Pelagic/hemipelagic rhythmites of the Greenhorn Limestone (Upper Cretaceous) of northeastern New Mexico and southeastern Colorado

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PELAGIC/HEMIPELAGIC RHYTHMITES OF THE GREENHORN LIMESTONE (UPPER CRETACEOUS) OF NORTHEASTERN NEW MEXICO AND SOUTHEASTERN COLORADO

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Abstract—Across much of the central Great Plains and Southern Rocky Mountains, the Late Cenomanian-early Middle Turonian part of the marine Cretaceous is represented by pelagic/hemipelagic sedimentary rocks classified as Greenhorn Limestone. Part of this formation, the Bridge Creek Member, is characterized by limestone/shale couplets that have been demonstrated to be time parallel. Bedding rhythmicity is believed to reflect climatic variations that were forced by Earth's orbital perturbations. The Bridge Creek contains readily identifiable limestone and bentonite marker beds that have been traced previously across Kansas and eastern Colorado and are shown in this report to extend also throughout the field-conference area.

Bridge Creek strata equivalent to the Jetmore Member of central Kansas display remarkable stratigraphic uniformity, and include some of the most widely traceable cratonic limestone beds reported from anywhere in the world. In contrast, Bridge Creek strata equivalent to the Hartland Member of central Kansas manifest considerable stratigraphic variation in number, thickness and spacing of pelagic limestone beds. Such variations may have resulted from such factors as scour, eastward pinchout of individual shaly beds, regional variations in effects of climatic signals on pelagic productivity or wedging out of beds against highs. Locally, the entire Bridge Creek section is greatly condensed. General correspondence of condensed sections with structural highs suggests depositional control by tectonic features.

Pelagic and hemipelagic Bridge Creek sediments were deposited in relatively deep water, and accumulated under conditions of generally poor benthic circulation. Isolated beds of skeletal grainstone are attributed to storms. Stratigraphic intervals characterized everywhere by abundance of skeletal debris are attributed to general shallowing related to eustacy. Skeletal grainstones occur essentially throughout condensed Bridge Creek sections, owing apparently to shallower water conditions over the postulated sea-floor highs.

INTRODUCTION

Within the Late Cretaceous Western Interior sea, major accumulation of pelagic carbonate sediment occurred on two occasions. The first of these produced what is today called Greenhorn Limestone (upper Cenomanian-middle Turonian; Fig. 1) and the second produced the Niobrara Chalk or Formation (uppermost Turonian-lowermost Campanian). Monographic study of the Kansas Greenhorn (Hattin, 1975) characterizes four members composed predominantly of chalky or marly shale, each distinguished from the others by the nature of the accompanying limestones. Of special interest are numerous beds of bioturbated chalky limestones that occur within the Hartland, Jetmore and Pfeifer members of the central Kansas outcrop (Fig. 2) and alternate in generally rhythmic fashion with usually thicker beds of chalky shale. For ease of reference the most easily identifiable and most widely traceable of these limestone beds have been code named (Hattin, 1971, 1975, 1985). Three beds lying in the middle part of the Hartland have been designated HL-1 through HL-3, and two bentonite beds lying higher in the unit have been code named HL-4 and HL-5. Thirteen subequally-spaced Jetmore limestone beds have been designated JT-1 through JT-13. Although most Pfeifer limestone beds are nodular or concretionary, two that are continuous have been code named PF-1 and PF-3. These marker beds, as well as other chalky limestone beds within the Greenhorn, are known to be time parallel on the basis of sequence, fossils or associated bentonite seams (Hattin, 1971, 1975, 1985). These marker beds can be traced to westernmost Kansas, where strata equivalent to the central Kansas Hartland and Pfeifer contain more beds of resistant limestone, and where lithologic distinction between Hartland, Jetmore and Pfeifer is less clear. Accordingly, the entire interval that is characterized by rhythmic alternations of limestone and marly shale is termed "Bridge Creek Member" (Fig. 2; Bass, 1926), which is known to be the precise

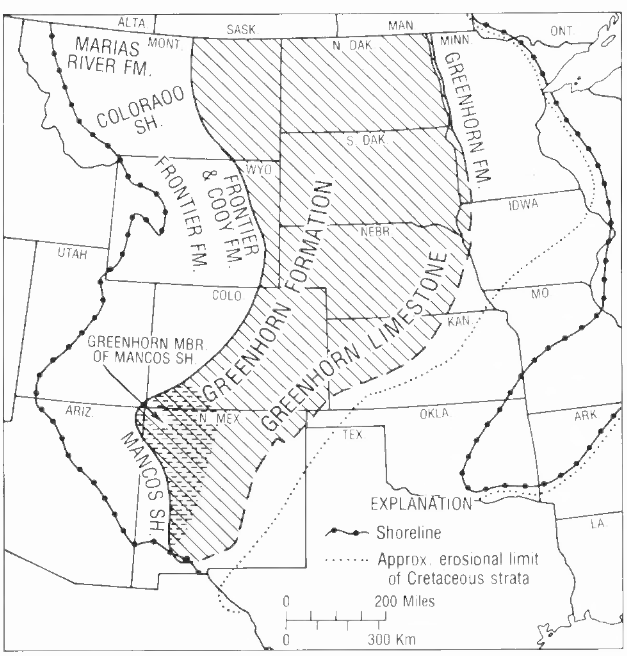


FIGURE 1. Map showing distribution of Greenhorn Limestone/Greenhorn Formation, and units into which the formation passes laterally. Eastern margin of sea is conjectural.

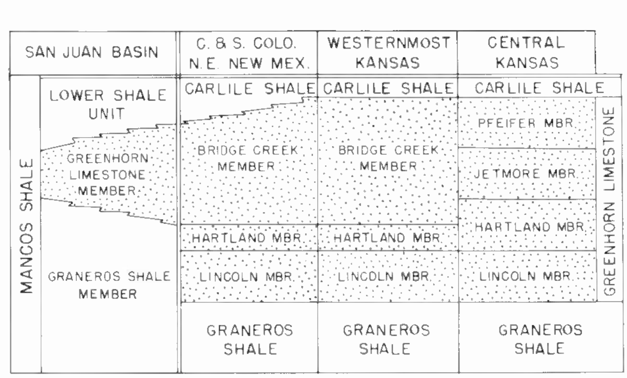


FIGURE 2. Classification of Greenhorn Limestone (stippled), showing westward contraction of interval properly called Greenhorn.

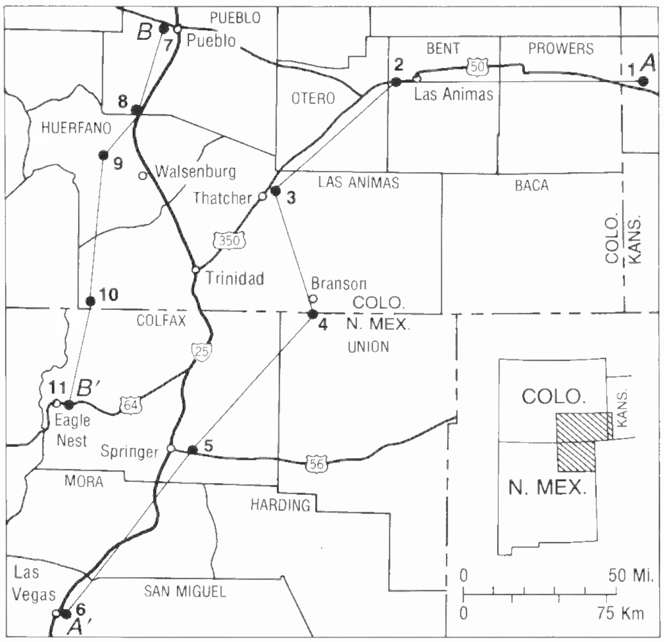


FIGURE 3. Map of field-conference area, showing lines of cross section depicted in Figures 5 and 6. Locality 1: SW1/4 sec. 14 and NE1/4 sec. 22, T23S, R42W, along East Bridge Creek, Hamilton County, Kansas; locality 2: SE1/4 NW1/4 sec. 13 and SE1/4 NW1/4 sec. 16, T23S, R53W, west of Las Animas, Colorado; locality 3: NW1/4 NW1/4 sec. 6 and NW1/4 NW1/4 sec. 4, T29S, R59W, north-northeast of Thatcher, Las Animas County, Colorado; locality 4: SW1/4 SE1/4 sec. 20, T32N, R29E, 12 mi north of Folsom, Union County, New Mexico; locality 5: cut banks along intermittent tributary to Canadian River, approximately 0.2 mi north of U.S. 56 at Taylor Springs, Colfax County, New Mexico; locality 6: composite section based on exposures in quarry beside Santa Fe Railroad track approximately one mi north of Las Vegas, San Miguel County, New Mexico; roadcut on NM Highway 104, 0.2 mi east of Las Vegas, New Mexico; and quarry in bluff situated approximately one mi east of southern end of Las Vegas, New Mexico; locality 7: NW1/4 NE1/4 sec. 31 and SW1/4 and NW1/4 NW1/4 sec. 30, T20S, R65W, west edge of Pueblo, Pueblo County, Colorado; locality 8: SW1/4 SW1/4 sec. 31, T24S, R66W, on east side of I-25, Pueblo County, Colorado; locality 9: SE1/4 SE1/4 sec. 5, T27S, R68W, at Badito, Huerfano County, Colorado; locality 10: hillside above irrigation ditch situated approximately 1.5 mi north-northwest of Torres, Las Animas County, Colorado; locality 11: roadcut on U.S. 64 approximately 1.6 mi east of Eagle Nest, Colfax County, New Mexico.

stratal equivalent of the interval extending from the base of marker bed HL-1 to the top of marker bed PF-3 (Hattin, 1975). The Greenhorn of central Kansas has a conspicuously chalky aspect that diminishes progressively westward so that the type Bridge Creek (Fig. 3, locality 1) comprises a section in which the marker beds are better termed limestone and most of the interbeds are better termed marly shale.

Westward and southwestward from locality 1 (Fig. 3) the entire Bridge Creek manifests gradual change of facies, the limestones becoming generally darker in color, somewhat less pure, much better cemented and generally thicker than in Kansas. Concomitantly, the intervening shaly beds become less calcareous, so that in Colorado and New Mexico the terms marly and calcareous shale are usually appropriate. These lithologic changes reflect the progressively greater influence of siliciclastic source areas that were situated along the western margin of the Western Interior basin. Accompanying this westward change of facies is progressive, but irregular, loss from the Bridge Creek interval of limestone beds that are the principal basis for defining that unit. Limestone beds disappear first from the Pfeifer equivalent (Fig. 2), which in the plains of eastern Colorado and northeastern New Mexico loses most of its limestone content and at least locally becomes highly calcarenitic. Although exact stratal equivalence with the Pfeifer of central Kansas can be demonstrated as far to the west as Pueblo, Colorado (Cobban and Scott, 1972), the unit contains almost no true limestone beds there and is inappropriately classed as part of the Bridge Creek Member. As a result of facies change in the Pfeifer interval, Bridge Creek exposures in southeastern Colorado and northeastern New Mexico are usually capped by marker bed JT-13, which is a major bench-forming limestone.

BRIDGE CREEK MEMBER OF FIELD-CONFERENCE AREA

In the field-conference area the Bridge Creek is best defined as the interval embracing strata lying between the base of marker bed HL-1 and the top of maker bed JT-13. The chief distinguishing feature of this interval is the occurrence of closely- and subequally-spaced beds of pelagic limestone that alternate in rhythmic fashion with beds of pelagic/hemipelagic marly or calcareous shale. Where this interval is more chalky (toward the east), the weathered outcrop is characterized usually by pale grayish-orange coloration. Where less chalky, especially along the Southern Rocky Mountains foothills and westward, the Bridge Creek outcrop is marked by an unmistakable very light gray blaze on the landscape.

Rhythmically-bedded Bridge Creek strata are well exposed in the field-conference area (Figs. 3, 4), and throughout the region can be

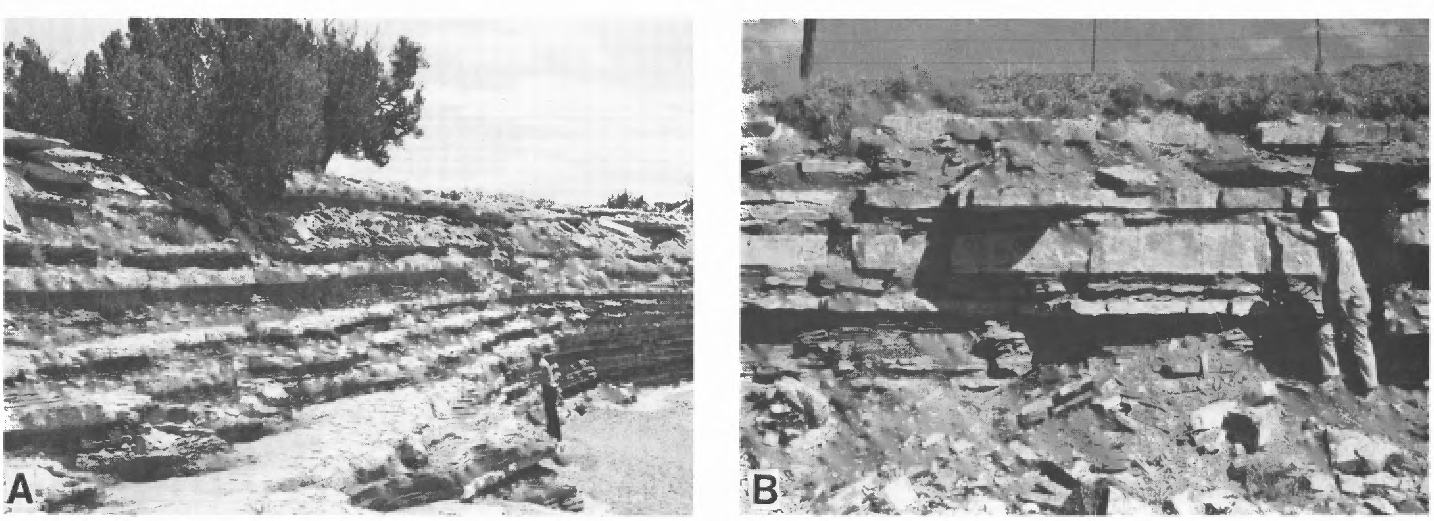


FIGURE 4. A, Typical exposure of Jetmore equivalent, Bridge Creek Limestone Member in field-conference area, showing rhythmic alternations of thin bioturbated limestones and thicker marly shales. Cut bank in NW1/4 NW1/4 sec. 4, T29S, R59W, 5 mi northeast of Thatcher, Colorado. B, Exposure of lower part of Bridge Creek Member as developed approximately one mi north of Las Vegas, New Mexico, in quarry situated on west side of Santa Fe Railroad track. Note left-to-right thickening of bed beneath Cal James' right hand.

correlated precisely on the basis of the above-mentioned marker beds. Eleven sections situated in or adjacent to the field-conference area are depicted graphically in Figures 5 and 6, and document lateral continuity of the marker beds, even where sections are greatly condensed. Brief descriptions of the markers are included here in order to facilitate the work of other investigators.

Marker bed HL-1 lies at the base of the Bridge Creek section and is consistently one of the thickest beds in the member (Fig. 7A). Within the area of Figure 3, thickness of this bed ranges from 0.5 to 1.71 ft (15.2 to 52 cm), averaging 0.90 ft (29.9 cm; n = 11). In central Kansas this bed becomes extensively fractured during weathering and breaks readily under the hammer, but in the area of Figure 3 the bed is nearly everywhere very hard and brittle, and usually weathers to form large joint blocks. At locality 4 (Fig. 5) the position of HL-1 is occupied by a unique conglomeratic crumbly limestone that bespeaks local benthic conditions that were different from other Bridge Creek localities yet examined by the author.

Marker bed HL-2 is separated from HL-1 by a shaly interval that contains at least one relatively thick bentonite seam. In central Kansas, HL-2 is overlain by one or more very thin bentonite seams or by a thin interval of bentonitic marly shale. In southeastern Colorado and northeastern New Mexico the bed is commonly concretionary, and the associated bentonite seam is overlain by a limestone bed that has strongly undulatory surfaces, is itself somewhat concretionary and locally has knobby protuberances on the lower surface (Fig. 7B). Within the area of Figure 3, HL-2 ranges in thickness from 0.25 to 0.5 ft (7.6 to 15.2 cm), averaging 0.35 ft (10.6 cm; n = 10). Marker beds HL-1 and HL-2 essentially define the *Sciponoceras gracile* assemblage zone, some characteristic species of which are illustrated in Figure 8. This zone is recognized essentially throughout the Western Interior as well as in the Upper Cretaceous section of the western Gulf Coastal Plain.

Throughout Kansas and the field conference area marker bed HL-3 is identifiable largely by association with a major, overlying seam of bentonite (Fig. 9). In central Kansas the bed is relatively thin, commonly soft and usually crumbly, but within the area of Figure 3 the bed is very hard, brittle limestone that contains few macrofossils and forms a prominent ledge, the thickness of which ranges from 0.19 to 0.75 ft (5.8 to 22.9 cm), averaging 0.5 ft (15.2 cm; n = 11).

Marker bed JT-1 (Fig. 10) is identified readily by association with a thin underlying seam of bentonite (= HL-5) that is separated from the limestone by a very thin shaly interval. This bed is further characterized by its macrofauna, which includes some forms that are unknown elsewhere in the Bridge Creek section. Most characteristic are *Vascoceras birchbyi* Cobban & Scott, *Watinoceras coloradoense* (Henderson) and *Mytiloides* cf. *M. columbianus* Heinz (Fig. 11). Within the area of Figure 3 this bed ranges in thickness from 0.26 to 0.5 ft (7.9 to 15.2 cm), averaging 0.38 ft (11.6 cm; n = 12). Marker beds JT-1 through JT-9 are very much alike lithologically and are more evenly spaced than pelagic limestone beds that lie below JT-1 and above JT-13. Several features of the JT-1 through JT-9 sequence are surprisingly consistent. For example, beds JT-3, 6 and 7 are normally thicker than beds JT-2, 4, 5, 8 and 9, and the interval between JT-6 and JT-7

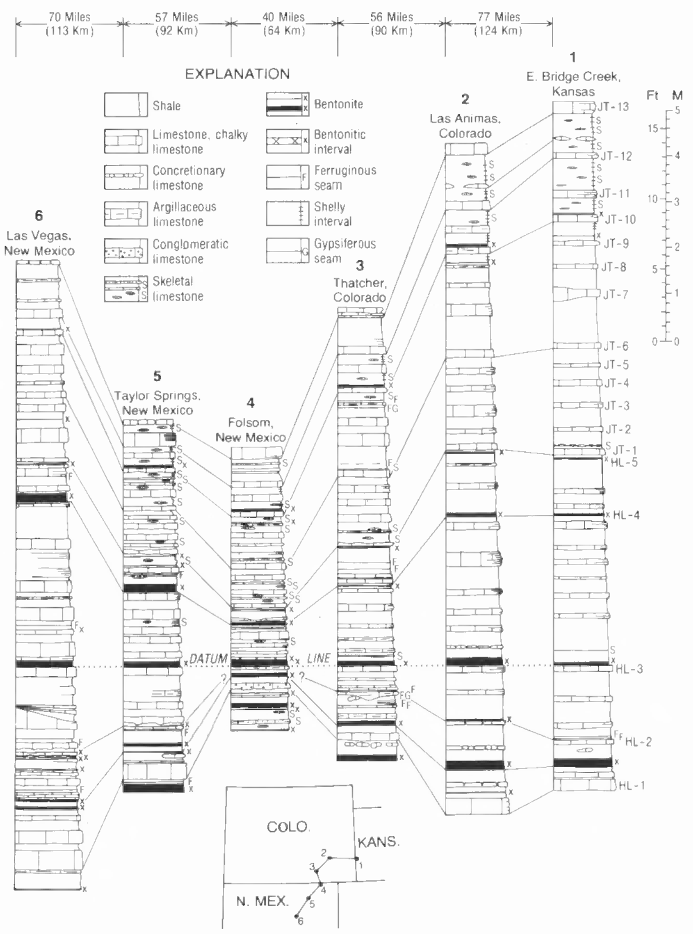


FIGURE 5. Correlation of rhythmically bedded part of Greenhorn Limestone along line of section extending from type locality of Bridge Creek Member southwestwardly to Las Vegas, New Mexico (Fig. 3). Code names of the most readily identifiable and/or most widely traceable markers are shown at right. The term "shale" embraces chalky shale, marly shale and calcareous shale.

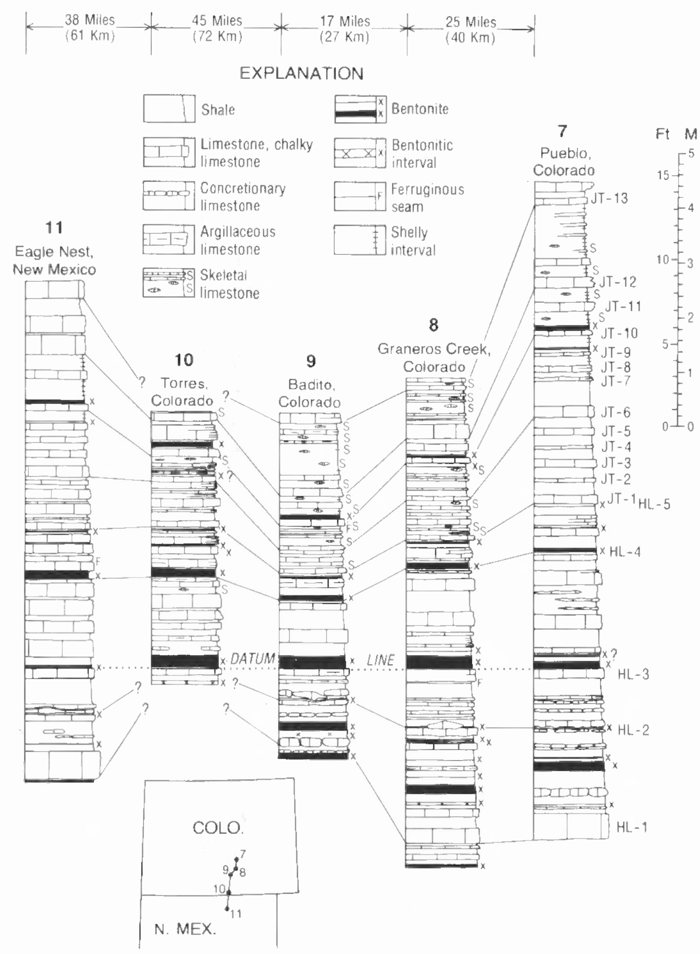


FIGURE 6. Correlation of rhythmically-bedded part of Greenhorn Limestone along line of section extending from the Rocky Canyon anticline, west of Pueblo, Colorado, to Eagle Nest, New Mexico (Fig. 3). The term "shale" embraces chalky shale, marly shale and calcareous shale.

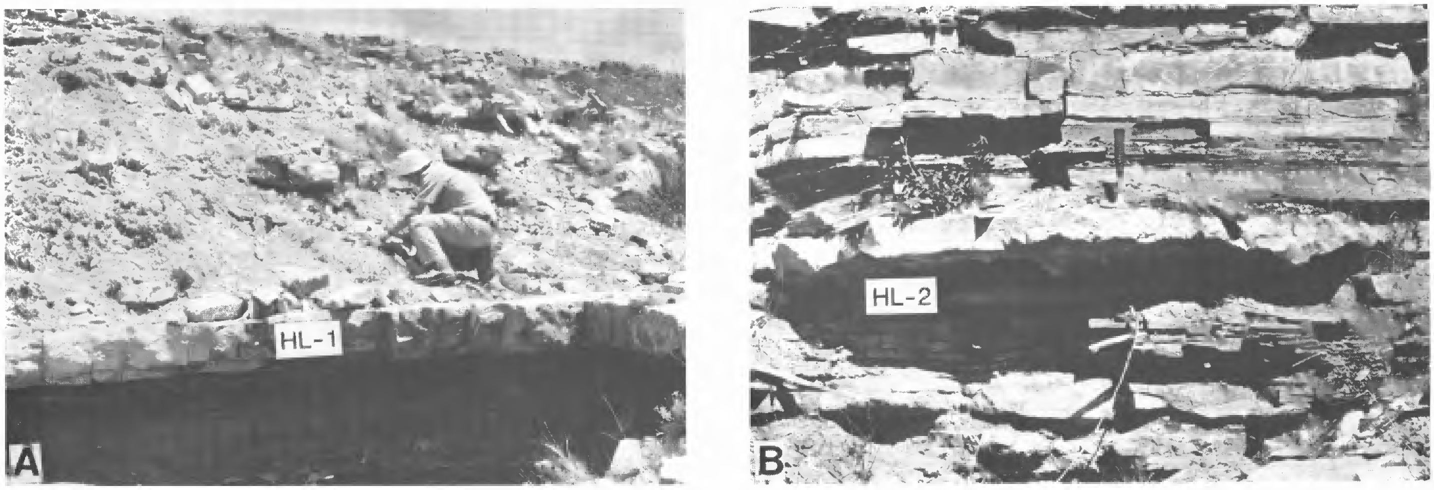


FIGURE 7. A, Exposure of marker bed HL-1, beneath Cal James' feet, in cut bank of small tributary to Canadian River, approximately 0.1 mi north of U.S. 56 at Taylor Springs, New Mexico (locality 5 of Fig. 3). B, Exposure of marker bed HL-2 at locality 6 (Fig. 3), and overlying bed of limestone that has knobby protuberances on lower surface. West-facing wall of quarry situated off east side of U.S. Highway 85, approximately 1 mi north of Las Vegas, New Mexico.

is usually thicker than intervals separating the other beds. In the JT-1 through JT-3 interval, JT-3 is usually thickest, and JT-2 is thinnest. The interval between JT-1 and JT-2 nearly everywhere contains very thin lenses or a thin-lensing bed of foraminiferal limestone, which can be recognized from northeastern Kansas to the Four Corners area of New Mexico. JT-9 is weakly developed in some areas, and is lacking in a few otherwise normal (i.e., noncondensed) sections. Finally, a very thin bentonite seam or its ferruginous, weathered equivalent, lies low in the interval separating marker bed JT-9 from JT-10. These are the sorts of criteria that lend certainty to the precise correlations that are depicted graphically in Figures 5 and 6. Within the area of Figure 3, marker bed JT-6 is one of the more readily identifiable beds, ranging in thickness from 0.2–0.66 ft (6.9 to 12 cm) and averaging 0.42 ft (12.8 cm; n = 12).

The interval containing marker beds JT-10 through JT-12 (Fig. 12) is distinguishable on several criteria, the most notable of which are superior resistance to erosion, uniform spacing, large numbers of inoceramid valves (*Mytiloides mytiloides* [Mantell]) that are usually preserved in-the-round, association with shaly beds that contain an abundance of inoceramid valves and shelly debris and, commonly, very thin lenses of skeletal limestone composed predominantly of inoceramid-bivalve debris. Furthermore, a conspicuous bentonite seam everywhere lies directly on or very slightly above marker bed JT-10. From central Kansas westward to Cañon City, Colorado, weathering of these three

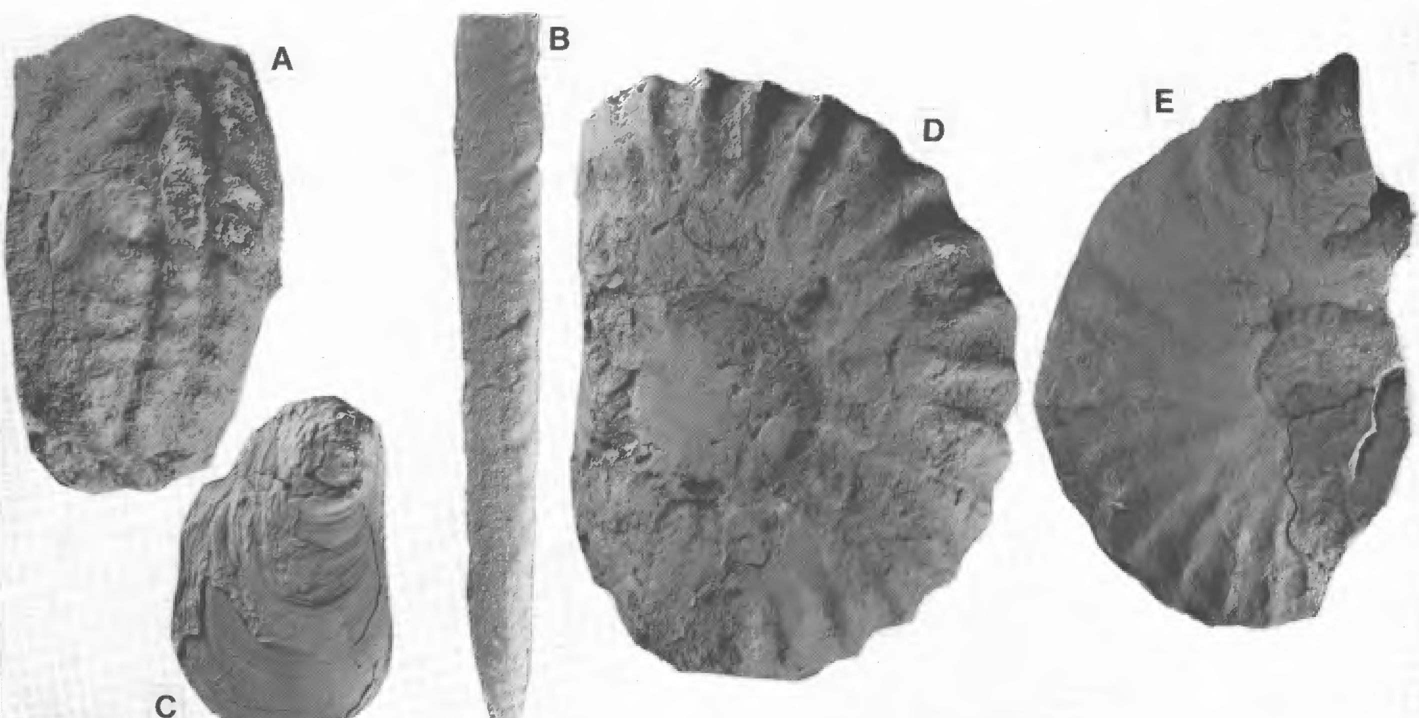


FIGURE 8. Some characteristic fossils of the *Sciponoceras gracile* assemblage zone in the field-conference area. A, *Enomphaloceras septemseriatum* (Cragin) from crumbly limestone bed beneath HL-2 at locality 9. Ventral view, ×2. B, *Sciponoceras gracile* (Shumard) from limestone bed beneath HL-2 at locality 7, ×2. C, *Inoceramus pictus* Sowerby from crumbly limestone bed lying between marker beds HL-1 and HL-2 at locality 8, ×1. D, *Pseudocalycoceras dentonense* (Moreman) from crumbly bed of limestone lying between marker beds HL-1 and HL-2 at locality 8, ×1. E, *Metoicoceras geslinianum* (d'Orbigny) from marker bed HL-1 at locality 3, ×1/2.

limestone beds usually produces conspicuous, irregular, more or less horizontal fractures that contrast markedly to the vertical joints that characterize most beds higher and lower in the section. Within the field-conference area these beds break blocky, except at locality 3 (Fig. 3), where the more typical horizontal fracturing is developed. The JT-10 to JT-12 interval lies within the range zone of *Mammites nodosoides* (Schlotheim), and beds in this interval contain conspicuously greater numbers of inoceramid remains (*Mytiloides mytiloides*) than other parts of the Bridge Creek section (Fig. 13). Within the area of Figure 3, marker bed JT-10 ranges in thickness from 0.28 to 0.5 ft (8.5 to 15.2 cm), averaging 0.4 ft (12.1 cm; n = 12). Marker bed JT-12 ranges in thickness from 0.14 to 1.17 ft (4.2 to 35.6 cm), averaging 0.6 ft (18.2 cm; n = 11).

Because of its relatively large thickness and resistance to erosion, marker bed JT-13 forms a bench at the top of many exposures in the area of Figure 3. This bed commonly preserves molds of *Baculites* and locally displays large thalassinoid burrow-structures. In central Kansas, the bed is commonly divided by a central bedding plane along which are preserved very large numbers of compressed *Mytiloides labiatus* (Schlotheim) valves. Westward from Kansas, the central bedding plane is commonly replaced by a thin bed of chalky or marly shale, as at localities 1, 6, 7 and 8 (Fig. 3). In central Kansas and at localities 1 and 2 (Fig. 3), the shale that separates JT-12 and JT-13 contains one or more layers of chalky limestone concretions, the lower of which becomes a continuous bed of limestone in eastern Colorado (Hattin, 1985, fig. 2). At all Kansas localities and most of those in the area of Figure 3 the shaly interval separating JT-12 from JT-13 contains an abundance of shelly debris (or molds of such debris) derived from inoceramid bivalves. In the area covered by this report JT-13 ranges in thickness from 0.3 to 1.35 ft (9.1 to 41 cm), averaging 0.8 ft (24.4 cm; n = 10).

The exact stratal equivalent of the Pfeifer Member of central Kansas is identifiable precisely at localities 1, 5 and 7 (Fig. 3), where marker beds PF-1 through PF-3 (Hattin, 1975) can be recognized. Marker beds PF-1 and PF-2 are exposed also at locality 4 (Fig. 3). Except in the eastern part of the field conference area (e.g., localities 1 and 4) the

FIGURE 9. Marker bed HL-3 and overlying seam of bentonite in Bridge Creek section exposed along intermittent tributary to Canadian River, approximately 0.1 mi north of U.S. Highway 56 at Taylor Springs, New Mexico (locality 5 of Fig. 3).

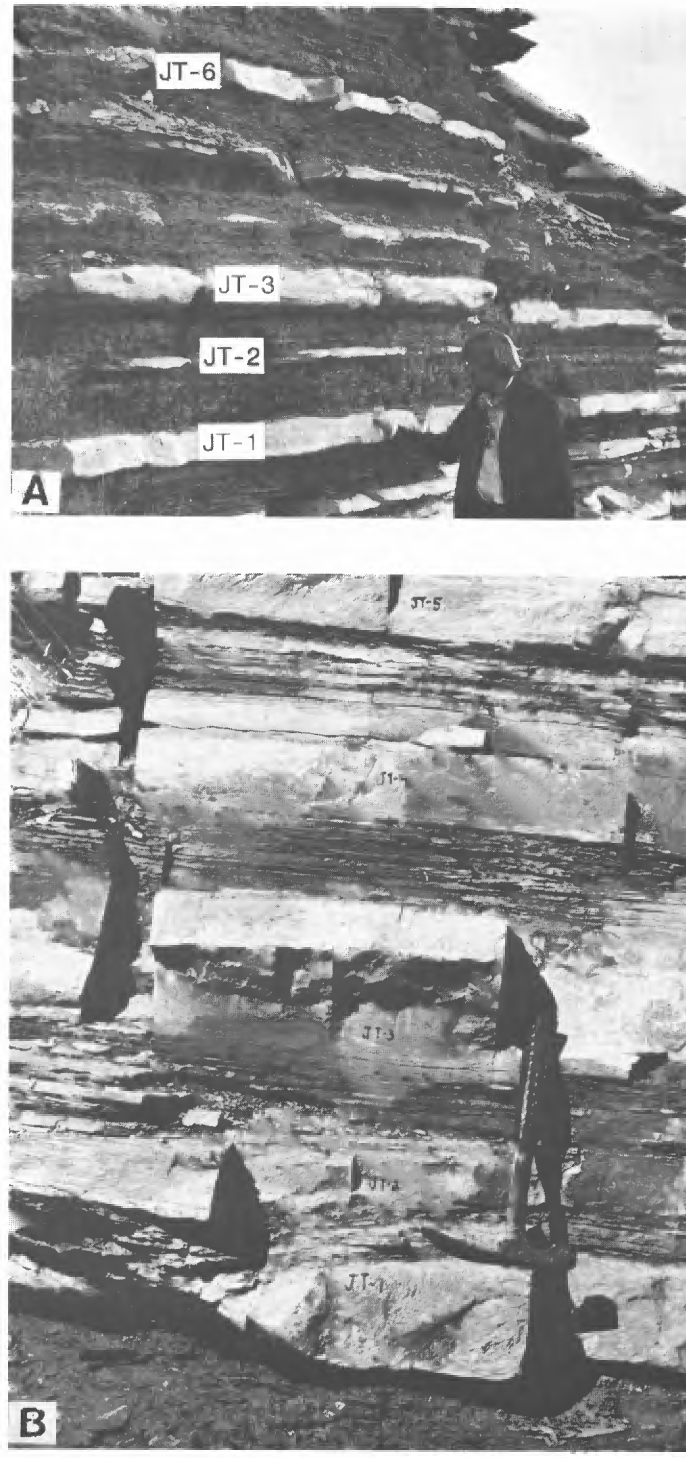


FIGURE 10. Marker bed JT-1 and overlying beds JT-2 through JT-6 at locality 7, west of Pueblo, Colorado. Note relative thicknesses of JT-1 through JT-3, and compare with comparable beds illustrated in Figure 12B. B, Marker bed JT-1 and overlying beds JT-2 through JT-5 at locality 5, Taylor Springs, New Mexico.

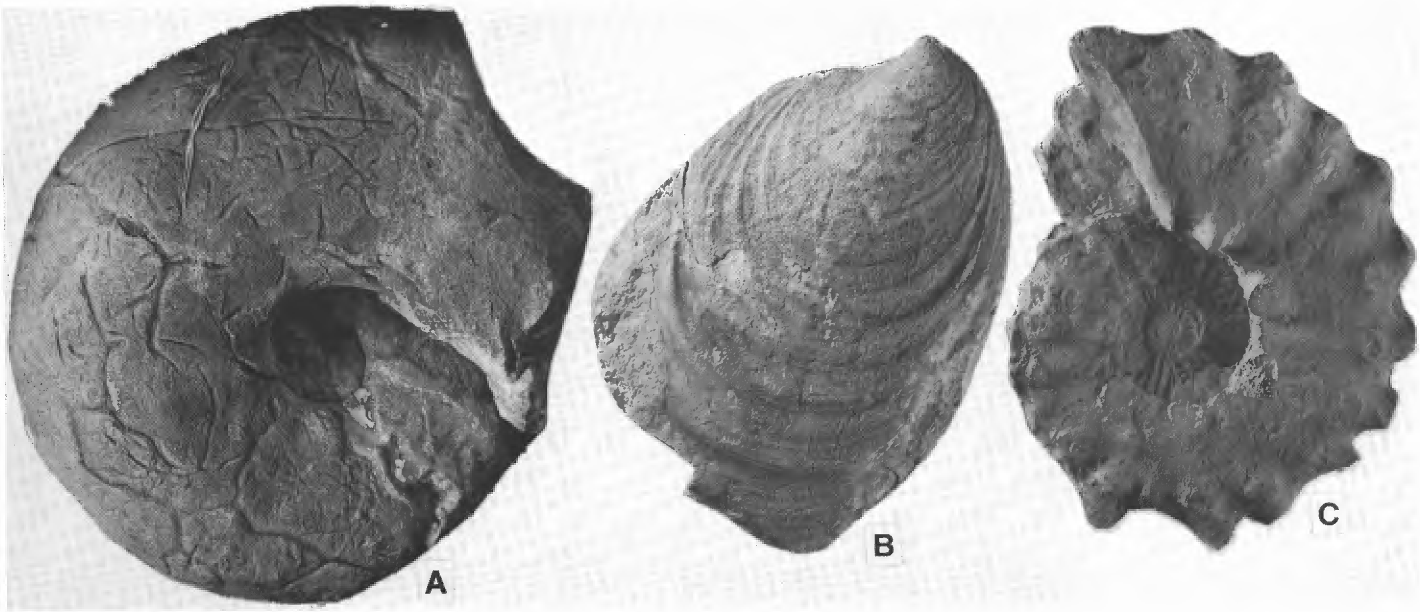


FIGURE 11. Some characteristic fossils of the *Vascoceras birchbyi-Watinoceras reesidei* assemblage zone. A *Vascoceras birchbyi* Cobban & Scott from marker bed JT-1 at locality 7 (Fig. 3), ×0.65. B, *Mytiloides* cf. *M. columbianus* Heinz from marker bed JT-1 at locality 7, ×1. C, *Watinoceras coloradoense* (Henderson) from marker bed JT-1, 4.8 mi northeast of Cañon City, Colorado.

Pfeifer interval bears little resemblance to the remainder of the Bridge Creek, and may require nomenclatural revision. Only that part of the Colorado and New Mexico Greenhorn which is characterized by a sequence of subequally-spaced limestone beds that alternate with beds of shale is properly termed Bridge Creek (see Bass, 1926).

PETROLOGY

Pelagic limestones of the Bridge Creek Member are predominantly biomicritic wackestones within which wide compositional and textural variations occur. Nearly all of the beds were extensively bioturbated (Fig. 14), which resulted in a random microfabric. In some samples the matrix grades locally from micrite to microsparite, and burrows of sediment-ingesting organisms are commonly filled with microsparite. In contrast, originally-open dwelling structures are filled usually by sparry calcite. Principal skeletal grains are tests of planktonic foraminifers, fragments and isolated prisms derived from the shells of inoceramid bivalves, calcispheres, echinoderm debris, oyster fragments, very thin valves presumed to be those of paper pectens and fragmentary remains of vertebrates. Foraminiferal tests range widely in degree of preservation, as do calcispheres, and the walls of these fossils may be essentially intact or obliterated entirely. Sediment fillings of many foraminiferal test chambers consist of micrite or of microsparite/pseudosparite derived therefrom. Other Foraminifera escaped filling by sediment, and the chambers are instead filled with blocky calcite spar that comprises from one to a few large, usually well-defined crystals. Calcispheres exhibit similar, though less obvious, variations in the character of the chamber filling. Oysters and the prismatic layer of inoceramid valves were originally calcitic, and tend to suffer little diagenetic alteration. Pyrite, or its oxidized equivalent, occurs as framboids within chambers of foraminiferal tests, as a skeletal replacement mineral or as crystals that developed within the matrix. Vertical hairline fractures that are filled with sparry calcite are common in the more brittle limestones that characterize Bridge Creek sections situated in more westerly portions of the area shown in Figure 3. Siliciclastic grains large enough to be detected by light microscopy are very sparse to absent in a majority of limestones from the same area.

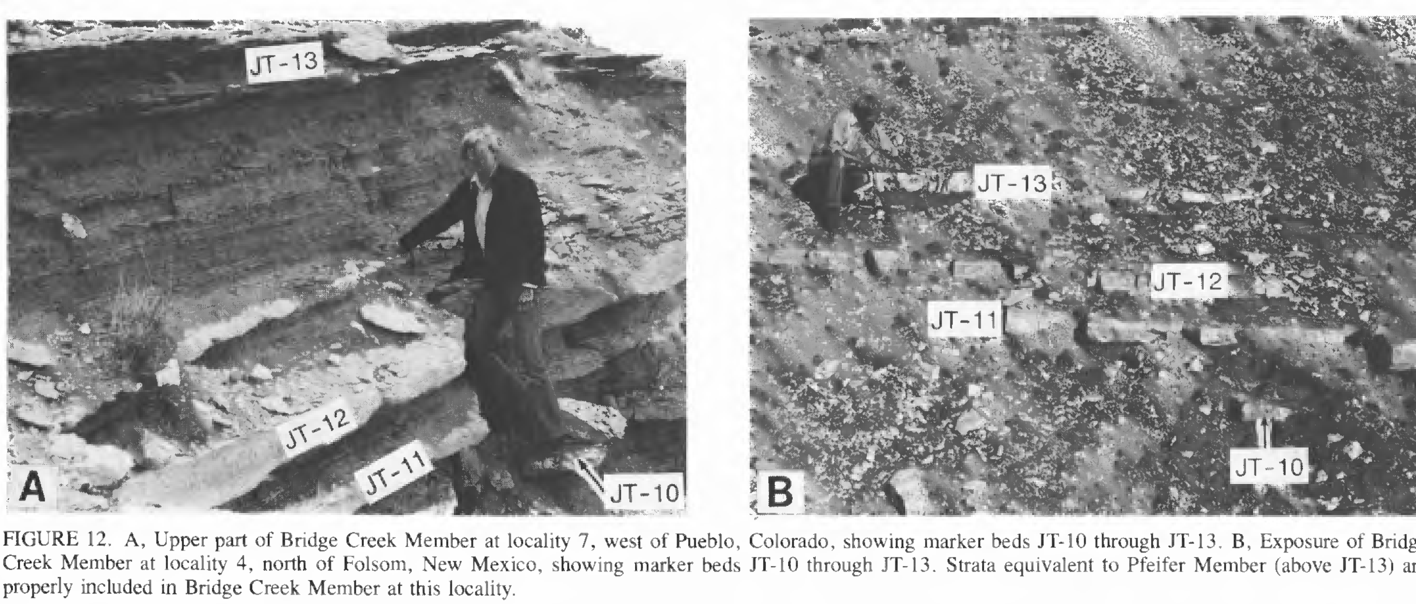


FIGURE 12. A, Upper part of Bridge Creek Member at locality 7, west of Pueblo, Colorado, showing marker beds JT-10 through JT-13. B, Exposure of Bridge Creek Member at locality 4, north of Folsom, New Mexico, showing marker beds JT-10 through JT-13. Strata equivalent to Pfeifer Member (above JT-13) are properly included in Bridge Creek Member at this locality.

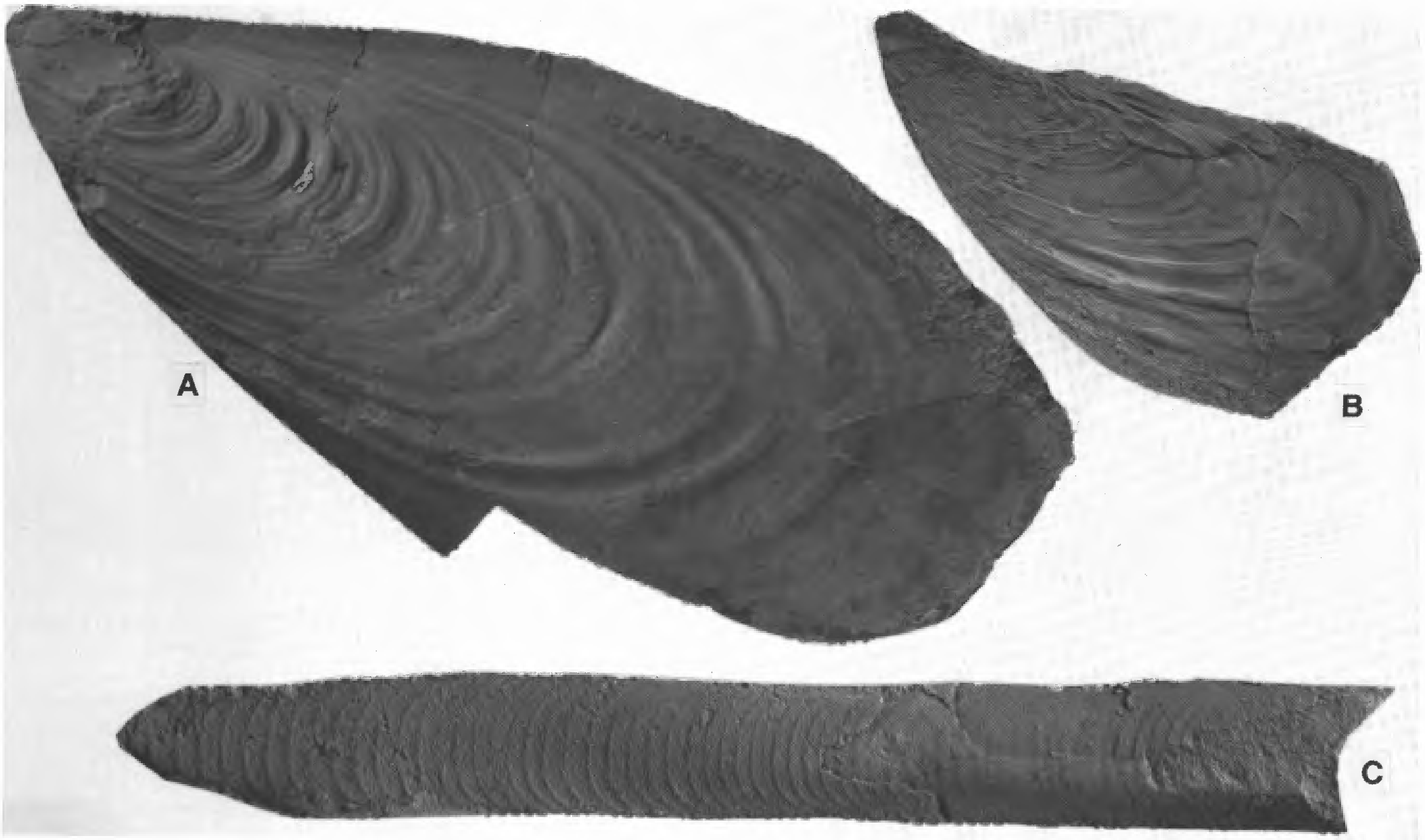


FIGURE 13. Characteristic fossils of the *Mammites nodosoides* zone in the field conference area. A, *Mytiloides mytiloides* (Mantell) from marker bed JT-10, 4.8 mi northeast of Cañon City, Colorado, ×1. B, *Mytiloides mytiloides* (Mantell) from marker bed JT-10, cut at south end of dam, El Vado, New Mexico, ×1. Specimen distorted by compaction. C, *Baculites* cf. *B. yokoyamai* Tokunaga & Shizimu from marker bed JT-11, roadcut situated approximately 8 mi NNE of Dorrance, Kansas, ×1.

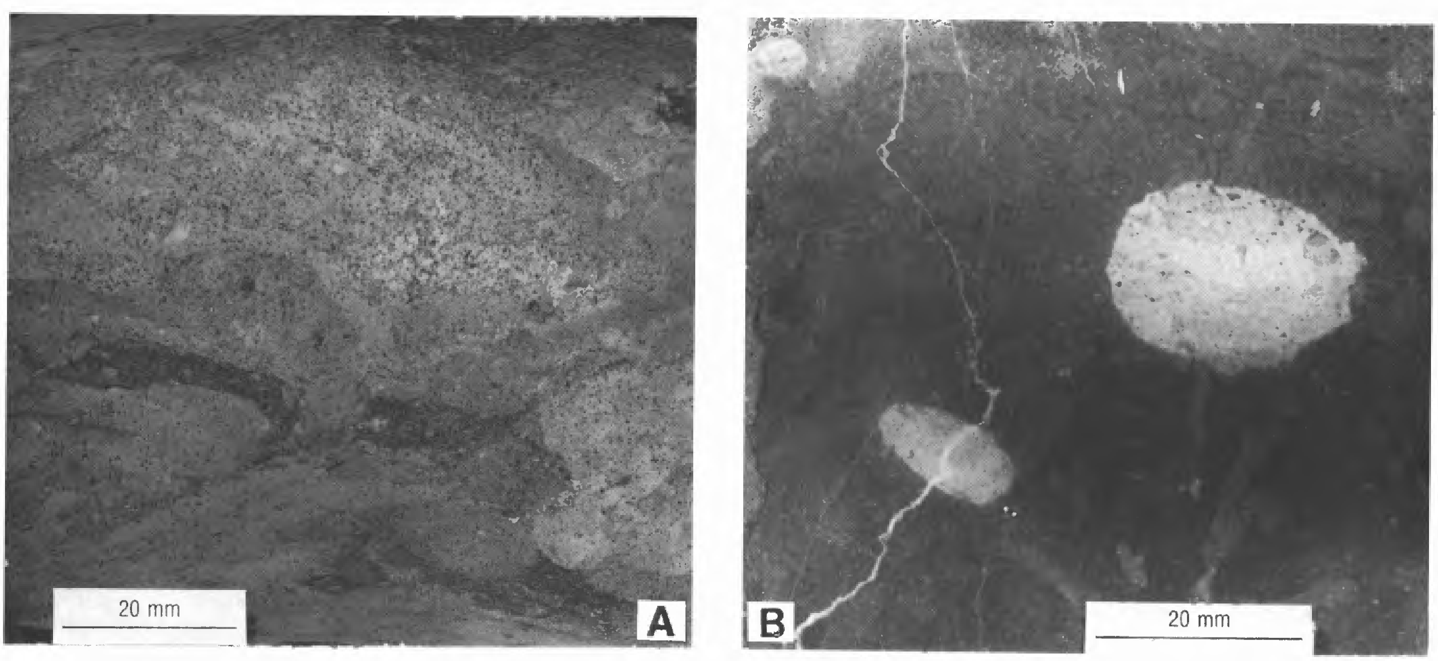


FIGURE 14. A, Polished surface of sample from marker bed JT-6, locality 9, showing thoroughly bioturbated internal structure that is typical of such beds wherever the Bridge Creek is developed. B, Polished surface of sample from marker bed HL-2, locality 11, showing bioturbated texture, including large circular burrow structures that have thalassinoid affinity.

Petrographic analysis of limestone from the field-conference area suggests that significant vertical variations occur within the Bridge Creek interval, as shown earlier for the entire Greenhorn section of Kansas (Hattin, 1975). For example, calcispheres are especially abundant in marker beds HL-1 and HL-2, and commonly dominate the skeletal element of these rocks. Beds JT-10 through JT-12 are characterized by expectably great abundance of grains derived from inoceramid bivalves. Marker bed JT-13 is typically a foraminiferal/inoceramid packstone. At nearly all localities in the field-conference area marker bed JT-1 contains fragmentary skeletal grains that display unit extinction and were apparently derived from an echinoderm. Such grains are not unique to JT-1, but are associated especially with that bed. Petrologic differences of these kinds are of use in confirming physical correlation of beds, determining relative rates of pelagic productivity, evaluating conditions in the local benthic environment and quantifying regional changes of facies. Microscopic features of representative samples of Bridge Creek biomicrites are illustrated in Figure 15A–D.

Chalky, marly and calcareous shale interbeds of the Bridge Creek differ petrologically from the limestones in several important respects. Fecal pellets, which in limestone-forming muds were nearly all destroyed by bioturbation, are common in the shales, especially those of more chalky character (Fig. 15E). Because of bioturbation, primary fabric has not been destroyed, so that nearly all tabular or elongated grains are aligned parallel to bedding, imparting a generally laminated appearance. These rocks contain more insoluble material, especially very fine-grained terrigenous detritus and organic matter, the latter usually occurring as black wisps scattered through the rock (Fig. 15E). The shales also show considerable effect of pressure solution, which has produced microstylolites that occur either in isolation or as swarms. Layering of these rocks is enhanced by very thin concentrations of skeletal grains, especially foraminiferal tests. Where shale-forming muds were stirred by currents, especially in greatly condensed sections, the shales contain skeletal concentrations that range from laminations that are only one grain in thickness to lenses or thin-lensing beds of sparry calcite-cemented grainstones (Fig. 15F). The gradation of shale texture from biomicritic wackestones to biosparitic grainstones is a direct response to levels of current (or wave) energy that were expended on the Late Cretaceous sea floor.

ORIGIN OF RHYTHMIC BEDDING IN BRIDGE CREEK MEMBER

G. K. Gilbert (1895) was first to suggest that rhythmically bedded Greenhorn strata are a reflection of global climatic changes that are caused by perturbations in the Earth's orbit. In recent years that interpretation of Greenhorn rhythmites has been revived by Fischer (1980), documented by Pratt (1984) and interpreted on an interregional scale by Hattin (1986a). Orbital forcing of climate results in alternation between arid and humid climatic episodes, which are best recorded in pelagic and hemipelagic sediments that are deposited in deeper, quieter parts of sedimentary basins (R.O.C.C. Group, 1985). The Bridge Creek Member of the field-conference area is representative of such sedimentary conditions. During arid climatic episodes, terrestrial runoff to the Western Interior basin was slight, benthic waters were aerated, and basin-center sedimentation was dominated by pelagic carbonate mud that served as a substrate for both epibenthic and endobenthic organisms. Lithification of such sediments produced the Bridge Creek limestone beds. During pluvial climatic episodes, runoff from the Sevier highlands produced a plume of sediment-laden brackish water that spread far to the east in the Western Interior sea. Under these conditions, the water column became salinity stratified, bottom waters became oxygen deficient, and pelagic ooze deposition was diluted by hemipelagic mud that was only slightly bioturbated, if at all. Lithification of these sediments produced the Bridge Creek shaly interbeds.

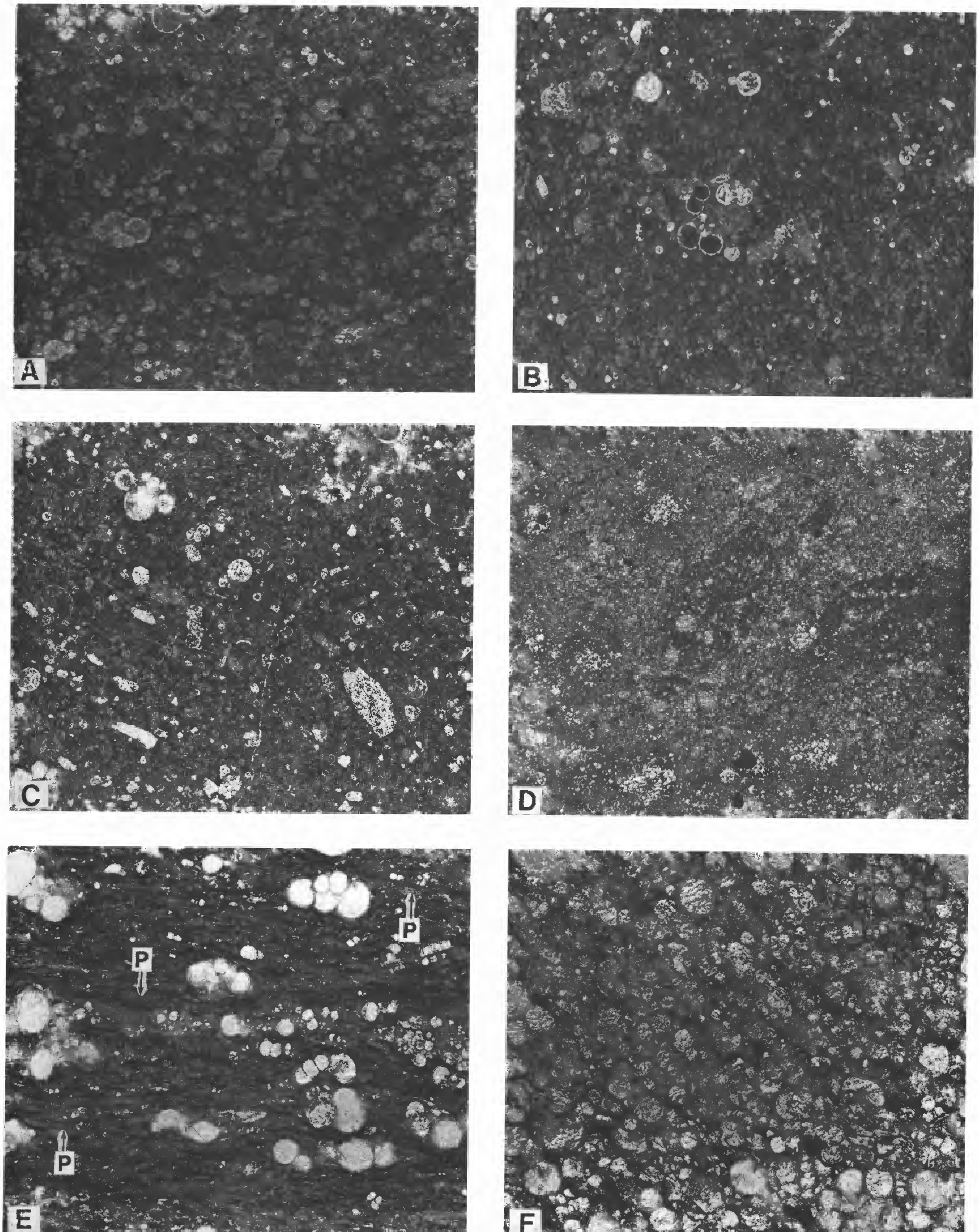
In the Bridge Creek interval, alternating climatic signals were best recorded in the geographically central part of the basin, which corresponds tectonically to the eastern shelf (or ramp) area of the Western Interior sea. Toward the western side of the basin, these signals were damped by progressively greater volumes of siliciclastic influx and shallower water depths in which salinity stratification probably did not occur. Toward the eastern side of the basin the climatic signals were damped because influx of siliciclastic sediment was very small and the area was beyond the reach of any brackish-water plumes. The relationships of sections produced under these contrasting sets of conditions have been modeled recently by Hattin (1986a).

STRATIGRAPHIC VARIATIONS AMONG BRIDGE CREEK RHYTHMITES

Within the Bridge Creek Member of the field-conference area, in all of central Kansas and adjacent to the Arkansas River between Cañon City, Colorado, and the Kansas border, the most systematic record of alternating climatic signals occurs in strata equivalent to the Jetmore Member (Figs. 2, 4A). This part of the section is the most uniform stratigraphically, contains the most widely traceable cratonic limestone beds yet reported from anywhere in the world and probably includes beds deposited during a major transgressional peak. In contrast, Bridge Creek strata equivalent to middle and upper parts of the Hartland Member of central Kansas (Fig. 2) manifest considerable variation, not only in thickness and spacing of individual beds but in the number of limestone beds that lie between readily recognizable marker beds. For example, within the area of Figure 3 the number of well-developed limestone beds between marker beds HL-2 and HL-3 ranges from one to four. Similarly, the number of well-developed limestone beds between HL-3 and HL-4 ranges from two to six, and between HL-4 and HL-5 from one to four (Figs. 5, 6). Such variation may result from erosional scour, which apparently has eradicated HL-2 at locality 4 (Fig. 5); wedging out of beds against abnormally thickened parts of other beds, e.g., at locality 6; omission of beds in greatly condensed sections, as at localities 4 and 10; eastward pinchout of individual shaly beds, so that two limestone beds merge into one (e.g., HL-1 in all areas east of locality 1 of Figure 3); and regional variations in productivity among pelagic organisms, which could account for the occurrence of a well-developed limestone bed beneath HL-4 at localities 5, 9 and 11 of the field-conference area and absence of such a bed at all localities situated farther to the east. In fact, most hard, brittle limestones of the lower Bridge Creek of the field-conference area are unrepresented in central Kansas, or are represented there only by nonresistant beds of soft bioturbated chalk. This suggests that the contrasts between climatic signals were weaker in central Kansas than in southeastern Colorado and northeastern New Mexico.

One of the most interesting stratigraphic variations is great condensation of the Bridge Creek section at some localities, e.g., localities 4, 9 and 10 of Figure 3 (Fig. 16). Commonly, as at locality 9, all marker beds are present, and the shaly beds are much thinner than usual. Attention has been called to this phenomenon by Hattin (1985), who →

FIGURE 15. Photomicrographs of thin sections cut from samples of limestone and shale of the Bridge Creek Member (×40, plane-polarized light). A, Biomicritic wackestone in which calcispheres are the predominant grain type. Sample collected from marker bed HL-1, locality 7, Pueblo, Colorado. B, Biomicritic wackestone that contains subequal proportions of foraminiferal tests, calcispheres and inoceramid bivalve debris. Sample collected from marker bed HL-3, locality 5, Taylor Springs, New Mexico. C, Biomicritic wackestone from marker bed JT-10, locality 5, Taylor Springs, New Mexico. High grain density and abundance of grains derived from inoceramid bivalves are characteristic of this bed. D, Biomicritic to biomicrosparitic wackestone from marker bed JT-13, locality 4, north of Folsom, New Mexico. Neomorphism of micrite to microsparite has obliterated skeletal structure of foraminifers. Rock is locally a packstone. Note pelletal grains near center of photomicrograph. E, Biopelmicritic wackestone/packstone from shaly bed lying between marker beds JT-2 and JT-3, locality 1, East Bridge Creek, Hamilton County, Kansas. Note excellent preservation of foram tests, which are the principal skeletal grains. Black streaks are wisps of organic matter. Light-colored part of matrix consists largely of fecal pellets (P). F, Biosparitic grainstone in which nearly all grains are tests of planktonic foraminifers. From shaly interval between marker beds HL-4 and JT-1, locality 5, Taylor Springs, New Mexico.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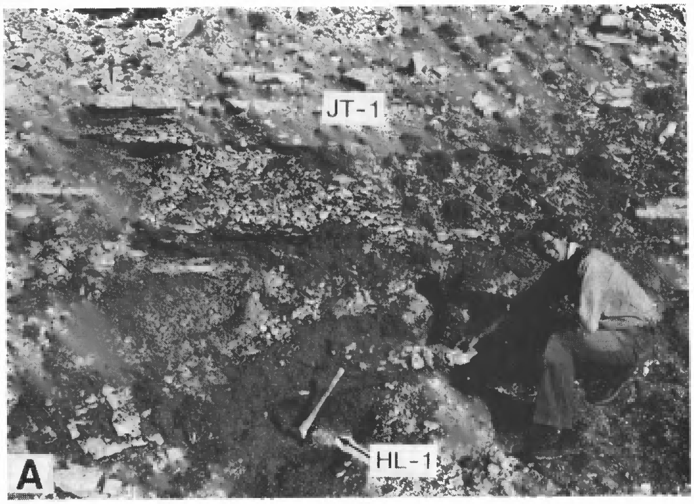

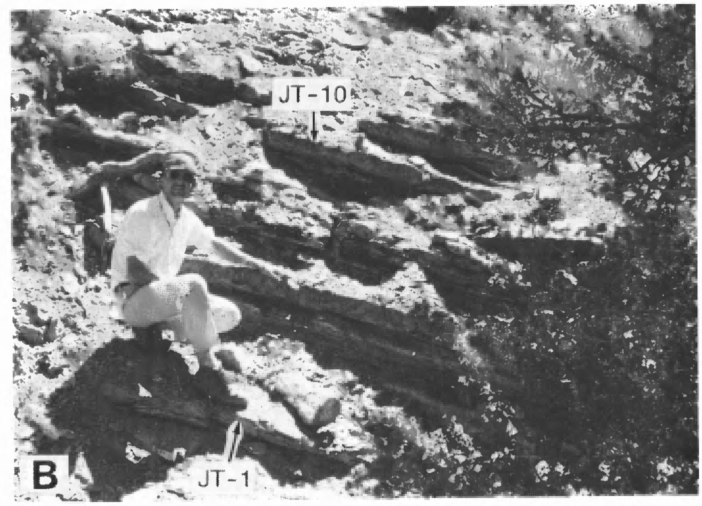

FIGURE 16. A, Roadcut in Bridge Creek Member at locality 4, north of Folsom, New Mexico, showing greatly condensed section between base of marker bed HL-1 and base of marker bed JT-1. B, Natural exposure of Bridge Creek Member at locality 10, northwest of Torres, Colorado, showing greatly condensed section between base of marker bed JT-1 and top of marker bed JT-10.

noted correspondence of condensed sections to structural highs of the western Great Plains and Southern Rocky Mountain regions. For example, the sections near Thatcher, Badito and Folsom (Figs. 5, 6) are much thinner than the sections at Pueblo, Las Animas or East Bridge Creek (Figs. 5, 6). The Thatcher section lies directly on the Model Anticline (Bass and others, 1947), the Folsom section lies near the axis of the Sierra Grande arch, and the Badito section lies on the southern nose of the Wet Mountains uplift. The writer (Hattin, 1985) opined that correspondence of the thinner sections with such structures relates to depositional control by early vertical movements of Laramide origin. Of course, any such movements may have involved reactivation of older structures, such as the Sierra Grande arch, which apparently had a profound effect on development of the Folsom section (Figs. 5, 16A). Whatever the cause of condensed sections in the Bridge Creek, relatively little effect has been detected in the younger Fort Hays Limestone Member of the Niobrara Chalk. Regional surface and subsurface study of the Niobrara Formation generally (Weimer, 1978) and of the Fort Hays Member in particular (Laferriere et al., 1987) revealed no sections that are condensed to the degree that Bridge Creek sections are condensed at Thatcher, Badito and Folsom. Depositional topography that prevailed during Bridge Creek deposition, whether of Laramide or earlier origin, must have been largely buried at the advent of Fort Hays deposition. Establishment of Laramide versus pre-Laramide origins for topographic features that influenced Bridge Creek deposition will require evaluation of a much-expanded stratigraphic data base, including an extensive network of subsurface sections. Such a study would facilitate detailed definition of thinning trends and permit better matching of condensed or greatly thickened sections with either preexisting or contemporaneous structural/topographic highs.

DEPOSITIONAL ENVIRONMENTS

Rhythmically-bedded deposits of the Bridge Creek Member were laid down on a vast shelf (or ramp) on which topographic highs locally interrupted the otherwise flat and exceedingly monotonous submarine plain. Pelagic carbonate and hemipelagic siliciclastic sediments settled in relatively deep water, and accumulated under conditions of generally poor benthic circulation. Even the best of circumstances favored benthic faunas having low overall diversity (cf. Elder and Kirkland, 1985) and consisting largely of oysters and inoceramid bivalves. During most episodes of increased siliciclastic influx, the upper part of the water column was probably brackish, pelagic productivity was diminished, benthic circulation was at a minimum, and endobenthic organisms were scarce or nonexistent (Hattin, 1971; Pratt, 1984; Fischer and others, 1985). During times of lesser siliciclastic influx, all of the water column was probably closer to normal marine salinity, benthic circulation was better, an extensive endobenthos became established, accumulating sediments were thoroughly bioturbated, and the sediments probably underwent early lithification as indicated by the manner in which body and trace fossils are preserved (Hattin, 1986b).

Contrasting with such sediments are lenses and very thin lensing beds of skeletal grainstone that bespeak winnowing of bottom sediments and lag concentration of largely disarticulated oyster valves, inoceramid bivalve debris, planktonic foraminiferal tests, calcispheres and vertebrate skeletal elements. Such lenses are concentrated in three parts of the Bridge Creek section. The first is between marker beds JT-1 and JT-2, where a thin bed or group of lenses of skeletal grainstone, largely foraminiferal, occurs at nearly all localities between northeastern Kansas and the Four Corners area of New Mexico. Clearly, this occurrence bespeaks a single, nearly basinwide event, such as a major storm (Hattin, 1986b). Skeletal grainstones are also characteristic of the shaly intervals that lie between marker beds JT-9 and JT-13, inclusive (Figs. 5, 6), and consist mostly of debris derived from inoceramid bivalves, which abound not only in the shaly beds but also in marker beds JT-10 through JT-12. Essentially basinwide occurrence of greatly increased numbers of these bivalves and of bivalve-derived grainstones throughout the interval suggests a prolonged change in the degree of benthic circulation and strength of benthic currents. I suggest that the grainstone-rich interval represents an episode of shallowing which, because the affected area is so vast, was probably of eustatic origin. The third major concentration of Bridge Creek grainstones occurs within the Pfeifer equivalent, and is separated from that in the upper Jetmore equivalent by only a thin interval of shaly rock that lacks skeletal grainstone. Widespread development of grainstones in the Pfeifer equivalent apparently represents another eustatically controlled sea-level drop, which began the general regression that is manifest in stratigraphically-upward change to entirely siliciclastic facies within the overlying Carlile Shale.

In addition to the stratigraphic occurrences outlined above, skeletal grainstones occur more generally through the Bridge Creek Member wherever the section is greatly condensed (Figs. 5, 6). If the condensed sections do, indeed, mark ancient sea-floor highs (Hattin, 1985, 1986a), the water depths over such highs would have been shallower than elsewhere, and benthic circulation would have been much greater than off the highs, even during times of water-column stratification (Hattin, 1986a). The inverse relationship between thickness of the HL-1 through JT-13 interval and the extent of skeletal grainstone development within this interval suggests that the two are related genetically.

CONCLUDING STATEMENT

Within the field-conference area, rhythmically bedded Bridge Creek strata display more vertical and lateral variation than is usual for equivalent strata in Kansas and along the Arkansas River in eastern Colorado. Sea-floor highs related to the reactivation of Late Paleozoic structures or to the early onset of Laramide tectonics are the probable cause of these irregularities, which include greatly condensed sections, locally great increases in abundance and vertical distribution of skeletal grainstones, scour features, variation in number of limestone-shale couplets between well-defined marker beds of the HL-1 to JT-1 interval, local development of limestone-pebble conglomerate and marked increase in thickness of single beds within short distances. Most of these variations are probably attributable to the vagaries of current and/or wave action on and adjacent to local highs. This question is currently under investigation by the Cretaceous Research Group at Indiana University.

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Cone of an extinct volcano (center) at Yankee, Colfax County, New Mexico. Photograph by W. T. Lee circa 1900–1910, courtesy of the U.S. Geological Survey and R. Eveleth, NMBMMR.