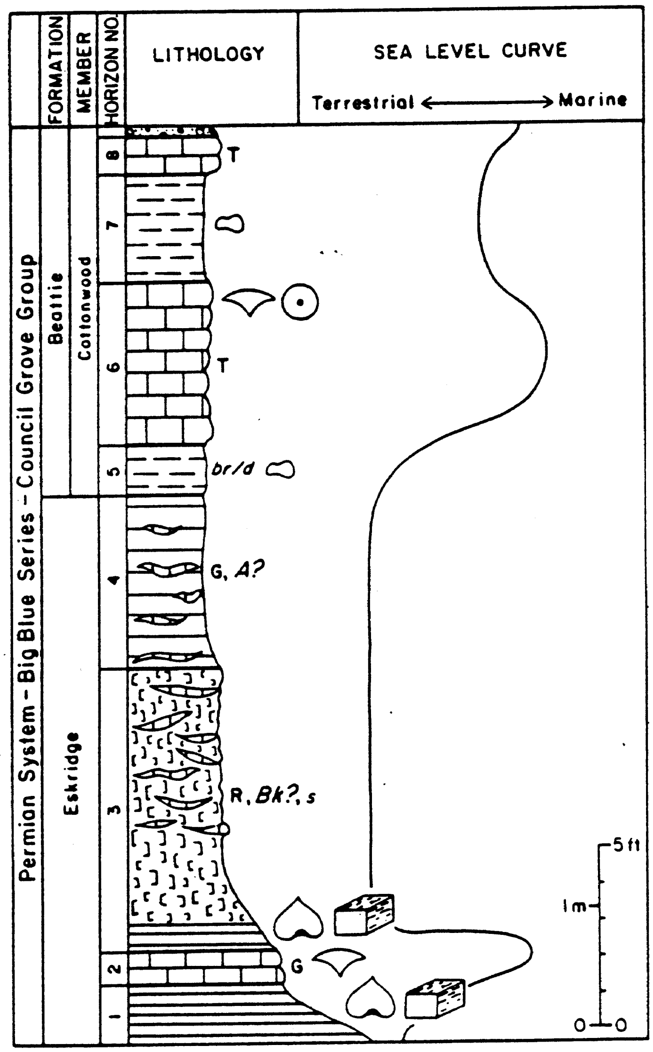


Fig. 29. Geologic section exposed at stop 11.

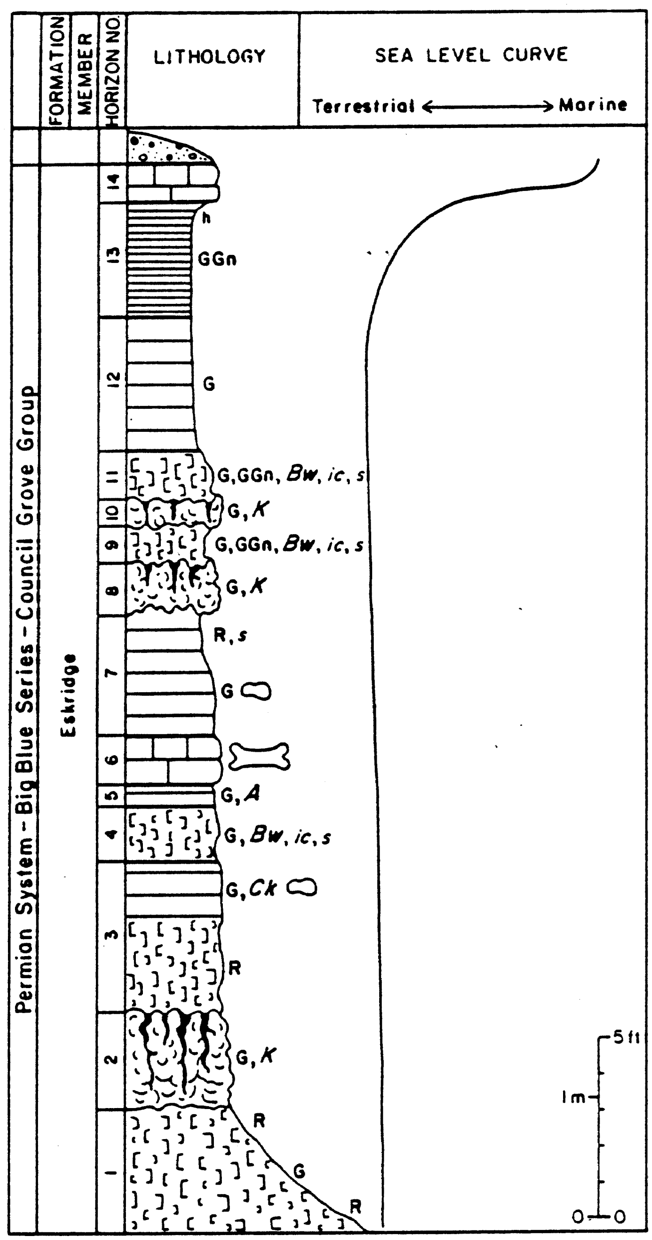


Fig. 30. Geologic section exposed at stop 12.

the three nodular horizons is not as well developed or well indurated as the lower two. A fourth horizon of carbonate enrichment lies between the two well-expressed nodular horizons, and consists of diffuse, weak red (2.5YR 4/2) carbonate patches and nodules in a light gray (5GY 7/1) calcareous mudstone with prominent joints. In all four cases, the carbonate horizons here are overlain by what appears to be paleosol Bw or weak Bt horizons, which are distinguished by their gray (5Y 5/1) color, weak red (10R 4/2) cutans (indicating illuviation of iron, and possibly some clay, through the profile), faint, small slickensides, and tendency to weather in a blocky fashion. The three nodular horizons are interpreted as paleosol K horizons because they are continuous, well-indurated horizons of fine-grained carbonate. The fourth horizon is best interpreted as a paleosol Ck horizon. The phenomenon of stacked, even "welded" (*sensu* Ruhe and Olson, 1980), paleosol horizons at stop 12 suggests a relatively complex geomorphic history of incremental deposition and pedogenesis during Eskridge times--a sequence perhaps similar, although smaller in scale, to "welded" calcrete-soil profiles associated with late Cenozoic land surfaces (e.g., Holliday, 1988).

The paleosols at stops 11 and 12 are significant indicators of protracted subaerial exposure and terrestrial geomorphic stability. By comparison with modern analogs, the paleosols probably record arid or semi-arid climatic conditions (Goudie, 1983; Machette, 1985). Paleosols at both stops show evidence of gleying (a change from reddish to greenish colors caused by the pedochemical reduction of iron) interpreted as a product of saturation associated with changes in groundwater and/or surface-water conditions during the Permian. At stop 11, the upper part of the paleosol is gleyed from the ancient land surface down, whereas at stop 12 localized gleying is present throughout the profile. Because the gleying at stop 11 is spatially associated with marine transgressive surfaces, I propose that it was produced by water-table rising and/or saturation of the soil surface caused by the succeeding marine transgression (which, in turn, deposited the Cottonwood Limestone on top of the former land surface). Analogous early diagenetic effects at stop 12 are more difficult to interpret and probably record a more complex series of events.

The research summarized in the descriptions of stops 11 and 12 was supported by a Sigma-Xi Grand-in-Aid of Research awarded to R. M. Joeckel.

STOP 13A: ROADCUTS ABOUT 2.5 MI SOUTH OF HUMBOLDT SHOWING MOSTLY EARLY PERMIAN STRATA OF ADMIRE AND COUNCIL GROVE GROUPS, ALONG EL SE 1/4 SEC. 21 AND WL NW 1/4, SEC. 27, T. 2 N., R. 13 E., RICHARDSON COUNTY (fig. 31) (40 minutes).

Leaders: Roger K. Pabian, R. F. Diffendal, Jr.

Things to see: Pennsylvanian-Permian contact; Admire cycles with poorly developed regressive facies; Humboldt Fault Zone; return to more normal depositional patterns with deeper transgressive facies and more fully developed regressive facies in Council Grove Group.

That the geology in Pawnee and Richardson counties is very difficult to interpret is well illustrated at stop 13A. The problems are compounded by several factors; these are summarized in Burchett and Arrigo (1978), and the ones germane to this study are given below. The Humboldt Fault is not a single structure but is a complex zone of faults and steep dips. The only fault actually observed in an outcrop is in the Cottonwood Limestone in the SW 1/4, Sec. 36, T. 3 N., R. 13 E. (stop 11). Displacements along other faults are not observable in outcrops.

The oldest rocks seen here are the upper Pony Creek Shale, a terrestrial to nearshore shale unit, and the Brownville Limestone Member of the Wood Siding Formation. They are of Late Pennsylvanian age (units 1-7, fig. 31). The Pennsylvanian-Permian contact is currently placed at the conformable contact between the Brownville Limestone and the overlying Towle Shale Member of the Onaga Formation (Mudge and Yochelson, 1962). We have not yet determined whether or not the section here is a boundary section.

Several minor marine pulsations occur in the Onaga and Falls City formations. The Towle Shale Member is overlain by a hardground that may be in the same stratigraphic position as the Aspinwall Limestone Member. The Hawxby Shale Member is a nearshore unit overlain by the Miles Limestone. The absence of any offshore shale suggests the Miles was deposited during a rapid transgression and regression (cf. Heckel, 1985). Another short marine pulsation is shown by the Lehmer Limestone.

The West Branch-Hamlin interval is not differentiated and subdivided here. The lower part (horizon 14, fig. 31) contains alternating, thin beds of limestone and shale, and the upper part is almost entirely covered. Burchett (1987) stated that about 24 m (80 ft) of section is missing here and that this is due to displacement along the Humboldt Fault Zone. Some honeycomb structure occurs in horizon 14 here, suggesting that the surface was emergent sufficiently long for some pedogenic processes to take place.

The Americus Limestone Member of the Foraker Formation is the oldest unit in the Council Grove Group. It appears to contain the transgressive limestone of a new cyclothem, and it includes a dark gray, carbonaceous shale that may be an offshore shale. The Hughes Creek Shale is the regressive sequence of this cyclothem; it contains a diverse marine biota including bryozoans, echinoderms, and brachiopods. Avers (1968) has shown that the upper Hughes Creek Shale develops a regressive limestone in it near Westmoreland in Pottawattamie County, Kansas. The sequence here shows a return to more normal sedi-

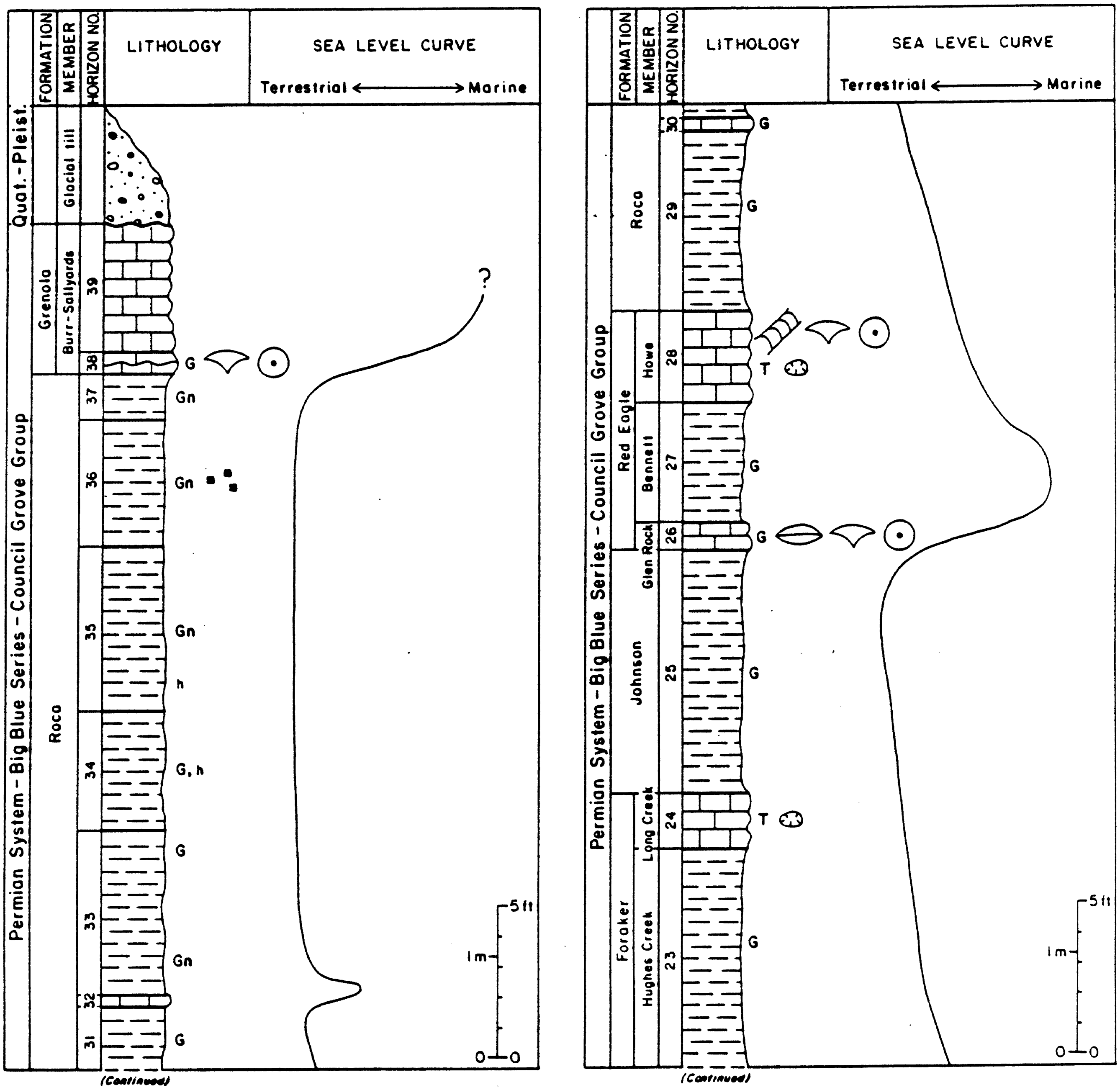
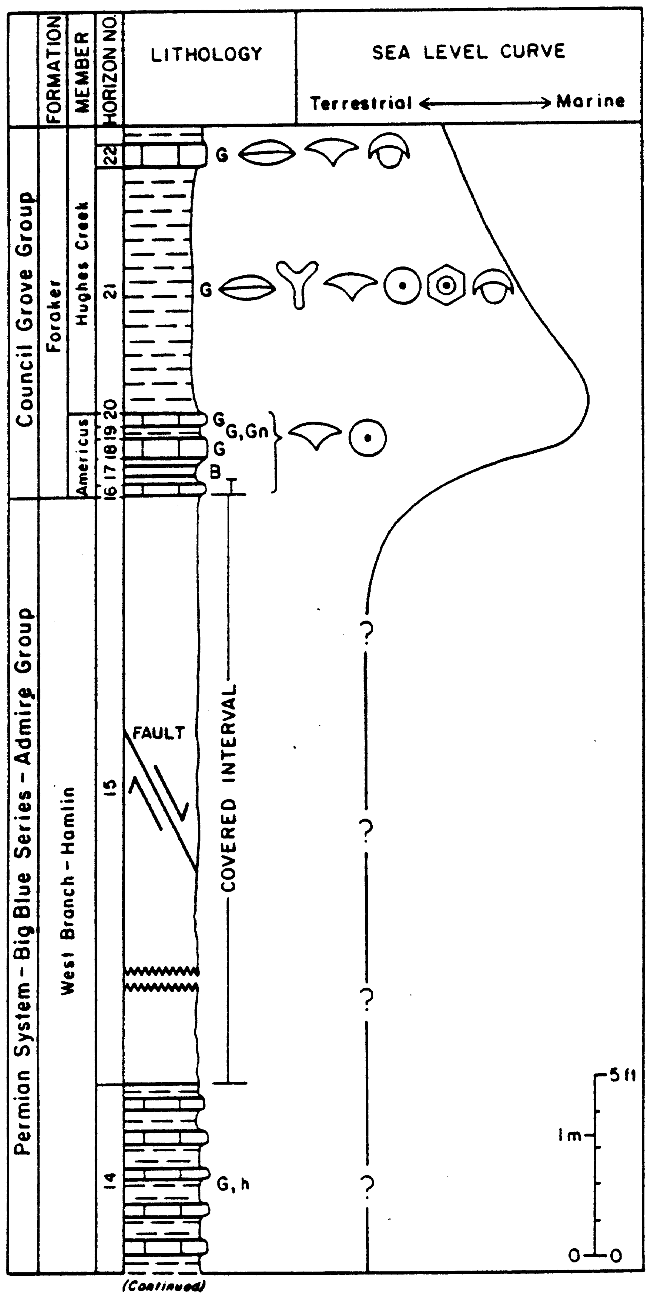


Fig. 31. Geologic section exposed at stop 13A. Units 1-13 measured by Pabian and Diffendal. Units 14-39 measured by Burchett, Pabian, and Diffendal.


FORMATION
MEMBER
HORIZON NO.
LITHOLOGY
SEA LEVEL CURVE
Terrestrial ←→ Marine
Council Grove Group
Foraker
Hughes Creek
Americus
Permian System - Big Blue Series - Admire Group
West Branch - Hamlin
FAULT
COVERED INTERVAL
G, h
G,Gn
(Continued)

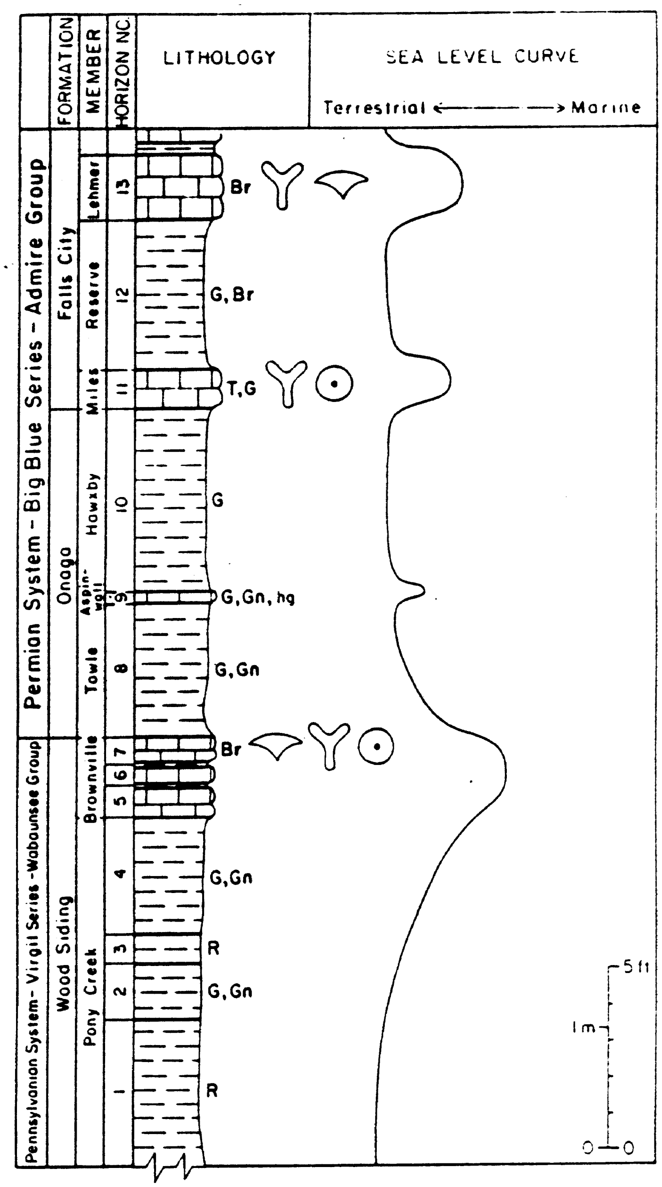

FORMATION
MEMBER
HORIZON NO.
LITHOLOGY
SEA LEVEL CURVE
Terrestrial ←→ Marine
Permian System - Big Blue Series - Admire Group
Falls City
Onaga
Lehmer
Reserve
Miles
Hawxby
Aspinwall
Towle
Brownville
Pennsylvanian System - Virgil Series - Wabaunsee Group
Wood Siding
Pony Creek
G,Br
T,G
G,Gn, hg
G,Gn

Fig. 31. (Cont.)

mentary sequences that were abandoned after deposition of the Howard Cyclothem.

Evidence of an eroded and weathered surface occurs in the Long Creek Limestone (unit 24, fig. 31), which has honeycomb structures and calcite-filled geodes near its upper surface. The overlying Johnson Shale (unit 25, fig. 31) is badly covered here, but in other exposures, it contains gypsum and calcareous concretions, suggesting subaerial rather than submarine conditions.

The Glenrock Limestone and Bennett Shale are both poorly exposed here, and they will be treated in greater detail at stop 16. Suffice it to say here that the Glenrock Limestone is a dense, skeletal calcilutite and that the Bennett Shale contains a dark brown to dark gray zone that may be an offshore sequence, and the Howe Limestone above is a regressive sequence; these units suggest more normal sedimentation sequences as seen in the previous Foraker Cyclothem.

The Roca Shale appears to have been a continental deposit too; it contains numerous calcareous concretions, but unit 36 at stop 13A (fig. 31) is burrowed. No fossils have yet been found with the burrows. The overlying Grenola Formation is poorly exposed here and will be treated in greater detail at stop 17.

STOP 13B. ROADCUT ABOUT 6.75 MI SOUTH OF HUMBOLDT ON HIGHWAY 105, WL, SW 1/4 NW 1/4, SEC. 10 AND EL NE 1/4 SE 1/4, SEC. 9, T. 1 N., R. 13 E., RICHARDSON COUNTY (fig. 32) (40 minutes).

Leaders: Roger K. Pabian, R. F. Diffendal, Jr.

Things to see: continental deposits in Dry Shale; new cycle beginning with deposition of Grandhaven Limestone; transgressive units in Jim Creek Limestone and French Creek Shale; coals in French Creek Shale; intraformational conglomerates in Nebraska City and Gray Horse limestones; Pennsylvanian-Permian contact.

Only the upper part of the Dry Shale (horizon 1, fig. 32) occurs here, and it includes red beds and calcareous concretions, suggesting subaerial exposure. About 3 mi west-southwest of here, only the lowest part of the Dry Shale is present; it is a marine unit that contains an immature molluscan fauna. Shields (1987) has suggested that the Dry Shale in this area marks a long, emergent period and that the Grandhaven Limestone Member of the Stotler Formation is the transgressive limestone of a new cyclothem.

The Friedrich Shale Member of the Root Formation contains yellow-brown to brown and red beds, suggesting subaerial exposure. A new transgression began with the deposition of the Jim Creek Limestone Member (units 7-9, fig. 32). The lower bed of the Jim Creek is a late unit in a nearshore shale; it is very fossiliferous (unit 7, fig. 32) and is overlain by a thin shale (unit 8) and, finally, a transgressive limestone (unit 9). The offshore shale sequence is shown by unit 10 (fig. 32), the lowest bed in the French Creek Shale Member; it contains limonite concretions and an immature molluscan fauna of bivalves, snails, and rare goniatites.

The French Creek Shale Member (units 10-16, fig. 32) contains coal and sandstones, indicative of continental origin, and represents nearshore shales in the sequence.

The Nebraska City Limestone (unit 17, fig. 32) represents a new transgression; it contains limonite fossils. These fossils were probably originally pyrite and have since been oxidized to limonite. The Plumb Shale Member of the Wood Siding Formation generally contains red beds and probably marks old soil horizons.

The Gray Horse Limestone Member (unit 19, fig. 32) contains numerous intraclasts, suggesting that the sediment was periodically broken up by wave action and that the water depth was less than the depth of the effective wave base. The Pony Creek Shale Member (units 20-22, fig. 32) represents a regressive sequence, and the Brownville Limestone Member is a new transgressive sequence here. Deposition appears to have been continuous through the Miles Limestone Member of the Falls City Formation. Unit 26 here is a thin, concretionary zone between the Towle Shale (units 24 and 25, fig. 32) and the Hawxby Shale members (units 27 and 28, fig. 32) of the Onaga Formation; it appears to be a hardground, and it may correlate with the Aspinwall Limestone (unit 9, fig. 31) at stop 13A.

STOP 14. HOWARD CYCLOTHEM EXPOSED ON ROY FARWELL FARM SECTION MEASURED IN STREAM BANK, 150 FT SOUTH OF BRIDGE IN NW 1/4 NW 1/4 NE 1/4, SEC. 23, T. 1 N., R. 12 E., PAWNEE COUNTY (fig. 33) (25 minutes).

Leaders: R. F. Diffendal, Jr., Roger K. Pabian

The Severy Shale and Howard Limestone formations form a stratigraphically compact, very complete cyclothem. In the nearshore shale sequence are sandstones in the creek bed that show ripple marks. These rocks are overlain by silty and clayey shales; the shale directly below the Nodaway Coal (unit 3, fig. 33) is in some places composed of a sticky clay that may be the underclay (cf. Weller's unit 3, p. 9, or Moore's unit 1b, p. 11) in the cyclothem. Unit 4 (fig. 33) is a dark gray shale that has calcareous nodules at its base. These nodules contain pyritized fossils, and they may represent an underdeveloped transgressive limestone (cf. "Illinois" type cyclothem, Heckel, 1985). Units 5 and 6 (fig. 33) are gray to dark gray to black shales, some of which are fissile; these units are in the same stratigraphic position of a lithologically similar shale in Kansas that is called the Aard. These beds, however, have not yet been shown to be stratigraphically equivalent to the Aard. The Church Limestone,

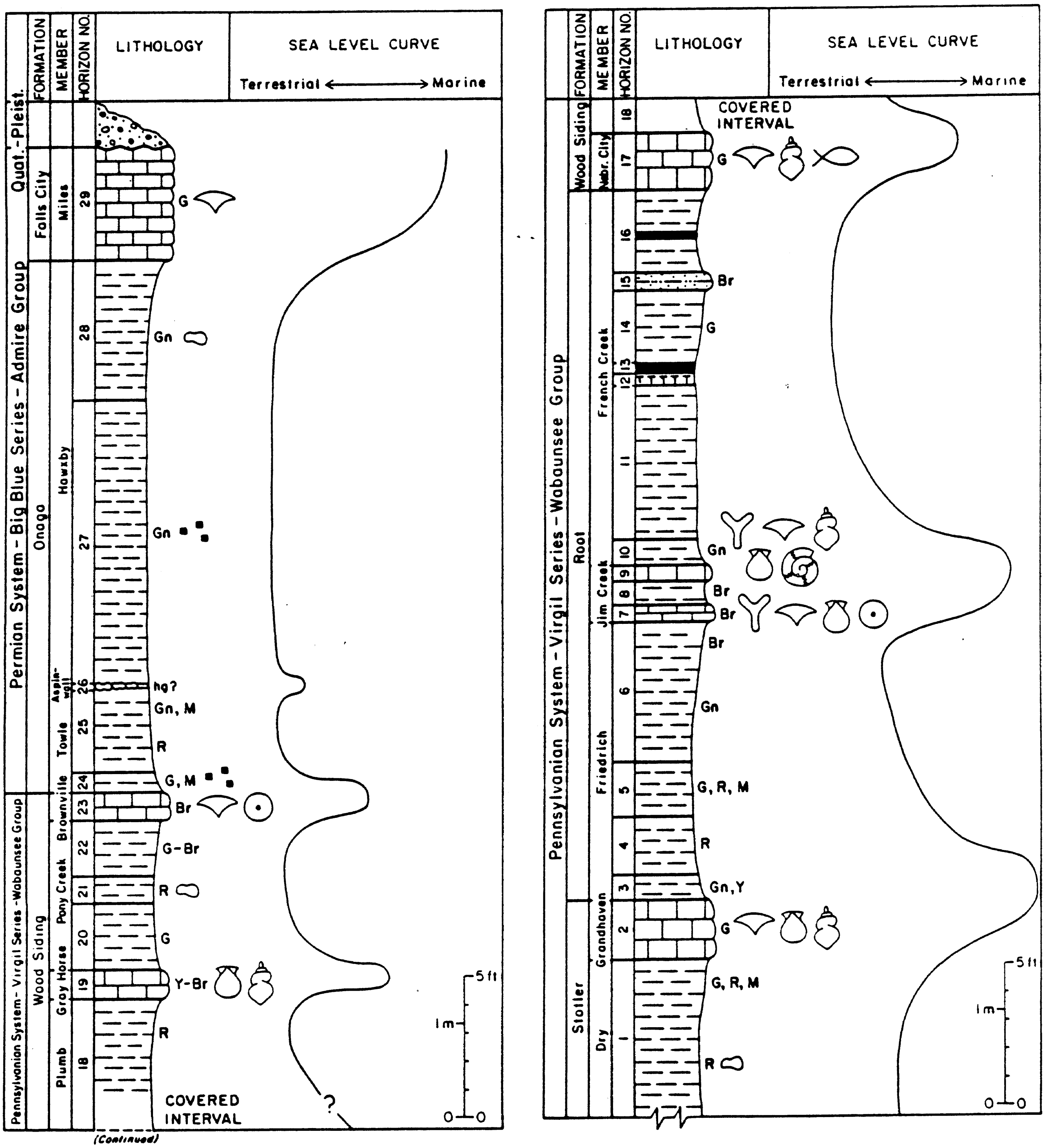


Fig. 32. Geologic section exposed at stop 13B.

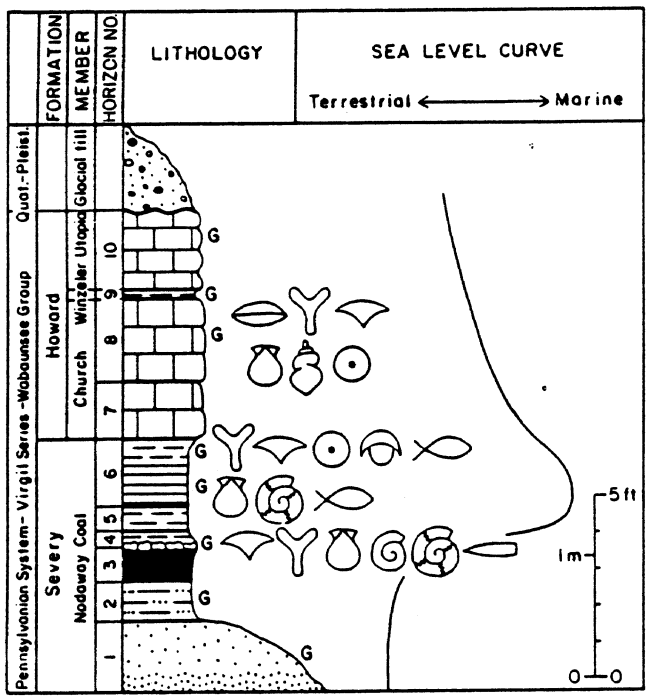


Fig. 33. Geologic section exposed at stop 14.

Winzeler Shale, and Utopia Limestone members of the Howard Formation are the regressive sequence of this cyclothem. The poorly developed transgressive facies, the well-developed offshore shale and well-developed regressive limestone suggest a rapid rise of sea level followed by a slow decline (cf. Heckel, 1985).

The regressive sequence in the Howard Cyclothem is the last one in which a thick regressive limestone has developed in the Wabaunsee Group. Thick, regressive limestones do not develop in cyclothems again until the deposition of the Council Grove Group of the lower Permian. In all of the cyclothems between the Howard Cyclothem and the Hughes Creek Cyclothem, the thick, regressive limestones failed to develop.

STOP 15A. OUTCROP IN EMERGENCY SPILLWAY FOR DAM AT IRON HORSE LAKE, ABOUT 0.5 MI NORTH AND 2.5 MI WEST OF DUBOIS, E 1/2 NW 1/4 SE 1/4, SEC. 17, T. 1 N. R. 12 E., PAWNEE COUNTY (fig. 34) (90 minutes).

Leaders: Theodore Huscher, Roger K. Pabian

Things to see: Minor cycles in Emporia and Willard formations with immature molluscan faunas; coquinoid limestone and root-mottled shale in Elmont Limestone; new transgressive sequence in upper Elmont Limestone.

The rocks were exposed during construction of an emergency spillway for the dam at Iron Horse Lake. The geologic marker at the east end of the dam was built by the Nemaha Natural Resources District.

The Auburn Shale is considered a nearshore shale (*sensu* Heckel, 1977). Outcrops just south of the county road that leads to the lake's entrance reflect the terrestrial nature of the lower and middle Auburn Shale. The upper Auburn Shale at the spillway outcrop marks the beginning of a new cyclothem (Heckel, 1977; Moore, 1936).

The relatively thick, fossiliferous limestones and shales of the Reading Limestone Member appear to demonstrate several minor cycles, the first of which is shown by a dense limestone and dark shale (horizons 2, 3, fig. 34) near its base. Several minor marine pulsations are represented by alternating, thin limestones and shales (horizons 6-9, fig. 34), and a minor cycle begins with deposition of horizon 10 (fig. 34), which is a transgressive limestone. The Harveyville Shale is an offshore unit. The presence of deep-water mature and immature molluscan communities found within its very dark gray shales suggests this was the greatest that water depths reached, or a point of maximum transgression (Boardman, *et al.*, 1985). The sea was likely not deep enough to establish conditions to form a fissile, phosphatic black shale.

Regression is recorded in the cross-bedded coquinoid limestone of the lower Elmont. This is possibly a beach deposit. That the basal Elmont Limestone (horizon 12, fig. 34) is a regressive unit is further supported by the fact that the immediately overlying shale bed (horizon 13) is root mottled (D. Loope, personal communication, 1986). A shale with possibly some sand at its top overlies this bed. A hard, dense fossiliferous limestone, the top bed of the Elmont, marks the beginning of a new transgression.

A few feet up into the Willard Shale, a relatively deep-water, immature molluscan community is found, reflecting another period of maximum transgression. The overlying limonite concretion zone with its mature, deep water mollusk shells reflects a somewhat shallower, although still relatively deep, water column. The red shales in the middle and upper Willard Shale found south of the county road south of the park's entrance suggest that regression continued and non-marine conditions were again established.

STOP 15B. ROADCUT ABOUT 0.2 MI SOUTH AND 1.5 MI WEST OF DUBOIS, NE 1/4 NW 1/4 NE 1/4, SEC. 28, T. 1 N., R. 12 E, PAWNEE COUNTY (fig. 35) (30 minutes).

Leaders: Roger K. Pabian, Theodore Huscher

Things to see: algal limestones in Reading Limestone; hardground in Harveyville Shale.

The upper Auburn Shale is overlain by the Reading Limestone Member of the Emporia Formation, which contains phylloid algae (horizon 3, fig. 15B) and was probably deposited in shallow water. The algal limestone has not been traced farther north but a silicified algal bed occurs in the same stratigraphic section about 8 mi due south, near St. Benedict, Kansas.

The Harveyville Shale has an algal (unit 5, fig. 35) limestone that contains weathered fossils, including crinoids, bivalves, and ammonoids; it is about 0.05 to 0.15 ft (0.15-0.45 cm) thick and may correlate with a hardground seen at two localities about 6.5 and 8.0 mi east-northeast of here.

STOP 16. ROADCUT ABOUT 8 MI SOUTH OF HUMBOLDT, NW 1/4 SW 1/4, SEC.15, T. 1 N., R. 13 E., RICHARDSON COUNTY (fig. 36) (30 minutes)

Leader: Peter F. Holterhoff, Roger K. Pabian

Things to see: Red Eagle Cyclothem with transgressive limestone, core shale with immature mollusks, and regressive limestone with brachiopod-echinoderm fauna.

The Johnson Shale is a nearshore unit and the Glenrock Limestone Member of the Red Eagle Formation is the transgressive limestone in this sequence. The Bennett Shale Member of the Red Eagle Formation contains an important immature molluscan fauna that suggests it is an offshore shale. The Howe Limestone Member contains at least a part of the regressive sequence, and the regressive units may extend upward into the lower Roca Shale.

The Bennett Shale is about 3.3 m (10 ft) thick and is

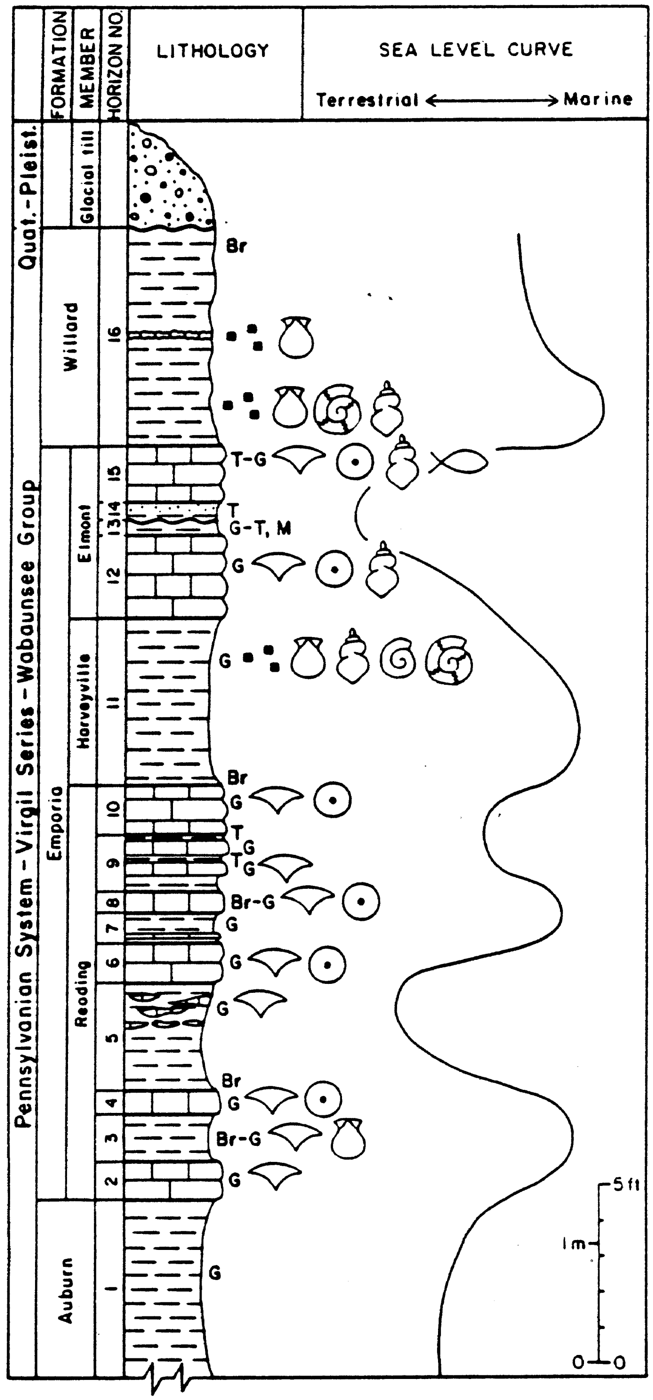


Fig. 34. Geologic section exposed at stop 15A.

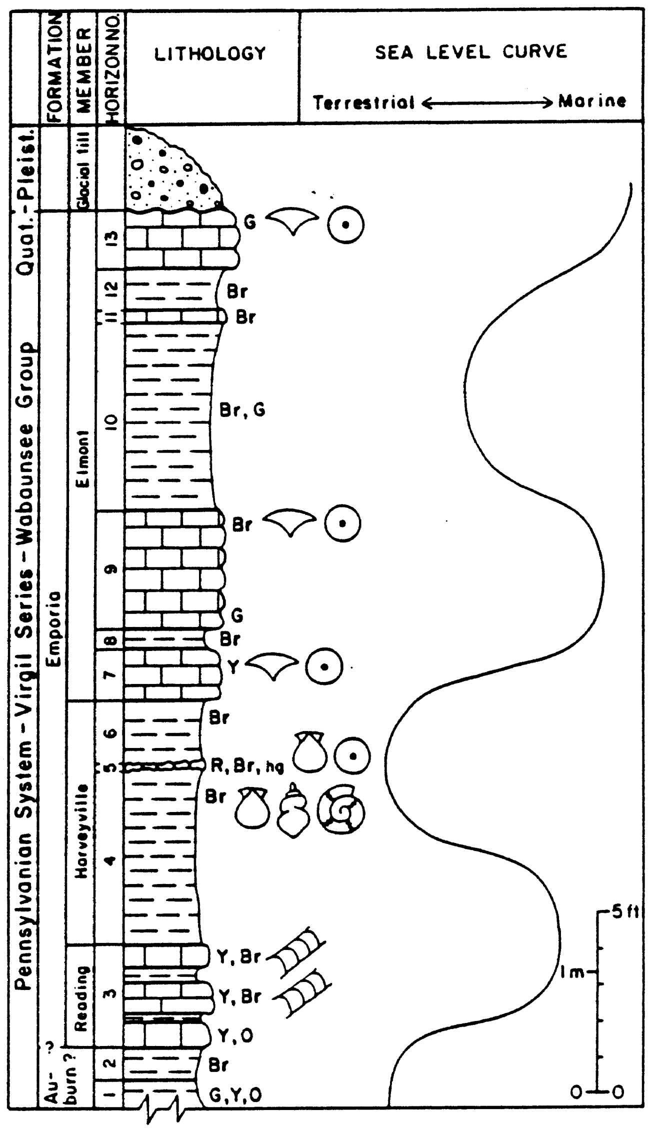


Fig. 35. Geologic section exposed at stop 15B.

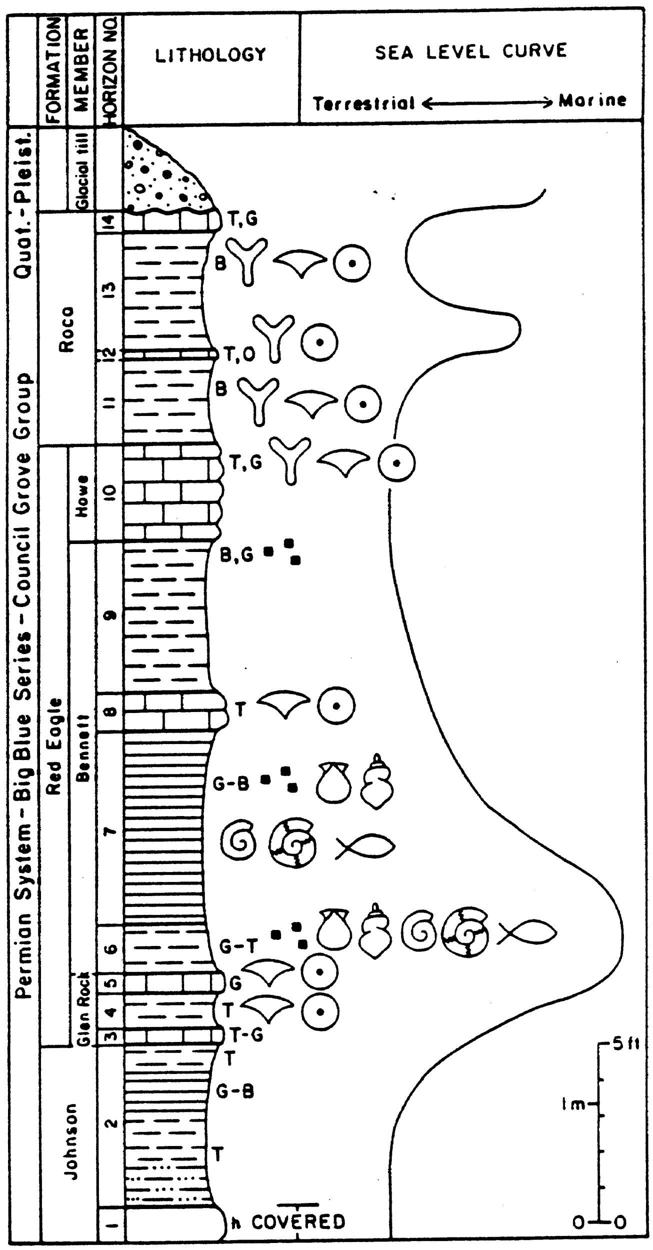


Fig. 36. Geologic section exposed at stop 16.

dominated by fissile, gray-to-black, clayey-to-silty calcareous shale. Four shale units are separated by thinly bedded, argillaceous, highly fossiliferous wackestones and packstones (fig. 36). Abundant, large pyritized mollusks occur at the base of the Bennett Shale Member in a light gray clay-shale that is gradational with dense, fossiliferous wackestone of the Glenrock Limestone Member. Smaller, sparsely distributed mollusks occur in the overlying thick, dark gray, fissile shale.

The Bennett Shale at its type locality, about 60 mi northwest of here, is about 2.5 m (8.5 ft) thick and is composed of alternating beds of shale and limestone/calcareous mudstone (McCrone, 1963). O'Connor and Jewett (1952) also reported four dark shales separated by limestones within the type Bennett Shale. These shale units may be correlative between the type Bennett Shale and the Richardson County locality within the framework of four sixth-order, transgressive shale, regressive limestone depositional packages (*sensu* Busch *et al.*, 1984).

The expanded Bennett Shale sequence here may be due to its position on a down-dropped block along the Humboldt Fault Zone (Burchett and Arrigo, 1978; plate 1). This locality is on the eastern flank of the Nemaha Arch on the western edge of the Forest City Basin. This transitional position between the subsiding basin and the rising shelf may have had a significant impact on the depositional systems affecting the biota in this area.

Many pyritized and limonitized ammonoids were collected from the lower shale interval; this fauna is dominated by *Eoasianites* sp. cf. subtilicostatus with accessory *Prothalassoceras* sp. and *Mescalites discoidale* (B. F. Glenister, written communication, 1988). The smaller size fraction (< 4 mm [0.15 in.]) from this sample had many gastropods and ammonoids. Subordinate, abundant additional molluscs include nuculoid bivalves and bactritoids. Other fauna include sponge spicules, vertebrates, and large, platform conodonts.

The smaller-size fraction produced many ammonoids, gastropods, and bivalves; subordinate fauna include crinoid ossicles, steinkerns of the brachiopod, *Crurithyris*, and vertebrates. In general, faunal elements from this horizon are smaller and less abundant than comparable taxa from the underlying light gray shale.

Both samples had limonite tubes and rods that may be fillings of burrows of soft-bodied organisms analagous to small burrows found in otherwise unbioturbated fine clastics of modern oxygen-stressed marine environments (Savrda *et al.*, 1984).

Most of the fossils from the two shale intervals, excepting vertebrates and conodonts, are pyrite or limonite casts and steinkerns. These may have been originally preserved as pyrite that was altered to limonite at or near the surface. Such preservation characterizes dysaerobic to anaerobic marine environments. Oxygen-stressed conditions are necessary to promote metabolic sulfate reduction by anaerobic bacteria that decompose organic matter. The sulfides combine with iron to form pyrite. Moderate bioturbation may aid in the formation of pyrite in sediments by supplying sulfates to the reducing bacteria; however, the influx of oxygenated water will shut down pyrite formation (Brett and Baird, 1986). The limonite tubes may be the remains of mucus-lined or fecal-filled burrows of bioturbating organisms. Early diagenetic formation of pyrite is suggested by the lack of euhedral pyrite and the fine-grained, or drusy, nature of the fossil-forming pyrite (Brett and Baird, 1986). Allison (1988) stated that fairly low dispersed organic content of sediment enhances pyrite fossil preservation by localizing organic iron reduction around the decaying organism compared to the scavenging of the reduced iron by the surrounding organic-rich sediment. This is best facilitated by rapid burial of the dead animal in an oxygen-poor environment (Allison, 1988; Brett and Baird, 1986).

The Bennett Shale Member represents the deepest phase of transgression within the Red Eagle Formation, based on faunal and taphonomic similarities with Middle and Late Pennsylvanian offshore faunas and with Devonian and Mississippian faunas described by Kammer *et al.* (1986). This interpretation differs with that of McCrone (1963), who stated that maximum transgression within the Red Eagle Formation occurred during deposition of the fusulinid facies of the Glenrock Limestone Member. The sporadic distribution of the Glenrock Limestone in Kansas (O'Connor and Jewett, 1952; McCrone, 1963), coupled with the laterally persistent distribution of the Bennett Shale (cf. Pennsylvanian core shales), in addition to faunal data, deems this reinterpretation valid.

The tectonic setting of this stop may have been responsible for the localized development of the molluscan biofacies. The western margin of the subsiding Forest City Basin was the site of accelerated sedimentation during deposition of the Bennett Shale, thus enhancing preservation potential of the above assemblages. Differential subsidence may also have had a sill affect, enhancing the development of oxygen-stressed conditions by restricting circulation of oxygenated surface waters into the deeper portions of the basin (Demaison and Moore, 1980).

The vertical transition from dense, skeletal wackestone with a diverse suspension-feeding epifauna into the light gray clay-shale containing a diverse, pyritized, scavenging and deposit-feeding molluscan fauna reflects trophic restructuring due to the sharp change in habitat brought on by near-maximum transgressive conditions. The diminutive, less diverse molluscan fauna of the overlying dark gray shale reflects the transition from slightly dysaerobic to strongly dysaerobic conditions at maximum transgression. This sequence of community replacement (*sensu* Miller, 1986) is analogous to the allogenically controlled community succession described by Boardman *et al.* (1984).

The ecologic stability of a unique association of cephalopod, gastropod, and bivalve mollusks, preserved as pyritized and limonitized casts and steinkerns, has been well documented for Middle and Late Paleozoic sequences from the eastern and midwestern United States (Kammer *et al.*, 1986). These faunas have been interpreted as offshore, deep marine assemblages living in close proximity to slightly through strongly dysaerobic to anaerobic bottom water. Of particular note are the repetitive mollusk assemblages from the Middle and Upper Pennsylvanian cyclic sequences of Kansas, Oklahoma, Texas, and Nebraska (Boardman *et al.* 1984; Malinky and Mapes, 1982; Pabian, 1983; Pabian, *et al.*, 1983, 1984). During the Pennsylvanian, the oxygen-stressed bottom waters developed during periods of maximum marine inundation of the continental interior. The units that were deposited at maximum transgression contain the molluscan faunas that have been associated with the core shale of the Kansas cyclothem model (Heckel, 1977; Boardman *et al.*, 1984). Thus, this unique biofacies is an excellent indicator of the core shale, or maximum transgression, within Pennsylvanian cyclothems.

Many pyritized and limonitized ammonoids were found on the surface of the Bennett Shale here, and additional *in-situ* bulk samples yielded a diverse dysaerobic molluscan fauna analogous to the Pennsylvanian molluscan faunas noted above, indicating that similar maximum transgressive environmental conditions continued to periodically develop into the Permian and further points out the ecologic stability of this biofacies.

STOP 17. FOUR MILE HILL, ABOUT 8.5 MI SOUTH AND 1.0 MI EAST OF HUMBOLDT, SW 1/4 SW 1/4, SEC. 14 AND SE 1/4 SE 1/4, SEC. 15, T. 1 N., R. 13 E., RICHARDSON COUNTY (fig. 37) (60 minutes).

Leaders: Roger K. Pabian, R. M. Joeckel

Things to see: cyclothems in Grenola Formation; continental deposits in Eskridge Shale; brackish water deposits in Eskridge.

The lower part of the Roca Shale (horizons 1-8, fig. 37) is poorly exposed; the upper part is unfossiliferous, however, and some horizons contain calcareous con-cretions. The shale may be blocky and chunky in some areas. The lithologies here suggest that the Roca is a nearshore unit.

The Sallyards Limestone Member of the Grenola Formation is a very dense, finely crystalline limestone that is overlain by the Legion Shale. The Legion contains gray-green to dark brown shales, some of which are fissile. These units may be the transgressive limestone and offshore shale of a new cyclothem above the Red Eagle Cyclothem.

The Burr Limestone Member contains several fossiliferous units, and the upper unit appears to have been subaerially exposed.

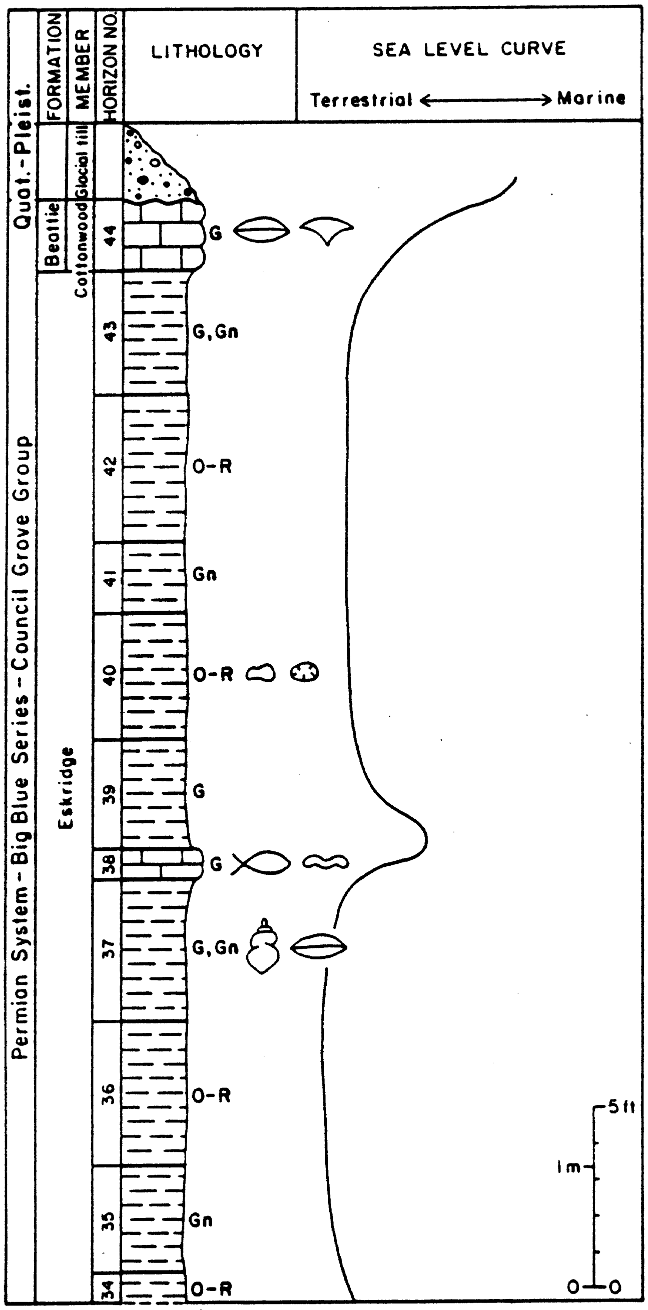
The Salem Point Shale (unit 21, fig. 37) is a massive siltstone in its lower part. It contains concretions that are similar to those found in Pleistocene loess deposits. These were first observed by R. M. Joeckel (personal communication, 1988), who suggested this might be an eolian deposit. About 0.3 m (1 ft) below the top of the Salem Point, there is a thinly bedded, burrowed, sandy siltstone with shrinkage cracks on its upper surface, suggesting a drying out pond environment.

The lowest limestone bed in the Neva Limestone Member is dense and finely crystalline; it contains numerous, small invertebrates at the top, and it appears to be a transgressive unit. It is overlain by a dark gray shale that contains phosphate nodules and phosphate-shelled brachiopods, suggesting offshore conditions. Much of the upper part of the Neva has either been quarried out or is covered here; it is not possible to suggest its cyclothemic relationships solely at this outcrop. However, the Neva does develop several prominent ledges in Richardson County, Nebraska, and Nemaha County, Kansas. Therefore, it may be the regressive limestone of a cyclothem.

The Eskridge Shale (units 29-43, fig. 37) at stop 11 shows a lengthy time of emergence; there are several red beds and units with calcareous nodules and chert. Calcite geodes are also found in the Eskridge. Unit 36 here contains a very unusual limestone that gets up to 0.25 m (0.8 ft) thick; this limestone contains the tubes of spirorbid worms, a few bivalves, and fish remains, including xenacanthid sharks that are thought to have been freshwater denizens. Unit 36 is, thus, considered to be a freshwater limestone. Unit 35, below, is a gray-green calcareous shale that appears to have been root mottled and contains marine fossils. The freshwater limestone bed can be traced to the Eskridge Shale in an outcrop that is located about 2.75 mi north of here.

Acknowledgments

Typing and drafting services were provided by the Conservation and Survey Division, IANR, University of Nebraska-Lincoln. The research summarized in the descriptions of stops 11 and 12 was supported by a Sigma-Xi Grant-in-Aid of Research awarded to R. M. Joeckel. Charles Flowerday edited the manuscript.



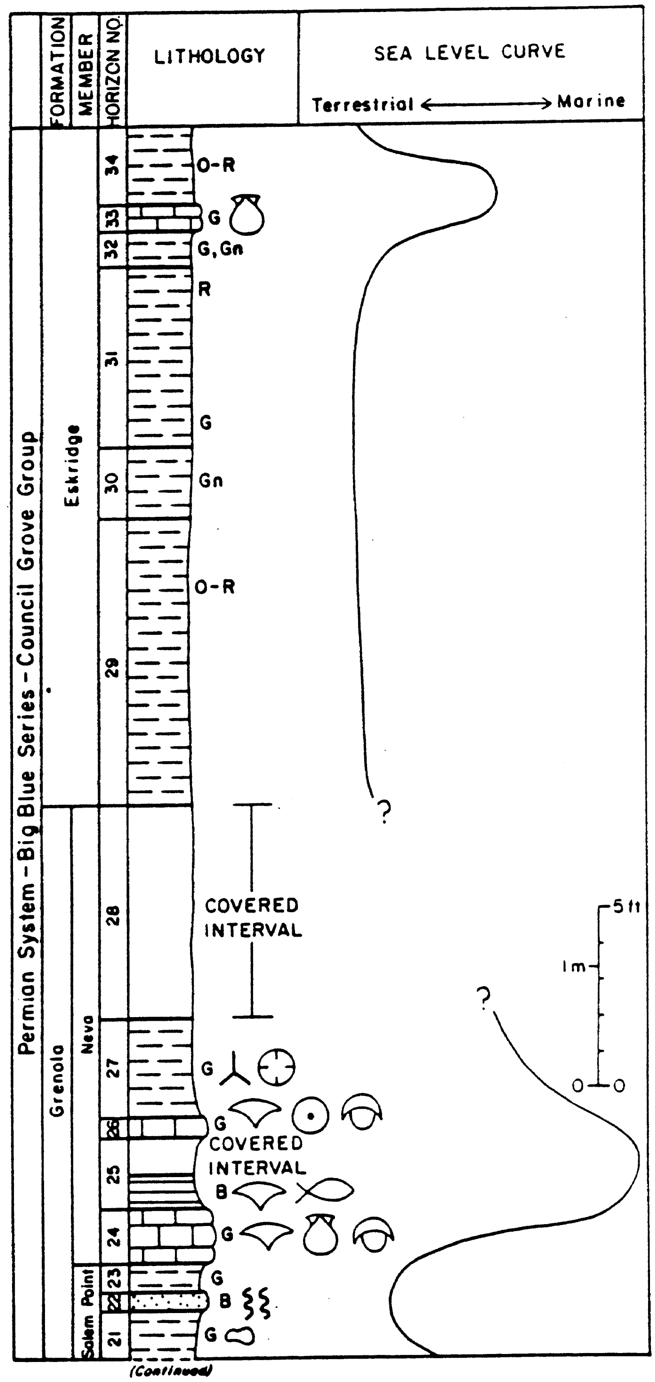


Fig. 37. Geologic section exposed at stop 17. (Units 1-8, 29-38 modified from Avers, 1968).

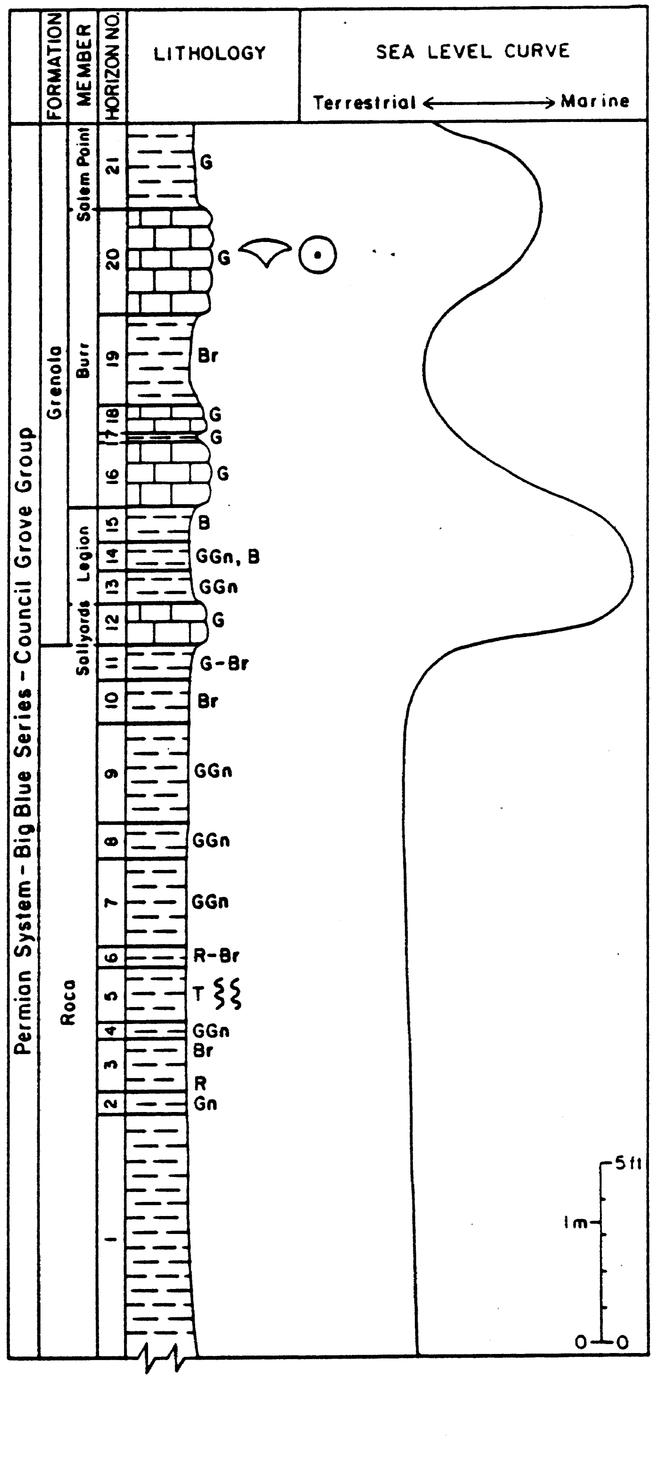

FORMATION
MEMBER
HORIZON NO.
LITHOLOGY
SEA LEVEL CURVE
Terrestrial ⟷ Marine
Permian System - Big Blue Series - Council Grove Group
Grenola
Roca
Salem Point
Burr
Legion
Sallyards
G
Br
B
GGn, B
GGn
G-Br
R-Br
T
Br
R
Gn
5 ft
1m
0
0

Fig. 37. (Cont.)

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ERRATA: Due to incorrect information supplied to the Conservation and Survey Division, the title, "Geology and Paleontology of the Hamilton Quarries (Pennsylvanian/Permian) in Southeast Kansas" is in error. It should read "Regional Geology and Paleontology of the Upper Paleozoic Hamilton Quarry Area."

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Roadlog

FIRST DAY: Buses ready to load at 6:45 a.m. Leave motel at 7 a.m. Drive about 20 miles S on I-435 toward Kansas City, Kansas: **STOP 1.**

Drive 5 mi S on I-435, 1.5 mi across river and take exit around to right, pulling off before meeting Holliday Rd. (10 minutes): **STOP 2.**

Drive about 45 mi S and E on I-435, S on US 69, to gravel road 13 mi south of K-68 (Kansas Hwy. 68), Louisburg exit. Many exposures of Wyandotte are seen along US 69. South of Louisburg, some dip to the southwest, apparently reflecting topography on the underlying thinning Liberty Memorial prodeltaic shale (60 minutes): **STOP 3.**

Drive 12 mi S on US 69 to Trading Post, descending "Bronson" escarpment held up by Dennis, Swope, and Hertha limestones over Pleasanton prodeltaic shales (15 minutes). **Lunch at STOP 4A** (60minutes).

Drive 3 mi E on county road, bearing right at intersection at foot of hill (5 minutes).

Drive about 32 mi S on US 69 through Pleasanton; west on K-52 through Mound City to Blue Mound, continuing S on county road at south side of town for 4 mi; then west at intersection on curve 0.3 mi to roadcut. Prominent escarpment seen to west, ascended west of Mound City and visited at stops 4A-C, is the same one held up by Dennis, Swope, and Hertha Limestones over Pleasanton prodeltaic shales (40 minutes): **STOP 4B.**

Drive 2.5 mi E on county road, passing Bethany Falls oolite overmottled calcilutite near top of first hill (5 minutes): **STOP 4C.**

Drive 55 mi E to K-31 and S into Mapleton, W on K-65 through Xenia to K-3; S to Bronson, W on US 54 to Iola, S on US 169 to K-39 exit at Chanute; take exit ramp, cross K-39 and stop along ramp leading S back to US 169 (65 minutes):

Drive about 4 mi, S on US 169 to first exit, then E into Chanute for dinner and overnight.

SECOND DAY: Buses ready to load at 6:45 a.m. Leave motel at 7 a.m.

Drive 24 mi: S on US 169; W on K-47 through Altoona to gravel road 0.5 mi W of Verdigris River bridge, N 0.7 mile, W 1 mile, S uphill (30 minutes). Drive 1 mi S, then E on K-47; park at quarry entrance on right, Reddish Rock Lake sandstone on left at junction (10 minutes): **STOP 6.**

Walk 0.4 mi E along north side of K-47, partway down hill (10 minutes). Begin new odometer readings from stop 6.

0.0 At quarry entrance. Continue W on K-47.

6.0 Fredonia, Kansas, city limits.

7.3 Junction of K-96 and K-39. Turn right on K-96 west.

13.2 Stop sign. Continue W (left) on K-96.

35.0 Junction K-99. Turn right on K-99 N toward Eureka and Hamilton.

47.7 Junction, US 54. Turn right and continue on K-99 N.

51.1 Left turn. Continue on K-99 N toward Hamilton.

60.5 Hamilton, Kansas, city limits.

60.7 Right turn toward Virgil via county road (one block S of Main Street).

61.0 Right turn onto unpaved road at T-junction.

64.1 Low water bridge.

64.2 Right turn into active quarry. Follow haulage road onto floor of quarry: **STOP 7A.**

Hamilton to Waverly to Maple Hill (stops 8 and 9)

0.0 Leave "active" Hamilton Quarry--Marlin Quarry

0.3 Cattle guard and junction with E-W county road---turn left (W).

0.5 Limestone outcrop in road; conglomerate bed well exposed approximately 100 m N of road.

0.6 Turn N on county road.

0.9 Conglomerate bed in road and high creek-bank cliff on W side of road. Cross creek at low water bridge. Note exposure of Ervine Creek Limestone and (?) Larsh-Burroak Shale to the E in low creek bank.

1.0 Conglomerate bed in road coming up out of creek bed. T-junction with county road to E--continue N.

1.3 Hamilton Quarries on E side of road--"South Quarry," site of numerous specimens of terrestrial fauna in laminated, clayey carbonate---first in a "string" of quarries that extends N along E side of road.

1.7 **STOP 7B**--sites of most recently quarried area for fossils by research groups.

1.9 Stop sign--junction with E-W county (Virgil) road--turn E toward Virgil, Kansas.

2.0 Lockhard house on right (S) of road. Walter Lockhard discovered the Hamilton fossils in the 1960s.

8.6 Bridge over Verdigris River.

9.1 City limits, Virgil, Kansas; type area of the Virgilian Series. Virgil is situated midway between the upper and lower limits of the Virgilian Series. Approximately 960 ft of Virgilian strata are exposed along the Verdigris River from Madison, Kansas, to central Wilson County.

9.4 Jog S--continue E on FAS-291.

12.2 County line--leave Greenwood Co., enter Woodson Co.

24.4 Junction with US 75--turn left at stop sign. Proceed N on US 75.

28.5 County line, leave Woodson Co.; enter Coffey Co.

31.5 Junction K-57 E.

32.5 Junction K-57 W to Bridley.

38.9 Burlington, Kansas, city limits--continue N.

43.9 New Strawn, Kansas, city limits. Road W to John Redmond Lake.

50.1 Turn right (E) on county road to Halls Summit. Proceed to stop 7.

STOP 8: WAVERLY SECTION.

60.2 County line, leave Coffey Co.; enter Osage Co.

60.5 I-35 overpass.

65.3 Stop sign; turn left (W) toward Melvern Lake.

65.4 Turn right (N)--onto US 75 N.

67.5 Junction K-278 to Melvern State Park. Continue N on US 75.

72.4 Lyndon, Kansas, city limits (county seat of Osage Co.).

74.7 Junction with K-31 W, K-268 E to Pomona Lake.

77.0 Rest area.

91.0 County line. Leave Osage Co.; enter Shawnee Co.

97.2 Pauline, Kansas, city limits; grain elevator on left.

98.6 Topeka, Kansas, city limits.

99.7 Bear right onto I-470.

100.1 Keep right toward I-70 W--Denver, Colorado.

106.8 Kansas Museum of History on the right (N).

107.1 Merge with I-70 W. Between here and stop, we will see numerous exposures of Wabaunsee Group and uppermost Shawnee Group (Virgilian stage).

108.9 Outer Limits on left (S). Excellent exposures visible just off of I-70 to the south (not visible from I-70).

116.2 County line. Leave Shawnee Co.; enter Wabaunsee Co.

121.3 Mile marker 341--underpass of Maple Hill exit (K-3).

121.9 **STOP 9**--Outcrop: MAPLE HILL SECTION.

125.5 Rest area on left. Numerous exposures of Permian strata visible along route as we travel W and N.

134.8 Junction K-99 and I-70 exit. E about 30 miles to US 75, and N about 100 miles to Auburn, Nebraska.

THIRD DAY: AUBURN, NEBRASKA, TO ST. LOUIS, MISSOURI, via KANSAS CITY, MISSOURI.

0.0 Leave motel 7 a.m., go S on US 75.

15.0 Junction, US 75 and N-4 (Nebraska Hwy. 4), turn right (W).

20.5 Junction N-4 and N-105; continue W on 4.

28.0 Table Rock, Nebraska; junction N-4 and county road; turn left (S). County road doubles back; cross RR at about 28.2 (caution!) and continue SE 2.7 miles from road junction.

30.7 **STOP 10.** Return to junction of county road and N-4.

33.4 Junction of county road and N-4.

42.5 Junction of N-4 and county road; turn left (N), go 0.1 mi.

42.6 **STOP 11.** Return to junction of county road and N-4.

42.7 Junction of county road and N-4. Turn left (E), go 2 mi.

44.7 Junction of N-4 and county road. Turn right (S), go 1.9 mi.

46.6 **STOP 12.** Continue 0.1 mi to crossroads.

46.7 Crossroads. Turn right (W) and follow winding county road about 4.3 mi to junction with N-105.

50.9 Junction of county road and N-105, on south end of Humboldt. Turn left (S) and go 3.2 mi.

54.2 **STOP 13A:** Continue (S) on N-105 for 2.7 mi.

56.9 **STOP 13B:** Continue (S) 0.3 mi.

57.2 Junction of N-105 and N-8. Turn right (W).

61.3 Junction of N-8 and county road. Turn left (S).

61.8 Junction, county roads, turn right (W).

62.3 **STOP 14:** Continue W 0.5 mi.

62.8 Junction of county road and N-50. Continue W.

65.4 Entrance Iron Horse Lake. Traffic loop. Park here, walk about 0.5 mi across dam.

STOP 15: return to traffic loop.

65.9 County road. Turn right (W).

66.3 Junction, county roads. Turn left (S).

67.3 Junction, county roads. Turn left (E).

68.9 **STOP 15B**: continue E on county road.

70.3 Junction of county road and N-50. Turn left (N).

72.8 Junction of N-50 and N-8. Turn right (E).

78.0 Junction of N-105 and N-8. Turn right (S).

78.8 **STOP 16**: continue (S) 0.2 mi.

80.0 Junction of county roads. Turn left, 0.9 mi.

80.9 **STOP 17**: last stop.

82.5 Junction, county roads. Turn left (N).

83.5 Junction of county road and N-8. Turn right (E), and continue through Falls City and Rulo, Nebraska, into Missouri. Pickup I-35 (S) to Kansas City Airport for car pick up. Bus will continue to St. Louis. Thank you. Good luck!

Nebraska Geological Survey
Conservation and Survey Division
Institute of Agriculture and Natural Resources
University of Nebraska–Lincoln