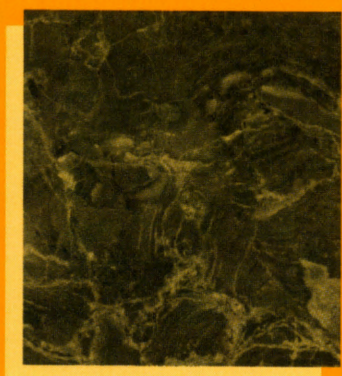
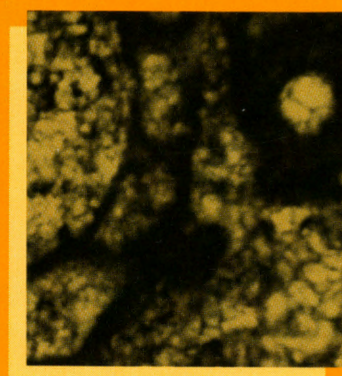
Structural control of the distribution of subtidal to supratidal paleoenvironments of the Americus Limestone Member (lowermost bed) in eastern Kansas


Jonathan C. Sporleder

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Abstract

The Americus Limestone Member of the Foraker Limestone (Wolfcampian) in Kansas formed during transgression of an epeiric sea. Lateral differentiation of paleoenvironments resulted from differences in paleotopography of the seafloor, which overlies buried anticlinal structures. Eight paleoenvironmental stages of transgression are recognized in a typical vertical succession of lithofacies: (1) formation of limestones and shales under hypersaline, brackish, and subaerial conditions and deposition of lime sand under freshwater conditions preceding inundation and deposition of the Americus limestone; (2) deposition of a thin layer of shale during initial inundation; (3) transition from brackish to restricted marine paleoenvironments characterized by development of peloid-alga boundstones (stromatolites); (4) restricted marine paleoenvironments characterized by encrustations of *Spirorbis*-foraminifer-alga boundstones; (5) deposition of carbonates under conditions that were transitional from restricted marine to nearly normal marine, characterized by abundant *Calcivertella* foraminifers, ostracodes, and gastropods, and foraminifer-alga boundstone; (6) deposition of carbonates under more nearly normal to normal marine conditions characterized by grapestones, ooids, echinoids, crinoids, bryozoans, brachiopods, sponge spicules, pectinoid and myalinid bivalves, and a variety of foraminifers; (7) turbid marine conditions corresponding to the deposition of shale with some crinoids, brachiopods, and bivalves; and (8) formation of the upper limestones of the Americus under normal marine conditions, characterized by abundant fusulinids, crinoids, brachiopods, bryozoans, and bellerophontid gastropods. The lower limestone of the Americus indicates lateral differentiation of paleoenvironments with more nearly normal marine conditions toward the south. Differences in paleotopography of the seafloor resulted in high areas characterized by supratidal to relatively high-energy shallow-water paleoenvironments and low areas characterized by relatively low-energy deeper-water paleoenvironments. Paleotopographically high areas are generally characterized by packstones and grainstones, thin intervals of overlying shale, discrete plates of *Spirorbis*-foraminifer-alga boundstone, laterally discontinuous stromatolites with extensive fenestrae, rip-up clasts of boundstone, thick stromatolitic layers with extensive encrustations, high-domed stromatolites, and *Globivalvulina* foraminifers and pectinoid and myalinid bivalves. Paleotopographically low areas are characterized by lime mudstones and wackestones; thick intervals of overlying shale; and thin, flat-layered to low-domed stromatolites. Paleotopographically high areas of the ancient seafloor coincide with such structural features as the Nemaha anticline, the Alma–Davis Ranch anticline, the Bourbon arch, and the Beaumont anticline, indicating that these structural features were ultimately responsible for lateral differentiation of paleoenvironments either by differential compaction or by subtle tectonic movement. It should be possible to use these relationships in similar strata to locate potential anticlinal structures.

Introduction

The purpose of this study was to determine the environments of deposition of the lowermost bed of the Americus Limestone Member (Wolfcampian) in Kansas and to discern the effects of buried structural features on the lateral distribution of paleoenvironments. Fisher (1980) studied the Americus limestone in the vicinity of the Nemaha anticline, and his interpretation of paleoenvironments was used to determine the paleoenvironmental significance of stromatolite morphologies (Denver, 1985) and species of ostracodes and foraminifers (Peterson, 1978; Peterson and Kaesler, 1980; Kaesler and Denver, 1988). This project extends the paleoenvironmental framework southward into south-central Kansas.

The lower Americus Limestone Member was deposited in supratidal to subtidal environments during transgression of an epeiric sea. The lateral distribution of depositional environments of the Americus was influenced by more nearly normal marine conditions toward the south and by paleotopography. Areas of relatively high paleotopography, although quite subtle, evidently were the locations of higher depositional energy. Areas of positive seafloor paleotopography coincided with anticlinal structures, indicating that these structures were the ultimate control on the lateral differentiation of paleoenvironments. The locations of relatively high seafloor paleotopography and buried anticlinal structures are characterized by thin deposits of shale, low mud content in limestone, distinctive stromatolite morphologies, and distinctive fossils. These characteristics can be used in similar strata to locate minor anticlines and arches that are not otherwise clearly expressed at the surface.

Stratigraphy

Although the primary concern of this study was the lowermost limestone bed of the Americus Limestone Member of the Foraker Limestone (Council Grove Group), overlying shales and limestones of the Americus and the underlying Hamlin Shale Member of the Janesville Shale (Admire Group) also were examined where possible. Figure 1 shows the position of the Americus within the Foraker Limestone and associated stratigraphic units.

The limestones of the upper part of the Americus Limestone Member characteristically weather into distinctive large slabs that form the first prominent bench of the Flint Hills. These features, along with a typical stromatolite layer at the base of the lower limestone bed of the Americus and an orange lime-sand mudstone to grainstone at the top of the Hamlin Shale Member, facilitate recognition and correlation of units in the field (Mudge and Yochelson, 1962). A summary of the lithology of the Hamlin shale and the Americus limestone is provided in appendix F.

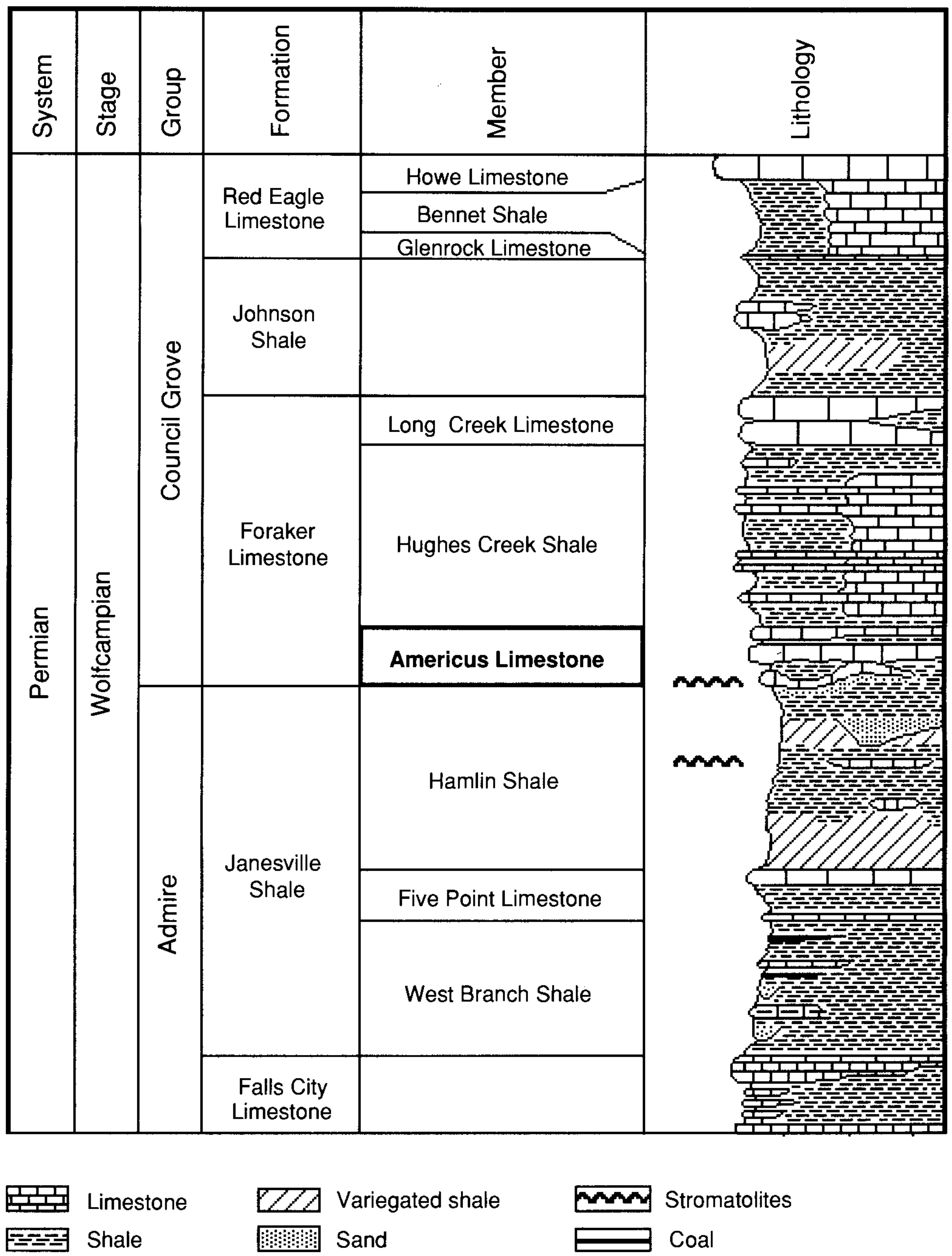


FIGURE 1—GENERALIZED STRATIGRAPHIC SECTION of the Americus Limestone Member of the Foraker Limestone and associated units [after Mudge and Yochelson (1962)].

Methods

I measured and sampled 35 outcrops of the Americus Limestone Member along an outcrop belt 210 km (130 mi) long from Wabaunsee County to Cowley County, Kansas (fig. 2). I also examined several localities within the area studied by Fisher (1980) and Denver (1985). The field procedure included photographing, sketching, and measuring outcrops; describing vertical and lateral relationships, especially the in situ position of stromatolites; and sampling representative rocks, fossils, and stromatolites.

More than 80 polished slabs and more than 150 5 × 7.5 cm (2 × 3 in.) thin sections were prepared and examined. Stromatolite morphologies were characterized in detail and compared with those studied by Denver (1985). Ostracodes were picked from washed residue for future study. Lithology, paleontology, stromatolite morphology, and corresponding lateral and vertical facies relationships were used to interpret depositional environments.

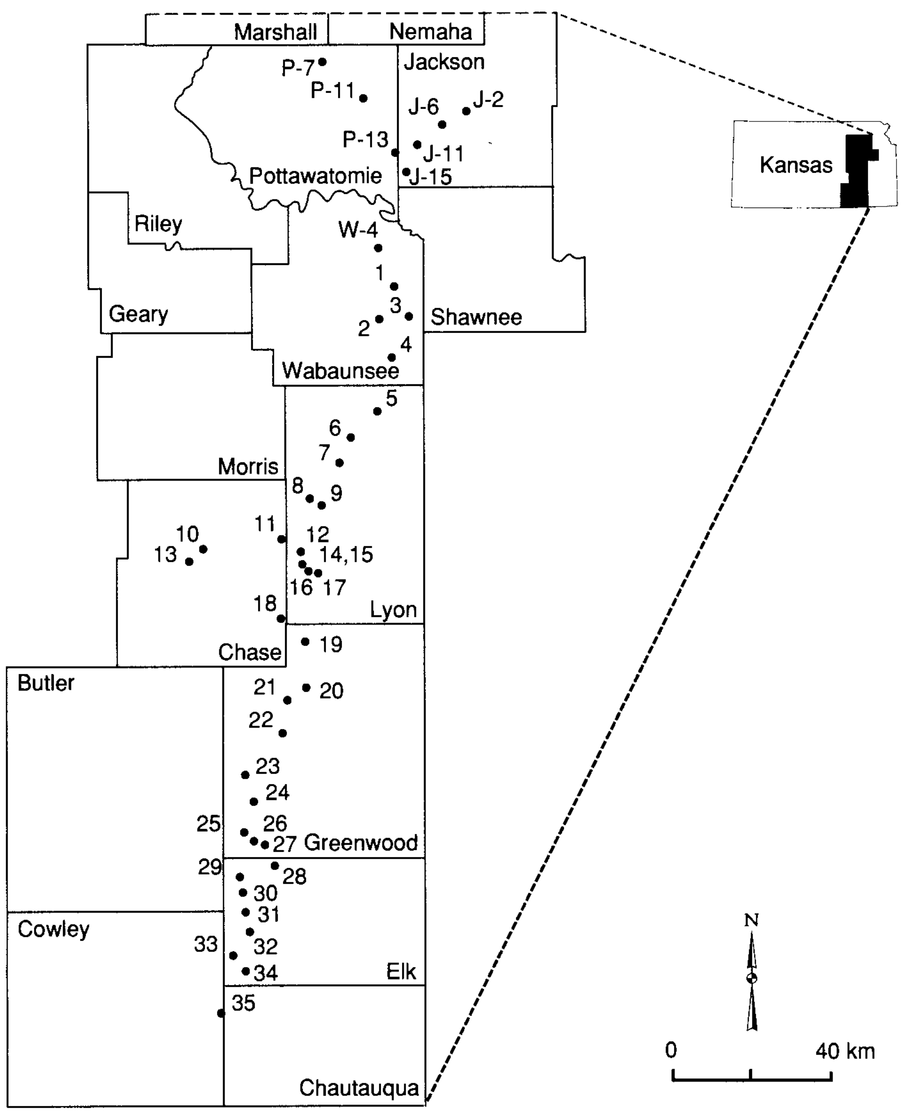


FIGURE 2—Index map of study area showing sample localities (filled circles). See appendix E for detailed locations and appendix G for measured sections.

Vertical succession of paleoenvironments

The Hamlin Shale and Americus Limestone members contain a vertical succession of facies indicative of deposition during eight stages of inundation by an epeiric sea. The following discussion refers to fig. 3, which shows a generalized stratigraphic section of the upper Hamlin and the Americus, the corresponding stages of inundation, and the associated paleoenvironments. (See appendix F for a description of the lithologic units of the Hamlin shale and the Americus limestone in Kansas.)

Stage 1: Paleoenvironments of the Hamlin shale before inundation

The Hamlin Shale Member contains features that indicate deposition under hypersaline, brackish, freshwater, and terrestrial conditions that preceded inundation by the sea re-

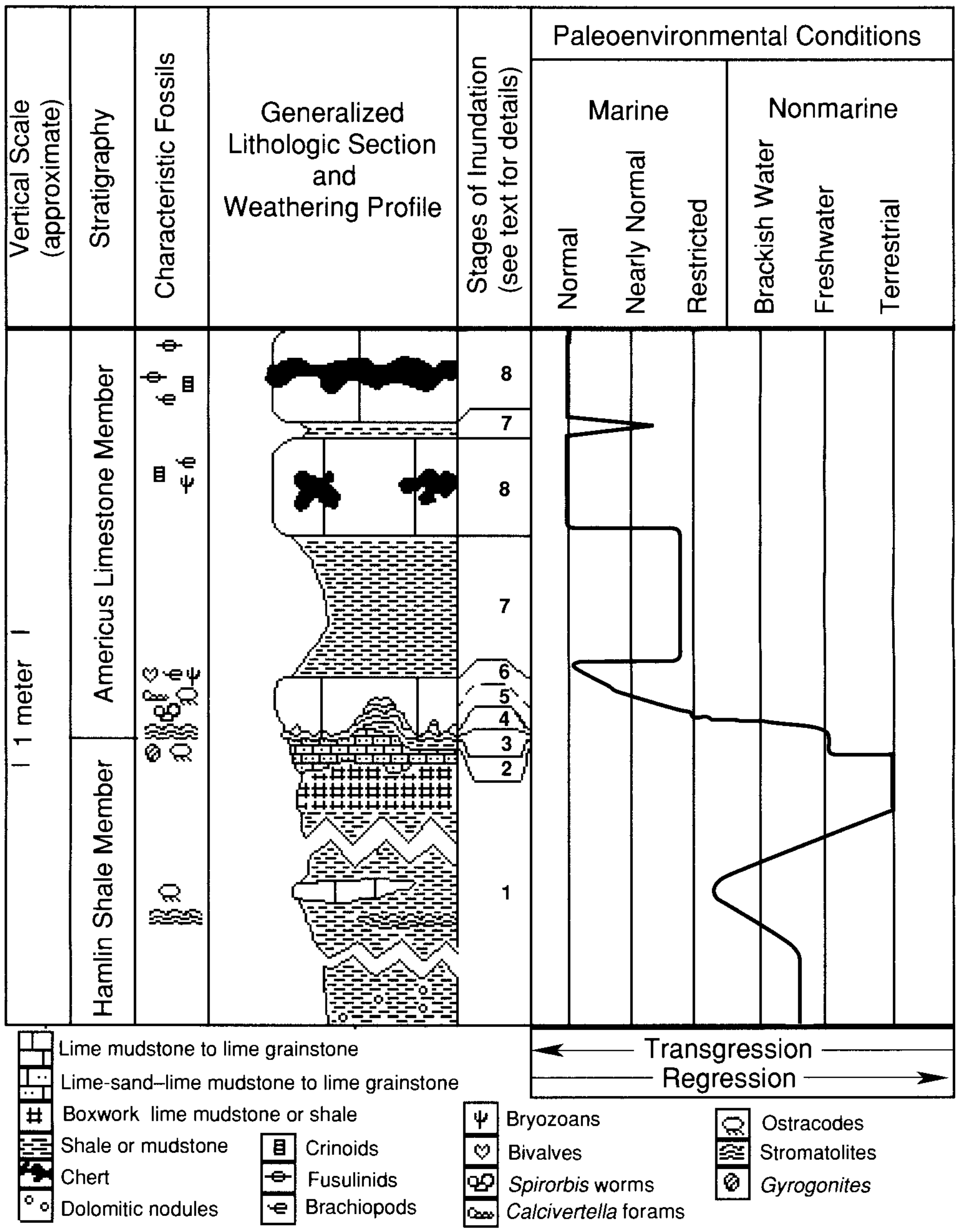


FIGURE 3—GENERALIZED VERTICAL SECTION of the upper part of the Hamlin Shale and the Americus Limestone members showing typical rock types and fossils, weathering profile, and paleoenvironments and correlative stages of inundation by epeiric sea.

sponsible for deposition of the Americus Limestone Member. Laterally discontinuous stromatolites with interlaminated gypsum suggest deposition under hypersaline restricted conditions (Kendall and Skipwith, 1969). The low faunal diversity in laterally discontinuous, ostracode-containing lime mudstones and wackestones further indicates deposition in a restricted environment, possibly a result of fluctuating salinity or temperature. The light color of the typically orange, white, tan, light-gray, and brown shales and terrigenous mudstones may indicate oxidizing terrestrial conditions. Boxwork structures (Read, 1974), fenestral porosity (Shinn, 1968; Grover and Read, 1978), pervasive skew and horizontal joint planes (Freytet and Plaziat, 1982; Goldstein, 1986), and polygonal mudcracks are interpreted as the effects of desiccation in supratidal to subaerial environments.

A distinctive orange lime-sand rock unit at the top of the Hamlin Shale Member is evidently the result of deposition by freshwater flowing over an erosional surface. This lithology differs between localities from an orange shale or terrigenous mudstone with a few sand-size lime grains to a conglomeratic lime-sand grainstone with medium sand sized to pebble-size lithoclasts; however, the rock is typically a lime-sand packstone or wackestone (fig. 4). Its thickness varies from 0 to 0.3 m (0–1 ft). Ostracodes and small, well-rounded bivalve fragments are typical; crossbedding is generally observed where the unit is thick. This rock contains no fossils or cements with definite marine affinities. Up to 9 cm (4 in.) of relief on the basal surface of the lime-sand bed suggests erosion, possibly by streams flowing in small channels. The relatively large size of the lime grains indicates sediment transport by moderately strong currents. The lime grains are allochthonous lithoclasts of lime mudstone and are well rounded, suggesting that the sediment was transported across an appreciable distance. *Gyrogonites*, the fruiting bodies of charophyte algae, are typically present and suggest deposition associated with a freshwater environment based on analogy with modern charophytes (Wray, 1977, pp. 110–111). Coal stringers, plant fragments, and petrified logs have been noted at some localities (Bernasek, 1967; Fisher, 1980), providing additional evidence of deposition in or near freshwater. These features suggest that the Hamlin was being eroded by streams just before inundation by an epeiric sea.

Stage 2: Initial inundation by the epeiric sea

At many localities an orange to gray shale or terrigenous mudstone, generally less than 1 cm (0.4 in.) thick, was deposited directly over the orange lime-sand packstone or wackestone of stage 1. This shale or terrigenous mudstone resulted from deposition of suspended fine sediments from relatively quiet water, indicating a significant decrease from depositional energies of the underlying lime-sand rocks. The paleoenvironmental significance of this shale or terrigenous mudstone is problematic. It may have resulted from flooding by freshwater streams at the end of stage 1, or it may have developed during initial inundation by seawater that terminated the stream activity of stage 1. The inundating waters were probably saline, but the orange color of the shale or terrigenous mudstone suggests affinity with the freshwater paleoenvironment of the underlying orange lime-sand rocks. It is therefore reasonable to assume that the water at this stage was brackish or fluctuated between marine water and freshwater. Fluctuations between saline and freshwater conditions would have produced an environment unfavorable to most marine and freshwater metazoans and thus would have favored growth of stromatolites (stage 3).

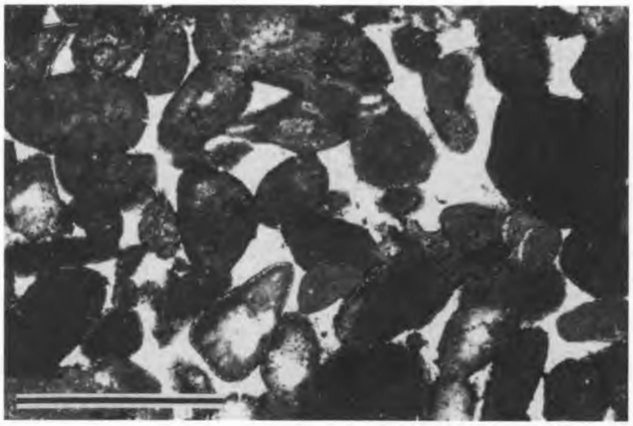


FIGURE 4—Photomicrograph of lime-sand packstone to grainstone of the upper Hamlin Shale Member from locality 6 (plane-polarized light). Scale bar is 1 mm. KUMIP 227,000.

Stage 3: Transition from brackish to restricted marine conditions

The base of the Americus Limestone Member is characterized by a stromatolite layer that probably formed during the transition from brackish-water to restricted marine conditions. Stromatolites are the result of sediment binding (Black, 1933; Logan, 1961; Logan et al., 1964; Gebelein, 1969) and possibly precipitation of calcium carbonate (Dalrymple, 1966; Monty, 1967) by microbial communities dominated by blue-green algae (Golubic, 1976). The stromatolites of the Americus generally occur as laminations of micritic peloids and are classified as peloid-alga boundstones (Dunham, 1962; see appendix A). The peloids are irregularly shaped to oval and are generally coarse silt to fine sand sized (fig. 5). In thin section these peloids appear to float in PE32 calcite cement (Folk, 1965; see appendix B). Internal laminations are generally 1–6 mm (0.04–0.2 in.) thick. Cement-filled horizontal fenestrae are common (fig. 6). Typically, no grains other than peloids are incorporated in the boundstone layers. Exceptions are rare mollusk fragments, lime-sand grains, and palynomorphs (fig. 7).

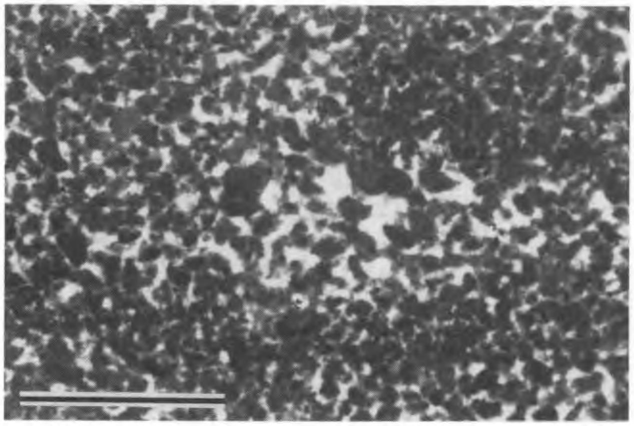


FIGURE 5—PHOTOMICROGRAPH OF PELOID-ALGA BOUNDSTONE from locality 7 (plane-polarized light). Scale bar is 1 mm. KUMIP 227,001.

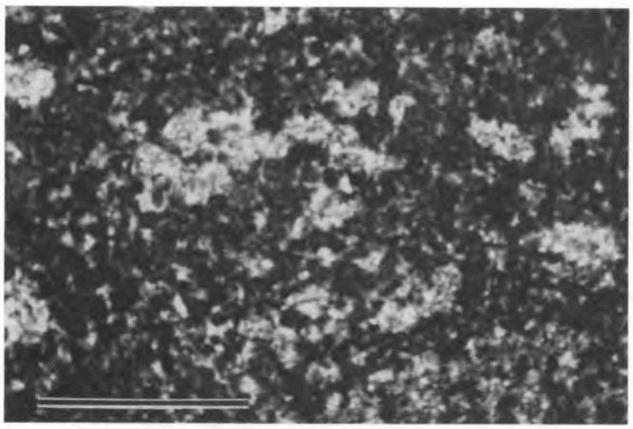


FIGURE 6—PHOTOMICROGRAPH OF FENESTRAL POROSITY (arrow) in peloid-alga boundstone from locality 17 (plane-polarized light). Scale bar is 100 µm. KUMIP 227,002.

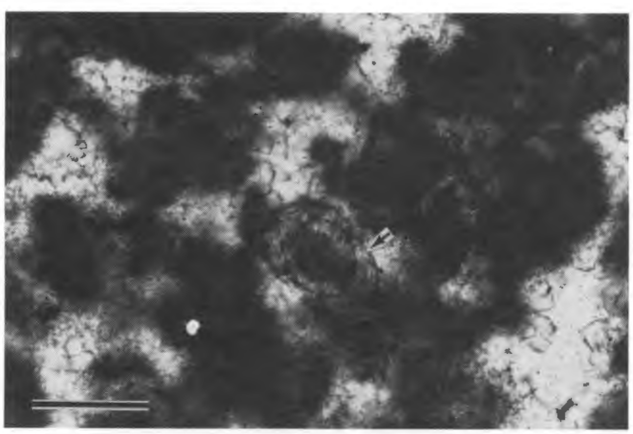


FIGURE 7—PHOTOMICROGRAPH OF PALYNOMORPH (arrow) in peloid-alga boundstone from locality 12 (plane-polarized light). Scale bar is 100 µm. KUMIP 227,003.

Traces of algal filaments were noted in many samples (figs. 8 and 9). These traces occur in dense micritic laminations and appear in thin section as subtle horizontal threadlike features. The filaments, never longer than 0.5 mm (0.02 in.), have bright micritic hollow centers, about 0.02 mm (0.0008 in.) thick, and dark micritic walls, about 0.01 mm (0.0004 in.) thick. These dimensions compare favorably with those of *Scytonema*, a modern stromatolite-producing alga (Bathurst, 1975; Golubic, 1976), but are slightly larger than those of the modern Oscillatoriales, including *Schizothrix* (Golubic, 1976). The dimensions of the filaments are also about the same as those of some species of *Girvanella* (Riding, 1975; Wray, 1977); however, the irregular and indistinct outline of the filament traces in the stromatolites of the Americus are unlike those generally observed in *Girvanella*.

Rare pseudomorphs of evaporites occur within the algal laminates (figs. 10 and 11). At some localities the lower laminations of the stromatolite are disrupted and contain alveolar structures (figs. 12 and 13).

The rarity of incorporated fossil fragments indicates that the depositional conditions were too harsh for the existence of most metazoans. Such harsh conditions may have been the result of fluctuating salinity or temperature, desiccation, or anoxic or otherwise poisonous conditions caused by the stromatolites themselves (Monty, 1973). Conditions of fluctuating salinity are suggested by the stratigraphic position of the stromatolites between nonmarine and marine deposits and the presence of rare pseudomorphs of evaporites. The fenestral porosity suggests early diagenesis in shallow-water to subaerial environments (Shinn, 1968; Grover and Read, 1978) and may have resulted from the oxidation of algal matter (Monty and Hardie, 1976). Alveolar structures, a type of root trace (Esteban and Klappa, 1983), suggest that the stromatolitic layer was affected by a brief period of subaerial exposure, probably the result of a minor fluctuation in sea level. The thickness and morphology of the stromatolite layer varies laterally from locality to locality, a result of laterally different paleoenvironmental conditions. This lateral variation is described in detail in later sections.

Stage 4: Restricted marine conditions

When formation of peloid-alga boundstone ceased, the exposed surface became encrusted with *Spirorbis*, foraminifers, and algae under shallow-water restricted marine conditions. These encrustations formed a boundstone ranging in thickness from <1 cm (<0.4 in.) to 19 cm (7.5 in.). In thin section these boundstone encrustations appear as ragged, porous, dense, micritic crusts containing abundant to common *Spirorbis* worm tubes and tangled tubiform features (fig. 14). Tiny bivalves (figs. 15 and 16) are enmeshed within the thick encrustations at localities 25 and 27. The taxonomic

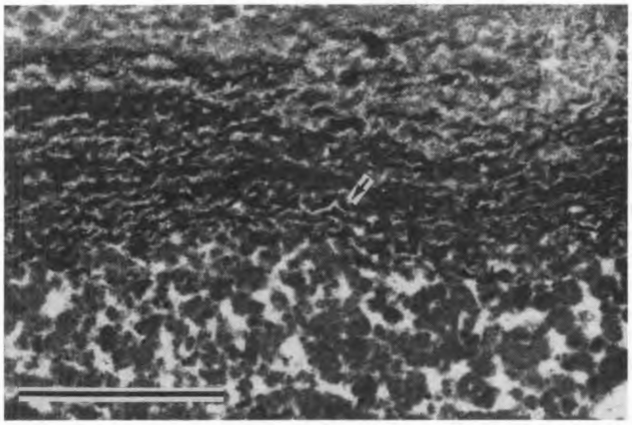


FIGURE 8—PHOTOMICROGRAPH OF ALGAL FILAMENTS (arrow) in peloid-alga boundstone from locality 7 (plane-polarized light). Scale bar is 1 mm. KUMIP 227,001.

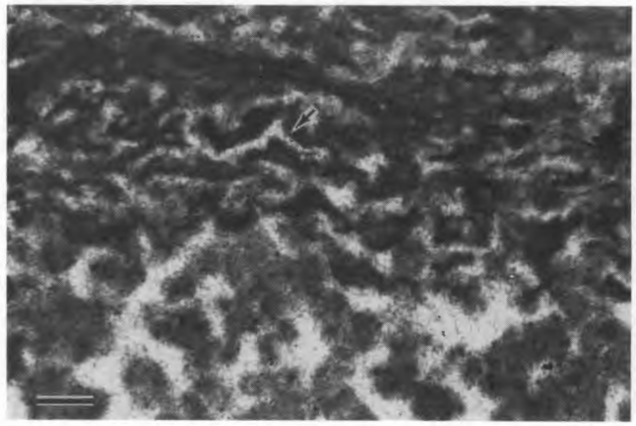


FIGURE 9—PHOTOMICROGRAPH SHOWING IN GREATER DETAIL THE SAME ALGAL FILAMENTS as those in fig. 8 (plane-polarized light). Scale bar is 100 μm.

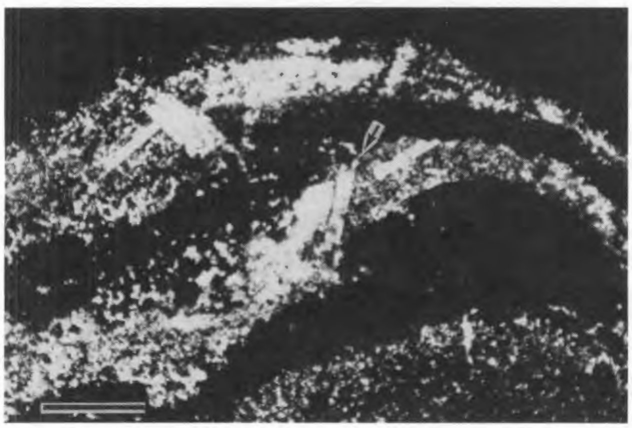
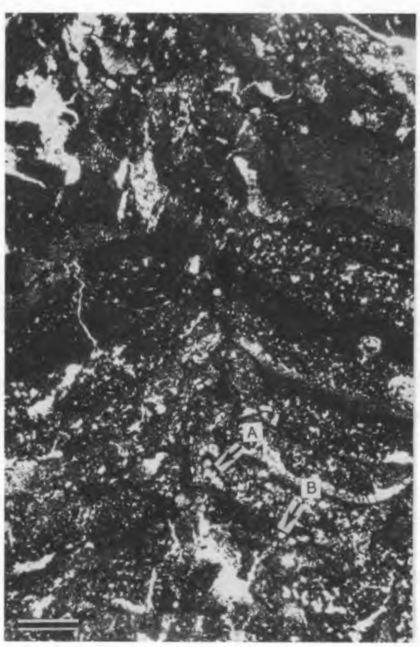


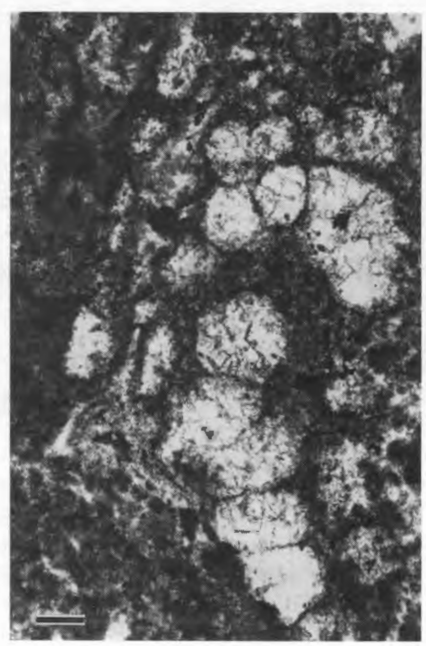
FIGURE 10—PHOTOMICROGRAPH OF PSEUDOMORPHS OF EVAPORITES (arrow) in peloid-alga boundstone from locality 18 (plane-polarized light). Scale bar is 1 mm. KUMIP 227,004.

FIGURE 11—PHOTOMICROGRAPH AT HIGHER MAGNIFICATION OF THE SAME PSEUDOMORPHS of evaporites shown in fig. 10. Scale bar is 1 mm.

FIGURE 12 (right)—PHOTOMICROGRAPH OF DISRUPTED LAMINATIONS AND ALVEOLAR STRUCTURES (arrows) in peloid-alga boundstone from locality 25 (plane-polarized light). Scale bar is 1 mm. KUMIP 227,005.

FIGURE 13 (far right)—PHOTOMICROGRAPH OF ALVEOLAR STRUCTURE (A) from fig. 12 (plane-polarized light). Scale bar is 100 μm.





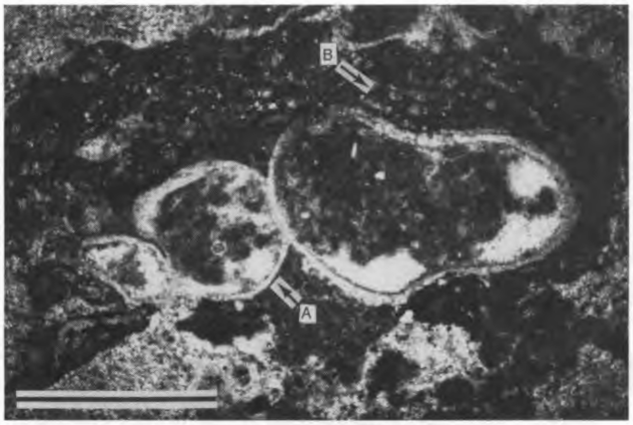


FIGURE 14—PHOTOMICROGRAPH OF ENCRUSTATION of *Spirorbis*-foraminifer-alga boundstone on peloid-alga boundstone from locality 11 (plane-polarized light). Arrow A points to *Spirorbis* worm tube; arrow B points to a tubiform encruster, probably a foraminifer or an alga. Scale bar is 1 mm. KUMIP 227,006.

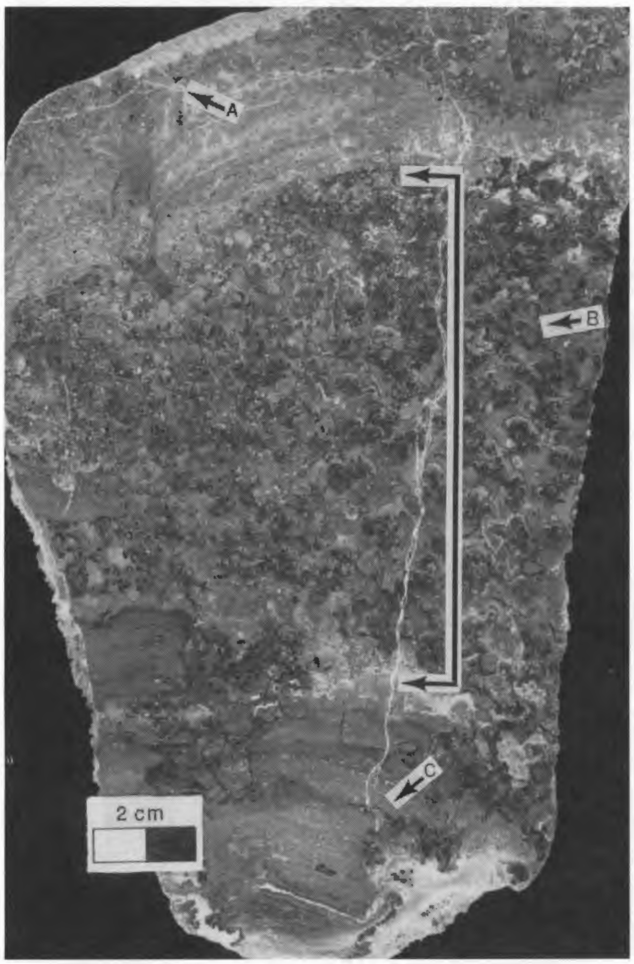


FIGURE 15—POLISHED SLAB from locality 27 showing thick encrustation of *Spirorbis*-foraminifer-alga boundstone (bracket) on peloid-alga boundstone. Arrow A points to bores in foraminifer-alga boundstone; arrow B points to bivalve within *Spirorbis*-foraminifer-alga boundstone; arrow C points to disrupted peloid-alga boundstone. Scale bar is 2 cm. KUMIP 227,007.

affinity of the tubiform features is problematic because of poor preservation. The micritic tube walls are only slightly darker and the tube centers only slightly brighter than the surrounding micrite. The tubes are nonbranching and have an outside diameter of 0.03–0.05 mm (0.001–0.002 in.). The diameter and morphology of the tubes conform to those of *Girvanella* (Riding, 1975; Wray, 1977) and tubiform foraminifers and may be the remains of either or of both (Henbest, 1963; Toomey et al., 1977).

The abundance of *Spirorbis* worm tubes suggests deposition in shallow restricted marine water. Modern *Spirorbis* worms typically inhabit the littoral zone and thrive in restricted tidal pools. They can tolerate brief periods of subaerial exposure and are unaffected by temperature fluctuations from extremely warm to subfreezing (Abe, 1943). Toomey and Cys (1977) described the occurrence of *Spirorbis* in stromatolites from what they interpreted as restricted marine to brackish water deposits, and Toomey and Cys (1979) regarded similar foraminifer-alga boundstones as a pioneer-stage community that formed in shallow marine water. Water depth may have been the factor responsible for restricted conditions. A covering of relatively shallow marine water probably would have lacked strong circulatory currents, and solar heating would have elevated the temperature and salinity. Salinity of such a shallow body of water may also have fluctuated as a result of dilution by precipitation. The truncated upper surface of the *Spirorbis*-foraminifer-alga encrustations (figs. 16 and 17) may have resulted from high-energy conditions during storms or from bioerosion during a later, more nearly normal marine stage.

Stage 5: Transition from restricted marine to nearly normal marine conditions

Stage 5 is characterized by foraminifer- and ostracode-rich lime wackestones and packstones and by peloid-intraclast wackestones to grainstones. These deposits formed in a restricted marine environment that became nearly normal marine with time. The fauna was dominated by *Calcivertella* foraminifers, ostracodes, and tiny high-spired gastropods (figs. 18 and 19). *Calcivertella* are normally encrusters, but in the Americus Limestone Member they are generally unattached. Their typically curved to circular base of attachment indicates encrustation on perishable objects, probably aquatic vegetation. The great abundance of free *Calcivertella* suggests that this vegetation was abundant. *Spirorbis* is generally absent in this stage; however, a foraminifer-alga boundstone formed at some locations on the truncated surface of the underlying *Spirorbis*-foraminifer-alga boundstone. This subsequent encrustation was digitate, lacked worms, and incorporated bryozoans toward the top (fig. 20). Features

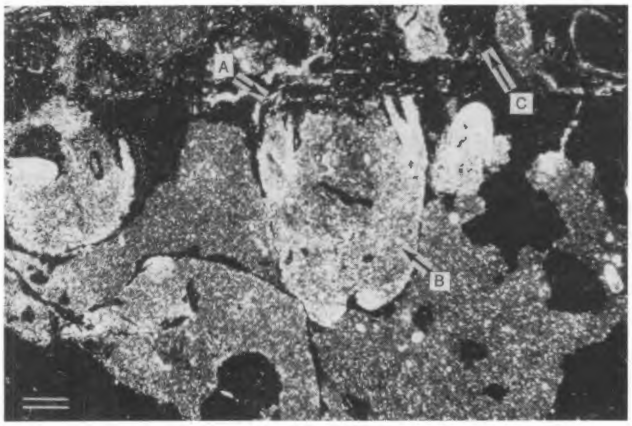


FIGURE 16—PHOTOMICROGRAPH OF TRUNCATED BIVALVES within *Spirorbis*-foraminifer-alga boundstone from locality 25 (plane-polarized light). Arrow A points to truncated surface; arrow B points to truncated bivalve; arrow C points to digitate foraminifer-alga growths on truncated surface. Scale bar is 1 mm. KUMIP 227,008.

FIGURE 17—PHOTOMICROGRAPH OF *SPIRORBIS*-FORAMINIFER-ALGA BOUNDSTONE showing typically truncated upper surface from locality 18 (plane-polarized light). Boundstone is overlain by a foraminifer-ostracode wackestone to packstone. Arrow A points to truncated surface; arrow B points to a *Spirorbis* worm tube. Scale bar is 1 mm. KUMIP 227,004.

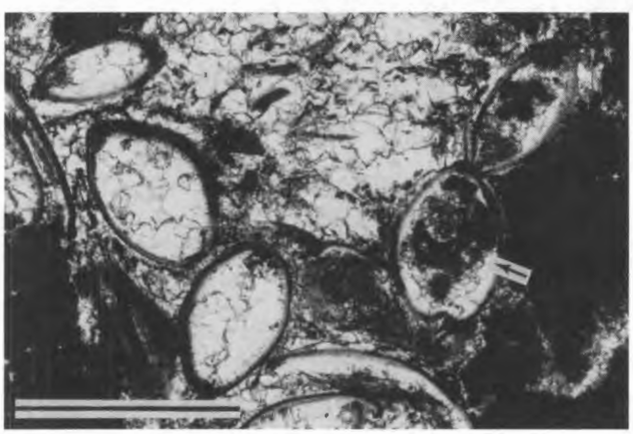


FIGURE 18—PHOTOMICROGRAPH OF OSTRACODES AND *CALCIVERTELLA* from locality 18 (plane-polarized light). Arrow points to a *Calcivertella* within an ostracode. Scale bar is 1 mm. KUMIP 227,004.

FIGURE 19—PHOTOMICROGRAPH OF AN OSTRACODE AND *CALCIVERTELLA* from locality 11 (plane-polarized light). Note curved base of attachment (arrow) on the foraminifer. Scale bar is 100 µm. KUMIP 227,006.

FIGURE 20—POLISHED SLAB SHOWING COALESCING DIGITATE FORAMINIFER-ALGA BOUNDSTONE (bracketed) containing bryozoans, developed on truncated surface (arrow) cutting *Spirorbis*-foraminifer-alga boundstone and peloid-alga boundstone from locality 27. The light-gray zone directly over the foraminifer-alga boundstone is a diagenetic effect and does not contain boundstone. Scale bar is 2 cm. KUMIP 227,009.

indicative of relatively high depositional energies developed at localities interpreted as paleotopographic highs. These high-energy features include rip-up clasts of peloid-alga boundstone, algae-coated grains (oncolites), and packstone or grainstone depositional textures.

The low diversity but great abundance of fossils in this stage suggests deposition in a restricted marine environment. High-energy features, presumably the result of waves and storms in areas of shallow water, indicate that, adjacent to shallow areas, the water had become deep enough to allow the generation of waves that dissipated their energy on shoals. The occurrence of such normal marine fossils as brachiopods, bryozoans, and crinoid fragments, although rare, suggests that the environment was becoming more nearly normal marine.

Stage 6: Nearly normal to normal marine conditions

Fossils and features indicative of marine conditions are prevalent near the top of the lower limestone of the Americus Limestone Member. These include echinoid spines, crinoids, bryozoans, brachiopods, sponge spicules, pectinoid and myalinid bivalves, grapestone, and ooids. The foraminifers *Globivalvulina*, *Tetrataxis*, and *Syzaria* occur at this stage. Borings with a diameter of 3 mm (0.1 in.) in the foraminifer-alga boundstone of stage 5 probably occurred during this stage.

The high-diversity fauna with marine affinities indicates deposition under normal marine conditions. Many of these organisms relied on currents for delivery of food and dispersal of larvae, indicating that the water was deep enough to allow circulatory currents to develop. The continued occurrence of *Calcivertella*, however, suggests partial persistence of the conditions of stage 5.

Stage 7: Turbid marine conditions

Deposition in turbid marine waters resulted in deposits up to 2.5 m (8.2 ft) thick of black, brown, and gray shales. These shales consist of a lower shale situated between the lower and upper limestone beds and a thinner upper shale within the upper limestone bed of the Americus Limestone Member. At some localities thin beds of micaceous quartz sand are interbedded with the lower shale. The fine grain size indicates that the terrigenous material was probably derived from a distant source and accumulated in the deeper, quieter portions of the inundated shelf. Sparse fragments of crinoids, brachiopods, and bivalves reported by Fisher (1980) in the lower shale suggest deposition under restricted marine conditions. Perhaps extensive colonization by normal marine organisms was restricted by the turbid water and slightly lower salinity that may have accompanied the influx of terrigenous sediment. More nearly normal marine conditions evidently were associated with the development of the upper shale, as suggested by the prevalence of fusulinids at some localities.

Stage 8: Normal marine conditions

The upper limestones of the Americus Limestone Member contain a diverse fauna that indicates normal marine conditions. This fauna includes abundant fusulinids, crinoids, brachiopods, bryozoans, and bellerophontid gastropods. [See Harbaugh and Demirmen (1964) and Fisher (1980) for discussions on paleoenvironmental trends within the upper limestone beds of the Americus. Also see appendix G, outcrop 32.]

Lateral distribution of paleoenvironments of the lower Americus Limestone Member

Paleoenvironments changed laterally within the lower part of the Americus Limestone Member, as evidenced by changes in thickness of shale, lithologic texture, morphology of boundstones, and fossils. Differentiation of paleoenvironments is largely the result of differences in the paleotopography of the seafloor, which causes differences in depositional conditions. Anticlinal structures in the subsurface are located at the sites of paleotopographic highs, indicating that the paleotopography and the differentiation of paleoenvironments were governed by structural features.

Thickness of shale as an indicator of paleoenvironment

In general, topographically low areas with relatively deep water were the sites of low-energy deposition, which favored the accumulation of thick deposits of terrigenous mud. Topographically high areas, the sites of relatively shallow-water and somewhat higher-energy deposition or subaerial exposure, subsequently received thinner deposits of terrigenous mud. Figure 21 shows in cross section four paleotopographically high areas of seafloor as delineated by relatively thinner intervals of shale. Each area is interpreted as having been the site of relatively shallow-water deposition at some time during transgression. The exaggeration of the shale thickness that results from differential compaction between shale and interbedded quartz sandstone at localities (outcrops) 21 and 22 is negligible because correction for it does not alter the location of thick and thin intervals of shale. It can be argued that thick intervals of shale are delta lobes that prograded with little or no relationship to topography. This is unlikely because, as will be shown, lithologic texture and the morphology of boundstone in the lower limestone bed indicate that areas covered by thin shales were indeed deposited under conditions of relatively higher energy and that areas covered by thick shales were deposited under conditions of relatively low energy. The reasonable explanation for these relationships is that topography controlled depositional patterns.

Lithologic texture as an indicator of paleoenvironment

In general, carbonate rocks that contain less mud and are grain supported, such as grainstones and packstones, are believed to have been deposited under higher energy conditions than those that contain more mud and lack grain support, such as wackestones and mudstones (Dunham, 1962; see appendix A). Figure 22 illustrates the lateral distribution of the various rock types of the lower limestone bed, and fig. 23 shows the locations of relatively low- and high-energy deposits as indicated by lithologic texture. As expected, each of the four locations regarded as the probable site of a shallow-water paleoenvironment contains or is closely flanked by rocks with less mud, indicating deposition under relatively high energy. Muddier rocks, on the other hand, occur primarily at localities associated with thick overlying intervals of shale, indicating that these areas had

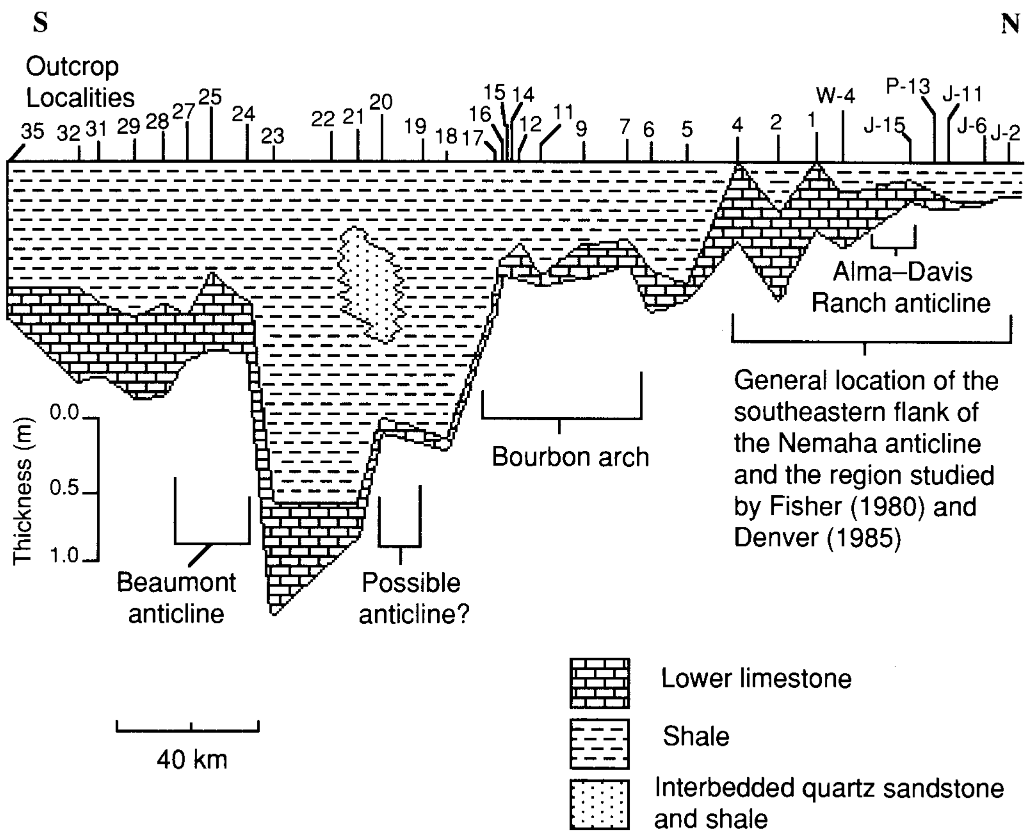


FIGURE 21—Cross section of the lower part of the Americus Limestone Member from Jackson County to Cowley County, Kansas, showing sample localities and known locations of structural features. Areas of relatively thin shale are the probable locations of paleotopographically high seafloors [see Jewett and Merriam (1959) and Fisher (1980); see also fig. 43]. Datum is base of limestone above lowermost limestone.

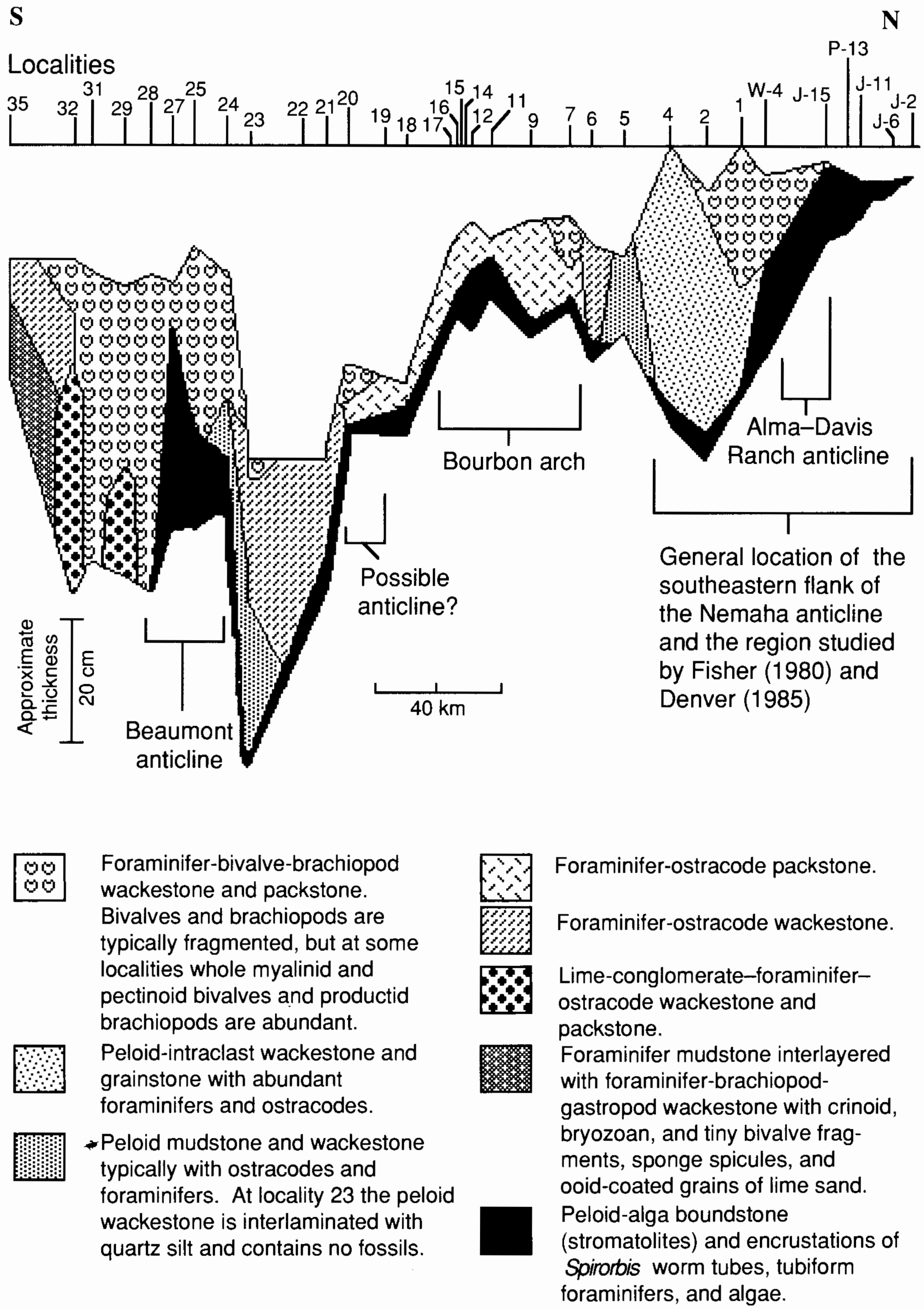


FIGURE 22—SCHEMATIC CROSS SECTION OF THE LOWER LIMESTONE BED OF THE AMERICUS LIMESTONE MEMBER showing distribution of lithofacies and locations of structural features. Datum is the base of the limestone above the lowermost limestone of the Americus. [See Jewett and Merriam (1959) and Fisher (1980).]

low-energy depositional environments. The conglomeratic lime-foraminifer-ostracode wackestone to packstone (fig. 24), which is limited to localities 29 and 32, may have resulted from erosion of nearby paleotopographically high areas during storms.

Morphology of boundstone as an indicator of paleoenvironment

Recognition of paleoenvironmentally controlled features in the peloid-alga boundstones (stromatolites) and associated *Spirorbis*-foraminifer-alga boundstones provides clues to the conditions that prevailed at the time of deposition. Although the biology of algae and other microorganisms is an important control of morphology of stromatolites (Raaben, 1969; Golubic, 1976; Monty, 1977), such environmental conditions as wave energy, desiccation, and substrate stability have also been shown to affect morphology (Logan, 1961; Gebelein, 1969; Logan et al., 1974; Hardie and Ginsburg, 1977; Hoffman, 1976).

Boundstones in the Americus Limestone Member occur as far north as locality P–7 (Fisher, 1980) in central Pottawatomie County and, as rare clasts, as far south as locality 31 in northern Elk County, Kansas. Lack of boundstones to the north is evidently the result of subaerial conditions (Fisher, 1980), which were unfavorable to the growth of algae (Hoffman, 1976), encrusting tubiform

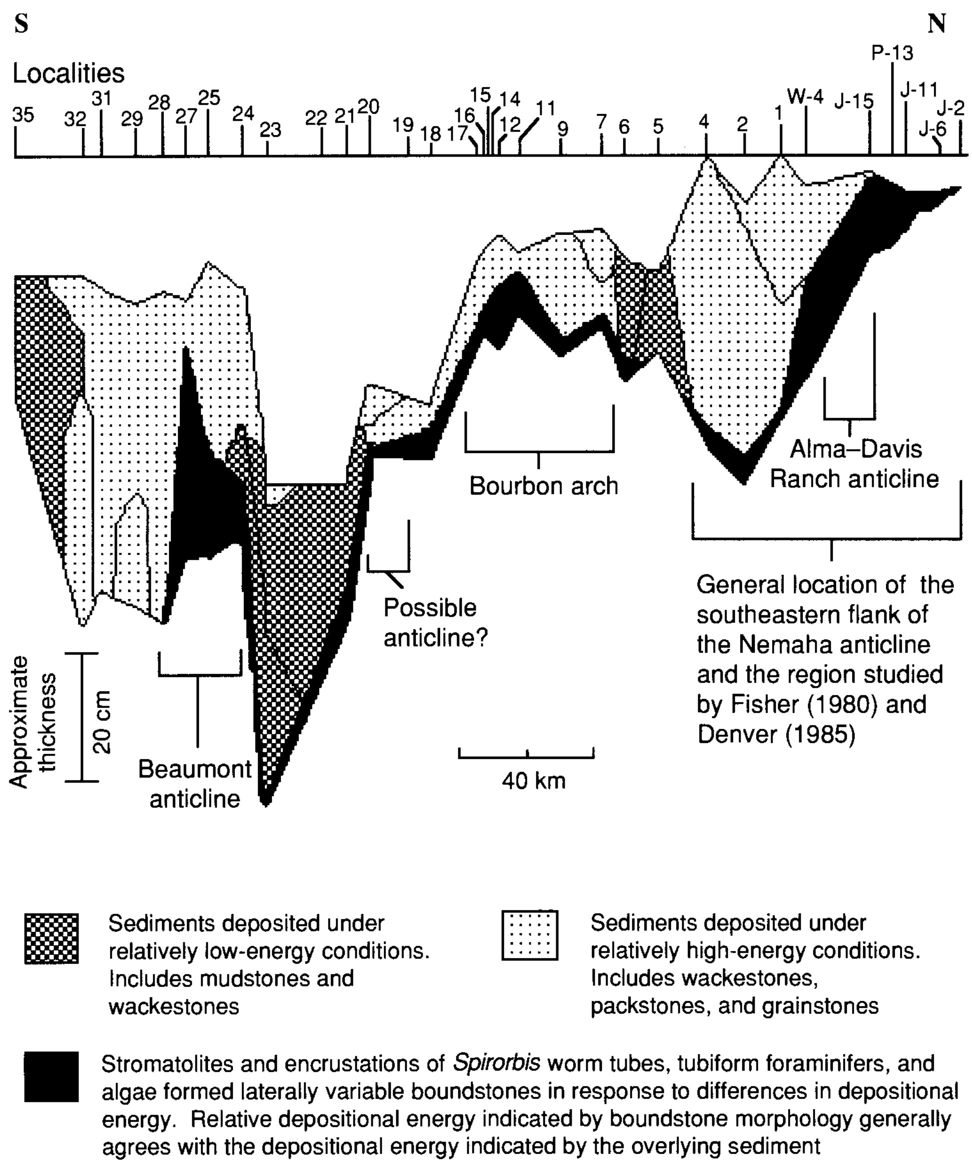


FIGURE 23—SCHEMATIC CROSS SECTION OF THE LOWER LIMESTONE BED OF THE AMERICUS LIMESTONE MEMBER showing distribution of lithofacies resulting from deposition under relatively high- or low-energy conditions and locations of structural features. Datum is the base of the limestone above the lowermost limestone of the Americus. [See Jewett and Merriam (1959) and Fisher (1980).]

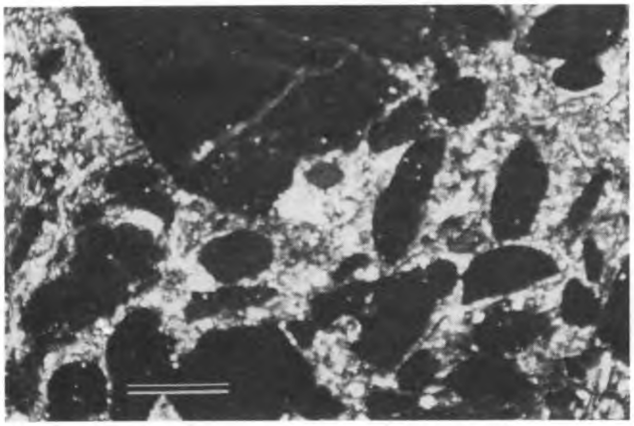


FIGURE 24—Photomicrograph of conglomeratic foraminifer-ostracode wackestone to packstone from locality 29 (plane-polarized light). Scale bar is 1 mm. KUMIP 227,010.

foraminifers, and *Spirorbis* worms. The lack of intact peloid-alga boundstones south of locality 28 may be the result of more nearly normal marine conditions to the south, indicated by the greater abundance of marine fossils and the occurrence of such typically marine features as ooids and grapestone. This southern environment may have favored metazoans, which prevented the development of stromatolites by grazing and by disrupting the substrate (Garrett, 1970; Awramik, 1971; Monty, 1973; Hoffman, 1976; Gebelein, 1976).

Boundstones in the Americus Limestone Member occur in six paleoenvironmentally significant morphologic types (forms): (1) discrete plates of *Spirorbis*-foraminifer-alga boundstone; (2) laterally discontinuous alga boundstone with extensive fenestrae; (3) rip-up clasts of boundstone; (4) thick layers of peloid-alga boundstone with extensive encrustations; (5) high-domed peloid-alga boundstone; and (6) thin, flat-layered to low-domed peloid-alga boundstone. The distribution of the types of boundstone morphology of the lower bed of the Americus is provided in fig. 25.

Type 1 morphology

Type 1 morphology consists of discrete plates of *Spirorbis*-foraminifer-alga boundstone (fig. 26), which Fisher (1980) described as pustular crusts of *Ottonosia*. These plate-shaped masses, typically 3–20 cm (1.2–7.9 in.) across and 5 cm (2 in.) thick, contain abundant *Spirorbis* worm tubes, tubiform foraminifers, algae, and less abundant fragments of brachiopods. This morphology differs from encrustations of *Spirorbis*-foraminifer-alga boundstone found elsewhere in the Americus because it occurs as discrete plates independent of peloid-alga boundstone, is vertically cracked in its top surface, and contains pervasive pore spaces lined with multiple generations of pendant PF2 cement and filled with terrigenous mudstone (figs. 27 and 28). Type 1 boundstone is characteristic of the lower limestone of the Americus at its northern limits.

Abundant *Spirorbis* worm tubes indicate shallow-water restricted marine conditions (Abe, 1943). The vertical cracks in the tops of the plates suggest desiccation resulting from subaerial exposure. The pendant habit and fibrous crystals of cement suggest precipitation in a marine phreatic environment (Longman, 1980). These features indicate that deposi-

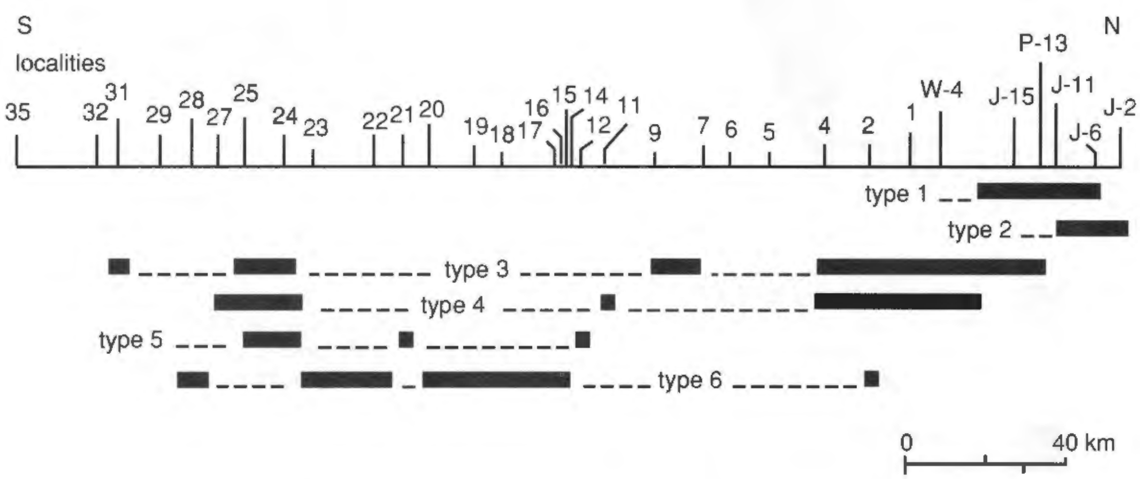


FIGURE 25—Distribution of types of boundstone morphology of the lower limestone bed of the Americus Limestone Member.

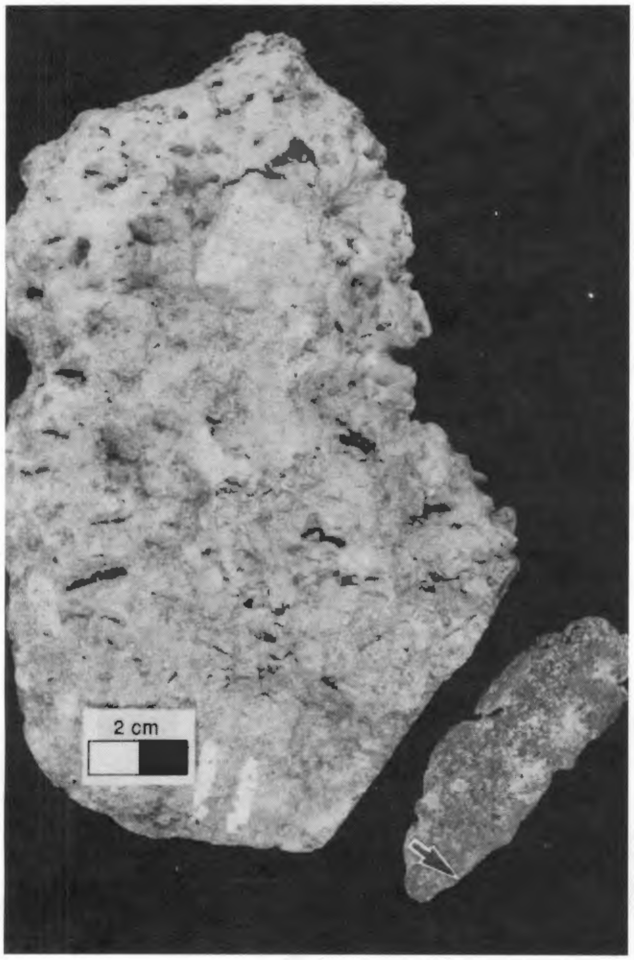


FIGURE 26—TOP SURFACE OF HAND SAMPLE OF TYPE 1 BOUNDSTONE (discrete plates of *Spirorbis*-foraminifer-alga boundstone) from locality P–11. Slab (right) shows typical thickness, and arrow indicates the up direction. Scale bar is 2 cm. KUMIP 227,011.

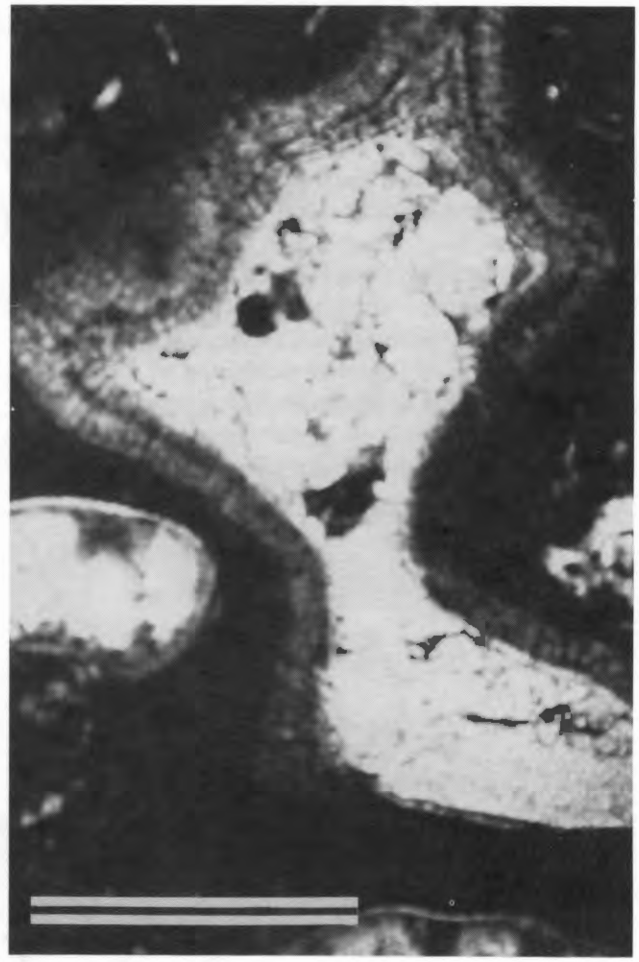


FIGURE 28—PHOTOMICROGRAPH SHOWING CLOSE-UP OF PENDANT CEMENT shown in fig. 27 (plane-polarized light). Scale bar is 1 mm.

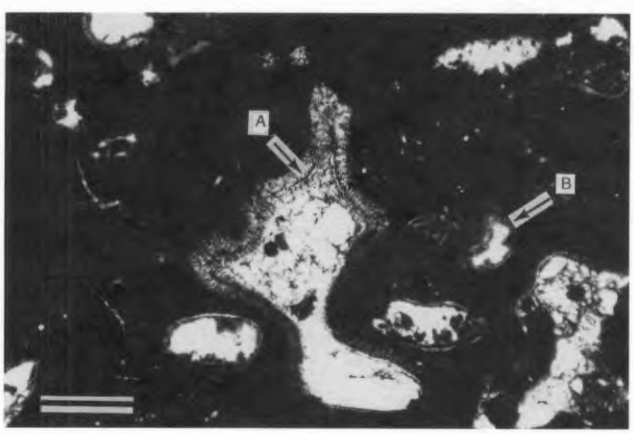


FIGURE 27—PHOTOMICROGRAPH OF PENDANT PF2 CEMENT (arrow A) within type 1 boundstone from locality P–11 (plane-polarized light). Arrow B points to a *Spirorbis* worm tube. Scale bar is 1 mm. KUMIP 227,012.

tion occurred on a paleotopographically high seafloor that was occasionally subaerially exposed. Fisher (1980) interpreted this type as having formed in a tidal flat (fig. 29). Brachiopod fragments also indicate proximity to normal marine paleoenvironments. The mud that covered and infiltrated this boundstone probably was deposited at a later stage, when somewhat deeper marine water covered the paleotopographic high.

Type 2 morphology

Type 2 morphology consists of laterally discontinuous alga boundstone with extensive fenestrae (fig. 30). Denver (1985, p. 24) described such boundstones as "laminoid, domal, ... largely of limonitic mud, silt, and scattered peloids ... [and] characterized by horizontal and vertical fenestrae up to 2 cm long that are lined with clear, equant spar but otherwise open." Type 2 boundstones occur in laterally discontinuous patches, 15 cm (5.9 in.) wide and 2–3 cm (0.8–1.2 in.) high. Associated fossils, including *Spirorbis* tubes, are rare. Denver (1985) noted that this morphology is rare and that it is generally surrounded by shale. Type 2 boundstones occur in the same general geographic area as type 1 boundstones, that is, at the northern limits of the lower limestone bed.

Denver (1985) found that the type 2 morphology occurs only in the area that Fisher (1980) identified as a tidal flat facies and concluded, based on pervasive fenestral porosity and desiccation cracks, that the rocks formed in an upper intertidal environment which was frequently subaerially exposed. Denver (1985) interpreted the patchy lateral distribution as the result of subaerial weathering of a polygonal pattern developed in an algal mat. Although domal features can result from deposition under high-energy conditions (Hoffman, 1976), the fine size of the incorporated sediment suggests that this morphology did not develop in a high-energy environment. In this case the domal features may have formed from arching caused by gas trapped beneath the algal mat.

Type 3 morphology

Type 3 morphology is characterized by rip-up clasts of boundstone. These rocks consist of small intraclasts of both peloid-alga boundstone and *Spirorbis*-foraminifer-alga boundstone and large clasts of peloid-alga boundstone. The smaller clasts are generally no larger than 7 mm (0.3 in.) across and are irregular (fig. 31). Larger clasts are 1–2 cm (0.4–0.8 in.) thick and up to 20 cm (8 in.) wide (fig. 32). The clasts are generally in a matrix of foraminifer-ostracode

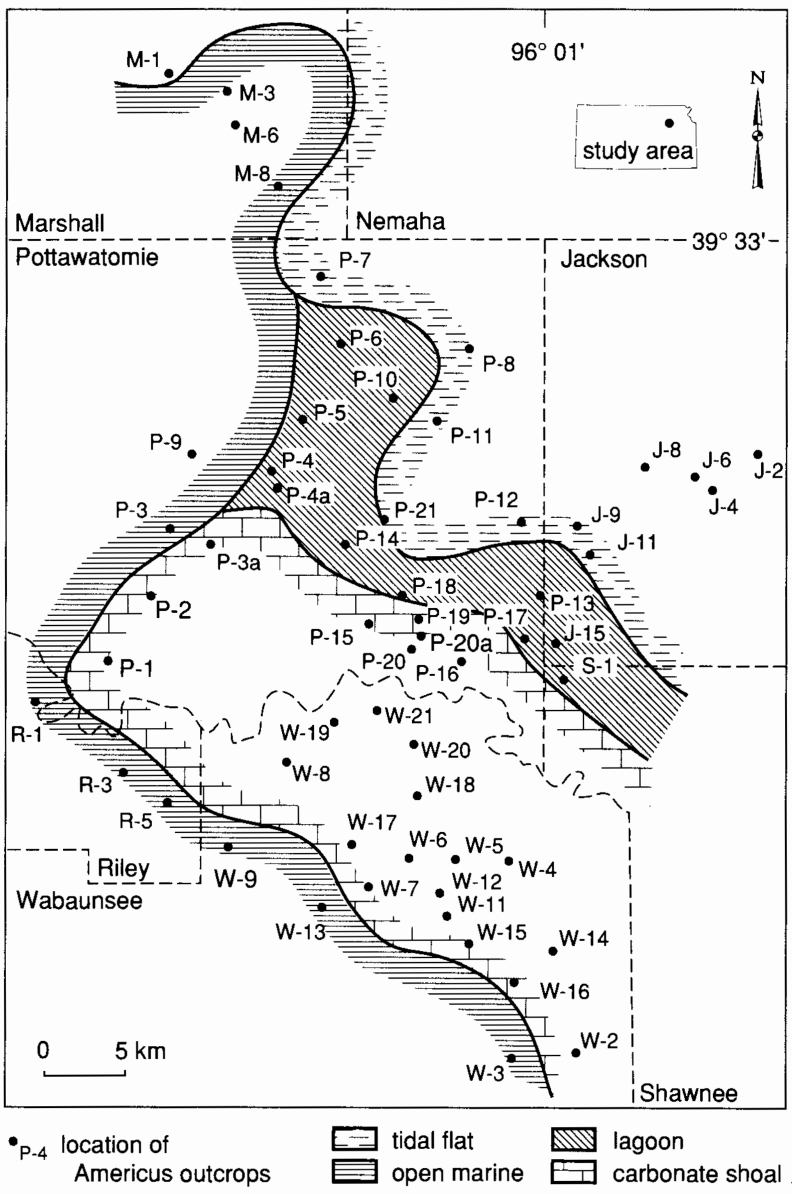


FIGURE 29—FISHER'S (1980) PALEOENVIRONMENTAL FACIES of the lower Americus limestone bed in north-central Kansas. [From Denver (1985), after Fisher (1980).]

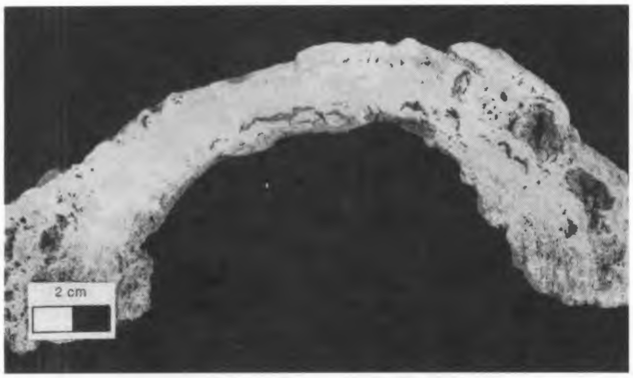


FIGURE 30—Polished slab of type 2 boundstone (isolated boundstone with extensive fenestral porosity). Scale bar is 2 cm. KUMIP 214,825.

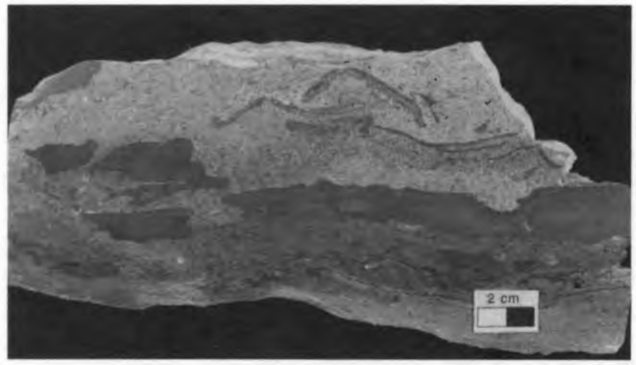


FIGURE 32—Polished slab showing type 3 boundstone (rip-up clasts of peloid-alga boundstone) from locality 9. Scale bar is 2 cm. KUMIP 227,014.

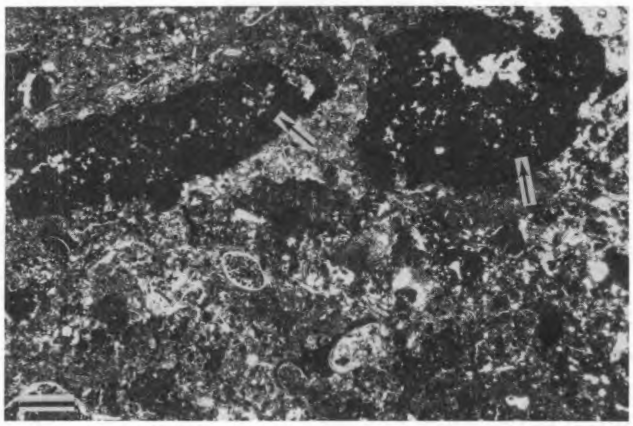


FIGURE 31—Photomicrograph of type 3 boundstone [rip-up clasts (arrows) of peloid-alga boundstone] from locality 2 (plane-polarized light). Scale bar is 1 mm. KUMIP 227,013.

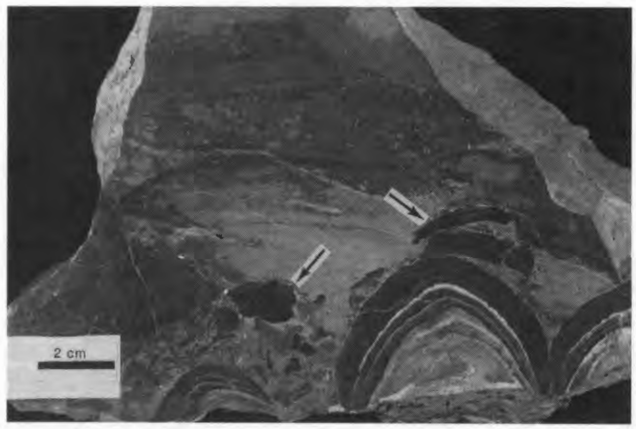


FIGURE 33—Polished slab showing rip-up clasts of type 3 boundstone (arrows) and proximity to domal (type 5) and thick (type 4) boundstone from locality 24. Scale bar is 2 cm. KUMIP 227,015.

packstone or wackestone and are typically associated with thick domal boundstone (fig. 33). At locality 25 the clasts seem to be concentrated in a 0.4-m-deep (1.3-ft-deep) trough developed between deposits of boundstone. The clasts generally are not coated, but some larger ones have been encrusted with both *Spirorbis*-foraminifer-alga boundstone and peloid-alga boundstone (fig. 34). Fisher (1980) noted extremely thick encrustations of *Spirorbis*-foraminifer-alga boundstone around clasts of peloid-alga boundstone, which he referred to as reef rock. These reef rocks, which are actually encrustations on large stabilized oncolites, are typically 20 cm (8 in.) thick but may be "40 cm high and nearly a meter across" (Fisher, 1980, p. 44). Clasts of boundstone are numerous at localities 1, 2, 4, 9, 24, and 25, but they also occur at localities 7, 11, 22, and 31.

In the north rip-up clasts of boundstone are limited to the vicinity of Fisher's (1980) carbonate-shoal and lagoonal facies. Relatively thin overlying shale at locations 9, 24, and 25 (see fig. 22) suggests deposition in relatively shallow water. The clasts are interpreted as the result of storm erosion in areas of shallow water adjacent to areas of relatively deep water. Rolling during subsequent storms allowed some clasts to acquire oncolitic coats of boundstone. The abundance of oncolites in Fisher's (1980) lagoonal facies suggests that part of the environment was a swash zone rather than a protected lagoonal environment. Boundstones that were not ripped up, however, must have been protected from high-energy waves, developing behind a protective barrier, on a substrate below the wave base, or in wide, shallow areas that damped waves.

Type 4 morphology

Type 4 morphology is characterized by relatively thick layers of peloid-alga boundstone and extensive encrustation with *Spirorbis*-foraminifer-alga boundstone. This morphology includes Denver's (1985) smooth and laminoid forms. Type 4 boundstones are generally 5–20 cm (2–8 in.) thick and contain coalescing columnal, hemispherical, and horizontal laminations of peloid-alga boundstone. Stromatolites with this morphology typically display extensive ragged pores

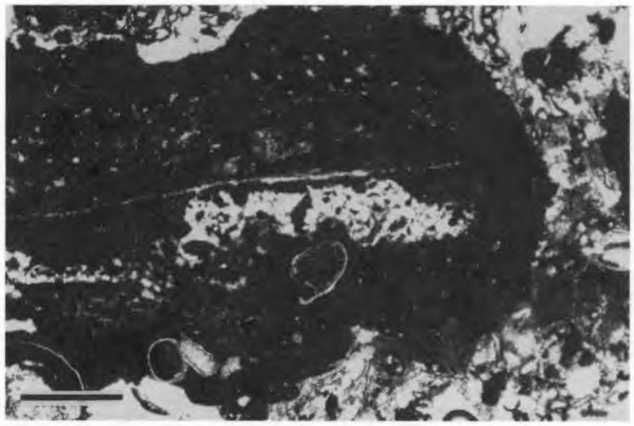


FIGURE 34—Photomicrograph of rip-up clasts (type 3 boundstone) with organic coatings from locality 2 (plane-polarized light). Scale bar is 1 mm. KUMIP 227,016.

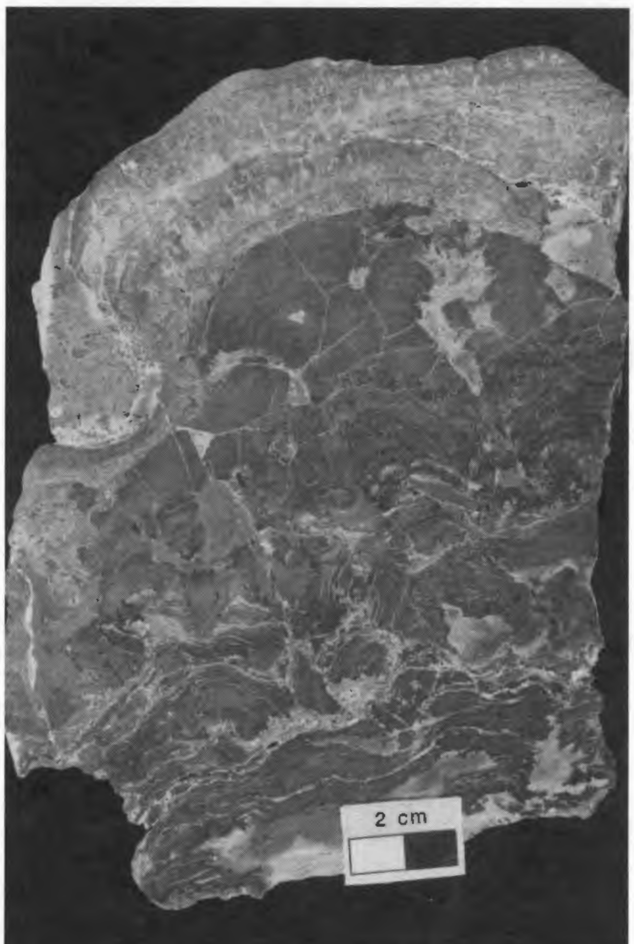


FIGURE 35—Polished slab showing type 4 boundstone (thick, porous, encrusted boundstone with disrupted laminations) from locality 25. Scale bar is 2 cm. KUMIP 227,017.

filled with foraminifers and ostracodes from overlying sediment and are lined with encrustations of *Spirorbis*-foraminifer-alga boundstone (fig. 35). Laminations in the lower 5 cm (2 in.) are typically disrupted and brecciated and commonly have alveolar structures (figs. 12 and 13).

The upper surfaces of the peloid-alga boundstone commonly display two generations of encrustations. The first generation is a *Spirorbis*-foraminifer-alga boundstone, up to 11 cm (4.3 in.) thick, containing common tiny bivalves (figs. 15 and 16) and having a truncated upper surface. The second generation of encrustation is a coalescing digitate foraminifer-alga boundstone with bryozoans incorporated in the upper portions (fig. 20). This second generation is typically bored (fig. 15), but its upper surface is not truncated.

Type 4 morphology occurs at several locations in Fisher's (1980) carbonate-shoal facies and elsewhere at localities 11, 24, 25, and 27. At all locations type 4 boundstones are associated with a dramatic thinning of the overlying shale, suggesting deposition on a substrate of relatively high paleotopography. The coalescing columnar and hemispheroidal laminations and the relatively high relief of the boundstone suggest deposition in a relatively high-energy environment (Logan, 1961; Gebelein, 1969; Hoffman, 1976; Playford and Cockbain, 1976). Alveolar structures and associated disrupted layers indicate a period of subaerial exposure that enabled vegetation to develop. These features can be explained by a lowering of sea level that exposed isolated areas of high paleotopography. The upper layers of peloid-alga boundstone contain no alveolar features, indicating that subaerial exposure was temporary. Under subsequent deeper-water conditions the paleotopographically high seafloors were evidently ideal habitats for encrusting foraminifers and *Spirorbis* worms.

Type 5 morphology

Type 5 morphology, a variant of Denver's (1985) smooth and laminoid morphologies, is characterized by layers of peloid-alga boundstone arched into relatively high domes (fig. 36). The height of the domes typically is 4–7 cm (1.6–3 in.), and the width ranges from 5 cm to 15 cm (2–6 in.). The domes typically have an inner core of orange shale or terrigenous mudstone. Encrustations of *Spirorbis*-foraminifer-alga boundstone are generally less than 1 cm (0.4 in.) thick. At location 21 postdepositional compaction has partially crushed the domes. Type 5 morphology occurs at localities 12, 21, 24, and 25.

As with morphology types 3 and 4, the high-relief domal features of type 5 morphology probably indicate deposition in moderately high-energy environments (Logan, 1961; Gebelein, 1969; Hoffman, 1976). Figure 21 suggests that localities 12, 24, and 25 were probably the sites of relatively high-energy deposition on a seafloor with relatively high paleotopography.

Type 6 morphology

Type 6 morphology is characterized by low-domed to thin, flat layers of peloid-alga boundstone. These boundstones would have been classified by Denver (1985) as either smooth or laminoid. The layers generally range in thickness from 0.6 cm to 3.5 cm (0.2–1.4 in.) and commonly occur as laterally discontinuous plates, 12–30 cm (4.7–12 in.) wide, with the edges curled under. Low domal features, if present, generally have a height of 1.5 cm (0.6 in.) and are typically oblong in plan view with a maximum length of 12 cm (4.7 in.). Encrustations of *Spirorbis*-foraminifer-alga boundstone on the upper surface of the peloid-alga boundstone are patchy and 0.4–1 cm (0.2–0.4 in.) thick. Type 6 morphology occurs at localities 2, 15, 16, 17, 18, 19, 20, 22, 23, and 28.

At localities 18, 19, 22, and 23 the boundstone is characterized by relatively flat layers with microcolumns and tiny troughs (fig. 37). These flat layers are 2 cm (0.8 in.) thick and are dissected by tiny troughs, 4 mm (0.2 in.) wide and 1.5 cm (0.6 in.) deep, that form microcolumns 2 cm (0.8 in.) wide. In plan view the trough pattern is roughly polygonal. The troughs are generally filled with foraminifer-ostracode packstone to wackestone and often contain tiny gastropods. Laminae of peloid-alga boundstone are generally turned down at the edges of the microcolumns. The trough and microcolumnar structures are believed to have resulted from grazing by tiny metazoans along the edges of desiccation cracks developed in a thin, flat to undulated mat of algally bound peloids. Tiny cracks would have provided refuge for such small metazoans as ostracodes and gastropods, which may have widened the cracks by browsing. Subsequent algal activity formed additional boundstone layers that either turned down at the edge of the trough or, more rarely, bridged the trough to connect adjacent microcolumns. The laterally discontinuous plates with curled-under edges probably resulted from suhaerial modifications of larger desiccation polygons early in the inundation.

The low relief of this morphology suggests deposition in a low-energy environment (Logan, 1961; Gebelein; 1969; Hoffman, 1976; Playford and Cockbain, 1976). Figure 21 shows that localities with type 6 morphology have relatively thick intervals of shale and thus probably had deeper-water low-energy environments at maximum transgression. This morphology evidently developed in the wide low-lying areas that were the initial sites of inundation. With continued transgression these initial deposits were soon below the wave base and thus did not develop features indicative of a high-energy environment. Shale probably first accumulated in these low-lying areas and evidently prevented extensive encrustations of *Spirorbis*, foraminifers, and algae.

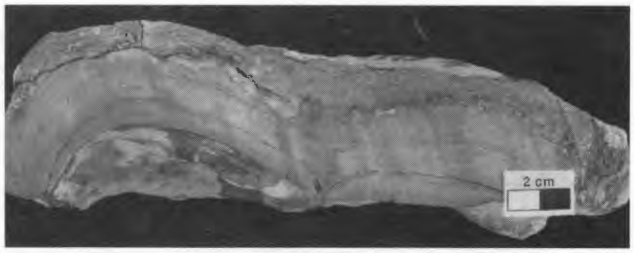


FIGURE 36—LARGE DOMES OF PELOID-ALGA BOUNDSTONE typical of type 5 boundstone from locality 12. Scale bar is 2 cm. KUMIP 227,018.

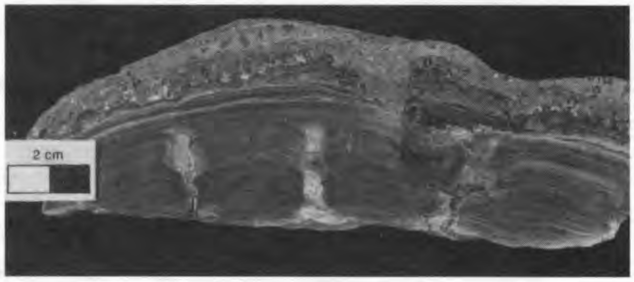


FIGURE 37—MICROCOLUMNS AND TROUGHS DEVELOPED IN THE LOW-RELIEF LAYERS OF TYPE 6 BOUNDSTONE from locality 22. Scale bar is 2 cm. KUMIP 227,019.

Distribution of fossils and other constituents as indicators of paleoenvironment

Lateral distribution and relative abundance of fossils and other constituents provide additional information on the paleoenvironment of the lowermost bed of the Americus Limestone Member. Figure 38 shows that such normal marine fossils as calcareous sponge spicules, echinoid spines, bryozoan fragments, crinoid fragments, and, to some extent, gastropods are more abundant to the south. Fragments of brachiopods occur at many locations, but unfragmented *Linoproductus*, *Derbyia bennetti*, and dictyoclostid brachiopods are abundant only at locality 28 on the flank of the southernmost paleotopographically high seafloor. Ooids, ooid-coated grains, and grapestones (fig. 39)—features typical of agitated seafloors under normal marine conditions (Bathurst, 1975)—occur at only a few southern outcrops. This evidence suggests that normal marine influences were greater in the south than in the north. Subaerial exposure at paleotopographically high locations is indicated by pendant PB5 cement (fig. 40) within molds of bivalves from locality 25 and alveolar structures at localities 24 and 25.

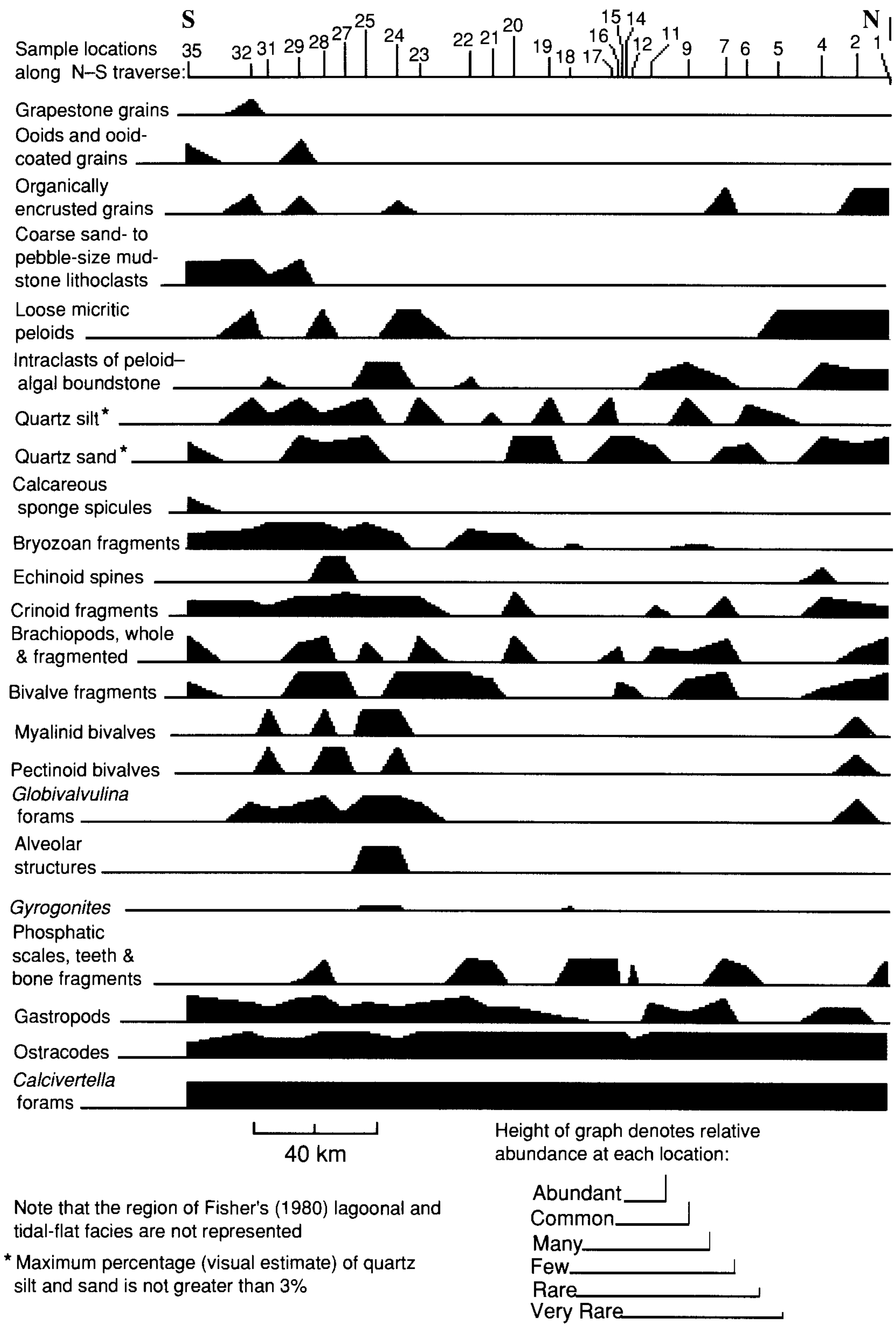


FIGURE 38—Distribution and relative abundance of fossils and other rock constituents at each locality.

FIGURE 39—Photomicrograph of ooid-coated foraminifer (A) and ostracode (B) from locality 29 (plane-polarized light). Scale bar is 100 μm. KUMIP 227,020.

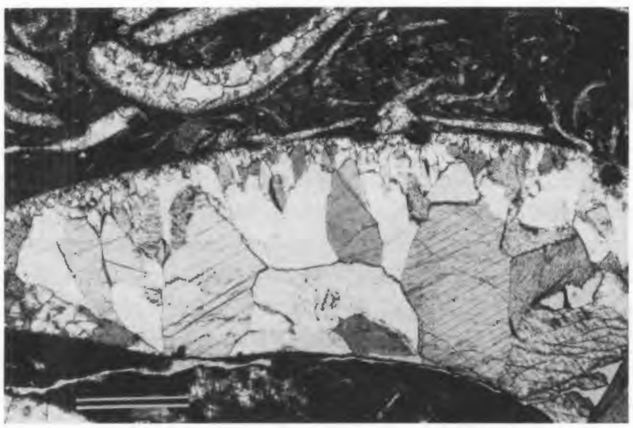


FIGURE 40—Photomicrograph of bivalve molds from locality 25 displaying pendant PB5 cement (cross-polarized light). Scale bar is 1 mm. KUMIP 227,021.

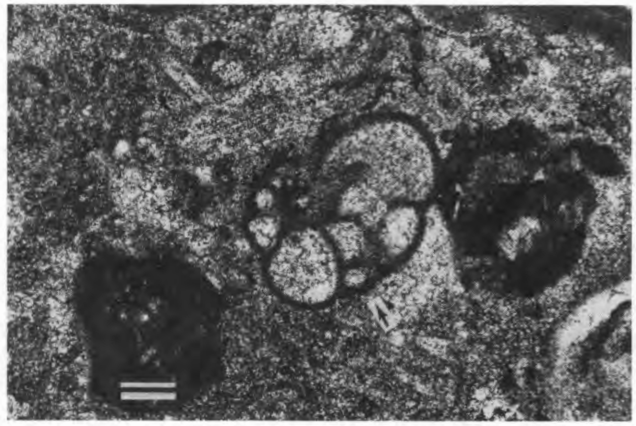


FIGURE 41—Photomicrograph of the foraminifer *Globivalvulina* (arrow) from locality 29 (plane-polarized light). Scale bar is 100 μm. KUMIP 227,020.

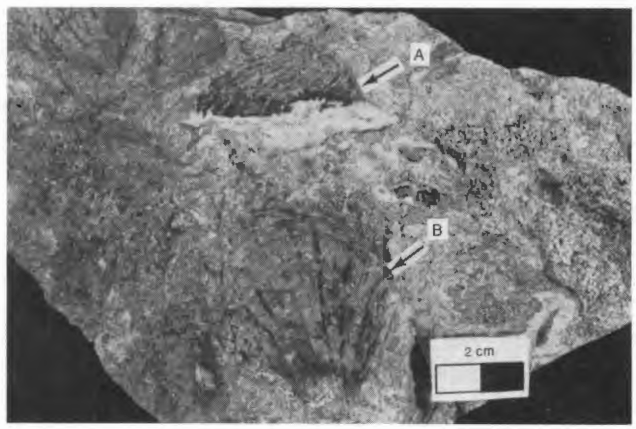


FIGURE 42—Myalinid (A) and pectinoid (B) bivalves on the weathered surface of the lowermost limestone bed of the Americus Limestone Member from locality 31. Scale bar is 2 cm. KUMIP 227,022.

The paleoenvironmental significance of the distributions of other constituents shown in fig. 38 is more problematic. *Gyrogonites* is present at localities 18, 24, and 25 but is quite rare. It may have been derived from the underlying freshwater lime sand of the Hamlin Shale Member. Indeed, the lower limestone bed at localities 24 and 25 displays a basal surface with irregularities that suggest erosion, and at these localities *Gyrogonites* occurs with ripped up fragments of boundstone. If not allogenic, *Gyrogonites* may have originated from charophytes living in freshwater during periods of subaerial exposure on paleotopographically high areas.

The environmental significance of the distribution of silt- and sand-size quartz grains and tiny fragments of bone, teeth, and scales typically found immediately above the stromatolite layer is not known. Some of the scales are from acanthodian fish, which are believed to have lived in both marine and freshwater environments (Schultze, 1985). *Calcivertella* foraminifers, ostracodes, and tiny high-spired gastropods are present at nearly all locations and occur in greater abundance than any other fossil in the lowermost bed of the Americus. This abundant low-diversity fauna suggests deposition in an overall restricted environment. Kaesler et al. (1990) examined the distribution patterns of ostracode species to determine their paleoenvironmental significance.

The distribution of *Globivalvulina* foraminifers and pectinoid and myalinid bivalves provides insight into their environmental preferences. *Globivalvulina* foraminifers (fig. 41) are more abundant toward the south, suggesting that these foraminifers preferred more nearly normal marine conditions. Furthermore, *Globivalvulina* and pectinoid and myalinid bivalves (fig. 42) are bimodally distributed, with clusters located between localities 1–4 and localities 23–32. These were locations of relatively high depositional energies on paleotopographically high seafloors, suggesting that these organisms preferred such habitats. The distribution may be similar to that of the modern *Pinna–Pinctada* community in Shark Bay, Australia, which is characteristic of sublittoral sills covered by no more than 2 m (7 ft) of water and periodically exposed during the summer (Read, 1974, p. 15).

Effects of structural features

Tectonic structures affected the strata of the midcontinent during the Pennsylvanian and Early Permian (Lee, 1943; Jewett and Abernathy, 1945; Jewett, 1949; Jewett and Merriam, 1959; Mudge, 1967; Harris and Larsh, 1979), and several locations of high paleotopography of the Americus Limestone Member (see fig. 21) correspond to known structural features. North of locality 4, in the region of the carbonate-shoal, lagoonal, and tidal flat facies (Fisher, 1980), is the Alma–Davis Ranch anticline and the southeastern flank of the Nemaha anticline. The paleotopographically high area at localities 9–17 corresponds to the general location of the Bourbon arch, a broad feature that separates the Forest City basin to the north from the Cherokee basin to the south. Localities 24–28 are the site of a shallow-water to subaerial paleoenvironment that existed at the location of the Beaumont anticline. The minor paleotopographic high indicated between localities 19 and 22 might also be the location of a previously unrecognized structural uplift.

The structural features caused lateral differentiation of paleoenvironments by forming topographically high areas directly over uplifts, probably by differential compaction or by subtle tectonic movements. The paleotopographically high areas were the locations of shallow-water high-energy to subaerial environments of deposition; deeper-water low-energy environments of deposition developed between anticlines. Figure 43 shows the lateral distribution of paleoenvironments in the lowermost bed of the Americus Limestone Member and associated structural features.

Conclusions

The upper Hamlin Shale and Americus Limestone members record a vertical succession of paleoenvironmental conditions ranging from freshwater to normal marine. The lateral distributions of fossils and other constituents in the lower limestone bed of the Americus indicate that more nearly normal marine conditions existed toward the south. Differences in paleotopography of the seafloor caused lateral differentiation of depositional environments by forming localized areas of shallow-water high-energy to supratidal environments. Paleotopographically high areas are characterized by thin intervals of overlying shale or terrigenous mudstone, packstones and grainstones, distinctive boundstone types, and the presence of *Globivalvulina* foraminifers and pectinoid and myalinid bivalves. The coincidence of such structural features as the Nemaha anticline, the Alma–Davis Ranch anticline, the Bourbon arch, and the Beaumont anticline with the locations of shallow-water, high-energy, and supratidal depositional environments indicates that these structural features were ultimately responsible for the lateral differentiation of the paleoenvironments. It should be possible to use such relationships in similar strata to locate similar minor anticlines and arches.

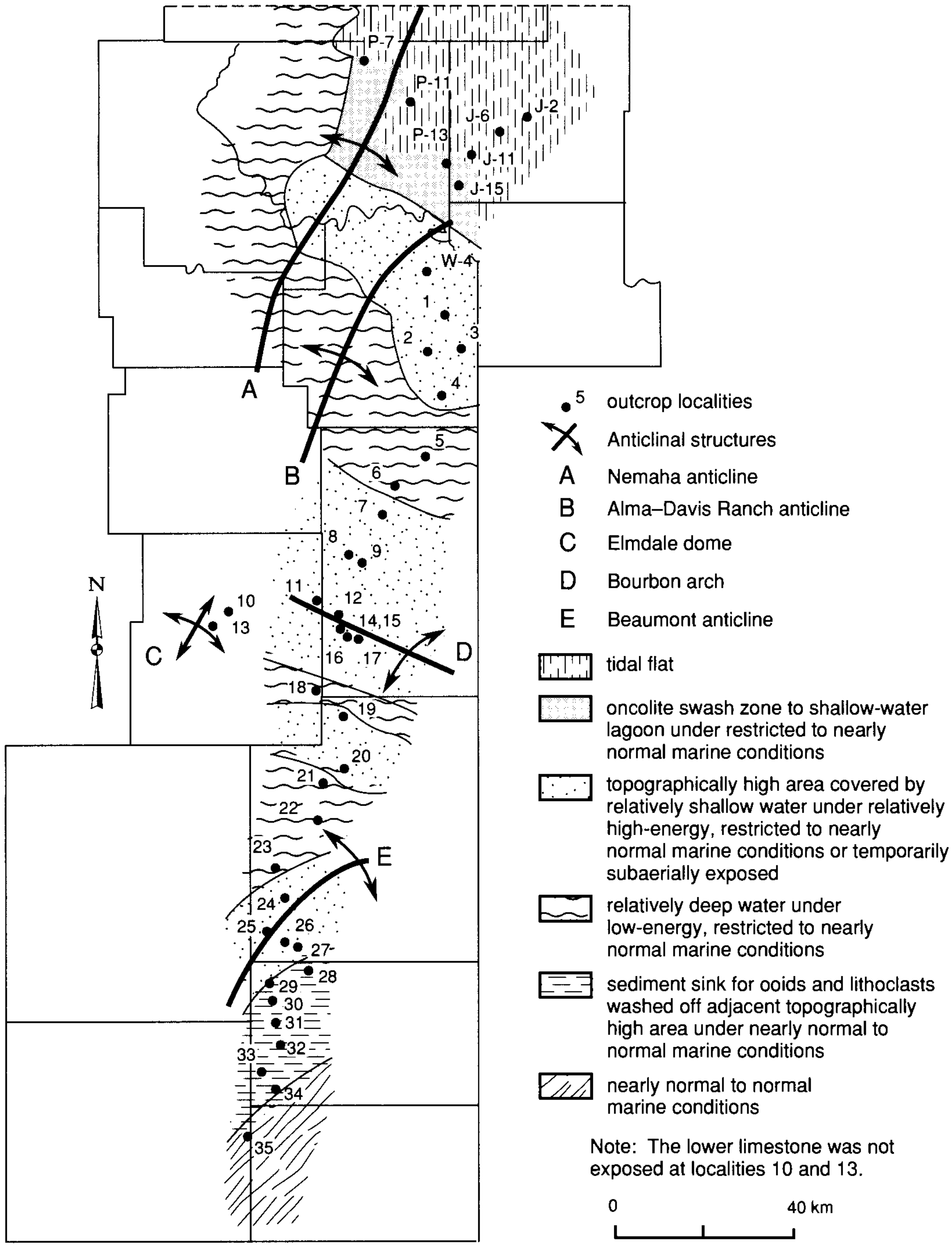


FIGURE 43—Distribution of depositional environments of the lowermost limestone bed of the Americus Limestone Member and associated structural features from north-central Kansas to extreme south-central Kansas [see Jewett and Merriam (1959) and Fisher (1980)].

Appendix A: Dunham's (1962) classification of carbonate rocks according to depositional texture

<table>
<tr><td colspan="5">Depositional texture recognizable</td><td>Depositional texture not recognizable</td></tr>
<tr><td colspan="4">Original components not bound together during deposition</td><td rowspan="3">Original components were bound together during deposition, as shown by intergrown skeletal matter, lamination contrary to gravity, or sediment-floored cavities that are roofed over by organic or questionably organic matter and are too large to be interstices</td><td rowspan="3">(subdivided according to classifications designed to bear on physical texture or diagenesis)</td></tr>
<tr><td colspan="2">Contains mud (particles of clay and fine-silt size)</td><td rowspan="2">Grain supported</td><td rowspan="2">Lacks mud and is grain supported</td></tr>
<tr><td>Less than 10% grains</td><td>More than 10% grains</td></tr>
<tr><td>Mudstone*</td><td>Wackestone</td><td>Packstone</td><td>Grainstone</td><td>Boundstone</td><td>Crystalline carbonate</td></tr>
</table>

Dunham (1962) used "lime" as an adjective to differentiate between limestones and dolomites. Because none of the rocks in this study were dolomites, "lime" was deemed superfluous and was not used to modify the types of carbonate rocks.

*A terrigenous mudstone denotes in this publication a shalelike rock that does not display obvious laminae (i.e., not a limestone).

Appendix B: Folk's (1965) code for classification of calcite cement

I. Mode of formation
  - P: Passive precipitation
  - D: Displacive precipitation
  - N: Neomorphism
  - R: Replacement

II. Shape
  - E: Equant, axial ratio <1.5:1
  - B: Bladed, axial ratio 1.5:1 to 6:1
  - F: Fibrous, axial ratio >6:1

III. Crystal size
  - 7: Extremely coarsely crystalline, >4.0 mm
  - 6: Very coarsely crystalline, >1.0 mm
  - 5: Coarsely crystalline, >0.25 mm
  - 4: Medium crystalline, >0.062 mm
  - 3: Finely crystalline, >0.016 mm
  - 2: Very finely crystalline, >0.004 mm
  - 1: Aphanocrystalline

IV. Foundation
  - O: Overgrowth, in optical continuity with nucleus
  - C: Crust, physically oriented by nucleant surface
  - S: Spherulitic with no obvious nucleus

Example: PE2 is a passively precipitated, very finely crystalline, equant calcite cement.

Appendix C: Classification of porosity from Choquette and Pray (1970)

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Basic Porosity Types

Fabric selective		Not fabric selective		Fabric selective or not	
	interparticle (BP)		fracture (FR)		breccia (BR)
	intraparticle (WP)		channel* (CH)		boring (BO)
	intercrystal (BC)		vug* (VUG)		burrow (BU)
	moldic (MO)		cavern* (CV)		shrinkage (SK)
	fenestral (FE)				
	shelter (SH)				
	growth-framework (GF)				

*cavern applies to human-sized or larger pores of channel or vug shapes.

Modifying terms

Genetic modifiers

Process		Direction or stage	
solution	s	enlarged	x
cementation	c	reduced	r
internal sediment	i	filled	f

Time of formation

Primary	P
pre-depositional	Pp
depositional	Pd
Secondary	S
eogenetic	Se
mesogenetic	Sm
telogenetic	St

Genetic modifiers are combined as follows:

Process + Direction + Time

Examples:		
	solution - enlarged	sa
	cement - reduced primary	crP
	sediment - filled eogenetic	ifSe

Size* modifiers

Classes				mm†
megapore	mg	large	lmg	256
		small	smg	32
mesopore	ms	large	lms	4
		small	sms	1/2
microsporemc	mc			1/16

Use size prefixes with basic porosity types:

mesovug	msVUG
small mesomold	smsMO
microinterparticle	mcBP

*For regular-shaped pores smaller than cavern size.
†Measures refer to average pore diameter of a single pore or the range in size of a pore assemblage. For tubular pores use average cross section. For platy pores use width and note shape.

Abundance Modifiers

percent porosity (15%)
or
ratio of porosity types (1:2)
or
ratio and percent (1:2) (15%)

Construction of Porosity Designation

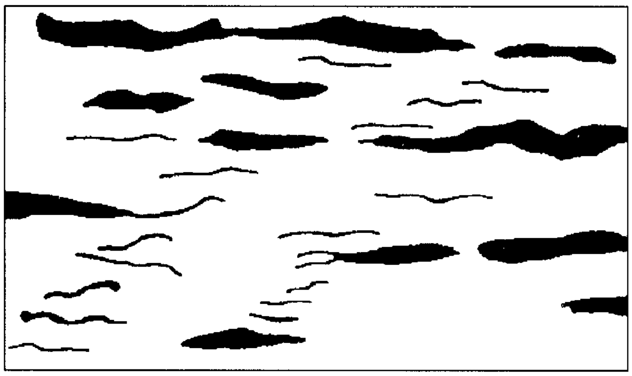
Any modifying terms are combined with the basic porosity type in sequence given below:

Genetic modifier + size modifier + basic porosity type + abundance

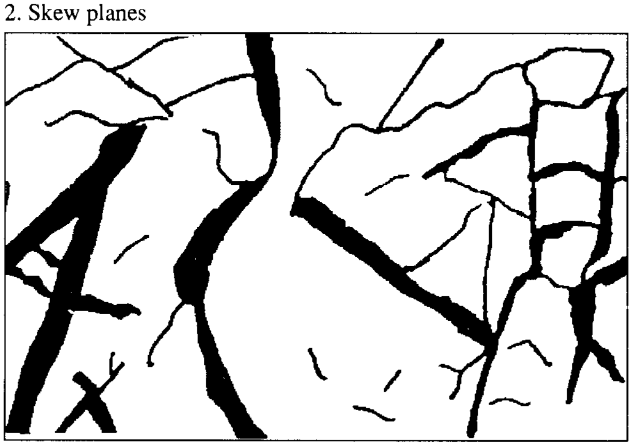
Appendix D: Classification of fractures from Freytet and Plaziat (1982)

Illustration from Goldstein (1986), after Freytet and Plaziat (1982), shows types of fracture patterns that can be found in hand sample or thin section. Reprinted by permission.

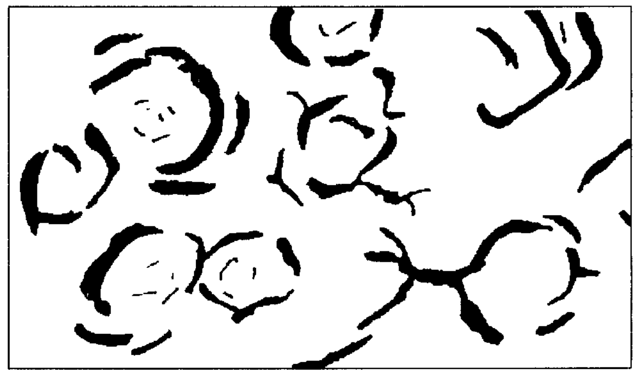
1. Horizontal joint planes



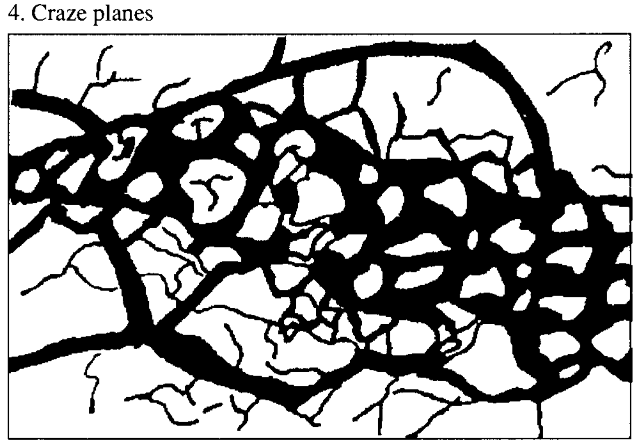
2. Skew planes



3. Curved planes



4. Craze planes



Appendix E: Register of localities

Locality Number	Location Description
P–7	NWNENW sec. 14, T. 6 S., R. 10 E., Pottawatomie County
P–11	NENENE sec. 26, T. 7 S., R. 11 E., Pottawatomie County
J–2	SWSESE sec. 35, T. 7 S., R. 14 E., Jackson County
J–6	SWSWNW sec. 8, T. 8 S., R. 14 E., Jackson County
J–11	SWSESE sec. 29, T. 8 S., R. 13 E., Jackson County
P–13	SESWSE sec. 11, T. 9 S., R. 12 E., Pottawatomie County
J–15	NENWNE sec. 25, T. 9 S., R. 12 E., Jackson County
W–4	SWSW sec. 27, T. 11 S., R. 12 E., Wabaunsee County
1	NESESE sec. 24, T. 12 S., R. 12 E., Wabaunsee County
2	SWNENE sec. 21, T. 13 S., R. 12 E., Wabaunsee County
3	SENENE sec. 19, T. 13 S., R. 13 E., Wabaunsee County
4	NWNW sec. 23, T. 14 S., R. 12 E., Wabaunsee County
5	SWNW sec. 4, T. 16 S., R. 12 E., Lyon County
6	NWNW sec. 35, T. 16 S., R. 11 E., Lyon County
7	NENW sec. 21, T. 17 S., R. 11 E., Lyon County
8	NWSW sec. 14, T. 18 S., R. 10 E., Lyon County
9	NENE sec. 26, T. 18 S., R. 10 E., Lyon County
10	SESWNW sec. 26, T. 19 S., R. 7 E., Chase County
11	SENE sec. 24, T. 19 S., R. 9 E., Chase County
12	SWSW sec. 33, T. 19 S., R. 10 E., Lyon County
13	NW sec. 3, T. 20 S., R. 7 E., Chase County
14	SWSE sec. 4, T. 20 S., R. 10 E., Lyon County
15	NENW sec. 9, T. 20 S., R. 10 E., Lyon County
16	SENW sec. 9, T. 20 S., R. 10 E., Lyon County
17	SESW sec. 14, T. 20 S., R. 10 E., Lyon County
18	SE sec. 25, T. 21 S., R. 9 E., Chase County
19	NNE sec. 21, T. 22 S., R. 10 E., Greenwood County
20	SWSE sec. 23, T. 23 S., R. 10 E., Greenwood County
21	NW sec. 5, T. 24 S., R. 10 E., Greenwood County
22	NENE sec. 36, T. 24 S., R. 9 E., Greenwood County
23	SW sec. 1, T. 26 S., R. 8 E., Greenwood County
24	SESE sec. 31, T. 26 S., R. 9 E., Greenwood County
25	NENW sec. 36, T. 27 S., R. 8 E., Greenwood County
26	SESW sec. 31, T. 27 S., R. 9 E., Greenwood County
27	NESE sec. 4, T. 28 S., R. 9 E., Greenwood County
28	SWNE sec. 23, T. 28 S., R. 9 E., Elk County
29	SWSW sec. 31, T. 28 S., R. 9 E., Elk County
30	NW sec. 18, T. 29 S., R. 9 E., Elk County
31	SW sec. 32, T. 29 S., R. 9 E., Elk County
32	NW sec. 20, T. 30 S., R. 9 E., Elk County
33	NWNW sec. 11, T. 31 S., R. 8 E., Elk County
34	NE sec. 13, T. 31 S., R. 8 E., Elk County
35	SESE sec. 21, T. 32 S., R. 8 E., Cowley County

Appendix F: Description of the lithology of the Hamlin Shale and Americus Limestone members (Wolfcampian) in Kansas

In this appendix I give a generalized summary of the lithologies of the Hamlin Shale Member of the Janesville Shale (Admire Group) and the Americus Limestone Member of the Foraker Limestone (Council Grove Group). The generalized stratigraphic column (fig. 1) shows the vertical relationships of these units to associated units; fig. 3 shows the stratigraphic position of interpreted stages of inundation by the epeiric sea. Appendix G provides detailed lithologic descriptions at individual localities.

Hamlin Shale Member

In general, less than 2 m (7 ft) of the upper part of the Hamlin Shale Member is exposed; however, outcrops displaying 4 m (13 ft) or more of Hamlin shale occur at localities 15 and 27, in Lyon and Greenwood counties, respectively. The Hamlin shale, although highly variable from locality to locality, is characterized by shales and terrigenous mudstones, thin, laterally discontinuous limestones, boxwork structures in the upper part, and a lime-sand mudstone to grainstone capped by a thin shale or terrigenous mudstone at the top.

Shale and terrigenous mudstones are the dominant rock types of the Hamlin Shale Member. The shales and terrigenous mudstones, typically tan, gray, white, brown, or orange, are either fissile or blocky and are commonly calcareous. A purple to red noncalcareous shale with dolomitic nodules occurs low in the section at locality 15 in Lyon County. Blocky terrigenous mudstones tend to be more numerous toward the top.

A white to tan lime mudstone or indurated claystone with pervasive boxwork structures occurs near the top of the Hamlin Shale Member at many localities. The boxwork structures are horizontal and vertical fractures filled with calcite cement that tend to weather in relief. These rocks are typically void of fossils and other detritus; however, disseminated quartz-silt grains are abundant within the boxwork mudstones at localities 25 and 29.

Thin, laterally discontinuous limestone beds are common in the upper Hamlin shale. A stromatolitic unit, 0.1 m (0.3 ft) thick, occurs 0.13 m (0.43 ft) below the top of the Hamlin shale at locality 1 in Wabaunsee County. The domal, cream-colored stromatolites are peloid-alga boundstones, and they display pervasive fenestrae filled with pink gypsum. A layer of brecciated stromatolites covers the in situ stromatolites. Laterally discontinuous beds of lime mudstone and wackestone, typically less than 0.1 m (0.3 ft) thick and generally containing peloids, ostracodes, or quartz silt, occur within 2 m (7 ft) of the top of the Hamlin at localities 2, 5, 6, 7, 9, 20, 27, 28, 29, and 31. These beds tend to be more numerous in the south, where they commonly display fenestral porosity, extensive in situ brecciation, and craze and joint fractures. The upper surface of a lime mudstone near the top of the Hamlin at locality 20 in Greenwood County displays a polygonal crack pattern. These thin limestones are either nonfossiliferous or contain a low-diversity fossil assemblage consisting of abundant ostracodes or, in some instances, rare gastropods. However, a wackestone [0.09 m (0.3 ft) thick] containing abundant *Calcivertella* foraminifers, bivalve fragments, ostracodes, and gastropods occurs just below the top of the Hamlin at locality 35 (the southernmost outcrop visited) in Cowley County. This wackestone, with its relatively high-diversity assemblage, is atypical of the Hamlin Shale Member.

The top of the Hamlin shale is typically marked by a distinctive orange rock, generally a lime-sand packstone or wackestone. This unit varies from an orange shale or terrigenous mudstone with a few sand-size lime grains to a conglomeratic lime-sand grainstone with mudstone lithoclasts of medium sand to pebble size. It varies in thickness from almost 0 to 0.3 m (1.0 ft) and is evidently not present at localities 29, 31, and 32. Crossbedding is generally observed where the unit is thick. Between-particle pore spaces are generally filled with orange terrigenous mudstone or by PE34 calcite cement. Ostracodes and well-rounded bivalve fragments are abundant to common, and *Gyrogonites* is typically present. Coal stringers, plant fragments, and petrified logs have been noted within this lime-sand rock at some northern localities (Bernasek, 1967; Fisher, 1980). The lower contact of this bed is abrupt and irregular, often with relief of 9 cm (4 in.).

At many localities a gray to orange shale, generally less than 1 cm (0.4 in.) thick, overlies the lime sand. This represents stage 2 in fig. 3. The remainder of the Hamlin shale represents stage 1.

Americus Limestone Member

The Americus Limestone Member generally consists of three limestones separated by shales. It ranges in thickness from 1.5 m (5 ft) at locality 1 in Wabaunsee County to 6 m (20 ft) at locality 23 in Greenwood County. The different subunits of the Americus change in thickness and, to some extent, in composition from locality to locality.

The lowermost bed of the Americus limestone, the focus of this study, is a white to tan limestone that ranges in thickness from 5 cm to 70 cm (2–28 in.) and pinches out north of Pottawatomie County. The upper surface and base of this limestone are relatively flat, except at localities 24, 25, and 27 in Greenwood County, where the base displays up to 0.36 m (1.2 ft) of relief. A stromatolite layer (fig. 3, stage 3) characterizes the base of this limestone at virtually all localities north of locality 28 in Elk County. These stromatolites are composed of peloid-alga boundstone. The peloids are irregularly shaped to oval and are generally coarse silt to fine sand sized. In thin section the peloids appear to float in PE32 calcite cement. Internal laminations are generally 1–6 mm (0.04–0.2 in.) thick. Typically, no grains other than peloids are incorporated in the boundstone layers. Exceptions are rare mollusk fragments, lime-sand grains, and palynomorphs.

Traces of algal filaments were noted in many samples. These traces occur in dense micritic laminae and appear in thin section as subtle horizontal threadlike features. The filaments, never longer than 0.5 mm (0.02 in.), have bright micritic hollow centers that are 0.02 mm (0.0008 in.) thick and dark micritic walls that are 0.01 mm (0.0004 in.) thick.

Rare pseudomorphs of evaporite crystals occur at locality 18 in Chase County. At localities 24 and 25 in Greenwood County, the stromatolite layer is brecciated and contains alveolar structures. The stromatolite layer ranges in thickness from 0.6 cm to 20 cm (0.2–8 in.) and displays a variety of morphologies, including thick horizontal-laminated to digitate layers, high domes, rip-up clasts, discontinuous patches with extensive fenestrae, and low-domed to flat layers. This stromatolite layer is typically encrusted with *Spirorbis* worm tubes, algae, and tubiform foraminifers [up to 19 cm (7.5 in.) thick at locality 27 in Greenwood County].

Two generations of encrustations are recognized. The first generation (fig. 3, stage 4) of encrustation includes *Spirorbis* worm tubes and incorporates tiny bivalves. The second generation of encrustation (fig. 3, part of stage 5) formed on the truncated upper surface of the first-generation encrustations. This second generation typically contains no *Spirorbis* worm tubes or bivalves. It consists of digitate growths of tubiform foraminifers and algae, incorporates bryozoans, and is typically penetrated by borings 3 mm (0.1 in.) in diameter.

Discrete plates [20 cm (8 in.) across and 5 cm (2 in.) thick] of *Spirorbis*-foraminifer-alga boundstone (fig. 3, included in stage 4) with fractured upper surfaces and pendant cements represent the lower limestone bed at its northern limits. The upper part of the lower limestone bed (fig. 3, stages 5 and 6; the lower contact of stage 6 is gradational and marked by the upward occurrence of typically normal-marine fossils) is laterally variable but is characterized by *Calcivertella* foraminifer- and ostracode-rich lime wackestones and packstones and peloid-intraclast wackestones to grainstones. Peloid mudstones occur at locality 5 in Lyon County and at localities 23 and 24 in Greenwood County. A lime-conglomerate–foraminifer–ostracode wackestone to packstone occurs at localities 29 and 32 in Elk County, and a foraminifer mudstone interlayered with foraminifer-brachiopod-gastropod wackestone with crinoid, bryozoan, and tiny bivalve fragments, sponges spicules, and ooid-coated grains occurs at locality 35 in Cowley County. Myalinid and pectinoid bivalves, productid brachiopods, crinoids, and a variety of foraminifers, including *Globivalvulina*, are abundant toward the top of the lower limestone at several locations.

Black, brown, and gray shale (fig. 3, stage 7), up to 2.5 m (8.2 ft) thick, overlies the lower limestone, except where the lower limestone coalesces with the middle limestone of the Americus at localities 1 and 4 in Wabaunsee County. This shale is generally fissile and calcareous and commonly displays orange and tan layers. Fisher (1980) reported sparse fragments of crinoids, brachiopods, and bivalves in this shale interval. An interbedded tan to orange sandstone and silty shale interval, 0.5 m (1.6 ft) thick, occurs in the middle of the shale at localities 20 and 21 in Greenwood County. The sandstone consists of very fine sand sized quartz grains, mica, few ostracode valves, and quartz cement in the pore spaces.

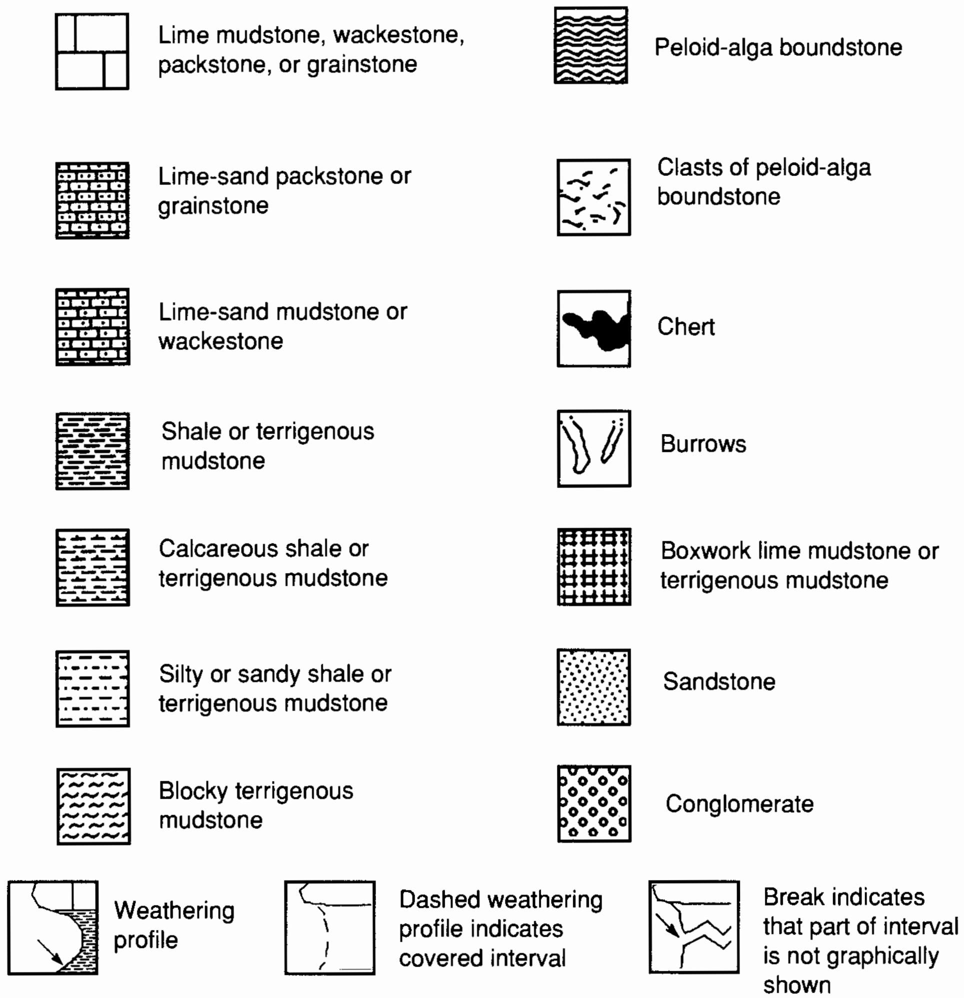
The middle limestone (fig. 3, stage 8) of the Americus Limestone Member is typically a gray crinoid wackestone, 0.3 m (1 ft) thick in the north to 0.76 m (2.5 ft) thick in the south. This resistant limestone, informally referred to by some researchers as the main ledge (Harbaugh and Demirmen, 1964), weathers into distinctive slabs. The upper surface is flat, whereas the base commonly displays relief of up to 0.23 m (0.75 ft). Typical fossils include crinoid debris, commonly with a diameter of 1 mm (0.04 in.); brachiopod fragments; fusulinid, *Nodosia*, and biserial foraminifers; bryozoans; bellerophontid gastropods; and rare trilobites. A packstone composed of abraded bellerophontid gastropods occurs at the base of the limestone at localities 12, 14, 16, and 17 in Lyon County. At locality 16 this gastropod packstone also contains abundant myalinid fragments, many granule-size, bored mudstone lithoclasts, and a few bryozoan fragments. Pink geodes of both quartz and calcite occur at locality 4 in Wabaunsee County. Chert containing abundant fusulinids is a common feature at most outcrops south of locality 25.

A gray to yellow calcareous shale or terrigenous mudstone (fig. 3, stage 7) typically separates the middle limestone from the upper limestone. This shale ranges in thickness from 0.07 m (0.2 ft) at locality 35 in Cowley County to 1.4 m (4.6 ft) at locality 12 in Lyon County. At several northern localities the upper part of this shale contains lenses of fusulinid packstone that may represent the poorly developed base of the upper limestone of the Americus.

The upper limestone (fig. 3, stage 8) of the Americus Limestone Member is generally less resistant and more laterally variable than the middle limestone. In the north the upper limestone varies in Wabaunsee County from a gray brachiopod-crinoid wackestone [0.11 m (0.36 ft) thick] with pink quartz geodes at locality 1 to a 0.52-m-thick (1.7-ft-thick) friable brachiopod wackestone with abundant whole brachiopods at locality 2. From locality 12 in Lyon County to locality 20 in Greenwood County, the upper bed is divided into an upper 0.25-m-thick (0.82-ft-thick) brachiopod mudstone; a 0.11-m-thick (0.36-ft-thick) silty shale; and a lower 0.1-m-thick (0.3-ft-thick) fusulinid packstone. At locality 23 in Greenwood County the upper bed is again two limestones: an upper 0.36-m-thick (1.2-ft-thick) cherty fusulinid wackestone and a lower 0.57-m-thick (1.9-ft-thick) cherty fusulinid-crinoid wackestone, separated by 0.2 m (0.7 ft) of calcareous shale with abundant fusulinids. South of locality 25, the upper limestone is a relatively resistant fusulinid wackestone [0.7 m (2 ft) thick] with a distinctive chert layer in the middle.

Appendix G: Selected measured sections

Explanation for Measured Sections



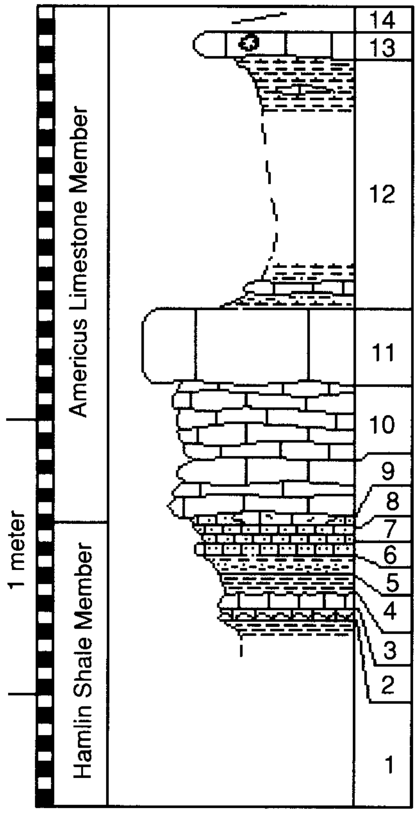
See fig. 2 for locations of outcrops

Classification References

Carbonate Rocks: Dunham (1962); see appendix A
Cement: Folk (1965); see appendix B
Porosity: Choquette and Pray (1970); see appendix C
Fractures: Freytet and Plaziat (1982); see appendix D

Relative Abundance

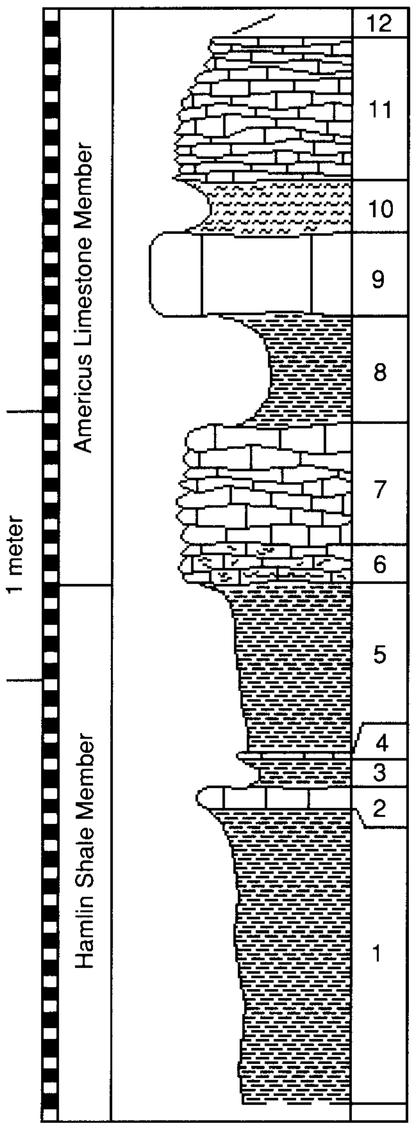
Abundant
Common
Many
Few
Rare



Outcrop 1—NESESE sec. 24, T. 12 S., R. 12 E., Wabaunsee County. Outcrop is south of pond on west side of road.	**Thickness** m	ft
14. Covered		
13. Crinoid wackestone, gray, with many brachiopods and few pink quartz geodes	0.11	0.36
12. Shale, calcareous, gray to yellow, with lenses of brachiopod wackestone, tan, with abundant *Neochonetes granulifer* brachiopods, common bivalve fragments, few crinoids and *Composita* brachiopods, and rare bryozoans and echinoid spines; covered in part	0.6	2.0
11. Crinoid wackestone, gray, with abundant tiny brachiopod fragments, common fusulinids, few *Nodosia* and biserial foraminifers,and rare bryozoans, *Bellerophon* gastropods, and trilobite fragments	0.28	0.92
10. Foraminifer–coated-shell-fragment wackestone, white, with abundant loose and encrusting *Calcivertella* foraminifers and tiny (0.5 mm thick and 1 mm long) bivalve and brachiopod fragments coated with foraminifer-alga boundstone, few ostracodes, and rare crinoids	0.27	0.89
9. Foraminifer-brachiopod packstone, white, with abundant loose *Calcivertella* foraminifers and tiny brachiopod fragments (not coated), common tiny phosphatic bone (?) fragments, many ostracodes, and rare bryozoan fragments	0.2	0.7
8. Peloid-ostracode packstone lenses, gray, with medium sand sized micritic peloids (10% of rock), abundant ostracodes and very fine sand sized quartz grains, many tiny (6 mm in diameter) intraclasts of dense micrite and peloid-alga boundstone, and few loose *Calcivertella* foraminifers; interbedded with lime-sand packstone, orange	0.05	0.2
7. Lime-sand packstone, orange, friable, with abundant fine to medium sand sized lime grains	0.03–0.05	0.1–0.2
6. Lime-sand grainstone, orange, with coarse sand sized lime grains (45% of rock), many granule- and pebble-size clasts of laminated peloid-alga boundstone, gray, and rare tiny bivalve fragments; between-particle pore spaces generally filled with PE34 calcite cement	0.03–0.05	0.1–0.2
5. Shale, orange, silty (?)	0.05	0.2
4. Shale, gray to brown, fissile	0.08	0.3
3. Lime-breccia wackestone, cream-white, with abundant brecciated (in situ?), flat and curved (fragments of stromatolite domes?), laminated mudstone fragments (4 × 6 mm, i.e., pebble size), possible root traces; pervasive horizontal joints or fenestral pores filled with PE3 calcite cement; abundant very fine sand sized quartz toward top; tiny boxwork features toward base	0.05	0.2
2. Peloid-alga boundstone, cream-white; laterally linked hemispheres and domes (4.5 cm wide and 3–4 cm high), composed of layers of peloid-alga boundstone	0.06	0.2

(Outcrop 1, continued)

		Thickness m	ft
	and dense micrite arched over brecciated micrite with pink gypsum crystals filling fracture pores		
1.	Shale, yellow		

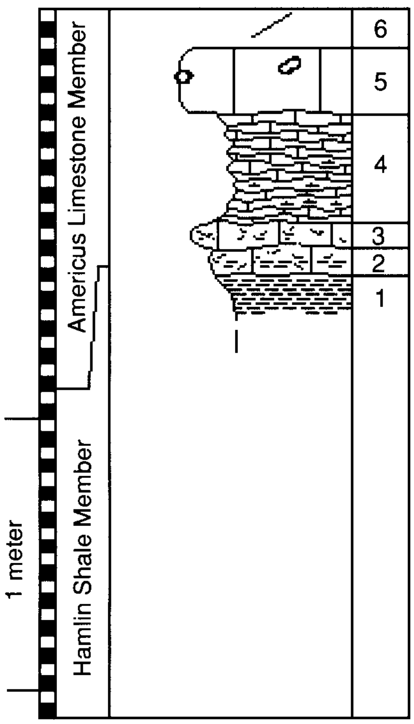


Outcrop 2—SWNENE sec. 21, T. 13 S., R. 12 E., Wabaunsee County. Outcrop is at end of road, west of destroyed bridge.

		m	ft
12.	Covered		
11.	Brachiopod wackestone, gray to white, friable, wavy bedded, with abundant brachiopod fragments and spines and whole *Neospirifer* and dictyoclostid brachiopods, common echinoid spines, few ostracodes and *Globivalvulina* foraminifers, and rare trilobite fragments; abundant *Neochonetes* and few *Composita* brachiopods occur near base	0.52	1.7
10.	Mudstone, blocky, terrigenous	0.2	0.7
9.	Crinoid wackestone, gray, with many brachiopods	0.31	1.0
8.	Shale, gray to tan, fissile	0.4	1.3
7.	Foraminifer wackestone, gray to white, wavy bedded, with abundant loose and encrusting *Calcivertella* foraminifers, common *Globivalvulina* and "Hobsonites–Z" foraminifers and ostracodes, many whole and fragmented pectinoid and myalinid bivalves, foraminifer-alga coated intraclasts of peloid-alga boundstone (1 mm thick and 5 mm long), crinoid fragments, and very fine sand sized quartz grains, few gastropods and brachiopod fragments, and rare echinoid spines	0.46	1.5
6.	Peloid-alga boundstone, gray; overlain by peloid-foraminifer-intraclast packstone, with micritic peloids (3–15%), loose *Calcivertella* foraminifers (15%), and clasts of peloid-alga boundstone and *Spirorbis*-foraminifer-alga boundstone (4%), common ostracodes, many tiny heart-shaped bivalves, few brachiopod fragments, and rare crinoids; underlain by same packstone with numerous orange shale stringers; intraclasts are fragments of peloid-alga boundstone and *Spirorbis*-foraminifer-alga boundstone and range in size from 1 mm in diameter to 2 × 6 cm chips; burrowed areas contain mudstone, gray, with many *Globivalvulina* foraminifers and rare scolecodonts (?); peloid-alga boundstone is a 1.5–2-cm-thick horizontal layer of peloid and micrite laminations, brecciated, laterally discontinuous, with 8-mm-thick irregular encrustation of *Spirorbis*-foraminifer-alga boundstone on upper surface	0.14	0.46
5.	Shale, tan to gray, fissile	0.65	2.1
4.	Peloid mudstone, laminated, with many very fine sand sized quartz grains and tiny bivalve fragments	0.02–0.03	0.07–0.1
3.	Shale, yellow to tan	0.06–0.1	0.2–0.3

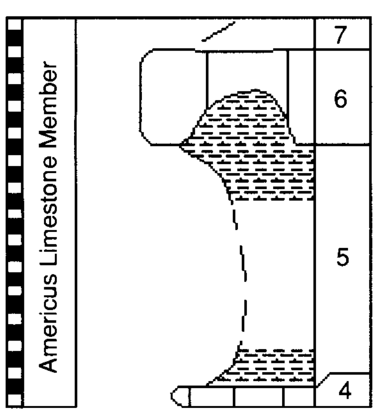
(Outcrop 2, continued)

		Thickness m	Thickness ft
2.	Quartz silt and sand wackestone, buff, with quartz silt and very fine grained sand (10% of rock)	0.09	0.3
1.	Shale, gray, tan, and buff in upper part, blocky (?); blue-gray, fissile in lower part	1.1+	3.6+



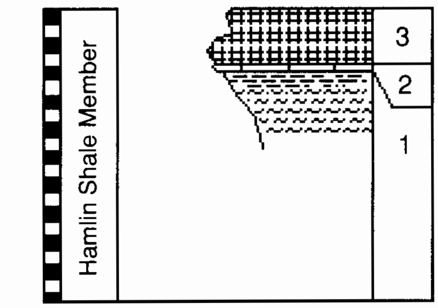
Outcrop 4—NWNW sec. 23, T. 14 S., R. 12 E., Wabaunsee County. Outcrop is in creek bed, 11 m (36 ft) upstream from small pond.

		m	ft
6.	Covered		
5.	Crinoid wackestone, gray, with few brachiopods and 10-cm-diameter pink geodes of quartz and calcite	0.25	0.82
4.	Foraminifer wackestone, shaly; grades into calcareous shale, gray, resistant	0.4	1.3
3.	Peloid-intraclast grainstone to packstone, tan, with fine sand sized micritic peloids (40%), intraclasts (4%), and fine sand sized quartz grains (2%), few loose *Calcivertella* foraminifers, and rare ostracodes, tiny bivalve fragments, and loose *Spirorbis* worm tubes; interbedded with 6-mm-thick layers of foraminifer-ostracode packstone and stringers of orange shale; intraclasts appear to be rip-up clasts of peloid-alga boundstone with an average size of 2 × 7 mm; clasts are either horizontally oriented or inclined at low angles; between-particle pore spaces generally filled with bright PE3 calcite cement	0.1	0.3
2.	Peloid–intraclast–quartz-sand wackestone, yellow, with fine sand sized micritic peloids (25%), very fine sand sized quartz grains (5%), and intraclasts of peloid-alga boundstone (5%), common *Calcivertella* foraminifers (some encrusted on micritic peloids) and ostracodes, and few gastropods and echinoid spines; interbedded with orange terrigenous mudstone laminations, which are more abundant toward base; between-particle pore spaces generally filled with micritic sediment	0.1	0.3
1.	Shale, yellow		



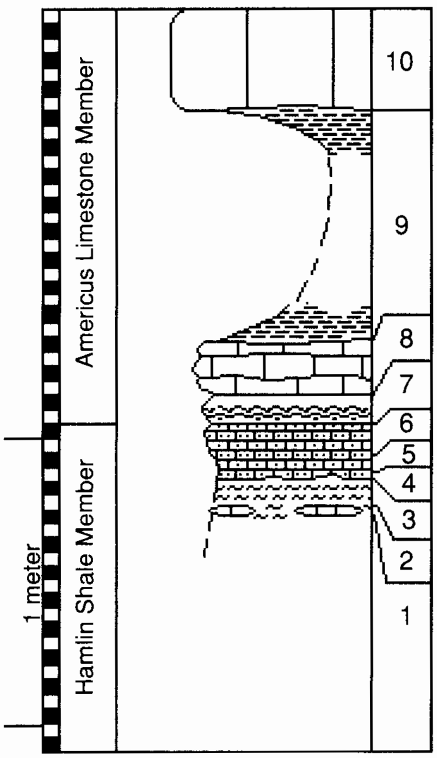
Outcrop 5—SWNW sec. 4, T. 16 S., R. 12 E., Lyon County. Outcrop is in a pasture on the west side of K–99.

		m	ft
7.	Covered		
6.	Crinoid wackestone, gray, with many brachiopods	0.12–0.35	0.39–1.1
5.	Shale, calcareous, to limestone, white, shaly, covered in part	0.9	3.0
4.	Peloid-ostracode mudstone, gray, with coarse sand sized micritic peloids (3%) and ostracodes (2%), few quartz silt, and rare loose *Spirorbis* worm tubes; pervasive burrow disruption; one 2-mm-thick burrow is filled with micritic sediment and PE34 calcite cement	0.08	0.3



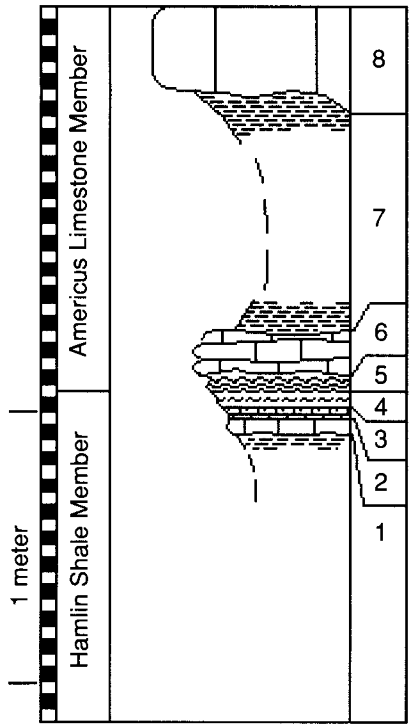
(Outcrop 5, continued)

		Thickness m	Thickness ft
3.	Boxwork mudstone, tan; some boxwork fractures display botryoidal PF–B32 cement	0.2	0.7
2.	Fenestral mudstone, with pervasive diagenetic disruption of laminations by cross-textural growth of PB56 calcite crystals	0.01	0.03
1.	Shale, yellow to tan at top; grades into mudstone, gray to white, blocky, terrigenous, with depth		

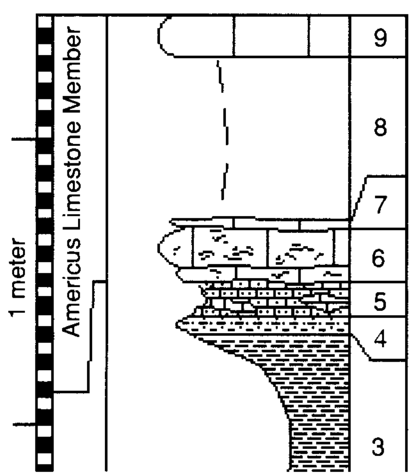


Outcrop 6—NWNW sec. 35, T. 16 S., R. 11 E., Lyon County. Outcrop is in pasture near stream.

		Thickness m	Thickness ft
10.	Crinoid wackestone, gray, with many brachiopods	0.35	1.1
9.	Shale, greenish-gray to tan, noncalcareous, covered in part	0.8	2.6
8.	Foraminifer-ostracode wackestone, gray to white, wavy bedded, with loose *Calcivertella* foraminifers (20%), abundant ostracodes, many very fine sand to silt sized quartz grains and bone (?) fragments, and few tiny bivalve fragments; between-particle pore spaces filled with micrite and PE32 calcite cement	0.2	0.7
7.	Peloid-alga boundstone, gray; within a foraminifer-ostracode wackestone with many bone (?) fragments; boundstone is 2.5-cm-thick peloid-alga sediment undulated into laterally linked, low-relief domes (8 cm wide, inner height of 1.5 cm); lower surface is irregular and brecciated with 3–5 mm of PE34 calcite cement separating the overlying boundstone from the underlying wackestone in geopetal fashion	0.1	0.3
6.	Lime-sand grainstone, orange, with coarse sand sized lime grains (45%), few ostracode fragments, and rare tiny bivalve fragments; grains typically display orange crust of PB23 calcite cement; between-particle pore spaces generally filled with PE34 calcite cement	0.11	0.36
5.	Lime-sand wackestone, orange, friable, with abundant medium sand sized lime grains; between-particle pore spaces generally filled with orange micritic mud	0.07	0.2
4.	Lime-sand grainstone, orange; same as unit 6	0.02	0.07
3.	Mudstone, light-gray, blocky, terrigenous	0.1+	0.3+
2.	Lenses of ostracode–peloid–quartz-silt wackestone, light-gray, with ostracodes (7%), peloids (4%), and quartz silt (2%); pervasive burrows (1 mm wide) filled with gray shale	0.02	0.07
1.	Mudstone, light-gray, blocky, terrigenous		

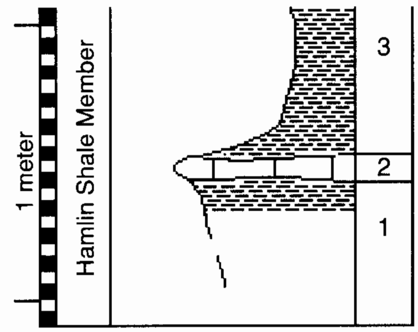


Outcrop 7—NENW sec. 21, T. 17 S., R. 11 E., Lyon County. Outcrop is in gully on south side of east-west road.	**Thickness** m	ft
8. Crinoid wackestone, gray, with abundant fusulinids and few brachiopod fragments	0.3–0.4	1.0–1.3
7. Shale, gray, covered in part	0.8	2.6
6. Bivalve-foraminifer wackestone to packstone, light-gray with dark-gray mottling, with abundant tiny (1 mm long) fragments (8%) coated with *Girvanella* algae and *Calcivertella* foraminifers, abundant loose *Calcivertella* foraminifers and tiny gastropods, common brachiopod fragments and ostracodes, many echinoderm fragments, few very fine sand sized quartz grains, and rare granule-size clasts of peloid-alga boundstone; between-particle pore spaces filled with micrite or PE3 calcite cement	0.13	0.43
5. Peloid-alga boundstone, dark-gray; upper surface encrusted with dense foraminifer-alga boundstone (2 mm thick), porous, with many *Spirorbis* worm tubes, outer edge eroded, draped by 0.5-mm-thick layer of tiny bone (?) fragments; overlain by foraminifer-ostracode packstone, light-gray, with abundant loose *Calcivertella* foraminifers and ostracodes, common gastropods, and rare crinoids (0.5 mm in diameter); peloid-alga boundstone is 2-cm-thick layer undulated into low-relief domes (9 cm wide, inner height of 1.5 cm); peloid-alga boundstone is a laminated peloidal sediment with dense micritic laminations displaying threadlike features thought to be traces of algal filaments	0.06	0.2
4. Mudstone, white to gray, blocky, terrigenous	0.06	0.2
3. Lime-sand wackestone, orange, friable	0.04	0.13
2. Quartz-silt mudstone, gray to white, with abundant (2%) quartz silt and rare ostracode fragments	0.06	0.2
1. Shale (?), covered		



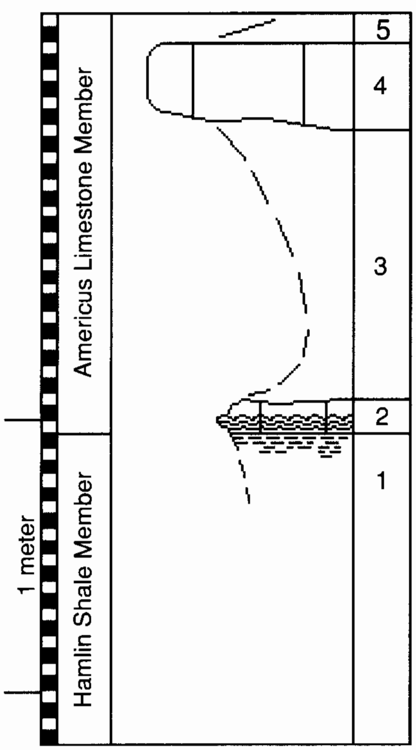
Outcrop 9—NENE sec. 26, T. 18 S., R. 10 E., Lyon County. Outcrop is at side of road on top of hill, south of the Neosho River.

9. Crinoid wackestone, gray	0.2	0.7
8. Covered	0.6	2.0
7. Foraminifer-ostracode packstone, white-gray, with loose *Calcivertella* foraminifers (15%) and ostracodes (4%), many quartz-silt grains and tiny bivalve fragments, and rare gastropods and tiny micritic intraclasts; some PE32 calcite cement in between-particle pore spaces	0.03	0.1
6. Intraclast-foraminifer-ostracode wackestone and packstone, light-gray; interbedded with shale containing 2% quartz silt and abundant medium lime sand; packstone and wackestone areas contain abundant loose *Calcivertella* foraminifers, ostracodes, and intraclasts, few crinoids (0.5 mm in diameter), and rare gastropods, brachiopod fragments, and bryozoan	0.19	0.62



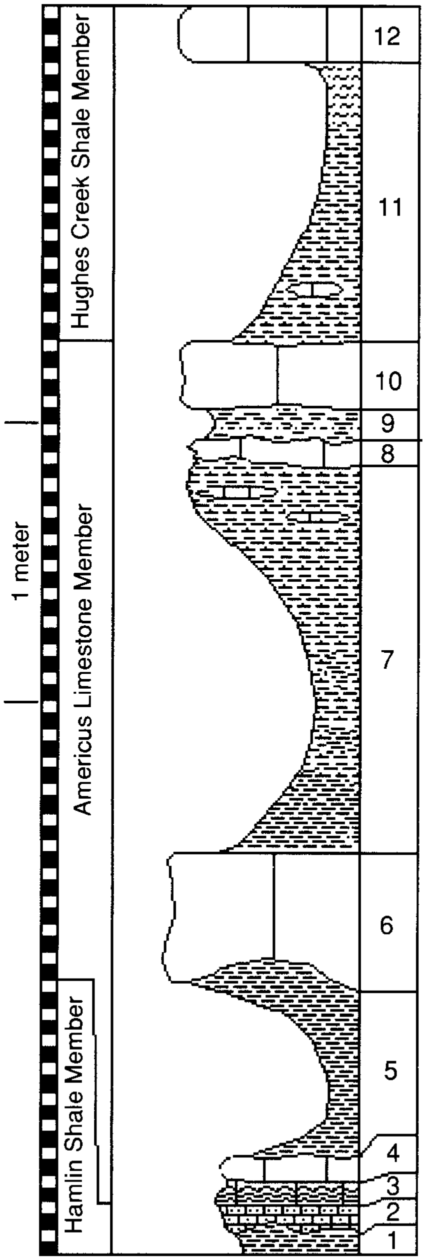
(Outcrop 9, continued)

		Thickness m	ft
	fragments; intraclasts range in size from 2 mm to 2 cm thick and are up to 20 cm long and are composed of peloid-alga boundstone with abundant 1–4-mm-thick encrustations of foraminifer-alga growths; clasts are horizontally situated or inclined at low angles and generally display brecciated, eroded edges		
5.	Lime-sand packstone, orange, with abundant ostracodes and tiny bivalve fragments and rare *Gyrogonites*; interbedded with lense of cream-colored mudstone	0.13	0.42
4.	Interlaminated quartz-silt wackestone and siltstone, calcareous, yellow, top tan, with medium-sized quartz silt	0.07	0.2
3.	Shale, gray to white	0.8	2.6
2.	Mudstone, buff, with common ostracodes and quartz silt, disrupted laminations	0.1	0.3
1.	Shale, gray to white		



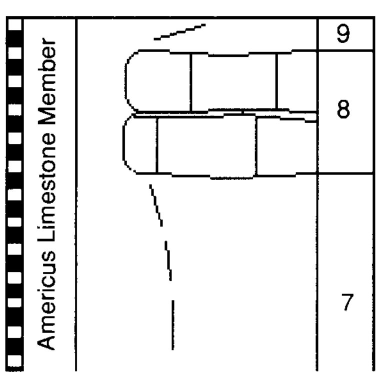
Outcrop 11—SENE sec. 24, T. 19 S., R. 9 E., Chase County. Outcrop is in ditch at side of road.

		m	ft
5.	Covered		
4.	Crinoid wackestone, gray, with abundant fusulinids toward top, many brachiopods	0.23–0.32	0.75–1.0
3.	Covered; contains abundant float (lenses?) of crinoid wackestone, gray, with abundant fusulinids and brachiopods	0.8	2.6
2.	Peloid-alga boundstone, gray to red-brown; upper surface encrusted with *Spirorbis*-foraminifer-alga boundstone (0.2–1 cm thick), porous, with eroded edges and truncated upper surface; overlain and underlain by foraminifer-ostracode packstone to wackestone, light-gray, with loose *Calcivertella* foraminifers (15%) and ostracodes (10%) and many very fine quartz sand grains and gastropods; upper part contains few crinoids and brachiopod fragments; lower part (underlying peloid-alga boundstone) contains tiny pebble-size intraclasts of peloid-alga boundstone and 4-mm-thick by 6-cm-wide peloid-alga (?) lenses; peloid-alga boundstone is 6 cm high, laterally linked, columnar to domal, flat topped, separated every 10 cm by channel rills (1 cm wide and 4 cm deep), with ragged edges; rills and larger pores generally filled with foraminifer-ostracode packstone; dark-gray shale to mudstone fills upper part of some large pores; domal features (2 cm inner height) visible only on basal surface of the 6-cm-thick layer of peloid-alga boundstone	0.1	0.3
1.	Shale, yellow to tan		



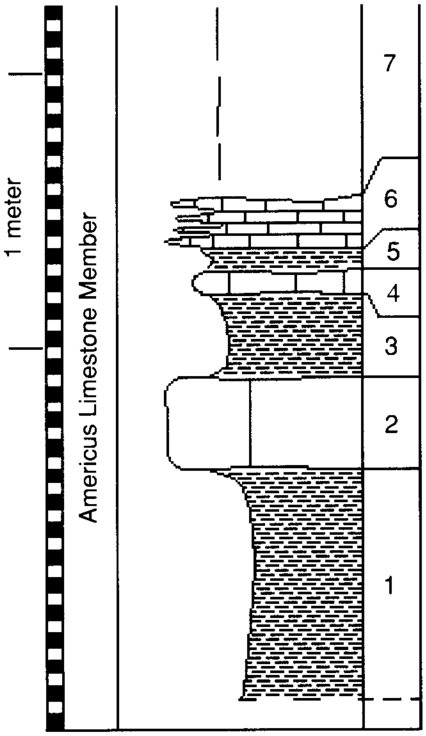
Outcrop 12—SWSW sec. 33, T. 19 S., R. 10 E., Lyon County. Excellent exposure along road, south of creek.

	Thickness m	Thickness ft
12. Fusulinid wackestone, gray, with many crinoids and brachiopod fragments	0.2	0.7
11. Shale (blocky, terrigenous mudstone), greenish-gray at top, to calcareous shale, tan, toward base, with abundant fusulinids; lenses of fusulinid packstone occur near base	1.0	3.3
10. Mudstone, gray, with few brachiopods	0.25	0.82
9. Shale, yellow, silty	0.11	0.36
8. Fusulinid packstone, light-gray	0.1	0.32
7. Shale, buff, calcareous, with pods of fusulinid packstone near top	1.4	4.6
6. Crinoid wackestone, gray, with abundant brachiopods and gastropods near base	0.4–0.5	1.3–1.6
5. Shale, gray at top, red and orange streaks in middle, tan in lower part, fissile	0.6	2.0
4. Quartz-sand–foraminifer wackestone (at top) to packstone (at base), light-gray, wavy bedded, with very fine to fine grained quartz sand (3%) and loose *Calcivertella* foraminifers (3%), abundant silt-sized brown organic particles (plants?), many ostracodes and bone (?) fragments, few brachiopod fragments and *Bradyina* foraminifers, and rare tiny bivalve fragments and crinoids; numerous gray shale partings	0.08–0.1	0.26–0.32
3. Peloid-alga boundstone, buff to orange at base; upper surface encrusted with 1-cm-thick foraminifer-alga boundstone, dense, porous, with abundant *Spirorbis* worm tubes; bisaccate palynomorph noted in a peloid lamination; peloid-alga boundstone has high domal features (6–7.5 cm high, 13–15 cm wide, inner height of 2–3 cm) and is internally composed of laminations of micritic peloids and micritic sediment with dark ribbons or threads (0.002 mm thick), assumed to be traces of algal filaments; domes overlie and cup cores of orange calcareous shale or terrigenous mudstone	0.07–0.15	0.23–0.49
2. Lime-sand packstone, orange, with medium sand sized lime grains (25%), few ostracodes, tiny bivalve fragments, and *Gyrogonites*, and rare tube-shaped gastropods; interlaminated at base with orange shale and mudstone	0.03–0.1	0.1–0.3
1. Shale, tan to gray		



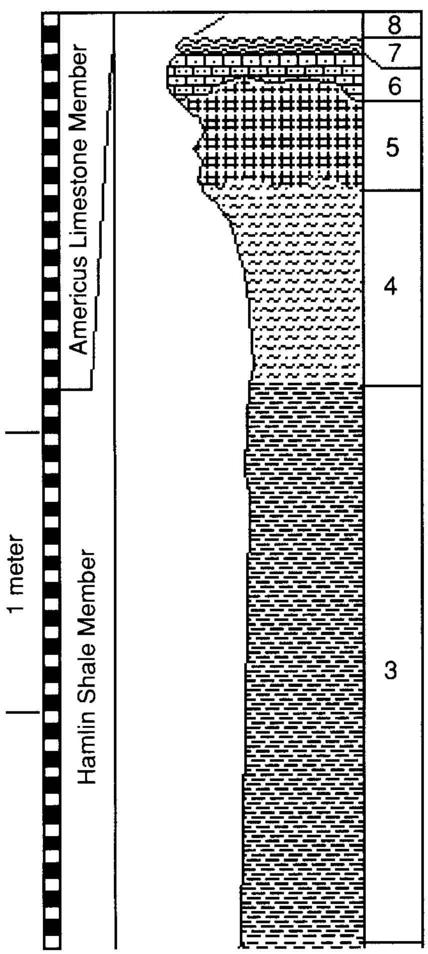
Outcrop 13—NW sec. 3, T. 20 S., R. 7 E., Chase County. Outcrop is at YMCA Camp Wood, in creek ravine northeast of lake.

	m	ft
9. Covered		
8. Fusulinid wackestone to packstone (almost a grainstone near base), gray, with abundant 1-mm bioclasts, many biserial foraminifers and ostracodes, few crinoids, coated grains, and brachiopod fragments, and rare trilobite fragments and dasyclad algae; brachiopods more abundant near base	0.44	1.4



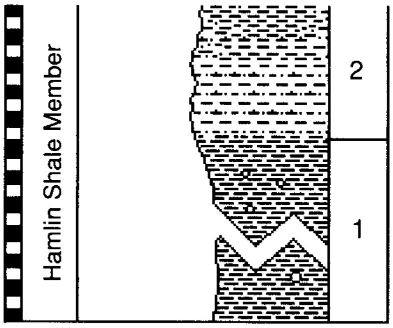
(Outcrop 13, continued)

	Thickness m	ft
7. Covered (shale, yellow?)	1.4	4.6
6. Brachiopod mudstone, tan, friable, platy, with few *Neochonetes* and dictyoclostid brachiopods and rare echinoderm, trilobite, and bryozoan fragments	0.2	0.7
5. Shale, yellow	0.08	0.3
4. Brachiopod packstone, greenish-gray to yellow-gray, with abundant *Neochonetes* and *Chonetina* brachiopods, many bryozoan and echinoderm fragments, few dictyoclostid brachiopods and bivalve fragments, and rare gastropod and trilobite fragments; a few brachiopod spines are encrusted with *Calcivertella* foraminifers	0.1	0.3
3. Shale, yellow to dark-gray at base, fissile	0.3	1.0
2. Fusulinid-bioclast packstone, gray, with abundant <1-mm-size bivalve clasts and fusulinids, common brachiopod fragments, many crinoids and biserial foraminifers, and few ostracodes and *Amphiscapha* gastropods; weathers into large resistant blocks	0.32	1.0
1. Shale, black, fissile; lower contact submerged below water line of creek	0.84	2.8



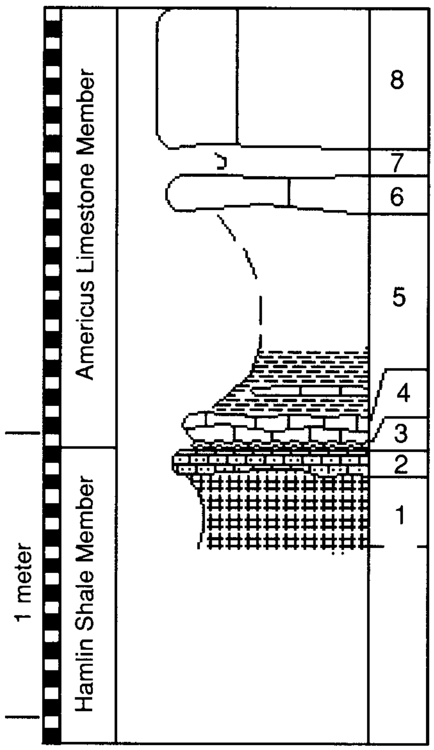
Outcrop 15—NENW sec. 9, T. 20 S., R. 10 E., Lyon County. Outcrop is in cutbank on south side of creek, about 90 m (300 ft) south of road.

	m	ft
8. Covered		
7. Peloid-alga boundstone, gray to buff; upper surface encrusted with 5-mm-thick foraminifer-alga boundstone, porous, with few *Spirorbis* worm tubes; overlain by foraminifer–ostracode–quartz-sand packstone to wackestone (a wackestone with brachiopod fragments and spines occurs 5 mm above boundstone), total thickness unknown; peloid-alga boundstone is 3.5-cm-thick undulated mats of laminated peloidal sediment, 22 cm wide, with low domal features (11 cm wide, inside height of 1 cm) on basal surface and curled-under edges; space beneath domes was filled with a shale, now weathered out	0.06	0.2
6. Lime-sand packstone, orange, crossbedded, with abundant coarse to medium sand sized lime grains (45%) and tiny bivalve fragments, many granule-size lime grains, and rare ostracodes; crossbeds at low angle and delineated by drapes of orange shale laminations; between-particle pore spaces filled with orange micritic material and PE5 calcite cement; grain-size distribution displays fining-upward trend; relief noted on basal surface	0.07–0.16	0.23–0.52
5. Boxwork mudstone, tan; rectangular fractures (mud cracks?) noted on upper surface; no fossils	0.32	1.0
4. Mudstone, tan to gray, blocky, terrigenous	0.7	2
3. Shale, gray, fissile	2	7



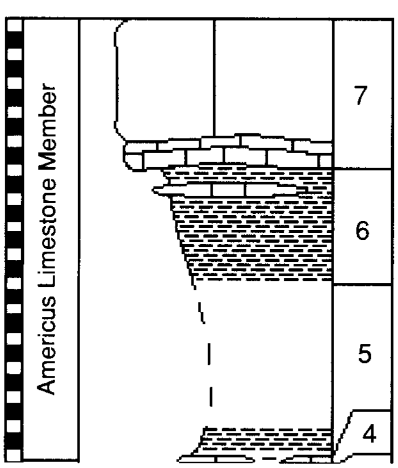
(Outcrop 15, continued)

		Thickness m	Thickness ft
2.	Ostracode–quartz-silt–peloid wackestone, gray, interlaminated with shale, green-gray; wackestone layers (5 mm thick) contain ostracodes (8%), coarse silt sized quartz grains (8%), and silt-sized micritic peloids (4%)	0.5	1.6
1.	Shale, purple to red, noncalcareous, with 3-cm-diameter dolomitic nodules	2.2	7.2



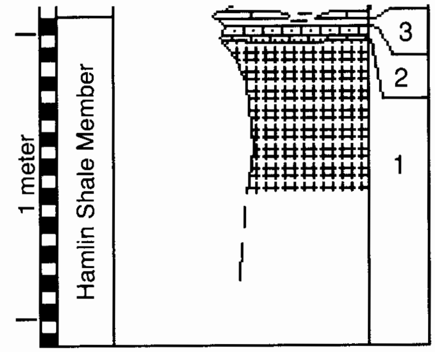
Outcrop 16—SENW sec. 9, T. 20 S., R. 10 E., Lyon County. Outcrop is along Kansas Turnpike I–35.

		m	ft
8.	Crinoid wackestone, gray, with common *Neospirifer* brachiopods; weathers to massive blocks	0.5	1.6
7.	Covered	0.1	0.3
6.	Bivalve-gastropod packstone, gray to yellow, with abundant myalinid bivalve fragments and *Bellerophon* gastropods, many granule-size mudstone lithoclasts (bored), few bryozoans, and rare red-algae fragments	0.1–0.14	0.33–0.46
5.	Covered; shale at base, tan to gray, with few limestone lenses	0.7	2.3
4.	Foraminifer–ostracode–quartz-sand packstone, light-gray, wavy bedded, with loose *Calcivertella* foraminifers (25%), ostracodes (3%), and very fine grained quartz sand (2%), many tiny gastropods, and few tiny bivalve fragments; between-particle pore spaces filled with both micritic and PE3 calcite spar	0.1	0.3
3.	Peloid-alga boundstone, gray at top to orange at base; upper surface encrusted with 3-mm-thick foraminifer-alga boundstone, porous, truncated, with a few *Spirorbis* worm tubes; peloid-alga boundstone has linked low-relief domes (3.5 cm high, inside height 1.5–2.5 cm) and is oval to bowling pin shape (6 cm wide and 12 cm long; long dimension trends N. 45° E.)	0.02–0.04	0.07–0.13
2.	Lime-sand packstone, orange, crossbedded	0.04–0.1	0.13–0.3
1.	Boxwork mudstone; covered at base		



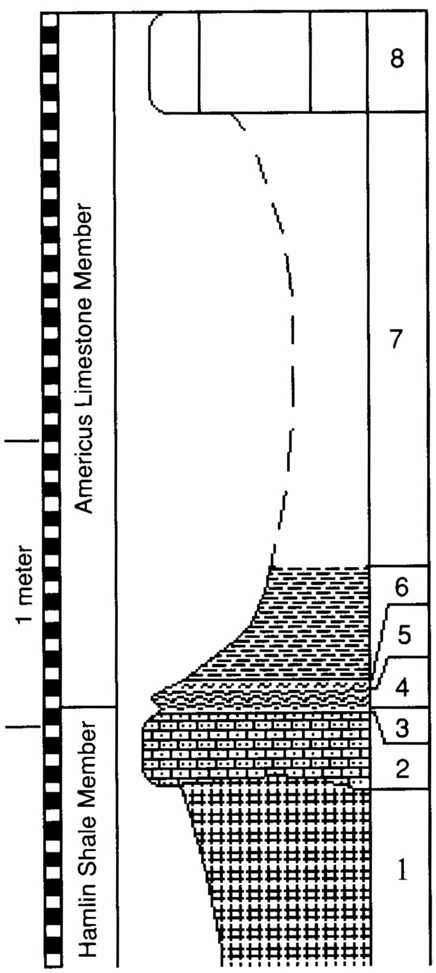
Outcrop 17—SESW sec. 14, T. 20 S., R. 10 E., Lyon County. Outcrop is at side of road.

		m	ft
7.	Crinoid wackestone, gray, with many brachiopods; wavy lamination of fossil fragments near base	0.53	1.7
6.	Shale, gray, with lenses of brachiopod wackestone near top; base covered	0.4	1.3
5.	Covered; shale at base, gray, fissile	0.6	2.0
4.	Peloid-alga boundstone, gray to orange, encrusted with rare patches of tiny (1 cm wide by 2 mm high) foraminifer-algal growths; overlain by 2-mm-thick drape of foraminifer–ostracode–quartz-silt–quartz-sand packstone, gray, with abundant loose *Calcivertella* foraminifers, ostracodes, bone (?) fragments, and quartz	0.02	0.07



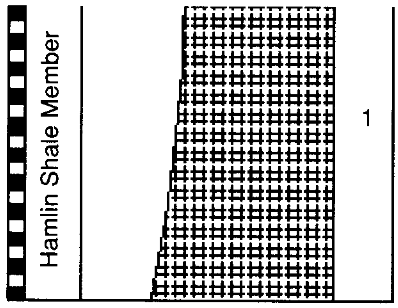
(Outcrop 17, continued)

		Thickness m	ft
	silt to fine-grained sand; overlies 2-mm-thick layer of interlaminated orange shale and peloidal mudstone; boundstone occurs in laterally discontinous flat mats (1–2 cm thick, 20 cm wide), oval in plan view, edges of mat curled under and back about 3 cm; upper 1 cm of boundstone contains horizontal fenestral pores filled with dirty PE4 or pendant PB–F43 calcite cement; upper surface displays parallel shallow grooves or troughs (oscillation ripples?), 5 mm deep with wave-length of 2 cm, long dimension trends N. 45° E.; basal surface displays low-relief (<4 mm) wavy pattern		
3.	Shale, tan to gray	0.02	0.07
2.	Lime-sand grainstone, orange, conglomeratic, with fine sand sized lime clasts (30%), abundant pebble-size lime clasts, many ostracode and tiny bivalve fragments, and rare gastropods and *Gyrogonites*; grains typically have orange PF23 calcite crust; between-particle pore spaces filled with PE3 calcite cement	0.05	0.16
1.	Boxwork mudstone, cream-gray to tan, friable, contains root (?) molds; covered toward base	0.5	1.6

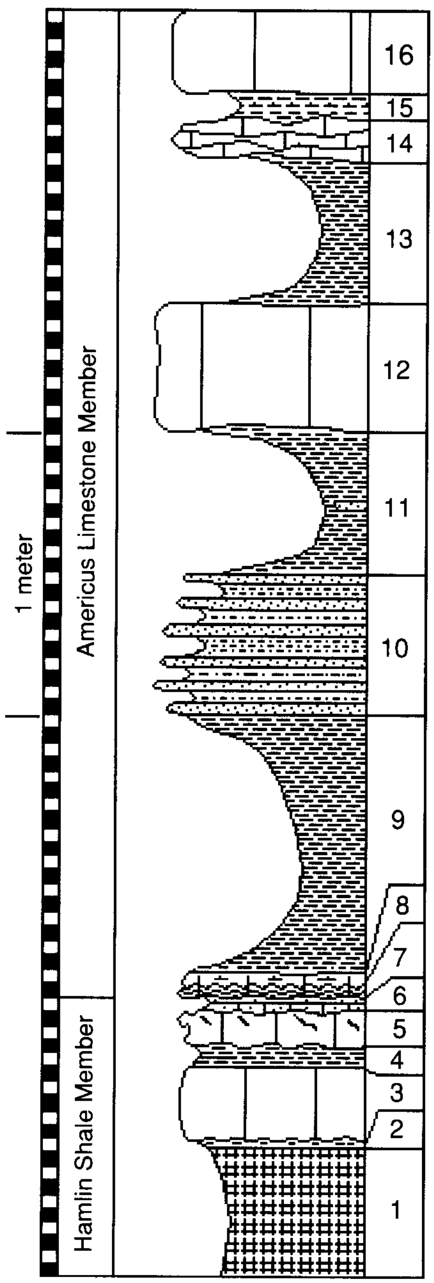


Outcrop 18—SE sec. 25, T. 21 S., R. 9 E., Chase County. Outcrop is on south bank of small creek.

		m	ft
8.	Crinoid wackestone, gray, with few brachiopods	0.36	1.2
7.	Covered	1.6	5.2
6.	Shale, gray and tan, laminated	0.4	1.3
5.	Mudstone, white, terrigenous, blocky	0.02	0.07
4.	Peloid-alga boundstone, gray to light-brown; encrusted with *Spirorbis*-foraminifer-alga boundstone growths, porous, 0.5–1 cm thick, upper part truncated; overlain by *Calcivertella* packstone, with abundant ostracodes and rare bryozoan fragments, gastropods, and *Gyrogonites*; overlies a 4-mm-thick wavy laminated mudstone; peloid-alga boundstone has total thickness of 1.5–2 cm, wavy-laminated in lower part with microcolumnar features (1 cm wide, 1.5 cm high) in upper part, typically linked toward top; troughs generally have ragged edges and are filled with ostracode packstone; some ragged pores may be current erosion features or pores enlarged by grazing metazoans; convex-up arc-shaped fenestral pores display lath-shaped calcite pseudomorphs after selenite (?)	0.07	0.2
3.	Mudstone, gray, terrigenous, blocky	0.01–0.08	0.03–0.3
2.	Lime-sand packstone, orange with yellow clasts, conglomeratic, with abundant medium sand sized to pebble-size lime grains, abundant tiny bivalve fragments and ostracodes, few tubular gastropods, and rare *Gyrogonites*; abundant mudstone stringers	0.27	0.89
1.	Boxwork mudstone, tan to gray, terrigenous	2.6+	8.5+

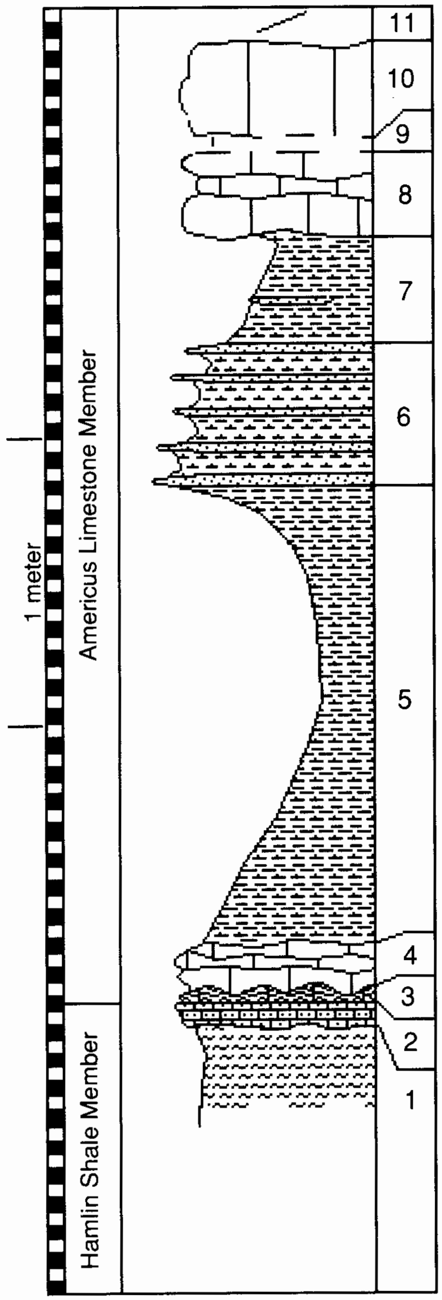


(Outcrop 18, continued)



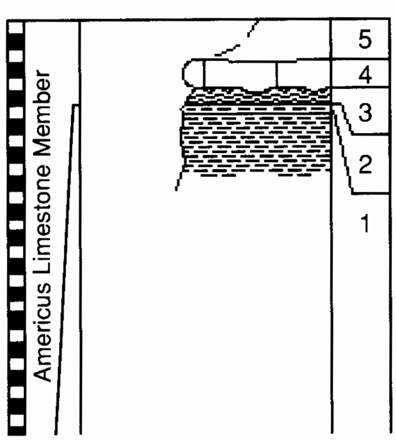
Outcrop 20—SWSE sec. 23, T. 23 S., R. 10 E., Greenwood County. Outcrop is along road on hill.

	Thickness m	ft
16. Crinoid-brachiopod wackestone, gray	0.3	1.0
15. Shale, gray, calcareous, with abundant *Neospirifer* brachiopods	0.1	0.3
14. Fusulinid packstone, wavy bedded	0.15	0.49
13. Shale, orange to tan	0.5	1.6
12. Crinoid wackestone, gray, with many bryozoan and brachiopod fragments	0.45	1.5
11. Shale, tan to orange, with rare thin beds of quartz sandstone	0.5	1.6
10. Interbedded quartz sandstone and silty shale, orange to tan, micaceous, with very fine sand (65%), common ostracode fragments, and horizontal laminations (8 mm thick)	0.5	1.6
9. Shale, orange, tan, purple-brown, and gray	0.9	3.0
8. Brachiopod wackestone, yellow, shaly, with abundant foraminifers and productid brachiopod fragments and spines, common crinoids, and few *Derbyia* brachiopods, gastropods, bryozoan fragments, and ostracodes; interlaminated with yellow calcareous shale	0.04	0.13
7. Peloid-alga boundstone, yellow-gray to yellow-orange at base; encrusted with 2-cm-thick *Spirorbis*-foraminifer-alga boundstone, porous, palmate to digitate; overlain by ostracode-*Calcivertella* wackestone to packstone, 2 cm thick, with calcareous shale stringers (one of which drapes top of boundstone) and quartz sand; overlies 8-mm-thick wavy-laminated quartz-silt mudstone; peloid-alga boundstone occurs in thin, flat mats (30 cm wide, 6 mm thick), horizontal to wavy bedded, with curled-under edges	0.06	0.2
6. Lime-sand wackestone, orange, friable, with abundant ostracodes, *Gyrogonites*, and tiny bivalve fragments	0.04	0.13
5. Mudstone, white, friable toward base, with rare tubular to ram's horn shaped gastropods; 2-cm-thick upper crust displays polygonal crack patterns	0.13	0.42
4. Mudstone, orange to gray, terrigenous, powdery	0.07	0.23
3. Mudstone, tan, brown, and gray, with pervasive skew planes and horizontal joint planes or fenestral pores	0.27	0.89
2. Mudstone, orange, terrigenous, powdery, with thin resistant domal structures (3 cm wide, 1 cm high) (algal boundstone lenses?)	0.02	0.07
1. Boxwork mudstone, tan to white, terrigenous		



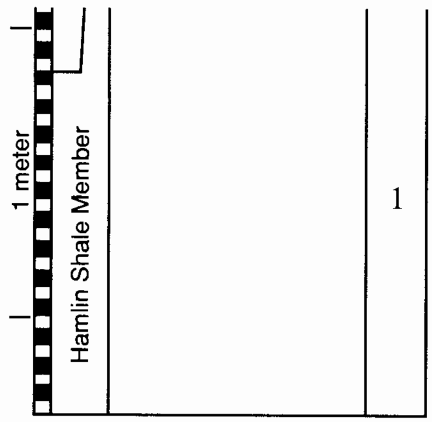
Outcrop 21—NW sec. 5, T. 24 S., R. 10 E., Greenwood County. Outcrop is in pasture along west side of stream.

	Thickness m	ft
11. Covered		
10. Crinoid wackestone, gray, with few fusulinids	0.33	1.1
9. Covered	0.05	0.16
8. Upper 0.05 m: Brachiopod wackestone, with abundant productid brachiopods and spines and tiny bivalve fragments, many very fine quartz-sand grains (2%), few bryozoan fragments; pervasive burrows filled with calcareous shale, dark-gray. Lower part: *Bellerophon*-brachiopod packstone, gray with yellow-stained areas, with rare fenestrate bryozoans; 1-cm gastropods and fragments of *Derbyia bennetti*? arranged in horizontal layers	0.29	0.95
7. Shale, yellow, calcareous, with rare thin lenses of very fine grained quartz sandstone	0.37	1.2
6. Quartz sandstone, yellow to tan, very fine grained sand (40%), micaceous, some quartz-silt grains, few ostracodes, quartz cement in between-particle pore spaces; layers about 1 cm thick interbedded with yellow calcareous shale	0.5	1.6
5. Shale, tan to gray, calcareous	1.6	5.2
4. Foraminifer-ostracode wackestone, white, with *Calcivertella* foraminifers (15%) and ostracodes (3%), common tiny bivalve and bone (?) fragments, few quartz-silt grains, gastropods, and bryozoan fragments, and rare tiny mudstone clasts	0.16	0.52
3. Peloid-alga boundstone, white to tan; upper surface encrusted with patches of 1-cm-thick porous *Spirorbis*-foraminifer-alga boundstone; peloid-alga boundstone occurs as linked domes, some fractured and flattened, oval outline in plan view (15 × 10 cm); dome height is 5 cm	0.03–0.06	0.1–0.2
2. Upper part: Quartz-silt shale, orange, calcareous, mudcracked, with many *Gyrogonites*. Lower part: Lime-sand wackestone, orange, conglomeratic, with abundant pebble-size clasts of white mudstone and coarse lime sand, common ostracodes and tiny bivalve fragments, and many tubular gastropod (?) fragments	0.08	0.3
1. Mudstone, gray to tan, terrigenous, blocky		



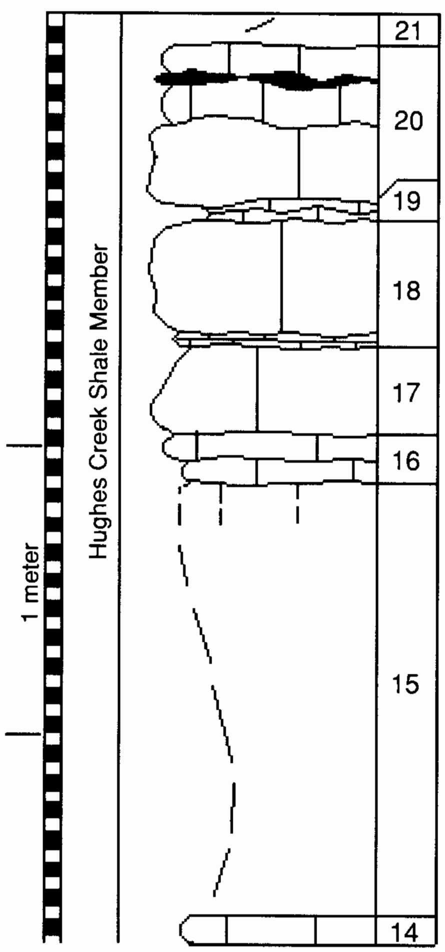
Outcrop 22—NENE sec. 36, T. 24 S., R. 9 E., Greenwood County. Outcrop is near top of hill on west side of road.

5. Covered; crinoid wackestone, gray, rubble at top of hill		
4. Bivalve-foraminifer wackestone to packstone, gray, with abundant bone (?) fragments, ostracodes, and loose *Calcivertella* foraminifers, few gastropods, and rare loose *Tetrataxis* foraminifers; tiny bivalve fragments (4 mm long), moldic, seem to have been from a thin-shelled bivalve, 5 mm long; loose foraminifers typically have arc-shaped base, suggesting earlier	0.1	0.3



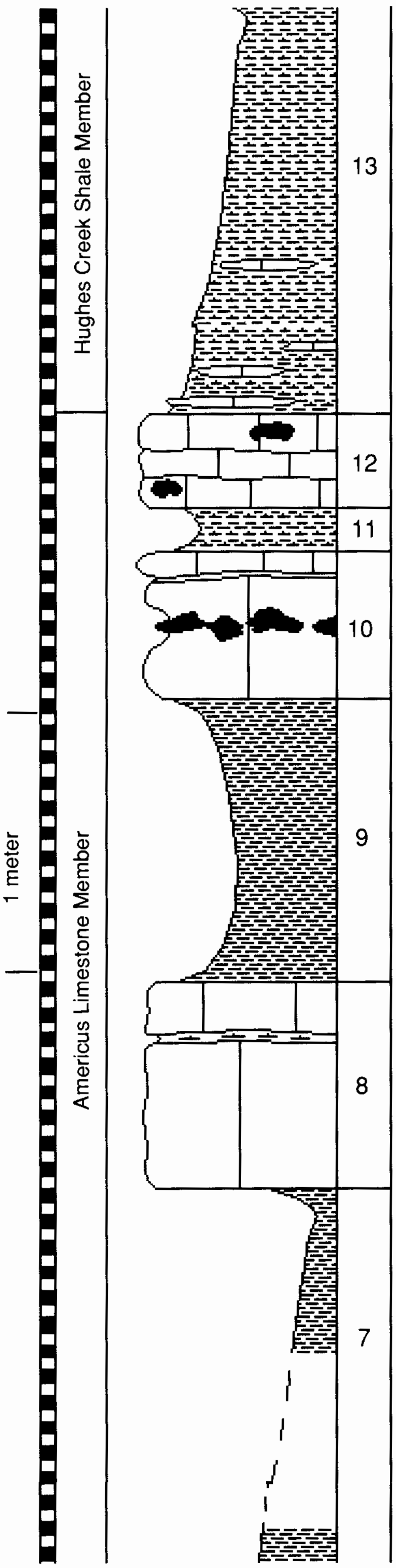
(Outcrop 22, continued)

	Description	Thickness m	Thickness ft
	encrustation on an object (aquatic vegetation?) with a diameter of 0.5 mm; tiny burrows filled with foraminifer mudstone		
3.	Peloid-alga boundstone, gray to tan, burrowed; overlain by drape of bone-gastropod-*Calcivertella* wackestone with abundant ostracodes, common bryozoan fragments, few quartz-silt grains, and rare tiny bivalve fragments; upper surface of peloid-alga boundstone encrusted with digitate growths (1 cm high, 2 cm wide) of foraminifer-alga boundstone, very porous, containing few *Spirorbis* worm tubes; peloid-alga boundstone occurs as tiny columns (2 cm wide by 3 cm high), typically separated by 4-mm-wide troughs and linked horizontally by laminations at top; troughs generally have ragged edges and are filled with ostracode-peloid wackestone, with gray mudstone just under linking laminations; tiny columns developed on wavy surface that delineates low domes (14 cm wide by 2 cm high)	0.07	0.2
2.	Lime-sand wackestone, orange; interlayered with shale, orange, calcareous	0.02	0.07
1.	Shale, gray		



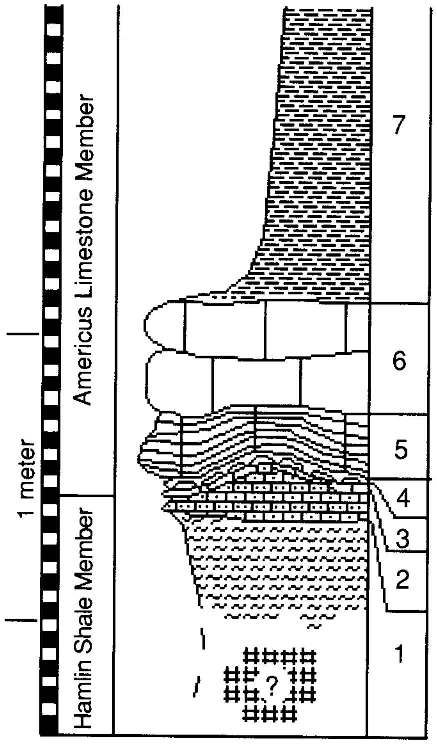
Outcrop 23—SW sec. 1, T. 26 S., R. 8 E., Greenwood County. Outcrop is between old and new US–54, west of Reese, Kansas.

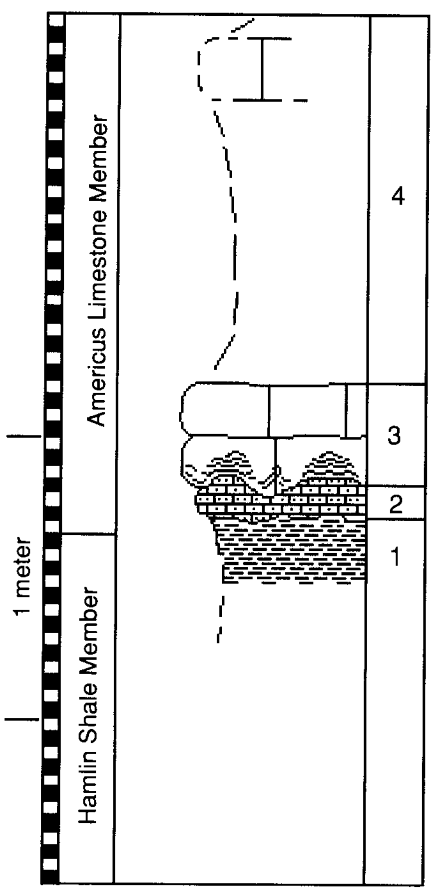
	Description	Thickness m	Thickness ft
21.	Covered		
20.	Fusulinid wackestone, gray, cherty, with abundant fusulinids, few crinoids, rare solitary corals; lenticular chert layer near top	0.56	1.8
19.	Fusulinid mudstone, gray, platy	0.06	0.2
18.	Crinoid wackestone, dark-gray, rare fusulinids; crinoid diameter 1–5 mm	0.39	1.3
17.	Fusulinid-gastropod wackestone, gray; abundant bellerophontid gastropods near base	0.3	1.0
16.	Mudstone, gray, shaly, with abundant fusulinids and crinoids	0.18	0.59
15.	Covered interval with 0.03 m of fusulinid mudstone exposed near top	1.5	4.9
14.	Gastropod wackestone, yellowish-gray, with abundant bellerophontid gastropods	0.11	0.36
13.	Shale, yellow, calcareous, with lenses of brachiopod-crinoid wackestone, yellow, burrowed, with abundant *Derbyia* brachiopods and fenestrate bryozoans, few ostracodes, and rare mobile foraminifers	1.6	5.2
12.	Fusulinid wackestone, gray, cherty, with abundant fusulinids in upper part and abundant 1-mm-diameter crinoids	0.36	1.2
11.	Shale, yellow, calcareous, with abundant fusulinids	0.18	0.59
10.	Fusulinid-crinoid wackestone, gray, cherty, with bedded chert in middle of bed	0.57	1.9



(Outcrop 23, continued)

		Thickness m	ft
9.	Shale, yellow and black, fissile	1.1	3.6
8.	Crinoid wackestone, gray, with abundant 1-mm-diameter crinoids and common 1-cm-diameter crinoids; calcareous shale parting occurs 0.16 m from top	0.8	2.6
7.	Shale, yellow and gray	2.54	8.33
6.	Foraminifer wackestone to mudstone, whitish-gray, burrowed, with abundant *Calcivertella* foraminifers (8%), productid brachiopod fragments and spines, and ostracodes, many crinoid fragments and gastropods, and few *Globivalvulina* and *Nodasaria* foraminifers; tiny bivalve fragments abundant in upper 2 cm; gastropods and crinoids become rare toward base; burrows (4 mm in diameter) filled with foraminifer mudstone	0.31	1.0
5.	Peloid–quartz-silt mudstone to wackestone, light-gray, planar bedded, no fossils, ripple laminated; micritic peloids up to 30% of rock; wavy base; 5-mm-thick horizontal layers display fining-upward trend in peloid size from fine-grained sand to coarse-grained silt	0.15–0.22	0.49–0.72
4.	Peloid–quartz-silt mudstone and boundstone, light-brown; mudstone contains few ostracodes and tiny bivalve fragments and, toward top, abundant quartz silt; boundstone occurs as 21-cm-long, 10-cm-wide, 2-cm-thick plates with curled-under edges; plates contain 2-cm-wide hemispherical mounds with turned-down edges, suggestive of algal growth; tiny mound features are made of peloid mudstone and contain no laminations or other internal features (such as thread-like tubes or between-peloid spar) typically seen elsewhere in peloid-alga boundstone	0.01–0.03	0.03–0.10
3.	Peloid–quartz-silt wackestone, yellow to orange, with many tiny bivalve fragments and ostracodes, horizontal joint cracks	0.02	0.07
2.	Lime-sand–bivalve packstone to grainstone, orange, with coarse to fine sand sized lime grains (40%), tiny bivalve fragments, common ostracodes, few *Gyrogonites*, and rare fine quartz-sand grains; grains display PE1 crust; between-particle pore spaces filled with PE34 spar cement	0.1	0.3
1.	Mudstone, yellow to tan, terrigenous, blocky; lower part covered but float indicates boxwork terrigenous mudstone		





(Outcrop 23, continued)

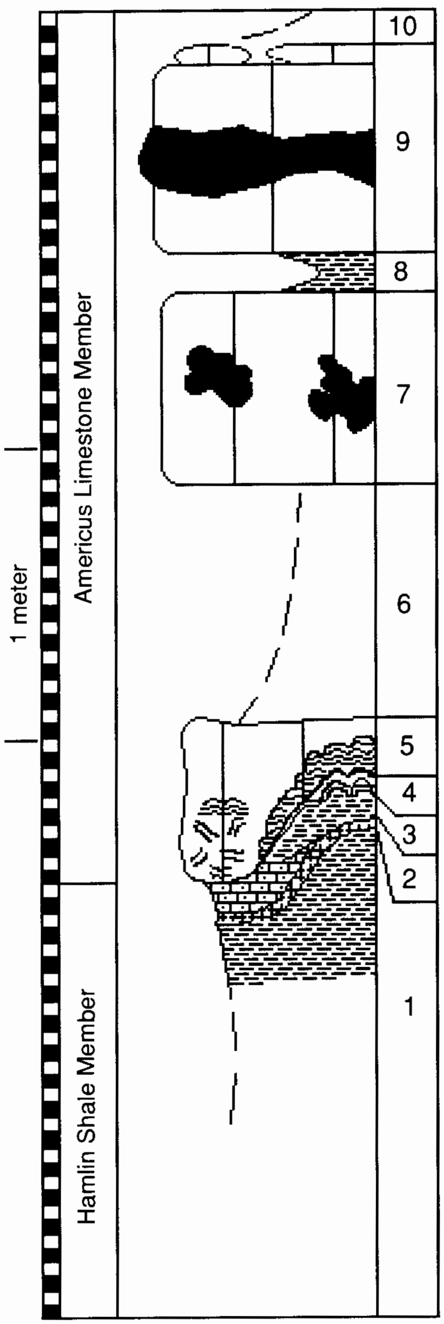
	Thickness m	Thickness ft

Outcrop 24—SESE sec. 31, T. 26 S., R. 9 E., Greenwood County. Poor exposure along road.

	m	ft
4. Covered, with large blocks of crinoid wackestone, gray, at top of hill, 1 m above unit 3		
3. Upper 0.19 m: Brachiopod-bivalve-foraminifer wackestone, gray, with abundant productid brachiopods, *Myalina* (?) and pectinoid bivalves, and loose *Calcivertella* and *Globivalvulina* foraminifers, many crinoid fragments, and few ostracodes, gastropods, and fenestrate bryozoans. Lower 0.18 m: Peloid-alga boundstone, gray, with in situ brecciation and partially ripped up clasts, laterally transitional with intraclast–lime-sand wackestone, yellow, orange, and brown, with abundant broken *Spirorbis* tubes, tiny bivalve fragments, and ostracodes and rare foraminifer-algal oncolites, bryozoan fragments, and *Gyrogonites*; intraclasts consist of peloid-alga boundstone, typically with a subsequent peloid-algal encrustation; directly overlying peloid-alga boundstone is peloid-*Syzrania* (foraminifer) wackestone to mudstone, dark-gray, with rip-up clasts of peloid-alga boundstone and small burrows filled with wackestone from above; peloid-alga boundstone overlies thin layer of ostracode–quartz-sand–lime-sand wackestone to mudstone, orange, with few tiny bivalve fragments; boundstone occurs as tall domes (3 cm high, 4.5 cm wide), overlain by 3-cm-thick disrupted horizontal layers; layers incorporate fine lime sand, tiny bivalves, and ostracodes in addition to silt-size micritic peloids typically found elsewhere in peloid-alga boundstone	0.37	1.2
2. Lime sand to pebble–quartz-silt packstone, orange, with abundant tiny bivalve fragments, many ostracodes, few *Spirorbis* tubes, and rare *Gyrogonites*	0.11	0.36

(Outcrop 24, continued)

		Thickness m	ft
1.	Shale, gray to yellow		

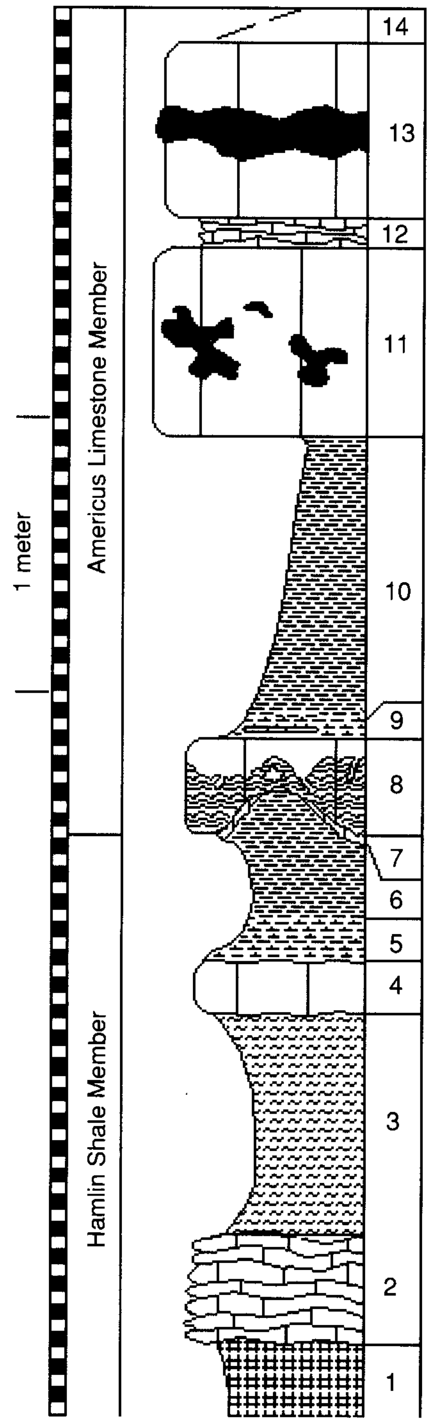


Outcrop 25—NENW sec. 36, T. 27 S., R. 8 E., Greenwood County. Outcrop is on west side of road on north side of ravine.

		m	ft
10.	Covered		
9.	Fusulinid wackestone, gray, cherty, with rare crinoids; chert bed in middle	0.72	2.4
8.	Shale, gray, fissile	0.14	0.46
7.	Crinoid wackestone, gray, cherty; crinoid diameter averages 1.5 mm; cherty areas contain common fusulinids	0.66	2.2
6.	Covered (shale?)	0.8	2.6
5.	Upper part: Foraminifer-bivalve wackestone, gray, with abundant loose *Calcivertella* and *Globivalvulina* foraminifers, large myalinid bivalves, and bryozoans, many brachiopod and echinoderm fragments, and few gastropods; infiltrated into pores within underlying boundstone; patches of bioclastic packstone present; bivalves are moldic and display pendant PB5 cement. Lower two-thirds: Peloid-alga boundstone, yellow-gray, with 3–11-cm-thick brecciated laminae and erosion (?) enlarged pores; joint cracks and alveolar structures abundant in lower part; pores filled with upper-part wackestone and with ostracode-gastropod-*Calcivertella* wackestone; boundstone is digitate in upper part to lamellar toward base; digitate structures best developed on topographic highs delineated by basal contact of bed; rip-up clasts of boundstone numerous in base of apparent troughs within bed; upper surface and edges of some pores within boundstone encrusted with two generations of *Spirorbis*-foraminifer-alga boundstone growths; first generation contains abundant *Spirorbis* tubes and few tiny bivalves enmeshed within foraminifer-algal growths, occurs on upper surface and on edges of larger pores, and is truncated on upper surface; second generation occurs as lamellar to digitate patches of foraminifer-algal growths (6 cm wide and 3 cm high), is bored, and contains few *Spirorbis* worm tubes	0.2–0.56	0.7–1.8
4.	Quartz-sand–quartz-silt–peloid wackestone, orange-yellow, current rippled, 2.5 cm thick, with abundant ostracodes and tiny bivalve fragments and rare *Gyrogonites*; quartz grain distribution shows fining-upward trend from silt to very fine grained sand; quartz grains make up 5% of rock; overlies quartz-silt–ostracode mudstone to boundstone with disrupted laminae and joint cracks; boundstone occurs as high oval domes (10–14 cm wide, 7 cm high); domes observed only at top of paleotopographic highs, as indicated by relief in base of unit 5	0.0–0.07	0.0–0.2

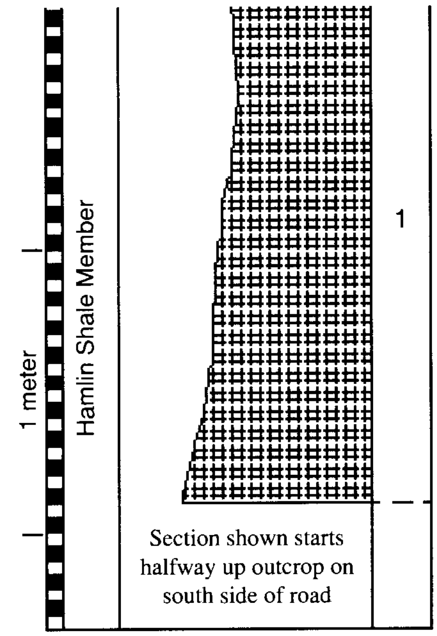
(Outcrop 25, continued)

		Thickness m	Thickness ft
3.	Shale, gray, to lime-sand mudstone, orange; shale occurs on highs under domal boundstone of unit 4; mudstone is thicker facies of unit 3 and occurs beneath troughs of unit 5	0.07–0.15	0.2–0.49
2.	Boxwork mudstone, tan, with abundant quartz silt and joint cracks	0.03	0.1
1.	Shale, brown, base covered		



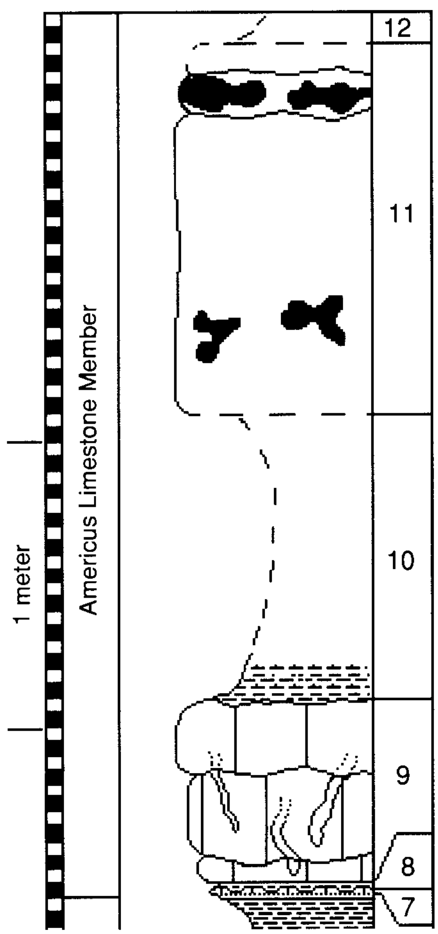
Outcrop 27—NESE sec. 4, T. 28 S., R. 9 E., Greenwood County. Outcrop is on both sides of K–96, west of Piedmont, Kansas.

		m	ft
14.	Covered to top of hill		
13.	Wackestone, gray, cherty, skeletal, with abundant fusulinids, common large crinoids, few brachiopods; chert layer in middle contains abundant fusulinids	0.64	2.1
12.	Fusulinid packstone to wackestone, gray, platy	0.11	0.36
11.	Crinoid wackestone, gray, cherty, with abundant fusulinids in lower part	0.68	2.2
10.	Shale, black and brown, tan near top, fissile	0.9	3.0
9.	Interlayered shale, tan, and mudstone lenses, gray; lenses 3 mm thick	0.2	0.7
8.	Upper part: Bivalve-foraminifer wackestone to mudstone, gray, with abundant pectinoid (*Clavicosta*?) bivalves and loose *Calcivertella* foraminifers, common crinoid and bryozoan fragments, and rare gastropods and *Globivalvulina* foraminifers; fills pore spaces in underlying boundstone; toward top is <1-cm-thick discontinuous layer of skeletal packstone with abundant echinoid spines, crinoids, ostracodes, *Calcivertella*, and bivalve fragments. Lower two-thirds: Peloid-alga boundstone, yellow, 15–20 cm thick, brecciated, joint cracked, with pervasive erosion-enlarged pores and truncated upper surface; occurs as wavy, linked, hemispherical to horizontal laminations; on upper surface and in some pore walls are encrustations of foraminifer-alga boundstone and *Spirorbis*-foraminifer-alga boundstone; latter boundstone encrustations are 3–15 cm thick, truncated, contain enmeshed tiny bivalves, and are encrusted with digitate foraminifer-alga boundstone patches up to 4 cm thick; uppermost part of digitate foraminifer-algal growths are bored and contain enmeshed bryozoans; base shows maximum relief of 0.16 m	0.18–0.34	0.59–1.1
7.	Mudstone, orange, friable, with abundant tiny bivalve fragments, common phosphatic bone (?) fragments, few medium-size lime-sand and quartz-silt grains, and rare ostracodes and *Gyrogonites*	0.0–0.04	0.0–0.13
6.	Shale, brown, noncalcareous, fissile	0.3	1.0
5.	Shale, white to gray, calcareous, fissile	0.14	0.46
4.	Mudstone, white to tan, fractured, with rare ostracodes and pervasive horizontal joint cracks	0.2	0.7



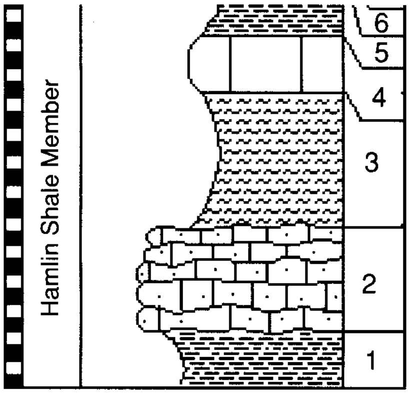
(Outcrop 27, continued)

	Thickness m	ft
3. Mudstone, white to gray, terrigenous, blocky	0.8	2.6
2. Mudstone, tan to brown, friable, with pervasive horizontal fenestrae or joint cracks and vague horizontal laminations (algal?)	0.4	1.3
1. Boxwork mudstone, gray to tan, terrigenous, blocky	2.0+	6.6+



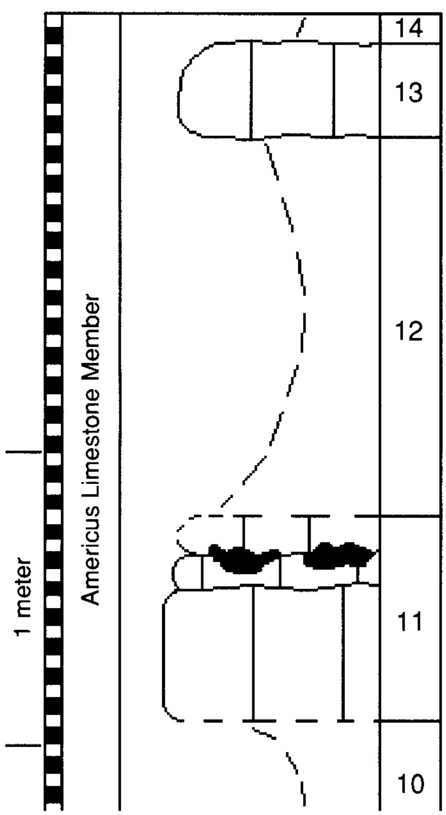
Outcrop 28—SWNE sec. 23, T. 28 S., R. 9 E., Elk County. Outcrop is on hill on north side of road.

	m	ft
12. Covered		
11. Fusulinid-crinoid wackestone, gray, cherty; crinoids 1–5 mm in diameter; dark chert layer with fusulinids near top	1.3	4.3
10. Covered; dug to expose shale, brown, fissile, near base	1.0	3.3
9. Upper 0.25 m: Brachiopod-bivalve-foraminifer wackestone, gray, with abundant brachiopods (15%) (*Linoproductus*, *Derbyia bennetti*, dictyoclostids), pectinoid and myalinid bivalves, loose *Calcivertella* and *Globivalvulina* foraminifers (2%), fenestrate bryozoans, gastropods, echinoid fragments and spines, and peloids and few quartz-silt grains. Lower 0.39 m: Bivalve-foraminifer-gastropod wackestone to packstone, gray, burrowed, with abundant *Calcivertella*, *Globivalvulina*, and *Syzrania* foraminifers (5%), common brachiopod fragments, many crinoid fragments, few ostracodes, bryozoan fragments, and very fine grained quartz sand, and rare *Ammobaculites* foraminifers and *Spirorbis* worm tube fragments; bivalves are tiny fragments (10%); burrows (2 cm in diameter) filled with mudstone containing less fossils; tiny bivalve and brachiopod fragments decrease in abundance toward base; gastropods increase in abundance toward base	0.64	2.1
8. Shale, dark-gray, fissile	0.02	0.07
7. Peloid-alga boundstone, yellow-gray at top to orange at base, with very fine grained lime sand, tiny bivalve fragments, and interlaminated quartz-silt shale partings; occurs as flat mat at least 20 cm wide and 2 cm thick, with edges curled under; internally has undulated laminations forming low, linked hemispheres (5 mm high and 2 cm wide); upper surface encrusted with	0.02	0.07



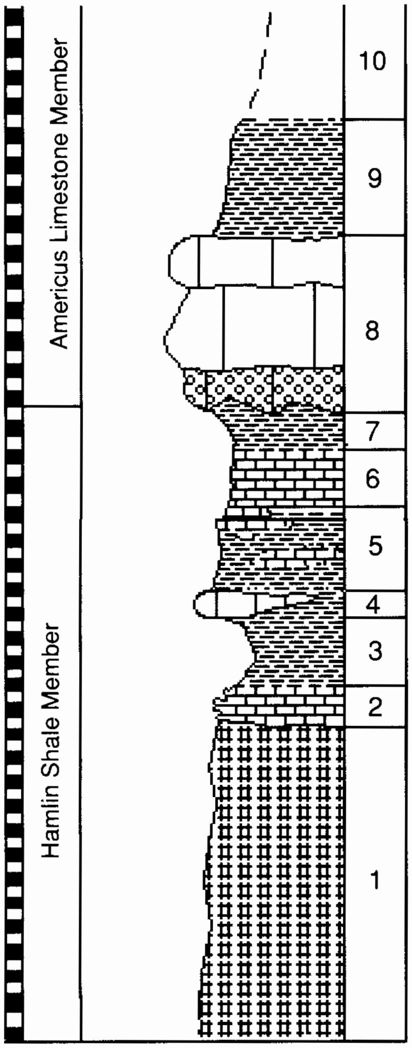
(Outcrop 28, continued)

		Thickness m	ft
	patches of foraminifer-algal growths (4 mm high and 2 cm wide); overlain by drape of muddy ostracode-echinoderm wackestone with common bone, mollusk, and bryozoan fragments and few *Calcivertella* foraminifers and brachiopod fragments; overlies quartz-silt–peloid–lime-sand wackestone layer (1.5 mm thick), orange, with tiny bivalve fragments and wavy laminations		
6.	Peloid–lime-sand–quartz-sand–quartz-silt packstone (possibly with some boundstone laminations), orange-yellow, with abundant tiny bivalve fragments, many ostracodes, and rare *Gyrogonites*; peloids (30%) are irregular, brown, silt-size; lime sand makes up 7% and quartz grains 5% of rock; base of layer displays convex-up plates (6 × 3 × 0.3 cm) suggestive of desiccation polygons in algal laminated sediment	0.01	0.03
5.	Shale, tan-brown	0.2	0.7
4.	Ostracode-peloid wackestone, tan, with abundant quartz silt; ostracodes (5–10%) are thin shelled; peloids (3%) are micritic and fine sand sized	0.2	0.7
3.	Mudstone, gray, terrigenous, blocky	0.45	1.5
2.	Peloid–lime-sand wackestone, orange-tan, muddy, laminated, with rare horizontal joint cracks or fenestrae; peloids (10%) are very fine sand sized; lime sand (5–25%) is fine sand sized	0.35	1.1
1.	Shale, yellow; base covered		



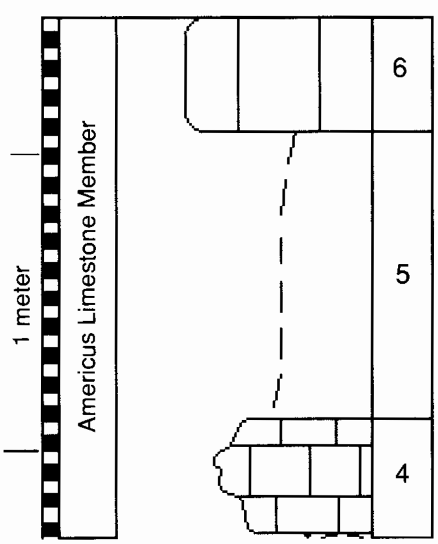
Outcrop 29—SWSW sec. 31, T. 28 S., R. 9 E., Elk County. Outcrop is on north side of road.

		m	ft
14.	Covered		
13.	Fusulinid wackestone, gray	0.23	0.75
12.	Covered	1.3	4.3
11.	Fusulinid wackestone to crinoid wackestone, gray, cherty; fusulinids abundant toward top; crinoids (1–4 mm in diameter) abundant in lower 0.45 m	0.7	2
10.	Covered	0.7	2
9.	Shale, gray, fissile	0.4	1.3
8.	Upper 0.18 m: Ooid-bivalve-foraminifer wackestone, gray, with abundant bryozoan fragments, many ostracodes and brachiopod and echinoderm fragments, and common gastropods; ooid coatings on most of abundant coarse lime-sand grains and on a few of abundant loose *Calcivertella* foraminifers; *Calcivertella* abundant both loose and encrusting tiny bivalve fragments; other foraminifers include many *Globivalvulina* and *Ammobaculites*. Middle: Foraminifer–bryozoan–quartz-silt–quartz-sand wackestone, gray, with abundant *Calcivertella*, many ostracodes and gastropods, few tiny bivalve and brachiopod fragments and coated grains, and rare echinoderm fragments and phosphatic bone (?) fragments.	0.61	2.0



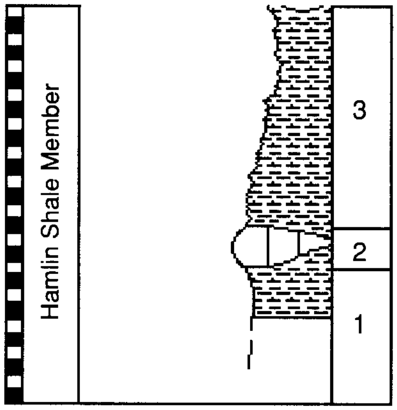
(Outcrop 29, continued)

		Thickness m	ft
	Lower 0.16 m: Lime-conglomerate–*Calcivertella*–ostracode packstone, with many tiny bivalve fragments, common quartz silt to sand grains, few bryozoan and phosphatic bone (?) fragments, and rare *Spirorbis* tubes and echinoderm fragments; conglomerate (20%) consists of coarse sand sized to pebble-size lime lithoclasts, which are rounded to angular, fractured, and contain ostracode fragments		
7.	Shale, yellow to gray, fissile	0.13	0.43
6.	Ostracode wackestone, mottled buff and gray, brecciated, with possible alveolar root structures	0.2	0.7
5.	Shale, yellow to gray, and lense of ostracode wackestone, mottled buff and gray, brecciated	0.27	0.89
4.	Ostracode–quartz-silt mudstone, brecciated; lower 1 cm is ostracode–quartz-silt wackestone, gray to buff, laterally discontinous; ostracodes most abundant in tiny burrows and in fractures in brecciated mudstone; mudstone has fine contorted laminations suggestive of algal growth; in situ brecciation suggests desiccation and root effects	0.1	0.3
3.	Shale, gray, yellow, and orange, fissile	0.24	0.79
2.	Quartz-silt mudstone, buff-white to yellow, fenestral, with a characteristic weathered surface resembling popcorn	0.15	0.49
1.	Boxwork mudstone, tan, with abundant quartz silt and extensive horizontal joint and craze plane fractures	1.0+	3.3+



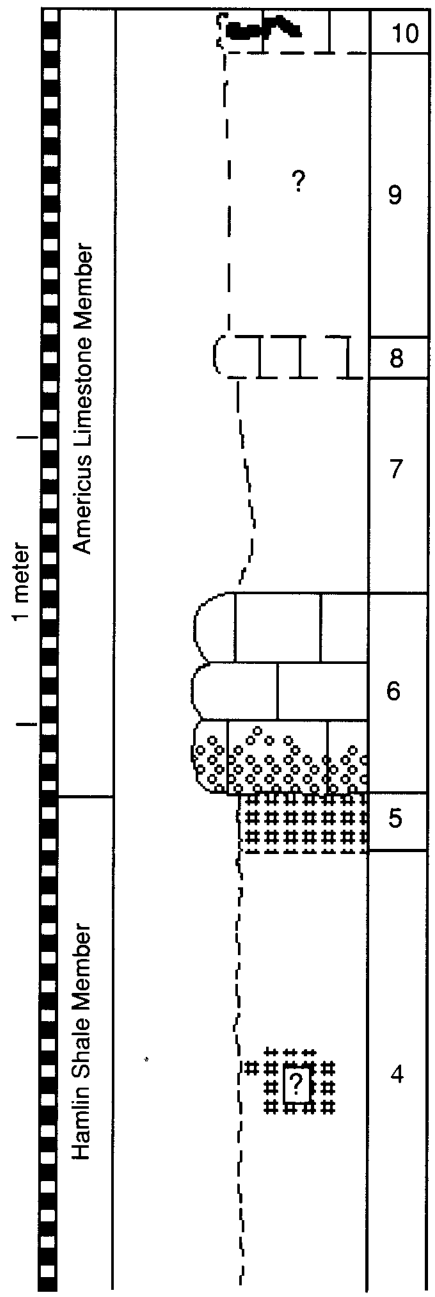
Outcrop 31—SW sec. 32, T. 29 S., R. 9 E., Elk County. Outcrop is at end of road at top of hill.

		m	ft
6.	Fusulinid wackestone to crinoid wackestone, gray; fusulinids abundant toward top; erodes as massive blocks	0.4	1.3
5.	Covered	1.0	3.3
4.	Bivalve-*Calcivertella*-bryozoan wackestone, gray, with many ostracodes, few *Globivalvulina* foraminifers and quartz silt grains, and rare gastropods, lime granules, and crinoids; bivalves are pectinoid and myalinid forms; at base are loose, rounded, elongate (0.8 × 8 cm) lithoclasts consisting of encrusted, imbricated peloid-alga-*Spirorbis* wackestone to mudstone intraclasts containing ostracode fragments and quartz silt	0.5	1.6
3.	Shale, yellow to gray, calcareous	1.0	3.3



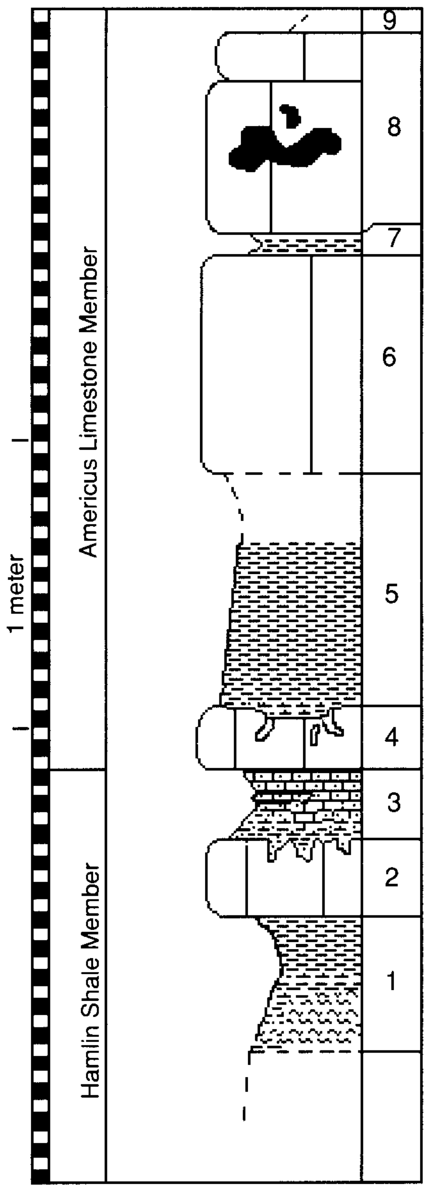
(Outcrop 31, continued)

	Thickness m	Thickness ft
2. Intraclast-ostracode wackestone, buff to gray; intraclasts composed of alga boundstone and mudstone, angular to rounded with some in situ brecciation, and set in micritic (mud) matrix; laterally discontinuous	0.1	0.3
1. Shale, yellow to gray; lower contact not determined		



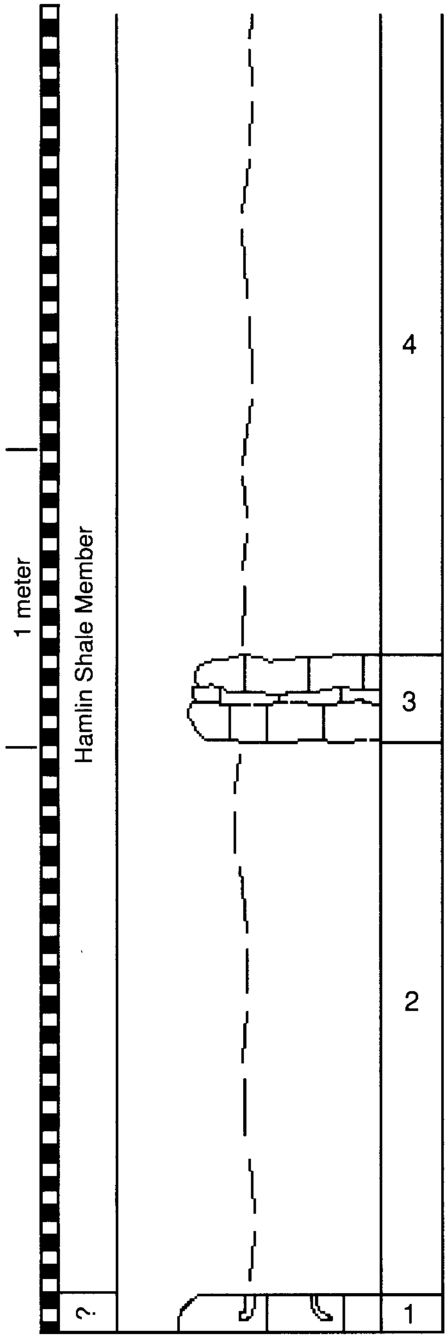
Outcrop 32—NW sec. 20, T. 30 S., R. 9 E., Elk County. Poor exposure along east side of road. Harbaugh and Demirmen (1964) reported that the main ledge or middle limestone of the Americus Limestone Member is highly atypical at this locality, and they used data from this single locality to suggest the presence of a tiny shoal or tidal flat in the middle of the generally normal marine paleoenvironments of the middle limestone. Examination of their fig. 2 (Harbaugh and Demirmen, 1964, p. 3) suggests that they correlated the middle limestone with unit 6 at this locality. Although the rocks at this outcrop are generally poorly exposed, the stratigraphic position (see outcrop 29, this appendix) and the characteristic fossils and other constituents of unit 6 indicate that this unit is the lower limestone of the Americus rather than the middle limestone. Harbaugh and Demirmen's apparent miscorrelation explains the apparent atypical nature of the middle limestone at this location [see Harbaugh and Demirmen (1964, locality 5, figs. 3 and 15)].

	m	ft
10. Fusulinid wackestone, gray, cherty, with abundant brachiopods and crinoids; poorly exposed; difficult to determine lower and upper contacts	?	?
9. Covered; float suggests may be limestone	1.0	3.3
8. Bivalve–coated-grain–quartz-sand packstone, gray, with many crinoids and brachiopods; bivalves occur as tiny fragments	≥0.15	≥0.49
7. Covered; float in upper 0.3 m indicates presence of limestone near top	0.9	3.0
6. Upper 0.2 m: *Calcivertella*-bivalve wackestone, gray, with abundant coarse quartz-silt grains, many *Globivalvulina* foraminifers, gastropods, bryozoans, and ostracodes, few crinoid fragments and *Ammobaculites* foraminifers, and rare tiny lithoclasts; bivalves occur as tiny fragments. Middle 0.14 m: *Calcivertella*-ostracode wackestone, gray, with abundant quartz silt grains, many *Globivalvulina* foraminifers, common tiny lime lithoclasts, and few crinoid fragments. Base: Lime-conglomerate–*Calcivertella* wackestone to packstone, gray, with	0.7	2.3



Outcrop 35—SESE sec. 21, T. 32 S., R. 8 E., Cowley County. Outcrop is on north side of K–38.

	Thickness m	ft
9. Covered		
8. Fusulinid wackestone, dark-gray, resistant, with some chert	0.7	2
7. Shale, gray, fissile	0.07	0.2
6. Crinoid wackestone, dark-gray, with abundant crinoid ossicles (2 mm in diameter)	0.76	2.5
5. Shale, yellow in upper part, dark-gray in middle, light-gray in lower 22 cm, fissile to platy; grades into shaly limestone at base	0.9	3
4. Foraminifer wackestone to mudstone, gray to buff. Upper part: *Calcivertella* wackestone, burrowed, with few productid brachiopods, ostracodes, and crinoids. Lower part: *Calcivertella* mudstone, burrowed, interlayered with *Calcivertella*–productid–gastropod–lime-sand wackestone; also contains tiny bivalve, crinoid, and bryozoan fragments, very fine quartz sand, and calcareous sponge (?) spicules; many lime-sand grains have ooid coatings	0.21	0.69
3. Lime-sand–ostracode wackestone to packstone, orange to yellow, fenestral, 30% fine lime sand, 1% very fine quartz sand, abundant ostracodes, many tiny bivalve fragments; silty calcareous shale at base	0.25	0.82
2. Upper half: *Calcivertella* wackestone, gray, skeletal, with abundant tiny bivalve fragments, gastropods, and ostracodes and rare mobile foraminifers; burrows filled with shale. Lower half: Peloid mudstone, gray, with few gastropods, bivalve fragments, and tubular foraminifers; peloids are tiny	0.09	0.3
1. Shale to claystone, brown to gray; blocky shale in upper 0.23 m; yellow claystone in lower 0.25 m; covered at base	0.48	1.6



(Outcrop 32, continued)

	Description	Thickness m	ft
	abundant peloids, few grapestone clumps, quartz silt, and bryozoan fragments and rare bivalve fragments and *Spirorbis* worm tubes; conglomerate clasts (30% of basal part of rock) consist of coarse sand sized to pebble-size mudstone lithoclasts containing ostracode fragments, typically encrusted with foraminifers		
5.	Boxwork mudstone, tan, desiccation cracked	0.2	0.7
4.	Covered; float indicates boxwork mudstone, buff to tan	3.8	12
3.	Quartz-sand–*Calcivertella* wackestone, dark-gray, with many pectinoid bivalves, few ostracodes, and rare bryozoan fragments; quartz sand is fine grained	0.3	1.0
2.	Covered	1.9	6.2
1.	Crinoid wackestone, dark-gray to orange, burrowed; shale at base, gray	1.3	4.3

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