ratigraphy and Depositional Environment of Greenhorn Limestone (Upper Cretaceous) of Kansas

nald E. Hattin

Bulletin 209

Kansas Geological Survey University of Kansas Lawrence, Kansas 1975

Cover photograph of Jetmore Member, Russell County (see Figure 10A)

BULLETIN 209

Stratigraphy and Depositional Environment of Greenhorn Limestone (Upper Cretaceous) of Kansas

By

Donald E. Hattin
Indiana University

Printed by authority of the State of Kansas
Distributed from Lawrence
UNIVERSITY OF KANSAS PUBLICATIONS
MAY 1975

Contents

Figures

Plates

Tables

Donald E. Hattin[1]

Stratigraphy and Depositional Environment of Greenhorn Limestone (Upper Cretaceous) of Kansas

RESUMÉ

In Kansas the Greenhorn Limestone consists predominantly of dark colored, impure shaly chalk and has an average thickness of 94.8 feet in surface exposures studied. The basal, Lincoln Member is characterized by abundance of skeletal grainstone and numerous thin seams of bentonite. Based on 11 measured sections the member ranges from 16.2 to 33 feet in thickness. The overlying Hartland Member has little skeletal grainstone but in central Kansas contains three widely traceable, time-parallel beds of burrow-mottled chalky limestone and four equally widespread bentonite seams. Based on 14 measured sections the Hartland ranges from 8.6 to 68 feet in thickness. In central Kansas the Hartland is overlain by the Jetmore Member, which is characterized by thirteen ledge-forming beds of chalky limestone that can be traced confidently for hundreds of miles. In 18 measured sections the Jetmore ranges from 12.9 to 22.6 feet in thickness. Comprising the upper part of the Greenhorn in central Kansas, the Pfeifer Member is characterized best by its content of concretions and concretionary beds of chalky limestone. In 14 measured sections the member ranges from 15.2 to 25.8 feet. Presence of widespread marker beds makes possible the recognition of exact equivalents of the Pfeifer, Jetmore, and most of the central Kansas Hartland in the Bridge Creek Member of western Kansas. Chalky strata of the Greenhorn Limestone are related genetically to the superjacent Fairport Member of the Carlile Shale.

The Greenhorn Limestone is disconformable on the Graneros Shale across most of central Kansas. The Graneros-Greenhorn contact is diachronous, ascending temporally in a northeasterly direction. Most of the type Hartland grades northeastward into the Lincoln Member of central Kansas, and the lower part of the Bridge Creek Member passes northeastward into the central Kansas Hartland. The Hartland-Jetmore, Jetmore-Pfeifer, and Pfeifer-Fairport contacts are time parallel.

Inoceramid bivalves are the only ubiquitous Greenhorn macroinvertebrates and almost everywhere are represented only by the prismatic shell layer. Ammonites are common in some beds and are preserved mostly as molds. Diversity of macroinvertebrates is very low in most beds. A sequence of assemblage zones has been established, based on common, *readily identifiable* forms. The major assemblage zones (ascending) are characterized by the following species: *Acanthoceras wyomingense*; *Calycoceras? canitaurinum-Exogyra* aff. *E. boveyensis; Sciponoceras gracile*; *Mytiloides labiatus-Watinoceras reesidei*; *M. labiatus-Mammites nodosoides wingi*; and *M. labiatus-Collignoniceras woollgari-Inoceramus cuvieri*. In respective order these zones occur in (1) the lower Lincoln of Hodgeman, Ford, and Kearny Counties and upper Graneros of Mitchell County; (2) lower Lincoln of central Kansas and middle or upper Lincoln in Hodgeman, Ford, and Kearny Counties; (3) near middle of Hartland Member in central Kansas and in lower part of Bridge Creek in western Kansas; (4) upper part of Hartland and lower part of Jetmore in central Kansas and stratally equivalent part of Bridge Creek in western Kansas; (5) upper two thirds of Jetmore and equivalent part of Bridge Creek; and (6) middle part of Pfeifer and equivalent part of Bridge Creek to basal part of Fairport Member, Carlile Shale. Greenhorn beds below the top of the S. *gracile* zone are of late Cenomanian age; the remainder of the formation is of early Turonian age.

Thin section study is the basis for recognition of three major carbonate rock types, viz. skeletal grainstone, micritic shaly chalk having both packstone and wackestone textures, and micritic to microsparitic chalky limestones that have mudstone, wackestone, and packstone textures with wackestone predominating. Principal allochems are foraminifer tests, *Inoceramus* debris, and fecal pellets, with locally abundant calcispheres. Unaltered micritic matrices are composed largely of coccoliths. During diagenesis compaction was greatest in shaly chalks, cementation was greatest in skeletal grainstones, and neomorphism was widespread among chalky limestones.

Greenhorn carbonates are predominantly of pelagic origin and were deposited on the broad, flat eastern shelf area of the Western Interior region, far from major sources of terrigenous detritus. The formation was deposited near and at the peak of an eastwardly directed marine transgression that began in Cenomanian time and reached its maximum during early Turonian time. Concentrations of skeletal grainstones in the basal part of the Lincoln Member reflect a far-offshore high-energy

[1] Department of Geology, University of Indiana, Bloomington, Indiana.

depositional environment that was bordered on the east by a shallower water area of terrigenous mud deposition (Graneros) and on the west by a deeper water, lower-energy environment in which most sediment was carbonate mud.

Although wide diversity of opinion is evident in literature on depth of Cretaceous chalk deposition, and even for chalks of the American Western Interior region, the Greenhorn of Kansas was probably laid down at depths considerably less than 600 feet. During deposition, bottom conditions were generally unfavorable to development of a diverse epibenthos, and reducing conditions precluded an endobenthos in most shaly-chalk-producing sediments. Widespread, time-parallel beds of chalky limestone resulted from periods of reduced rates of sedimentation which generally fostered development of a burrowing endobenthos. Generally poor circulation of bottom water is manifest in the more or less laminated, dark-colored shaly chalk strata that dominate the formation (energy level 1). Zones of small lenses of fairly well-washed skeletal limestone and beds with great abundance of *Inoceramus* reflect times of increased circulation by moderate-strength bottom currents (energy level 2). Discontinuous beds and zones of lenses of skeletal grainstone, mostly in the Lincoln Member, represent a still higher level of energy expenditure on the sea floor (energy level 3). At the base of the Lincoln Member, beds of crossbedded skeletal grainstone, commonly containing a variety of rudaceous components, represent the highest energy levels of the Greenhorn (energy level 4).

Broad uniformity of paleobiotic composition suggests stable salinity. Diverse assemblages of coccoliths and planktonic foraminifera, as well as ammonites, pycnodont oysters and probably the inoceramids as well, suggest water of normal salinity in the far-offshore area of Greenhorn deposition.

Zoogeography of Greenhorn invertebrates suggests the area lay near the southern limit of the North Temperate realm with corresponding warm-temperate waters. The gross imbalance between numbers of benthonic and planktonic foraminifera is a result of poor oxygenation on the sea floor. Most Greenhorn ammonites seem to have been nektobenthonic forms. Occurrence of abundant epizoal oysters parallels that of skeletal limestones and is related to periods of better circulation of bottom waters. The inoceramids were predominantly free-living benthonic forms that owe their ubiquitous distribution to environmental adaptability.

INTRODUCTION

Purpose and Scope of the Investigation

Description of the Greenhorn Limestone in Kansas is included in a large number of State Geological Survey bulletins that treat collectively the geology of most counties lying along the outcrop. In these reports the detail with which the formation is described ranges widely in quality and completeness. Except for studies in Russell County (Rubey and Bass, 1925) and of Greenhorn ammonites by Morrow (1935) and by Cobban and Scott (1972) little has been published on the stratigraphic distribution of the macroinvertebrate fossils, and almost nothing has been published concerning geographic distribution of the fossils. The writer (Hattin, 1971) has discussed the regional stratigraphy and origin of burrow-mottled limestone beds in the middle part of the formation but no other attempt has been made previously to synthesize stratigraphic, lithologic, and paleontologic data gathered from all areas of the Kansas outcrop.

This study is based on field investigations conducted during parts of each summer from 1962 to 1968, and 1971, and on laboratory study of rock samples and fossils collected during that period. Locality data for all studied sections are summarized in Table 1. Detailed measurement of the Greenhorn section at key locations across the State has been used to document the remarkable lateral persistence of many limestone beds in the formation and to demonstrate the uniformity of vertical sequence in most areas. These features are depicted graphically in Plate 1 (pocket). Special attention has been accorded the systematic search for macroinvertebrate fossils for the following reasons: 1) this part of the fauna is incompletely known, 2) the formation has not been zoned adequately throughout the State, and 3) because of the need to effect more accurate correlation with other parts of the Western Interior region, with the Gulf Coast region, and with other parts of the world. Lithologic composition, texture, and structure; stratigraphic distribution of rock types; and distribution, diversity, and abundance of fossils all have been used to shed light on the probable conditions of origin of Greenhorn rocks in the State. A primary objective of this investigation has been the interpretation of depositional environments, paleoecology, and the evolution of the Kansas section as a part of the Upper Cenomanian and Lower Turonian stratigraphic framework of the Western Interior region.

Although a great body of data has been gleaned from X-ray analyses, thin section point counting, study of laminations, and insoluble residue determinations, as well as from field study of measured sections, a report including all these aspects of the rocks would be needlessly cumbersome. Therefore, some parts of the study have been treated as separate entities and are published elsewhere (Hattin, 1968, 1969, 1971; Hattin & Darko, 1971; Hattin and King, in prepration; Kauffman and Hattin, in preparation). The results of these separate studies are merely summarized and the conclusions therein incorporated in the general synthesis. It is hoped that this report will stimulate further investigation of Greenhorn rocks in Kansas; of especial interest in this regard are quantitative studies of trace-fossil distribution and diversity, geochemical studies directed toward further evaluation of depositional conditions for chalk deposits, and ultramicroscopic analysis of fine-grained carbonate rocks.

Previous Work[1]

Among the earliest accounts of beds referable to the Greenhorn Limestone are those by Hayden (1872, p. 67), Mudge (1876, p. 219; 1877, p. 289; 1878, p. 64) and St. John (1883, p. 589; 1887, p. 145). In all of these reports the stratigraphic descriptions are brief; in the first three and in the last of the six papers cited the Greenhorn beds were assigned erroneously to the Niobrara Chalk. Mudge (1876, 1877) recorded the fossils *Inoceramus problematicus (I. labiatus)*, *Gryphaea*[2], *Belemnite* (sic), and an *Ammonite* (sic) in a persistent, thin stratum which from description is apparently the Fencepost limestone bed. In a later paper St. John (1883, p. 589) reported the presence of *Ostrea congesta* in limestones of the Fort Benton Group but he included the Fort Hays Limestone Member (of the present nomenclature) in the Benton and did not make clear to which limestone he referred. In yet another description of the Benton in Kansas, Hay (1889, p. 101) reported the common occurrence of petrified logs in beds now assigned to the Greenhorn. Division of the Kansas Benton on a sound lithologic basis was attempted by Cragin (1896) but his work was ignored, presumably because formational names used by him were preoccupied. He was apparently first to use the name "fencepost bed" for the top layer of chalky limestone in the Greenhorn, and the name "Lincoln Marble" for beds now included in the Lincoln Member. In a more comprehensive division of the Benton, Logan (1897, p. 216) also used the name "Lincoln Marble" for basal beds of the Greenhorn; names used by him for other parts of the Greenhorn have since been dropped. The earliest major work involving Greenhorn fossils in Kansas is that of Logan (1898) who described fossils of the Benton, Niobrara, and Fort Pierre Groups. In a table he listed 23 species of invertebrates, ascribing 11 to the Lincoln Marble and the rest to the Limestone Group (remainder of Greenhorn of present usage). In the text, however, four of the species tabulated as Lincoln are described as coming from beds *below* the Lincoln and six more of these are not described at all. In addition, four species described in his text as occurring in the Lincoln or Fort Benton Limestone Group are not included in his table of species. Of the Greenhorn species I have recorded in the present report, only two (*Collignoniceras woollgari* and *Mytiloides labiatus*) are included in Logan's work. Some of the species that Logan attributed to the Greenhorn are now known to be restricted to younger beds, and a few of the forms he described are now recognized under totally different names. Many of the species he recognized in the Kansas section are illustrated by figures of non-Kansas specimens and were taken from older works. In terms of biostratigraphy and taxonomic paleontology much of his work is meaningless.

In a later work Logan (1899) gave a detailed description of the Limestone Group (Greenhorn of present nomenclature) of Kansas; though still retaining the Bituminous shale (Graneros Shale) in the Limestone group, he described the former unit separately, perhaps recognizing the need for classification as a discrete unit the shales now called Graneros. In this paper he gave the name *Ostrea congesta* var. *bentonensis* to the little oyster that is common in the upper part of the Greenhorn and lower part of the Fairport Member of the Carlile Shale. He (Logan, 1899, p. 91) terminated the paper with a table showing correlation of the Bituminous shale and the Limestone group of Kansas with the Graneros Shale and Greenhorn Limestone, respectively, of Colorado. In another work on the Cretaceous fossils from Kansas, Logan (1899a, p. 214, 215) described *Ostrea beloiti* and *Astrocoenia conica*[3] from the Lincoln.

The term "Greenhorn" was first used for Kansas rocks by Darton (1904, pl. 36); he (Darton, 1905, p. 152-154) summarized briefly the stratigraphy of the Kansas section, using the nomenclature of Logan (1897), but recognizing a unit called "shales" between the Lincoln marble and the Flag horizon.

An abbreviated account of the Kansas Greenhorn appeared in the work "Oil and Gas Resources of Kansas" by Moore and Haynes (1917, p. 129) and Moore (1920, p. 129) repeated this description verbatim. Darton (1920, p. 2) described the Greenhorn of the Hamilton and Kearny County area, but persisted in using the nomenclature of Logan (1897). For Kansas geology Darton's publication marked the end of an era that was characterized by generalized descriptions of the Greenhorn.

Beginning with the Russell County report of Rubey and Bass (1925) the State Geological Survey issued over a period of eight years a series[4] of Bulletins describing the geology of nine counties that include parts of the Greenhorn outcrop. These reports contain the most comprehensive treatments of the Greenhorn that have been published heretofore and founded our present knowledge of thickness, lithology, important fossils, and correlations. The Greenhorn members, as now rec-

[1] Paleontologic studies of vertebrate fossils are omitted.

[2] To my knowledge *Gryphaea* does not occur in the Greenhorn of Kansas. Prof. Mudge may have referred to small specimens of *Inoceramus cuvieri* which are common in the upper part of the Greenhorn and which, when not completely exposed, bear superficial resemblance to *Gryphaea*.

[3] No subsequent record of this coral is known to me.

[4] Bull. 10, 1925; Bull. 11, 1926; Bull. 15, 1930; Bull. 16, 1930; Bull. 19, 1932.

ognized by the Kansas Geological Survey, were named and defined in the first two of these bulletins. A tabulation of fossils by members is included in Bulletin 10 (Rubey and Bass, 1925). Paleontologic studies of Colorado Group microfossils (Morrow, 1934) and cephalopods (Morrow, 1935) include descriptions of many species, several of them new, from the Greenhorn Limestone. Morrow's unpublished Ph.D. thesis (Yale Univ., 1941) includes the most comprehensive treatment of invertebrate fossils from the Greenhorn of Kansas. A detailed report on the Upper Cretaceous stratigraphy of the Arkansas River region of eastern Colorado was published by Dane and others (1937). This useful work includes a list of Greenhorn fossil species and discussion of the relationship of those strata to the Greenhorn Limestone of Kansas.

Beginning in 1942, the Kansas Geological Survey commenced publication of county geology and ground-water reports in a cooperative program with the U.S. Geological Survey. This series of bulletins has been continued to the present time and includes reports on many counties that contain part of the Greenhorn outcrop. All of these bulletins contain descriptions and usually representative measured sections of the formation, but the information is designed largely for non-geologists and stratigraphic details commonly have been taken from older reports.

The Greenhorn of west-central Kansas was the subject of an unpublished master's thesis by D. W. Bergman (1949). He measured partial sections of the formation at a number of localities and traced this unit and its members across a large part of the outcrop. Bergman (1949) recognized many of the marker beds referred to in the present report and traced some of them, especially the Fencepost bed, Sugar sand, Shell-rock bed, three hard beds in the upper part of the Jetmore Chalk Member, and the bentonite lying at the top of Hartland Shale Member, across the entire central Kansas outcrop. He erred in concluding that the only widely traceable marker in the Hartland is the bentonite lying near the top of that unit. He (p. 24) noted the similarity of the Pfeifer Member and lower part of the overlying Carlile Shale, as did Rubey and Bass (1925), and regarded the contact between the Lincoln and Hartland Members as the most difficult to establish. He stated (p. 24) "In some cases it might be as well not to attempt to separate the lower Greenhorn limestone into its two members." Bergman (1949, p. 23) summarized the conditions of Greenhorn deposition in Kansas.

Subsurface studies of western Kansas have resulted in publication of several Oil and Gas Investigations stratigraphic cross sections by the State Geological Survey. Cross sections prepared by Merriam (1957) are parts of a general study of Mesozoic rocks in the western part of the State and include the Greenhorn Formation. These cross sections indicate that Greenhorn beds underlie virtually all of western Kansas north of the Arkansas River and west of the Greenhorn outcrops. Merriam (1957) used the top of the Fencepost limestone bed as datum for his cross sections, and described its characteristic electric log kick. An interesting, popularized account (Muilenburg, 1958) of the Fencepost bed and its utilization includes much information of historical significance.

In a paper treating Carlile ammonites from Trego County, Kansas, Matsumoto and Miller (1958, p. 354) were first to record *Collignoniceras woollgari* (Mantell) in the uppermost part (Fencepost limestone bed) of the Greenhorn Limestone. A brief summary of Greenhorn stratigraphy was compiled by Merriam (1963, p. 51) for his compendium on the geologic history of Kansas. The writer (Hattin, 1964) described lithologic and paleontologic aspects of the Greenhorn, and broad features of depositional environments of the formation, in a paper on cyclic sedimentation in the Colorado Group. Upper Cretaceous strata of western Kansas have been treated extensively in a guidebook prepared by the writer (Hattin, 1965) for the 1965 annual meeting of the Geological Society of America. Salient features of stratigraphy, paleontology, and depositional environment of the Greenhorn, as well as detailed measured sections, appear in that work. In a recent symposium on Upper Cretaceous paleoecology of the Western Interior Region (Kauffman and Kent, coch., 1967) several of the authors include brief discussion of various paleoecologic aspects of Greenhorn Limestone of Kansas. Biostratigraphic relationships adjacent to the Graneros-Greenhorn contact have been documented by the writer (Hattin, 1968) in a paper concerned largely with recent, significant discoveries of the ammonite *Plesiacanthoceras wyomingense* (Reagan). A reference section for the Lincoln Member of the Greenhorn has been described recently by the author (Hattin, 1969). Recent interest in Late Cretaceous microfossils has sparked a series of papers that include material from the Greenhorn Limestone of Kansas. Eicher (1969) has summarized the stratigraphic distribution of Western Interior planktonic foraminifera of Cenomanian and Turonian age. Cepek and Hay (1969) have established a zonation of the Greenhorn Limestone of Russell County, Kansas on the basis of calcareous nannoplankton. Eicher and Worstell (1970) have documented the stratigraphic distribution of *Lunatriella* in the Greenhorn and lower Carlile Shale of Kansas and other areas, and Eicher and Worstell (1970a) have completed a comprehensive taxonomic study of Greenhorn foraminifera. Abun-

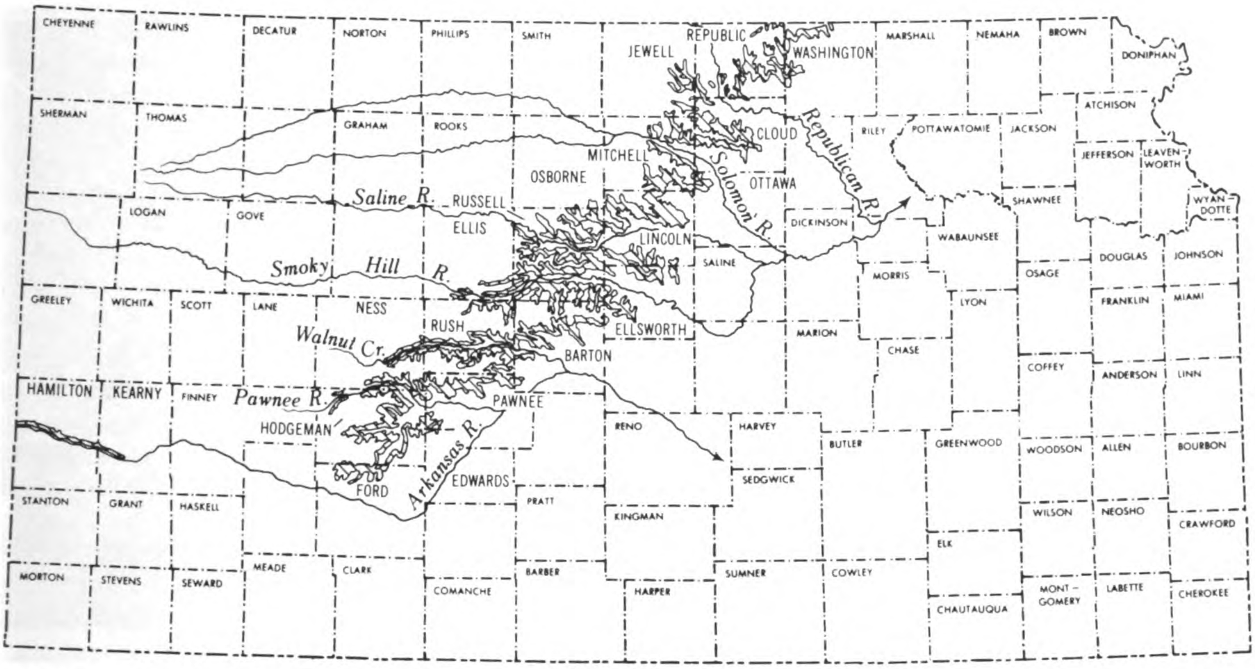


Figure 1.—Map of Kansas showing outcrop (diagonal ruling) of Greenhorn Limestone. Named counties are those in which Greenhorn Limestone crops out.

dance of coccoliths in shaly chalk of the Kansas Greenhorn was discussed by Hattin and Darko (1971). The writer (Hattin, 1971) has published a detailed account of the stratigraphy, trace fossils, petrology and origin of widespread, time-parallel limestone beds in the Hartland and Jetmore Members of the Greenhorn. Cobban (1971, p. 16) reported *Calycoceras naviculare* (Mantell) from the lower part of the Bridge Creek Limestone Member in Hamilton County, Kansas, and, in a comprehensive report on ammonites from the Graneros Shale and Greenhorn Limestone, Cobban and Scott (1972) have presented an account of the type Bridge Creek and its macroinvertebrate fauna in Hamilton County, Kansas. In this work they report the presence of many ammonite species not recorded previously in the Greenhorn and in Hamilton County they discovered several species not known in central Kansas. Finally, Huh and Smith (1972) have described coccoliths from the Fencepost Limestone bed of northwestern Kansas.

Location and Description of the Area

Geography.—In central Kansas the Greenhorn outcrop trends almost exactly northeastward from the southern terminus in Ford County to the Nebraska border in Washington County and occupies parts of fifteen intervening counties (Fig. 1). The outcrop area is a maximum of 215 miles long and is approximately 50 miles wide across Ellsworth, Russell, and Ellis Counties, measured perpendicular to the outcrop trend. The best natural exposures of the Greenhorn are along major drainage courses including, from south to north, Pawnee River and its southern tributaries (Sawlog and Buckner Creeks), Walnut Creek, Smoky Hill River (Fig. 2,A) and one of its northern tributaries (Big Creek), Saline River and one of its northern tributaries (Wolf Creek), Solomon River and one of its southern tributaries (Salt Creek), Republican River and one of its southern tributaries (Buffalo Creek) and Mill Creek (a western tributary to Little Blue River). Road and dam construction has produced many excellent artificial exposures (Fig. 2,B), some of which span the entire thickness of the formation. Natural exposures are poor in much of the northern part of the outcrop area, owing to Pleistocene surface deposits and heavy vegetation, and in Barton and Pawnee Counties owing largely to relatively gentle terrain.

Interstream areas of the central Kansas outcrop are mostly flat to gently rolling uplands (Fig. 2,C) largely underlain by Greenhorn Limestone and the lower part of the Carlile Shale (Fairport Chalk Member), and are devoted extensively to the growing of wheat and other grain crops or to pasturage. Along the walls of larger streams, hilly terrain underlain by Greenhorn rocks is utilized chiefly as pasturage. Erosion has not produced notable landmarks in the Greenhorn outcrop, but hills along the Greenhorn escarpment, described below, add scenic interest to the landscape.

In western Kansas, the Greenhorn Limestone crops out mainly along the north bluffs of the Arkansas River

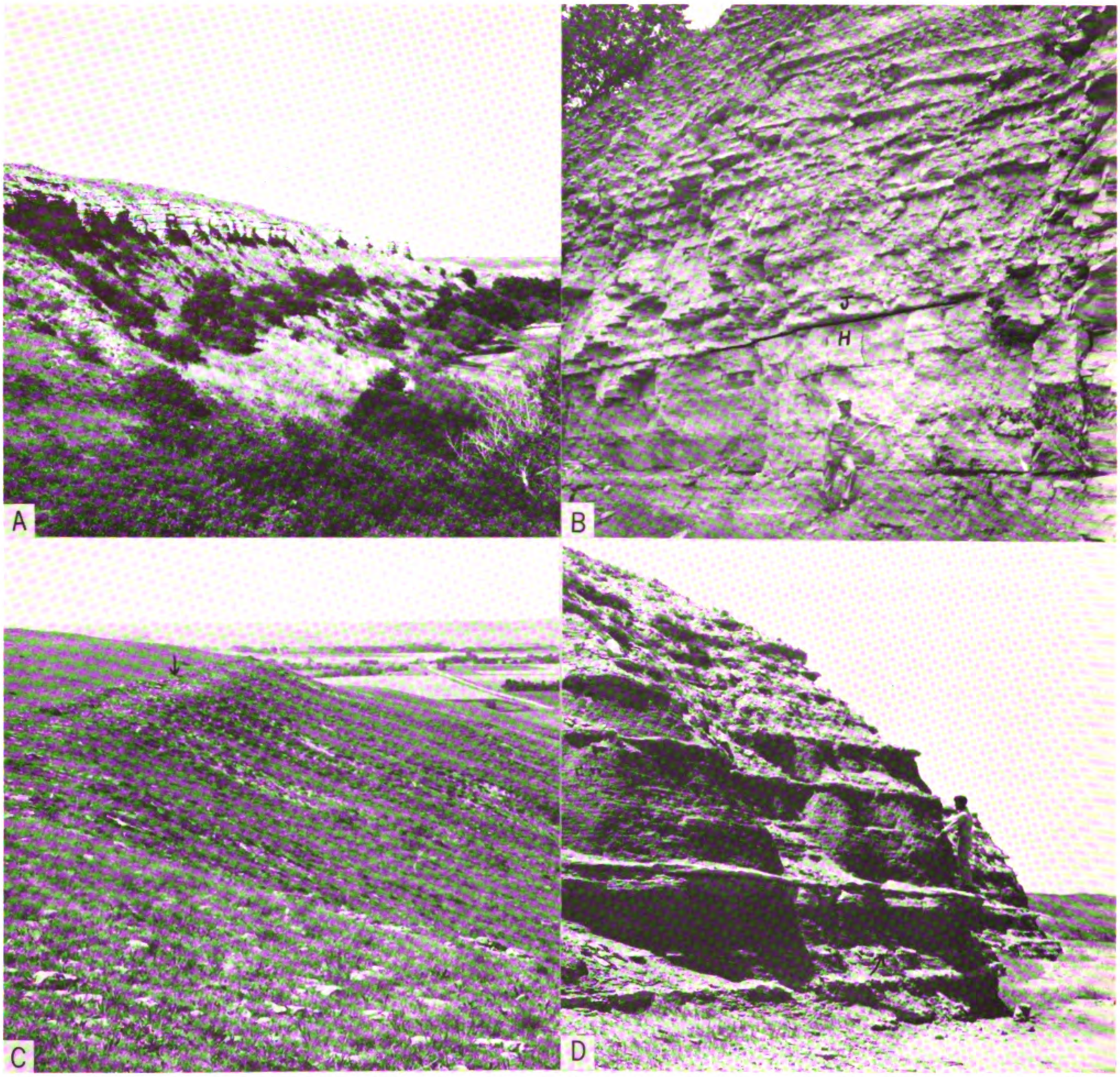


FIGURE 2.—Characteristic exposures and topographic features of Greenhorn Limestone. A) Natural exposure of Greenhorn Limestone in bluff along north side of Smoky Hill River, sec. 18, T. 15 S., R. 15 W., Russell County (Loc. 40). Bluff is part of Greenhorn escarpment. Cliffs are formed by Jetmore Member; slope below is formed by Hartland Member. B) Cut on former route of Missouri Pacific Railroad at Glen Elder, sec. 27, T. 6 S., R. 9 W., Mitchell County (Loc. 63). Contact between Hartland and Jetmore Members is marked by the black line. C) View toward south across Saline River valley showing flat topography (distant uplands and at far left) developed on Greenhorn Limestone in interstream areas, sec. 2, T. 13 S., R. 11 W., Russell County (¼ mi. E. of Loc. 28). Hills are part of Greenhorn escarpment. Shellrock bed forms bench indicated by arrow. D) Natural exposure of Bridge Creek Limestone Member on East Bridge Creek, sec. 14, T. 23 S., R. 42 W., Hamilton County (Loc. 14). Jim Cocke is standing on Shellrock limestone bed. Arrow marks beds of chalky limestone concretions.

in a slender belt approximately 40 miles long and extending from near Hartland, Kearny County, west-northwestward to the Colorado border. In addition small inliers have been mapped south of the river in Hamilton County (see Bass, 1926). The major outcrop reaches a maximum width of approximately two miles along valleys of northern tributaries to the Arkansas River; most exposures are natural, the best being along these tributaries (Fig. 2,D). Along the main outcrop the hilly terrain is devoted almost entirely to pasturage.

General Geology.—The Greenhorn Limestone has long been classified as part of the Colorado Group which in Kansas is divided as shown in Figure 3.

In Hamilton and Kearny Counties rocks equivalent to the Pfeifer, Jetmore, and upper two thirds or more of the Hartland are included in a unit called Bridge Creek Limestone Member.[5]

Throughout most of western Kansas the Greenhorn lies disconformably on the Graneros Shale (Hattin, 1965a, p. 11; 1968) but locally, as at Locality 6 (see Table 1 for a description of the localities) in Washington County, Locality 1 in Mitchell County, and in Kearny County (Loc. 12), this contact is conformable or nearly so. The Greenhorn is overlain conformably by Fairport rocks of the same lithology that have been excluded, incorrectly in my view, from the Greenhorn.

At the northeastern end of the central Kansas outcrop, in Washington and Republic Counties, the Greenhorn is overlain locally by Pleistocene deposits. At the southern end of this outcrop, in Hodgeman and Ford Counties, the Greenhorn is truncated by the east-dipping beds of the Ogallala Formation (Pliocene), especially in the vicinity of Sawlog Creek. At all other places studied by the writer, the Greenhorn underlies the present land surface or is overlain by younger Cretaceous strata.

In central Kansas the Greenhorn crops out in a northeast-trending belt that lies in the eastern part of the Blue Hills district of the Dissected High Plains (Schoewe, 1949, p. 309). Width of Greenhorn outcrop ranges from less than one-fourth mile in bluffs along larger streams, to several miles in interstream areas having gentle slopes such as north of the Smoky Hill River in Russell and Ellsworth Counties, and adjacent to Walnut Creek in Rush County. The southeastern outcrop margin is marked by the intricately dissected Greenhorn escarpment (Figs. 2,A,C) which serves to define the boundary between Blue Hills and Smoky Hills. Relief at this escarpment is greatest along the valleys of the major streams which flow across the outcrop in a dominantly eastward direction. The escarpment is deeply embayed where these streams intersect the southeastern border of the outcrop. In these valleys local topographic relief commonly exceeds 200 feet at the northern and southern ends of the outcrop and is more than 300 feet along Saline River valley in northeastern Russell County and west of Delphos in Ottawa County. Near the southeastern edge of the outcrop, limestones in the Lincoln Member, the Shellrock limestone bed in the Jetmore Member, the Fencepost limestone bed in the Pfeifer Member, and the lowest persistent chalky limestone bed in the Fairport Member of the Carlile have served as major controls in the development of upland topography in bluffs adjacent to stream courses (Figs. 4,A,B,C). These same beds locally form well-developed benches below the upland level (Fig. 2,C). In some parts of the area outliers of the Greenhorn form prominent hills whose butte- or mesa-like profiles have been subdued because the bedrock is soft and the caprock thin. One of the more accessible of these hills is crossed by Interstate Highway 70 at Locality 68, Lincoln County.

COLORADO GROUP	NIOBRARA CHALK SMOKY HILL CHALK MBR. FORT HAYS LIMESTONE MBR.
	CARLILE SHALE CODELL SANDSTONE MBR. BLUE HILL SHALE MBR. FAIRPORT CHALK MBR.
	GREENHORN LIMESTONE PFEIFER SHALE MBR. JETMORE CHALK MBR. HARTLAND SHALE MBR. LINCOLN LIMESTONE MBR.
	GRANEROS SHALE

FIGURE 3.—Stratigraphic classification of Colorado Group in central Kansas.

The full thickness of the Greenhorn is exposed in some steep bluffs along Saline and Smoky Hill Rivers or in artificial cuts at damsites and along roads that cross the Greenhorn Escarpment as at Localities 2, 3, 28 and 62 in Russell County, at Localities 1 and 4 in Mitchell County, and at Locality 68 in Lincoln County. The most striking natural exposures are in cliffs or steep bluffs held up by chalky limestone beds in the upper part of the formation; such exposures are numerous along nearly every major stream course. Because of the large number and close spacing of limestone and chalky limestone beds in the Jetmore, this member is the chief cliff-forming unit and is therefore the best-exposed part of the Greenhorn in central Kansas.

In Hamilton and Kearny Counties the Greenhorn is exposed mainly in a narrow outcrop along the north side of Arkansas River. Here the river and its northerly tributaries have sliced through the Tertiary cover of the High Plains, thus exposing the underlying Cretaceous rocks in bluffs along the stream courses. Local relief in this area ranges from 150 to 180 feet, but the entire thickness of the Greenhorn is not exposed at any one locality. As in central Kansas, local benches are developed on limestones in the Lincoln Member and on the Shellrock and Fencepost beds in the upper part of the formation. A more prominent bench is developed on a thick chalky limestone marker bed that

[5] At the recommendation of Dr. Hattin the Stratigraphic Names Committee of the Kansas Geological Survey has voted to accept the Bridge Creek Limestone Member as a formal name in Hamilton and Kearny Counties.

FIGURE 4.—Features of the Greenhorn Limestone. A) Bluff held up by Lincoln Member, sec. 5, T. 25 S., R. 24 W., Ford County. B) Upland surface underlain directly by Fencepost limestone bed, sec. 3, T. 13 S., R. 11 W., Russell County (Loc. 28). Arrow marks position of sugar sand bed. C) Upland surface underlain directly by lowest persistent limestone bed (arrow) in Fairport Member, Carlile Shale, sec. 18, T. 13 S., R. 12 W., Russell County (Loc. 3). The bed beneath Jim Cocke's feet is Fencepost limestone. Note use of limestone posts in fence. D) Abandoned Fencepost limestone quarry, sec. 25, T. 21 S., R. 26 W., Hodgeman County (Loc. 10).

lies at the base of the Bridge Creek Member and that is equivalent to a bed in the Hartland Member that is referred to as HL-1 elsewhere in this report.

The top of the Greenhorn Limestone (Fencepost limestone bed) and, locally, the top of the Jetmore Member (Shellrock limestone bed) have been used as structural datum planes in some of the earlier maps of counties lying athwart the Greenhorn outcrop. As recorded on these maps local structural relief in the west-central Kansas outcrop is 10 to 12 feet per mile to the northwest in Republic and Cloud Counties (Wing, 1930, p. 42), 10 to 15 feet per mile to the north in Osborne and Mitchell Counties (Landes, 1930, p. 42), an average of 7 feet per mile in Russell County (Rubey and Bass, 1925, p. 66), 10 feet per mile just east of north in Ellis County (Bass, 1926, p. 42) and 10 feet per mile slightly east of north in Ness and Hodgeman Counties (Moss, 1932, p. 40). Regional

TABLE 1.—Description of Localities.

The first 24 localities listed below are those at which detailed stratigraphic sections were measured. The remaining localities (25 through 70) are sections of the Greenhorn that were examined for fossil content and supplementary stratigraphic detail. Thickness of selected marker beds and intervals between these marker beds were measured at localities 31, 36, 45, 47, 48, 50, 51, 56, 57, 58, 62, 64, 67, and 68.

Locality Number	Location	Description
1	SW¼ SW¼ sec. 27, T. 6 S., R. 9 W., Mitchell County.	Cut at north end of Glen Elder Dam at southwest corner of Glen Elder. Complete section.
2	West line, NW¼ sec. 35, and east line NE¼ sec. 34, T. 12 S., R. 14 W., Russell County.	Road cuts on U.S. Highway 281 shortly north of Saline River. Complete section.
3	West line, sec. 18, T. 13 S., R. 12 W., Russell County.	Road cuts on Luray-Bunker Hill road approximately 3½ miles north of Bunker Hill. Complete section.
4	East line, SE¼ SE¼ sec. 24, T. 8 S., R. 6 W., Mitchell County.	Road cuts and quarry on north-south county road approximately 3 miles south of Simpson. Complete section.
5	N½ sec. 28, T. 15 S., R. 17 W., Ellis County.	Bluff on north side of Smoky Hill River approximately 2½ miles WNW of Pfeifer. Complete section. ADJACENT TO PFEIFER TYPE SECTION.
6	South line, SW¼ sec. 5 and north line, NW¼ sec. 8, T. 3 S., R. 1 E., Washington County.	Road cuts on both sides of U.S. Highway 36 approximately 3 miles southwest of Haddam. Nearly complete section.
7	South line, SW¼ SW¼ sec. 4, T. 3 S., R. 1 W., Republic County.	Road cut on north side of U.S. Highway 36 approximately ¾ mile northeast of Cuba. Upper part of Pfeifer Member. Sections at localities 6 and 7 comprise a complete composite section.
8	SW¼ sec. 5, T. 25 S., R. 24 W., Ford County.	Cut bank and pasture on south side of Sawlog Creek approximately 10 miles north and 2 miles east of Dodge City. Lincoln Limestone Member; lower part of Hartland Member.
9	NW¼ sec. 13, T. 23 S., R. 24 W., Hodgeman County.	Cut bank on intermittent stream approximately 1½ miles southwest of Jetmore. Upper part of Hartland Member; Jetmore Member.
10	NE¼ SE¼ sec. 25, T. 21 S., R. 26 W., Hodgeman County.	Cut bank and abandoned fencepost quarry on south side of Pawnee Creek approximately 14 miles northwest of Jetmore. Upper ⅔ of Hartland Member; Pfeifer Member.
11	NE¼ sec. 10, T. 23 S., R. 23 W., Hodgeman County.	Draw in south wall of Buckner Creek valley approximately 2¾ miles ESE of Jetmore. Middle part of Hartland Member. Sections at localities 8 through 11 comprise a complete composite section of the Greenhorn.
12	NE¼ sec. 12, T. 25 S., R. 38 W., Kearny County.	Cut bank on southwest side of intermittent stream approximately 6½ miles southeast of Kendall. Lincoln Member.
13	NE¼ sec. 32, T. 24 S., R. 38 W., Kearny County.	Road ditch and bluff on northeast side of county road approximately 2½ miles ESE of Kendall. Hartland Member. APPARENT TYPE SECTION OF HARTLAND.
14	SW¼ sec. 14, NE¼ sec. 22, T. 23 S., R. 42 W., Hamilton County.	Cut banks on East Bridge Creek approximately 5½ miles ENE of Coolidge. Bridge Creek Member. Sections at localities 12 through 14 comprise a complete composite section of the Greenhorn.
15	SW¼ NE¼ sec. 5, T. 19 S., R. 16 W., Rush County.	Cut banks and bluff on south side of Dry Walnut Creek approximately 5 miles southeast of Timken. Upper part of Hartland Member; Jetmore Member.
16	NW¼ sec. 6, T. 20 S., R. 16 W., Pawnee County.	Bluff on east side of intermittent stream approximately 11 miles north and 2 miles west of Larned. Lincoln Member.
17	SW corner sec. 33, T. 18 S., R. 17 W., Rush County.	Cut bank on intermittent stream approximately 5 miles ESE of Rush Center. Upper part Lincoln Member; lower part of Hartland Member.
18	East line, SE¼ NE¼ sec. 21, T. 19 S., R. 18 W., Rush County.	Road cut on west side of U.S. Highway 183 approximately 5½ miles south of Rush Center. Lower part Pfeifer Member.
19	SE¼ SW¼ sec. 1, T. 19 S., R. 17 W., Rush County.	Dry silo in bluff of Dry Walnut Creek approximately 3½ miles SSE of Timken. Upper part of Pfeifer Member. Sections at localities 15 through 19 comprise a complete composite section of the Greenhorn.
20	NE¼ SE¼ sec. 12, T. 5 S., R. 7 W., Jewell County.	Road cuts on north-south county road and farm lane approximately ¾ mile south of Randall. Nearly complete section.
21	Near center, sec. 21, T. 9 S., R. 8 W., Mitchell County.	Cut bank on south side of Rock Creek approximately 9½ miles ENE of Hunter. Lincoln, Hartland, and Jetmore Members; lower part of Pfeifer Member.
22	SE¼ SE¼ sec. 20, T. 1 S., R. 2 W., Republic County.	Cut bank on tributary to Rose Creek approximately 9 miles NNE of Belleville. Upper part of Pfeifer Member.
23	NE¼ SE¼ sec. 11, T. 24 S., R. 22 W., Hodgeman County.	Cut bank on small tributary to Sawlog Creek approximately 10 miles south of Hanston. Lower part of Lincoln Member.
24	South line, SE¼ SE¼ sec. 31, T. 12 S., R. 10 W., Lincoln County.	Cut on north side of east-west county road approximately one mile east of Lake Wilson overflow spillway. Lincoln and Hartland Members; basal part of Jetmore Member. LINCOLN REFERENCE SECTION.
25	East line, NE¼ SE¼ sec. 5, T. 13 S., R. 15 W., Russell County.	Cut on west side of Fairport-Gorham road. Upper part of Hartland Member; Jetmore and Pfeifer Members.

TABLE 1.—*(Continued)*

Locality Number	Location	Description
26	NW¼ NW¼ sec. 4 and NE¼ NE¼ sec. 5, T. 12 S., R. 15 W., Russell County.	Cut bank on small tributary to Saline River and cut on Fairport-Gorham road approximately 1½ miles east of Fairport. Lincoln and Hartland Members; lower part of Jetmore Member.
27	NE¼ sec. 6, T. 14 S., R. 10 W., Ellsworth County.	Cut on west side of north-south county road approximately 2½ miles north of Wilson. Lincoln, Hartland, Jetmore Members; lower part of Pfeifer Member.
28	NE¼ sec. 3, T. 13 S., R. 11 W., Russell County.	Cut on west side of north-south county road approximately 8 miles NNE of Dorrance. Complete section.
29	West line, NE¼ sec. 18, T. 11 S., R. 12 W., Russell County.	Cut on east side of north-south county road approximately ½ mile south of Luray. Lincoln and Hartland Members.
30	SE¼ SW¼ sec. 24, T. 22 S., R. 22 W., Hodgeman County.	Cut on east-west county road approximately 1 mile east of Hanston. Lower part of Lincoln Member.
31	NE¼ sec. 21, T. 9 S., R. 8 W., Mitchell County.	Cut bank on Rock Creek approximately 9¾ miles ENE of Hunter. Part of Lincoln Member.
32	West line, SW¼ sec. 30, T. 10 S., R. 7 W., and east line, SE¼ sec. 25, T. 10 S., R. 8 W., Lincoln County.	Cuts on both sides of Kansas Highway 14 approximately 7 miles north of Lincoln. Part of Lincoln Member.
33	NW¼ NW¼ sec. 1 and NE¼ NE¼ sec. 2, T. 13 S., R. 13 W., Russell County.	Cuts on both sides of north-south county road approximately 5½ miles north and 1 mile west of Bunker Hill. Jetmore Member.
34	East line, NE¼ sec. 2, T. 14 S., R. 8 W., Ellsworth County.	Cut on Kansas Highway 14 approximately 9 miles NNE of Ellsworth. Upper part of Lincoln Member; lower part of Hartland Member.
35	South line, SW¼ sec. 6 and north line, NW¼ sec. 7, T. 12 S., R. 9 W., Lincoln County.	Cuts on both sides of Kansas Highway 18 approximately 1½ miles northeast of Sylvan Grove. Upper part of Lincoln Member; Hartland and Jetmore Members; basal part of Pfeifer Member.
36	South line, SE¼ sec. 7 and north line, NE¼ sec. 18, T. 10 S., R. 7 W., Lincoln County.	Cuts on both sides of east-west county road approximately 9½ miles north and ½ mile east of Lincoln. Hartland, Jetmore and Pfeifer Members.
37	NE¼ NE¼ sec. 10, T. 7 S., R. 8 W., Mitchell County.	Bluff on south side of Solomon River approximately 1 mile south of Solomon Rapids. Upper part of Lincoln Member; Hartland Member; lower half of Jetmore Member.
38	NW¼ NW¼ sec. 26 and NE¼ NE¼ sec. 27, T. 14 S., R. 15 W., Russell County.	Cuts on both sides of north-south county road approximately 5 miles south and 3 miles east of Gorham. Nearly complete section of Lincoln Member; upper two thirds of Jetmore Member; lower two thirds of Pfeifer Member.
39	West line, NW¼ sec. 3, T. 16 S., R. 10 W., Ellsworth County.	Cut on east side of north-south county road approximately 7 miles north and ½ mile west of Holyrod. Lower part of Lincoln Member.
40	SW¼ sec. 18, T. 15 S., R. 15 W., Russell County.	North bluff of Smoky Hill River approximately 9½ miles south and ½ mile west of Gorham. Lincoln, Hartland and Jetmore Members.
41	West line, SW¼ NW¼ sec. 27, T. 15 S., R. 18 W., Ellis County.	Cut on east side of U.S. Highway 183 approximately ½ mile northeast of Schoenchen. Upper part of Pfeifer Member.
42	West line, NW¼ sec. 5, T. 19 S., R. 17 W., Rush County.	Cut on east side of north-south county road approximately 4½ miles SSE of Rush Center. Upper part of Hartland Member; lower two thirds of Jetmore Member.
43	SW¼ SE¼ sec. 32, T. 18 S., R. 17 W., Rush County.	Cut bank of intermittent stream and eroded pasture approximately 5 miles SSE of Rush Center Kansas. Upper part of Lincoln Member; upper two thirds of Hartland Member; lower part of Jetmore Member.
44	North line, NE¼ sec. 30, T. 18 S., R. 20 W., Rush County.	Cut on south side of Kansas Highway 96 approximately 1 mile west of Alexander. Upper part of Jetmore; lower two thirds of Pfeifer Member.
45	NE¼ SW¼ sec. 14, T. 9 S., R. 5 W., Ottawa County.	Cut on county road near crest of Boyers Hill approximately 4 miles west of Delphos. Upper part of Lincoln Member; Hartland and Jetmore Members; lower part of Pfeifer Member.
46	South line, SE¼ SE¼ sec. 7 and NE¼ NE¼ sec. 18, T. 8 S., R. 3 W., Cloud County.	Cut on U.S. Highway 24, 1.1 miles west of junction with U.S. Highway 81. Upper part of Lincoln Member; Hartland and Jetmore Members; lower part of Pfeifer Member.
47	South line, SW¼ SW¼ sec. 22, T. 6 S., R. 3 W., Cloud County.	Cut on north side of east-west county road approximately 3½ miles south of Concordia. Lincoln Member; lower part of Hartland Member.
48	NE¼ sec. 16, T. 6 S., R. 3 W., Cloud County	Cut on east side of U.S. Highway 81, approximately 1½ miles south of Concordia. Upper two thirds of Hartland Member; most of Jetmore Member.
49	Center of west line. sec. 21, T. 7 S., R. 7 W., Mitchell County.	Cut on east side of Kansas Highway 14 approximately 1½ miles south of Beloit. Top bed of Jetmore Member; Pfeifer Member.
50	West line, NE¼ sec. 7, T. 23 S., R. 23 W., Hodgeman County.	Cut on east side of north-south county road approximately ¼ mile south of Jetmore. Upper part of Hartland Member; Jetmore Member; lower part of Pfeifer Member. JETMORE TYPE SECTION.
51	West line, SW¼ SW¼ sec. 5, T. 25 S., R. 24 W., Ford County.	Cuts along north-south county road approximately 9 miles north and 1 mile east of Dodge City. Upper part of Hartland Member; lower part of Jetmore Member.

TABLE 1.—*(Continued)*

Locality Number	Location	Description
52	North line, NW¼ NW¼ sec. 16, T. 25 S., R. 25 W., Ford County.	Cut on east-west county road approximately 8 miles north and 3 miles west of Dodge City. Middle part of Jetmore Member.
53	Center, SW¼ sec. 9, T. 25 S., R. 25 W., Ford County.	Cut bank and bluff on east side of Sawlog Creek approximately 9 miles north and 3 miles west of Dodge City. Upper two thirds of Hartland Member; Jetmore Member.
54	SW¼ NW¼ sec. 33, T. 18 S., R. 17 W., Rush County.	Cut bank on southern tributary to Walnut Creek. Lincoln Member.
55	East line, NW¼ SW¼ sec. 35, T. 24 S., R. 23 W., Hodgeman County.	Cut on north-south county road approximately 11 miles SSE of Jetmore. Lower half of Lincoln Member.
56	East line, SE¼ SE¼ sec. 1, T. 19 S., R. 22 W., Ness County.	Cut on west side of north-south county road approximately 1 mile south of Bazine. Upper two thirds of Jetmore Member; lower part of Pfeifer Member.
57	Center of west line, sec. 7, T. 19 S., R. 21 W., Ness County.	Cut on east side of north-south county road approximately 1½ miles south of Bazine. Upper part of Pfeifer Member.
58	SW¼ sec. 27, T. 18 S., R. 21 W., Ness County.	Cut on south side of Kansas Highway 96 approximately 2½ miles east of Bazine. Jetmore Member.
59	NE¼ SE¼ sec. 2, T. 18 S., R. 12 W., Barton County.	Cut on Missouri-Pacific Railroad approximately 4 miles west and ¾ mile south of Claflin. Lower part of Lincoln Member.
60	West line, NE¼ SW¼ sec. 32, T. 17 S., R. 14 W., Barton County.	Cut on north-south county road approximately 6½ miles west of Hoisington. Lower part of Lincoln Member.
61	NW¼ sec. 21, T. 15 S., R. 10 W., Ellsworth County.	Small southern tributary to Smoky Hill River. Lowermost Lincoln Member.
62	NW¼ sec. 36, T. 12 S., R. 11 W., Russell County.	Cut on road at northwest end of Wilson Dam. Complete section.
63	SW¼ sec. 27, T. 6 S., R. 9 W., Mitchell County.	Cut on former line of Missouri Pacific Railroad along south edge of Glen Elder. Upper part of Hartland Member; Jetmore Member; Pfeifer Member (essentially same as no. 1).
64	SW¼ NW¼ sec. 23, T. 4 S., R. 6 W., Jewell County.	Stream bank and bluff on West Marsh Creek approximately 5 miles northeast of Randall. Poor exposure of Lincoln, Hartland, and Jetmore Members.
65	South line, SE¼ SW¼ sec. 3 and north line, NE¼ NW¼ sec. 10, T. 3 S., R. 3 W., Republic County.	Cuts on both sides of U.S. Highway 36 shortly east of junction with U.S. Highway 81 approximately one fourth mile west of Belleville. Jetmore Member; lower part of Pfeifer Member.
66	NE¼ sec. 19 and SW¼ NW¼ sec. 20, T. 12 S., R. 12 W., Russell County.	Cuts on both sides of county road approximately 9 miles WSW of Lucas. Lincoln, Hartland, and Jetmore Members.
67	South line, SW¼ SW¼ sec. 4, T. 3 S., R. 1 W., Republic County.	Cut on north side of U.S. Highway 36 approximately ¾ mile northeast of Cuba. Upper part of Hartland Member; Jetmore and Pfeifer Members.
68	S½ sec. 36, T. 13 S., R. 7 W., Lincoln County.	Cut on south side of Interstate 70 approximately 13 miles SSE of Lincoln. Complete section.
69	NE¼ SE¼ sec. 7, T. 13 S., R. 14 W., Russell County.	Cut bank on east side of Canyon Road approximately 4½ miles northeast of Russell. Lower half of Lincoln Member.
70	SW¼ SE¼ sec. 30, T. 11 S., R. 12 W., Russell County.	Cuts on east side of north-south county road and east-west county road approximately 3½ miles south of Luray. Upper part of Jetmore Member, Pfeifer Member.
71	SW¼ sec. 31, T. 15 S., R. 10 W., Ellsworth County.	Cut on west side of north-south county road approximately 8½ miles south of Wilson. Upper part of Lincoln Member, Hartland Member, Jetmore Member, lower part of Pfeifer Member.

structure maps are not available for the Greenhorn of western Kansas but such maps have been compiled for the top of the Dakota Formation (Merriam, 1957a) and base of the Niobrara Chalk (Morrow, 1941). In the central Kansas area, regional dip at the top of the Dakota is 8 to 9 feet per mile to the north northeast or north; in Hamilton County this surface dips 21 feet per mile towards the northeast (Merriam, 1957). Average dip along a line extending from Hamilton County to northeastern Phillips County is 11.5 feet per mile to the northeast on top of the Dakota (Merriam, 1957a) and 10 feet per mile to the northeast at the base of the Niobrara (Morrow, 1941). Merriam (1958, p. 90) has noted that structure maps drawn on various datum surfaces show "essentially the same structure as that on top of the Dakota."

The regional structure of Cretaceous beds is complicated by numerous small anticlinal and synclinal features that have been described in several county reports and summarized by Jewett (1951) and Merriam (1963). Some of the named structures discernable in the Greenhorn outcrop are the Syracuse anticline (Hamilton County), Bazine anticline (Ford, Ness, and Hodgeman Counties), Beeler anticline (Hodgeman and Ness Counties), Pfeifer anticline (Ellis and Russell Counties), Fairport-Natoma anticline (Ellis, Russell, and Osborne Counties), Tipton anticline (Mitchell County), and Salt Creek structure (Mitchell County). Small normal faults are numerous in exposures of Niobrara Chalk through much of the outcrop. Similar faults are known in the Greenhorn but, as noted by Rubey and Bass (1925, p. 69) for Russell County, are less common therein. Bass (1926, p. 81) reported a fault in the Lincoln Member in Hamilton

County. I have discovered an apparently faulted section in the lower part of the Greenhorn in NW¼ sec. 7, T. 13 S., R. 9 W., Lincoln County. In his Ellis County report Bass (1926, p. 47) mentioned faults in the Greenhorn but did not indicate that he actually saw any in that County.

The Greenhorn Limestone has been used as a source of structural stone throughout the area of the Kansas outcrop (Fig. 4,D). Large numbers of public buildings, homes, and farm out-buildings have been constructed of blocks quarried largely from the Fencepost limestone bed and, to a lesser extent, from the Shellrock limestone bed. Even the most casual traveler can not fail to note the extensive use of stone for fenceposts (Fig. 4,C) throughout most of the central Kansas outcrop area. Like the building stone, these posts have been quarried mostly from the Fencepost bed but many were taken also from the Shellrock bed. The use of these limestone beds for purposes stated above, and also for stepping stones, watering troughs, tombstones, telephone poles, and clothesline poles is beautifully demonstrated at the Post Rock Museum in Lacrosse, Kansas. In an authentic pioneer home constructed of Greenhorn stone, a dedicated group of Rush County citizens has assembled materials for an excellent display that commemorates the role the "post rock" has played in the settlement of the eastern Great Plains. Muilenburg (1958) and Risser (1960, p. 92-94) have discussed the uses to which the Fencepost and Shellrock limestone beds have been put.

The Greenhorn has been used locally for riprap in small dams but is not a suitable material for that purpose (Bayne and Walters, 1959, p. 18; Byrne and others, 1948, p. 45). Greenhorn rocks have been used as a source of road metal throughout most of the Kansas outcrop (Byrne and others, 1948, p. 41). The formation is not an aquifer but, in a few areas, hand-dug wells produce water from weathered and/or fractured Greenhorn strata. Such water supplies are unreliable and the water is generally of poor quality. The potential use of Greenhorn carbonate rocks as a source material for the manufacture of rock wool has been described by Plummer (1937, p. 57-64; 1937a, p. 20-22).

In Kansas the thickness of the Greenhorn Limestone ranges from 68.5 feet (Loc. 1) to 135.9 feet (Locs. 12, 13, and 14), averaging 94.8 feet for 11 measured sections. Five of these measured sections are composite.

Acknowledgments

I take keen pleasure in thanking my former students Dr. Craig B. Hatfield, Dr. Leslie Sponsel, Mr. Donald E. Hall, Dr. Robert W. Frey and Dr. Norman R. King, each of whom served for part of one summer as my field assistant. I would like also to thank Dr. Phil Heckel of the University of Iowa and Dr. James Cocke of East Tennessee State University for their help in a similar capacity. Special thanks are extended to Dr. Erle G. Kauffman, U.S. National Museum and Dr. W. A. Cobban, U.S. Geological Survey for checking my identifications of many of the Greenhorn mollusks and for opportunity to discuss in the field many aspects of Greenhorn paleontology and stratigraphy in other states. Mr. Myrl V. Walker of Fort Hays Kansas State College graciously arranged for the loan of specimens from the Sternberg Museum. X-ray analyses of bentonite samples and thin sections were made with the help of Dr. John B. Droste, Department of Geology, Indiana University, and chemical analyses of shaly chalk and chalky limestones were prepared by Indiana Geological Survey personnel under the direction of Mr. Richard K. Leininger; I thank both of these friends for these kindnesses. The use of scanning electron microscope facilities at the University of Illinois was arranged by Dr. W. W. Hay whose help and interest is gratefully acknowledged. Mr. Herschel Lentz arranged for my use of the scanning electron microscope at Indiana University. Technical assistance, including drafting, indoor photography, thin section preparation, and typing was furnished by the Department of Geology, Indiana University and I am thankful for this help. Lastly, I wish to thank my good friend Dr. Daniel F. Merriam, former Chief of Geologic Research, Kansas Geological Survey, whose enthusiasm and encouragement are largely responsible for the completion of this study.

HISTORY OF STRATIGRAPHIC NOMENCLATURE

Upper Cretaceous strata of the Western Interior region were first divided by Hall and Meek (1856) who recognized five major lithologic units that were numbered from one through five in upward order. Meek and Hayden (1861, p. 419) gave these units the geographic names Dakota, Fort Benton, Niobrara, Pierre, and Fox Hills respectively. Strata discussed in the present report were formerly classed as part of the Fort Benton Group, a unit that enjoyed formal status at least until 1920 (Moore, p. 83) but which was no longer used officially in Kansas at the time Rubey and Bass (1925) published their now-classic report on the geology of Russell County. The Benton Group included rocks now, as then, referred to as the (ascending) Graneros Shale, Greenhorn Limestone, and Carlile Shale.

Detailed studies of the Benton rocks in Kansas were slow to appear in print. In the first annual report on the geology of Kansas, Mudge (1866, p. 10) stated that the Cretaceous is "represented rather largely, but no definite examination has been made to show its extent, as it lies mostly beyond the settlements. Chalk is said to have been found in it." As late as 1875 Mudge (p. 111) reported "The Benton group appears also to be absent [from Kansas]; but as the upper part of the Dakota has few fossils, and is not well defined, there is a possibility that some traces of the Benton group may yet be detected. . . . Hostile Indians and an uninviting country have kept explorers from traversing the southwestern plains." Still later Mudge (1876, p. 219) reaffirmed his belief that Benton rocks are absent from Kansas, despite the fact that his report contains brief descriptions of limestone beds and shale beds that were later included in the Benton Group and that are now assigned to the Greenhorn and Carlile, respectively. However, this error stemmed from the identification as Niobrara some *Inoceramus*—filled chalky limestone at Wilson's Station (Wilson, Ellsworth County; brackets mine) by Hayden (1872, p. 67).[6] Within two years Mudge (1878, p. 64) had reversed his position and the existence of Benton rocks within the State was firmly established despite his inclusion within the group of the lower beds (Fort Hays Limestone Member) of the Niobrara. As late as 1887, however, beds now assigned to the Greenhorn were mistakenly identified as Niobrara by St. John (1887, p. 145, 146) whose errors are evident both in locality descriptions and stated thickness of the Benton interval in Hamilton County, Kansas.

First to subdivide the Benton Group of Kansas was Cragin (1896, p. 49) who recognized (ascending) the Russell Formation; embracing the present Graneros Shale, Greenhorn Limestone, and Fairport Chalk Member of the Carlile Shale; and the Victoria Formation which included the present Blue Hill Shale and Codell Sandstone Members of the Carlile Shale. In establishing this classification Cragin correctly interpreted the genetic relationship of the Greenhorn and Fairport. Unfortunately, the formational separation of carbonate and noncarbonate strata at the Fairport-Blue Hill contact was not perpetuated by later workers.

Beginnings of the present Greenhorn nomenclature in Kansas are seen in the work of Logan (1897, p. 215-219) who divided the Benton into two groups including "the lower, or limestone group, and the upper or shale group." In the upper group (Carlile Shale of later use), he included the Ostrea shales (Fairport of later usage) and Blue Hill shales. In the lower group Logan (1897, p. 215) recognized "five principal horizons, namely: 1, Bituminous shale; 2, Lincoln Marble; 3, Flagstone; 4, Inoceramus; and 5, Fencepost." The bituminous shale is now known formally as the Graneros Shale (see Hattin, 1965a, for detailed description). The remaining units belong to the present Greenhorn Formation; however, from Logan's text one gathers the impression that these are "key" or "marker" units and collectively do not represent the entire thickness of the Greenhorn. The Lincoln Marble horizon (Logan, 1897, p. 216) apparently corresponds to the Lincoln Member of present usage, but Logan's description is totally inadequate. The Flagstone horizon was described as lying conformably between the Lincoln Marble and the *Inoceramus* horizon yet was stated to be only 10 feet thick. Actual thickness of the interval separating the Lincoln and beds I believe to represent Logan's *Inoceramus* horizon, ranges from 16 to 82 feet, the smaller figure representing an abnormally thin, condensed section in Jewell County (Loc. 20). Furthermore, his description of the Flagstone horizon seems to fit best the lower part of Jetmore Member of the present nomenclature, and his classification leaves beds of the Hartland member unaccounted for. The *Inoceramus* horizon seemingly represents the upper part of the Jetmore Member, including the Shellrock limestone bed, lying at the top of the member, and one or more of the *Inoceramus*-rich limestone beds that lie shortly beneath the Shellrock bed and project conspicuously from weathered exposures of the members. The Fencepost horizon of Logan (1897, p. 217) comprises the uppermost unit in his limestone group and lies 14 to 24.5 feet above his *Inoceramus* horizon. First called *Downs limestone* by Cragin (1896, p. 50) this unit is known today as the Fencepost limestone bed and forms the topmost unit of the Greenhorn Formation in Kansas.

In Colorado, the Benton Group was divided by Gilbert (1896, p. 564) into three formations including (ascending) the Graneros Shale, Greenhorn Limestone, and Carlile Shale. This nomenclature has since become standard through most of the Great Plains region. Logan (1899, p. 84, 85) correlated his Bituminous shale with the Graneros Shale, and the remaining part of his Limestone group was correlated with Gilbert's Greenhorn Limestone. First formal use in Kansas of the three formational names proposed by Gilbert (1896) was that of Darton (1904, pl. 36). Because these formations, together with the overlying Niobrara Formation had long since been included in the Colorado Group of White (1878) the term "Benton Group" was no longer needed; accordingly, Benton Group lost official status in Kansas after 1920.

[6] In his "Sketch of the geological formations along the route of the Union Pacific Railway, Eastern Division" Hayden (1872, p. 67) recognized clearly the presence of Fort Benton shales along the bluff at Yocemento, five miles northwest of Hays, Kansas. Because the beds at Yocemento lie above the limestones exposed at Wilson's Station, Mudge concluded that the shales at Yocemento could not belong to the Fort Benton Group.

The next modification of Greenhorn nomenclature in Kansas came in 1915 when Rubey and Bass (p. 47) formalized the term "Lincoln limestone member," and proposed the term "Jetmore chalk member" (p. 46) for the part of the formation that is characterized by "alternating thin beds of chalk and chalky shale occupying the interval from 20 to 40 feet below the top of the Greenhorn formation," with the *Inoceramus* limestone (Shellrock limestone bed of this report) forming the uppermost bed thereof. Rubey and Bass recognized a third member lying between the Lincoln and Jetmore Members, and a fourth member lying above the Jetmore. These were given the respective names "Hartland shale member" and "Pfeifer shale member" by Bass (1926, p. 32, 33). Hattin (ms., 1967) presented to members of the Geologic Names Committee of the State Geological Survey of Kansas a proposal for major nomenclatural and classificatory revision of the Greenhorn Limestone. Among the proposals was a recommendation for elevating the Greenhorn to the rank of group and including as a formation therein the Fairport unit which is ranked currently as a member of the Carlile Shale. The proposed changes have not been adopted by the Survey and are, therefore, not used in the present report despite my firm belief that the revision is eminently desirable.

RELATIONSHIP OF GREENHORN TO ADJACENT UNITS

Graneros-Greenhorn Contact

In the area lying between Ford (Loc. 8) and Lincoln (Loc. 24) Counties the Graneros-Greenhorn contact is readily defined as the level at which predominantly noncalcareous gray silty clay shale of the Graneros underlies, with abrupt lithologic change and sharp stratigraphic contact, basal skeletal and/or chalky limestones of the Lincoln Member (Figs. 5,A,B; see also Hattin, 1965a, p. 11, 12). Paleontologic evidence demonstrates that this contact lies at an unconformity along which one of the standard Western Interior ammonite range zones is unrepresented (Hattin, 1965a, p. 44; 1968). From northern Pawnee County (Loc. 16, to Lincoln County (Loc. 24) the zone of *Acanthoceras wyomingense* (Reagan) is apparently absent and Greenhorn beds containing the *Dunveganoceras pondi* Haas? and *Calycoceras? canitaurinum* (Haas) fauna rests on Graneros strata containing *Acanthoceras amphibolum* Morrow, *Inoceramus rutherfordi* Warren, and *Borissjakoceras reesidei* Morrow. These Graneros strata were assigned to the *Ostrea beloiti* Assemblage Zone by Hattin (1965a, p. 40). In Ford (Loc. 8) and Hodgeman (Locs. 23, 30) Counties, where the Greenhorn lies on Graneros beds of the *Callistina lamarensis* Assemblage Zone (Hattin, 1965a, p. 40), the *O. beloiti* Assemblage Zone is not represented, but the lower part of the Greenhorn contains faunal elements of the *A. wyomingense* Zone. Thus between Ford and Lincoln Counties the unconformity separating the Graneros and Greenhorn appears to be diachronous (Hattin, 1968, p. 1087).

Despite the sharp change in fauna and lithology at most localities in the area discussed above, the upper part of the Graneros is locally calcareous, even approaching typical Lincoln lithology at a few places, for example at Locality 26 in Russell County, and the writer has suggested elsewhere that roughly the upper half of the Graneros was originally calcareous prior to weathering. At the time the break in sedimentation took place the environment which produced the sediments in the upper part of the Graneros was already changing toward that which produced chalky Greenhorn sediments. Despite local occurrences of calcareous or chalky shale in the upper part of the Graneros, the most practical, and long recognized, formational contact is at the unconformity, above which all strata are highly calcareous and at which there is a major faunal break.

North of Lincoln County, evidence for the unconformity diminishes and the Graneros-Greenhorn contact commonly lies within a stratal sequence that is transitional between noncalcareous clay shale below and skeletal or chalky limestone-bearing shaly chalk above. As established in this report, the contact is placed at the base of the first conspicuous bed or beds, or zone of lenses, of skeletal or chalky limestone above which or within which the predominant lithology is shaly chalk or chalky shale containing beds or lenses of skeletal limestone. At Locality 21 in southern Mitchell County, the contact is placed at the base of a 0.55-foot-thick, hard skeletal limestone lying 1.2 feet above a thick bentonite marker bed ("X" bentonite of authors) in the Graneros that can be traced through much of central Kansas (Hattin, 1965a, pl. 1). The limestone bed is overlain by 10.9 feet of shaly chalk and chalky shale that contains little skeletal limestone and is thus unlike the lower half of the Lincoln in areas south of Lincoln County. The contact is apparently equivalent to that farther south, and may represent the Graneros-Greenhorn unconformity, but there is no fossil evidence for such a break. Farther east, at Locality 4, also in Mitchell County, a 1.95 foot-thick unit consisting of skeletal limestone, calcareous shale, and calcareous sandstone or sandy limestone lies in sharp contact with weathered Graneros shale and lies 1.7 feet above the "X" bentonite. This calcareous unit may be equivalent to the basal Greenhorn skeletal limestone at Locality 21 but is overlain by a thick (13.2

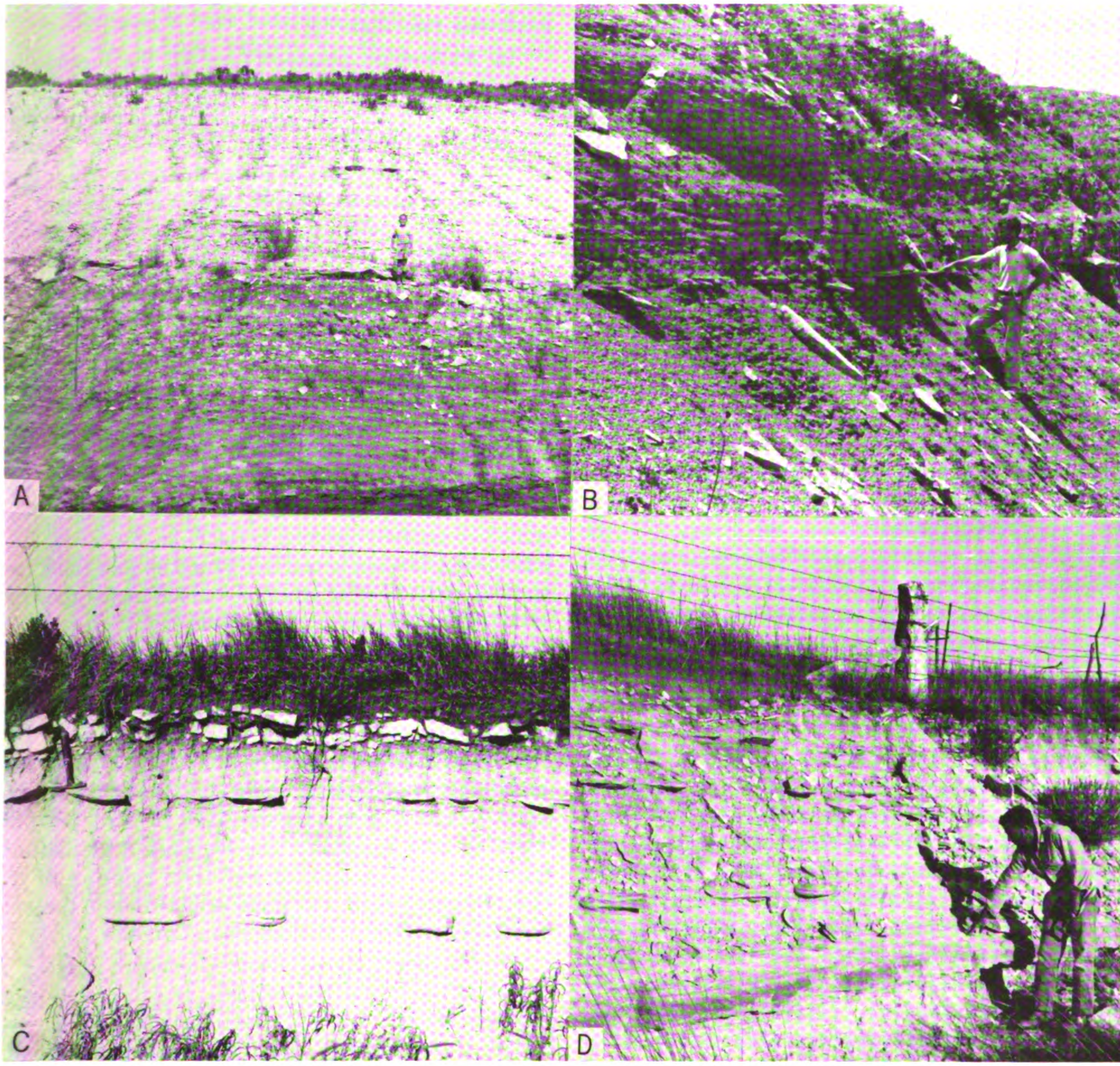


Figure 5.—Contacts between Greenhorn Limestone and adjacent strata. A) Graneros-Greenhorn contact (level of boy's feet) at Locality 3, sec. 18, T. 13 S., R. 12 W., Russell County. Note marked color contrast of two formations and bed of skeletal limestone at base of Greenhorn. B) Graneros-Greenhorn contact (Jim Cocke's hand) at Locality 8, sec. 5, T. 25 S., R. 24 W., Ford County. Carbonate rocks of Greenhorn lie in sharp contact on noncalcareous shale of Graneros. Thin, resistant bed of limestone at base of Greenhorn is packed with *Ostrea beloiti*. C) Upper few feet of Greenhorn Limestone at Locality 4, sec. 30, T. 8 S., R. 5 W., Cloud County. Weathered Fencepost limestone bed directly underlies upland surface. Note layers of chalky limestone concretions in shaly chalk below Fencepost bed. D) Fencepost limestone bed (Jim Cocke's hand) and lower few feet of Fairport Member, Carlile Shale, sec. 18, T. 13 S., R. 12 W., Russell County (Loc. 3). Note layers of chalky limestone concretions in shaly chalk above Fencepost bed. Compare photo with Figure 5,C.

feet) interval of chalky shale and sandy calcareous shale that is nearly devoid of skeletal limestone except in the uppermost foot. The calcareous unit and overlying shale section contain *Inoceramus prefragilis* Stephenson, a fossil associated typically with *Dunveganoceras pondi* and younger Greenhorn assemblages. However, at this locality the 13.2-foot-thick shale interval is nearly lacking in skeletal limestones and is much less calcareous than usual for the lower part of the Lincoln in central Kansas, suggesting that in eastern Mitchell County this part of the section manifests a lateral change of facies. Accordingly, the Graneros-Lincoln contact is placed at the top of the shale interval involved in the facies change (see Plate 1). At

Locality 47, less than 20 miles northeast of Locality 4, evidence of this facies change is more dramatic. The "X" bentonite is overlain in upward order by 1.2 feet of calcareous shale, 0.55 foot of unfossiliferous calcilutite, 4.3 feet of chalky shale and shaly chalk, the lower 3.0 feet of which contains very small skeletal limestone lenses, and 9.7 feet of shale the lower 5.8 feet of which is noncalcareous and the upper part of which grades upward from weakly calcareous shale to chalky shale. Except for the 3 feet of skeletal-limestone-bearing chalky shale and shaly chalk, none of the described section is typical of the Lincoln Member but bears close resemblance to upper Graneros strata. Although the section from the calcilutite bed upward was included by me (Hattin, 1965a) in the Greenhorn, I now conclude that logical placement of the formational contact is at the top of the section just described. As thus defined for this locality the base of the Lincoln Member consists of a 0.15-foot-thick discontinuous bed of granular chalky limestone above which the remaining part of the exposed section, all assigned to the Lincoln, is dominated by highly calcareous rocks including numerous beds and lenses of skeletal or chalky limestone. At Locality 47 approximately 14.5 feet of strata that are apparently correlative with the lower part of the Lincoln at Localities south of Mitchell County are assigned to the Graneros Shale (see Plate 1).

At Locality 1, in northwestern Mitchell County, the stratigraphic interval separating the "X" bentonite from typical skeletal limestones and shaly chalk of the Lincoln Member is 17.5 feet thick and consists mainly of weakly calcareous to calcareous shale that grades uniformly upward to chalky shale. A skeletal limestone bed 0.25 foot thick lies 0.12 foot above the "X" bentonite and a few very thin skeletal limestone lenses lie in the upper foot of this interval. The shale interval contains streaks of quartz silt, a layer of septarian concretions 3.3 feet below the top, and specimens of ammonites with preserved shell material. These three features are common in the upper part of the Graneros Shale farther to the southwest, especially in fresh exposures where the shale is calcareous, as at the overflow spillway of Wilson Dam, Russell County. The thick shale interval just described is lithogenetically related to the Graneros and has been so assigned by me (Hattin, 1968). Specimens of *Acanthoceras wyomingense,* presumably from the layer of septarian concretions just mentioned, suggest that at Locality 1 the unconformity separating Graneros and Greenhorn beds elsewhere, if present at all, lies much farther above the "X" bentonite than to the south. However, the base of the Lincoln at Locality 1, though rather well defined, lies within a sequence of lithologic gradation and lacks the sharpness seen in sections exposed in Russell, Ellis, Ellsworth and other counties lying to the southwest (see Plate 1).

In Washington County (Loc. 6), the formational contact also lies in a gradational lithologic sequence and has been described previously by the writer (Hattin, 1965a, p. 11; 1968, p. 1085). Here the "X" bentonite is overlain by 4 feet of shale, the upper 1.8 feet of which is calcareous. These strata are overlain by chalky shale containing numerous very thin lenses of fine-grained skeletal limestone that marks the base of the Lincoln Member. The overlying 3.2 feet of shale are all chalky, containing numerous lenses of *Inoceramus*-rich skeletal limestone, followed upward by a bed of chalky limestone. Evidence of unconformity is totally lacking at this exposure. At Locality 12, Kearny County, the Graneros-Lincoln transition is similar to that at Locality 6. The "X" bentonite is overlain by 9.8 feet of calcareous and chalky shale that are virtually devoid of skeletal limestone and are best assigned to the Graneros Shale. The base of the Lincoln is marked by a 0.08-foot-thick bed of chalky and skeletal limestone which marks the base of the continuously chalky, overlying succession of Greenhorn strata, consisting in the first 4.8 feet mostly of chalky shale but including two seams of bentonite and numerous thin to very thin lenses of brittle, gritty, laminated chalky limestone. Above this, and lying 14.7 feet above the "X" bentonite is a 2.55-foot-thick unit containing, in addition to shaly chalk and chalky limestone, several thin to very thin beds of hard, petroliferous, skeletal limestone. The sequence is gradational from the bentonite upward, and lacks evidence of the unconformity which is so prominent farther to the east in Ford (Fig. 5,B) and Hodgeman Counties.

In summary, the Graneros-Greenhorn contact is placed at the lowest bed or beds, or concentration of lenses, of skeletal or chalky limestone above which the section is continuously chalky and consists principally of shaly chalk through which are scattered numerous beds and lenses of chalky and skeletal limestone. Across much of central Kansas this contact is sharply defined and lies at an unconformity. In areas of lithologic transition between typical Graneros and typical Greenhorn lithology, designation of the contact is somewhat arbitrary, but the criteria outlined above serve well in distinguishing between the two formations.

Greenhorn-Carlile Contact

Since the work of Logan (1897) appeared, the top of the Fencepost limestone bed has been regarded as marking the contact between formations now called Greenhorn Limestone and Carlile Shale. This bed can be traced through all areas of Greenhorn outcrop in

Kansas and is readily mapped owing to the good exposure and extensive quarrying operations in many areas. Statements have been made (Rubey and Bass, 1925, p. 49; Landes, 1930, p. 21; Moss, 1932, p. 26) and the implication made (Bass, 1926, p. 31) that the top of the Fencepost is coincident with a faunal change, and this belief has been used to support the placement there of the formational contact. This argument notwithstanding, the top of the Fencepost does not coincide with a lithogenetic boundary worthy of recognition as a formational contact. Furthermore, no significant paleontological change occurs at this stratigraphic position. Major elements of the Pfeifer fauna occur also in at least the lower few feet of the Fairport Member of the Carlile Shale. These forms are: *Mytiloides labiatus* (Schlotheim) var., *Inoceramus cuvieri* Sowerby, *Collignoniceras woollgari* (Mantell), *Baculites* cf. *B. yokoyamai* Tokunaga and Shizimu, and *Pseudoperna bentonensis* (Logan). It seems obvious that the contact as presently defined cannot (and should not) be defended on paleontological grounds.

Lithology of the upper part of the Pfeifer and lower part of the Fairport are essentially identical (Fig. 5, C,D). Soft-weathering shaly chalk both above and below the Fencepost contains numerous layers of concretionary chalky limestone occurring mostly as oblate spheroids. In fact, concretionary masses of chalky limestone characterize the entire interval between the uppermost of three hard limestone beds in the Jetmore (marker bed JT-12 of this report) and a widespread chalky limestone bed 0.45 to 0.6 foot thick that lies 4 to 6 feet above the Fencepost bed in central Kansas and is Fairport marker bed no. 2 of Hattin (1962, p. 44). Although a few concretions occur above this bed, such structures are lacking in Hamilton and Washington Counties and are uncommon above the bed at most localities lying in between. Lithologic homogeneity of beds above and below the Fencepost bed dictates change in definition of the Greenhorn-Fairport contact so as to include the 4- to 6-foot thick concretion-bearing shaly chalk that rests on the Fencepost, together with the overlying chalky limestone bed. This chalky limestone directly underlies the margin of upland surfaces in many places (Fig. 4,C) and is the uppermost bed exposed in many roadcuts that expose the Pfeifer Member. The bed is also well exposed in cut banks along streams, and is better exposed than the Fencepost in many abandoned post-rock quarries, for example in SE¼ sec. 3, T. 20 S., R. 22 W., Ness County and NE¼ sec. 27, T. 15 S., R. 18 W., Ellis County. In a few areas such as Hamilton and Washington Counties, where I have not observed concretions above the Fencepost bed, the contact is appropriately placed at the top of the Fencepost, below which the section does contain concretions. Thus, the formational boundary would no longer be coincident with a single marker bed but be based strictly on lithogenetic differences in character of the rock section. Despite the need for redefinition of this contact, for purposes of the present report the Greenhorn-Fairport contact is defined as the top of the Fencepost limestone bed.

STRATIGRAPHY OF THE GREENHORN LIMESTONE

Lincoln Limestone Member

General Description.—The Lincoln Member of the Greenhorn was the first part of the formation to receive a formal name. The unit was originally called Lincoln Marble by Logan (1897, p. 215) and was renamed Lincoln Limestone Member by Rubey and Bass (1925, p. 47). No type section was designated by these earlier workers but the writer (Hattin, 1969) has described as standard reference section the exposure in SE¼ SE¼ sec. 31, T. 12 S., R. 10 W., Lincoln County (Loc. 24) where the member is 24.1 feet thick and is well exposed in a recently excavated road cut.

The member consists primarily of shaly chalk through which are scattered numerous, usually thin to very thin beds and lenses of well-cemented skeletal limestone, seams of bentonite, and a few, commonly discontinuous thin beds of chalky limestone. Chalky shale is included in the lower part of the member at a number of localities in north-central and westernmost Kansas. Unconsolidated skeletal sand occurs in the lower part of the member at Locality 24, and hard, fine-grained concretionary limestone occurs near the base of the member at locality 62. In Kansas, thickness of the Lincoln Member ranges from 16.2 feet (Loc. 12) to 33 feet (Loc. 4), averaging 23.1 feet for eleven measurements including two (Locs. 47 & 48; Locs. 16 & 17) that are composites. The lower contact of the member, defined in detail in the foregoing section of this report, is at a widespread unconformity in much of central Kansas but lies within a gradational lithologic sequence in north-central and westernmost Kansas. The top of the Lincoln is designated as the uppermost bed, group of beds and lenses, or zone of abundant lenses of skeletal limestone lying at the upper limit of the interval that is characterized by general abundance of such rock (Fig. 6,A). As thus defined in the area extending from Rush County northeastward to Washington County, the contact lies close to or at a widespread bentonite seam and between 0.12 to 3.9 feet below the more conspicuous, readily identifiable, highly fractured, burrow-mottled chalky limestone marker bed that is designated HL-1 elsewhere in this report and on Plate 1. I have assumed

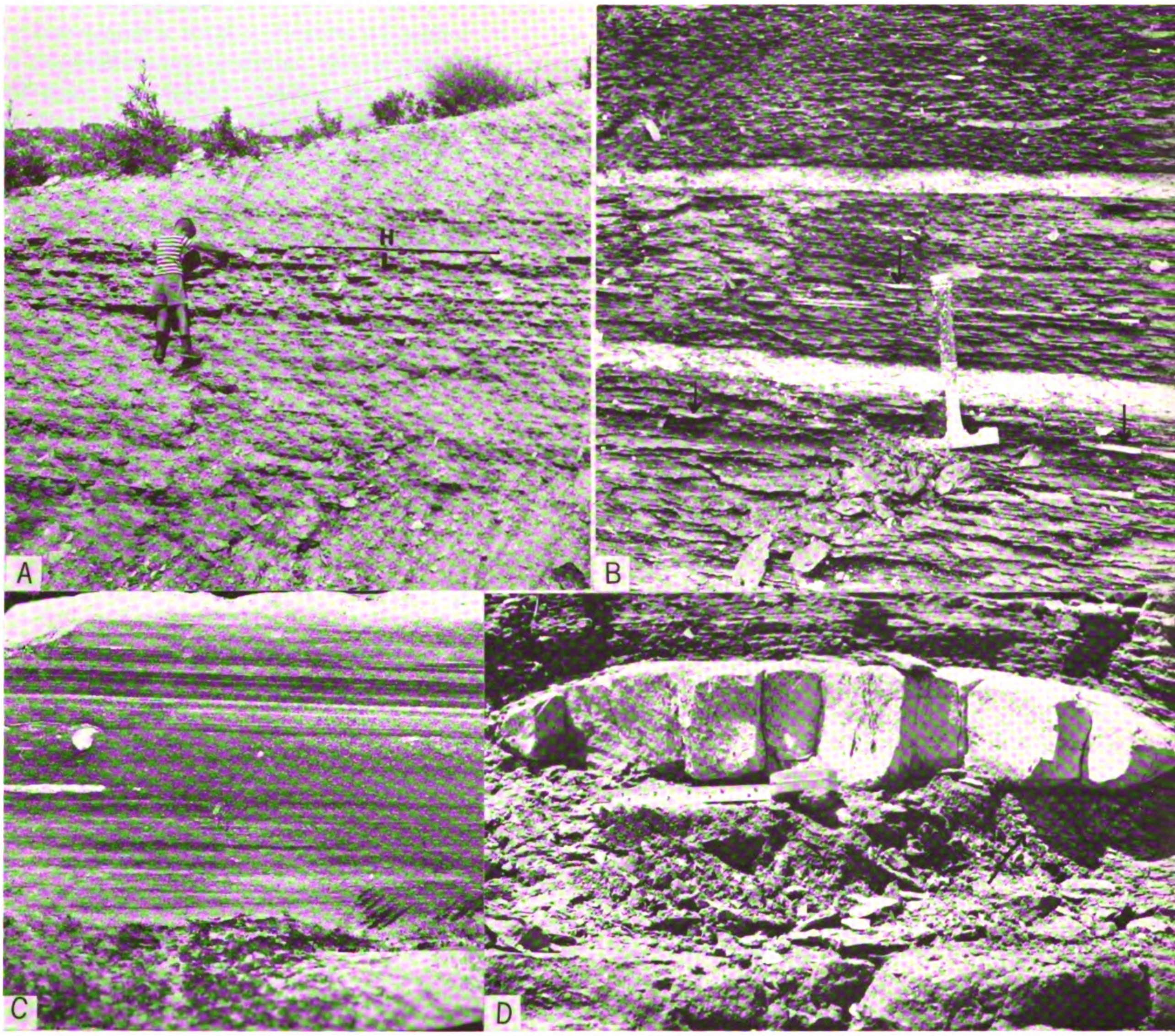


FIGURE 6.—Stratigraphic features of Lincoln Member. A) Lincoln-Hartland contact (horizontal line) 3 miles north of Bunker Hill, sec. 18, T. 13 S., R. 12 W., Russell County (Loc. 3). Note abundance of thin beds and lenses of skeletal limestone at top of Lincoln. B) Typical exposure of shaly chalk in Lincoln Member, sec. 22, T. 6 S., R. 3 W., Cloud County (Loc. 47). C) Specimen of thinly laminated shaly chalk from middle part of Lincoln Member, sec. 18, T. 13 S., R. 12 W., Russell County (Loc. 3). X1. D) Concretionary masses of granular limestone lying 0.5 foot above base of Lincoln Member and on a bentonite seam (arrow), sec. 36, T. 12 S., R. 11 W., Russell County (Loc. 62).

that the first bentonite beneath HL-1 is everywhere the same seam. At most localities a few very thin lenses of skeletal limestone lie above the contact as defined herein and represent the transition between typical Lincoln and typical Hartland depositional environments, but strata lacking conspicuous concentrations of such rock are better assigned to the Hartland Member. At Locality 6, Washington County, the abundance of skeletal limestone decreases gradually upward in the Lincoln so that the contact between the Lincoln and Hartland Member is not defined sharply. Wing (1930, p. 28) recognized this problem and did not separate the two members, referring instead to the combined Lincoln-Hartland interval as the lower Greenhorn shale. At Locality 8, Ford County, Lincoln-like skeletal limestone beds and lenses occur in the Hartland in an interval 13 feet thick, the top of which lies about 13 feet below the HL-1 marker bed, and are apparently equivalent to the upper part of the Lincoln as that member is developed farther to the northeast. However, this 13-foot-thick interval is separated from the main body of the Lincoln by a 25-foot-thick interval consisting of Hartland-like shaly chalk and chalky limestone beds. Paleontologic evidence, discussed below, suggests that in Ford and Hodgeman Counties the basal part of the Lincoln is older than farther to the northeast (Hattin, 1965a, p. 44; 1968) and that much of the Lincoln, as developed in the latter area, passes southwestward into a Hartland-like section containing little skeletal limestone except for the 13-foot-thick interval mentioned above. Still father west, in Kearny County (Loc. 12) the top of the Lincoln lies 44.4 feet below HL-1 marker bed. Even at this locality a few very thin beds of calcarenite lie shortly beneath that marker and represent a horizon nearly equivalent to the top of the Lincoln in most of central Kansas, but by original definition of the Hartland (Bass, 1926) these skeletal limestones are included in the Hartland. In Kearny County, most of what is considered as Hartland is chronologically equivalent to Lincoln strata of the middle and northern parts of the central Kansas outcrop. At Locality 12, the top of the Lincoln is a chalky limestone bed that caps the uppermost portion of the part of the section that is rich in beds and lenses of skeletal limestone. Because the Lincoln does not consist predominantly of skeletal limestone, and because use of the term "limestone" does not, in the strict sense, distinguish this unit from overlying parts of the Greenhorn, I recommend that the name be simply "Lincoln Member."

Shaly chalk.—The predominant, though not characteristic, lithology in the Lincoln is shaly chalk, which occurs throughout the member (Fig. 6,B). In my detailed measured sections lithic units containing a preponderance of shaly chalk range in thickness from 6.7 feet to as little as 0.1 foot; however, thinner intervals of this kind of rock occur as interbeds in measured units consisting chiefly of skeletal or chalky limestone. Fresh shaly chalk is principally olive black and dark olive gray (5Y3/1),[7] usually drying upon exposure to medium light gray or, less commonly, to medium gray. This rock weathers mostly to grayish orange, dark yellowish orange, or dark yellowish brown and less commonly to other shades of brown and to various shades of gray. The sequence of color changes during weathering is apparently as follows: olive black and dark olive gray ⟶ light olive gray ⟶ brown ⟶ grayish orange ⟶ dark yellowish orange. These changes reflect progressive loss of organic matter and oxidation of iron compounds. The highest degree of weathering is apparently reflected in heavily iron-stained chalk of dark yellowish orange color. Limonitized pyrite nodules were recorded in shaly chalk from the basal part of the member at Locality 4 and from a thick shaly unit lying above basal skeletal limestone beds at Locality 59. Fine grained, granular to powdery gypsum is a common weathering product along joints and bedding fractures in many exposures of the Lincoln Member. Most of the shaly chalk is apparently more or less thinly and, generally, evenly laminated (Fig. 6,C) although uneven lamination is common in rock containing an abundance of foraminifera, small shell fragments, or other organic debris. Most of the rock is speckled to a greater or lesser extent by minute (less than 1 mm long), nearly white, oblate spheroidal fecal pellets that are rich in coccolith remains (see Goodman, 1951; Hattin, 1962, p. 40, 106, for prior discussion of such pellets). These pellets are most evident in unweathered rocks and contribute importantly to the laminated character of the shaly chalk. Samples of shaly chalk are generally gritty, owing to presence of calcareous silt and fine sand which ranges widely in abundance. The coarser grains are mostly *Inoceramus* prisms and tests of planktonic foraminifera, both of which are common in thin sections of shaly chalk (see section on petrography). In fresh exposures the shaly chalk is very tough and tends to break into irregular-shaped blocks, but where even slightly weathered the rock splits readily into innumerable small chips the long dimensions of which lie parallel to bedding. Unlike noncalcareous clayey shales of the Kansas Cretaceous, exposures of shaly chalk remain firm when water soaked.

Shaly chalk lithology is completely gradational with related chalky shale-calcareous shale and nonlaminated chalky lithologies. The gradation with chalky shale and calcareous shale is especially evident in the Graneros-Greenhorn transition at Localities 1, 4, 6, 12, and 47; chalky shale is common in the lower part of the Lincoln at Locality 21, Mitchell County, and at Locality 12, Kearny County. Both calcareous shale and chalky shale are included in the lower part of the Lincoln at Locality 6.

Most shaly chalk units in the Lincoln contain thin to very thin discontinuous beds or lenses, the latter from 0.25 foot to less than 0.01 foot in thickness, of skeletal limestone. These limestones, described below in the section on petrography, range from calcisiltites, composed of *Inoceramus* prisms and/or tests of planktonic foraminifera, to calcirudites composed largely of oyster and *Inoceramus* shells or shell fragments, with all possible gradations in between. These skeletal limestones, as well as whole and fragmentary valves of *Inoceramus*, project from rain-washed surfaces of units containing such structures. The characteristic association of shaly chalk and skeletal limestone is the principal basis for recognition of the Lincoln Member.

Although ranging widely in abundance, nearly ubiquitous fossils in Lincoln shaly chalks include whole and fragmentary valves of *Inoceramus prefragilis* Stephenson, tests of planktonic foraminifera, and fish scales, bones, and teeth. The *Inoceramus* valves are

[7] These number-and-letter designations are part of a standardized system of rock-color notations (Goddard and others, 1948).

generally flattened parallel to bedding. Just as invertebrate debris is locally concentrated as lenses or laminae of skeletal limestone, fish remains are likewise concentrated locally, though in far less abundance, and the whole skeleton of a small fish was recorded in shaly chalk of the middle part of the member at Locality 3. Small, cylindrical, white-weathering, brown phosphatic coprolites are a common constituent of the Lincoln shaly chalks but these occur as isolated specimens. Flattened molds of ammonites, especially including forms referable to *Eucalycoceras* and *Desmoceras* are common in shaly chalk of the middle Lincoln at Locality 26, and lower part of the Lincoln at Locality 12. A few other forms were collected but ammonites are generally uncommon in shaly chalk of the member. Details of Lincoln biostratigraphy are presented in a later section of this report.

Chalk and Chalky Limestone.—Every complete exposure of the Lincoln that I examined contains one or more beds, and at some places lenses, of nonlaminated chalk and/or chalky limestone. These are not characteristic of any one part of the member but, where several such beds or groups of lenses occur, tend to be scattered through the section. The more or less continuous units are mostly less than 0.3 foot thick but locally reach 2 feet (Loc. 8). In such lithic units the rock is mostly thin to very thin bedded. Lenses of chalk or chalky limestone range from less than 0.01 foot to as much as 0.5 foot in thickness. Lincoln chalk and chalky limestone is mostly olive gray (5Y4/1, 5Y3/2) to dark olive gray (5Y3/1) where fresh, and usually weathered to grayish orange or dark yellowish orange. Partly weathered rock is light olive gray (5Y6/1). All gradations exist between relatively soft, weakly resistant chalk to hard, well-lithified chalky limestone. Some of the chalky limestones contain thin, generally lenticular concentrations of skeletal debris that is cemented by sparry calcite to form hard calcarenite or calcisiltite. About 10 percent of the chalk or chalky limestone beds examined are at least in part thinly laminated. Unlike similar rocks in the overlying Hartland and Jetmore Members, chalk and chalky limestone of the Lincoln are virtually devoid of burrow structures. Some of the rocks examined contain pyrite nodules, or limonite nodules weathered from pyrite, and some rocks are banded with limonite. The most common fossils in these rocks are fish remains, *Inoceramus prefragilis,* and *Inoceramus* fragments, but a few molds of ammonites were collected, including *Eucalycoceras* sp. B. Some of these rocks contain an abundance of foraminifera or *Inoceramus* debris and are gradational between pure chalk and skeletal limestone.

At least two major kinds of chalk and chalky limestone are represented. The first is the common variety of very fine grained, relatively coherent rock much like that seen in the overlying parts of the Greenhorn and in the Fairport Member of the Carlile Shale. The second is a soft, granular rock that is invariably associated with bentonite seams and commonly occurs as lenses lying directly above bentonite seams. Excellent examples of the latter type include the following:

1. Loc. 3, 1.6 feet above base of Lincoln, discontinuous bed
2. Loc. 5, 9.1 feet above base of Lincoln, lenses
3. Loc. 6, 9.5 feet above base of Lincoln, lenses
4. Loc. 6, 12.2 feet above base of Lincoln, continuous? bed
5. Loc. 6, 13.6 feet above base of Lincoln, continuous? bed
6. Loc. 6, 20.1 feet above base of Lincoln, lenses
7. Loc. 8, 15.5 feet above base of Lincoln, continuous? bed
8. Loc. 24, 17.3 feet above base of Lincoln, lenses
9. Loc. 47, basal unit of Lincoln, lenses
10. Loc. 47, 11.3 feet above base of Lincoln, lenses

At Locality 24 and nearby Locality 62, about 0.6 foot above the base of the Lincoln, are white-weathering concretionary masses of fine-grained crystalline limestone up to 0.4 foot thick and 4 feet across (Fig. 6,D). These also lie on a bentonite seam and are apparently related genetically to the granular chalks tabulated above. In a few places the ordinary variety of chalk or chalky limestone lies on bentonite in the Lincoln, but even these rocks occur mostly as lenses. Most of the lenses of granular chalk associated with bentonite are poorly fossiliferous. It seems an obvious conclusion that such lenses are mainly diagenetic structures possibly resulting from precipitation or recrystallization of calcite by downward-percolating waters that were unable to penetrate a bentonite barrier. In a given section many bentonite seams apparently lack association with such rock, so that the mere presence of bentonite seams was obviously insufficient to produce lenses of granular or ordinary chalk and chalky limestone.

Skeletal limestone.—The Lincoln Member is characterized by the abundance of thin to very thin beds and lenses of skeletal limestone. Some of these are chalky, indicating genetic relationship with chalk and chalky limestone through a gradational series from chalk wackestones to grain-supported, spar-cemented skeletal rock. These skeletal limestones range from nearly pure foraminiferal and/or *Inoceramus*-prism calcarenite or calcisiltite to conglomeratic limestone containing several kinds of coarse skeletal and rock debris.

The coarsest-grained rock occurs at or near the base of the Lincoln and is especially well developed at Localities 2, 3, 5, 8, 23, 26, 27, and 69. At Locality 8, the basal bed of the Lincoln is 0.25 foot thick and consists largely of whole and broken valves of *Ostrea beloiti* together with *Inoceramus* prisms, bone pebbles, and a few shark teeth (Fig. 7,A). At Locality 23 the

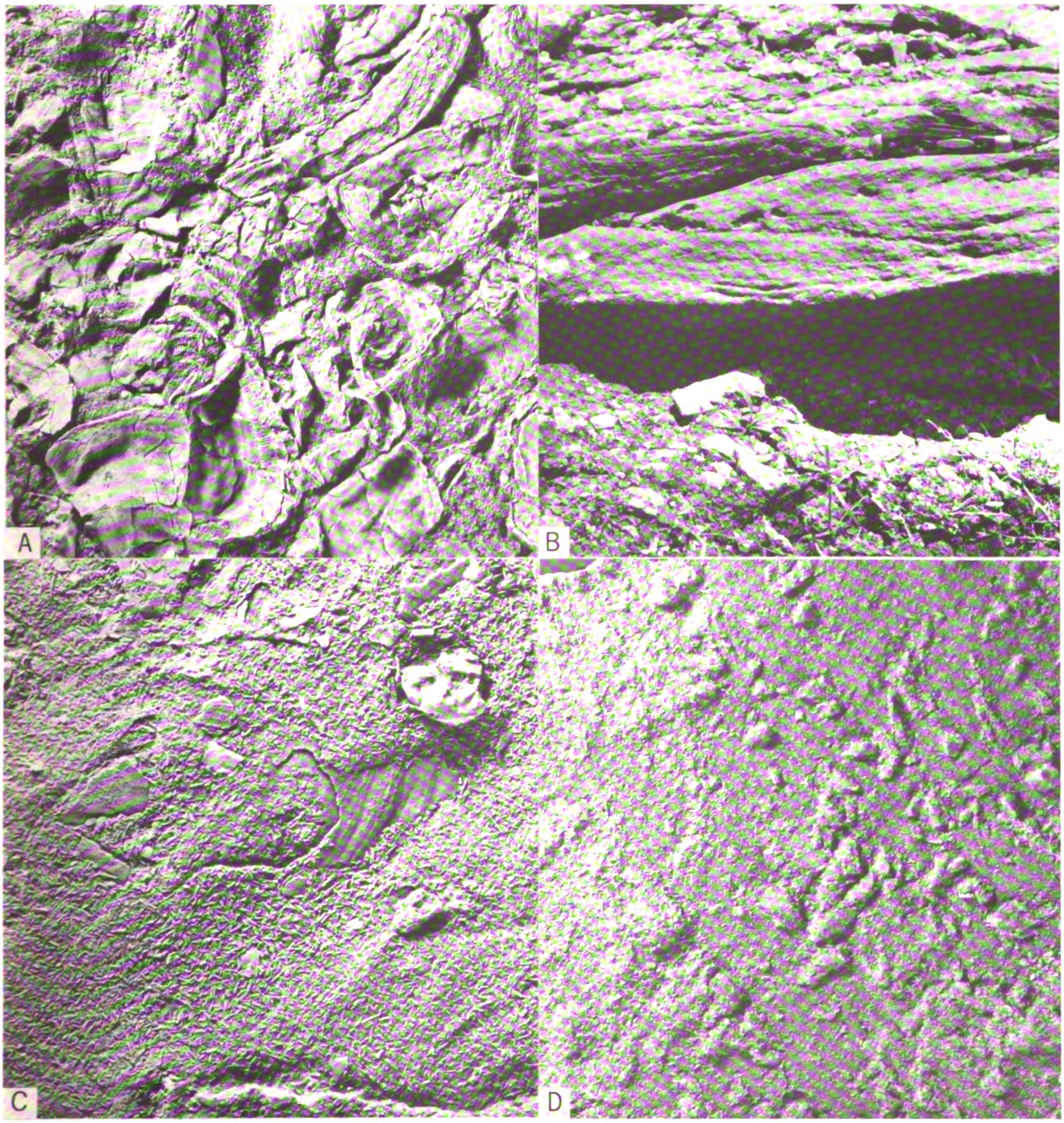


FIGURE 7.—Stratigraphic features of Lincoln Member. A) Upper surface of coquinoidal limestone lying at base of Lincoln Member, sec. 5, T. 25 S., R. 24 W., Ford County (Loc. 8), showing abundant valves and fragments of *Ostrea beloiti*. X1. B) Cross-bedded, conglomeratic skeletal limestone at base of Lincoln Member, sec. 18, T. 13 S., R. 12 W., Russell County (Loc. 3). C) Upper surface, parallel to bedding, of skeletal limestone from top of Lincoln Member, sec. 5, T. 25 S., R. 24 W., Ford County (Loc. 8), showing felt-like texture. Principal grains are isolated *Inoceramus* prisms. X2. D) Lower surface, parallel to bedding, of skeletal limestone from base of Lincoln Member, sec. 4, T. 12 S., R. 15 W., Russell County (Loc. 26), showing convex hyporeliefs believed to be fecal castings. X1.

lowest 2.5 feet of the Lincoln contains two conglomeratic units. The upper of these is 0.45 foot thick, consists of 3 thin beds of limestone separated by thin interbeds of shaly chalk, and thickens locally to 1.5 feet. This unit consists dominantly of *Inoceramus* prisms together with abundant small shell fragments and contains small limestone clasts. Where thicker, the rocks in this unit consist mainly of coarse skeletal fragments, valves of *Inoceramus*, chunks of calcified wood, irregular-shaped pebbles of fine-grained limestone, and many large, mostly fragmentary molds of ammonites. The basal conglomeratic limestone at Locality 5 and the conglomeratic rocks at or near the base of the member at the other localities cited above consist principally of *Inoceramus* prisms, oyster and *Inoceramus* valves and shell fragments, bentonite pebbles, phosphatic coprolites, fish bone fragments, shark teeth, and quartz sand grains. At a number of other localities, similar rocks lie at the base of the member but are finer grained and not so obviously polygenetic. Most of the conglomeratic rocks in the basal part of the Lincoln consist predominantly of *Inoceramus* prisms and small fragments of *Inoceramus* valves and these rocks are thus a variety of rock described below as inoceramite (Hattin, 1962, p. 41). At several places, especially Localities 2, 3, and 69, the conglomeratic rock grades upward into adjacent fine-grained inoceramite. At the localities mentioned, conglomeratic limestone units range in thickness from 0.15 to 1.85 feet in thickness and are unevenly very thin to medium bedded. Some are laminated, and some are cross laminated to cross bedded (Fig. 7,B). At Locality 5 (Ellis County) crossbed data are: strike—N8°E, dip—9° NW; Strike—N80°W, dip—17°NE. Data for cross beds in inoceramite at Locality 26 (Russell County) are: strike—N75°E, dip 10°NW; strike—N65°E, dip 14°NW. Cross beds in basal Lincoln inoceramite at Locality 69 are: strike N18°W, dip—15 to 17°NE. These limited data agree with data on current direction determined by the writer (1965a, p. 53) for the Graneros Shale, namely, that the prevailing current direction in the area between the present Smoky Hill and Saline Rivers was generally toward the north. The conglomeratic limestones described above are mostly hard, brittle, and resistant, but where weathered are crumbly, as at Locality 69. Where freshly broken these rocks have a petroliferous odor.

Most abundant of Lincoln skeletal limestones are the inoceramites, well-cemented rock composed mainly of *Inoceramus* prisms and commonly containing much coarse skeletal debris, especially valves or fragments of *Inoceramus,* and, less commonly, oyster valves and fragments, and scraps of fish bones, scales, and teeth. Complete gradation exists between the conglomeratic skeletal limestones at the base of the Lincoln and the predominantly sand-sized inoceramites. Inoceramites composed mostly of *Inoceramus* prisms have a felt-like appearance (Fig. 7,C) and strongly oriented grains were observed in some such rocks, especially in the basal part of the Lincoln at Locality 26 where aligned prisms lie parallel to the current flow direction as indicated by cross bedding. Some inoceramites consist exclusively of *Inoceramus* valve fragments that are commonly stacked parallel to bedding or imbricated in the small lenses where these fragments are concentrated. Many of the inoceramites contain tests of planktonic foraminifera, and a complete gradation exists between pure inoceramite and pure foraminiferal limestone. Similarly, a complete gradation exists between sparry calcite-cemented skeletal limestone, chalky skeletal limestones and highly fossiliferous chalk or chalky limestone, but this gradation is more typical of rocks in the Pfeifer Member than in the Lincoln. The inoceramites are scattered throughout the Lincoln, occurring as thin to very thin beds and thin to very thin irregular lenses (Figs. 6,A,B). Some measured units consisting mostly of thin to very thin bedded inoceramite are as much as a foot thick and lie mostly in the lower half of the Lincoln, toward the base of the member, but at many localities, more or less continuous thin or very thin beds of such rock occur also in the upper half of the Lincoln. Zones of thin to very thin lenses of inoceramite occur throughout the member and the uppermost such zone is regarded as marking the top of the member at several localities. In some shaly chalk units, however, inoceramite lenses are sparse to absent. Thus complete gradation exists between extensive, fairly thick units consisting solely of inoceramite and widely scattered small lenses of such rock. In general, the volume of inoceramite decreases upward in the section but there are many exceptions, especially at Localities 8, 21, and 37. At the last locality, the base of one inoceramite bed near the top of the Lincoln preserves interference ripple marks. Large pararipples with heights up to 0.5 foot and wave length up to 3.5 feet occur in the basal 0.85 foot of the Lincoln at Locality 54. The steep side of these ripples faces nearly east. In 1967 a possible parripple was observed in the basal Lincoln at Locality 64 but that section is now covered and no directional measurement is possible.

Sparse subaqueous plastic flow structures were recorded in inoceramite near the top of the Lincoln at Locality 3. Many beds and lenses of inoceramite bear well-preserved, elongate-elliptical, convex hyporeliefs believed to be invertebrate fecal castings (Fig. 7,D).

Like the *Inoceramus*-rich skeletal limestones, Lincoln foraminiferal limestone occurs as thin to very thin beds and lenses. Many of the lenses are pure calcite-cemented foraminiferal rock, with gradation locally to foram-rich chalk or chalky limestone, but thicker, more continuous beds of foraminiferal limestone generally contain at least some *Inoceramus* remains and other skeletal debris. Foraminiferal limestone commonly occurs as very small lenses or stringers only a millimeter or two in thickness and as little as 2 or 3 cm in width. Collectively these limestones are light olive gray (5Y6/1, 5Y5/2) to olive gray (5Y4/1) where fresh, weathering to pale yellowish brown, pale grayish orange, or other shades of orange and brown. Like the inoceramites, the foraminiferal limestones are scattered throughout the Lincoln, but tend to be more numerous in the upper half of the member. Some of these rocks are thinly laminated, and a few are cross laminated. The beds and thicker lenses may have irregular surfaces, but the very small, very thin lenses are usually quite smooth. Most of these limestones are hard, brittle, and resistant, and project from slopes of rain-washed exposures. A petroliferous odor was detected in many freshly broken samples.

Bentonite.—The Lincoln is characterized not only by its rich content of skeletal limestone but also by having a larger number of bentonite seams than other members of the Greenhorn (Fig. 6,B). In the central Kansas outcrop the number of bentonite seams ranges from 9 (Loc. 1) to 16 (Locs. 16, 47 & 48). The difference in number from locality to locality has three explanations. These are:

1. Some of the recorded bentonite seams are less than 0.01 foot thick and could be missed during section measurement, especially in exposures that require much ditching.
2. Some of the bentonite seams are discontinuous within a single exposure and may not be represented at adjacent localities.
3. Some of the bentonites that are included in the Lincoln at one locality are included in either the Graneros Shale or the Hartland Member of the Greenhorn depending upon the selection of contacts in gradational sequences of strata.

At Locality 12, where strata assigned to the Lincoln are believed to be largely older than most of the Lincoln in central Kansas, the member contains only 8 bentonite seams. However, the overlying Hartland, which is believed to be largely coeval with the Lincoln of central Kansas, contains 10 bentonite seams at Locality 13, bringing the total for the combined section to 18 seams. The Lincoln Member contains 12 bentonite seams at Locality 8, Ford County, but here, too, the Lincoln is believed to be largely older than farther to the northeast, and Hartland strata believed to be coeval with much of the Lincoln farther to the northeast contain 13 bentonite seams.

Correlation of Lincoln bentonite seams is difficult. Not only does the number of seams differ from one locality to the next, but thickness and spacing of bentonites range widely, the latter condition possibly reflecting differences in local rates of sedimentation. Usually a few bentonite seams can be traced from a given section to nearby sections, but with increasing distance, such correlations become very tenuous or impossible. Bentonite seams believed to be correlative are so indicated by interconnecting lines on Plate 1.

In a given section different Lincoln bentonite seams may be less than 0.01 foot to as much as 0.5 foot in thickness. Individual seams were observed to range laterally from a featheredge to 0.35 foot in thickness within a few feet. Some are arched over, or downward beneath, adjacent lenses of chalky limestone. Color of fresh or nearly fresh bentonite ranges widely. Most commonly encountered colors, in decreasing order of occurrence, are light olive gray (5Y4/1, 5Y5/2), light gray, yellowish gray (5Y8/1, 5Y7/2) and bluish or light bluish gray (5B6/1, 5B7/1). Each of several other shades of gray, and yellow, and also olive and green, were encountered in one or two places. The normal weathered colors of these bentonites is nearly white, but in most places the weathered rock is stained grayish orange to dark yellowish orange by limonite. Uncommon weathered colors are very pale orange, moderate olive brown, and moderate brown. Lincoln bentonite seams are commonly slightly to moderately silty, although nonsilty to very slightly silty seams also were observed. Minute biotite flakes are sparse to abundant in some bentonite seams at a number of localities. Beds or lenses of granular chalk or chalky limestone associated with bentonite seams have been described above. At a few places, some seams of bentonite are underlain or overlain by seams of vertically prismatic selenite, a common feature of bentonites in other Kansas chalks, especially the Fairport Member of the Carlile and Smoky Hill Member of the Niobrara.

A few powdered samples of Lincoln bentonite were examined by X-ray diffraction techniques and found to consist almost wholly of montomorillonite, with trace quantities of kaolinite and quartz.

Fossils.—Biostratigraphy of the Greenhorn is treated in a separate section of this report; however, the various range and assemblage zones are not based on all fossils known from the various members. The following list is a compilation of all macroinvertebrate species recorded during the present study. Appearance in the list does not indicate co-occurrence of species. Starred species are the most common; those marked by a dagger are rare or are known only from a single Greenhorn locality.

Bivalves:
- †*Camptonectes* sp. (undescribed), one specimen from Loc. 12
- **Exogyra* aff. *E. boveyensis* Bergquist
- *Exogyra columbella* Meek
- **Inoceramus prefragilis* Stephenson
- †*Inoceramus* cf. *I. rutherfordi* Warren (late form)
- *Inoceramus* cf. *I. tenuistriatus* Nagao & Matsumoto
- *Ostrea beloiti* Logan

Gastropods:
- †*Lispodesthes?* sp., single abraded specimen from Loc. 8

Ammonites:
- †*Borissjakoceras* cf. *B. orbiculatum* Cobban, crushed specimen from Loc. 12
- *Calycoceras? canitaurinum* (Haas)
- †*Desmoceras* sp.
- †*Desmoceras* (s.l.) sp.
- †*Dunveganoceras* cf. *D. pondi* Haas
- °*Eucalycoceras* sp. A.
- °*Eucalycoceras* sp. B
- *Acanthoceras wyomingense* (Reagan)
- †*Pseudocalycoceras* sp.
- °*Stomohamites* cf. *S. simplex* (d'Orbigny)

Cirripeds:
- †*Calantica?* sp.
- *scalpellid*, sp.
- †*Stramentum* sp. A (undescribed), Locality 3 only

Lincoln macroinvertebrate fossils are illustrated in Plates 2, 3 and 4.

Specimens of *Inoceramus* are represented almost exclusively by isolated prisms, whole valves, or valve fragments representing only the calcitic, prismatic shell layer. The originally aragonitic nacreous layer is preserved only rarely in calcareous shale or chalky shale transitional from the Graneros to the Lincoln and nearly everywhere assigned to the former unit. Weathered limestones from the lower part of the Lincoln commonly contain molds from which the prismatic layer has been partially or wholly exfoliated. Lincoln oysters are preserved almost entirely as calcitic valves or valve fragments and are abundant only in skeletal limestones. The sole specimen of *Camptonectes* is a flattened, calcitic valve from shaly chalk in the upper half of the member. The only gastropod collected in the Lincoln may have been reworked from the Graneros Shale and is a single abraded conch collected from an *Ostrea beloiti* coquina lying at the base of the member at Locality 8. Ammonites from the Lincoln are known almost entirely as internal and external molds. These are most common in skeletal limestones, sparse in chalky limestones, and least common in shaly chalk. Specimens in skeletal limestones are commonly little compacted; those in other kinds or rock have been more or less flattened by compaction. The cirripeds are mostly preserved as isolated, calcitic valves in skeletal limestones. At Locality 3, many articulated, calcitic specimens were collected from a small area on a single bedding plane in shaly chalk lying near the middle of the Lincoln.

The number of Lincoln macroinvertebrate species observed in mutual association is everywhere small, nowhere exceeding 8 species. Even where that number occur together, some of the species are pelagic forms, i.e. ammonites and possibly some or all of the cirripeds. This suggests that bottom conditions were generally hostile. Detailed discussion of paleoecology and depositional environments is presented in another section of this report.

Hartland Shale Member

General Description.—The Hartland[8] Shale Member of the Greenhorn was named by Bass (1926, p. 69) for "calcareous shale 23 feet thick that is almost devoid of limestone and contains numerous layers of bentonitic clay . . ." and lying between the Lincoln Member and the overlying Bridge Creek. Although no type section was designated specifically, Bass (1926, p. 69, 70) gave a generalized description of a section located halfway between Sutton,[9] Kearny County and Kendall, Hamilton County noting that the section there contains a few lenses of dark gray fossiliferous limestone. The exposure in NE¼, sec. 32, T. 21 S., R. 38 W., Kearny County (Loc. 13) is designated as the type section because it is probably the one described by Bass. Because the only practicable boundary between the Lincoln and Hartland Members is based on concentration of thin beds or lenses of skeletal limestone, the contact in the type section must be placed stratigraphically lower than indicated by Bass. As redefined here, the type Hartland is 44.5 feet thick. Strata included in the Lincoln by Bass, and here transferred to the Hartland, contain little, if any, skeletal limestone. The upper contact of the Hartland is placed at the base of the lowest of numerous, closely spaced, conspicuous hard beds of chalky limestone that characterize the Jetmore Member in central Kansas (Fig. 2,B; 8,A) and Bass' Bridge Creek Limestone Member of Kearny and Hamilton Counties. This contact is diachronous as explained below, with burrow-mottled chalk beds of the upper Hartland in central Kansas passing southwestwardly to Hodgeman County, then westwardly to Kearny and Hamilton Counties, into hard chalky limestone beds that resemble those of the central Kansas Jetmore.

In central Kansas the Hartland ranges in thickness from 8.6 feet at Locality 20, Jewell County, to approximately 68 feet in Ford and Hodgeman Counties, averaging 26.6 feet for 14 measured sections of which that in the latter area is a composite of Localities 8, 9, and 11. The wide range of thickness is explained in part by the diachronic nature of the Lincoln-Hartland contact mentioned above, and partly by condensation of the section in Ottawa, Mitchell, Cloud, and Jewell Counties where, with one exception, all of the principal marker beds are present but where member thickness is only about half that in counties lying directly to the south.

The Hartland does not consist of "shale" in the usual sense of the term, i.e., fissile clayey rock, nor

[8] Hartland was a small town located 6¼ miles southwest of Lakin, Kearny County. Although the name still appears on maps of the area, there is no longer a town.

[9] Sutton consists of a labeled siding on the Atchison, Topeka and Santa Fe Railroad.

FIGURE 8.—Stratigraphic features of the Hartland Member. A) Hartland-Jetmore contact (arrow), sec. 14, T. 9 S., R. 5 W., Ottawa County (Loc. 45). Reentrant beneath limestone bed at base of Jetmore is caused by weathering of thin bentonite seam nearly at top of Hartland Member. At this locality shaly chalk in upper part of Hartland has been hardened by weathering. B) Specimen of thinly laminated shaly chalk from upper part of member, sec. 18, T. 13 S., R. 12 W., Russell County (Loc. 3). X1. Light-colored laminae composed mostly of planktonic foraminiferal tests. C) Shaly chalk bedding plane showing scattered, broken fragments of *Inoceramus* from middle part of member, sec. 32, T. 24 S., R. 38 W., Kearny County (Loc. 13). X2. D) Exposure of lower half of Hartland Member, sec. 18, T. 13 S., R. 12 W., Russell County (Loc. 3), showing scattered beds of chalky limestones and thin layers (arrows) of nonlaminated chalk. Marker beds HL-1 and HL-2 are labeled. Note highly fractured nature of HL-1.

does shaly chalk, the main type of rock, serve to distinguish this unit from adjacent members. Therefore it is suggested that the name be amended to simply "Hartland Member." Because the unit consists largely of nonresistant rocks the member is a slope former. Natural exposures are common at the bases of cliffs held up by the resistant limestones of the overlying Jetmore Member (Fig. 2,A).

Shaly chalk.—As in the Lincoln Member, the Hartland consists chiefly of shaly chalk which, in sections measured by me, occurs in depositional units having thickness as little as 0.1 foot to as much as 11.1 feet. The fresh rock is mostly olive black or dark olive gray (5Y3/1), less commonly olive gray (5Y4/1), and dries to medium light gray. Partially weathered rock is mostly light olive gray (5Y6/1, 5Y5/2) or one of several shades of yellowish brown, or light- to very light gray. Where extensively weathered the shaly chalk is mainly grayish orange, very pale orange or pale grayish orange (10YR8/4) and is commonly stained yellowish orange by iron oxide. Other weathered colors include various shades of orange, yellowish gray (5Y7/2, 5Y8/1), pinkish gray, and pale yellowish brown. These colors exhibit all possible gradations. Nearly all of the shaly chalk is tough and breaks into irregular-shaped blocks where freshly ditched. After short exposure the rock breaks more or less parallel to bedding to form small chips. Weathered rock is soft and characteristically separates readily along laminations. Nearly all of the rock is thinly laminated (Fig. 8,B); the laminae are mostly even, but very irregular where the rock contains an abundance of foraminiferal tests. As in the Lincoln Member, most of the shaly chalk contains much calcareous silt or fine sand and is generally speckled by vertically compressed, nearly white, oblate spheroidal fecal pellets. Many of the shaly chalk units contain thin zones of nonlaminated, burrow-mottled chalk. Such chalk, and genetically related chalky limestone beds that were measured separately, is described in detail below. Some shaly chalk units contain very thin lensing beds or lenses of skeletal limestone like that characterizing the Lincoln Member. Most of these lenses lie in the Lincoln-Hartland transition interval, but skeletal limestone occurs also much higher in the section, even within the uppermost shaly chalk unit at some localities (e.g. 1, 2, 3, 13, 20). Hartland shaly chalk units locally contain thin streaks of ferruginous matter or granular gypsum. These may mark the position of very thin seams of bentonite that are now so weathered as to escape detection. In a few places shaly chalk lying adjacent to bentonite seams is waxy and less calcareous than usual. Such rock reflects dilution of calcareous mud by volcanic ash that has been altered to clay. Examples are mentioned below in the section on bentonite.

Hartland shaly chalk units are notably deficient in diversity of fossils. The only ubiquitous large invertebrates are species of *Inoceramus*. *I. prefragilis* ranges through most of the member and, in the central Kansas region, *Mytiloides labiatus* (Schlotheim) occurs in the upper few feet of the member. These fossils are represented by flattened, disarticulated valves and shell fragments (Fig. 8,C) that are locally so abundant as to litter the slopes with debris, but in some units these fossils are rare. Fish remains, including bones and bone fragments, teeth, and scales are present in most units and abundant locally. Valves of *Syncyclonema?* are abundant on some bedding planes at Localities 9 and 13. Rare specimens of *Phelopteria* have been collected from just below the middle of the member in central Kansas. Tests of planktonic foraminifera are distributed throughout the Hartland, commonly in sufficient abundance to cause a rough-textured surface on planes of fissility or to form thin lenses or laminae in the rock (Fig. 8,B). Rare molds of acanthoceratid ammonites and a few burrow structures comprise most of the remaining shaly chalk fossils.

Chalk and Chalky Limestone.—Chalk or chalky limestone beds are distributed unevenly throughout the Hartland Member (Fig. 8,D). Such beds are as little as 0.05 foot to as much as 1.0 foot thick. Some of these beds pinch and swell within a single exposure, in some places expanding locally to two or three times the usual thickness. Some chalk or chalky limestone layers are discontinuous, and a few consist of widely spaced lenses. Nearly all of these rocks contain one or more types of discrete burrow structures and many are extensively mottled (Fig. 9,A). Shaly chalk directly adjacent to the chalks and chalky limestones is also more or less burrowed, with maximum density of such structures coinciding with the latter rocks. Lack of lamination in all but a few such beds suggests that lithologic homogeneity in the chalk and chalky limestone lithologies has resulted from burrowing activities of a mobile infauna (Hattin, 1969a; 1971). Laminations, usually faint or poorly developed and generally not extending throughout the bed, were observed in chalk and chalky limestone beds at a few localities. Such laminations are not restricted to a particular bed, but are more common in the lower part of the Hartland at Localities 8 and 13 than elsewhere in the section. Where laminated, these rocks contain few or no burrow structures. Complete gradation exists between shaly chalk, chalk, and chalky limestone lithologies. Contacts of the burrowed units are commonly gradational (Fig. 9,B), especially between shaly chalk and soft chalk units, but in weathered sections the chalk and chalky limestone beds are usually well defined with upper and lower surfaces apparently in sharp contact with adjacent shaly chalk. The chalk beds are generally soft, nonresistant, and generally thin; the chalky limestones range from relatively hard to very hard, resistant beds that project conspicuously from surfaces of rain-washed exposures. Some of the chalky limestone beds become soft and crumbly upon weathering and one bed, designated HL-1, tends to shatter irregularly, even where freshly exposed (Fig. 8,D).

Where fresh these rocks are most commonly olive gray (5Y4/1) or light olive gray (5Y6/1 in color. Dark olive gray (5Y3/1), olive black, or medium-dark to very light gray coloration is uncommon. In some exposures the latest-formed chalk-filled burrow structures are noticeably darker in color than the surrounding rock (Fig. 9,B). These rocks dry to light-gray or very light gray. Partially weathered rock is yellowish gray (5Y8/1) or less commonly, moderate yellowish brown. Where extensively weathered these rocks are usually grayish orange, pale grayish orange (10YR8/4), or very pale orange, and less commonly pale yellowish brown, yellowish gray (5Y7/2) or other light shades of yellow and orange. A majority of the chalk and chalky limestone units consist of a single massive bed, but some consist of two or more thin to very thin

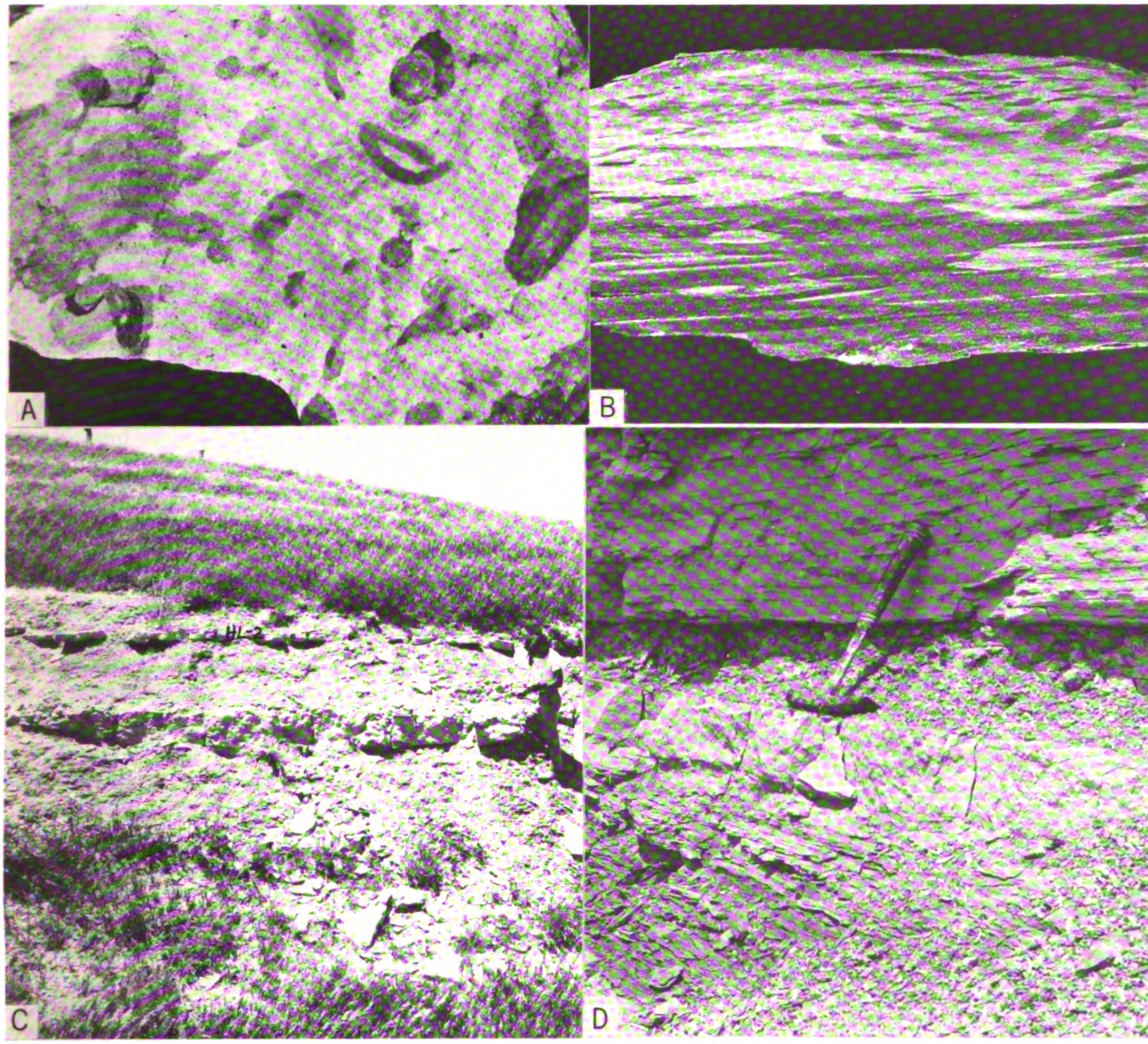


FIGURE 9.—Stratigraphic features of Hartland Member and equivalent part of Bridge Creek Member. A) Burrow-mottled chalky limestone, cut parallel to bedding, from lower part of Hartland Member, sec. 10, T. 23 S., R. 23 W., Hodgeman County (Loc. 11). X1. Note that last-formed (cross-cutting) structures are of darker color than the others. B) Gradational contact between laminated, little-burrowed shaly chalk and lighter-colored, highly burrowed, chalky limestone from Hartland equivalent of Bridge Creek Member, sec. 22, T. 23 S., R. 42 W., Hamilton County (Loc. 14). Cut normal to stratification. X1. C) Lens of foraminiferal chalky limestone in Hartland Member, sec. 2, T. 14 S., R. 8 W., Ellsworth County (Loc. 34), resulting from localized episode of scour and fill. Note resistant marker bed HL-2 at level of Dick Schuman's head. D) Hartland marker bed HL-3 (beneath hammer head) and superjacent seam of bentonite, sec. 27, T. 6 S., R. 9 W., Mitchell County (Loc. 63). Note thinly laminated character of overlying shaly chalk.

irregular beds. Where weathered, many of these units become slabby, often breaking apart so as to litter the underlying slopes with small rock chips. Most of these rocks are dominantly micrograined, but some consist largely of planktonic foraminifera and these have coarser texture. *Inoceramus* prisms are locally a prominent constituent in chalky limestone, as for example, in marker bed HL-1 (see Pl. 1) at Locality 29. Weathered surfaces of chalk and chalky limestone beds are commonly studded with foraminifera, especially those beds lying above the marker referred to in this report as HL-3, but markers HL-1, and HL-2 are also rich in foraminifera locally. Lenses of chalk or chalky limestone rich in forams lie 1 to 3 feet below HL-1 at Localities 3, 5, 11, and 34. These may be related genetically to one another. Maximum development of foraminiferal chalky limestone at that horizon is at Locality 34 where a flat-topped lens of such rock is 2 feet thick and 23 feet wide (Fig. 9,C). The lens is broadly convex below and gently cross laminated, the whole recording a rare episode of large-scale scour and fill on the sea floor during Hartland deposition. At Locality 11 a conspicuous, lensing bed of chalky limestone from 0.5 to 1.0 foot in thickness and lying 0.7 foot below marker bed HL-1 contains conspicuous thin laminae composed largely of planktonic foraminiferal tests.

Many of the Hartland chalk and chalky limestone beds are speckled by the same kind of nearly white, spheroidal fecal pellets as characterize the intervening shaly chalk beds. Burrowing activities of a highly mobile infauna may have contributed to less uniform preservation of these pellets as compared to adjacent non-burrowed shaly chalk beds. Pellets are commonly more apparent in well-preserved burrow structures than in the surrounding rock, possibly because last-formed burrows are, in many places, of darker color than adjacent rock, and the pellets stand in marked contrast to the dark burrow fill.

Other than burrows, chalk and chalky limestone beds nearly all contain valves or molds of *Inoceramus*, most of which lie essentially parallel to bedding. Some of these valves are fragmentary, but large concentrations, or lenses, of such debris were recorded. Marker beds referred to as HL-1 and HL-2 (see Pl. 1), as well as a nearly equally widespread chalk or chalky limestone bed lying shortly above HL-2 contain elements of the most diversified fossil assemblage in the Greenhorn of Kansas, i.e., the *Sciponoceras gracile* (Shumard) assemblage. This contains numerous species of ammonites, 7 mostly rare species of pelecypods, a gastropod, a brachiopod, and sparse borings of acrothoracian cirripeds. In the upper part of the member, above marker bed HL-3, a few molds of *Tragodesmoceras* and *Watinoceras* have been collected from beds of chalk or chalky limestone.

In chalk or chalky limestone beds some burrow structures are partially or wholly filled with coarsely crystalline sparry calcite and/or pyrite, some of which has been oxidized to limonite in weathered beds. Locally, such rocks contain irregular-shaped blebs or nodules of pyrite or marcasite and, in weathered beds, limonitized remains of such nodules. At several localities in central Kansas, especially Localities 1, 3, and 5, the first widespread chalky limestone bed above HL-2 contains molds of *Phelopteria, Baculites,* and *Calycoceras* that are commonly enveloped by a thin black film that possibly represents the remains of organic matter contained in the original shell.

Marker Beds.—Among the chalky limestone beds of the Hartland Member are three which can be traced widely and serve as useful marker beds. For convenience these have been assigned the alphanumeric code designations (ascending) HL-1, HL-2, and HL-3 which will be used throughout this report.

Marker bed HL-1 is the thickest chalky limestone in the Hartland (Fig. 8,D). In the area of central Kansas lying between Washington and Rush Counties the bed lies 0.91 (Loc. 20) to 11.68 (Loc. 5) feet above the top of the Lincoln Member, this interval generally increasing towards the southwest. The interval increases from 10 feet in southeastern Rush County (Locs. 15, 17) to approximately 40 feet in Ford County (Loc. 8) owing to lateral change of lithofacies whereby the middle and upper parts of the Lincoln pass southwestward into rocks assigned in this report to the Hartland Member, as explained above in the section concerned with the Lincoln-Hartland contact. At Locality 8, only a small part of this 40-foot interval contains an abundance of skeletal limestones, the uppermost beds of such rock lying approximately 9 feet below HL-1, or very nearly the same horizon as the top of the Lincoln Member in Rush County. This westward change of facies is virtually complete at Locality 13 in Kearny County where the interval from top of Lincoln to base of HL-1 is 44.4 feet thick and contains almost no skeletal limestone. At locality 13, however, HL-1 is the basal bed of the Bridge Creek Limestone Member and beds equivalent to most of the central Kansas Hartland are represented by the lower 24 feet of the Bridge Creek Limestone Member.

In central Kansas marker bed HL-1 ranges in thickness from 0.4 foot (Locs. 1 and 68) to 0.9 foot (Loc. 6), averaging 0.56 foot for 14 measurements. In western Kansas the marker is 1.25 foot thick at Locality 13 (Kearny County) and 1.33 foot thick at Locality 14 (Hamilton County) where it is separated into two beds by a 0.13-foot-thick layer of shaly chalk. At nearly all exposures examined, including a large number not measured, this bed is extensively fractured (Fig. 8,D) and under the hammer shatters readily into sharp-edged slabs. The bed is everywhere rich in trace fossils, characteristic among which are threadlike, limonite-stained burrows named *Trichichnus* by Frey (1970, p. 20), *Chondrites* Sternberg, and cylindrical, non-branched, smooth-walled burrows 2 to 5 mm in diameter that are filled usually by pyrite, limonite, or calcite. Large-sized, chalky, limestone-filled, burrow structures referable to *Planolites* Nicholson are abundant, but not diagnostic. This marker is the lowest Greenhorn unit containing faunal elements of the *Sciponoceras gracile* Assemblage Zone, the full contents of which are discussed in the section on biostratigraphy.

Marker bed HL-2 lies anywhere from 1.1 (Loc. 6) to 2.5 feet (Loc. 11) above HL-1. The former is well developed at every Hartland exposure examined except that at Locality 20 where the normal stratigraphic position of HL-2 is occupied by 0.2 foot of dusky yellow to dark yellowish orange clay, the marker bed apparently having been removed there by intrastratal solution. At Locality 48 the bed is present but discontinuous. These two areas of abnormality may be related to factors which resulted in a condensed stratigraphic interval extending from HL-1 through the lower part of the Jetmore Member in the Jewell and Cloud Counties area. Despite the drastic, localized thinning of this interval, every marker bed is present with the single exception of HL-2 at Locality 20. Overall sedimentation rates were obviously lower along a line from Randall, Jewell County, to just south of Concordia, Cloud County, and for a short distance on either side of this line, than elsewhere in the State, perhaps owing to slight shallowing of the sea in this area. This suggestion is supported by the unusual presence in this area of skeletal limestone lenses in the upper part of the Hartland at Locality 20 and between markers HL-1 and HL-2 at Locality 46.

Disregarding very localized discontinuity in an otherwise continuous bed, marker bed HL-2 exhibits its maximum and minimum thickness of 0.2 and 0.6 foot at Locality 6. Such wide range at a single locality is not common, and is largely the result of small areas of downward expansion of the bed. Normal thickness at Locality 6 is about 0.35 foot. Similar downward expansions to 2 or 3 times the normal thickness were observed at Localities 3 and 15. Not including local discontinuity and local downward expansions, the bed averages 0.28 foot in thickness for 14 measurements. This bed contains all but two of the species associated with the *Sciponoceras gracile* assemblage of Kansas, and is characterized by in-the-round preservation of highly inflated valves of *Inoceramus prefragilis* specimens. Nodules of pyrite, or their limonitized counterparts were observed locally, but in the Hartland are not unique to this bed, and a pyritized specimen of *Inoceramus prefragilis* was observed at Locality 3. This bed contains many burrow structures, the most common of which are slender, smooth-walled, mostly calcite-filled, nonbranched cylindrical forms, and large, branched, chalky-limestone filled burrows assignable to *Planolites*. The most striking attribute of this important bed is its remarkable resistance to weathering. Although relatively soft and subject to platy fracturing where freshly uncovered, this marker hardens upon exposure to become one of the most resistant beds in the entire formation (Figs. 8,D; 9,C). Slabs of this hard, brittle rock commonly litter slopes below a small bench held up by the bed. Marker bed HL-2 is readily recognizable by its highly diversified fauna, the abundance of well-preserved *Inoceramus prefragilis* valves, the hardness and resistance to erosion, and its proximity to the equally distinctive HL-1 marker. The thin shaly chalk interval separating these two beds contains a conspicuous seam of bentonite that ranges from 0.12 to 0.71 foot in thickness and lies only 0.3 to 0.7 foot above HL-1. Approximate parallelism of HL-1, HL-2 and the intervening bentonite over an extraordinarily long distance (at least as far west as Pueblo County, Colorado) together with remarkably uniform lithology over much of the Kansas outcrop, suggests that the two limestones lie parallel to isochrones. It is simpler to account for slight differences in intervals separating the bentonite from the two limestones at various localities by assuming differential sedimentation, which can be demonstrated in several parts of the Greenhorn section, than to suggest that these thickness differences reflect diachronism of the two marker beds. A full discussion and interpretation of apparently time-parallel burrow-mottled limestone beds in the Hartland, Jetmore, and Bridge Creek Members has been published elsewhere (Hattin, 1971).

I have chosen these limestones as marker beds, rather than the adjacent bentonite seam because the latter could not be identified consistently were it not for the association with the two limestones. The three beds together comprise a clearly recognizable group of markers that in Kansas cannot be mistaken for any other part of the Greenhorn section.

In central Kansas, marker bed HL-3 lies 1.85 feet (Loc. 48) to 5.5 feet (Loc. 15) above HL-2, this interval thickening generally toward the southwest (see Pl. 1). From Locality 15 the interval thins to approximately 4.7 feet at Locality 8, Ford County, thence maintaining uniform thickness westward to Hamilton County where the interval is 4.8 feet thick at Locality 14. At Locality 20, Jewell County, HL-3 lies only 1.0 foot above the clayey deposit representing the position of HL-2, but the original distance between HL-2 and HL-3 is unknown.

Marker bed HL-3 ranges from 0.2 to 0.45 foot in thickness, averaging 0.32 foot for 12 measurements. Except at Locality 14, Hamilton County, where the unit is brittle chalky limestone, HL-3 is generally soft, burrow-mottled chalk that is in most places rich in tests of planktonic foraminifera and that crumbles readily upon exposure to weathering. Ready recognition of the bed is afforded by association with a prominent, overlying seam of bentonite that ranges from 0.25 to 0.6 foot in thickness, averaging 0.46 foot for 18 measurements, and that is nearly everywhere thicker than any other bentonite seam in the Greenhorn of Kansas (Fig. 9,D). The top of this bentonite is only 4.28 feet below the base of the Jetmore at Locality 20, Jewell County, but this interval thickens northeastward to 6.0 feet at Locality 6 and southwestward to 18.7 feet at Locality 15, Rush County. From Rush County this interval thins southwestward to 16.7 feet at Locality 51, Ford County, thence thinning further to only 14.8 feet at Locality 14, Hamilton County where all of the section in question is classified as a part of the Bridge Creek Member.

In most Kansas localities, three additional markers are recognized in the Hartland or in its Bridge Creek equivalent. These are bentonite seams and include 1) the first bentonite seam below HL-1, lying less than 2.5 feet below HL-1 from southeastern Mitchell County northeastward to Washington County, and between 3.6 and 7.8 feet below HL-1 between western Mitchell County and Rush County. Correlation of this bentonite seam is uncertain south of Rush County. 2) A bentonite seam lying approximately 2/3 to 3/4 the distance from HL-3 to the base of the Jetmore (JT-1), and lying 19.7 feet above the base of the Bridge Creek Member in Hamilton County. This bentonite seam can be traced throughout the State and is labeled HL-4 on Plate 1. 3) A bentonite seam 0.04 to 0.13 foot thick lying 0.0 to 0.19 foot below to base of the Jetmore. This seam is traceable throughout the Kansas outcrop and lies 23.8 feet above the base of the Bridge Creek Member in Hamilton County. These bentonites are not traceable on their field characteristics alone but must be identified according to stratigraphic position with respect to other marker beds, or, in the case of the last-mentioned seam, by its close association with the hard, brittle, chalky limestone bed that marks the base of the Jetmore Member in central Kansas.

Facies Changes in Hartland Member.—Both lower and upper parts of the Hartland Member grade laterally, by gradual change of facies, into rocks assigned to other members of the Greenhorn. The Lincoln-Hartland contact descends stratigraphically in a southwestward direction from the northern part of central Kansas to Ford County as has been remarked above. The evidence may be summarized briefly, as follows: 1) In the area from Washington County to Hodgeman County the interval separating the top of the Lincoln from Hartland marker HL-1 increases irregularly from 2.5 feet at Locality 6 to at least 12.4 feet at Locality 11. 2) Still farther southwest, at Locality 8 (Ford County) this interval is 40 feet thick and consists mostly of shaly chalk of Hartland aspect, i.e., nearly free of skeletal limestone. However, within this 40-foot interval are approximately 13 feet of shaly chalk containing Lincoln-like lenses and a few thin beds of skeletal limestone. The top of the skeletal-limestone-bearing interval lies 12.7 feet below HL-1 and is regarded as the approximate lithostratigraphic equivalent of the top of the Lincoln in Rush (Locs. 15, 17) and Ellis (Loc. 5) Counties. In Ford County the Lincoln would thus appear to be mostly older than farther to the northeast. This conclusion is borne out by biostratigraphic evidence. 3) To the west of Ford County the top of the Lincoln lies 44.4 feet below HL-1 and therefore lies nearly the same distance below that marker as in Ford County. Fossils in the upper part of the Lincoln in Ford and Kearny Counties are species found in the lower part of the Lincoln farther to the northeast.

At Locality 6 in western Washington County, the Hartland contains only three chalky limestone beds, namely HL-1, HL-2, and HL-3. In addition, a single burrow-mottled shaly zone lies near the top of the Hartland, above HL-3. Southwestward from Locality 6 additional chalky limestone beds and zones of burrow-mottled chalk characterize a progressively thicker interval between HL-1 and the top of the member (see Pl. 1). Thus, at Locality 4 (Mitchell County) a burrow-mottled chalk bed is present between HL-2 and HL-3, and there are four burrow-mottled chalk beds between HL-3 and the top of the Hartland. At Locality 3 (Russell County) the HL-2 to HL-3 interval contains a burrow-mottled chalky limestone bed probably equivalent to the burrow-mottled chalk bed at Loc. 4 and, below this, a discontinuous layer of chalky limestone lenses. A 0.1-foot thick bed of burrowed chalk lies 0.7 foot below HL-3 at Locality 3. Above HL-3 the section contains six burrow-mottled chalk layers. At Locality 15, Rush County, the HL-2 to HL-3 interval contains the same burrow-mottled chalky limestone as at Locality 3 and also a burrow-mottled chalk layer 0.6 foot below HL-3, but the discontinuous chalky limestone bed of Locality 3 is missing. Above HL-3, the Hartland contains four, perhaps five, beds of burrow-mottled chalky limestone and three beds of burrow-mottled chalk, as well as three non-burrowed chalk beds. At Locality 9, Hodgeman County, the interval from HL-2 to HL-3 is not exposed, but above HL-3 are ten beds of chalky limestone, most of which are harder and thicker than chalk or chalky limestone beds in this interval farther to the north. Burrow mottling is evident in all of these beds either here or at a more weathered section that is exposed one mile to the northeast (Loc. 50). Although I have made no effort to trace regionally the individual chalky limestone beds above HL-3, it is apparent from the spacing and relationship to marker beds that some of those at Localities 9 and 50 represent beds that occur farther to the northeast. Because of the regionally widespread character of Hartland marker beds and nearly all limestone beds in the Jetmore it is suggested that each of the Hartland burrowed chalk beds lying above HL-3 in the more northeasterly areas of central Kansas are represented by one of the chalky limestone beds at Localities 9 and 50. Thus, as one traverses the outcrop from northeast to southwest, in the Hartland interval above HL-3 the number of burrow-mottled beds is greater, individual beds are thicker, and lithology changes from chalk to chalky limestone. At Localities 9 and 50 the chalky limestones are not as hard or resistant to weathering as in the overlying Jetmore so that despite considerable resemblance to the Jetmore this part of the section was not included in that member by Moss (1932, p. 29). In western Kansas, at Locality 14 (Hamilton County) two hard burrow-mottled chalky limestone beds lie between HL-2 and HL-3, HL-3 is also harder than to the east and northeast, and several chalky limestones lying between HL-3 and the base of the Jetmore equivalent are hard and burrow mottled as in the Jetmore. At this locality the section between the base of HL-1 and the Fencepost limestone is more homogeneous than in central Kansas, consisting essentially of thin to medium beds of hard chalky limestone alternating with thicker units of shaly chalk. The entire interval was called Bridge Creek Limestone Member by Bass (1926, p. 67) and the term Bridge Creek has been widely adopted for this part of the Greenhorn section in Colorado. The term "Bridge Creek" is retained for this interval in the present report, although I can easily recognize in the member the exact equivalents of the middle to upper Hartland, the Jetmore, and the Pfeifer of central Kansas. There is no doubt whatsoever that the middle and upper parts of the central Kansas Hartland pass laterally into the lower part of the Bridge Creek Member, with the result that the Hartland-Bridge Creek contact of Hamilton County represents an older horizon than does the Hartland-Jetmore contact in central Kansas. In central Kansas the base of HL-1 lies as little as 0.9 foot above the *base* of the Hartland (Loc. 20). At Localities 13 and 14 (Kearny and Hamilton Counties) the base of HL-1 is at the *top* of the Hartland. From these facts stems the conclusion that nearly all of the type Hartland is older than the Hartland of the northern part of central Kansas. This conclusion is supported fully by biostratigraphic data that are discussed in detail below.

Skeletal limestone.—Thin to very thin, usually small lenses or very thin beds of hard skeletal limestone are distributed sparingly in the Hartland Member. In most central Kansas exposures a scattering of such limestone occurs in the lower few feet of the member testifying to the gradational change of depositional environment that led from the Lincoln to the Hartland kind of sedimentation. Sparse skeletal limestone occurs locally between Hartland marker beds HL-1 and HL-2 (Loc. 46), shortly above marker bed HL-2 (Locs. 3, 20, 24) and in the upper part of the Hartland (Locs. 20, 24). At no place in central Kansas does hard skeletal limestone comprise a characteristic feature of the member. At Locality 8 (Ford County) a portion of the Hartland that is judged to be equivalent to the middle and upper Lincoln of areas farther to the northeast contains numerous thin beds and lenses of skeletal limestone, but at Locality 13 (Kearny County) the same part of the section contains little rock of this kind. At Locality 14 (Hamilton County) the lower part of the Bridge Creek Member contains a little skeletal limestone above marker bed HL-3. At several localities thin laminae or lamina-like lenses of planktonic foraminiferal tests help to impart a laminated appearance to the section, especially in the upper part of the section (see Fig. 8,B).

Most of the Hartland skeletal limestones are of the kind I call inoceramite, i.e., composed largely of *Inoceramus* prisms and commonly containing larger pieces of broken *Inoceramus* valves. A few are composed principally of planktonic foraminiferal tests, chiefly *Hedbergella,* and there are gradational varieties comprising mixtures of these two components. These rocks are most commonly pale yellowish brown, weathering grayish orange, but a few are light olive gray (5Y5/2) or, rarely, yellowish brown (10YR5/2). Some of the lenses or very thin laminae of foraminiferal limestone occurring above marker bed HL-3 are light gray in color.

Skeletal limestones of the Hartland usually emit a petroliferous odor when freshly broken. The rocks are usually hard and brittle, owing to tight cementation by sparry calcite, and are resistant to erosion. The thicker lenses and beds project prominently from weathered slopes but rarely litter the surface with slabs as in the Lincoln Member.

Bentonite.—Various exposures of the Hartland Member contain differing numbers of bentonite seams. In a section that contains so many widespread limestone and bentonite seams the fact that the number of bentonite seams differs from one area to another needs explanation. Possible reasons are: 1) the Hartland of Ford County (Loc. 8) and Kearny County (Loc. 13) embraces a part of the section that is largely older than the Hartland elsewhere in Kansas and therefore does not contain the same sequence of seams; 2) some bentonite seams are very thin (less than 0.01 foot thick) and are difficult to detect, especially in weathered sections; and 3) some bentonite seams, especially very thin ones, may be discontinuous. The minimum number of bentonite seams observed in any of the detailed measured sections is 6, at the northeastern end of the central Kansas outcrop (Locs. 4, 6, 20).

Towards the southwest this number increases to 7 at Locality 1, 8 at Locality 3, 9 at Localities 5 and 15, and 10 at a composite section including Localities 9 and 11. The increase in number of bentonite seams parallels the southwestward increase in number of Hartland chalk and chalky limestone beds. At Locality 8, where the Hartland includes beds that are older than farther to the northeast, the member includes 21, or possibly 22, bentonite seams. In Kearny and Hamilton Counties a composite section (Locs. 13 and 14) equivalent to the Hartland at Locality 8, and including the lower part of the Bridge Creek Member contains 20, or possibly 21, bentonite seams.

Hartland bentonite seams range in thickness from less than 0.01 foot to a maximum of 0.71 foot. The bentonite seam lying on marker bed HL-3 (Fig. 9,D) has the greatest average thickness, 0.45 foot for 19 measurements, and ranges from 0.25 foot at Locality 14, where it is included in the Bridge Creek Member, to 0.6 foot at Localities 1 and 4. The bentonite lying between marker beds HL-1 and HL-2 is the second most conspicuous, ranging from 0.12 foot (Locs. 6 and 20) to 0.71 foot (Loc. 15), averaging 0.31 foot for 16 measurements.

The bentonites are seen mostly in a deeply weathered state. The most common coloration is nearly white, very light gray, grayish orange and, overwhelmingly dominant, dark yellowish orange. The last two colors are believed due to limonite staining. A wide variety of other colors were recorded, mainly including several shades of grayish yellow, yellowish gray, and olive gray. Coloration of apparently unweathered bentonite is medium gray, light bluish gray, or medium olive gray but such rocks are rare. In many places the bentonite is noticeably gritty owing to small amounts of quartz silt that has been detected in X-rayed samples, and possibly to undevitrified glass. Biotite was observed in bentonite seams at several localities. The seam lying nearly at the top of the member is most consistent in containing minute flakes of a biotite-like mineral. Seams of granular selenite occur commonly above and/or beneath Hartland bentonite seams and small crystals of selenite are incorporated in the seams at a few places. Pyrite nodules, or limonite nodules altered from pyrite, were recorded in bentonite seams at a few localities but are rare compared with those found in bentonite seams of the Smoky Hill Member of the Niobrara Chalk. Not all Hartland bentonite seams are continuous. Seams that can be traced to a featheredge within a single exposure were noted at two localities and the differing number of seams noted at various places is owing at least in part to such discontinuities.

Several samples of Hartland bentonite were analyzed by X-ray diffraction techniques. These include two samples of the bentonite lying between marker beds HL-1 and HL-2, four samples of the bentonite lying on marker bed HL-3, one sample of the bentonite labeled HL-4 on Plate 1, and five samples from seams lying below HL-1, including three from the type Hartland. Of these samples 8 are composed dominantly of montmorillonite and 4 are composed dominantly of kaolinite. All of the kaolinite-rich samples are from Localities 13 and 14 in Kearny and Hamilton Counties; however, two samples from these localities are dominated by montmorillonite. At Locality 3 the bentonite lying between HL-1 and HL-2 is nearly pure montmorillonite and contains a trace of quartz; at Locality 13 this same bentonite contains kaolinite. At both localities the adjacent rock can be described as unweathered. The bentonite lying on marker bed HL-3 is pure montmorillonite at Localities 3, 4, and 6, central Kansas, but is composed mostly of kaolinite at Locality 14 (Hamilton County). Locally this bentonite contains a little feldspar. Quartz is present mostly in trace quantities in half of the samples analyzed. Gypsum, a product of weathering, was recorded in two of the samples. Trace quantities of feldspar and/or mica (probably biotite) were recorded in a few of the X-rayed samples.

Macroinvertebrate Fossils.—The biostratigraphic zonation of Hartland strata, treated in a later section of this report, is not based on all macroinvertebrate species in the member. The following list includes all forms recorded in the Hartland and equivalent Bridge Creek strata during the present study. Inclusion of a taxon in this list does not indicate co-occurrence with all of the other species. Common forms are preceded by an asterisk. Rare forms, or those known from only one locality, are preceded by a dagger.

Brachiopods:
- †*Discinisca* sp.

Gastropods:
- °*Cerithiella* sp. A (undescribed)

Bivalves:
- *Inoceramus flavus* Sornay
- °*Inoceramus (Mytiloides) labiatus* (Schlotheim)
- °*Inoceramus prefragilis* Stephenson
- *Inoceramus* cf. *I. tenuistriatus* Nagao & Matsumoto
- †*Martesia?* sp.
- †*Plicatula?* sp.
- *Phelopteria* sp. A (undescribed)
- *Syncyclonema?* sp.
- †*Teredolithus* sp.

Cephalopods:
- *Allocrioceras annulatum* (Shumard)
- °ammonite molds, unidentified fragments
- °*Baculites* sp. (smooth)
- †*Calycoceras* cf. *naviculare* (Mantell)
- †*Calycoceras?* sp.
- *Desmoceras* (s. l.) sp.
- *Eucalycoceras* sp. B
- *Hemiptychoceras reesidei* Cobban & Scott
- °*Kanabiceras septemseriatum* (Cragin)
- *Metoicoceras whitei* Hyatt
- †*Pseudocalycoceras dentonense* (Moreman)

†*Puebloites* sp.
†*Scaphites brittonensis* Moreman
Sciponoceras gracile (Shumard)
†*Stomohamites?* sp.
†*Tragodesmoceras bassi* Morrow
°*Watinoceras reesidei* Warren
°*Worthoceras vermiculum* (Shumard)
Worthoceras gibbosum Moreman

Cirripeds:
acrothoracian barnacle borings

Hartland macroinvertebrate fossils are illustrated in Plates 5 and 6.

A single brachial-valve mold of *Discinisca* was collected from the Bridge Creek Member in marker bed HL-1 at Locality 14. A minute portion of the original, probably phosphatic valve adheres to this mold. The gastropod referred to as *Cerithiella* sp. A is most abundant in marker bed HL-2. The original aragonitic valves have been converted to sparry calcite that preserves every external detail of the skeleton. The most common Hartland fossils are valves of *Inoceramus* which occur in abundance throughout the Hartland and equivalent part of the Bridge Creek. In most of these the calcitic prismatic layer is preserved but the presumably aragonitic nacreous layer is invariably lacking. In weathered rocks even the prismatic layer may be missing, leaving only molds of the original specimens. Broken *Inoceramus* valves are common, especially in skeletal limestones, and many of the skeletal limestones are composed principally of isolated prisms from valves that have suffered extreme disintegration of the prismatic layer. Rare specimens of *Phelopteria,* recorded mostly from marker bed HL-2, are preserved generally as molds. A few specimens collected from HL-2 and from shaly chalk directly above HL-2 retain a thin shell composed of calcite. In the first widespread chalky limestone bed lying above HL-2 molds of *Phelopteria* are invested by a thin, nearly black coating that may represent organic material originally incorporated in the valves. The boring mollusk referred to *Martesia?* sp. is represented by a mold of the paired valves of a single specimen. *Teredolithus,* a catchall term for the calcareous tubes of boring bivalves, is represented by rare calcitic specimens recorded only in marked bed HL-1. Specimens identified as *Plicatula?* sp. and *Syncyclonema?* sp. are represented by flattened valves preserved in shaly chalk. All of these are calcitic and the valves of the latter are paper thin. With one exception Hartland ammonites are preserved exclusively as molds. A baculitid preserving a small bit of irridescent, nacreous shell material was collected from marker bed HL-2 at Locality 3. In shaly chalk the ammonite molds are much flattened by compaction; in chalky limestone some specimens have been flattened by compaction but a majority of the ammonite molds are preserved in-the-round or with only slight compactional effects. Throughout the Kansas outcrop ammonite molds preserved in the first widespread chalky limestone bed above HL-2, like *Phelopteria* specimens in the same bed, are commonly coated by a thin layer of nearly black material that may represent organic matter once incorporated in the conchs. To a lesser extent this phenomenon has been recorded also in marker bed HL-2.

Jetmore Chalk Member

General Description.—The Jetmore was named "Jetmore chalk member" by Rubey and Bass (1925, p. 45) from "exposures south and east of Jetmore, along the south side of Buckner Creek, in Hodgeman County, Kansas." Moss (1932, p. 29) designated as type locality a site located one-half mile south of Jetmore where the member is 22.5 feet thick. The only complete exposure of Jetmore beds in this vicinity is on the east side of a north-south county road in NW¼ sec. 7, T. 23 S., R. 23 W. (Loc. 50). I have remeasured this section and found Moss' figure to be exact. Because the term "chalk" conveys the notion of lithologic homogeneity not manifest in the shaly chalk, chalky limestone, and limestone content of the Jetmore, and because chalk lithology does not distinguish the Jetmore from adjacent members, I recommend that the name be emended to simply Jetmore Member.

As defined by Rubey and Bass (1925, p. 46, 47) the Jetmore occupies the stratigraphic interval extending from 20 to 40 feet below the top of the Greenhorn formation (sic) and consists of chalky shale (sic) and 12 to 15 beds of chalky limestone of which the "*Inoceramus* limestone" (Shellrock limestone bed of present report) is uppermost and lies at the top of the member. Although the upper few feet of the Jetmore are more closely related lithologically and genetically to overlying beds of the Pfeifer, for purposes of this report I have accepted the top of the Shellrock bed as upper limit of the member.

The base of the Jetmore was not well defined in the earlier county reports because chalky limestone beds in the lower part of the members were said to be thinner (Rubey and Bass, 1925, p. 47; Bass, 1926, p. 33) and fewer (Bass, 1926, p. 33) than higher in the section, the Hartland and Jetmore thus being gradational. In all central Kansas sections that I have examined the Hartland-Jetmore contact is readily defined on the basis of abrupt upward change from a part of the Hartland dominated by shaly chalk, and containing scattered thin beds of chalk or soft chalky limestone, to an interval in the Jetmore that includes numerous, closely spaced beds of resistant, brittle-weathering chalky limestone that project conspicuously from slopes and that weather to noticeably lighter colors than does the adjacent rock (Fig. 2,B). The lower part of the Jetmore includes nine such beds at virtually every locality that I have studied. A thin seam of bentonite lying within 0.13 foot of the top of the Hartland Member serves to identify unquestionably the lowermost of these beds even in exposures where adjacent, thoroughly weathered, case-hardened shaly chalk units take on some of the characteristics of chalky limestone (Fig. 8,A).

As defined herein, the upper and lower limits of the Jetmore correspond to those indicated in sections measured by Wing (1930, p. 27) and Moss (1932, p. 29) and are recognized readily throughout the central Kansas outcrop. Exactly corresponding limits can be recognized also in Hamilton County (Loc. 14) where the Jetmore equivalent has been included in a stratigraphically more embracive unit called Bridge Creek Limestone Member by Bass (1926, p. 66).

In central Kansas the Jetmore ranges in thickness from 12.9 to 22.6 feet, averaging 18.7 feet for 18 measurements, including one that is a composite section. Thickness of the exactly corresponding interval in Hamilton County is 25.4 feet. Thickness values are lowest in Jewell and Cloud Counties in the northeast and thicken gradually and almost uniformly towards the southwest.

The Jetmore can be divided into four submembers (Fig. 10,A). The lowest, and thickest, subdivision is characterized by nine thin to medium beds of mostly hard chalky limestone that are separated from each other and from the overlying limestone beds by thicker intervals of shaly chalk (Fig. 10,B). The second submember consists of three hard, brittle, limestone or chalky limestone beds that contain a profusion of *Mytiloides labiatus* valves and that project from weathered slopes and roadcuts somewhat more prominently than most other beds in the Jetmore (Fig. 10,C). Shaly chalk units rich in skeletal debris separate these three beds and the lowest limestone bed is everywhere overlain by a thin, locally discontinuous seam of bentonite. The third submember is a shaly chalk interval that contains from one to three, but usually two, layers of nodular to concretionary chalky limestone (Fig. 10,C). The fourth submember is the Shellrock limestone bed which is the thickest chalky limestone bed in the Kansas Greenhorn (Fig. 10,C). All four submembers can be recognized in Hamilton County (Locality 14) where they are included in the Bridge Creek Member.

Basal submember.—The nine chalky limestone beds and associated shaly chalk units which in central Kansas characterize the basal submember apparently correspond to the Flagstone horizon of Logan (1897, p. 215). This distinctive unit ranges in thickness from 6.2 feet in Cloud County (Loc. 46) to 15.6 feet in Hodgeman County (Loc. 9). At Locality 14, in Hamilton County, the exactly equivalent interval in the Bridge Creek Member is 16.6 feet thick; however, total thickness of Bridge Creek strata containing chalky limestone beds like those of the basal submember is 40.6 feet and includes lateral equivalents of the middle and upper parts of the central Kansas Hartland. The basal submember is conspicuous in the close spacing of subequally thick chalky limestone beds and their light-colored weathering. These beds are most extensively exposed in cuts along roads that cross bluffs adjacent to streams and are also exposed commonly in cliffs and along cut banks of streams as at Localities 5, 9, 10, 21, and many others. For convenience the chalky limestone beds are designated JT-1 through JT-9, respectively, and will be referred to as such hereinafter.

The shaly chalk interval between JT-6 and JT-7 is consistently thicker than that between any other two chalky limestone beds, and permits ready division of the submember into upper and lower parts (Fig. 11,A). A zone of thin-bedded chalk is developed in this thicker shaly interval at many localities and is especially obvious at Localities 9, 15, and 50 near the southwestern end of the central Kansas outcrop. At most localities the most conspicuous chalky limestone beds are JT-1 and JT-6 by reason of generally greater thickness as well as greater resistance to erosion. Bed JT-1 ranges in thickness from 0.25 to 0.4 foot, averaging 0.34 foot for 19 measurements. Bed JT-6 ranges in thickness from 0.3 to 0.6 foot, and averages 0.44 foot for 19 measurements. The other chalky limestone beds are mostly continuous, but discontinuities have been recorded locally in JT-4, JT-5, JT-8, and JT-9. Thickness of beds other than JT-1 and JT-6 ranges from zero (where discontinuous) to a maximum of 1.7 feet. The latter figure is the result of very local thickening of JT-7 at Locality 14 where normal bed thickness is 0.55 foot (see Figure 11,A). Some of the beds, including JT-4, JT-5, and JT-9, are poorly developed locally, consisting of relatively thin, burrowed chalk, rather than hard chalky limestone. Bed JT-4 exhibits this character most commonly. Most of these same beds can be recognized in the Front Range foothills of Pueblo County, Colorado, 145 miles west of Hamilton County, Kansas (see Hattin, 1971).

Fresh color of these limestones ranges from light olive gray (5Y6/1) to dark olive gray (5Y3/1) and the most common weathered colors are grayish orange, pale grayish orange, yellowish gray (5Y8/1), very pale orange, and grayish yellow. All of these beds contain numerous chalk-filled burrow structures and are mottled in consequence of these structures (Figs. 11,B,C). The mottles are most evident in the least-weathered

FIGURE 10.—Stratigraphic features of the Jetmore Member. A) Exposure of the Jetmore Member west of Canyon Road, sec. 20, T. 13 S., R. 14 W., Russell County showing four submembers that are marked with vertical bars labelled A through D in ascending order. B) Exposure of lower part of lower submember, sec. 16, T. 6 S., R. 3 W., Cloud County (Loc. 48). Chalky limestone beds are numbered. Bed labelled "F" is skeletal limestone composed of planktonic foraminifer tests. C) Exposure of upper three submembers on north side of U.S. Highway 24 at Glen Elder, sec. 27, T. 6 S., R. 9 W., Mitchell County, Kansas. Lowest three beds and intervening shaly chalks comprise second submember. A widespread bentonite seam lies at the level of Bob Frey's right foot. Third submember is shaly chalk interval between JT-12 and JT-13 (arrows mark positions of chalky limestone layers). Fourth submember, labelled JT-13, is Shellrock limestone bed.

beds and burrow fill is generally the darkest part of the rock. Highly weathered rocks are also mottled but in these the individual burrows are distinguished with difficulty. Most of the chalk-filled burrows are assignable to *Planolites* Nicholson. Calcite, pyrite or limonite-filled burrows, including simple tubular types and *Chondrites* Sternberg, are common in some beds, especially in the interval JT-1 to JT-6. These trace fossils have been illustrated elsewhere (Hattin, 1971). Dark yellowish-orange limonite stains are common in

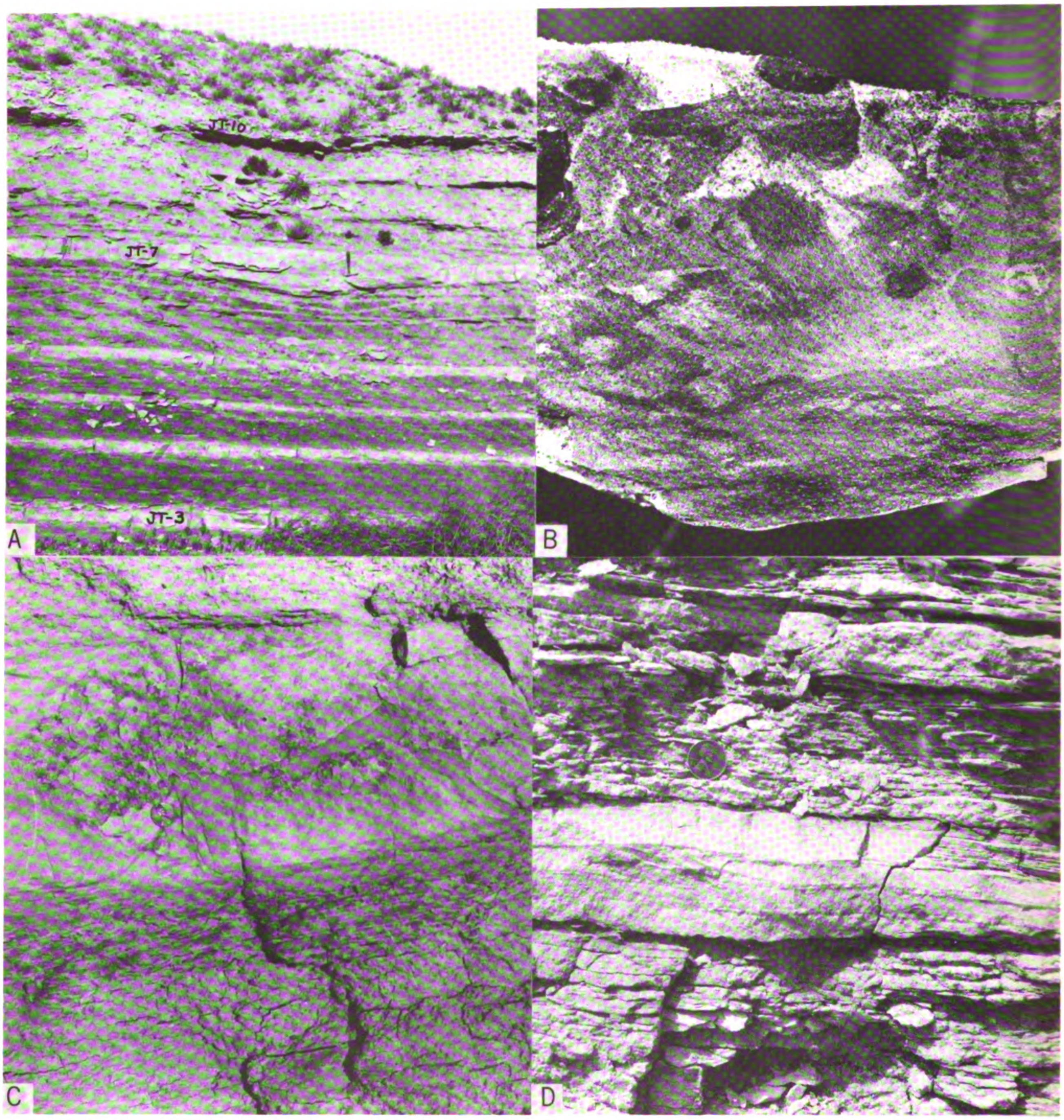


FIGURE 11.—Stratigraphic features of the lower submember of the Jetmore and equivalent part of the Bridge Creek Member. A) Exposure of middle part of Bridge Creek Member, sec. 14, T. 23 S., R. 42 W., Hamilton County (Loc. 14) showing strata equivalent to most of lower submember beds (JT-3 to JT-10). Note thicker interval of shaly chalk separating JT-6 from JT-7 and local thickening in JT-7. B) Burrow-mottled chalky limestone from marker bed JT-3, sec. 5, T. 13 S., R. 15 W., Russell County (Loc. 25). Structures are mostly referrable to *Planolites* Nicholson. X1. C) Burrow-mottled chalky limestone bed (JT-7) in Bridge Creek Member, sec. 14, T. 23 S., R. 42 W., Hamilton County (Loc. 14). Note lack of stratification within bed and gradational contact, especially at base, with adjacent shaly chalk units. Cent for scale. D) Exposure of lower part of Jetmore Member, sec. 18, T. 13 S., R. 12 W., Russell County (Loc. 3), showing laminated nature of shaly chalk (surrounding cent) and laminated bed of skeletal limestone (F) composed mainly of planktonic foraminifer tests.

most weathered beds and are commonly concentrated around burrow structures and in the most highly burrowed parts of the beds. The central portion of some beds, especially beds JT-3, JT-6, and JT-7, is much stained by limonite in some weathered exposures, probably owing to oxidation of pyrite formed in association with burrow structures. Some of the beds contain pyrite nodules, usually near the bed centers, and where weathered these nodules have been oxidized to limonite. Such nodules have been observed in JT-1, JT-2, JT-3, JT-6, JT-7, and JT-9.

The chalky limestones are usually tough where fresh, and are hard, brittle, and commonly manifest blocky fracture where weathered. In most places the chalky limestone beds are resistant to weathering and project as ledges from eroded slopes and weathered road cuts. The beds are nearly everywhere massive, i.e., lacking laminations (Fig. 11,C). This is interpreted as the result of extensive burrowing by a highly mobile infauna. At Locality 14, a chalky limestone bed in the Bridge Creek Member, below JT-1, contains thin laminations that are truncated and destroyed locally by burrowing. Concretionary chalky limestone, so much in evidence in younger parts of the Greenhorn section, is virtually absent in the basal submember. However, where chalky limestone beds are discontinuous, e.g., JT-9 at Locality 45 (Cloud County) the bed segments take on a concretionary appearance. The Hartland equivalent of the Bridge Creek Member, which is part of the same lithofacies as the basal submember, contains concretionary chalky limestone just below marker bed HL-2 at Locality 14.

Chalky limestone layers in the basal submember tend to be uneven at top and base. Where weathered, the beds may stand out sharply from the surface, usually with well-defined upper and lower contacts, but in fresh exposures the contacts are commonly gradational, suggesting that conditions which created the beds were initiated and terminated gradually (Fig. 11,C).

The most common body fossils in these chalky limestone beds are *Mytiloides labiatus* and *Watinoceras reesidei* (Warren). The former, known from all nine beds, is usually preserved in the round, suggesting that these beds were lithified sooner than the adjacent shaly chalk beds where all such bivalves are thoroughly flattened. Specimens in the limestones retain only the calcitic prismatic layer or are preserved as molds, and occur whole or as fragments; no large concentrations of shells were observed in any bed. *Watinoceras reesidei* has been recorded in all beds except JT-9, but this species also occurs stratigraphically higher in the section. All of these ammonites are preserved as molds and most are preserved in-the-round, but many have suffered a little flattening by compaction. The largest concentrations of *W. reesidei* are in beds JT-1 and JT-6; specimens were collected in greatest numbers at Locality 43 (Rush County) in bed JT-1. Other fossils in the nine chalky limestone beds include *Mammites nodosoides* subsp. *wingi* Morrow, occurring mostly in JT-6 but also in JT-2 and JT-8, *Baculites* cf. *B. yokoyamai* Tokunaga and Shimizu which apparently ranges throughout the submember, *Tragodesmoceras bassi* (JT-8); *Pycnodonte* sp. A (JT-8), sparse unidentified ostreids (JT-1, JT-2) and rare specimens *Discinisca* sp. and *Anomia* sp. A. At Locality 14 nine Bridge Creek beds that are equivalent to the basal submember of central Kansas have *Mytiloides labiatus* (all beds); *Vasoceras birchbyi* (JT-1); *Baculites* cf. *B. yokoyamai* (JT-4, 6, and 9); *W. reesidei* (JT-1); *Discinisca* sp. (JT-3, 5, and 7); *Anomia* sp. A (JT-4 and 6); and *Mammites nodosoides wingi* (JT-6). At Locality 14 the following additional species occurrences have been reported by Cobban and Scott (1972, p. 21); *Neoptychites* cf. *N. cephalotus* (Courtiller (JT-1), *T. bassi* (JT-7 and JT-9) and *Baculites* cf. *B. yokoyamai* (JT-2 and JT-7).

Shaly chalk beds in the basal submember and in equivalent and older Bridge Creek strata, are essentially like those of the Hartland Member. Predominant color of the fresh rocks is dark olive gray (5Y3/1) to olive black and weathered rock exhibits a wide range of colors including light olive gray (5Y6/1, 5Y5/2), yellowish gray (5Y8/1, 5Y7/2), medium yellowish brown (10YR5/2) and grayish orange. Weathered rocks are commonly stained yellowish orange along joints and bedding surfaces. The rock is tough and breaks blocky where fresh, and is soft and flaky where weathered. Like other shaly chalk units these are nearly everywhere speckled by minute nearly white, oblate spheroidal fecal pellets and contain much calcareous silt and fine sand. All of the shaly chalk is laminated (Figs. 11,D; 12,A), but that near the base of the submember tends to be more thinly and evenly laminated than that near the top (Fig. 12,B). The laminae tend toward obliteration in extensively weathered exposures. In the part of the Bridge Creek Member representing the lower submember of the Jetmore some shaly chalk units contain one or more very thin seams of selenite; a few of these are limonitic. These may represent the position of thin films of bentonite. In the interval between marker beds JT-1 and JT-10 measured thickness of the shaly chalk beds ranges from a minimum of 0.45 feet between JT-3 and JT-4 and between JT-4 and JT-5 (Loc. 20) to a maximum of 3.15 feet between JT-6 and JT-7 in the Bridge Creek Member at Locality 14.

In these shaly chalk beds *Mytiloides labiatus* is ubiquitous, occurring as fragments and as whole shells lying parallel to bedding and thoroughly flattened by compaction. In nearly every locality studied, shaly chalks above JT-8, and locally also between JT-7 and JT-8, are crowded with shells, shell fragments, and lenses of shell fragments of *M. labiatus*. These project conspicuously from weathered surfaces, thus marking a pronounced change from environmental conditions

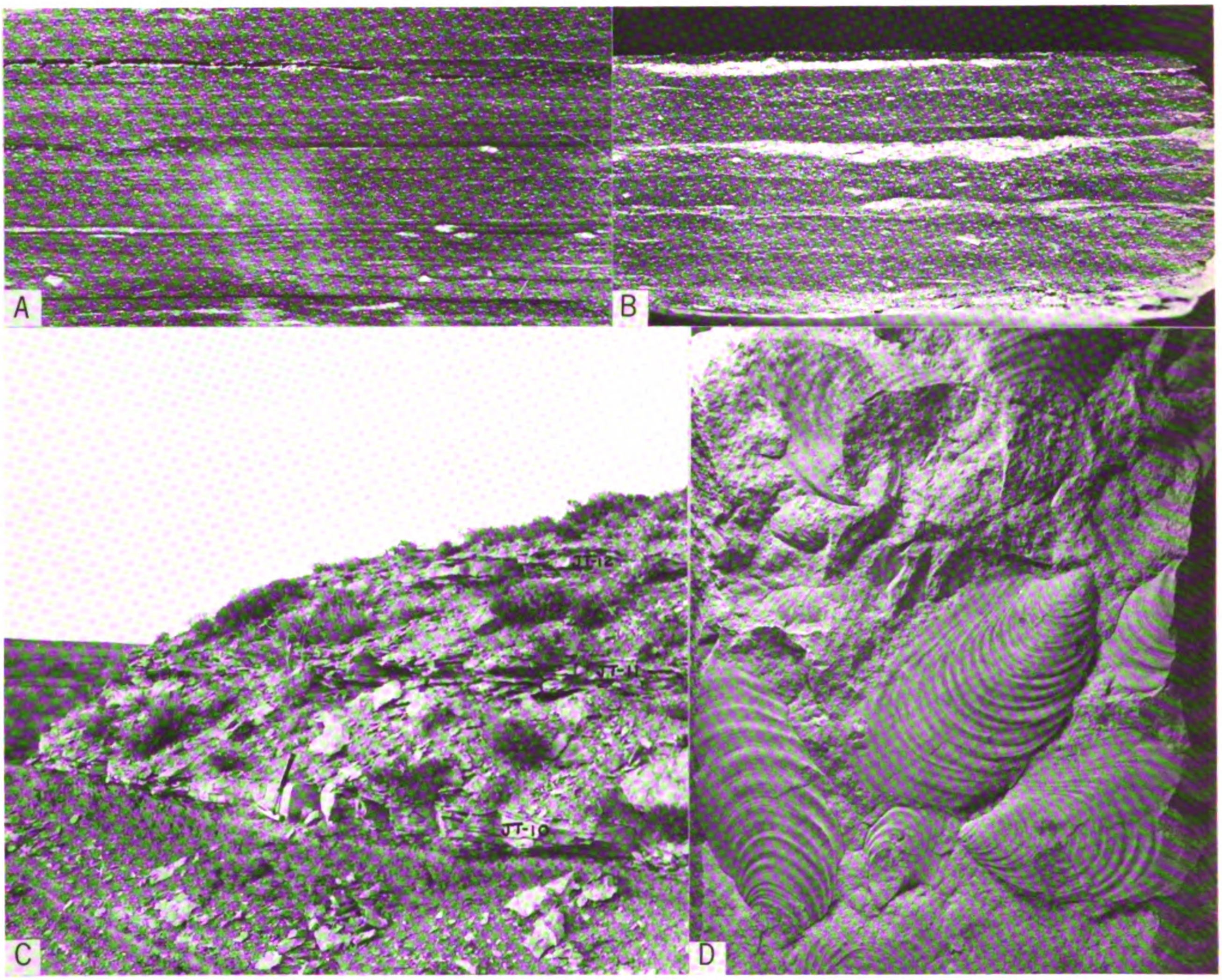


FIGURE 12.—Stratigraphic features of the Jetmore Member and equivalent part of Bridge Creek Member. A) Shaly chalk specimen from between JT-2 and JT-3, cut normal to bedding, showing thin laminations characteristic of lower part of basal submember, sec. 18, T. 13 S., R. 12 W., Russell County (Loc. 3). X1. B) Shaly chalk specimen from between JT-7 and JT-8, cut normal to bedding, showing imperfectly laminated rock from upper part of basal submember, sec. 27, T. 6 S., R. 9 W., Mitchell County (Loc. 1). Light-colored grains are foraminifera. Light-colored, lensing laminae are composed mostly of foraminifera. X1. C) Exposure of "hard beds" submember, sec. 14, T. 23 S., R. 42 W., Hamilton County (Loc. 14). This locality is 230 miles from the exposure illustrated in Figure 10, C. Note tendency of these beds to fracture roughly parallel to bedding. D) Upper surface of limestone slab (float) from one of three "hard beds," sec. 18, T. 8 S., R. 3 W., Cloud County (Loc. 46), showing little-flattened molds of *Inoceramus (Mytiloides) labiatus*. X½.

represented by the underlying beds. Clusters of the oyster *Pycnodonte* sp. A are commonly attached to the valves of *Mytiloides labiatus* in these shell-crowded beds, especially in that lying above JT-9. Planktonic foraminifera are also ubiquitous in the shaly chalk beds, and cause textural roughness where sufficiently abundant to stud the bedding surfaces. Very thin, waferlike lenses of foraminiferal limestone were recorded in shaly chalks between JT-1 and JT-3, and some lenses rich in forams occur also in the *Mytiloides*-crowded beds above JT-7 (see Fig. 12,B). Fish scales, bones, and a few teeth are scattered through shaly chalk beds in the lower submember. Sparse burrow structures, although more characteristic of the chalky limestone beds, have been recorded in shaly chalk of the basal submember at a few localities.

In most Kansas exposures a discontinuous, lensing layer of foraminiferal limestone lies in the shaly chalk that separates marker beds JT-1 and JT-2 (Fig. 10,B). At Localities 10 and 20 the basal 0.5 and 0.2 foot, respectively, of the shaly chalk unit contains several very thin lenses of foraminiferal limestone any one or all of which may represent the foram bed of other localities. At Localities 4 and 15 the foraminiferal limestone is apparently absent. The foram bed lies anywhere from 0.25 to 0.5 foot above the top of JT-1. Color is olive gray where fresh and grayish orange and very pale orange to very pale yellowish brown where weathered. The bed is thinly laminated (Fig. 11,D), and locally cross laminated. At Locality 3 the cross laminae dip 7° to 15° in a N 10° E direction. This is in general correspondence with current data for skeletal limestones in the lower part of the Lincoln Member (see above). Foram-filled burrow structures of the *Planolites* type up to 13 mm in diameter were recorded in this bed of Localities 45, 48 and 68.

Very thin (0.01-foot-thick) bentonite seams were observed a short distance above JT-2 at Localities 14 and 50; otherwise this submember apparently lacks bentonite.

Hard Beds.—Because of greater resistance to the hammer and to erosion I refer to limestones of the second submember of the Jetmore as the "hard beds" (Figs. 10,C; 12,C). In Hamilton County (Loc. 14) these beds are included in the Bridge Creek Member. Thickness of this interval ranges from 2.6 feet (Locality 20, Jewell County) to 4.0 feet (Locality 14, Hamilton County) averaging 3.1 feet for 20 measurements. For convenience the three limestone marker beds in this submember are designated (ascending) JT-10, JT-11, and JT-12. Thickness of these beds is as follows:

Bed	Thickness, range, feet	Average thickness, feet	No. of measurements
JT-10	0.25 to 0.55	0.41	19
JT-11	0.2 to 0.6	0.36	19
JT-12	0.2 to 0.45	0.36	19

Where least weathered the color of these beds is dark olive gray (5Y3/1) to light olive gray (5Y6/1, 5Y5/2) or yellowish gray (5Y7/2). Weathered beds are pale grayish yellow, grayish orange, or pale grayish orange. At most places these limestones are harder, and more brittle than adjacent chalky limestone beds and during weathering tend to shatter more or less parallel to the bedding (Fig. 12,C). Upper and lower surfaces of the beds are generally undulatory. All of the beds contain burrow structures and these are most abundant in JT-10 but these limestone beds are not as extensively burrowed as beds JT-1 through JT-9. The burrows are of two major kinds including large irregularly meandering chalk-filled structures assignable to *Planolites* and slender (2 to 4 mm diameter) smooth-walled straight to slightly sinuous structures filled with phanerocrystalline calcite or, less commonly, pyrite. The second type may be oriented at any angle to the bedding.

At all localities examined the three limestones contain abundant disarticulated valves and valve fragments of *Mytiloides labiatus*. No definitely articulated valves were observed during this study. In contrast to specimens preserved in the adjacent shaly chalk beds the valves of this clam are not much flattened by compaction (Fig. 12,D). A few lie at angles to the bedding but the vast majority are parallel to the general stratification. A few specimens bear attachment scars of a large, nearly circular, thin-shelled pelecypod that is probably *Pycnodonte* sp. A. At Locality 3 shell fragments 3 to 4 mm in thickness indicate that some specimens of *M. labiatus* reached large size and at Locality 46 one broken specimen was found to be 26 cm high. Two one-meter-long taut-line counts of *M. labiatus* were made on a float slab from one of the hard beds at Locality 6, with counts of 13 and 25 specimens respectively. Two parallel, meter-long counts on bed JT-12 at Locality 46 yielded 5 and 10 specimens, respectively. These limited data give some appreciation of the great abundance of clams in these limestone beds. Valve orientation was measured at two localities with the following results:

	convex up	concave up
Loc. 3, JT-10	16	15
Loc. 3, JT-11	10	35
Loc. 3, JT-12	18	45
Loc. 46, JT-10	18	23
Loc. 46, JT-11	31	19
Loc. 46, JT-12	14	33
Loc. 46, float	24	59

These data suggest either that the valves have suffered little transport, or that the concave up position is the more stable. The former interpretation is regarded as the more likely.

Other fossils in the hard beds include *Baculites* cf. *B. yokoyamai*, which is better preserved here than in other parts of Jetmore, molds of a smooth baculitid that may be imperfectly preserved *B.* cf. *B. yokoyamai*, sparse oysters (probably *Pycnodonte* sp. A), and rare specimens of *Tragodesmoceras bassi* (Locality 66), *Mammites nodosoides wingi* (Locs. 46 and 65), and *Watinoceras reesidei* (Locality 35). Specimen abundance was measured in two 1/4-meter areas on bed JT-10 at Locality 3, with the following results:

Area 1	
Mytiloides labiatus	30
Baculites cf. *B. yokoyamai*	1
Burrow cast	1
Mytiloides, small fragments	several
Area 2	
Mytiloides labiatus	79
Baculites cf. *B. yokoyamai*	1
Mytiloides, small fragments	several

The two shaly chalk beds separating the three hard limestone beds of the second submember are usually seen in a weathered condition because so many of the best exposures are in topographically high parts of the outcrop. The unweathered rock is olive black or dark olive gray (5Y3/1); color of the weathered rock is light gray and yellowish gray to pale yellowish brown and grayish orange. Dark yellowish-orange limonite stains are common in weathered exposures. Like other shaly chalk units these beds are speckled by nearly white fecal pellets, contain much calcareous silt and fine sand (mostly foraminifera and inoceramid prisms), and are thinly laminated. Extensive weathering has virtually obliterated the laminations locally and abundance of skeletal debris and lenses of skeletal limestone cause the laminations to be less obvious than in older parts of the section. These two shaly chalk units contain abundant shells and shell fragments of *Mytiloides labiatus* which project conspicuously at the surface and litter the slope of weathered exposures. Some of the specimens of *M. labiatus* reached exceptionally large size. Thin lenses of inoceramite and lenses consisting of stacked valves or valve fragments of *Mytiloides* are common in the shaly chalk. Both shaly chalk units locally contain irregular zones of shell-rich chalky limestone wherever abundant *Mytiloides* remains have been tightly welded together in a chalk matrix. At Localities 1 and 20 the upper shaly chalk unit contains a layer of chalky limestone concretions that are filled with remains of *Mytiloides*. In addition to *M. labiatus* these beds have also yielded specimens of *Pycnodonte* sp. A. The last are attached to *M. labiatus*, usually in clusters, and in some places two generations of oysters are represented.

At all localities examined marker bed JT-10 is overlain directly by a thin to very thin seam of bentonite. In most of central Kansas the bentonite is 0.02 foot or less in thickness and is commonly discontinuous within a single exposure. In the Bridge Creek Member of Hamilton County (Loc. 14) the seam is 0.14 foot thick. This bentonite can be identified also in Cimarron County, New Mexico (Kauffman, Hattin, & Powell, in preparation) and in Pueblo County, Colorado (Hattin, 1971) where its association with the lowermost hard limestone bed containing abundant *Mytiloides labiatus* is unmistakable. In Kansas the bentonite is olive gray in rare fresh exposures, light olive gray (5Y6/1) to very light gray in partially weathered exposures, and, most commonly, dark yellowish orange where stained by limonite in much-weathered exposures.

Third Submember.—The third submember of the Jetmore includes strata lying between marker beds JT-12 and JT-13 (Shellrock limestone bed). This interval is composed mostly of shaly chalk and averages 2.66 feet in thickness for 20 measurements, including Locality 14 (Hamilton County) where these strata are included in the Bridge Creek Member. The shaly chalk is dark olive gray (5Y3/1) to olive black in sparse, unweathered exposures and yellowish gray (5Y7/2) to grayish orange or pale grayish orange (10YR8/4) in weathered exposures. The rock is at least in part thinly laminated, contains much calcareous silt and fine sand (mostly foraminifera and inoceramid prisms), and is speckled by nearly white, oblate spheroidal fecal pellets. The last are difficult to detect in weathered rocks. At all exposures studied shaly chalk in this stratigraphic interval contains an abundance of whole and broken valves of *Mytiloides*. Small lenses of skeletal limestone, consisting of stacked, imbricated, or irregularly arranged *Mytiloides* fragments, as well as prisms, are common in this interval, especially in the lower part. *Mytiloides* valves and fragments and lenses of skeletal limestone project conspicuously from weathered slopes and litter the eroded surface (Fig. 13,A). In this submember lamination of shaly chalk is best developed where abundance of *Mytiloides* remains is least. The shaly chalk usually grades into the overlying Shellrock limestone bed through 0.55 foot or less of very thin bedded chalk.

The shaly chalk interval separating the uppermost hard bed (JT-12) from the Shellrock limestone bed (JT-13) contains from one to three beds of chalky limestone (Fig. 10,C). At most localities examined there are two such beds, at two localities only one was observed, and at two localities three beds were recorded. At all localities where two beds are exposed, the lower bed is discontinuous, consisting of mostly irregular-shaped concretionary bodies that are rich in whole and fragmentary valves of *Mytiloides labiatus*; this limestone is lithologically similar to that of the three hard beds although not everywhere as hard and brittle, and reaches maximum thickness of 0.3 foot. The upper bed lies at or just above the middle of the third submember and consists of concretionary chalky limestone that is sparingly fossiliferous and generally softer than that below. At three localities (3, 4, 20) the upper layer is thin (0.1 to 0.2 foot thick), flat at top and base, and continuous across the respective exposures, but at all other places consists of smooth-surfaced oblate spheroidal concretions ranging from 0.18 to 0.3 foot in thickness. The origin of these structures is manifest not only in their shape but in the preservation within them, at several localities, of thin laminations similar to those in the surrounding shaly chalk. At some localities the upper bed contains fairly common specimens of *Baculites* cf. *B. yokoyamai* and *Anomia* sp. A.

At localities where only one of these limestone beds is present between JT-12 and JT-13, as at Localities 14 and 15, it is the lower, discontinuous, shell-rich bed that lies in the lower half of the interval (Figs. 2,D; 13,B). Where more than two beds are present, as at Localities 6, 20, and 68, the additional bed is in the lower half of the interval and is lithologically and paleontologically similar to the lower, discontinuous, shell-rich bed of chalky limestone. These chalky limestones are usually speckled by nearly white spheroidal pellets, like those in adjacent shaly chalk. In most

FIGURE 13.—Stratigraphic features of the upper part of the Jetmore Member and equivalent part of Bridge Creek Member. A) Weathered surface of shaly chalk between JT-12 and JT-13, sec. 18, T. 8 S., R. 3 W., Cloud County (Loc. 46), showing characteristic abundance of *Inoceramus* fragments. Cent for scale. B) Single bed of irregular-shaped, lens-like bodies of shell-rich limestone in part of Bridge Creek Member that is equivalent to the third submember of the Jetmore, sec. 14, T. 23 S., R. 42 W., Hamilton County (Loc. 14). Laminae of adjacent shaly chalk arch above and bend beneath the concretionary masses of limestone. C) Exposure of Shellrock limestone, sec. 28, T. 15 S., R. 17 W., Ellis County, showing oblate-spheroidal concretions in upper part of bed. D) View, normal to bedding, of central part of Shellrock limestone bed, sec. 18, T. 8 S., R. 3 W., Cloud County (Loc. 46), showing abundant whole valves of *Inoceramus (Mytiloides) labiatus.* Cent for scale.

sections studied the limestones are weathered, with grayish orange, pale grayish orange (10YR8/4) and yellowish gray (5Y7/2, 5Y8/1) colors prevailing. Where least weathered the lower, shell-rich concretionary bed is olive gray (5Y4/1) and the layer of oblate spheroidal concretions is medium gray. Both kinds of limestone project conspicuously from weathered slopes. Adjacent layers of shaly chalk generally arch above and bend beneath these limestone bodies, suggesting that lithification was well advanced prior to final compaction of the shaly chalk (Fig. 13,B).

These chalky limestones are identical, respectively, to the irregular, discontinuous, shell-rich, concretionary beds and layers of oblate spheroidal concretions that characterize the Pfeifer Member; furthermore, the Shellrock limestone bed, which overlies the third submember, is not only concretionary in its upper part but also lithologically more like beds of chalky limestone in the Pfeifer than like the limestones in Jetmore beds JT-1 through JT-12. Jetmore strata above JT-12 are related genetically to the Pfeifer and should be reclassified as a part of the Pfeifer Member (Hattin, 1968a).

Shellrock limestone bed.—The fourth submember of the Jetmore, designated JT-13 on Plate 1, and known informally as the Shellrock limestone bed, comprises a relatively hard, resistant chalky limestone unit that can be traced across the entire Greenhorn outcrop of Kansas. The Shellrock is a prominent benchmaker (Fig. 2,C) and underlies the upland surface directly at a number of places. Thickness of the Shellrock bed ranges from 0.9 (Locs. 14, 48) to 1.35 feet (Loc. 20), averaging 1.1 feet for 20 measurements. At some localities this unit comprises a single massive bed containing no partings, and having homogeneous lithology. At other localities one or more bedding fractures are developed, probably in response to weathering (Fig. 10,C). The center of the unit is very thin bedded at Locality 6; the lower part is very thin bedded, and more or less transitional with the underlying shaly chalk at Localities 9, 14, and 20. In central Kansas the upper part of the unit is generally concretionary although this feature is not evident at every locality. Concretionary structure ranges from oblate hemispheroidal bulges on the upper surface of the Shellrock bed to well-defined oblate spheroidal concretions (Fig. 13,C). At Locality 6 concretionary rock forms most of the upper surface, depressions between concretionary areas resembling the button areas of a sofa pillow. At Locality 20 an oblate spheroidal concretion was recorded in very thin bedded chalky limestone at the base of the Shellrock unit. Where least weathered the Shellrock bed is olive gray. In most exposures the rock exhibits weathered coloration that ranges from yellowish gray (5Y8/1, 5Y7/2) to grayish orange or pale grayish orange (10YR8/4). Dark yellowish orange limonite stains are common. The rock is generally speckled throughout by nearly white spheroidal fecal pellets.

Except for concretionary rock at the top of the Shellrock, the bed usually is crowded with whole shells and fragments of *Mytiloides labiatus* (Fig. 13,D). These are usually more concentrated near the middle or in the lower half of the unit. The shells are nearly all arranged parallel to bedding and virtually all are disarticulated. Most specimens retain some of the original convexity; orientation is mostly concave down. Sparry calcite-filled sheltered voids were observed beneath valves of *Inoceramus* at Locality 50. Meter-long taut-line counts of whole valves on bed surfaces were made at three localities with the following results:

Loc. 3, 1st count:	11,	2nd count:	9
Loc. 5, 1st count:	10,	2nd count:	13
Loc. 6, 1st count:	6,	2nd count:	7
Loc. 6, 1st count:	19,	2nd count:	17

Baculites cf. *B. yokoyamai,* usually consisting of flattened molds, but locally of crystalline calcite, is common on the non-concretionary upper surface of the unit. Compass bearings were recorded for orientation of 44 baculitid molds at the top of the Shellrock at Locality 4. These were plotted as a rose diagram; no preferred orientation was detected. Coiled ammonites are very rare in the Shellrock bed; fragmentary specimens of *Mammites nodosoides wingi* (Localities 46 and 50), unidentified ammonite molds (Localities 44 and 46), and *Stomohamites* cf. *S. simplex* (Locality 46) are the only non-baculitid specimens I discovered. Chalk-filled and rare calcite-filled burrow structures are preserved in the Shellrock at a few localities, the former are especially common on a bedding surface in the middle of the unit at Locality 63 where maximum observed width of randomly branching thalassinoid burrows is approximately 1.5 cm. *Pseudoperna bentonensis* was observed in the Shellrock at Localities 5 and 50. At Locality 5 these oysters were encrusted on the interior surface of a *Mytiloides* valve. *Anomia* sp. A was recorded from the unit at Locality 50 and a large petrified log was recorded in the bed at Locality 10.

Macroinvertebrate Fossils.—As noted above, the biostratigraphic zonation of the Greenhorn is treated in a separate part of this report and is not based on all of the macroinvertebrate species. The following list includes all macroinvertebrates recorded in Jetmore and equivalent Bridge Creek strata during the present study. Inclusion of a taxon in this list does not indicate co-occurrence with all the other species. Common forms are preceded by an asterisk. Rare forms, or those known from only one locality, are preceded by a dagger.

Brachiopods:
- †*Discinisca*

Bivalves:
- *Anomia* sp. A
- **Inoceramus (Mytiloides) labiatus* (Schlotheim)
- †*Pseudoperna bentonensis* (Logan)
- **Pycnodonte* sp. A
- **Teredolithus* sp.

Cephalopods:
- ammonite molds, unidentified
- °*Baculites* cf. *B. yokoyamai* Tokunaga & Shimizu
- °*Mammites nodosoides* (Schlotheim) subsp. *wingi* Morrow
- *Mammites* sp. (fragments)
- †*Stomohamites* cf. *S. simplex* (d'Orbigny)
- †*Tragodesmoceras bassi* Morrow
- †*Vascoceras birchbyi* Cobban & Scott
- °*Watinoceras reesidei* Warren

Cirripeds:
- †acrothoracian borings (in *Mytiloides* valve)
- †scalpellid, sp. (undescribed)

The Jetmore species identified as *Pseudaspidoceras cornucostale* by Morrow (1935, p. 469) was not recorded during the course of my study. Jetmore macroinvertebrate fossils are illustrated in Plates 7, 8, and 9.

Brachial valves of 7 specimens of *Discinisca* were recovered from the Jetmore Member. In chalky limestones these are preserved as skeletal material preserving the original luster or as molds. A single specimen from shaly chalk is a valve from which most of the inorganic matter has been leached. Specimens of *Anomia* are preserved as calcitic valves and many preserve the original pearly luster. Most specimens of *Inoceramus* retain the calcitic prismatic layer; the aragonitic nacreous layer is nowhere preserved. A few specimens in weathered chalky limestone occur as molds and these commonly are heavily stained by limonite, especially those from the three hard beds (JT-10, 11, & 12). *Pycnodonte* and *Pseudoperna* are preserved mostly as calcitic valves that are usually attached to valves of *Mytiloides* but are found also as isolated, disarticulated valves. *Teredolithus* occurs as limestone molds of original tubes having bulblike terminations. A single, large cluster of calcitic *Teredolithus,* originally in wood of which almost no trace remains, was collected as float from either JT-10, 11, or 12 at Locality 28. Regardless of lithology, Jetmore and Bridge Creek cephalopods nowhere are preserved as original skeletal material. All are molds in chalky limestone except for a few baculitids which are lined or filled with visibly crystalline calcite. Sparse, disarticulated plates of a scalpellid are preserved as calcite that is probably little altered.

Pfeifer Shale Member

General Description.—The Pfeifer Shale Member of the Greenhorn was named by Bass (1926, p. 32) for exposures near the town of Pfeifer (Pi'fer), Ellis County, Kansas. The Pfeifer is well exposed here in bluffs that rise above the north side of Smoky Hill River. According to Bass a measured section of the Pfeifer in SE¼ sec. 21, T. 15 S., R. 17 W. is 18 feet 11 inches in thickness and the member ranges from 19 to 21 feet in the County. At Locality 5, 2.5 miles west northwest of Pfeifer, I found the Pfeifer to be 19.8 feet in thickness. The member includes strata lying between the Shellrock limestone bed (JT-13) and the top of the Fencepost limestone bed and is composed primarily of shaly rock through which are scattered continuous beds; irregular, discontinuous, shell-rich, concretionary beds; or layers of oblate spheroidal concretions of chalky limestone. In Hamilton County the member was included by Bass (1926, p. 69) in the more embracive Bridge Creek Limestone Member of the Greenhorn, but the exact equivalent of the Pfeifer is readily recognizable there (see Plate 1). The Pfeifer member has received formal recognition only in Kansas where the thickness ranges from 15.2 (Loc. 1) to 25.8 feet (Loc. 14, Pfeifer equivalent in Bridge Creek Member) generally thickening from NE to SW, and averaging 19.72 feet for 14 measurements.

The most characteristic feature of the Pfeifer is the rich content of discontinuous beds of shell-rich concretionary limestone and layers of chalky limestone concretions. Such rocks are a common feature of the carbonate section beginning above bed JT-12 in the Jetmore Member and continuing upward in the section to a position between marker beds 2 and 3 of the Fairport Member of the Carlile Shale (see Hattin, 1962). Because the upper and lower contacts of the Pfeifer were defined arbitrarily in earlier reports, rather than on objective lithologic criteria, I believe that the Pfeifer should be redefined so as to include the section extending from the top of JT-12 to the top of Fairport marker bed number 2. As thus redefined the Pfeifer would include all of the stratigraphic interval that contains numerous irregular, discontinuous beds of concretionary limestone and/or layers of oblate spheroidal limestone concretions, and would incorporate the Shellrock limestone bed and Fairport marker bed number 2, both of which are lithologically comparable to the Fencepost limestone bed, within the framework of the member. Such revision is in accord with lithostratigraphic classification at member rank as explicitly advanced by the American Commission on Stratigraphic Nomenclature (1970, p. 7) who state "A member is established when it is advantageous to recognize a *specially developed part* of a varied formation" (italics mine).[10] The classification of the part of the carbonate section that includes abundant concretionary masses of chalky limestone as parts of three members belonging to two formations simply is not in accord with accepted stratigraphic practice.

The Pfeifer contains three widely traceable marker units that can be recognized throughout the Kansas outcrop. For convenience these are designated PF-1 (Fig. 14,A), PF-2 (Fig. 4,B), and PF-3 (Fig. 4,B,C,D; 5,C,D) and consist, respectively, of an unnamed bed

[10] The Stratigraphic Names Committee of the Kansas Geological Survey does not agree that this change is warranted at present.

of chalky limestone that everywhere directly overlies a thin seam of bentonite, a bentonite and granular-calcite unit known as the sugar sand, and the Fencepost limestone bed (see Pl. 1). The member contains three other widely traceable marker beds. Two of these are bentonite seams which can be identified positively throughout central Kansas. These seams lie close to the sugar sand and Fencepost bed, respectively, and cannot be recognized on their own merits. The third is a thin flat bed of chalky limestone lying less than a foot above the sugar sand and has been observed at all but a few central Kansas exposures. Marker beds PF-1 and PF-3 are readily identified in the Pfeifer equivalent of the Bridge Creek in Hamilton County (Loc. 14), and the identification of PF-2 is reasonably certain. Of the remaining three, noncoded markers, only one, a bentonite seam lying shortly below the Fencepost bed, can be recognized at Locality 14.

EXPLANATION OF PLATE 2

Bivalves and ammonites from the Lincoln Member.

A,F, *Exogyra columbella* Meek: Exterior views of left valves, both X1, KU82083, KU82084, lower part of Lincoln Member at Locality 23.

B-E, *Ostrea beloiti* Logan: B, interior view of right valve, X1, KU82073, lowermost bed of Lincoln Member at Locality 8; C, exterior view of right valve, X1, KU82074, lowermost bed of Lincoln Member at Locality 8; D, interior view of left valve, X1, KU82072, lowermost bed of Lincoln Member at Locality 8; E, interior view of left valve, X1, KU82071, lowermost unit of Lincoln Member at Locality 28.

G, *Inoceramus* cf. *I. tenuistriatus* Nagao and Matsumoto: internal mold of left valve, X1, KU82094, middle part of Lincoln Member at Locality 12.

H, *Acanthoceras?* sp.: flattened internal mold, X1, KU82099, lower part of Lincoln Member at Locality 12.

I,J, *Stomohamites* cf. *S. simplex* (d'Orbigny): I, internal mold, X2, KU82122, lower part of Lincoln Member at Locality 23; J, crystalline-calcite internal mold, X2, KU82081, lowermost unit of Lincoln Member at Locality 3.

K-M, Q, *Eucalycoceras* sp. B: K, L, latex casts of external molds, K is X2, L is X1, KU82091, KU82090, middle part of Lincoln Member at Locality 26; M, latex cast of external mold, X1, KU82089, lower part of Lincoln Member at Locality 30; Q, internal mold, X2, KU82092, middle part of Lincoln Member at Locality 26.

N, *Borissjakoceras* cf. *B. orbiculatum* Stephenson: internal mold, X1, KU82100, lower part of Lincoln Member at Locality 12.

O,S-U, *Eucalycoceras* sp. A: O, latex cast of external mold, X1, KU82088, middle part of Lincoln Member at Locality 8; S, internal mold fragment, X1, KU82086, lower part of Lincoln Member at Locality 23; T, latex cast of external mold fragment, U, ventral view of internal mold fragment, both X1, KU82087, KU82085, lower part of Lincoln Member at Locality 23.

P, *Desmoceras* (s.l.) sp.: internal mold, X1, KU82082, middle part of Lincoln Member at Locality 26.

R, *Camptonectes* sp.: flattened valve, X2, KU82093, lower part of Lincoln Member at Locality 12.

V, *Desmoceras* sp.: flattened internal mold, X1, KU82189, lower part of Lincoln Member at Locality 12.

EXPLANATION OF PLATE 3

Bivalves from the Lincoln Member.

A-F, *Exogyra* aff. *E. boveyensis* Berquist: A, interior view of left valve, X2, KU82080, uppermost unit of Lincoln Member at Locality 8; B, exterior view of right valve, X2, KU82078, uppermost unit of Lincoln Member at Locality 8; C, interior view of two left valves, X2, KU82076, lowermost unit of Lincoln Member at Locality 26; D, cluster of valves on *Inoceramus*, X½, KU82077, lowermost unit of Lincoln Member at Locality 26; E, interior view of right valve, X2, KU82075, lowermost unit of Lincoln Member at Locality 5; F, interior view of right valve, X1, KU82079, uppermost unit of Lincoln Member at Locality 8.

G, *Inoceramus* sp., partially crushed right valve, X2, KU82098, middle part of Lincoln Member at Locality 47.

H-N, *Inoceramus prefragilis* Stephenson: H, partially crushed internal mold of left valve, X1, KU82102, uppermost unit of Lincoln Member at Locality 8; I, flattened internal mold of left valve, X½, KU82107, lowermost unit of Lincoln Member at Locality 26; J,N, internal molds of left valve (J) and right valve (N), both X1, KU82096, KU82152, middle part of Lincoln Member at Locality 8; K, internal mold of left valve, X1, KU82097, basal unit of Lincoln Member at Locality 40; L, flattened internal mold, X1, KU82186, Graneros-Greenhorn transition beds at Locality 12; M, flattened internal mold of right valve, X1, KU82095, middle part of Lincoln Member at Locality 26.

EXPLANATION OF PLATE 4

Ammonites from the Lincoln Member.

A,C, *Calycoceras? canitaurinum* (Haas): A, internal mold fragment, X½, KU82105, basal unit of Lincoln Member at Locality 3; C, internal mold, X½, KU82104, basal unit of Lincoln Member at Locality 61.

B, *Dunveganoceras* cf. *D. pondi* Haas: latex cast of external mold fragment, X½, KU82103, basal unit of Lincoln Member at Locality 61.

D,F, *Acanthoceras wyomingense* (Reagan): A, internal mold fragment, X½, KU82153, lower part of Lincoln Member at Locality 23; F, internal mold, X½, KU82106, basal unit of Lincoln Member at Locality 69.

E, *Pseudocalycoceras* sp.: internal mold, X1, KU82101, lower part of Lincoln Member at Locality 23.

EXPLANATION OF PLATE 5

Mollusks from the Hartland Member

A,F,K, *Worthoceras vermiculum* (Shumard): A,F, crushed internal molds, both X2, KU82116, KU82115, marker bed HL-2 at Locality 11; K, internal mold, X2, specimen collected by W. A. Cobban, marker bed HL-2 at Locality 3.

B,C, *Allocrioceras annulatum* Shumard: internal mold fragments, B is X2, C is X1, KU82125, KU82124, marker bed HL-2 at Locality 6.

D, *Hemiptychoceras reesidei* Cobban & Scott: latex cast of internal mold, X2, KU82123, marker bed HL-2 at Locality 2.

E,J, *Phelopteria* sp. A: E, flattened left valve, X1, KU82138, marker bed HL-2 at Locality 5; J, interior view of right valve, X1, KU82137, marker bed HL-2 at Locality 3.

G,H,I, *Cerithiella* sp. A: G, calcite replica, X2, KU82140, marker bed HL-2 at Locality 66; H, recrystallized shell, X2, KU82141, marker bed HL-2 at Locality 11; I, recrystallized shell, X1, KU82139, marker bed HL-2 at Locality 35.

L,M, *Inoceramus prefragilis* Stephenson: L, internal molds of two left valves, X1, KU82129, marker bed HL-2 at Locality 35; M, internal mold of left valve, X1, KU82128, marker bed HL-2 at Locality 3.

N,O, *Martesia?* sp.: calcareous tubes, both X1, KU82135, KU82136, marker bed HL-2 at Locality 35.

P, *Mytiloides labiatus* (Schlotheim): partially preserved, flattened right valve, internal aspect, X1, KU82131, lower part of Bridge Creek member equivalent to upper part of Hartland Member of central Kansas, Locality 14. Cont. on page 58.

Q,R, *Inoceramus flavus* Sornay: Q, latex cast of interior of right valve, X1, KU82190, marker bed HL-2 at Locality 3; R, paired internal molds of deformed specimen (possibly *I. prefragilis* Stephenson), X1, KU82130, middle part of Hartland Member at Locality 13.

S, *Inoceramus* cf. *I. tenuistriatus* Nagao & Matsumoto: internal mold of left valve, X1, KU82133, marker bed HL-2 at Locality 4.

T, *Inoceramus* sp.: Flattened internal mold of right valve, X1, KU82132, upper part of Hartland Member at Locality 9.

U, Acrothoracian barnacle boring impressions on internal mold of *Inoceramus*, X1, KU82134, lower part of Hartland Member at Locality 5.

EXPLANATION OF PLATE 6

Ammonites from the Hartland Member

A,B,N, *Sciponoceras gracile* (Shumard): A, latex cast of ex-

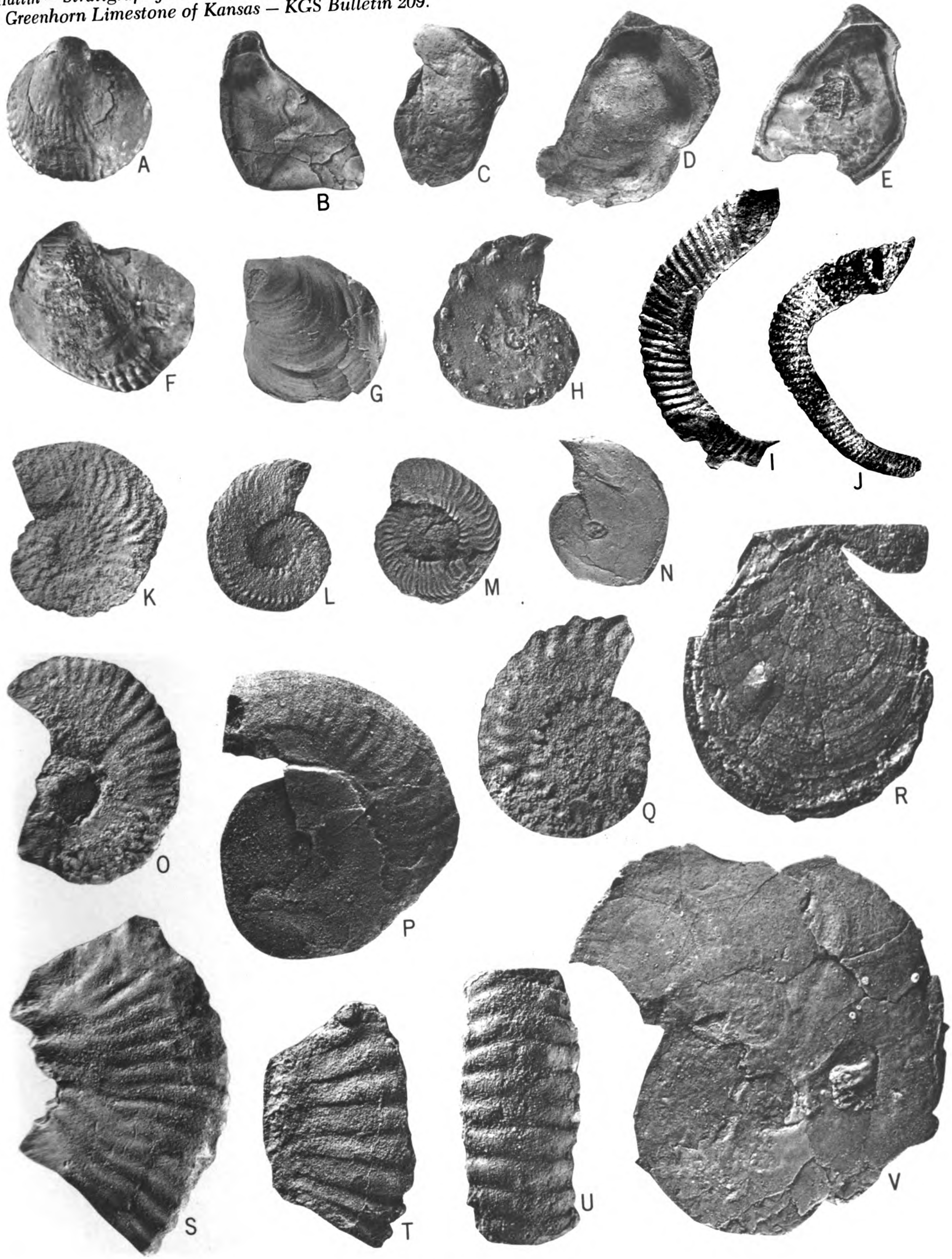


PLATE 2

PLATE 3

PLATE 4

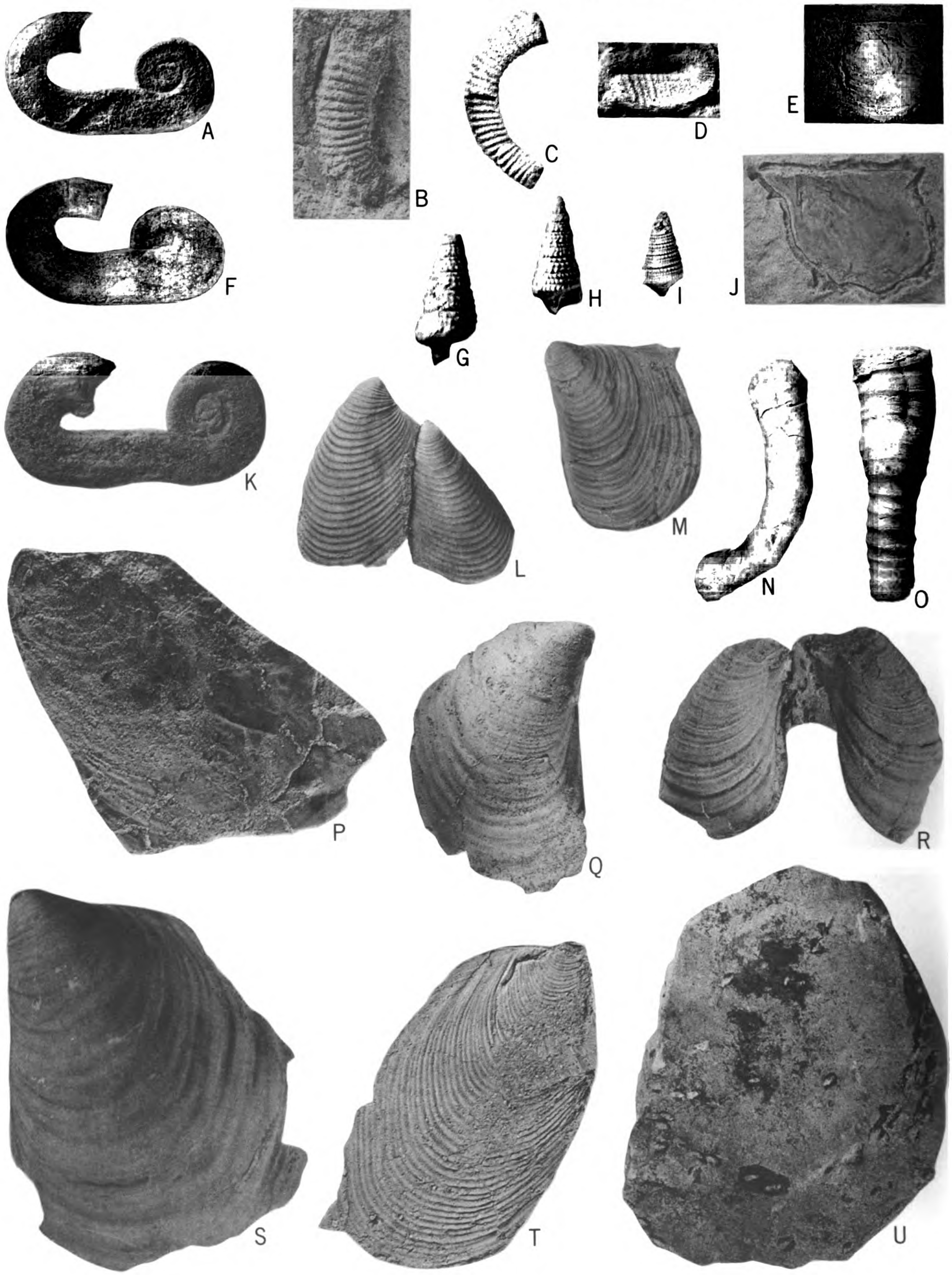


PLATE 5

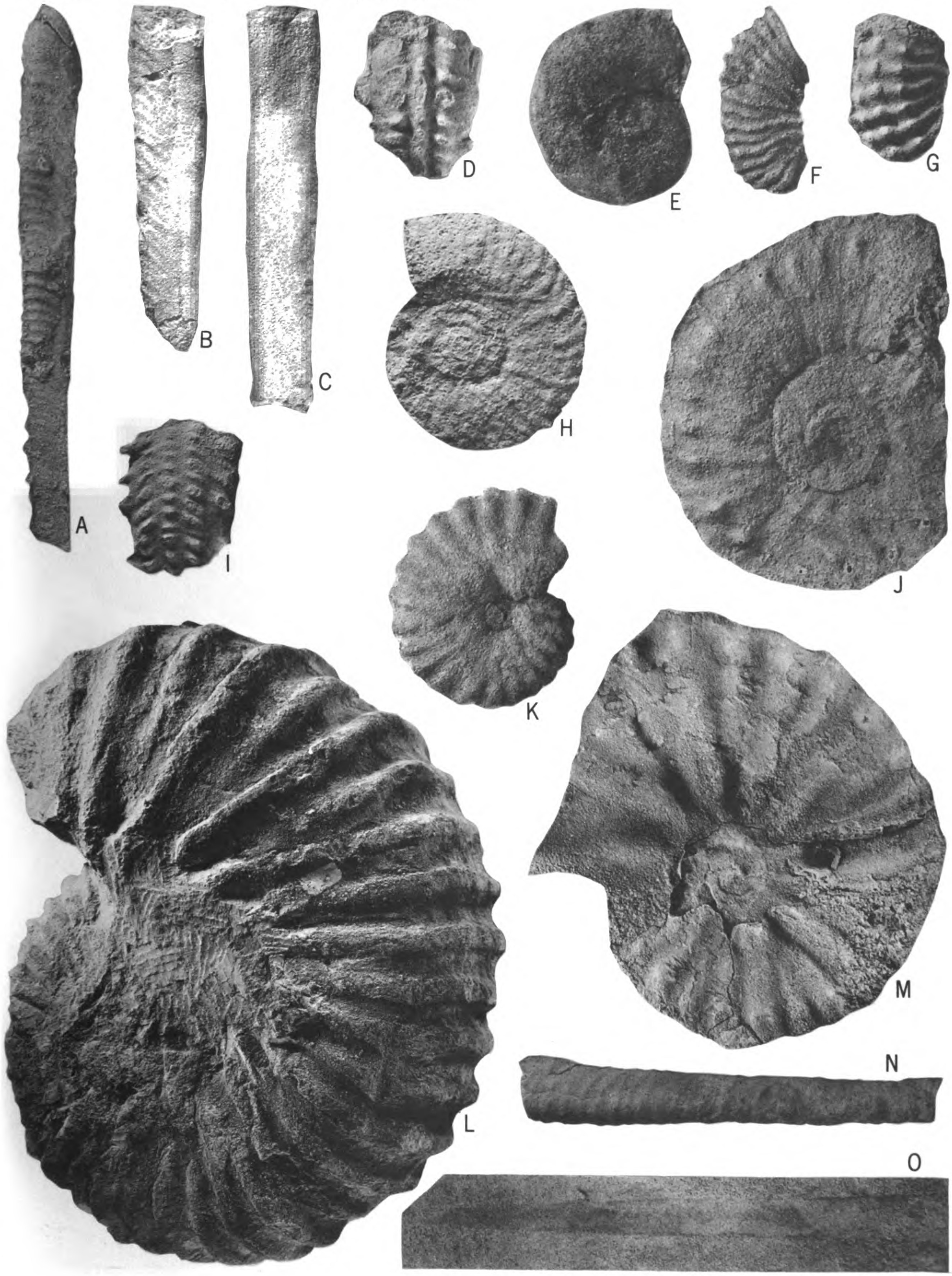


PLATE 6

PLATE 7

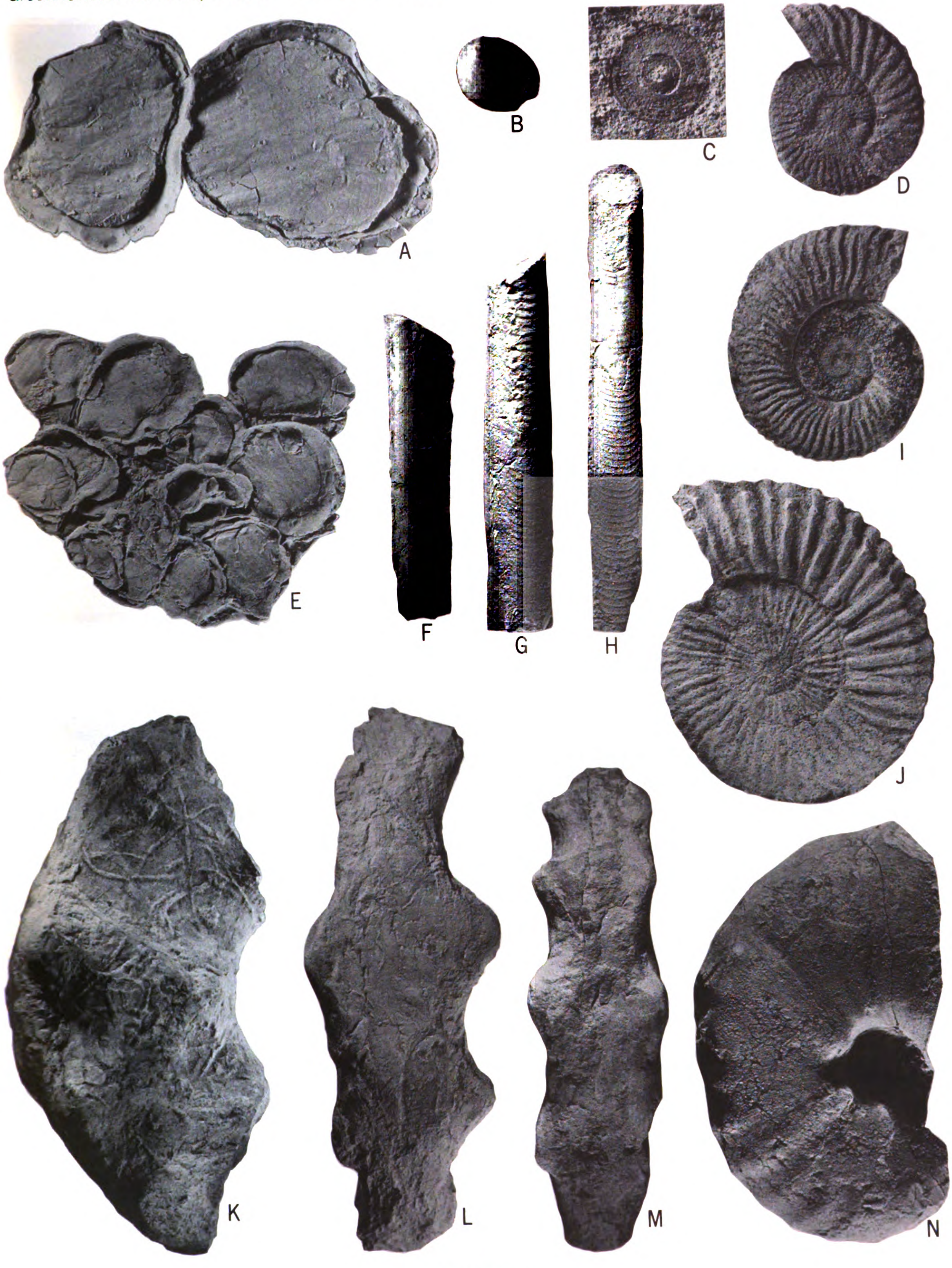


PLATE 8

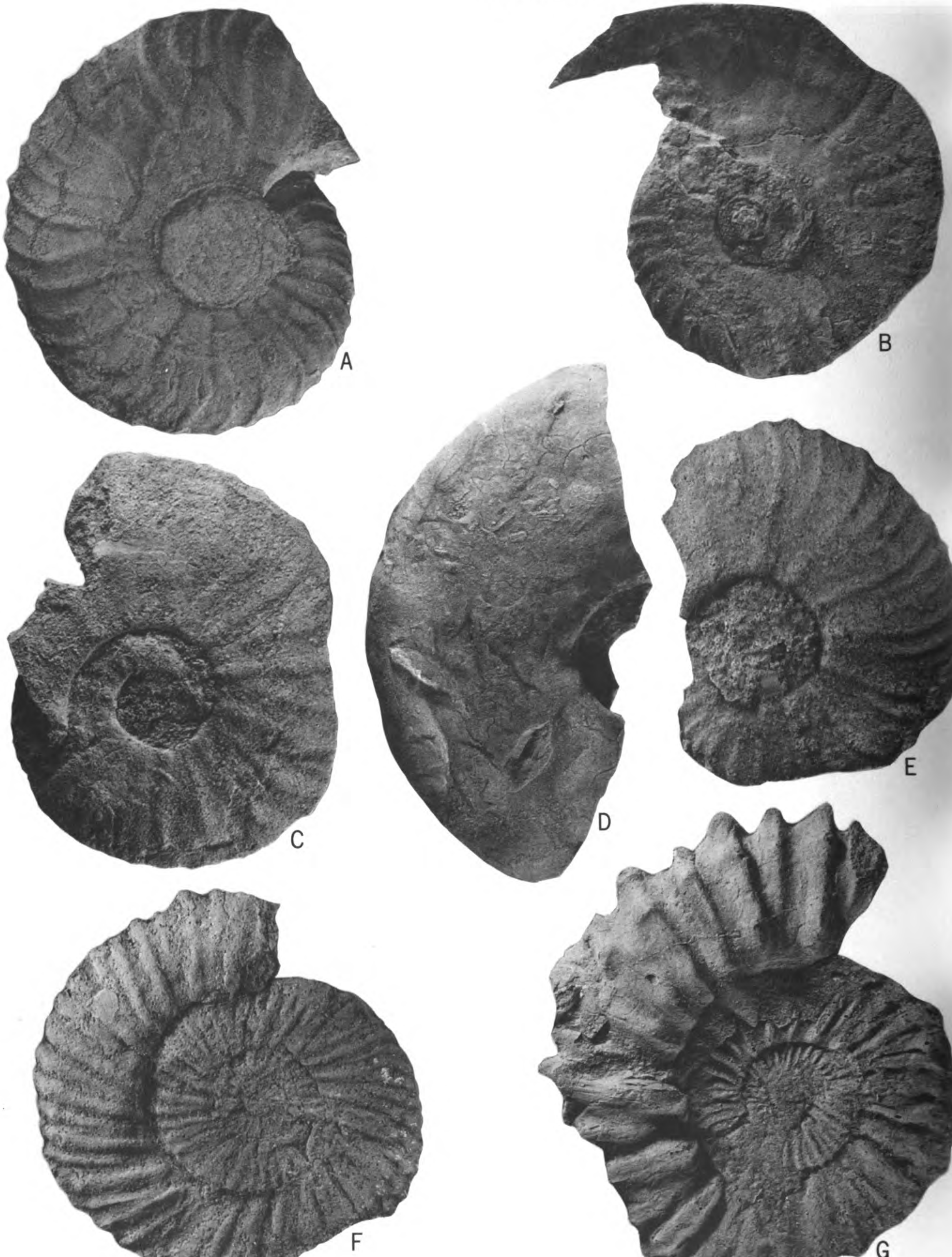


PLATE 9

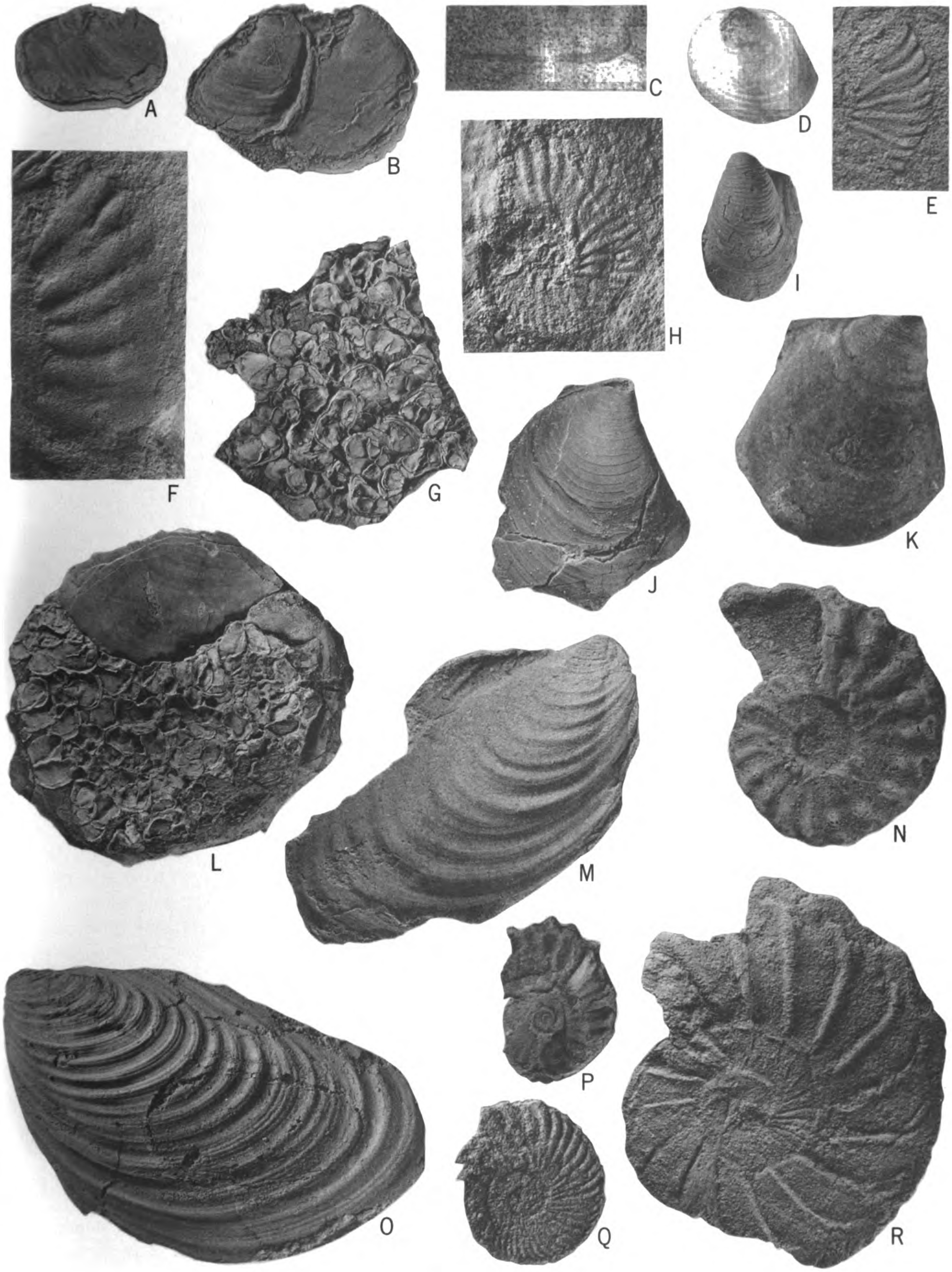


PLATE 10

ternal mold, X1, KU82109, marker bed HL-2 at Locality 24; B, fragment of internal mold, X1, KU82110, marker bed HL-2 at Locality 26; C, internal mold, X½, KU82108, float from marker bed HL-2 at Locality 3.
C,O, *Baculites* sp.: C, internal mold fragment, X1, KU82111, marker bed HL-2 at Locality 26: O, flattened mold, X1, KU82112, marker bed HL-2 at Locality 11.
D,I, *Kanabiceras septemseriatum* (Cragin): internal mold fragments, ventral aspect, both X1, KU82119, KU82120, marker bed HL-2 at Locality 3.
E, *Desmoceras* (s.l.) sp.: internal mold, X1, KU82121, middle part of Hartland Member at Locality 13.
F,G, *Pseudocalycoceras dentonense* (Moreman): F, fragment of internal mold, X1, KU82114, marker bed HL-2 at Locality 11; G, latex cast of external mold fragment, X1, KU82113, marker bed HL-2 at Locality 11.
H, *Tragodesmoceras bassi* Morrow, internal mold, X1, KU82127, upper part of Hartland Member at Locality 51.
J, *Watinoceras* sp. (possibly a coarse variant of *W. reesidei* Warren): latex cast of external mold, X1, KU82126, upper part of Hartland Member at Locality 51.
K,M, *Metoicoceras whitei* Hyatt: K, internal mold of young specimen, X1, KU82118, marker bed HL-2 at Locality 15. M, internal mold, X1, KU82117, marker bed HL-2 at Locality 3.
L, *Calycoceras* cf. *C. naviculare* (Mantell): distorted internal mold, X½, specimen from Fort Hays Kansas State College collection, 13967, probably from first bed above marker bed HL-2 at Locality 1.

EXPLANATION OF PLATE 7

Bivalves from the Jetmore Member
A-G, *Mytiloides labiatus* (Schlotheim): A, internal mold of right valve, X1, KU82160, middle part of Jetmore Member at Locality 6; B, internal mold of right valve, not coated, X1, KU82159, middle part of Jetmore Member at Locality 38; C, internal mold of left valve, X1, KU82162, basal bed of Jetmore equivalent of Bridge Creek Member at Locality 14; D, internal mold of right valve, X½, KU82165, middle part of Jetmore Member at Locality 46; E, internal mold of right valve, X1, KU82163, lower part of Jetmore Member at Locality 38; F, internal mold of right valve, X1, KU82161, middle part of Jetmore Member at Locality 4; G, internal mold of right valve, X1, KU82164, middle part of Jetmore Member at Locality 28.

EXPLANATION OF PLATE 8

Mollusks and a brachiopod from the Jetmore Member
A,E, *Pycnodonte* sp. A: A, view of two articulated specimens, X2, KU82166, middle part of Jetmore Member at Locality 38; E, cluster of articulated valves, X1, KU82167, middle part of Jetmore Member at Locality 38.
B, *Anomia* sp. A: left valve, X2, KU82169, uppermost bed of Jetmore Member at Locality 50.
C, *Discinisca* sp.: largely exfoliated brachial valve, X2, KU82158, middle part of Jetmore Member at Locality 50.
D,I,J, *Watinoceras reesidei* Warren: D, latex cast of external mold, X1, KU82150, basal bed of Jetmore Member at Locality 66; I, internal mold, X2, KU82148, basal bed of Jetmore Member at Locality 43; J, latex cast of external mold, X1, KU82149, middle part of Jetmore Member at Locality 35.
F,G,H, *Baculites* cf. *B. yokoyamai* Tokunaga & Shizimu: F,G, internal molds, both X1, KU82168, KU82154, lower part of Jetmore Member at Locality 38; H, internal mold, X1, KU82155, middle part of Jetmore Member at Locality 28.
K,L,M, *Mammites nodosoides wingi* (Morrow): K,L, lateral and ventral views of internal mold fragment, X½, KU82157, lower part of Jetmore Member at Locality 20; M, ventral view of internal mold fragment, X½, KU82156, middle part of Jetmore Member at Locality 6.
N, *Vascoceras birchbyi* Cobban & Scott: lateral view of incomplete internal mold, X1, KU82142, basal bed of Jetmore equivalent of Bridge Creek Member at Locality 14.

EXPLANATION OF PLATE 9

Ammonites from the Jetmore Member
A,B,C,E, *Tragodesmoceras bassi* Morrow: A, internal mold, X1, specimen from Fort Hays Kansas State College collection, 11847, probably from one of the three hard beds of the Jetmore Member. Locality unknown; B, combination of internal and external mold, X1, KU82146, middle part of Jetmore Member at Locality 66; C, flattened internal mold, XI, KU82144, middle part of Jetmore Member at Locality 67; E, latex cast of external mold, X1, KU82145, middle part of Jetmore Member at Locality 28.
D, *Vascoceras birchbyi* Cobban & Scott, fragment of internal mold, X½, KU82143, basal bed of Jetmore equivalent of Bridge Creek Member at Locality 14.
F,G, *Watinoceras reesidei* Warren: F, latex cast of external mold, XI, KU82147, lower part of Jetmore Member at Locality 20; G, internal mold, X1, KU82151, float from lower part of Jetmore Member at Locality 1.

EXPLANATION OF PLATE 10

Ammonites and bivalves from the Pfeifer Member
A,B,G,L, *Pseudoperna bentonensis* (Logan): A articulated specimen, X1, KU82173, B, pair of articulated specimens, X2, KU82172, A & B from middle part of Pfeifer Member at Locality 25; G, cluster of articulated valves on fragment of *Inoceramus* valve, X1, KU82170, middle part of Pfeifer Member at Locality 4; L, cluster of valves on *Inoceramus* fragment, X½, KU82171, middle part of Pfeifer Member at Locality 10.
C, Hamitid; compressed mold of juvenile specimen, X2, KU82184, lower part of Pfeifer Member at Locality 44.
D, *Anomia* sp. A: left valve, X2, KU82174, lower part of Pfeifer Member at Locality 40.
E,H, *Tragodesmoceras bassi* Morrow?: E, fragment of internal mold, X2, KU82183, H, internal mold, X1, KU82188, both from middle part of Pfeifer Member at Locality 49.
F, *Watinoceras reesidei* Warren?: fragment of internal mold, X1, KU82185, lower part of Pfeifer Member at Locality 4.
I,J,K, *Inoceramus cuvieri* Sowerby: I, left valve, X1, KU82178, upper part of Pfeifer Member at Locality 19; J, right valve, X1, KU82176, upper part of Pfeifer Member at Locality 1; K, internal mold of right valve, X2, KU82177, uppermost bed of Pfeifer Member at Locality 4.
M,O, *Mytiloides labiatus* (Schlotheim): M, internal mold of right valve, X1, KU82175, lower part of Pfeifer Member at Locality 4; O, internal mold of left valve, X1, KU82188, uppermost bed of Pfeifer Member at Locality 20.
N,P,Q,R, *Collignoniceras woollgari* (Mantell): N, latex cast of external mold, X1, KU82182, upper part of Pfeifer Member at Locality 38. P, deformed internal mold, X1, KU82180, uppermost bed of Bridge Creek Member (Fencepost bed) at Locality 14; Q, internal mold of juvenile specimen, X1, KU82179, uppermost bed of Pfeifer Member at Locality 3; R, incomplete internal mold, X1, KU82181, uppermost bed of Pfeifer Member at Locality 3.

Shaly Chalk.—The dominant lithology in the Pfeifer Member and equivalent part of the Bridge Creek Member (Loc. 14), is shaly chalk. For practical purposes the shaly chalk may be divided into three, rather embracive units, including the intervals from top of JT-13 to PF-1, from top of PF-1 to PF-2, and from top of PF-2 to PF-3 (Fencepost limestone bed). The lowest of these intervals ranges from 4.5 (Loc. 20) to 8.3 feet (Loc. 18), averaging 6.6 feet for 17 measurements. The second interval ranges from 5.3 (Loc. 10) to 11.8 feet (Loc. 14), averaging 6.6 feet for 17 measurements. The third interval of shaly chalk ranges in thickness from 3.8 (Loc. 20) to 5.9 (Loc. 5) feet, averaging 4.8 feet for 14 measurements.

Because of the superior resistance to erosion of the Fencepost limestone bed the Pfeifer Member is exposed most commonly in the upper parts of slopes and bluffs held up by that marker. In consequence the better exposures are generally much weathered. Where

FIGURE 14.—Stratigraphic features of Pfeifer Member and equivalent part of Bridge Creek Member. A) Exposure of Pfeifer Member, sec. 18, T. 13 S., R. 12 W., Russell County (Loc. 3), showing marker bed PF-1. B) Exposure of Pfeifer equivalent of Bridge Creek Member, sec. 14, T. 23 S., R. 42 W., Hamilton County (Loc. 14), showing laminated character of shaly chalk. Slabby weathering bed (arrow) is Fencepost limestone. C) Exposure of upper part of Pfeifer Member, sec. 3, T. 13 S., R. 11 W., Russell County (Loc. 28), showing nearly continuous bed of coalescent chalky limestone concretions. D) Chalky limestone concretion from upper part of Pfeifer Member, sec. 3, T. 13 S., R. 11 W., Russell County (Loc. 28), showing extraordinarily large specimen of *Inoceramus cuvieri* that apparently served as a nucleus for concretion development. Cent for scale.

fresh the shaly chalk is olive black or dark olive gray (5Y3/1) and where partly weathered the color is light olive gray (5Y6/1, 5Y5/2) or, less commonly, light to very light gray. Extensively weathered rock is mostly grayish orange to pale grayish orange (10YR8/4) or, less commonly, yellowish gray (5Y8/1, 5Y7/2) and various pale shades of brown. Such weathered rock is commonly stained dark yellowish orange by limonite, especially along fractures. The fresh rock is tough and breaks blocky; weathered rock is soft and crumbly.

Shaly chalk units contain much calcareous silt and/or fine sand, much of which is tests of planktonic foraminifera and inoceramid prisms. The rock is generally speckled throughout by minute, nearly white, spheroidal fecal pellets although these are usually difficult to detect in highly weathered samples. Most of the rock is thinly laminated (Fig. 14,B) but especially below the sugar sand (PF-2) the laminations are commonly made uneven because the rock there contains a profusion of inoceramid fragments and small lenses of skeletal limestone. In addition to this skeletal debris shaly chalk below PF-2 usually contains numerous irregular and discontinuous beds of concretionary, shell-rich chalky limestone, and a few oblate spheroidal concretions of chalky limestone that are deficient in macroinvertebrate remains. Between marker bed PF-2 and the Fencepost bed (PF-3) the shaly chalk section is characterized by its content of oblate spheroidal concretions of chalky limestone, and does not contain an abundance of shell fragments or skeletal limestone; furthermore, shell-rich concretionary limestone is lacking in this interval at nearly all exposures examined.

In an interval extending from the base of the Pfeifer to within a foot of the sugar sand (marker bed PF-2) the shaly chalk is characterized by a profusion of inoceramid valves and valve fragments and by small, mostly very thin lenses of skeletal limestone or chalky skeletal limestone. At one extreme these lenses consist of stacked or imbricated fragments of inoceramid valves; at the other they consist wholly of inoceramid prisms and/or tests of planktonic foraminifera. In general the finer grained lenses are very thin, usually less than 0.01 foot in thickness. Such rocks have a chalky matrix or a cement consisting of sparry calcite. The latter have a characteristic pale yellowish-brown to dark yellowish-brown color. Some of the lenses are thinly laminated to gently cross laminated. These lenses project conspicuously from weathered exposures and litter the slopes with their debris. Such lenses of limestone are less common, and locally rare, in the basal few feet of the Pfeifer.

In the shaly chalk interval extending from a foot or less below tthe sugar sand to the Fencepost limestone bed (PF-3), inoceramid valves are much less common, and the section contains few skeletal limestone lenses except for sparse, almost paper-thin lenses of foram tests. Lenses or very thin layers of soft, nonlaminated chalk occur locally at the top of the PF-2 to PF-3 shaly chalk interval, apparently representing a transition to the Fencepost limestone bed.

Mytiloides labiatus and fish remains, especially scales, are the only ubiquitous macrofossils in Pfeifer shaly chalks. The *Mytiloides* valves invariably have been flattened by compaction and lie parallel to stratification, commonly in great profusion. *Inoceramus cuvieri* Sowerby is common in chalky limestones of the upper half of the member, so some of the flattened and broken valves in that interval doubtlessly belong to this species. Although the range zone of *Pseudoperna bentonensis* embraces the entire member, and its Bridge Creek equivalent at Locality 14, few specimens were recorded in shaly chalk between the sugar sand (PF-2) and the Fencepost limestone bed (PF-3). These oysters are common in the lower 1 to 3 feet of the member and between PF-1 and PF-2; they occur as clusters of specimens attached to valves of *M. labiatus* or as isolated, disarticulated valves. In central Kansas stalked scalpellid cirripeds occur sparsely in the same two intervals. Abundant specimens of *Syncyclonema?* sp. were recorded in shaly chalk in the middle and upper parts of the Pfeifer equivalent of the Bridge Creek Member at Locality 14. Rare molds of *Baculites* were recorded at two localities. Ammonites are apparently of extreme rarity in Pfeifer shaly chalk units; I found none other than the baculitids noted above.

Chalky Limestone.—Like the Jetmore the Pfeifer Member is characterized by rich content of chalky limestone. This rock takes the form of widely traceable, continuous beds, including marker beds PF-1 and PF-3; numerous irregular, discontinuous, shell-rich, concretionary beds of chalky limestone; and layers of oblate spheroidal chalky limestone concretions that are usually deficient in fossils. Because of their special stratigraphic importance the two limestone marker beds are described separately in a later section. The remaining limestones are discussed as components of the intervals JT-13 to PF-1, PF-1 to PF-2, and PF-2 to PF-3 and called, respectively, lower, middle, and upper part of the member.

In central Kansas the lower part of the member contains from 2 (Loc. 18) to 9 (Locs. 3, 20) irregular and discontinuous beds of concretionary shell-rich chalky limestone. In Hamilton County (Loc. 14) the equivalent interval in the Bridge Creek member contains no irregular, discontinuous layers of such rock. Individual shell-rich chalky limestone bodies range from 0.05 foot or less to as much as 0.3 foot in thickness. Small, hemispheroidal concretions of fossil-poor chalky limestone are attached to some shell-rich limestone bodies at a few localities and a few oblate spheroidal concretions of chalky limestone also occur in this interval. The middle part of the member contains from 1 (Loc. 14) to 9 beds of shell-rich concretionary limestone, some of which are virtually continuous, although pinching and swelling, within the span of a single exposure. Locally, as in the lower part of the member, a few hemispheroidal concretions of poorly fossiliferous chalky limestone are attached to the irregular bodies of shell-rich chalky limestone. In addition this interval contains from none (Loc. 6) to 3 (Loc. 18) layers of oblate spheroidal chalky limestone concretions that range from 0.15 to 0.4 foot in maximum thickness. At several localities this interval contains one continuous bed of shell-rich chalky limestone and at Locality 14 contains 4 continuous beds of chalky limestone.

The interval from PF-2 to PF-3 is characterized by presence of from one to three layers of smoothly rounded, oblate spheroidal, chalky limestone concretions that range from 0.15 to 0.55 foot in maximum thickness. Although mostly isolated from one another the concretions are commonly coalescent (Fig. 14,C) or even greatly elongated. Discontinuous beds of shell-rich chalky limestone are rare in this interval. At Locality 14 the Bridge Creek equivalent of the upper Pfeifer contains a single, 0.35-foot-thick, dark olive gray (5Y3/1), concretionary limestone bed that is harder and more brittle than concretions in central Kansas and that breaks into angular blocks. This bed is structureless, was not observed to contain macrofossils, and terminates laterally with marked abruptness. At many localities the upper Pfeifer contains, in addition to layers of oblate spheroidal concretions, from one to three (Loc. 5) virtually continuous beds of poorly fossiliferous chalky limestone, none of which exceeds 0.3 foot in thickness. At Locality 5, stratigraphic position with respect to bentonite markers demonstrates that two of these chalky limestone beds represent locally more persistent development of the concretion layers and, like the concretions, are poorly fossiliferous. The most persistent and conspicuous of these beds is a thin, flat, usually laminated bed of chalky limestone that averages 0.12 foot in thickness (11 measurements) and lies an average of 0.72 foot above marker bed PF-2. This limestone bed is moderately hard, locally brittle and except for foraminifera is poorly fossiliferous.

Chalky limestones of the Pfeifer are olive black, dark olive gray (5Y3/1) or olive gray (5Y4/1) where fresh and light olive gray (5Y5/2, 5Y6/1) where partly weathered. The weathered rock exhibits a wide range of coloration but is mostly grayish orange, pale grayish orange (10YR8/4), very pale orange, yellowish gray (5Y7/2, 5Y8/1) or, less commonly, pale shades of brown. In more highly weathered exposures many of the limestones are partially stained dark yellowish orange by limonite. Some of the limestone beds, several of the discontinuous beds of shell-rich limestones, and many of the oblate spheroidal concretions are stained heavily by limonite along a thin central or near-central zone, parallel to stratification.

Nearly all of these rocks are relatively hard and resistant to erosion despite their distinctly chalky character. The weathered rocks are commonly harder and more brittle. Eroded slopes are usually covered by limestone debris from these beds and layers. Like the surrounding shaly chalk most of the chalky limestone is speckled by nearly white spheroidal pellets but this feature tends toward obliteration during weathering. At many places shaly chalk beds arch above and bend beneath shell-rich limestone bodies or concretions suggesting that these rocks lithified before final compaction of the section.

The irregular, shell-rich beds of chalky limestone are characterized by an abundance of *Mytiloides labiatus* valves and valve fragments. Most of this shelly material lies parallel to bedding but some lies at steep angles to the general stratification. These bivalve remains are not flattened completely as are those in adjacent shaly chalk units. At several localities, especially where weathered, the shell-rich limestones are tightly cemented, at least in part, by visibly crystalline calcite. Thin laminae are preserved in some of these rocks at a number of localities; some of these laminae are better cemented than the sourrounding chalky limestone and are locally contorted. Many of the shell-rich limestone bodies are more or less gradational with the surrounding rock, especially in the lateral direction. Surfaces of the limestone masses may be ragged owing to differing hardness of shelly debris and matrix. Except for marker bed PF-1 most of the locally continuous beds of chalky limestone lying below the sugar sand (marker bed PF-2) represent more persistent local development of the irregular, discontinuous, shell-rich limestones. This is especially evident at Locality 14 where the Bridge Creek equivalent of lower and middle parts of the Pfeifer contains few irregular, discontinuous limestones but contains a larger-than-normal number of continuous, mostly shell-rich beds of chalky limestone.

Oblate spheroidal chalky limestone concretions of the Pfeifer differ from the shell-rich limestones in being smooth-surfaced, mostly in sharp contact with the surrounding rock, poorly fossiliferous, and with inoceramids usually preserved with little or no flattening. The concretions tend to split easily through the centers, parallel to stratification. Some preserve thin laminae but the majority appear non-bedded. Most seem to have developed beneath or around large fossils such as *Inoceramus cuvieri* (Fig. 14,D), *Mytiloides labiatus*, or logs. Where logs are present the concretions are greatly elongated. At Locality 10 (Hodgeman County) a concretion in the upper part of the Pfeifer is 1.1 foot wide, 0.65 foot thick, and 23 feet long and for nearly its full length contains a largely calcitized log that is approximately 0.25 to 0.35 foot in diameter. At Locality 70 (Russell County) a chalky limestone concretion lying shortly above marker bed PF-2 is 0.5 foot wide, 0.25 foot thick, and 8 feet long and contains a "*Teredo*"-bored log.

In addition to species of inoceramids various chalky limestones of the Pfeifer have yielded also sparse molds of ammonites, calcite-filled molds of baculitids and hamitids, *Pseudoperna bentonensis, Anomia* sp. A, a scalpellid, and rare trace fossils. The cirripeds and oysters occur mainly on inoceramid valves.

Marker Beds.—Lowest marker unit in the Pfeifer Member is a thin bed of chalky limestone lying between 4.5 and 8.25 feet, and averaging 6.6 feet (n=17), above the base of the member (Fig. 14,A). The marker ranges from 0.15 to 0.3 foot in thickness, averaging 0.2 foot for 17 measurements. This bed is notable for its continuity in a part of the Pfeifer that is characterized by the irregular, discontinuous shell-rich beds of chalky limestone and is sufficiently resistant to project conspicuously from most cut banks and road cuts. The bed is easily recognized in the Pfeifer equivalent of the Bridge Creek Member of Hamilton County (Loc. 14). The rock is relatively hard and tough, but is brittle where much weathered (Loc. 1) or visibly crystalline (Loc. 14). Upper and lower surfaces of this marker are usually very flat in the central Kansas area, but in some places one or both contacts are gently undulatory and the basal surface is mammilated at Locality 5. Except for scattered fossils the texture is homogeneous and the rock is everywhere speckled by nearly white, spheroidal, fecal pellets. Ubiquitous fossils in PF-1 include whole and broken valves of *Mytiloides labiatus* that lie mostly parallel to stratification. The fragmentary valves are scattered through the rock rather than being concentrated in layers or lenses. At Locality 1 the upper half of the bed is composed largely of foraminifera. Other fossils include a single specimen of *Stomohamites* cf. *S. simplex* (Loc. 14), *Pseudoperna bentonensis* attached to inoceramids (Loc. 3), sparse fish remains, and a few molds of *Baculites* cf. *B. yokoyamai.* Sparse, irregular burrow structures were recorded at Locality 14.

Everywhere in Kansas PF-1 is underlain by a thin seam of bentonite that is separated from the limestone by a layer of granular calcite or shaly chalk. The bentonite ranges in thickness from less than 0.01 to 0.09 foot, is light gray (5Y7/2) where fresh and dark yellowish orange where weathered, and lies between 0.01 and 0.11 foot below PF-1.

The second readily recognizable marker unit in the Pfeifer is a bentonite seam that is overlain in most central Kansas exposures by a layer of granular calcite. The granular calcite is generally absent at localities in Mitchell, Cloud, and Republic Counties, and is absent in the Bridge Creek Member at Locality 14 (Hamilton County). This bentonite-calcite unit, known as the sugar sand, lies 4.0 (Loc. 14) to 5.5 (Loc. 19) feet below the Fencepost limestone bed, averaging 4.8 feet for 14 measurements. Recognition of the sugar sand unit is readily afforded by its association with two other bentonites and, usually, two layers of chalky limestone. Stratigraphic details of the interval including these units are summarized in Table 2.

TABLE 2.—Summary of stratigraphic data for sugar sand and associated beds.

Unit	Lithology	Thickness, feet	Remarks
9	Chalky limestone	0.0 to 0.2	Generally very flat at top and base, usually laminated, rich in forams, locally absent.
8	Bentonite seam	0.01 to 0.03	Overlain by granular calcite at some places; probably represented by a 0.14-foot-thick bentonite seam at Loc. 14.
7	Shaly chalk	0.27 to 1.13	Chalky limestone, locally concretionary, near or at base of this unit at Loc. 4, 5, 10, 19, 38, 44, and 58.
6	Granular calcite	0.11 to 0.35	Sugar-sand. Not present at Locs. 7, 14, 20, 24, 48, and 49. Overlain by 0.01 to 0.03 foot bentonite seam at a few localities.
5	Bentonite	0.04 to 0.14	Sugar-sand bentonite. Present at all localities studied.
4	Shaly chalk	0.01 to 0.25	Units 2 and 4 total 0.3 to 0.66 feet at localities where unit 3 is absent.
3	Chalky limestone	0.0 to 0.35	Usually concretionary; discontinuous; absent at some localities; upper part nonconcretionary and laminated at Loc. 48.
2	Shaly chalk	0.1 to 0.35	This unit contains 0.1 and 0.06 foot-thick chalky limestone beds at base at Locs. 10 and 19, respectively.
1	Bentonite seam	0.08 to 0.12	Identified at all localities except Loc. 14 where general position is occupied by a selenite seam.

The sugar sand bentonite-calcite unit is identified in weathered exposures by a grayish-orange discoloration on rain-washed surfaces. Like other markers in the section, this unit has great utility as a datum in precise biostratigraphic work.

The Fencepost limestone bed (PF-3) is the most conspicuous of Pfeifer chalky limestones and is one of the most prominent marker beds in the Kansas Cretaceous. The Fencepost bed can be traced readily across the entire Greenhorn outcrop of Kansas. This feet, averaging 0.79 foot for 15 measurements, but unit has an apparent thickness range from 0.55 to 1.1

where the bed caps bluffs measurable thickness may be less than usual because under such circumstances weathering tends to disintegrate the upper part of the unit. Easy recognition of this bed is afforded by several criteria including: 1) invariable association with a very thin seam of bentonite that lies 0.07 to 0.7 foot below the Fencepost, 2) bench-forming characteristic, 3) quarries along outcrop marking sites of extensive removal of the rock for posts and building stone, 4) conspicuous ferruginous zone near the center of the bed in virtually all weathered exposures, and 5) presence of *Collignoniceras woollgari* (Mantell). The Shellrock limestone bed (JT-13), with which the Fencepost could be confused, is generally thicker, is at least in part crowded with shells of *Mytiloides labiatus,* lacks specimens of *C. woollgari,* and does not lie close to any persistent bentonite seam. Marker bed number 2 of the Fairport Member, Carlile Shale (see Hattin, 1962), which lies anywhere from 4.0 to 6.2 feet above the Fencepost, is nearly everywhere thinner than the Fencepost, contains many tapered, coarsely crystalline calcite structures that apparently are baculitids, and lies directly on a bentonite-granular calcite unit that ranges from 0.2 to 0.55 foot in thickness.

Because of superior resistance to erosion the Fencepost bed crops out extensively in bluffs, stream banks, and along roads crossing these features. The bed is most commonly observed in a weathered condition. Color of the fresh rock is olive gray; weathered rock exhibits a wide range of coloration from grayish orange (most common) and paler shades of orange to yellowish gray (5Y7/2, 5Y8/1), and is dark yellowish orange, moderate reddish brown, or light brown (5YR5/6) where stained by limonite. The rock is moderately hard and tough except at Locality 14 where the bed is harder and more brittle than usual at most central Kansas exposures. At most places the bed is not broken by bedding fractures but locally, as at Locality 1, is weathered to thin layers in the upper part, and contains a 0.2-foot-thick shaly reentrant lying 0.2 foot below the top at Locality 22. At many places the base of the Fencepost is gently undulatory. The rock is nearly homogenous in texture, everywhere contains white spheroidal fecal pellets and apparently lacks laminations at all but one place (Loc. 14) examined by me. Scattered small fragments of inoceramid fragments are virtually ubiquitous, but to my knowledge are nowhere concentrated in lenses or continuous layers. Specimens of *M. labiatus,* including some of broad form, are also ubiquitous in the bed. Other common species are *Collignoniceras woollgari, I. cuvieri,* and *Baculites* cf. *B. yokoyamai.* Specimens of *Pseudoperna bentonensis* were recorded at Localities 3, 14, 25, 41, and 49; a single articulated specimen of a scalpellid was collected at Locality 3; and a few fish scales and bones were observed. Unlike the Shellrock bed, which is locally much burrowed, the Fencepost contains few or none of these structures.

Facies Change in Pfeifer Interval.—In central Kansas the characteristic features of the Pfeifer Member are abundance of shell-rich, concretionary chalky limestone and, especially in the upper half, oblate spheroidal chalky limestone concretions. In marked contrast the exactly equivalent interval of the Bridge Creek Member (Loc. 14) contains, in addition to marker beds PF-1 and PF-3 (Fencepost bed), only 6 beds of the shell-rich variety of chalky limestone and only 3 layers of widely spaced chalky limestone concretions. The limestone content of the Bridge Creek equivalent is much less than in any Pfeifer exposure in central Kansas and is progressively less still farther to the west. In a road cut on Interstate Highway 25, directly south of Graneros Creek, Pueblo County, Colorado, the Pfeifer equivalent lacks chalky limestone beds and is included in the Fairport Member of the Carlile Shale.

Bentonite.—The Pfeifer Member contains 5 seams of bentonite that can be traced throughout central Kansas; four of these can be identified also in the Bridge Creek Member of Hamilton County (Loc. 14). These include 1) the seam lying directly beneath marker bed PF-1, 2) a seam that nearly everywhere lies less than one foot below marker bed PF-2, 3) the bentonite seam associated in most of central Kansas with granular calcite known as the sugar sand PF-2, 4) a seam that nearly everywhere lies less than one foot above the sugar sand and is associated commonly with a very thin, flat, foram-rich bed of chalky limestone, and 5) a very thin seam lying 0.7 foot or less below the Fencepost bed (PF-3). With only one recorded exception bentonites (2) and (3) are the only seams that are commonly greater than 0.1 foot thick. No bentonite seam that I measured is more than 0.14 foot thick; however, the granular calcite known as sugar sand (PF-2) apparently developed within a bentonite seam, so that the total bentonite-calcite-bentonite sequence is as much as 0.45 foot.

These bentonites exhibit a wide array of coloration that ranges from olive gray (5Y4/1) through light olive gray (5Y6/1, 5Y5/2) to light gray, very light gray, yellowish gray (5Y8/1), bluish white, and white. The darkest colors represent the unweathered or little-weathered rock, the lighter colors represent weathered bentonites. Most of the weathered bentonites are stained dark yellowish orange, at least in part, by limonite. Some such bentonites are pale yellowish brown, grayish orange, and moderate yellowish brown. Several of the bentonite seams are associated with seams of gypsum or granular calcite, especially (1) and (3).

The bentonites are commonly silty to slightly silty and mineral flakes resembling biotite were recorded locally in two of the seams. Four untreated samples of bentonite, including seams (2), (3), and (4), were analyzed by X-ray diffraction techniques. In all samples the principle mineral is montmorillonite. Two samples proved to be essentially pure montmorillonite. Two other samples also contained small quantities of kaolinite and trace quantities of quartz.

Macroinvertebrate Fossils.—Biostratigraphy of the Pfeifer and equivalent Bridge Creek beds is treated in a later section. However, not all species recorded in the Pfeifer are utilized in zoning the interval so the following list has been compiled for sake of completeness. Inclusion of a taxon in this list does not indicate co-occurrence with all other species named. Common species are preceded by an asterisk; rare species, or those known only from a single locality, are preceded by a dagger.

Bivalves:
- *Anomia* sp. A (undescribed)
- †*Syncyclonema*? sp.
- **Inoceramus cuvieri* Sowerby
- **I. (Mytiloides) labiatus* (Schlotheim), including broad form
- **Pseudoperna bentonensis* (Logan)

Cephalopods:
- ammonite molds, unidentified
- **Baculites* cf. *B. yokoyamai*
- hamitids, crystalline casts of juveniles
- **Collignoniceras woollgari* (Mantell)
- †*Stomohamites* cf. *S. simplex* (d'Orbigny)
- †*Tragodesmoceras bassi* Morrow?
- †*T. carlilense* Cobban
- †*Watinoceras reesidei* Warren

Cirripeds:
- †*Stramentum canadensis* (Whiteaves)
- †stramentid, sp.
- †scalpellid, sp.

Pfeifer macroinvertebrate fossils are illustrated in Plate 10.

Preservation of Pfeifer fossils is essentially the same as that observed in the Jetmore Member. Specimens of *Anomia* are preserved in-the-round in chalky limestone and the shells retain pearly luster. Specimens of *Syncyclonema*? from shaly chalk at Locality 14 are crushed flat, and consist of paper-thin calcitic valves. Specimens of inoceramids almost everywhere preserve only the calcitic prismatic layer or are molds. In the few specimens retaining the nacreous layer, the aragonite has been altered to coarsely crystalline calcite. *Pseudoperna* is preserved as calcitic valves. Nearly all ammonites are preserved only as molds; a few molds of hamitids and baculitids are filled with crystalline calcite. Cirripeds in Pfeifer rocks are preserved as calcitic articulated skeletons or isolated plates.

BIOSTRATIGRAPHY

Western Interior Standard Zones

Cobban and Reeside (1952) published a Western Interior zonal scheme that has wide application for Upper Cretaceous rocks in this huge area. Major revisions to that sequence of zones were made by Cobban (1961) and by Cobban and Scott (1972, p. 33) so that the published standard sequence of zones for the section including Graneros Shale, Greenhorn Limestone, and Fairport Member of Carlile Shale, and for equivalent strata, stands presently, as follows:

European Stages	Zones	Kansas Section
	Collignoniceras woollgari (Mantell)	Fairport Member, Carlile Shale
Turonian	*Inoceramus (Mytiloides) labiatus* (Schlotheim)	
	Sciponoceras gracile (Shumard)	
	Dunveganoceras albertense (Warren)*	Greenhorn Limestone
	Dunveganoceras conditum Haas*	
Cenomanian	*Dunveganoceras pondi* Haas	
	Acanthoceras wyomingense (Reagan)[11]	
	Acanthoceras amphibolum Morrow	Graneros Shale
	Cobban & Scott* *Acanthoceras muldoonense*	
	Cobban & Scott* *Acanthoceras granerosense*	
	Calycoceras (Conlinoceras) gilberti Cobban & Scott*	

Scott and Cobban (1972, p. 33) recognized that the zone of *Mytiloides labiatus* embraces zones of the ammonites *Watinoceras coloradoense* and *Mammites nodosoides* and overlaps the lower part of the *C. woollgari* range zone. Zones marked by an asterisk have not yet been recognized in Kansas. The *A. muldoonense* Zone may be represented by part or all of the *Callistina lamarensis* Assemblage Zone (Hattin, 1965a, p. 40). Fragmentary molds of large, sharply ribbed, horned ammonites have been collected from the interval separating Kansas beds with the *D. pondi* fauna from those with the *S. gracile* fauna, and may represent species of *Dunveganoceras*. The remaining zones are recognized in Kansas, but modification of these zonal concepts is necessary to account for the entire section, and to make best stratigraphic use of the many distinctive species occurring in these rocks. It seems useful to discuss the range zones of the ubiquitous inoceramid bivalves, as well as the assemblage zones of Greenhorn rocks; therefore, a scheme of range zones and assemblage zones is presented in the succeeding pages. The ranges of all taxa assignable at

[11] The genus *Plesiacanthoceras* was erected for this species by Haas (1964, p. 610), and the writer (Hattin, 1968) has used that generic designation for Kansas specimens. However, Matsumoto and Obata (1966, p. 46) and Kennedy and Hancock (1970, p. 465) regarded *Plesiacanthoceras* as a synonym of *Acanthoceras*.

least to the generic level are shown diagrammatically in Figure 15.

Range Zones of Inoceramid Bivalves

At least three readily identifiable species of inoceramids are represented in the Kansas Greenhorn. These are, in order of ascending stratigraphic position, *Inoceramus prefragilis* Stephenson, *Mytiloides labiatus* (Schlotheim) and *I. cuvieri* Sowerby. In central Kansas, except for Ford and southern Hodgeman Counties, *Inoceramus prefragilis* ranges from the base of the Lincoln Member to a position between HL-4 and the top of the Hartland Member. Because of poor preservation (flattened molds; jointing in shaly chalk) in the part of the section where *I. prefragilis* terminates upward, and where *Mytiloides labiatus* commences, the exact upper limit of the former is difficult to determine. The difficulty is compounded by the fact that earliest forms of *Mytiloides labiatus* are commonly more rounded and less oblique than typical specimens occurring higher in the section. The figures below show the approximate limits of these two species at three widely separated localities.

	Uppermost undoubted *I. prefragilis* **(feet above HL-4)**	**Lowermost undoubted** *Mytiloides labiatus* **(feet above HL-4)**
Loc. 1	2.7	4.6
Loc. 28	6.0	4.5
Loc. 14	3.4	3.4

At Localities 28 and 14 the two species overlap, but the stratigraphic thickness of this overlap is not great.

Mytiloides labiatus ranges from a position shortly above Hartland bentonite HL-4 to approximately one foot above the first widespread chalky limestone marker bed in the Fairport Member of the Carlile Shale. The most typical forms of this species characterize the upper part of the Jetmore Member and lower part of the Pfeifer Member. In this report the name *M. labiatus* is used in the broad sense and embraces forms manifesting wide morphologic variation, even within a single bed. The species is most abundant in the three hard beds and Shellrock limestone bed of the Jetmore. In the upper part of the Pfeifer, above the sugar sand, and especially in the lower part of the Fairport, the species is represented by a broad form referred to by Kaufman (1966, p. 36) as *I. labiatus* aff. *hercynicus.* This form is transitional with *Inoceramus latus* J. de C. Sowerby, a species that is characteristic of the Fairport Member, Carlile Shale (Hattin, 1962, p. 55).

The *Inoceramus cuvieri* Range Zone begins shortly above Pfeifer marker PF-1, at about the level where broad forms of *Mytiloides labiatus* first appear, and extends upward at least into the lower part of the Blue Hill Member of the Carlile Shale. Most specimens observed in the Pfeifer Member are small and, in the juvenile stages of growth, high inflated. One incomplete specimen 38.5 cm in height was collected from a concretion of chalky-limestone lying beneath the sugar sand marker bed at Locality 28, Russell County (Fig. 14,D). Larger specimens are abundant in the Fairport Member of the Carlile (see Hattin, 1962, Pl. 11, C).

At Locality 23, Hodgeman County, the lower part of the Lincoln contains rare *Inoceramus prefragilis* and a few specimens of *Inoceramus* resembling *I. rutherfordi* Warren; however, better-preserved material is needed to prove the apparent overlap of these two species. At Locality 12, Kearny County, where the Graneros is gradational with the Greenhorn, undoubted *Inoceramus rutherfordi* occur within 5 feet of the formational contact, and *Inoceramus prefragilis* occurs directly above the contact, but ranges of the two species have not been demonstrated to overlap.

Assemblage Zones

Acanthoceras wyomingense Assemblage Zone.—The oldest assemblage zone recognized in Greenhorn rocks of Kansas is that characterized by *Acanthoceras wyomingense*. This zone is well developed in the basal part of the Lincoln Member at Locality 23 where the assemblage is preserved in skeletal and chalky limestone of the lowest 2 feet of the formation. At this locality the assemblage includes the following species.

Ammonites:
- **Acanthoceras wyomingense* (Reagan)
- *Borissjakoceras* sp.
- *Eucalyoceras* sp. A.
- *Pseudocalycoceras* sp.
- *Stomohamites* cf. *S. simplex* (d'Orbigny)

Pelecypods:
- **Exogyra columbella* Meek
- *Inoceramus prefragilis* Stephenson
- *Inoceramus* cf. *I. rutherfordi* Warren

Common forms are preceded by an asterisk; the remaining forms each are represented in my collection by only a few specimens. At this locality Graneros beds containing the *Ostrea beloiti* Assemblage Zone of Hattin (1965, p. 40), are missing, and the Lincoln rests unconformably on Graneros beds containing the *Callistina lamarensis* Assemblage Zone (Hattin, 1965a, p. 44; 1968). At several nearby localities in Hodgeman and Ford Counties noncalcareous shale of the Graneros contains only fossils of the *C. lamarensis* Assemblage Zone and is overlain sharply by skeletal limestones of the basal Greenhorn. For example, at Locality 8, Ford County, the basal bed of the Lincoln is an *Ostrea beloiti* shell hash and this rests sharply on Graneros beds containing the *C. lamarensis* assemblage. The oysters probably represent a lag concentrate derived from the *O. beloiti* zone by sublevation that preceded the main phase of Lincoln deposition.

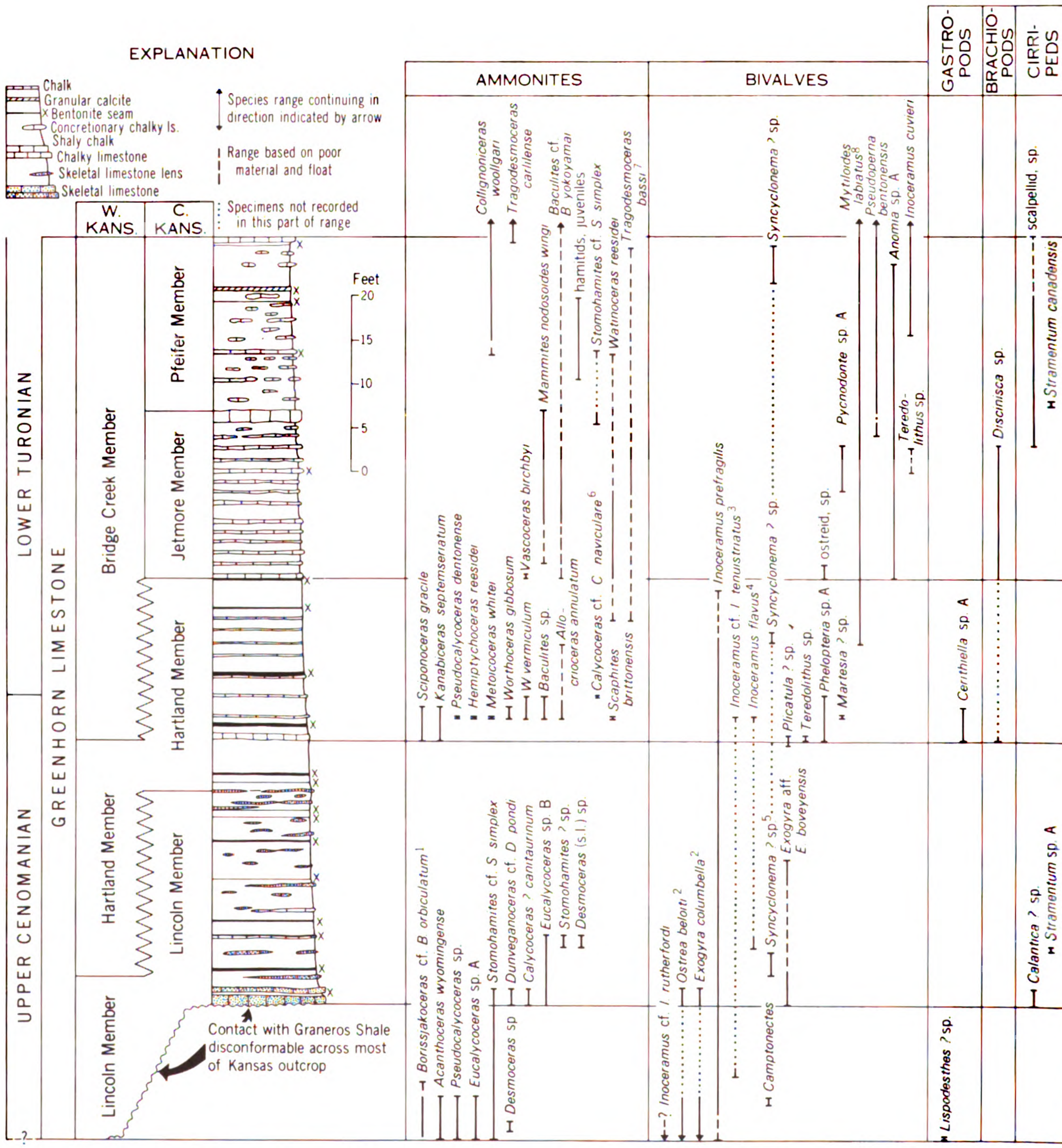


FIGURE 15.—Stratigraphic distribution of Greenhorn macroinvertebrate fossils in Kansas. The graphic column of the Greenhorn Limestone is a composite of central and western Kansas sections, with average thicknesses for members and for position of widely traceable bentonite seams and chalky limestone beds. Because the Lincoln Member lacks uniformity from one exposure to the next the lithologic and stratigraphic features are schematic. 1) In Mitchell County (Loc. 1) transitional beds near the top of the Graneros Shale, containing the *Acanthoceras wyomingense* Assemblage Zone, include both *Borissjakoceras orbiculatum* and *B. reesidei*. *B.* cf. *B. orbiculatum* has been recorded in this assemblage zone in the lower Lincoln at Locality 12, and *B.* sp. has been recorded from the lower Lincoln at Locality 23. 2) Across much of central Kansas specimens of *Exogyra columbella* and *Ostrea beloiti* in basal Lincoln skeletal limestones may have been reworked from the upper part of the Graneros Shale. 3) The range of *Inoceramus* cf. *I. tenuistriatus* is based on specimens from the middle Lincoln at Locality 12 and Hartland marker bed HL-2 at Locality 4 that were identified by E. G. Kauffman. 4) The range of *Inoceramus flavus* is based on specimens from the middle Hartland at Locality 13 and Hartland marker bed HL-2 at Locality 3 that were identified by E. G. Kauffman. The Hartland specimens are distorted by compaction and may be *I. prefragilis*. 5) In the lowest part of its range *Syncyclonema?* sp. has been collected from the Hartland Member at Locality 13 but has not been recorded from equivalent beds in central Kansas. 6) *Calycoceras* cf. *C. naviculare* is known in central Kansas from a single specimen collected as float at the Glen Elder dam excavation (Loc. 1) and probably also by fragments from the *Sciponoceras gracile* Assemblage Zone at a few other localities. 7) The level at which *Tragodesmoceras bassi* grades upward to *T. carlilense* has not been established in the Kansas section. 8) In the uppermost part of its range, *Mytiloides labiatus* is represented by a broad form that is transitional to *Inoceramus latus*.

The only other macroinvertebrate fossil recorded in this *O. beloiti* bed is an abraded gastropod identified as *Lispodesthes?* sp. *Inoceramus prefragilis* occurs in shaly chalk lying 6 feet above the base and well-preserved non-crushed specimens are preserved in a discontinuous bed of chalky limestone having ball-and-pillow structure that lies 7 feet above the base of the Lincoln. The species is common in strata above the limestone bed. At the same locality, poorly preserved molds of *Eucalycoceras* sp. A occur in a chalky limestone bed lying 10 feet above the base of the member. Proximity of Locality 8 to Locality 23, and similarity of stratigraphic relations at both, suggests that the lower part of the Lincoln Member at Locality 8 probably represents the *A. wyomingense* Assemblage Zone. At Locality 12, Kearny County, much of the Lincoln Member apparently lies in the *A. wyomingense* Assemblage Zone. Small, imperfect molds possibly belonging to this species have been collected from the lower part of the member and a single, large, flattened mold was recorded from 5.7 feet above the base of the member. At this locality *Inoceramus prefragilis* ranges throughout the member, but is not known from the *I. rutherfordi*-bearing beds that comprise a Graneros-Greenhorn transitional sequence at the top of the Graneros Shale. The lower few feet of the zone also contains *Ostrea beloiti, Desmoceras* sp., *Borissjakoceras* cf. *B. orbiculatum,* and *Eucalycoceras* sp. A. The last form compares well with some of the *Eucalycoceras* from Localities 8 and 23, but none are identifiable specifically. Graneros beds lying about 4 feet beneath the base of the Lincoln here contain excellent specimens of *Inoceramus rutherfordi, Ostrea beloiti,* molds of *Borissjakoceras* sp. and *Stomohamites?* sp., and the mold fragment of a large, horned ammonite. These upper Graneros fossils seemingly represent the uppermost part of the *O. beloiti* Assemblage Zone.

Northward from southern Hodgeman County (Loc. 23), the unconformity separating the Graneros and Greenhorn climbs in the section so that in the area between northern Pawnee and Lincoln Counties basal Greenhorn beds assigned to the *Calycoceras? canitaurinum-Exogyra* aff. *E. boveyensis* Assemblage Zone rest unconformably on Graneros beds containing the *Ostrea beloiti* Assemblage Zone (Hattin, 1968). In this area the contact lies on or as much as 3.2 feet above a regionally persistent bentonite seam ("X" bentonite of authors).

At some localities north of Lincoln County the Graneros-Greenhorn contact is apparently conformable, e.g. Localities 6 and 46, but fossil evidence is insufficient to document the biostratigraphic zonation. However, at Locality 1, Mitchell County, Graneros beds above the "X" bentonite are far thicker than usual (17.6 feet) and evidence is lacking for unconformity at the Graneros-Greenhorn contact (Hattin, 1968). These upper Graneros beds are silty and weakly calcareous at the base, grading upward to silty chalky shale at the top. This interval contains a layer of calcareous septarian concretions which is apparently the source of a few specimens of *Acanthoceras wyomingense* collected by local residents. The concretions also contain rare *Stomohamites* sp. Adjacent underlying calcareous and chalky shales contain the following forms.

Ammonites:
- *Borissjakoceras reesidei* Morrow
- *Borissjakoceras orbiculatum* Stephenson
- *Eucalycoceras* sp.
- *Stomohamites* cf. *S. simplex* d'Orbigny

Bivalves:
- corbulid (1 mold)
- *Inoceramus* cf. *I. rutherfordi*

This assemblage resembles those of the lower Lincoln at Localities 12 and 23 but occurs here in the Graneros Shale. Typical skeletal limestones of the basal Lincoln, with faunal elements of a succeeding assemblage zone, lie above the shale section just described.

Thus the *Acanthoceras wyomingense* Assemblage Zone is recognized with certainty only at three Kansas localities (12, 23, and 1). Stratigraphic considerations and limited paleontological data suggest that equivalent strata are present also in the lower part of the Lincoln at Locality 8. The assemblage zone is equivalent to the *Acanthoceras? wyomingense* zone of Cobban (1961) and according to Jeletzky (1968, p. 24) is approximately equivalent to the *Acanthoceras athabascense* zone of Canada.

Calycoceras? canitaurinum-Exogyra aff. *E. boveyensis Assemblage Zone*.—The second Greenhorn assemblage zone is known mostly from skeletal limestones (chiefly calcarenites) lying at the base of the Lincoln Member in the middle part of the central Kansas outcrop, from east-central Hodgeman County to Mitchell County. The zone probably is represented also by basal Lincoln beds farther to the northeast, but diagnostic species of the zone have not yet been recorded from that area. This assemblage is characterized by *Calycoceras? canitaurinum* Haas, *Exogyra* aff. *E. boveyensis* Bergquist and *Eucalycoceras* sp. B. These species represent the *D. pondi* zone of Cobban and Reeside (1952, p. 1017) and of Cobban (1961, p. 740), and the zone of *Calycoceras? canitaurinum* of the Pueblo, Colorado area (Cobban and Scott, 1972, p. 33). Specimens assigned to *D.* cf. *D. pondi* are known from two or three central Kansas localities, but are too rare to be considered as zonal indices. The *C.? canitaurinum* assemblage includes the following species.

Ammonites:
Calycoceras? canitaurinum (Haas)
†*Dunveganoceras* cf. *D. pondi* Haas
**Eucalycoceras* sp. B
**Stomohamites* cf. *S. simplex* d'Orbigny
Bivalves:
†*Exogyra columbella* Meek
**Exogyra* aff. *E. boveyensis* Bergquist
**Inoceramus prefragilis* Stephenson
Ostrea beloiti Logan
Cirripeds:
†*Calantica?* sp., isolated plates

Names preceded by an asterisk are most common, those preceded by a dagger are rare, all others are of intermediate abundance. No single locality has yielded all species in this assemblage; the best collections are from Localities 3 and 26 in Russell County.

At Locality 30, east-central Hodgeman County, the basal Lincoln contains *Ostrea beloiti, Inoceramus prefragilis,* and *Eucalycoceras* sp. B. This small assemblage is assigned to the *Calycoceras? canitaurinum-Exogyra* aff. *E. boveyensis* Assemblage Zone. Just 10 miles farther south, at Locality 23, the basal Lincoln contains the *Acanthoceras wyomingense* Assemblage Zone. This seemingly anomalous biostratigraphy has been explained by the writer (Hattin, 1965, p. 44) who showed that the unconformity separating the Graneros and Greenhorn climbs stratigraphically northward from Locality 23 so that at Locality 30 the basal Lincoln is younger than at Locality 23.

At Locality 55, southeastern Hodgeman County, *Exogyra* aff. *E. boveyensis* is common in beds lying 9 to 10 feet above the base of the Lincoln. Shortly, to the west, at Locality 8, Ford County, this species is common in the upper 4.3 feet of the Lincoln where it occurs with abundant *Inoceramus prefragilis,* isolated cirriped plates, and fragmentary ammonite molds that compare well with *Calycoceras? canitaurinum.* Still farther west, at Locality 12, Kearny County, *E.* aff. *E. boveyensis* occurs sparingly in the upper 6 feet of the Lincoln Member where it is associated with *Inoceramus prefragilis* and *Eucalycoceras* sp. *B.* At Locality 13, Kearny County, *I. prefragilis Eucalycoceras* sp. *B.*, and *Stomohamites* cf. *S. simplex* occur in the topmost bed of the Lincoln. At these five localities (30, 55, 8, 12 and 13) the stratigraphic position of elements of the *Calycoceras? canitaurinum* Assemblage Zone lends force to the argument that the Lincoln Member is diachronous, climbing the section from west to east, and that lower Lincoln beds in the middle part of the central Kansas outcrop pass southwestward into the middle and upper parts of the member in southern Hodgeman, Ford, and Kearny Counties.

In sections containing elements of the *Acanthoceras wyomingense* and *Calycoceras? canitaurinum* assemblages, the two zones are separated by a few feet of strata having *Inoceramus prefragilis* as the only common species. For example at Locality 12 approximately 5 feet of strata lying in the middle of the Lincoln Member are at present not assigned to either assemblage zone. At Locality 8, approximately 5 feet of strata, lying 4.3 to 9.3 feet below the top of the member, are unassigned. At Locality 1, the two assemblages occur within 1.5 feet of each other in Graneros-Greenhorn transition beds near the top of the Graneros Shale.

Undesignated Assemblage Zone.—The third well-defined Greenhorn assemblage zone is that of *Sciponoceras gracile*, discussed later, which lies in the midst of the Hartland section of central Kansas, and in the basal 6.7 feet of the Bridge Creek Member in Hamilton County. Between the *Calycoceras? canitaurinum* and *Sciponoceras gracile* Assemblage Zones are many feet of Lincoln and/or Hartland beds in which the only common macroinvertebrate fossil is *Inoceramus prefragilis.* Invertebrate fossils from this interval in central Kansas are listed below.

Ammonites:
ammonite mold, possibly *Dunveganoceras* (Loc. 3, near middle of Lincoln)
Desmoceras (s.l.) sp. (Loc. 26, in lower half of Lincoln)
Eucalycoceras sp. B (Locs. 2, 3, 26, 27, 38, lower half of Lincoln)
Stomohamites? sp. (Loc. 26)
Bivalves:
Exogyra aff. *E. boveyensis* Bergquist (Locs. 6, 47)
Inoceramus prefragilis Stephenson (throughout the interval)
ostreid fragments (Locs. 3, 26, 27, lower half of Lincoln)
Cirripeds:
Stramentum sp. A (Locs. 3, 4, 28)

In westernmost Kansas, beds containing the *Sciponoceras gracile* fauna lie in the lower part of the Bridge Creek Member rather than in the Hartland as in central Kansas. In this area apparently the entire Hartland lies between beds containing elements of the *Calycoceras? canitaurinum assemblage* and the base of the *Sciponoceras* zone. The Hartland Member contains the following forms at Locality 13, Kearny County.

Ammonites:
ammonite mold, possibly Dunveganoceras, upper part of Hartland
Desmoceras (s.l.) sp. (bed 19 feet above base of Hartland)
Eucalycoceras sp. B (lower half of Hartland)
Stomohamites? sp. (bed 19 feet above base of Hartland)
Bivalves:
Inoceramus flavus Sornay (distorted specimen, maybe *I. prefragilis*)
Inoceramus prefragilis Stephenson (throughout the Hartland)
Syncyclonema? sp. (lower part of Hartland)

Gross similarity is evident in the assemblage of fossils that appear in the two lists given above, but preservation of fossils recovered from the interval is mostly too poor for the collection to be of much biostratigraphic value at this time. At Locality 12, Kearny County, *Exogyra* aff. *E. boveyensis* ranges into the basal foot or two of the Hartland, and at Locality 13 *Eucalycoceras* sp. B ranges stratigraphically upward to a chalky limestone bed lying 19 feet above the top of the Lincoln. This suggests that the *Calycoceras? cantaurinum* assemblage may embrace part of the Hartland in that area. In central Kansas *Eucalycoceras* sp. B. occurs well above beds containing *C? canitaurinum* or *Dunveganoceras* cf. *D. pondi*. Until better-preserved ammonite specimens are recovered from the middle and upper parts of the Lincoln of central Kansas, and from the Hartland of western Kansas, the upper limit of the *C? canitaurinum-Exogyra* aff. *E. boveyensis* Assemblage Zone must remain undefined. For the present, most of the Lincoln and the lowermost Hartland of central Kansas, and possibly all of the type Hartland are considered simply as an undesignated assemblage zone. Apparently these beds correspond in large part to the *Dunveganoceras conditum* and *D. albertense* zones of Cobban (1961, p. 740) and of Cobban and Scott (1972, p. 33).

Sciponoceras gracile Assemblage Zone.—The most highly diversified faunal assemblage in Greenhorn rocks of Kansas is that belonging to the zone of *Sciponoceras gracile* (Shumard) of Cobban and Reeside (1952, p. 1017). In Kansas this assemblage consists of the following species:

Ammonites:
- *Allocrioceras annulatum* (Shumard)
- **Baculites* sp. (smooth form)
- †*Calycoceras* cf. *C. naviculare* (Mantell)
- †*Hemiptychoceras reesidei* Cobban & Scott (2 specimens, from Locs. 2 and 3)
- **Kanabiceras septemseriatum* (Shumard)
- *Metoicoceras whitei* Hyatt
- †*Pseudocalycoceras dentonense* (Moreman)
- †*Scaphites brittonensis* Moreman
- *Sciponoceras gracile* (Shumard)
- *Worthoceras gibbosum* Moreman
- **Worthoceras vermiculum* (Shumard)

Pelecypods:
- *Inoceramus flavus* Sornay
- **Inoceramus prefragilis* Stephenson
- *Inoceramus* cf. *I. tenuistriatus* Nagao & Matsumoto
- †*Martesia?* sp. (1 specimen)
- †*Plicatula?* sp. (2 specimens)
- *Phelopteria* sp. A.
- †*Teredolithus* sp.

Gastropods
- **Cerithiella* sp. A.

Brachiopods:
- †*Discinisca* sp.

Cirripeds:
- acrothoracian barnacle borings

In this list, the more common forms are preceded by an asterisk; rare forms are preceded by a dagger. The most abundant and characteristic species is a much-inflated form of *Inoceramus prefragilis*.

This assemblage characterizes Hartland strata in the interval extending from the base of marker bed HL-1 to the first continuous bed of chalky limestone lying above marker bed HL-2. *Plicatula?* sp., *Discinisca* sp. and *Teredolithus* sp. occur in marker bed HL-1, although one specimen of *Plicatula?* sp. was recorded also from 0.5 foot beneath that bed. The greatest diversity of species occurs in marker bed HL-2 from which 12 forms have been recorded. *Kanabiceras septemseriatum, Sciponoceras gracile, Phelopteria* sp. A, and *Cerithiella* sp. A first appear in bed HL-1 and, terminate at a discontinuous chalky limestone bed lying shortly above HL-2. Several species in this assemblage have been recorded only in marker bed HL-2 (Fig. 15). *Worthoceras vermiculum, Baculites* sp. and *Allocrioceras annulatum* first appear in bed HL-2 and range slightly higher in the section than *S. gracile.* Only *Inoceramus prefragilis* and *Phelopteria* sp. A range throughout the interval regarded as comprising this zone.

Elements of this faunal assemblage have been reported from localities scattered widely through the Gulf Coast and Western Interior region from Texas (esp. Moreman, 1942), where the fauna occurs in the Britton Formation, to Utah (Gregory, 1950; 1951), where the fauna occurs in the Tropic Shale, and north to Montana (Cobban, 1951, p. 2184) where this fauna occurs in the Greenhorn of the northwestern flank of the Black Hills. *Sciponoceras gracile,* the index species of this assemblage, occurs also as far to the northwest as the Sweetgrass Arch (Cobban, 1955, p. 202), where it occurs in the Colorado Shale. The fauna is well known in the lower part of the Bridge Creek Limestone Member of the Greenhorn in central Colorado (e.g. Scott, 1962, p. 13) and southeastern Colorado (Cobban & Scott, 1972, p. 31). Although *S. gracile* has not yet been reported from Canada, Stelck and Wall (1955, p. 16) reported *S.* cf. *S. gracile* from the Peace River area of Alberta and Jeletzky (1968, Fig. 2) recognizes a *Baculites (Sciponoceras)* cf. *gracile* and *Prionocyclus (Collignoniceras)* n. sp. subzone within the *Watinoceras* and *Inoceramus labiatus* zone of the Canadian Western Interior. This distinctive and extraordinarily widespread assemblage of organisms occurs in Kansas in a stratigraphic thickness of only 3.6 to 6.7 feet, thus making it one of the most distinctive and valuable biostratigraphic units in the Kansas Cretaceous.

Undesignated Assemblage Zone.—Above the *Sciponoceras gracile* Assemblage Zone are several feet of strata from which little else than *Inoceramus prefragilis* has been collected. This interval includes all beds from the uppermost occurrences of the *S. gracile* assemblage, i.e. the widespread chalky limestone bed[12] lying anywhere from 1.3 feet (Loc. 1) to 2.7 feet (Loc.

[12] Where this bed is missing, or poorly developed, as at Localities 4 and 6, the highest occurrence of the *S. gracile* assemblage is in HL-2.

14) above Hartland marker bed HL-2, to the apparent lowest occurrences of *Mytiloides labiatus* (Schlotheim), *Tragodesmoceras bassi* Morrow, and *Watinoceras reesidei* Warren. This interval reaches maximum known thickness at Locality 14 where it is 6.9 feet, and in central Kansas diminishes gradually and uniformly northeastward from Localities 8 and 51 where it is 4.7 feet thick.

Mytiloides labiatus-Watinoceras reesidei Assemblage Zone.—This assemblage zone is characterized generally by the two zonal indices and extends from the lowest occurrence of *M. labiatus,* in the upper part of the Hartland Member, upward approximately to and including Jetmore marker bed JT-6. The lowest observed occurrence of *Mytiloides labiatus* is in a 1.1-foot-thick shaly chalk unit lying 3.65 feet above marker bed HL-3 in the Bridge Creek Member at Locality 14. The species occurs also in the superjacent chalky limestone bed where *M. labiatus* is accompanied by *Tragodesmoceras bassi*?, *Puebloites,* and *Watinoceras reesidei*?; this limestone is the second one above marker bed HL-3. A mold of *T. bassi* (Pl. 6,H) was collected in the fourth chalky limestone bed above HL-3 at Locality 51 where the species occurs with *Watinoceras* sp. (probably a coarsely ribbed variant of *W. reesidei*). *Watinoceras reesidei* is abundant and well preserved in Jetmore markers JT-1 and JT-6. The upper limit of this zone is defined arbitrarily, because *W. reesidei* is known sparingly in the Jetmore to as high as marker bed JT-8, but other species are more characteristic of the interval above JT-6. Poorly preserved specimens of *Baculites* cf. *B. yokoyamai* are known in the interval extending from JT-1 to JT-5 but are more characteristic of the overlying assemblage zone. Species occurring in this assemblage zone are as follows:

Bivalves:
- *Anomia* sp. A.
- †*Inoceramus prefragilis* Stephenson (basal part of zone only)
- **Mytiloides labiatus* (Schlotheim)
- ostreid, sp.

Cephalopods:
- *Baculites* cf. *B. yokoyamai* Tokunaga and Shimizu (sparse, poorly preserved specimens)
- †*Mammites nodosoides* subsp. *wingi* Morrow? (JT-2 at Loc. 38)
- †*Tragodesmoceras bassi* Morrow
- †*Puebloites* sp. (Loc. 14 only, at base of zone)
- **Watinoceras reesidei* Warren
- †*Vasoceras birchbyi* Cobban & Scott (JT-1 only, Loc. 14)

Brachiopods:
- †*Discinisca* sp.

Common species are prefixed with an asterisk; rare species are prefixed with a dagger. This assemblage zone corresponds to the zone of *Watinoceras coloradoense* (Henderson) of Cobban and Scott (1972, p. 33).

Mytiloides labiatus-Mammites nodosoides wingi Assemblage Zone.—This assemblage zone overlaps that of the preceding zone in a single bed, JT-6, where *Mammites nodosoides* wingi is first an important species. The upper limit of this assemblage zone is the Shellrock limestone bed (JT-13) which is the known upper limit of occurrence of *M. nodosoides wingi.* The best preserved specimens of *Baculites* cf. *B. yokoyamai* occur within this assemblage zone, in beds JT-6 through JT-11. This assemblage is also characterized by *Tragodesmoceras bassi* most Kansas specimens of which were collected from the interval JT-8 to JT-12.

Fossils in the *Mytiloides labiatus-Mammites nodosoides wingi* Assemblage Zone include the following:

Ammonites:
- **Baculites* cf. *B. yokoyamai* Tokunaga and Shimizu
- **Mammites nodosoides* subsp. *wingi* Morrow
- *Stomohamites* cf. *S. simplex* (d'Orbigny) (mold in JT-13 at Loc. 46)
- *Tragodesmoceras bassi* Morrow
- **Watinoceras reesidei* Warren (common only in JT-6)

Pelecypods:
- **Anomia* sp. A.
- **Mytiloides labiatus* (Schlotheim)
- †*Pseudoperna bentonensis* Logan
- **Pycnodonte* sp. A.
- *Teredolithus* sp.

Brachiopods:
- †*Discinisca* sp.

Cirripeds:
- †scalpellid

Common forms are preceded by an asterisk; rare forms are preceded by a dagger. This assemblage corresponds to the *Mammites nodosoides* zone of Cobban and Scott (1972, p. 33).

Undesignated Assemblage Zone.—The stratigraphic interval from the top of the Shellrock limestone bed (JT-13) to the base of marker bed PF-1 contains no unique species that is common, and is therefore considered as an undesignated assemblage zone. Species recorded in this interval include the following:

Bivalves:
- *Anomia* sp. A
- **Mytiloides labiatus* (Schlotheim)
- **Pseudoperna bentonensis* Logan

Cephalopods:
- *Baculites* cf. *B. yokoyamai* Takunaga & Shimizu
- hamitids, juveniles
- †*Watinoceras reesidei* Warren
- †*Tragodesmoceras bassi* Morrow?

Cirripeds:
- *Stramentum canadensis* (Whiteaves)
- scalpellid, sp.

Common species are prefixed by an asterisk, rare species are prefixed by a dagger. The top of this zone marks the apparent upper limit of *Watinoceras reesidei* but the available material is of poor quality and specimens are very rare in this interval.

In this interval *Tragodesmoceras bassi* is known from poorly preserved material at a single locality.

Mytiloides labiatus-Collignoniceras woollgari-Inoceramus cuvieri Assemblage Zone.—The uppermost part of the Greenhorn in Kansas is characterized by late, usually broad forms of *Mytiloides labiatus*, together with *Inoceramus cuvieri* Sowerby and *Collignoniceras woollgari* (Mantell). The base of this assemblage zone is Pfeifer marked bed PF-1. *Collignoniceras woollgari* apparently first appears in the section at this level, based on poor material, and is known definitely from about 2 feet above this marker bed. *Inoceramus cuvieri* first appears 2.3 feet above PF-1 at Locality 19 (Rush County), 3 feet above PF-1 at Locality 5 (Ellis County), and in the first concretionary bed of chalky limestone below the sugar sand (PF-2) at a number of other localities. Molds of juvenile ammonites probably assignable to *Tragodesmoceras bassi* occur shortly below the sugar sand at Locality 49, Mitchell County and a single fragmentary mold suggesting this species was collected from the first chalky limestone marker bed of the Fairport Member in northeastern Ellis County, but the species, if indeed it is *T. bassi*, is rare in all beds above JT-12. At Locality 14, Hamilton County, *I. cuvieri* has not been identified positively in the Bridge Creek Member and *C. woollgari* was not recorded there below the Fencepost limestone bed. *Collignoniceras woollgari* and *I. cuvieri* range upward throughout the Fairport Member, Carlile Shale, and the latter apparently continues into the lower part of the Blue Hill Member, Carlile Shale, in central Kansas (Hattin, 1962, p. 82).

The top of the *Mytiloides labiatus-Collignoniceras woollgari-Inoceramus cuvieri* Assemblage Zone lies about 1 foot above the first chalky limestone bed in the Fairport Member, Carlile Shale, at the level where the broad form of *Mytiloides labiatus* gives way, by evolutionary gradation, to *Inoceramus latus* J. de C. Sowerby. This broad form of *M. labiatus* was referred to as *I. labiatus* aff. *hercynicus* by Kauffman (1966, p. 36). The assemblage zone contains the following species:

Bivalves:
- *Anomia* sp. A
- **Inoceramus cuvieri* Sowerby
- **Mytiloides labiatus* (Schlotheim)
- *Pseudoperna bentonensis* (Logan)

Cephalopods:
- **Baculites* cf. *B. yokoyamai* Tokunaga and Shimizu
- *Collignoniceras woollgari* (Mantell) (most abundant in Fencepost bed)
- †*Stomohamites* cf. *S. simplex* (d'Orbigny) (PF-1 at Loc. 14)
- *Tragodesmoceras bassi* Morrow?
- †*T. carlilense* Cobban
- hamitids (minute crystalline casts)

Cirripeds:
- scalpellid, sp.
- †stramentid, sp.

Common forms are preceded by an asterisk; rare forms are preceded by a dagger. Juvenile forms of *Tragodesmoceras* from the lower part of the zone are assigned questionably to *T. bassi* Morrow. A single specimen of *T. carlilense* Cobban, from the Fencepost limestone bed, was recorded from a block of stone that forms part of the east wall of Albertson Hall at Fort Hays Kansas State College in Hays. The assemblage zone corresponds roughly with the zone of overlap of *C. woollgari* and *Inoceramus labiatus* as shown by Cobban and Scott (1972, p. 33) but embraces also the lower few feet of the Fairport Member, Carlile Shale.

Correlation

The *Acanthoceras wyomingense* Assemblage Zone corresponds to the Western Interior zone of *Acanthoceras?* sp. A of Cobban and Reeside (1952, p. 1017), a species later identified as *Acanthoceras? wyomingense* by Cobban (1961, p. 739), and with the zone of *Plesiacanthoceras wyomingense* of Cobban and Scott (1972, p. 33). According to Jeletzky (1968, p. 24), the Canadian zone of *A. athabascense* Warren and Stelck is approximately equivalent to the zone of *A? wyomingense*. American occurrences of the zonal index species have been documented by Cobban (1951), Cobban and Reeside (1952a), and by Haas (1963, p. 13). In addition to Kansas occurrences, the species has been recorded in the uppermost part of the Belle Fourche Shale in the Black Hills (Cobban, 1951, p. 2182), near the middle of the Frontier Formation in central and south-central Wyoming (Cobban and Reeside, 1952a), in the upper half of the Frontier Formation in north-central Wyoming (Cobban and Reeside, 1952a, p. 1955), and from near the base of the Cody Shale in south-central Montana (Cobban and Reeside, 1952a, p. 1960). *Acanthoceras athabascense*, regarded as a synonym of *A. wyomingense* by Haas (1963, p. 3), has been recorded in the lower part of the Labiche Shale of Alberta.

In Kansas and elsewhere in the Western Interior region, beds containing *Acanthoceras wyomingense* are underlain by strata containing *Acanthoceras amphibolum* and *Inoceramus rutherfordi*. In a discussion of the *Acanthoceras rhotomagense* group of ammonites Kennedy and Hancock (1970, p. 488) noted that this nearly worldwide Middle Cenomanian group is apparently absent from the Western Interior and that its place "is possibly occupied by *A. amphibolum* Morrow." Kauffman (1966, p. 36) regarded the late forms of *Inoceramus rutherfordi*, which occur with *A. amphibolum*, as Middle Cenomanian in age, but Cobban and Scott (1972, p. 31) assigned this species to the Late Cenomanian. Haas (1963, p. 13) believed *A. wyomingense* indicated a Late Cenomanian age, as did Scott and Cobban (1972, p. 31, 33). Jeletzky (1968, p. 24) suggested that in Canada *A. athabascense* (=*A. wyomingense*) is of early Late Cenomanian age.

The earliest occurrences of *Inoceramus prefragilis,* which in Kansas are with *A. wyomingense,* were regarded as Late Cenomanian in age by Kauffman (1966, p. 36). This form was recorded in the Greenhorn of Colorado and westernmost Kansas as *Inoceramus pictus* J. de C. Sowerby by Cobban and Scott (1972) and was regarded as synonymous with *I. pictus* by Seitz (1959, p. 117). Apparently the two forms are biostratigraphically analagous, if not conspecific. Porthault and others (1966, p. 436) indicate that in France the earliest occurrences of *I. pictus* are early Late Cenomanian, and Seitz (1959, p. 120) showed the earliest occurrences in Germany also are of Late Cenomanian age.

The *Calycoceras? canitaurinum-Exogyra* aff. *E. boveyensis* Assemblage Zone corresponds to the zone of *Dunveganoceras pondi* of Cobban and Reeside (1952, p. 1017) and to the *Calycoceras? canitaurinum* zone of Cobban and Scott (1972, p. 33). Molds resembling *D. pondi* have been recorded in basal Lincoln strata at a few central Kansas localities. Haas (1949) described these two species on the basis of specimens from near the base of the Cody Shale close to Greybull, Wyoming. The two species occur also in the uppermost part of the Frontier Formation 16 miles south of Greybull, Wyoming (Cobban & Reeside, 1952a, p. 1957). In south-central Montana both species occur in the lower part of the Cody Shale in the Crow Indian Reservation (Cobban and Reeside, 1952a, p. 1961). In the Black Hills area these species occur in the basal part of the Greenhorn (Cobban and Reeside, 1952a, p. 1945). *Calycoceras? canitaurinum* has been reported from the upper part of the Lincoln Member in the Littleton area, Colorado (Scott, 1962, p. 13) and from the upper part of the Lincoln Member near Pueblo, Colorado (Cobban & Scott, 1972, p. 15). These last occurrences correspond in stratigraphic position with the upper Lincoln position of the *C? canitaurinum-E.* aff. *E. boveyensis* Assemblage Zone in Ford and Kearny Counties, Kansas. This zone is of Late Cenomanian age (Cobban, 1961, p. 740; Jeletzky, 1968, p. 27; Cobban and Scott 1972, p. 31).

The first of the three undesignated assemblage zones described above, representing the middle and upper parts of the Lincoln Member and lowermost Hartland of central Kansas, and virtually all of the type Hartland of Kearny County, corresponds to the Late zones of *Dunveganoceras conditum* and *D. Albertense* of Cobban (1961, p. 740) and of Cobban and Scott (1972, p. 33).

The *Sciponoceras gracile* Assemblage Zone has wide distribution in the Western Interior and Gulf Coast regions of the U.S., as outlined in an earlier section. In central Kansas it occurs in the middle part of the Hartland Member; in western Kansas it occurs in the lower few feet of the Bridge Creek Member. The assemblage occurs also in the lower part of the Bridge Creek Member of the Greenhorn in central and southern Colorado (Scott, 1962, p. 13; Kauffman, 1961, p. 329-330; Cobban & Scott, 1972, p. 31). In Utah the assemblage occurs in the Tropic Shale (Gregory, 1950, p. 104; 1951, p. 36). In central Texas the assemblage has been recorded in the Britton Formation (Moreman, 1942, p. 194) and in West Texas in the Chispa Summit Formation (Adkins, 1931, p. 38). Jicha (1954, p. 27) reported the assemblage from the lower part of the Colorado Shale (=Mancos Shale?, query mine) in southwestern New Mexico and Page and Repenning (1958, p. 118) noted occurrence of the assemblage in the lower part of the Mancos Shale in the Black Mesa Basin of Arizona. Farther north, elements of the *S. gracile* assemblage occur in the upper part of the Greenhorn Limestone in the Black Hills region (Cobban, 1951, p. 2185) and in the lower part of the Cody Shale along the east flank of the Bighorn Mountains of north-central Wyoming (Cobban and Reeside, 1952a, p. 1955). The zonal index, *S. gracile* has been recorded from as far to the northwest as the Sweetgrass arch of northwestern Montana where it occurs in the Colorado Shale (Cobban, 1951, p. 2186). Finally, S. cf. *S. gracile* has been reported from the Kaskapau Formation of Alberta (Stelck and Wall, 1955, p. 16) where, together with an undescribed species of *Prionocyclus,* it is the basis for a subzone that Jeletzky (1968, fig. 2) correlated with that of S. *gracile* in the U.S.

The *Sciponoceras gracile* Assemblage Zone was interpreted as lying at the base of the Turonian Stage by Cobban and Reeside (1952), but this zone and the equivalent Canadian zone were regarded by Jeletzky (1968, fig. 2) as lying shortly above the base of that stage. However, Cobban (1971, p. 18) has recently interpreted the zone as being of very late Cenomanian age and Cobban and Scott (1972, p. 31) regard this zone as being of latest Cenomanian age on the basis of occurrence in it of "*Pseudocalycoceras, Calycoceras* of the *naviculare* group, and *Inoceramus pictus*" (= *I. prefragilis* of the present report). The problem of the Cenomanian-Turonian boundary has been debated by numerous authors and will not be dealt with here. It is sufficient to note that the *S. gracile* assemblage contains elements that have been traditionally assigned to the Late Cenomanian as well as a few forms, such as *Worthoceras vermiculum* (Porthault & others, 1966, p. 436), that occur in the Early Turonian of Europe. In this report I am considering the *S. gracile* assemblage as latest Cenomanian in age on the basis of occurrence in it of *Calycoceras* cf. *naviculare* and *Pseudocalycoceras.*

The second undesignated assemblage zone apparently marks the base of the Turonian because none of the forms diagnostic of the Cenomanian have been recorded in it. This zone is characterized by the upper part of the range of *Inoceramus prefragilis.* In Europe, the equivalent species, *I. pictus,* crosses the Cenomanian-Turonian boundary (see Seitz, 1959, p. 120; Porthault & others, 1966, p. 436).

Mytiloides labiatus is universally accepted as an Early Turonian index fossil (Jeletzky, 1968, p. 28). The three Greenhorn assemblage zones containing this species are therefore all regarded as of Early Turonian age. The *Mytiloides labiatus-Watinoceras reesidei* Assemblage Zone corresponds with the zone of *Watinoceras coloradoense* (Henderson) of the Bridge Creek Member in Colorado (Cobban & Scott, 1972, p. 33) and represents the lower part of the zone of *Inoceramus labiatus* and *W. reesidei* of Cobban (1951, p. 2197). Less than a dozen specimens in my large *Watinoceras* collection seem to fit the description of *Watinoceras coloradoense,* but none of these specimens is complete and most are fragments of adult whorls. The vast majority of my specimens, more than 95%, are clearly assignable to *W. reesidei.* The adult stage of *W. reesidei* has not been described, so the questionable specimens may be *W. reesidei* rather than *W. coloradoense.* In my collection the larger specimens of *W. reesidei* include two varieties, one having dense ribbing and weak tuberculation (Pl. 8, J; 9, F) and another having less dense, very strong ribbing with strong tuberculation (Pl. 9,G). The latter form has dense ribbing in the earlier stages of growth and shows neither the thinning and increase in density of ribs nor decrease in size of tubercles in the adult stage as in *W. coloradoense* (Cobban and Scott, 1972, p. 76). The form shown in Plate 9,G is regarded as a coarse variant of *W. reesidei* and may be expression of sexual difference from the more densely ribbed variety. Cobban and Scott (1972, p. 21) reported *W. coloradoense* from the basal bed of the Jetmore equivalent of the Bridge Creek at my Locality 14 (Hamilton County). Poor material in my collection from the same bed is identified equivocally as *W. reesidei.*

Watinoceras reesidei is widely distributed in North America. This species occurs with *Mytiloides labiatus* in the lower part of the Colorado Shale in northwestern Montana (Cobban, 1956, p. 1003), and in the Greenhorn Member of the Cody Shale of southern Montana (Richards, 1955, p. 52). In Canada these two species occur together in many areas along the foothills of the Canadian Rockies and adjacent plains, including the lower part of the Alberta Group and equivalent strata. For example, cooccurrence of *W. reesidei* and *M. labiatus* has been reported in the Vimy Formation in southern Alberta (Stott, 1963, p. 45), from the Kaskapau Formation of northern Alberta (Warren, 1930, p. 58), and from equivalent rocks in the District of Mackenzie (Warren, 1947, p. 119). Cobban and Gryc (1961, p. 178) have recorded the cooccurrence of these two species in the Seabee Formation of the Arctic slope of Alaska.

The *Mytiloides labiatus-Mammites nodosoides wingi* Assemblage Zone corresponds to the *Mammites nodosoides* zone of Cobban and Scott (1972, p. 31) and spans an almost identical interval within the Jetmore Member of central Kansas as in the Bridge Creek Member near Pueblo, Colorado. *Mammites nodosoides* is a well-known Early Turonian species and is widely distributed in Europe, southern Asia, Africa, and South America (see Lawrence & others, 1966, p. 293; Cobban & Scott, 1972, p. 79). In the American West and Southwest forms referable to *W. nodosoides* have been reported from widely scattered localities in Texas (Powell, 1963, p. 310), New Mexico (Lawrence & others, 1965, p. 293), Colorado (Scott & Cobban, 1972, p. 81) and Kansas (Morrow, 1935, p. 467, 468), and *Mammites* aff. *nodosoides* has been reported from as far north as northern Wyoming where it occurs with *Inoceramus labiatus* and *Watinoceras* cf. *coloradoense* (Hose, 1955, p. 98). Specimens are sparse in all Kansas sections and the paucity of references to *M. nodosoides* in literature on the Western Interior suggests that the form was common only locally. Morrow (1935, p. 464) recorded *M. wingi* (=*M. nodosoides wingi* of this report) in the Pfeifer Member of the Kansas Greenhorn but to date I have found no specimens above the Shellrock limestone bed (JT-13) of the Jetmore Member.

The third undesignated Greenhorn assemblage zone occupies the lower few feet of the Pfeifer Member and lies within the range zone of *Mytiloides labiatus.* Its age is therefore early Turonian. This interval apparently corresponds to beds 121 through 129 in the Rock Canyon section described by Cobban and Scott (1972, p. 22).

The uppermost biostratigraphic unit in the Kansas Greenhorn is defined on the basis of overlap in the range of *Mytiloides labiatus* with the ranges of *Collignoniceras woollgari* and *Inoceramus cuvieri.* On the basis of overlapping range zones, this unit can be considered a concurrent range zone (American Commission on Stratigraphic Nomenclature, 1970, p. 12). The overlapping range of *M. labiatus* and *C. woollgari* is now widely recognized as evident in the work of Reeside (in Bass, 1926, p. 66), Matsumoto and Miller

(1958, p. 354), Hattin (1962, p. 54) Cobban and Scott (1972, p. 33), and Jeletzky (1968, p. 30).

Collignoniceras woollgari has wide distribution in the U.S. Western Interior, including an area extending on the east from central Kansas and southern Colorado to western Iowa, northeastern Nebraska and the Black Hills and on the west from northeastern Arizona to northwestern Montana. Although additional references could be cited, the principal ones are summarized by Cobban and others (1956, p. 1271-1272). Occurrences of this species in the Upper Cretaceous of Canada have been summarized briefly by Jeletzky 1968, p. 30). Matsumoto (1959, p. 106) stated that the species occurs in the Gulf Coast region (apparently in the Arcadia Park Formation of the Eagle Ford Group) and also in the Chispa Summit Formation of West Texas (1959, p. 92). Specimens are known also from the Upper Cretaceous of California and Oregon (Matsumoto, 1959, p. 108). In the British Chalk *C. woollgari* occurs in the zone of *Terebratulina lata* (Wright and Wright, 1951, p. 30) which also contains broad forms of *Mytiloides labiatus* (Woods, 1912, p. 13) and the earliest forms of *I. cuvieri* (Woods, 1912, p. 7). The *T. lata* zone therefore is at least in part correlative with the *Mytiloides labiatus* - *C. woollgari*-*I. cuvieri* Assemblage Zone of Kansas. Basse (1959, p. 15, 16) has indicated a Middle Turonian age for strata in northern France that contain *C. woollgari*, and Matsumoto (1959, p. 108, also noted the Middle Turonian age of this form. However, the small part of the *C. woollgari* Range Zone that overlaps the upper part of the *M. labiatus* Range Zone is here considered to be of latest Early Turonian age. Refinements in inoceramid taxonomy, involving broad forms of *M. labiatus* s.l., may eventually justify assignment of this assemblage zone to the early Middle Turonian.

PETROLOGY

Shaly Chalk

Throughout the Greenhorn Limestone of Kansas the most common lithology is shaly chalk; samples of this from throughout the section were studied in thin section. Shaly chalk is a micritic rock consisting of poorly lithified calcitic mud together with wide ranging amounts of allochems, organic matter, micrograined terrigenous detritus, and secondary minerals such as pyrite, hematite or limonite. The matrix is composed of grains less than 5μ in size and has a minutely grainy texture. Under plane-polarized light the color of the matrix is usually grayish orange to pale brown or yellowish gray but is darker shades of orange and brown where stained by organic matter or iron oxide. Scanning electron microscopy reveals that coccoliths are the principal component of the shaly chalk matrix (Fig. 16,A,B). Hattin and Darko (1971, p. 8) reported that some Greenhorn shaly chalk samples contain as many as 6 X 10^9 coccoliths per cm^3. Shaly chalk includes both packstone and wackestone depositional textures.

In addition to coccoliths the shaly chalk is characterized also by a variety of allochems. Stratigraphic variation in concentration of allochems accounts for much of the lamination that is evident in most exposures of shaly chalk. One of the two dominant allochems is fecal pellets (Fig. 16, C). These have been flattened during compaction and are fusiform in vertical section. Together with other elongate particles like fish scales and bits of organic matter the pellets commonly arch over or bend beneath more resistant grains including foraminifer tests and *Inoceramus* fragments. In plane-polarized light the pellets are light gray to yellowish gray, are nearly white in reflected light, and have a grainy texture. Pellets can be distinguished readily from the matrix by shape, lighter and more uniform color, and more homogeneous texture. Pellet borders are usually defined sharply so that pellets are in marked contrast to the adjacent matrix. However, many pellets have indistinct borders so that contact with the adjacent matrix is not easily detected. Pellets range greatly in size; the smallest are in the coarse silt range. The largest are as much as 0.5 to 0.6 mm in long dimension, but such wide specimens have resulted from lateral spreading during compaction and are very thin in proportion to length. Less-compacted pellets, having the outline of a football, are as much as 0.1 mm in thickness in specimens only 0.25 mm in long dimension. Because of great abundance these flattened pellets contribute significantly to the fissility of shaly chalk beds. Concentrations of fecal pellets are a common cause of lamination in shaly chalk (Fig. 16,D).

Equally important allochems include foraminifer tests; these are ubiquitous constituents of shaly chalk. In a recent study of the Greenhorn Limestone, Eicher and Worstell (1970) reported 22 species of planktonic foraminifera from shaly chalk beds at Locality 3 and 20 species from Localities 13 and 14. The most abundant species are *Heterohelix globulosa* (Ehrenberg), *Hedbergella delrioensis* (Carsey), *H. planispira* (Tappan), *H. amabilis* Loeblich and Tappan, H. *portsdownensis* (Williams-Mitchell), and *Whiteinella aprica* (Loeblich and Tappan). They found benthonic foraminifera to be generally rare in the formation.

Greenhorn foraminifera display a wide range in quality of preservation. At one extreme are tests that have been preserved intact, including details of pores and spines; at the other are specimens in which the

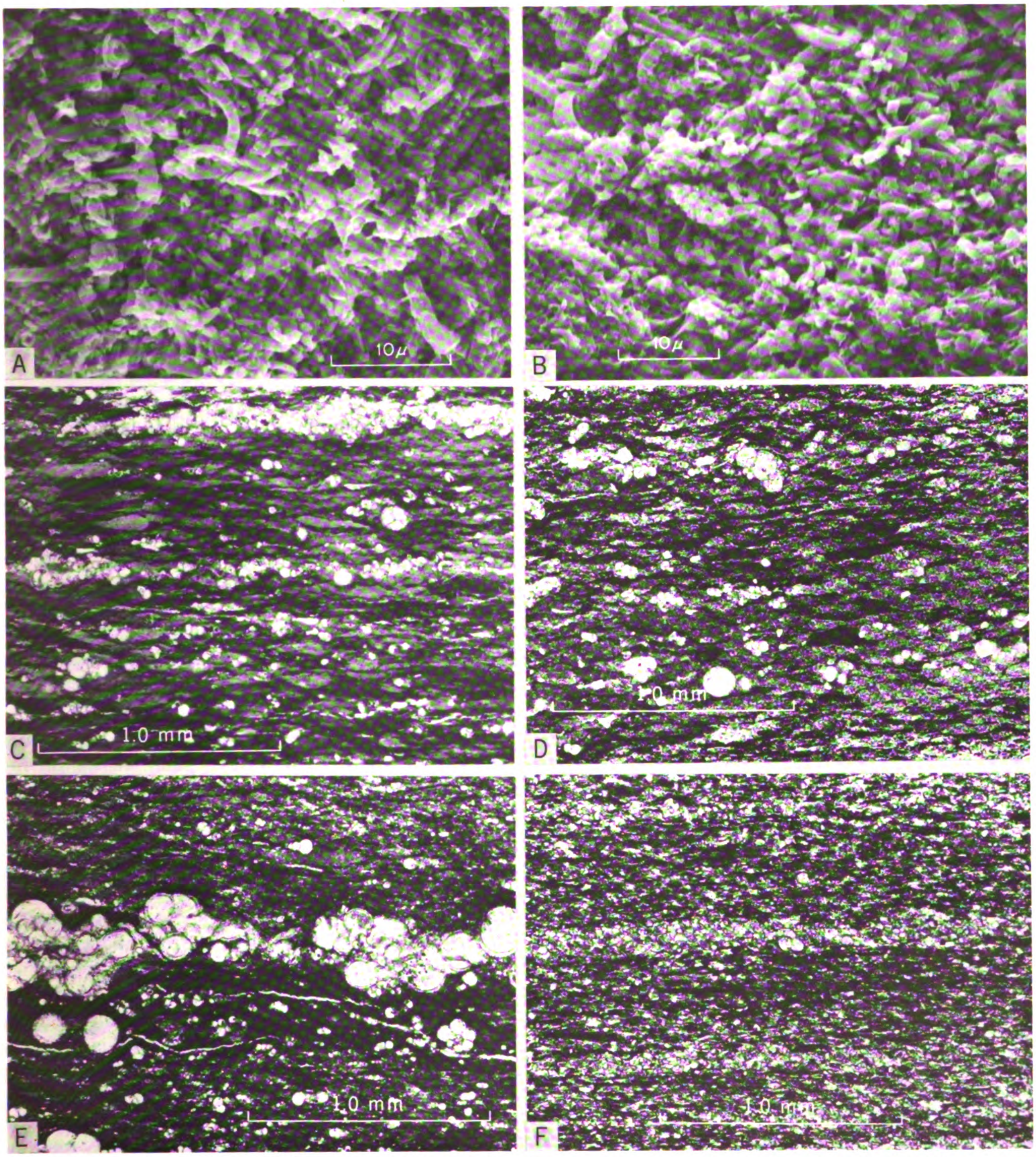


Figure 16.—Petrologic features of the shaly chalk. A) Scanning electron micrograph of shaly chalk from middle part of Lincoln Member at Locality 1 showing poorly cemented character of coccolith-rich shaly chalk, X1920. B) Same, lower part of Hartland Member at Locality 13, X1680. C) Photomicrograph of shaly chalk thin section from upper part of Lincoln Member at Locality 3 showing abundance of horizontally elongated, lenticular fecal pellets (gray bodies). Light-colored laminae are composed mostly of foraminifer tests. Plane-polarized light, X40. D) Photomicrograph of shaly chalk thin section from middle part of Lincoln Member at Locality 6 showing lamina composed mostly of compacted fecal pellets in lower half of photo. Plane-polarized light, X40. E) Photomicrograph of shaly chalk thin section from upper half of Hartland equivalent of Bridge Creek Member at Locality 14 showing lamina composed of large foraminifer tests. Note coarse spar calcite in chambers of tests. Plane-polarized light, X40. F) Photomicrograph of shaly chalk from lower part of Pfeifer equivalent of Bridge Creek Member at Locality 14 showing two very thin laminae composed predominantly of silt-size *Inoceramus* prisms. Note abundant wispy grains of organic matter (black) oriented parallel to bedding. Plane-polarized light, X40.

chamber walls have been partially or wholly obliterated by diagenetic processes. Many tests are broken, some by compaction, others by preburial processes as evident from isolated test fragments. Partial solution of tests has occurred along some grain-to-grain contacts, and some tests are truncated by solution contact with the adjacent matrix. The tests are composed of calcite. Size of tests ranges widely, even within a single thin section. The smallest specimens are in the coarse silt range, the largest are at the small end of the coarse sand range. A majority of all multichambered specimens fall in the very fine sand to medium sand range. The chambers of these tests are filled with sparry calcite occurring usually as a single crystal that joins the test wall without indication that the chambers were filled by inward growth of numerous fringing crystals. In some specimens, the spar in all chambers is in optical continuity and apparently represents a single large crystal. In a small number of specimens, one or more chambers are filled by more than one calcite crystal, but the number rarely exceeds four. Cleavage planes are visible in much of the chamber-filling calcite. Locally silica has replaced calcite in the chambers of some foraminifera.

In some thin sections of shaly chalk foraminifer tests are sparse; in others the rock is crowded with tests scattered irregularly through the rock. Tests concentrated in discrete layers are a common cause of even lamination in shaly chalk (Figs. 16,C,E). These laminae range from layers without stacking of tests and as little as 0.06 mm in thickness to laminae having tests stacked several high and 0.5 mm or more in thickness. In general, the thinnest laminae are composed of silt-size foraminifera whereas thicker laminae are composed of larger tests. The laminae are cemented by patches of sparry calcite but patches of micrite are commonly incorporated. Thin, even laminae of these types are more abundant in the Lincoln Member and upper part of the Hartland Member. Some foraminifer-rich laminae also contain pellets and other debris, all set in a micritic matrix. These represent less well-washed concentrations of tests. In addition to the thin, even laminae described above, some shaly chalk thin sections contain thicker, irregular laminae of foraminifer tests that also include *Inoceramus* prisms and valve fragments. These laminae are several millimeters in thickness and are actually thin lenses of biosparite which are described in detail in the next section. All of the well-washed concentrations of foraminifer tests are the result of very gentle current action that winnowed bottom sediments at irregular intervals.

Isolated prisms, valves, and valve fragments of *Inoceramus* are common in shaly chalk beds throughout the Greenhorn. The aragonitic nacre of such valves is not present in any thin sections studied by me. Valves or valve fragments rarely exceed 1 mm in maximum thickness; prisms range in diameter from silt to fine sand size. Tabular valve fragments and isolated prisms have markedly preferred orientation more or less parallel to general stratification; most such specimens consist of unrecrystallized calcite so that the prismatic structure is preserved in fine detail and growth lamellae are commonly visible also. In some thin sections irregular masses of pyrite have replaced small areas of some *Inoceramus* valve fragments. In a majority of specimens the *Inoceramus* grains are in sharp contrast with the adjacent matrix; a few grains have notched borders that have been infilled by the matrix. Partial solution has occurred along some grain-to-grain contacts, whether between *Inoceramus* grains or between *Inoceramus* and foraminifer tests. Some of these solution contacts are notched or sutured.

Inoceramus grains are common in laminae composed dominantly of foraminiferal tests; sparse, very thin laminae consist predominantly of *Inoceramus* grains (Fig. 16,F). Such laminae contain few to many foraminifer tests and are cemented by sparry calcite. In most shaly chalk samples *Inoceramus* grains are less abundant than either foraminifer tests or pellets.

Fragments of oyster valves were recorded in a few thin sections but these are rare. In one such sample a single valve fragment is partially silicified.

Shaly chalk samples also contain from less than 1 percent to approximately 10 percent matter having questionable composition. Minute, lenticular to wispy bodies of opaque material are scattered throughout most thin sections and are aligned parallel to general stratification (Fig. 16,D,E,F). Although some of these bodies are as much as 0.8 mm in length the vast majority are less than 0.25 mm long. The opaque bodies have a thickness maximum of about 0.1 mm but some of the longest bodies are less than half that thickness. These bodies are commonly surrounded by matrix that has been stained dark reddish brown, apparently by substances derived from this problematic material. The matrix is more heavily stained in shaly chalks having greatest abundance of these bodies. Like the pellets described above, these bodies apparently have suffered much compaction and are commonly draped over, or bent downward beneath, resistant skeletal grains. In some rocks concentrations of these bodies help to form yet another type of lamination, but laminae of this kind are not common. These bodies may be of multiple origin. The most obvious possibilities include a) inorganic matter consisting in part of terrigenous detritus, b) carbonaceous matter, and c) organic matter other than carbonaceous material. Although the many shaly chalk samples subjected to insoluble residue analysis contain from 9.5 to 56.6 percent insoluble residue, and although these residues consist largely of microscopic grains of terrigenous detritus (Hattin, 1971, p. 423), the bodies described here have shape and size that is difficult to reconcile with ordinary deposition of terrigenous detritus. The latter should occur as thin layers or as grains scattered throughout the rock, not as discrete lenticular bodies. Furthermore, the black bodies are opaque; silt and sand-size grains of terrigenous detritus would mostly be non-opaque. Chemical analyses of little-weathered shaly chalk samples contain 0.37 to 6.3 percent organic carbon, averaging 3.3 percent for 20 analyses. Only three of these values are below 2.3 percent. The range in percentage of opaque bodies in thin sections is compatible with the percentage of organic matter determined by chemical analysis. I have concluded that the opaque bodies are composed of some kind of organic matter. The reddish discoloration of matrix associated with the opaque bodies suggest iron oxide staining and high iron content in the bodies. If these bodies are organic, as seems likely, they may contain iron as a by-product of organic decay.

Skeletal remains of fish, and possibly other vertebrates, are evident in all thin sections studied. These bone fragments and scales are bright yellow- to deep amber-colored in plane-polarized light and are gray or opaque under crossed nicols. Most grains are elongate and oriented parallel to bedding. Such grains range widely in size and are scattered through the matrix and also occur sparingly in foraminiferal laminae.

The HCl-insoluble fraction of shaly chalks mostly is not obvious in thin section. The residues examined consist mainly of micrograined terrigenous detritus that apparently is disseminated throughout the rock matrix. Iron compounds, including pyrite, hematite, and limonite are second in abundance; these occur as partial replacement of skeletal debris, as silt-size blebs inside chambers of foraminifer tests in some thin sections, scattered through the matrix, and apparently also as a component of the opaque organic bodies described above. Chemical analysis of 19 samples of nonweathered, nonbentonitic shaly chalk gave a range in pyrite content from 0.64 to 6.94 percent, averaging 2.0 percent. In all but one pair of samples analyzed, pyrite content of shaly chalk is greater than that of the adjacent bed of chalky limestone. A few residues contain partially silicified *Inoceramus* fragments and/or siliceous replacements of the calcite filling of foraminifer chambers. Organic matter, sparse gypsum crystals, and silica make up the remainder of these residues. Percentage of residue in shaly chalk samples averages 31.9 percent for 88 samples. In a detailed study of Hartland, Jetmore, and Bridge Creek strata the writer (Hattin, 1971, p. 425, 426) determined that residue percentages generally decrease upward in the Greenhorn section and increase generally in a westward direction.

Biosparite

Lincoln Member.—Skeletal limestones of the Lincoln Member were studied under the petrographic microscope and classified into three major categories. These are, in order of decreasing abundance, *Inoceramus*-prism biosparite (Fig. 17,A) foraminiferal biosparite, (Fig. 17,B) and *Inoceramus*-fragment biosparrudite (Fig. 17,C). The principal constituents of each occur also in the other kinds of rock. In all three types of rock the *Inoceramus* prisms occur as single-crystal prisms derived from disintegration of the prismatic layers of *Inoceramus* valves. Prism diameters range from coarse silt to medium sand and reach lengths as great as two mm. In a majority of thin sections prisms have a strong preferred orientation parallel to stratification or cross-stratification planes. The prisms are generally in sharp, even contact with interstitial cement, but all thin sections contain numerous prisms exhibiting peripheral alteration that is related to the cementation process; parts of a given prism appear to have been invaded by calcite cement. A smaller number of prisms have an indistinct or blurred border where in contact with cement, or more commonly where in contact with micritic matrix that occurs locally in these predominantly sparry-calcite-cemented rocks. A few prisms exhibit sutured or notched contacts where in contact with adjacent prisms.

A majority of the *Inoceramus*-prism-rich biosparites contain coarse sand to small pebble size fragments of *Inoceramus* valves and these can be called rudaceous biosparites; however, only one thin section contained sufficient coarse particles to be classed as a biosparrudite. The *Inoceramus* fragments are generally in sharp contact with adjacent sparry calcite cement, but some exhibit a blurred contact, especially along the inner surface of the prismatic layer. Most tabular valve fragments show strong preferred orientation parallel to bedding. Biosparites dominated by prisms and fragments of *Inoceramus* have been called inoceramites by the writer (1962, p. 41).

Tests of planktonic foraminifera are nearly ubiquitous components of the biosparites, ranging among the allochems from strongly dominant to sparse or even absent in some rocks. In some samples laminae composed largely of foraminifera alternate with those composed mostly of *Inoceramus* prisms. In such rocks prisms associated with foraminifer tests are generally

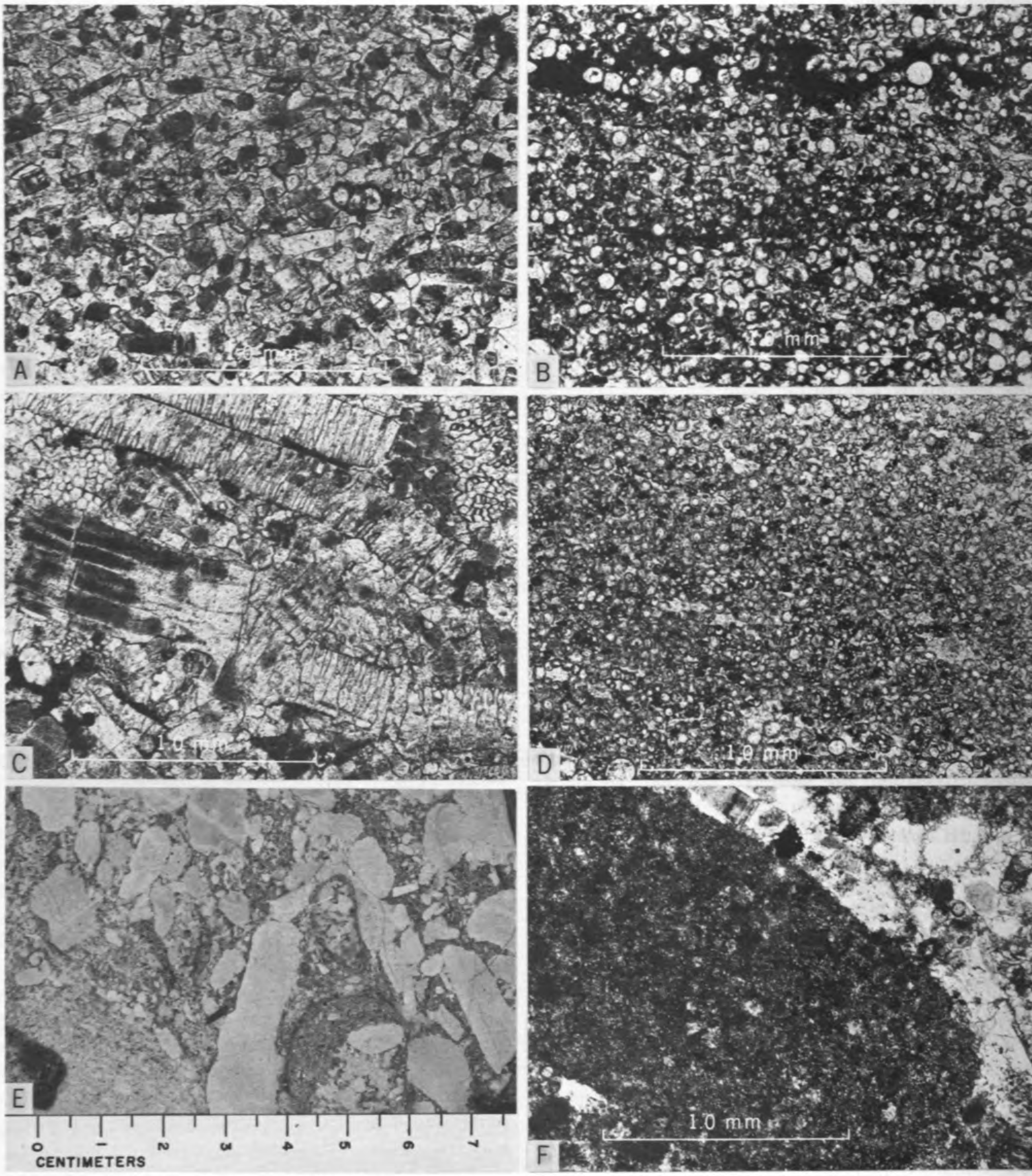


FIGURE 17.—Petrologic features of skeletal and intraclastic limestone. A) Photomicrograph of *Inoceramus*-prism biosparite from middle part of Lincoln Member at Locality 1. Plane-polarized light, X40. B) Photomicrograph of foraminiferal biosparite from middle part of Lincoln Member at Locality 16. Plane-polarized light, X40. Note areas of micritic matrix (dark). C) Photomicrograph of *Inoceramus*-fragment biosparrudite from upper part of Lincoln Member at Locality 3. Plane-polarized light, X40. D) Photomicrograph of calcisphere biosparite from middle part of Lincoln Member at Locality 12. Plane-polarized light, X40. E) Polished surface of fossiliferous intrasparrudite from lower part of Lincoln Member at Locality 23. X1. Matrix is *Inoceramus*-prism biosparite. F) Photomicrograph of fossiliferous intrasparrudite from lower part of Lincoln Member at Locality 23 showing rounded intraclast and "matrix" of biosparite. Plane-polarized light, X40.

smaller than the foram tests and are also smaller than prisms in the prism-dominated part of the rock. This feature has resulted from differences in energy levels required to concentrate prisms and tests of equal size. The latter, being largely hollow, had a smaller effective density than prisms of equal size, and therefore reflect weaker currents than the prism-rich laminae. This accounts for the usual disparity in size of tests and prisms in a single lamina. Many biosparite samples contain thin, irregular, commonly discontinuous laminae or patches of chalky micritic matrix. This material is generally associated with foraminiferal parts of the rock and represents a still lower level of energy expenditure during sedimentation. A sequence of relative energy levels is evident in the continuum embracing foraminiferal biomicrite (low energy), foraminiferal biosparite, foraminifer-*Inoceramus* prism biosparite, *Inoceramus* prism and fragment biosparite, and *Inoceramus* valve-fragment biosparrudite (high energy).

Preservation of foram tests ranges from specimens having well-preserved walls that retain details of microarchitecture (pores and spines) to specimens having the wall partially or wholly destroyed by diagenetic processes so that the presence of foraminifera is indicated by the arrangement of chamber-filling calcite crystals, perhaps outlined by a thin remnant of the original test wall. All of these degrees of preservation can be viewed in a single thin section. Broken foram tests are not common. In all varieties of biosparite a majority of the foraminifers are of medium sand size or smaller.

In these rocks the next most common grain types are of vertebrate origin including fish scales, teeth and bones or bone fragments. Most of the tabular grains show preferred orientation parallel to general stratification. Because of ease of transport, large fish scales are recorded commonly in biosparite samples having only small bone or tooth fragments. Other organic grains in Lincoln biosparites include fecal pellets (sparsely represented in a few foraminiferal or *Inoceramus* prism-foraminifer biosparites), oyster valve fragments, and calcispheres. The last are apparently spherical, and are thick-walled, non-spinose, non-perforate, single-chambered structures apparently identical with the "spheres" or *Oligostegina* of the English Chalk (Jukes-Brown and Hill, 1903, p. 500). These allochems are conspicuous in two nearly adjacent foraminiferal biosparite beds near the middle of the Lincoln Member at Locality 12. Because the maximum size is approximately 60μ, these structures tend to be concentrated separately from the foraminifers (Fig. 17,D).

Terrigenous quartz grains were recorded in nearly half the biosparite thin sections but are common only in the lower part of the Lincoln. In most samples these grains are of silt to very fine sand size, only two samples having grains as large as medium sand. The grains are mostly very angular; in three samples angular to subangular grains were recorded. Polycrystalline quartz grains were recorded in only one thin section. Quartz grains commonly have an irregular border zone in which the grains have been partially replaced by calcite. Sparse feldspar grains were recorded in less than one-fourth of the sections studied. The grains are mostly of silt and very fine sand size and are mostly very angular to angular. As with quartz grains, feldspar grain borders are commonly replaced by calcite.

Intraclasts consisting of micritic limestone pebbles characterize a bed of biosparrudite from approximately 2 feet above the base of the Lincoln Member at Locality 23. The rock contains numerous molds of broken ammonite conchs, pebbles of bone, rounded pebbles of limestone, much *Inoceramus* debris as isolated prisms and shell fragments, and sparse foraminifer tests. The whole assemblage indicates high energy conditions of deposition, probably the highest energy level manifested anywhere in the Greenhorn Limestone of Kansas. The intraclasts seem of local derivation, apparently from a layer of lime mud that was not well lithified so that good rounding was obtained readily (Figs. 17,E,F).

Lincoln biosparites are cemented by sparry calcite that occurs as crystals approximately the size of constituent grains. The more coarse the average grain size, the coarser the crystals of sparry calcite cement. This is the result of larger average size of interstitial spaces in the coarse-grained biosparites. All of the biosparites are grainstones, i.e., the grains form the supporting framework of the limestone. The cement is secondary pore-filling sparry calcite rather than recrystallized (neomorphosed) lime mud. The calcite cement does not exhibit gradation in crystal size from grain boundaries to the centers of original voids, nor is there indication that cementation began as acicular needles of aragonite. Foraminifer chambers are everywhere filled by one to a few blocky crystals of calcite.

A majority of Lincoln biosparites examined contain small amounts of chalky micritic matrix. This micrite occurs predominantly in irregular-shaped patches that are scattered irregularly through the rock, but some is in distinct, usually discontinuous laminae. Some micrite is associated with *Inoceramus* fragments, apparently because the fragments sheltered the micrite from current action. The more continuous micritic laminae occur in foraminiferal parts of the biosparites rather than in parts dominated by *Inoceramus* prisms.

Most of the thin sections examined contain at least a small amount, usually less than 1 percent, of pyrite or its oxidized equivalent in the form of hematite and/or limonite. The most common mode of occurrence is as silt-sized spherical blebs inside chambers of foraminifer tests. These minerals occur less commonly as replacement of foram tests, bone, or *Inoceramus* prisms. Small blebs or crystals of these minerals occur also within areas of sparry calcite cement and some is finely disseminated in micritic parts of some samples.

Silica occurs as a secondary replacement mineral in about one-fifth of the Lincoln biosparites examined in thin section. This occurs sparingly as a partial replacement of *Inoceramus* prisms and shell fragments and in fragments of oyster valves.

Hartland, Jetmore and Pfeifer Members.—Above the Lincoln Member biosparite is a much less conspicuous component of the Greenhorn section. Such rocks are most common as small, very thin lenses in the upper part of the Jetmore and lower half of the Pfeifer, and in the Hartland Member below marker bed HL-1. A majority of the thin sections examined are similar in general aspect to corresponding biosparites of the Lincoln, i.e., foraminifer- or *Inoceramus*-dominated rocks. For example, at Locality 13 the upper Hartland, laterally equivalent to the upper Lincoln and lower Hartland of areas to the northeast, contains thin lensing beds of biosparite that are composed mostly of *Inoceramus* debris or a subequal mixture of *Inoceramus* debris and foraminifer tests. The latter type contains patches of micritic matrix (Fig. 18,A) and both types contain more or less continuous laminae of biomicrite. Fine to very fine grains prevail but coarser sand and some pebble-size shell fragments are present. At Locality 8, the lower part of the Hartland, which is laterally equivalent to the middle and upper Lincoln of areas to the northeast, contains several beds of *Inoceramus* debris-rich biosparite all of which also contain a small proportion of foraminifer tests. These biosparites are dominantly fine to very fine grained or fine to medium grained; all have some coarser grains including pebble-size shell fragments. One of the studied thin sections is in part biosparrudite. Micrite is absent or only a minor component, occurring as small patches in sheltered areas adjacent to shell fragments, or in one sample as thin laminae. Oyster shell fragments are common in one sample lying 12 feet below marker bed HL-1. Detrital minerals were not observed in Hartland biosparites at these two localities. Partially or wholly silicified *Inoceramus* prisms and partially silicified *Inoceramus* or oyster fragments were observed in nearly all Hartland biosparites below marker bed HL-1 at Localities 8 and 13.

At Locality 34, the lens of skeletal limestone lying beneath HL-1 (Fig. 9,C) is a local scour feature filled with cross laminated foraminiferal biosparite. Approximately 95% of the allochems in this rock are whole and broken tests of planktonic foraminifers, the test fragments having preferred orientation more or less parallel to stratification. The rock is dominantly fine to very fine grained with some silt-size grains. In part this rock is a biomicrite where sparry calcite cement gives way to chalky matrix. Small average grain size and poorly washed condition is evidence that the forams were concentrated by weak currents.

Above marker bed HL-1 the Hartland contains biosparite in only a few places. At Locality 46 a lens of foraminiferal biosparite occurs one foot above the marker bed; the rock is fine to very fine grained with some silt-size grains. This rock is similar to that at Locality 34 but is better washed. At Locality 50, 3 feet above marker bed HL-3, a bed of chalky limestone has a lens of biosparite at its base. This rock is dominantly fine- to very-fine-grained inoceramite containing about 5 percent foraminifera and fragments of *Inoceramus* up to fine pebble size. The rock contains sheltered patches, discontinuous, and more or less continuous laminae of chalky micritic matrix. Other than these few occurrences of biosparite in the Hartland, scattered small, very thin lenses of foraminiferal biosparite were recorded between marker beds HL-2 and HL-3 at Locality 20 and between HL-3 and HL-4 at Localities 1 and 20. These scattered lenses represent the last, and local, traces of current action on the sea floor until after Jetmore deposition had begun.

The basal submember of the Jetmore contains only one significant bed of skeletal limestone (Fig. 10,B; 11,D). This lies between beds JT-1 and JT-2; the bed is developed throughout central Kansas and is represented at Locality 14, Hamilton County, by scattered lenses. At Locality 3 the rock is a laminated biosparite. Some of the laminae are nearly pure calcisphere biosparites, others are mixtures of calcispheres, pellets, and foraminifer tests. The latter are cemented generally by sparry calcite but also contain patches and discontinuous streaks of chalky micritic matrix and in such places are biomicrite packstones. *Inoceramus* prisms are rare and valve fragments are lacking. Calcisphere laminae are silt and very fine sand size. The pellet-rich laminae are silt to fine sand size with a few medium grains (larger pellets and foraminifer tests). In the same position at Locality 14, foraminiferal biosparite occurs in small lenses. The rock is poorly washed, containing patches, discontinuous streaks, and persistent laminae of chalky micrite matrix; part of the rock grades to biomicrite packstone. Elsewhere in the Jetmore section small, very thin

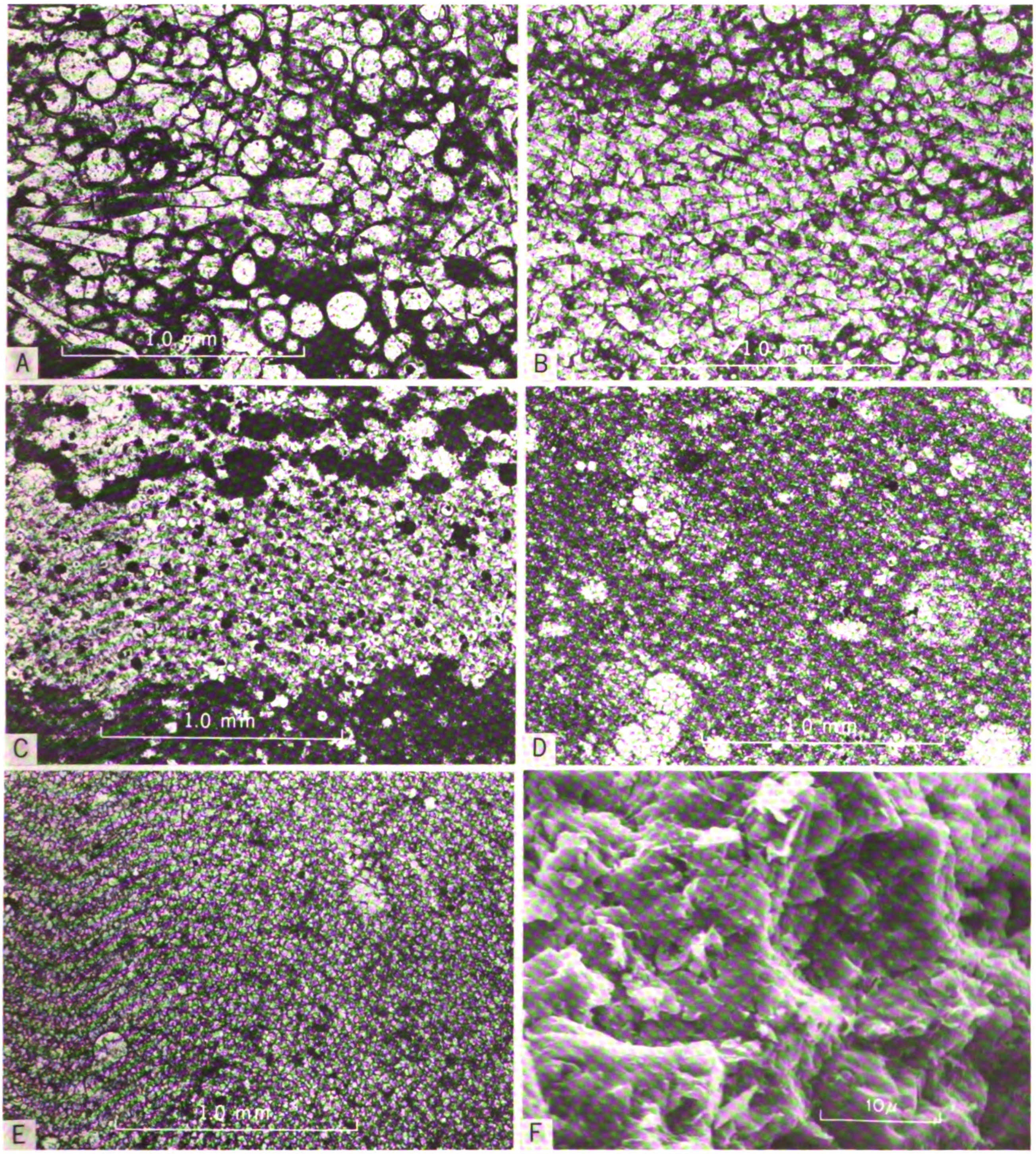


FIGURE 18.—Petrologic features of skeletal and chalky limestones. A) Photomicrograph of foraminiferal and *Inoceramus*-prism biosparite from upper part of Hartland Member at Locality 13. Plane-polarized light, X40. Note small areas of micritic matrix (dark). B) Photomicrograph of foraminiferal and *Inoceramus*-prism biosparite from lower part of Pfeifer Member at Locality 25. Plane-polarized light, X40. Note areas of micritic matrix (dark). C) Photomicrograph of specimen from widespread, thin flat chalky limestone bed above sugar sand marker bed of Pfeifer Member at Locality 49 showing lamina composed of calcisphere biosparite. Plane-polarized light, X40. Note pellets near top of photo and micritic nature of main part of bed at bottom of photo. Black grains in calcisphere lamina are blebs of pyrite. D) Photomicrograph of chalky limestone (wackestone) from lower part of Jetmore Member at Locality 9 showing foraminifera in matrix of fine microsparite. Plane-polarized light, X40. E) Photomicrograph of chalky limestone (mudstone) from lower part of Jetmore Member at Locality 6 showing sparse foraminifera in matrix of coarse microsparite. Plane-polarized light, X40. F) Scanning electron micrograph of chalky limestone from lower part of Fencepost limestone bed at Locality 14 showing crystalline nature of microsparite. X200. Note coccolith at left center of picture.

lenses of biosparite occur amongst abundant whole and broken *Inoceramus* valves in shaly chalk units in the interval from JT-8 or JT-9 to the base of the Shellrock limestone bed. These lenses consist predominantly of *Inoceramus* prisms and valve fragments, the latter commonly imbricated, and show all gradations from sparry calcite-cemented grainstones to biomicritic packstones.

In the Pfeifer Member shaly chalk beds lying below the sugar sand marker unit usually contain small, very thin, commonly irregular-shaped lenses of skeletal limestone. All gradations are evident from well-washed biosparites to poorly washed biomicrite packstones and this gradation can be observed within a single thin section. These lenses are composed of subequal mixtures of *Inoceramus* debris and foraminiferal tests (Fig. 18,B). Oyster fragments were recorded in a few of the thin sections examined and two samples apparently contain calcispheres. Because these rocks usually contain large fragments of *Inoceramus* or oyster valves, the overall range in grain size is very great; the finer component, consisting mainly of *Inoceramus* prisms and foraminifer tests, is dominantly fine to very fine grained in some samples, dominantly silt to very fine sand size in others. The larger tests of foraminifers are usually in the medium sand range. Most of the thin sections examined contain fine pebble size fragments of *Inoceramus* and some samples are at least in part biosparrudite. Many of these Pfeifer lenses are laminated, and alternate laminae consist predominantly of foraminifera or *Inoceramus* prisms. Micrite occurs as irregular-shaped interstitial patches in most of these thin sections; a few sections contain sheltered patches and/or discontinuous streaks of micritic matrix, and some sections have continuous laminae of biomicrite that alternate with laminae of biosparite.

From a position directly beneath the sugar sand marker bed to the base of the Fencepost limestone bed, biosparite is an inconspicuous part of the section. In this part of the section concretions and thin beds of chalky limestone contain a combination of pellets, foraminifer tests and calcispheres (Fig. 18,C). The calcispheres and forams are concentrated mostly in spar-cemented laminae having allochems mostly of very fine sand to silt size. These alternate with pellet-rich laminae that are pelmicrosparite packstones or wackestones (less common) having dominantly fine to very fine and some medium-size grains. These rocks are remarkably similar to one another and quite different from biosparites in the lower half of the Pfeifer.

In all of the biosparites above the Lincoln Member the cement is relatively coarse calcite spar that occurs as crystals more or less the size of the interstices they fill. As in the Lincoln there is little evidence that the voids were filled by growth of many small crystals outward from the allochems. Although most foraminifer chambers are filled by single or only two or three large crystals of calcite, in some samples in the upper Pfeifer, and especially where the test walls have been largely destroyed (as in micritic parts of thin sections), the chamber fill consists of a mosaic of smaller calcite crystals. There is, however, little evidence of gradual filling of the chambers by inward growth of small crystals of calcite. Details of the nature and preservation of *Inoceramus* prisms show the same features as in the Lincoln biosparites, i.e., sharp, fuzzy, calcite-replaced, and sutured (rare) prism borders. Bone fragments and/or scales occur in nearly all but some of the calcisphere-foraminifer-pellet biosparites in the upper Pfeifer. Elongate grains of all types are oriented parallel to stratification in nearly every section. Pyrite, or its oxide equivalents hematite and/or limonite, also occurs in nearly all thin sections. The most common occurrence is as silt size blebs in foraminifer chambers and also in calcispheres. Less commonly these minerals occur as partial replacement of foraminifer tests, *Inoceramus* prisms, or as crystals or blebs in sparry cement or in micrite. Except for the tendency toward increased amounts of biomicrite associated with biosparite, and the calcisphere-foraminifer-pellet rocks in the upper Pfeifer, the varieties of the biosparites in the Hartland, Jetmore, and Pfeifer Members are quite similar to respective rock types in the Lincoln. Above the Lincoln, however, the quantities of such material are relatively smaller and occur principally in small, very thin lenses rather than in conspicuous beds.

Chalky Limestone

Petrographic description of chalky limestone units is based on examination of 174 thin sections. In 87.4 percent of these thin sections the matrix consists of microsparite; in 68.4 percent of the slides the matrix is fine microsparite (Fig. 18,D) and in 19.0 percent the matrix is coarse microsparite (Fig. 18,E). In the latter group are a few slides containing both microspar and pseudospar. Microspar is neomorphosed mud ranging from 5 to 30 microns in diameter (Folk, 1965, p. 37) and I have divided this range arbitrarily at 15 microns. Fine microsparry rocks occur throughout the Greenhorn but are especially characteristic of the Jetmore and Pfeifer Members. Coarse microsparry rocks also are known from all members but are least common in the Jetmore Member. In the Hartland Member most coarse microsparites occur in Ford and Kearny Counties in beds equivalent to the upper Lincoln of areas farther to the northeast. Among thin sections of coarse microsparite, 81 percent are from Localities 8, 13 and 14, suggesting that a greater degree of recrystallization has taken place in sections located toward the southwest than elsewhere in Kansas. Scanning electron micrographs of microsparry rocks are illustrated in Figures 18,F and 19,A. Beds of chalk and chalky limestone having predominantly micritic matrix (Fig. 19,B) comprise only 12.6 percent of the slides examined; more than two thirds of these are from soft, burrow-mottled chalk beds lying in the upper part of the Hartland and all but one of the remainder are from the lower part of Jetmore. A scanning electron micrograph of micritic chalky limestone is illustrated in Figure 19,C.

In terms of depositional texture (Dunham, 1962) a majority of all rocks studied in thin section are wackestones (Figs. 18,D; 19,B) or transitional between wackestones and packstones. The remaining thin sections are nearly equally divided between packstone (Fig. 19,D) and mudstone (Fig. 18,E). Among thin sections of micritic rocks one is mudstone, one is transitional between wackestone and packstone, and three are packstones; all the other micritic rocks are wackestones. Micritic wackestone is characteristic only of the upper part of the Hartland Member. Among fine microsparitic thin sections a majority are wackestones (Fig. 18,D) or transitional between wackestone and packstone. The remaining microsparitic samples are mostly packstones; only 8 thin sections of microparitic rock have a predominantly mudstone texture. Taking into consideration the uneven distribution of chalky limestone in the Greenhorn, fine microsparitic wackestones are more characteristic of the Jetmore and Pfeifer Members. Fine microsparitic packstone is most characteristic of the Pfeifer Member. More than half of the coarse microsparitic thin sections have a mudstone texture (Fig. 18,E) and these are concentrated in the Lincoln Member or in that part of the southwestern Kansas Hartland that is correlative with the Lincoln of central Kansas. Coarse microsparitic wackestones are characteristic only of the lower part of the Hartland in southwestern Kansas. None of the coarse microsparitic rocks studied have a packstone texture. Stratigraphic distribution of thin sections according to depositional texture is set forth in Table 3.

Principal grain types recorded in Greenhorn chalky limestones include, in order of decreasing abundance, tests of planktonic foraminifera, debris from inoceramid bivalves consisting mainly of fragments and isolated prisms from the prismatic layer, fecal pellets, and calcispheres. In 76 percent of chalky limestone thin sections, the collective abundance of biogenic allochems is greater than 10 percent; these rocks are of four main types, namely biomicrites, biopelmicrites, biomicrosparites and biopelmicrosparites. The remaining rocks are mostly fossiliferous micrites, fossiliferous microsparites or, rarely, pelletal microsparites. Foraminifer tests are present in all thin sections studied; inoceramid debris is present in most thin sections but is sparse in many. Rocks in which foraminifer tests are the chief allochems (Fig. 18,D; 19,B) occur in the Lincoln Member (sparse), in marker beds HL-1 and HL-2, in chalk beds of the upper Hartland and in Jetmore beds JT-1 to JT-9. Hartland and Jetmore rocks of this type include both biomicrites and biomicrosparites. Rocks in which the allochems are mostly foraminifer tests plus inoceramid debris (Fig. 19,E) are nearly all fine biomicrosparites occurring in the lower part of the Jetmore Member, in beds JT-1 to JT-9. Foraminifer and pellet rocks are most common in that part of the Hartland of southwestern Kansas that is equivalent to the Lincoln of central Kansas, and in the Pfeifer Member. Such rocks also occur

Table 3.—**Stratigraphic distribution of chalky limestone thin sections according to depositional texture and nature of matrix.**

UNIT	PACKSTONE Micrite	PACKSTONE Fine Microsp.	PACKSTONE Coarse Microsp.	TRANSITIONAL Micrite	TRANSITIONAL Fine Microsp.	TRANSITIONAL Coarse Microsp.	WACKESTONE Micrite	WACKESTONE Fine Microsp.	WACKESTONE Coarse Microsp.	MUDSTONE Micrite	MUDSTONE Fine Microsp.	MUDSTONE Coarse Microsp.
Fencepost	--	--	--	--	5	--	--	1	2	--	--	--
Upper Pfeifer	--	--	--	--	1	--	--	6	2	--	--	2
Flat Bed	--	3	--	--	--	--	--	--	2	--	--	--
Sug. Sd. Conc.	--	--	--	--	--	1	--	1	1	--	--	1
Mid. Pfeifer	--	11	--	--	4	--	--	6	5	--	--	--
PF-1	--	1	--	--	1	--	--	3	1	--	--	--
Lower Pfeifer	--	4	--	--	4	2	--	3	--	--	1	1
JT-13	2	--	--	--	2	--	--	--	1	--	--	--
JF-12 to 13	--	3	--	--	--	--	--	1	--	--	--	--
JT-10 to 12	--	1	--	--	3	--	2	3	--	--	--	--
JT-1 to 9	--	2	--	--	8	--	2	17	1	--	2	1
Upper Hartland	--	--	--	--	1	--	11	4	--	--	5	--
HL-2	--	--	--	--	--	--	1	4	--	1	1	--
HL-1	1	--	--	--	--	--	2	3	1	--	--	1
Lower Hartland	--	--	--	--	--	--	1	--	5	--	--	6
Lincoln	--	--	--	1	--	2	--	3	--	--	--	5

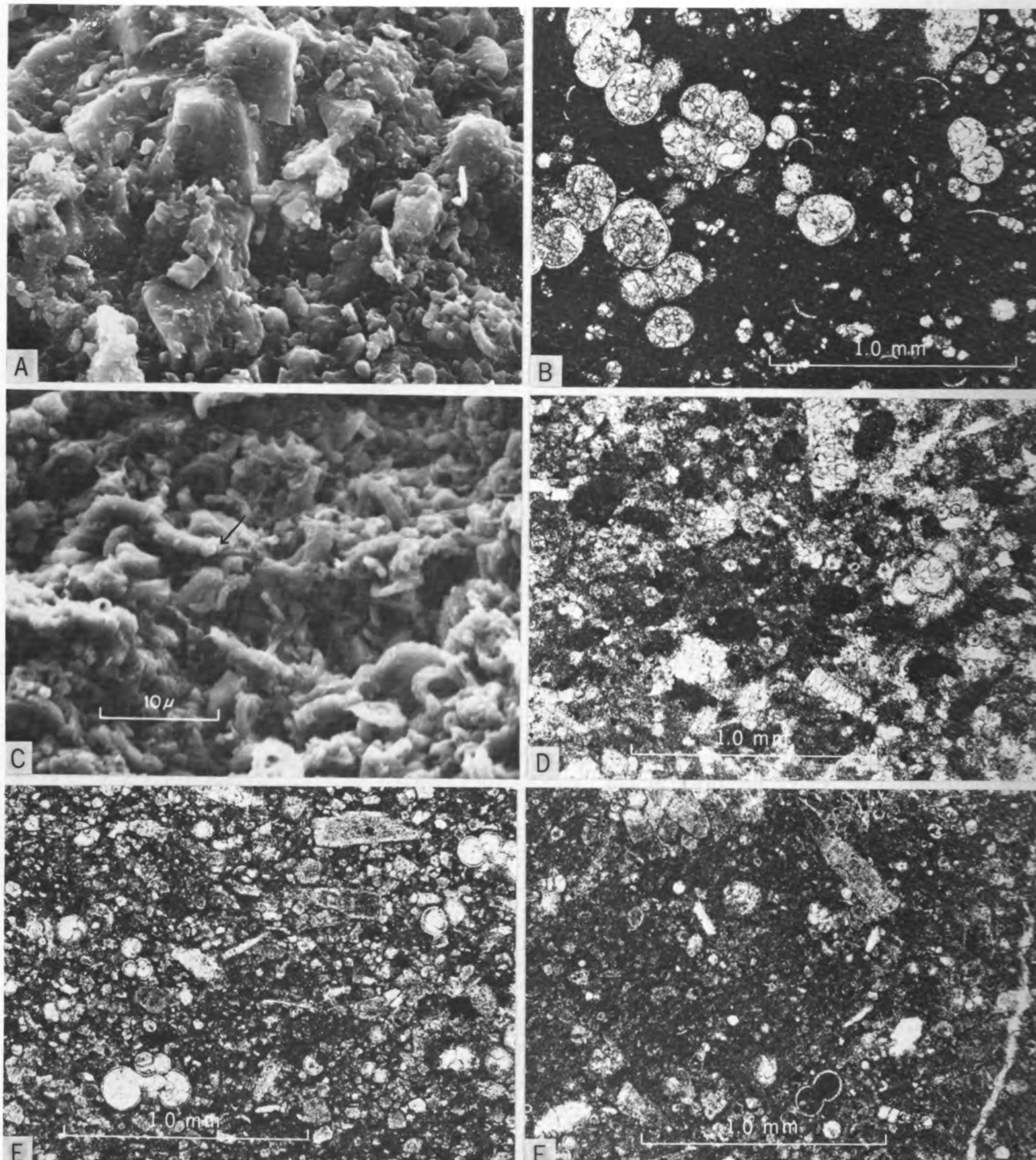


FIGURE 19.—Petrologic features of micritic and microsparitic chalky limestone. A) Scanning electron micrograph of microsparite from marker bed HL-1 in Bridge Creek Member at Locality 14, X2,200. Note coccolith at lower right. B) Photomicrograph of biomicritic chalky limestone (wackestone) from upper part of Hartland Member at Locality 1. Plane-polarized light, X40. Note sparry calcite filling of foraminifer tests. C) Scanning electron micrograph of micritic chalky limestone from upper part of Hartland Member at Locality 1, X1960. Note that this micritic chalky limestone is not as extensively recrystallized as the microsparites in Figs. 18, F and 19, A. Arrow indicates calcite overgrowth on a coccolith. D) Photomicrograph of foraminiferal-pellet-*Inoceramus* prism-calcisphere packstone from lower part of Pfeifer Member at Locality 1 showing matrix of fine microspar (biomicrosparite). Plane-polarized light, X40. E) Photomicrograph of foraminiferal-*Inoceramus* prism packstone from lower part of Jetmore Member at Locality 6 showing matrix of fine microspar (biomicrosparite). Plane-polarized light X40. F) Photomicrograph of foraminiferal-*Inoceramus* prism-calcisphere wackestone from middle part of Jetmore Member at Locality 1 showing matrix of fine microspar (biomicrosparite). Plane-polarized light, X40.

sparingly in the upper Lincoln of central Kansas. More than 75 percent of the foraminifer-pellet rocks are coarse biomicrosparites or biopelmicrosparites. In the Hartland of southwestern Kansas and locally in the Pfeifer, parts of some thin sections are pelmicrosparites. Thin sections having inoceramid debris, foraminifer tests and calcispheres as the prominent allochems are all fine biomicrosparites (Fig. 19,F) and are concentrated in the three beds, JT-10 to JT-12, of the Jetmore and in the upper part of the lower submember of the Jetmore. Thin sections containing an abundance of all four principal allochems (Fig. 19,D) are biomicrosparites or biopelmicrosparites. These are concentrated in the upper part of the Jetmore, JT-10 to JT-13 and in the lower and middle parts of the Pfeifer Member. Thin sections in which the principal allochems are pellets, foraminifer tests, and calcispheres (Fig. 18,C; 20,A) are characteristic of the Pfeifer, especially above PF-2 and including the Fencepost limestone bed. Included are biomicrosparites or biopelmicrosparites. In some of these upper Pfeifer rocks, pellets are segregated into discrete pelmicrosparite laminae and the calcispheres are segregated into thin laminae of biosparite (Fig. 18,C). In addition to the foregoing, I recorded other combinations of allochem dominance but only the six named above are common varieties of chalky limestone. Stratigraphic distribution of chalky limestone according to allochem types is shown schematically in Table 4.

Planktonic foraminifer tests preserved in chalky limestones exhibit the same general characteristics as in other groups of Greenhorn carbonate rocks. Tests of several different genera have been recognized in thin section, most notably *Hedbergella, Rotalipora,* and *Heterohelix,* with the first of these being by far the most prominent. Test-wall preservation ranges from entire to partially or wholly destroyed, even within a single thin section, and this observation pertains to all three textural groups of chalky limestone. The best-preserved tests show clearly the details of pores and surfical spines. Test chambers exhibit a wide variety of filling material. Where test walls are well preserved the chambers are filled with one to many crystals of sparry calcite cement that is in sharp contact with the chamber wall. Some chambers containing many crystals display centripetal increase in crystal size. In a few thin sections, test chambers are filled with micrite (Pl. 19,F); in others, an original micritic filling has been altered to microspar. Uncommonly, both microspar and blocky calcite occur together. Where the test wall has been destroyed, foraminifera are nevertheless readily identified by outlines of sparry calcite areas that are gradational in size with the surrounding microspar and usually have centripetal

Table 4.—Stratigraphic distribution of chalky limestone according to dominant allochems.

		Forams	Foram-Pellet	Foram-Inocer.	Foram-Inoc.-Calcispheres	Foram-Inoc.-Calci.-Pellet	Pellet-Calci.-Foram
PFEIFER	U						│
	M					│	│
	L		│			│	
JETMORE	13					│	
	12-13				│	│	
	10-12				│	│	
	1-9	│		│	│		
HARTLAND	U	│					
	1-2	│					
	L	│	│				
LINCOLN		│	│				

increase in grain size. Some foraminifer tests are partially to completely replaced by pyrite or hematite in nearly a dozen thin sections from throughout the Bridge Creek Member at Locality 14, and in one thin section from Locality 6. Small, rounded blebs or angular crystals of pyrite or hematite are a common feature within chambers of foraminifer tests, but these minerals are usually subordinate to the accompanying calcite.

Inoceramus debris in chalky limestones consists of unit crystals, derived from disintegration of the prismatic layer, and valve fragments of all sizes. The smooth inner surface of valve fragments is generally in sharp contact with the matrix but in a few fine biomicrosparite samples from the Pfeifer Member this surface adjoins coarsely recrystallized remnants of the nacreous layer. The proximal ends of many crystals from the prismatic layer are also mostly in sharp contact with the adjacent matrix. The remaining surfaces of unit crystals and the outer surfaces of valve fragments are commonly in irregular contact with the adjacent matrix as a result of diagenetic etching. In a few samples of biomicrosparite, individual crystals from the prismatic layer have been altered to polycrystalline units. The cause of such alteration is not known. Valve fragments showing partial silicification were recorded mostly in thin sections of fine biomicrosparite. This phenomenon is limited almost entirely to rocks in the upper part of the Jetmore, the Pfeifer, and equivalent rocks of the Bridge Creek Member. In no samples does silicification account for more than 1 percent of the thin section. In nearly half of the chalky limestone thin sections examined at least some inoceramid valves and/or prisms are replaced in small part by pyrite or, by oxidation of the pyrite, hematite. This phenomenon is common in the Hartland, Jetmore, Bridge Creek, and all but the upper part of the Pfeifer Member. The pyrite occurs usually as small discrete crystals having mostly irregular distribution but in some valve fragments pyrite or hematite is aligned parallel to the valve surface. Pyrite or hematite in *Inoceramus* valves is less than 1 percent of the entire rock in nearly all thin sections having this form of replacement.

Fecal pellets in chalky limestones are less uniformly distributed than in shaly chalks. Some chalky limestone thin sections contain laminae composed almost entirely of pellets; at the other extreme are thin sections in which pellets are lacking. In most chalky limestones the pellets have suffered little compaction, and in cross section are circular to elliptical. Grains having these shapes have diameters as great as 0.2mm, or dimensions as great as 0.4mm long and 0.18mm thick. Nearly all pellets are in the very fine to fine sand size range. In a few thin sections, especially those of coarse microsparites, pellets are roughly fusiform as a result of compaction or of compression during neomorphism. In plane-polarized light these grains are light gray to yellowish gray, and have a grainy texture as in shaly chalk fecal pellets. Almost all pellets have a more homogenous texture than the surrounding rock, and are differentiated clearly from the latter by shape, color and texture. Pellet borders are sharply defined in some thin sections, especially those of the Pfeifer Member, but are indistinct in most other rocks and are highly irregular in most coarse microsparites.

Calcispheres (Figs. 19,F; 20,A) are scattered through the matrix of many chalky limestone samples from the Jetmore and Pfeifer Members and in the latter are commonly concentrated in very thin laminae (Fig. 18,C). These structures range in diameter from 0.25 to 0.70 mm, have no visible pores or chamber openings, are smooth walled, and are infilled with sparry calcite. As with the foraminifers, the chamber of some calcispheres also contains a small crystal or bleb of pyrite or hematite. Calcisphere wall preservation ranges from entire to almost completely obliterated; secondary thickening of the wall apparently has occurred in some specimens.

Fish remains consisting of whole and fragmentary bones and scales were recorded in all but 4 of the 174 chalky limestone thin sections. These remains are pale yellow to amber-colored in plane-polarized light and gray or opaque under crossed nicols. In stratified rocks the tabular or elongate fragments are well aligned parallel to bedding but orientation is haphazard in bioturbated chalky limestones. Distribution of such durable remains is not controlled by bottom conditions but reflects a relatively steady contribution from the pelagic environment above. Disarticulation of skeletons and fragmentation of bones and scales is attributable to action of predators and scavengers. Total abundance of such remains is usually only a small fraction of 1 percent of the total rock.

Valves and valve fragments of oysters are not abundant in chalky limestones and were recorded only in those parts of the section in which oysters were recorded in the field. Because oysters are almost wholly calcitic most specimens preserve original lamellar structure. A few specimens have been recrystallized to coarsely crystalline calcite; partially pyritized or partly silicified remains are rare.

A few chalky limestone thin sections from the Hartland and Bridge Creek Members at Localities 13 and 14 contain sparse valves believed to belong to the paper pecten, *Syncyclonema*. Some such valves have been recrystallized. All the thin sections are from localities at which significant numbers of paper pectens were recorded in the field (Locs. 13, 14). All other groups of macroinvertebrates are scarce or not represented in the chalky limestones studied. Sparse ostracodes, rare benthonic foraminifers, possible sponge spicles, and extremely rare echinoderm plates account for the remainder of skeletal remains observed under the polarizing microscope.

Many chalky limestone thin sections contain silt sized "grains" and wispy bodies of black, and locally amber-colored material that is believed to be mostly organic matter. Such matter normally comprises only a small fraction of 1 percent of the thin section containing it. In 10 Hartland and 2 Pfeifer thin sections this matter comprises between ½ and 1 percent of the total. In rock that lacks bioturbation these bits of organic matter are aligned parallel to stratification; the matter is distributed irregularly through bioturbated rock. The black grains may be carbonaceous and some appear to represent organic structures; the sparse, amber-colored matter probably comprises complex organic substances.

Micrograined terrigenous detritus occurring as wispy or lenticular bodies, and apparently consisting largely of clay, was observed in some of the coarse microsparite thin sections, especially those from the Lincoln and Hartland Members. Chalky limestones of the Greenhorn contain as much as 23.3 percent (average 7.9 percent for 75 samples) insoluble residue, most of which is terrigenous detritus, but this is hard to identify in most thin sections, probably because of fairly uniform distribution through individual samples. Grains of terrigenous quartz were recorded with certainty in only 4 chalky limestone thin sections, all from the Hartland Member or Hartland equivalent of the Bridge Creek Member. These grains are silt sized and angular, and most have pitted edges. Occurrence of the silt in and shortly above the zone of *Sciponoceras gracile* may relate to conditions which fostered a greater diversity of benthonic invertebrates in this part of the section. This distribution corresponds to the benthonic foraminiferal zone of Eicher and Worstell (1970a, p. 276) which they attributed to increased circulation within the Western Interior sea (*ibid.*, p. 278).

Pyrite or its oxidized equivalent, hematite, was recorded in all but 6 thin sections of chalky limestones. These secondary minerals occur commonly as rounded blebs or angular crystal masses within the sparry calcite filling of foraminifer chambers or calcispheres (Fig. 18,C). Also common are pyrite or hematite as partial replacement of valve fragments or prisms of inoceramid bivalves. Especially at Locality 14 pyrite and hematite are common as replacement minerals in tests of planktonic foraminifera. These minerals occur also as crystalline masses scattered through or concentrated locally within the matrix of chalky limestone thin sections (Fig. 20,B); however, such general pyritization exceeds 5 percent of the total rock in only 2 thin sections. Most commonly the total pyrite and hematite content does not exceed 1 or 2 percent of the rock. Some thin sections of weathered rocks, especially from the Pfeifer Member, are stained throughout by dark yellowish-orange iron oxide, probably limonite.

Large, filled burrow structures in chalky limestone are evident in changes of color, texture, or fabric of the micritic or microsparitic matrix (Fig. 20,B). Open burrows, such as those produced by *Chondrites*, are filled by clear, secondary calcite that usually shows increase in grain size from periphery to center of the individual burrow. Coarse-grained sparry calcite occurs also as cementing matter in epigenetic fractures (Fig. 19,F). Such fractures were recorded in the upper half of the Jetmore and in the Pfeifer Member. All were in rocks that have been weathered.

Diagenesis

Post-depositional modification of Greenhorn sediments differed according to texture and composition of the sediments. The impure shaly chalks seem least modified; these are poorly cemented rocks in which original stratification is well preserved. The interstitial environment of these sediments was inhospitable to endobenthonic forms of life as evident in almost complete absence of burrow structures except where shaly chalk is gradational into burrow-mottled chalky limestone. The abundance of organic matter preserved in nonweathered shaly chalks suggests that rather strongly reducing conditions must have prevailed below the sediment-water interface. Compaction was a major factor in alteration of the shaly chalk-producing muds; evidence of compaction includes fusiform fecal pellets with attenuated lateral margins, completely flattened condition of inoceramid bivalves, compacted condition of sparse ammonite molds, and bending of microstratification around foraminifer tests and fragments of inoceramids. Upon even slight weathering, shaly chalk breaks apart to form small friable chips thus manifesting its poorly cemented nature. Why has this rock been so poorly indurated while adjacent chalky limestones are well lithified? Several explanations are suggested. 1) The high percentages of shaly chalk insoluble residue, consisting in part of clay-sized particles, may have been a major factor inhibiting widespread cementation and neomorphism (Bausch, 1968). 2) The postulated reducing environment would have inhibited cementation (de Groot, 1969, p. 67). 3) In the near absence of bioturbation, fresh supplies of seawater, bearing cementing materials in solution, did not circulate through the sediment. 4) the shaly chalk sediment was poor in aragonitic skeletal material which could, upon dissolution, furnish cementing materials. The first three of these possibilities are regarded as plausible. The last is ruled out because inoceramid bivalves are common throughout the shaly chalk beds and without exception these have lost their aragonitic nacreous layer. The sparse ammonites observed in shaly chalk strata likewise have lost their aragonitic conchs through dissolution. Whether this aragonite was lost early in the diagenetic process or at a much later time is uncertain. Even if it was lost at a relatively late stage of diagenesis the resulting void space would have been closed readily by the largely noncemented sediments. Evidence from the chalky limestone beds suggests that skeletal aragonite therein was lost during early diagenesis and I see no reason why that in shaly chalk beds could not also have been dissolved at an early stage. The small amounts of locally derived $CaCO_3$ in solution may have been redeposited as calcite chamber fillings in the planktonic foraminiferal tests and as interstitial cement in thin laminae or small lenses of skeletal debris within the shaly chalk. In recent sediments of the Bahamas, chambers of foraminifera commonly contain acicular crystals of aragonite or high-magnesium calcite, depending upon the mineralogy of the host (see Bathurst, 1971, p. 364). Is it not logical to assume that the cement that fills chambers of the calcitic planktonic foraminifera in shaly chalk beds would have been calcitic? The chamber-filling calcite usually consists of one to a few blocky crystals with little or

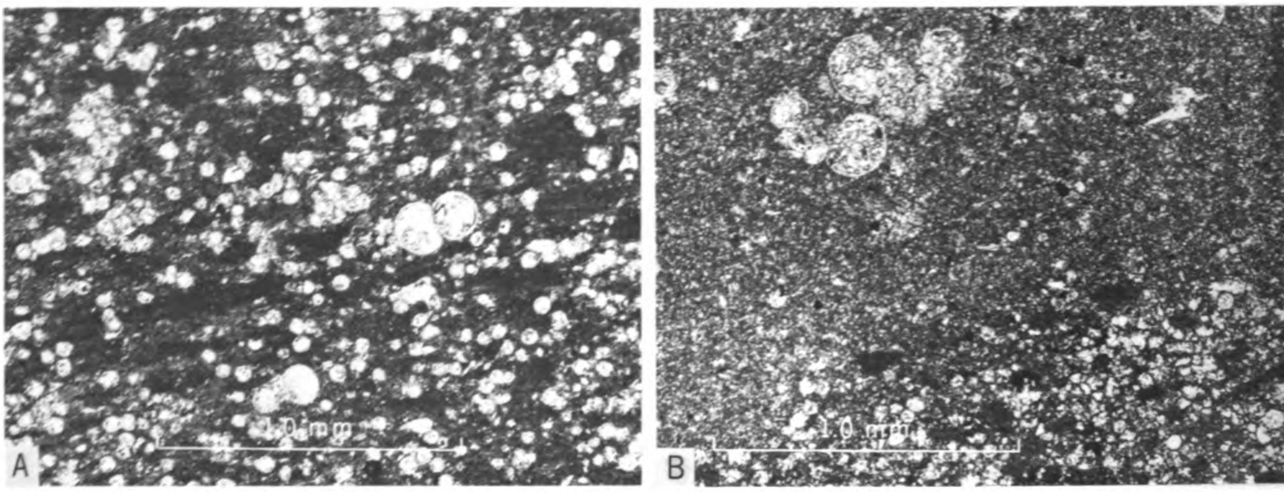


FIGURE 20.—Petrologic features of microsparitic chalky limestone. A) Photomicrograph of foraminiferal-calcisphere-pellet wackestone from Fencepost limestone bed at Locality 1 showing matrix of fine microsparite (biopelmicrosparite). Plane-polarized light, X40. B) Photomicrograph of chalky limestone from upper part of Hartland Member at Locality 1 showing textural difference caused by bioturbation. Plane-polarized light, X40. Portion of large burrow structure at lower right is characterized by coarse microsparite. Note pyrite (black spots) in fine microsparite (upper part of photo) and in sparry calcite filling of foraminifer test.

no evidence of an original fringe of tiny crystals or centripetal increase in crystal size. The sparry calcite in these chambers apparently developed slowly and from a few centers of growth.

In a few of the samples examined in thin section, pressure solution has resulted in notched or sutured contacts between prisms of inoceramids or foraminifer tests, or both where a prism is in contact with a foraminifer test, but this is not a widespread phenomenon of the shaly chalk. In some thin sections, areas of the micritic matrix has invaded the margins of inoceramid prisms or has destroyed portions of foraminiferal tests but such micritization is not common.

Diagenesis of biosparites consisted primarily of cementation including interstitial growth of calcite spar and filling of skeletal chambers (foraminifers, calcispheres, bones) usually by one to a few calcite crystals. Because these rocks are all grainstones there is little evidence of compaction. In general, interstitial voids and skeletal chambers show no evidence of centripetal increase in size of sparry calcite crystals. Even chambers that contain many crystals show no size gradient toward the chamber centers. In rare instances, the blocky spar inside a foraminifer chamber contains faint outlines of smaller crystals along the chamber wall, but the whole mass now behaves as a unit crystal. Perhaps the original chamber filling has been recrystallized to a single crystal or at most a few crystals, but the evidence is far too limited to suggest that this was a general phenomenon. Apparently the growth of calcite crystals in most interstices and skeletal chambers proceeded from relatively few centers, resulting in a coarse textured cement.

The source of cement in skeletal limestones could have included the following: 1) Carbonate from dissolution of aragonitic shells or parts of shells of ammonites, inoceramids, and other macroinvertebrates. The extreme paucity of benthonic foraminifera in all Greenhorn rocks rules out dissolution of tests composed of high-magnesium calcite as a significant source of cement. 2) Pressure solution; notched and sutured contacts between skeletal grains implies dissolution of calcitic grains and freeing of $CaCO_3$ for use as cement. This phenomenon is common in Greenhorn biosparites but was not developed on a scale sufficient to provide a major source for cement. 3) Bathing of the sediment by fresh supplies of $CaCO_3$-rich sea water while the sediment was still at or near the sediment-water interface. The water would have been pumped through the sediment by the currents that concentrated the skeletal debris, or possibly have been driven by wave action (see Riedl and others, 1972). Bathurst (1971, p. 442) opined that none of these sources of $CaCO_3$ cement was enough to account for the amount of cement that occurs in limestone. The time of cementation in Greenhorn biosparites is not known; however, if mechanism number (3) was at all important, it would have had to take place before the biosparites were buried under any appreciable thickness of shaly chalk-forming mud. Mechanism number (2) requires a certain amount of load, which implies that mechanisms (2) and (3) did not occur simultaneously. Folk (1973) has reviewed the evidence that early diagenetic marine cements consist of aragonite or Mg-calcite and that such cements may invert to equant calcite spar in the subsurface realm. He points out that the inversion from Mg-calcite to low-magnesium calcite can occur without visible change in texture (*ibid.*, p. 135). If Greenhorn biosparites were cemented during early diagenesis, and by Mg-calcite rather than aragonite, later inversion to the present low-magnesium calcite could have taken place with or without a change of texture in the cement. The cementation of Greenhorn biosparites apparently was a lengthy process, probably being completed after the eogenetic stage of diagenesis.

Chalky limestones of the Greenhorn manifest the greatest degree of post-depositional alteration among carbonate rocks of the formation. Whereas original textures of shaly chalk and biosparite are plainly preserved, nearly all the chalky limestones have been altered, at least in part, to microspar. The original carbonate matrix of these rocks is presumed to have been similar to that of the shaly chalks, that is, composed primarily of coccoliths and coccolith debris. Scanning electron microscopy (Hattin, 1971, fig. 23; Hattin & Darko, 1971, fig. 3, C, D; this paper, Fig. 18, F; 19,A) demonstrates that the chalky limestones consist now of an interlocking mosaic of 5 to 30μ or 40μ calcite spar that has obliterated most of the original coccoliths and rendered "blurry" some of those that were incompletely caught up in the neomorphism of the rock. That the microspar in chalky limestones is not a simple interstitial cement between silt- and sand-sized allochems is evident in the many thin sections that have wackestone or mudstone texture. In these examples the original sediment was composed primarily of mud in which allochems were widely dispersed. As Bathurst (1971, p. 486) has pointed out, in such cases it is assumed that the matrix of microspar has resulted from replacement of the original mechanically deposited matrix. In many Greenhorn chalky limestones the neomorphosed matrix is equigranular and fairly uniform throughout the thin sections, and resulted from the so-called coalescive neomorphism of Folk (1965, p. 22). However, both fine and coarse microspar occur in some thin sections and both micrite and microspar occur in others.

The mechanism of neomorphism in the chalky limestone-producing muds involved growth of crystals from calcite nuclei within the carbonate mud. Folk (1965, p. 22) and Bathurst (1971, p. 449) have described the process of aggrading neomorphism, of which the chalky limestone is an example, as involving the growth of calcite crystals within the original sediment, and enlargement of these crystals until a calcite mosaic has wholly replaced the primary fabric. Some of the crystals grow at the expense of many others until, when average grain size exceeds 4μ, a microsparry fabric is produced. It is concluded here that the nuclei for microspar crystal growth consisted of individual coccolith elements, as suggested by Bathurst (1971, p. 487, fig. 339) for certain Triassic limestones.

Bathurst (1970, p. 431) noted that the process of lithification in carbonate muds is twofold, involving precipitation of externally derived cement as well as neomorphism of the original carbonate grains. The cementation of an Oligocene South Atlantic chalk has been demonstrated admirably by Wise and Kelts (1972, pl. 11-13) who showed how nannofossils are cemented by ultramicroscopic calcite overgrowths on coccoliths and discoasters (see Fig. 19,C). Adelseck and others (1973, p. 2760) have suggested that the calcium carbonate for such overgrowths is derived from selective dissolution of the smallest particles, which were produced by the disaggregation of the smallest coccoliths. This process could have occurred during initial phases of lithification in the Greenhorn chalky limestones.

In Greenhorn chalky limestones, macroinvertebrate fossils, as well as burrow structures, are preserved mostly in-the-round or only partially flattened, and fecal pellets in these rocks are not compressed as in adjacent shaly chalks. These criteria are evidence that lithification proceeded at an early stage of diagenesis. Indeed, Zankl (1969, p. 249) stated that in fine-grained carbonate rocks the most important criterion of early lithification is lack of compaction. When the superjacent sediment load was enough to initiate compaction of the associated shaly chalk-producing muds the Greenhorn limestone beds were already sufficiently rigid to resist, if not totally withstand, compactional stresses.

The source of carbonate for lithification (=cementation plus neomorphism) is believed to be twofold. 1) In neomorphism the growth of some crystals occurred at the expense of their neighbors. This required no external source of carbonate. 2) Calcium carbonate utilized in initial cementation of the rock was derived by precipitation from interstitial fluids. Part of this may have been derived from interstitial seawater, circulation of which through the sediment would have been much enhanced by burrowing organisms, for which much evidence is preserved. This mechanism has been suggested by Bathurst (1971, p. 402) to account for early cementation of the so-called Bioturbation chalk (Upper Cretaceous) of Northern Ireland. Like most Greenhorn chalky limestones the bioturbation chalk shows little evidence of compaction (Wolfe, 1968, p. 274). Dissolution of the smallest carbonate grains could also have furnished cement for the chalky limestones. Dissolution of aragonite from ammonite conchs and the nacreous layer of inoceramids is a likely source for pore-filling cement in the Greenhorn chalky limestones. With insignificant exceptions the ammonites are preserved as molds or sparse crystalline casts and the nacre of inoceramids is absent. Except for a few crystalline casts of baculitids and hamitids, space once occupied by aragonitic ammonite conchs and inoceramid nacre was closed completely by unconsolidated sediment during a pre-lithification stage of diagenesis. This is in marked contrast to the English Chalk Rock and similar hardgrounds; in those beds aragonitic skeletons are now represented by hollow molds or crystalline casts, indicating that dissolution of skeletal aragonite followed lithification (personal observation; Bathurst, 1971, p. 404). Some of the best-cemented chalky limestones of the Greenhorn, i.e. marker beds HL-2, JT-1, JT-6, and JT-10 to 12, also contain the greatest concentrations of ammonites, inoceramids and, in the case of HL-2, other originally aragonitic macroinvertebrate skeletons.

Whereas the development of Greenhorn carbonate beds of high purity seems to reflect periods of reduced detrital sediment influx (Hattin, 1971, p. 429), the oblate spheroidal concretions of chalky limestone in the upper part of the Jetmore Member, and especially in the Pfeifer Member require separate comment. These structures are diagenetic, rather than primary, concentrations of high-purity carbonate. Like the continuous beds of chalky limestone, the concretions now have a neomorphosed matrix of microspar. These concretions usually formed around or beneath organic remains, including logs, inoceramids, or ammonites; development of some such structures apparently was initiated along thin laminae of foraminifera, fecal pellets, and calcispheres. Skeletal remains and fecal pellets are commonly preserved in-the-round so lithification began early in diagenesis. Concretion formation apparently was initiated by chemical reactions involving decomposition of organic matter as suggested by Weeks (1963, p. 16), Berner (1968) and Galimov and others (1968, p. 181), but details of this process await further investigation.

Calcite fillings of calcisphere and foraminiferal chambers represent growth of sparry cement in void spaces. Where only one or a few blocky crystals are present, void filling may have been effected from few centers of growth. Much less commonly, chamber filling in foraminifera occurred in the usual fashion, i.e. with small fringing crystals initially and large crystals at the chamber center. Except for the possibility of differential textural changes during inversion of an original cementing substance to the present low-magnesium calcite, there is no obvious explanation for the difference because both varieties of void filling can be seen in a single thin section. Foraminifer chambers that were filled with micrite have mostly been altered to microspar or pseudospar; in most such examples the test wall was destroyed. Conversion of chamber fill to microspar occurred at the same time that the matrix was being neomorphosed. The emplacement of sparry cement within test chambers apparently occurred during early diagenesis.

From the evidence outlined in the preceding paragraphs it is concluded that beds of chalky limestone began to lithify shortly after desposition, while still influenced by the marine environment. This is the eogenetic stage of burial of Choquette and Pray (1970, p. 215). That submarine lithification can and does take place in carbonate sediments is now so well known as to need no defense here.

The foregoing discussion touches only upon the major features of Greenhorn diagenesis. A more incisive analysis of the subject is beyond the scope of this bulletin and must be published elsewhere.

DEPOSITIONAL ENVIRONMENT AND PALEOECOLOGY

Regional Setting and Stratigraphic Framework of Greenhorn Deposition

Late Cretaceous marine rocks of Kansas represent erosionally truncated deposits laid down in the eastern part of a broad seaway that by Cenomanian time extended continuously from eastern Mexico to Arctic Canada (Cobban and Reeside, 1952, p. 1022). The subsiding trough that admitted these waters has been called the Rocky Mountain geosyncline by many authors (e.g. Gilluly, 1963, p. 146; Armstrong, 1968, p. 432). Throughout the U.S. Western Interior region, subsidence was greatest along the western edge of this structural depression. Locally, as in southwestern Wyoming and central Utah the Upper Cretaceous deposits alone reach thicknesses between 18,000 and 20,000 feet (Reeside, 1944). In addition, Late Cretaceous sedimentary deposits become generally coarser grained toward the western margin of the trough (Reeside, 1957, p. 508) where, in a complexly intertongued relationship, fine-grained offshore marine shales give way to nearshore and marginal marine sandstones and these in turn give way westwardly to nonmarine deposits of coastal swamps and piedmont areas (see Pike, 1947; Spieker, 1949; Weimer, 1970, p. 273). Distribution of lithofacies delineates clearly a major western source area for the trough-filling detritus. This detritus was derived from tectonic highlands, the Sevier orogenic belt (Fig. 21) of Armstrong (1968, p. 435), that were raised along the site of the former Cordilleran geosyncline (Gilluly, 1963, p. 146; Armstrong, 1968, p. 432; King, 1969, p. 70). As a part of the stable craton, the area to the east of the seaway

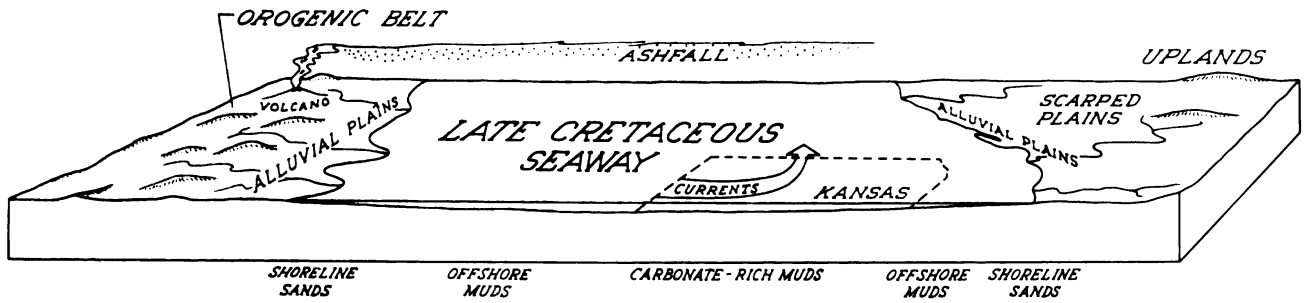


FIGURE 21.—Block diagram depicting a portion of the Western Interior Sea during deposition of the Greenhorn Limestone, and nature of bordering land areas.

was low and flat (Reeside, 1957, p. 509) and for most of Late Cretaceous time was not an important source area for sediment contributed to the seaway (Weimer, 1970, p. 273).

In many parts of the Western Interior region, Late Cretaceous rocks manifest marked cyclicity; nowhere is this cyclicity marked more clearly than along the western edge of the former seaway where dark-colored shales and light-colored sandstones are intimately intertongued. Pike (1947, p. 15) has reviewed the two major hypotheses that have been put forth to account for such intertonguing, namely 1) repeated vertical crustal oscillation within the seaway during deposition, and 2) alternation of transgression caused by downward movements of the crust and regression resulting from subsequent detrital infilling of the basin margin. The latter hypothesis was favored by Pike (1947) and is accepted by the author as the most reasonable explanation of recorded sedimentary features. Details of cyclic sedimentation in the Four Corners area and in central and eastern Utah have been elaborated by Pike (1947) and Spieker (1949), respectively, and Weimer (1960) has documented on a regional basis four major cycles of sedimentation that can be recognized through much of the Cretaceous System as developed in the Rocky Mountains and Great Plains areas. The cycles are most readily deciphered along the western side of the Late Cretaceous trough where transgressions are reflected in westward-directed tongues of dark-colored shale and regressions are marked by eastward-directed tongues of sandstone. The youngest of these regressive sandstone bodies corresponds to the Fox Hills Sandstone of the classic Western Interior section, and before erosion of the Great Plains during Tertiary time, may have extended across parts of Kansas. The other regressive sandstone bodies did not extend as far east as Kansas, so in that state the pattern of cyclicity is different than in western Colorado and Utah. In the lower part of the Upper Cretaceous section in Kansas, the writer (Hattin, 1964) recognized and described one complete cycle of sedimentation corresponding to the first cycle of Weimer (1960). The remainder of the Kansas section represents only part of a second and very large-scale cycle corresponding to the second, third, and probably part of the fourth cycles of Weimer (1960).

The first of the Kansas cyclothems embraces marine strata from the upper part of the Dakota Formation to the top of the Codell Member, Carlile Shale. The terminal units represent the beginning and end stages of transgression and regression, respectively. Maximum transgression (Fig. 22) is represented by relatively pure pelagic carbonates of the Jetmore and Pfeifer Members of the Greenhorn; for this reason the sequence was named Greenhorn cyclothem by Hattin (1962, p. 124). Initial deposits of the Greenhorn cyclothem are older in Colorado, where uppermost

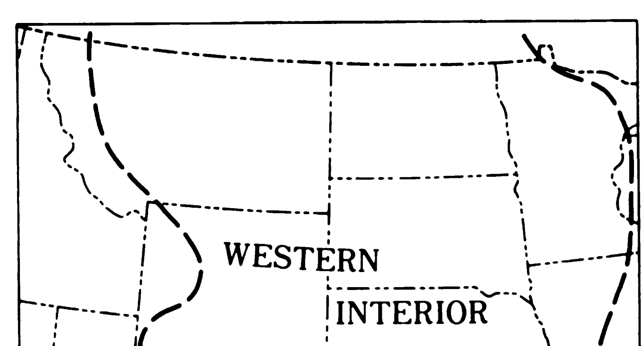


FIGURE 22.—Paleogeographic map showing extent of Western Interior Sea at time (Early Turonian) of maximum transgression. Adapted from Reeside (1957, fig. 8).

Dakota strata are of Late Albian age (Waagé, 1959), than in Kansas where marginal marine strata at the top of the Dakota are of Cenomanian age (Hattin, 1967, p. 588). The Dakota-Graneros contact is therefore diachronous, ascending chronologically in an eastward direction. Evidence has been presented above and in a previous work (Hattin, 1968) that the base of the Lincoln Member of the Greenhorn is also diachronous, climbing the section from southwest to northeast in western and central Kansas. The base of the sequence of close-spaced, resistant, chalky limestone beds of the Bridge Creek and Jetmore Members also is diachronous in an eastwardly ascending sense. The purest carbonate beds in the Greenhorn section are in the Jetmore and Pfeifer Members; the overlying Fairport Member, Carlile Shale, is lithologically similar to the Hartland and Lincoln Members and represents the initial phase of regression in the Kansas area of chalk deposition.

The Greenhorn Limestone of Kansas represents accumulation of carbonate-dominated sediments far from the major, western source area of terrigenous detritus (Fig. 21). The writer (Hattin, 1971, p. 426) has determined that terrigenous detritus content of the Hartland and Jetmore Members increases westward, apparently reflecting influence of western sources. This pattern suggests that eastern source areas had little influence on Greenhorn sedimentation either by reason of small contribution from low-lying land areas of the central craton, or because of great distance from the eastern shoreline, or both.

Greenhorn carbonates can be traced southwestward from Kansas across Colorado and northern New Mexico to the San Juan basin where they pass into shales and sandstones of the Mancos Shale (Dane and Bachman, 1957; Dane, 1960, p. 65, 66). Westward the Greenhorn thins gradually towards South Park, Colorado where a 40-foot-thick calcareous section containing as few as one bed of limestone was assigned to the Benton Formation by Stark and others (1949, p. 52). Beyond that area the Greenhorn interval is represented in westernmost Colorado and eastern Utah by white-weathering calcareous shale of the Mancos (Katich, 1956, p. 118). In northeastern Colorado and southeastern Wyoming the Greenhorn becomes less calcareous and is lost in a section called Benton Shale by McCrae (1956, chart); west of this area, the same interval is included in the Frontier Formation in southern Wyoming (Cobban and Reeside, 1952, chart 10b) and in northwestern Colorado (O'Boyle, 1955, p. 39). Northwestward from Kansas the Greenhorn persists as a carbonate unit as far as the Black Hills, but westward therefrom the carbonate units are replaced by shales and sandstones of the Frontier Formation and Cody Shale (Cobban and Reeside, 1952a, p. 1954-1955). Northwestward from the Black Hills the Greenhorn thins appreciably, becomes less calcareous and passes into calcareous shales and sandstones of the Colorado Shale in central Montana (Cobban, 1951, p. 2183-2185). In most of the eastern Montana subsurface, the Greenhorn equivalent is known as Greenhorn Formation (Billings Geol. Soc., 1969, p. 9). The Greenhorn extends northward from Kansas across much of Nebraska and South Dakota, and is recognized also throughout most of North Dakota by Hansen (1955, p. 29) who described the units as consisting in the subsurface of "dark gray calcareous soft shale with thin beds of very shaly limestone." In the latter state the strata apparently represent a broad transition zone wherein the Greenhorn grades progressively to less chalky and limy, and therefore less typical, lithology. North of the Canadian border, the Greenhorn is not recognized as a formal unit, but its position is recognized in the Favel Formation (second speckled shale unit of petroleum geologists) in Manitoba and Saskatchewan (Wickenden, 1945, p. 33). Regional distribution of the Greenhorn is depicted in Figure 23.

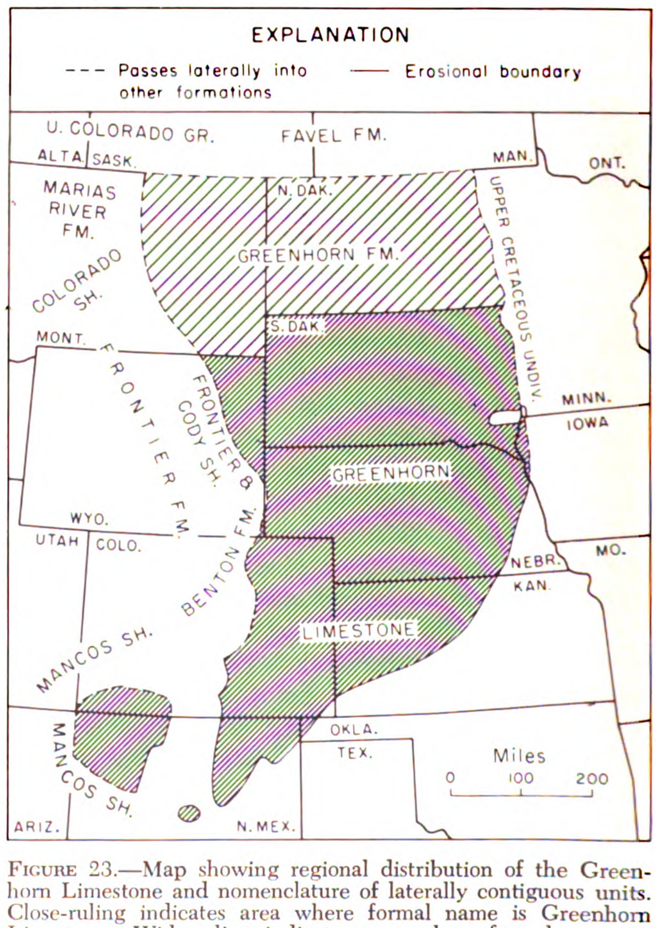


FIGURE 23.—Map showing regional distribution of the Greenhorn Limestone and nomenclature of laterally contiguous units. Close-ruling indicates area where formal name is Greenhorn Limestone. Wide-ruling indicates area where formal name is Greenhorn Formation.

Sources of Sediment

The principal component of most Greenhorn rocks is calcium carbonate, nearly all calcite, which occurs in many forms. Examination of samples in the field and of thin sections and scanning electron micrographs (Hattin, 1971; Hattin and Darko, 1971) has served to identify virtually all carbonate components. Shaly chalk, the most abundant variety of rock in the Kansas Greenhorn, consists largely of coccoliths. These minute fossils are the skeletal remains of coccolithophores, members of the Chrysophyceae (golden-brown algae), modern examples of which are mostly floaters in the open ocean. When coccolithophores die, the remains sink to the bottom where the tiny skeletal plates accumulate as part of the sea floor ooze. Alternatively, coccolithophores are eaten and their skeletons reach the sea floor as fecal pellets or in animal carcasses (Bathurst, 1971, p. 267). Coccolithophores must have been exceedingly abundant in Cretaceous seas because the widely distributed chalk deposits of that system are generally rich in coccoliths (Hatch, Rastall, and Black, 1938, p. 167).

Also abundant in Greenhorn rocks are tests of calcareous foraminifera; these occur in vast numbers in many calcarenites and are conspicuous in most samples of shaly chalk and chalky limestone. The vast majority of these foraminifera were planktonic forms (Eicher and Worstell, 1970a), especially including members of the Heterohelicidae and Rotaliporidae. Like coccoliths, the foraminifers sank upon death to the sea floor where the skeletal remains became part of the accumulating pile of carbonate sediment.

In a few calcarenites of the Lincoln Member and in certain pelletoidal limestones of the Pfeifer Member, large numbers of minute spherical structures are concentrated in very thin laminae. These structures are believed to be related to the so-called calcispheres of the Paleozoic. I believe that Greenhorn structures of this kind may have been derived from some form of planktonic algae. Rupp (1966, p. 186) stated the case for algal origin of calcispheres but concluded that they are of benthonic origin. Such structures have been reported previously from the Lower Cretaceous of Texas (Thomas, 1931) and from the Cretaceous of Mexico (Bonet, 1956; Bishop, 1970) but have not been reported previously from the Western Interior region. Both of the authors regarded the Mexican calcispheres as being of planktonic origin.

Shaly chalk, many chalky limestones, and a few calcarenites contain spherical, or where compressed ellipsoidal, calcareous pellets composed of micrite. These structures are common also in chalks of the Fairport Member, Carlile Shale. The writer (Hattin, 1962, p. 106) concluded that these are fecal pellets of a coccolithophore-eating organism. The same interpretation is accorded similar pellets in the Greenhorn. Scanning electron micrographs of such pellets show them to be composed of coccoliths and ultramicroscopic blocky crystals of calcite that look like broken coccolith elements.

The remaining carbonate components are of benthonic or diagenetic origin. Inoceramid valves, valve fragments, and isolated prisms are chief among these constituents of Greenhorn carbonate rocks. The commonly fragmented condition of inoceramid valves, and almost ubiquitous occurrence of isolated elements of the prismatic layer are probably owing largely to preburial oxidation of an organic matrix of the kind that occurs within both nacreous and prismatic layers of living bivalves (Wilbur, 1964). Such oxidation would result in ready disintegration of valves, a process capable of producing immense quantities of skeletal debris. Apparently Tarr (1925, p. 259) was first to offer this explanation for *Inoceramus* debris in Cretaceous rocks. Presence in Greenhorn rocks of teeth of the shell-crushing shark *Ptychodus* suggest that these predators exacted a toll among the larger benthonic invertebrates. However, teeth of these sharks are sparse everywhere but at the base of the Lincoln Member, and even the predation of sharks or other carnivores could not account for the enormous numbers of prisms that were separated from parent valves. Additional skeletal remains, usually in the form of whole or little broken valves of oysters, anomiids, rare entoliids, cirripeds, and other benthonic organisms make up most of the remainder of primary carbonate material in the Greenhorn Limestone of Kansas.

Additional sources of calcium carbonate must be sought to account for the void-filling sparry calcite of biosparites and biosparrudites and for calcite that played an important role in conversion of originally carbonate muds into the microsparite or pseudosparite that comprises most chalky limestone beds. Circulating interstitial seawater furnished some carbonate for cementation of biosparites and for initial cementation of soft, highly porous bioturbated muds. A second major source for such carbonate was early diagenetic dissolution of aragonitic skeletal material. In biosparites, pressure solution phenomena suggest a third source of carbonate cement.

Silt and finer-sized terrigenous detritus comprises the bulk of insoluble residues in most Greenhorn samples. For the Hartland, Jetmore, and Bridge Creek Members details of residue analysis have been furnished in a paper by the writer (Hattin, 1971, p. 427). In these members percentages of insoluble residue range from 1.6 to 23.3 percent in chalky limestone and 5.8 to 78.4 percent in shaly chalk. The one sample of shaly chalk having less than 9.5 percent residue contains many lenses of skeletal limestone. The small number of shaly chalk samples having greater than 50 percent insoluble residue are adjacent to bentonite seams and are bentonitic. In general, less than 10 percent of any residue consists of diagenetic or epigenetic minerals. In these members the volume of terrigenous detritus increases westward suggesting greater influence in that direction of a western source area. Detailed study of residues was made of the Lincoln and Pfeifer Members only at Locality 3; the percentages of residue for chalky limestones and shaly chalk of these members fell within the ranges stated above. Lincoln residue percentages are comparable with those of the Hartland Member and reflect relatively high rates of terrigenous detrital influx while transgression was in progress. Pfeifer residue percentages compare more closely with those from the Jetmore Member and reflect the smaller amount of terrigenous detritus that reached central Kansas during the stage of maximum transgression when the shores were most remote from the area (Fig. 22). During the Early or Middle Cenomanian, central Kansas was the scene of fluviatile and deltaic sedimentation (Plummer & Romary, 1942, p. 342; Hattin, 1967, p. 587) for which the principal transport direction was toward the southwest (Franks and others, 1959, p. 237). By the time of later Greenhorn deposition, eastward transgression of the sea had pushed the shoreline far to the east or northeast of the present line of outcrop, so that the influence of cratonic source areas to the northeast were probably of less importance volumetrically than were the orogenic source lands to the west.

Arenaceous terrigenous detritus, consisting of silt and very fine to fine-grained sand, dominantly quartz, but including small quantities of feldspar, is common at the base of the Lincoln Member. Coarser detritus of this kind is associated with high-energy rudaceous skeletal limestones. Across much of central Kansas, basal Lincoln strata rest sharply on Graneros Shale along a disconformity that manifests clear evidence of erosional truncation (Hattin, 1965a, p. 11; 1968). Occurrence of relatively coarse terrigenous detritus only in basal beds of the Greenhorn suggests reworking from the Graneros Shale.

Except in the Lincoln Member, bentonite seams in the Greenhorn of Kansas can be traced for long distances along the outcrop (Hattin, 1971). These bentonites are composed predominantly of montmorillonite as determined by X-ray diffraction techniques. These seams represent devitrified volcanic ash from sources in the Sevier orogenic belt (Fig. 21). In some sections bentonite occurs also as pebbles, apparently reworked from the Graneros Shale, mostly in rudaceous biosparites lying at the base of the Lincoln Member.

Skeletal grains of vertebrate origin, especially including shark teeth, teleost scales and teleost bone fragments are virtually ubiquitous in Greenhorn carbonate rocks but range widely in abundance. Such grains tend to be concentrated in the biosparites and biosparrudites and are especially abundant in the basal part of the Lincoln Member. However, scales, bones, or bone fragments were recorded in shaly chalk units at every section examined in detail and these rocks contain scattered shark teeth and sparse, semi-articulated teleost skeletons as well. Vertebrate remains are least common in chalky limestone. Except for the likelihood that vertebrate remains have been concentrated in the basal part of the Greenhorn by reworking of the Graneros in areas of unconformable contact, the fish that yielded these skeletal remains were inhabitants of the Western Interior Sea during deposition of Greenhorn sediments. Also of probable vertebrate origin are rounded, cylindrical, dark brown phosphatic pebbles less than one centimeter in diameter. Most of those observed were in basal skeletal limestones of the Lincoln; rare pebbles of this kind have been recorded higher in the Greenhorn. These pebbles are probably coprolites.

The final primary constituent of Greenhorn rocks consists of organic matter. Many thin sections of shaly chalk contain very fine wispy grains of deep-amber to black material that is oriented parallel to laminations. Samples of weathered and nonweathered shaly chalk were analyzed for organic carbon. The nonweathered rock, which is of olive gray to olive black color, contains greater percentages of organic carbon than the pale yellow and orange-colored weathered rocks. Furthermore, all nonweathered shaly chalk units analyzed have significantly greater quantities of organic carbon than do adjacent chalky limestone beds. Percentages of organic carbon in shaly chalk and chalky limestone units in the Hartland, Jetmore and Bridge Creek Members have been reported previously by the writer (Hattin, 1971, p. 427). The preservation of greater amounts of organic carbon in shaly chalk was interpreted as the result of reducing conditions in the interstitial environment of those sediments. The same interpretation is advanced here for shaly chalk beds of the Lincoln and Pfeifer Members. In analyzed samples of nonweathered shaly chalk from all members the percentage of organic carbon ranges from 0.37 to 6.3. In a total of 20 samples, only three contained less than 2.3 percent organic carbon, and all three of those samples are from a unit so diluted by bentonite that the rock is less than 50 percent carbonate. In contrast, 10 analyzed samples of little-weathered chalky limestone contain 0.1 to 0.5 percent organic carbon, averaging only 0.28 percent.

The organic matter in Greenhorn chalky rocks may be in part finely divided particles of carbon derived from vegetable matter in terrigenous source areas. However, the relatively high percentages of organic carbon (up to 6.3 percent in one Lincoln sample), and lack of obvious carbonaceous specks and woody fragments in most Greenhorn rocks, suggests that the carbon has been derived largely from organic matter of marine origin, i.e. from decay of coccolithophores, foraminifera, fish, *Inoceramus*, etc. on the sea floor.

Sequence of Depositional Events

During early Late Cretaceous time the Western Interior sea spread gradually eastward across the central Great Plains region. This transgression is manifested clearly in the succession of lithofacies embraced in the stratigraphic interval extending from the upper part of the Dakota Formation to the top of the Greenhorn Limestone. Within the Dakota fluviatile sandstones and mudstones give way upward to estuarine and other marginal marine sediments lying in the upper few feet of the formation (Plummer & Romary, 1942, p. 345; Hattin, 1964, p. 207; 1967, p. 582; Siemers, 1971, p. 30). The formation is overlain conformably by the Graneros Shale which consists in its lower part of noncalcareous sandy and silty shales and thin, discontinuous sandstones. These beds grade upward into less sandy, locally calcareous shales containing thin, discontinuous beds of calcareous, shelly sandstone and oyster-rich skeletal limestone (Hattin, 1965a). The stratigraphic sequence of lithologic, macrofaunal, and microfaunal changes suggests convincingly that as Graneros contains proportionately more planktonic, as was progressively farther from the edge of the still-advancing eastern shoreline, and that ultimately the sea in that area attained normal or nearly normal salinity (Hattin, 1965, p. 50). Towards its top the Graneros contains proportionally more planktonic, as contrasted to benthonic, foraminifera and the shales are locally calcareous to chalky; these lithologic and faunal changes reflect the onset of environmental conditions that produced the Greenhorn carbonates. The shift from dominance of terrigenous detrital deposition (Graneros) to carbonate deposition (Greenhorn) is a manifestation of increased distance from shore, such that accumulation of dominantly pelagic carbonate sediment was volumetrically greater than contributions from the terrigeneous detrital dispersal system.

In a few places, especially including Locality 12 (Kearny County) and Locality 6 (Washington County), the upward change from noncalcareous silty clay shales of the Graneros to chalky Greenhorn strata is transitional through several feet of conformable strata. However, at all localities from Ford County (Loc. 8) to at least as far north as Lincoln County, the Greenhorn rests on the Graneros with sharp discontinuity (Hattin, 1968) where noncalcareous or only weakly calcareous shales are overlain by well-washed skeletal limestones (biosparites and biosparrudites) of the basal Lincoln Member. Even in places of lithologic transition between the two formations the lower part of the Lincoln contains many beds and lenses of skeletal limestone. These limestones reflect high-energy conditions at the sediment-water interface, with considerable sea-floor scour across much of central Kansas. Reworking of the Graneros is evident in quartz- dominant sand and silt, bentonite pebbles, and certain macroinvertebrate remains contained in basal Lincoln skeletal limestones. Dominantly chalky strata above these limestones are firm evidence against regression having occurred at this time. Concentration of skeletal limestone is characteristic of the basal Lincoln across much of the Great Plains region and the explanation of these limestones requires a regional rather than a local mechanism. In an essay on epeiric clear water sedimentation, Irwin (1965, p. 450-454) discussed a model that explains development of skeletal limestones in a high-energy, offshore sea-floor zone of wave impingement and dissipation in a belt tens of miles wide. The effects of wave dissipitation in offshore zones of epeiric seas have been elaborated also by Shaw (1964, Chap. 6, 7). Both Irwin and Shaw were concerned with essentially autochthonous sediment models which, as applied to the Dakota-Graneros-Greenhorn example, must be modified so as to accommodate terrigenous detritus as the dominant kind of sediment landward to the high-energy zone. The basal Lincoln skeletal limestones may be viewed as the initial result of eastward or northeastward sweep across Kansas of a relatively wide, high-energy, offshore zone of wave impingement on the bottom during the transgressional phase of the Greenhorn depositional cycle. A broad, nearer-to-shore, mostly lower zone characterized by deposits of terrigenous mud (Graneros) was at first scoured, deeply in places, and then buried beneath deposits of skeletal debris. The time elapsed during passage of this high-energy zone across western and central Kansas is manifest in the diachroneity of the Graneros-Greenhorn contact (Hattin, 1968).

Impure carbonate mud, later weakly consolidated into shaly chalk, was the dominant sediment above the base of the Lincoln. This represents deposition of largely pelagic sediment in a lower energy, far offshore portion of the eastern shelf region of the Western Interior Sea. Sporadic surficial sediment reworking, and consequent winnowing of the fines, concentrated in thin lenses and lensing beds the skeletal debris that comprises biosparites in the middle and upper parts of the Lincoln Member. As transgression continued, the production of skeletal sands and silts waned, first in western Kansas, then at the southern end of the central Kansas region and finally in the northeastern part of the outcrop. Lincoln deposition was punctuated by ash falls, now bentonite seams, which attest to crustal unrest beyond the western edge of the seaway.

Shaly chalk, chalk, and chalky limestone of the Hartland Member reflect continued deposition of largely pelagic sediments in a zone still farther offshore than for Lincoln sedimentation, and in water too deep for the bottom to have been affected significantly by surface waves. This corresponds to zone X in the epeiric sea model of Irwin (1965, p. 450). At least in one place, however, a large lens of biosparite was produced where a scour channel was filled by a current-washed deposit of foraminifer tests (Fig. 9, C). From time to time the influx of terrigenous detritus waned, and layers of purer carbonate accumulated (Hattin, 1971). Where least well developed these are now beds of micritic chalk; where best developed these layers formed beds of microsparitic chalky limestone. Nearly all of these beds were extensively bioturbated.

During deposition of the Jetmore Member, and the stratally equivalent part of the Bridge Creek, impure carbonate mud deposition continued to predominate. These beds have been consolidated into shaly chalk. As during deposition of the Hartland and lower part of the Bridge Creek, whenever terrigenous detrital influx was reduced significantly, a bed of relatively pure carbonate mud accumulated. During deposition of the lower submember, and equivalent part of the Bridge Creek, 9 such beds were formed. All of these beds were homogenized by a burrowing endobenthos. In the interval between deposition of JT-1 and JT-2, currents swept the sea floor across most of the present outcrop and produced a widespread thin to very thin lensing bed (Fig. 11,D) or group of very thin lenses of foraminifer-dominated biosparite. Widespread development of this unit, together with unusually uniform stratigraphy in this part of the section, including regionally developed time-parallel limestone beds (Hattin, 1971) and thin bentonite seams, bespeak a nearly featureless sea floor of exceptionally low gradient.

In the upper foot or two of the lower submember, shaly chalk beds are crowded with valves, fragments, and small lenses of inoceramid remains that served as substrate for clusters of *Pycnodonte*. Better circulation, occasioned by general renewal of current impingement on the sea floor, generated these shell-rich beds. Abundance of inoceramid remains persists into the overlying submember, which includes the three hard beds, JT-10 to JT-12. The valves are typically disarticulated, but breakage was limited. These limestones contain burrow structures, but these are progressively fewer upward in the section. Like the subjacent limestone beds, the hard beds resulted from periods of reduced terrigenous detrital influx. Early diagenetic loss of skeletal aragonite from the myriads of inoceramids is offered as explanation for the superior hardness of these limestone beds. The very large numbers of inoceramid valves may have served to reduce burrowing activity in these beds.

In the third submember of the Jetmore, shaly chalk-forming mud continued as the dominant sediment type. The abundance of *Mytiloides* was reduced sharply and oysters once again were scarce. Bottom conditions favored a limited epifauna, but conditions below the sediment-water interface virtually excluded burrowers. From this part of the section upward chalky limestone is commonly concretionary, a fact that may relate to the greater purity of carbonates in shaly chalk beds of the Jetmore and Pfeifer Members. Diagenetic segregation of calcium carbonate resulted in development of oblate spheroidal concretions and non-burrowed thin beds of chalky limestone that are common above JT-12.

The Shellrock limestone bed represents widespread, prolonged reduction of terrigenous detrital influx, coupled with conditions favorable for proliferation of *Mytiloides* (Fig. 13,D) and extensive burrowing in the lower part of the bed. The upper part of the bed was formed by diagenetic segregation of calcium carbonate as evident in the mammilated and commonly concretionary (Fig. 13,C) nature. Except for portions containing crowds of *Mytiloides* and a thalassinoid type of burrower, the sparse benthos suggests that bottom waters were poorly circulated during deposition of the Shellrock bed.

Pfeifer deposition, like that of underlying members, was dominated by accumulation of impure pelagic muds that later became shaly chalk. These beds contain less impurity than those in the Lincoln and Hartland Members. The lower two thirds of the Pfeifer, from the top of JT-13 to PF-2 contains much inoceramid debris and many small lenses of biosparite, as well as an epifauna of somewhat greater density and diversity than most beds of the Jetmore. Improved circulation of bottom waters fostered this fauna. Gentle currents broke up fragile inoceramid valves and concentrated the skeletal debris as small lenses. This activity was less pronounced during deposition of an equivalent part of the Bridge Creek in western Kansas. Decreased detrital influx may have been responsible for widespread chalky limestone beds like PF-1, as well as for the less obviously continuous, irregular, shell-rich beds below PF-2 (sugar sand). In all these beds, as well as chalky limestones in the upper part of the Jetmore, density of allochemical grains is much greater, on the average, than for chalky limestones of the Hartland and lower Jetmore (Table 3). This suggests exceptionally slow rates of terrigenous detrital sedimentation and apparently also a slower rate of fine carbonate mud deposition. The high proportion of fecal pellets in upper Jetmore and Pfeifer chalky limestones (Table 4) corresponds with the appearance of rocks having higher densities of allochems. One may speculate that for these beds greater-than-usual volumes of coccoliths or coccolith debris reached the sea floor in fecal pellets.

The irregular, discontinuous beds of shell-rich chalky limestone in the lower one-half to two-thirds of the Pfeifer is indication that primary concentration of carbonate was expanded by diagenetic segregation of $CaCO_3$. Hemispheroidal concretions attached to these beds, and oblate spheroidal concretions amongst the beds lends force to this conclusion.

During deposition of upper Pfeifer sediments, from just below the sugar sand to the Fencepost limestone bed, the sea floor was once again quiescent. Currents that produced lower Pfeifer skeletal lenses had waned so that production of these lenses ceased. Foraminifera, calcispheres, and fecal pellets occasionally fell to the sea floor in sufficient numbers to form grainstone laminae, but for the most part shaly chalk-producing muds were deposited. Within the sediments of this quiet sea floor, large, oblate spheroidal concretions developed beneath, or sometimes enclosing, the decaying remains of various organisms.

The terminal event of Greenhorn deposition was deposition of the Fencepost limestone bed. This bed, like many others in the Pfeifer, has high allochem density and abundant fecal pellets. Very slow influx of terrigenous detritus, coupled with very high fecal pellet production, produced yet another widespread bed of rock having a relatively low volume of matrix. The depositional regime that produced the upper few feet of the Greenhorn persisted with no change during the early part of Carlile sedimentation.

Physical Aspects of the Environment

General Statement.—Much has been written about the depositional environment and paleoecology of Cretaceous chalk, especially the English and northwest European chalk. Until very recently the American chalk in general has received little study in this regard and the Greenhorn Limestone has been almost wholly ignored. The past few years have witnessed much-increased interest in this unit, with numerous authors making contributions to the better understanding of the conditions under which the formation was laid down. Still, no previous author has attempted embracive environmental synthesis of the Kansas Greenhorn. In the following sections pertinent environmental parameters are examined from the standpoint of organic and inorganic evidence. Paleoecology of important macroinvertebrate groups is given separate attention.

Depth of Deposition.—No environmental parameter of chalk deposition has been discussed at so great length and by so many authors as depth of deposition. For over a century debate has waxed and waned as whether the chalk is an ancient analog of deep sea oozes or the product of accumulation in a much shallower depositional regime. Space permits review of only a few of the major papers and the conclusions therein.

The abundance, or apparent abundance, of planktonic foraminifera in some chalk deposits led many early authors to conclude in favor of oceanic depths for deposition of the British and European chalk deposits (e.g. Huxley, 1858; Fuchs, 1883; Hume, 1894). At this time only Cayeux (1897, p. 527) argued forcefully against the deep-water interpretation, stating that the maximum depth of Chalk deposition in the Paris Basin was less than 150 fathoms (275 m). An intermediate viewpoint on depth of the British Chalk is found in the classic monograph of Jukes-Browne (1903, 1904). On the basis principally of foraminifera, supported by evidence from other fossil groups, he concluded that the Lower Chalk represents deposition at depths of 400 to 500 fathoms (732 to 915 m) (1903, p. 358), the Middle Chalk at depths at most times exceeding 500 fathoms (915 m) (1903, p. 557) and probably reaching a maximum of approximately 650 fathoms (1185 m), and the Upper Chalk at depths up to 700 fathoms (1281 m) (1904, p. 377). The evidence from foraminifera, including depth determinations by several authors, has been reviewed extensively by Earland (1939) who fairly well demolished the notion that chalk is to be compared with deep sea deposits. He concluded (*ibid.*, p. 20) that foraminifera and other fossils of the British Chalk suggest deposition at depths to 50 fathoms (92 m) or less (for impure chalk near the base of the Chalk) to a maximum of 300 fathoms (549 m). Earland reviewed the work of Jukes-Browne (1903, 1904), pointing out many errors in the interpretation of foraminifera.

Sorby (1861, p. 197) was aware that foraminifera may be comparatively rare in chalk, and that coccoliths are the chief constituent of the chalk matrix and on the basis of coccolith abundance he implied that the Chalk is a Cretaceous analog of modern deep Atlantic muds. Quite recently, however, Hay and others (1967, p. 431) mentioned the considerable abundance of coccoliths in shallower shelf deposits. Furthermore, Scholle and Kling (1972) have reported concentrations of coccoliths forming up to 20 percent of the sediment in lagoonal environments off British Honduras at depths no greater than 140 feet (43 m).

In a summary of chalk genesis, Tarr (1925, p. 253) cited the conclusions of workers who believed in great depth of deposition but noted that much of the chalk may have been deposited in depths less than 20 fathoms (37 m). In the past few decades, opinion has shifted in favor of shallower water origin for the European chalk. Boswell (1933, p. 201) stated that "conclusions as to the evidence of fossils would have been stated more boldly in favor of shallow depths but for considerations of the early globigerina ooze analogy." Recent study of percentages of planktonic foraminifera (Barr, 1961) suggests that the British Chalk need not have been deposited at depths much greater than 90 m and, for some parts of the section, at depths much greater than 30 m. By the use of discriminant functions to maximize differences in foraminiferal assemblages, and by comparing Chalk Marl foraminifera with comparable living forms Burnaby (1961) concluded that definite fluctuations occurred, with definite deep and shallow water phases. For the latter he estimated depths as little as 5 fathoms (9 m). For a higher part of the British section and on the basis of comparison with modern sponge bathymetry, Reid (1962) concluded that the Late Turonian Chalk Rock was deposited in water not less than 50 fathoms (92 m) deep and not necessarily more than 110 fathoms (201 m). For the Chalk as a whole he (Reid, 1968, p. 558) stated that the hexactinellid sponge evidence indicated depths of at least 100 m but not necessarily more than 200 to 300 meters. Continental geologists also have been revising to smaller figures the maximum depth of deposition of the Late Cretaceous chalks. Nestler (1965, p. 113) concluded that the benthos of the German Rügen Chalk could have lived at depths ranging from 100 to 250 meters. This is in marked contrast to the estimates of Voigt (1929) who, on basis of bryozoan abundance, concluded that the Rügen Chalk was deposited at depths ranging from 300 to 1000 m or more. Steinech (1965, p. 195) believed that this formation was deposited at depths not greater than 300 m on grounds of comparison with modern depth ranges of some brachipod genera found in the Rügen Chalk.

European and British chalk deposits contain numerous hardgrounds, nodular beds of chalk formed by submarine lithification. Voigt (1959, p. 144-145) has summarized some of the main arguments regarding hardground formation. Many authors believe hardgrounds represent subaerial exposure of carbonate muds, others believe that the hardgrounds represent submarine lithification during a period of shallowing and sedimentary stillstand when the sea floor had become sufficiently shallow to be affected by wave and current action. The occurrence of numerous, closely spaced incipient or fully developed hardgrounds, as in the section at the east cliff, Dover, England, suggests that the sea floor was subjected repeatedly to shallow water conditions. The origin of hardgrounds during episodes of shallowing is a view shared also by Bromley (1967, p. 507). For the well-known English hardground known as the Chalk Rock, he suggested that glauconitization occurred during shallowing to depths not less than 100 m and that phosphatization in this bed occurred during shallowing to depths not less than 50 m. In the Irish "chalk" near Glenoe, Northern Ireland, Mr. Robin Reid showed me some stromatolitic structures associated with a hardground which apparently represents near-sea-level conditions. For chalk deposits with hardgrounds the range of possibilities of depth of deposition is wide, but relatively shallow water, rather than oceanic depths, seems more likely.

Hudson (1967) concluded that the softness of the English Chalk is related to absence of aragonite in sediments initially. He interpreted this as the result of aragonite solution in a bathymetric range where particulate calcite is not dissolved. He stated that this would occur between depths of about 150 m and 280 m.

The preponderance of recent opinion favors deposition of the English and European chalks at depths less than 300 m with the sea at times less than 50 m in depth.

Little work as been done with regard to determination of Upper Cretaceous chalk deposition in the Western Interior and adjacent seas of North America. So far as known at present no European-type hardgrounds are present. Probable bathymetric ranges of 20 to 80 or 100 fathoms (37 to 146 or 183 m) were suggested by Scott (1940, p. 322) for the Eagle Ford and Austin groups of Texas on the basis of ammonite morphology. In a comparison of overall faunal characteristics of the Austin Chalk and Taylor Marl of Texas, Clark and Bird (1966, p. 323) stated that the range of depositional depth could be from 200 feet (61 m) to 6000 feet (1830 m) but this range was reduced to between 200 and 1600 feet (61 m and 488 m) on the basis of accompanying lithologic characteristics. Farther north the Niobrara Chalk is the Austin equivalent. For this unit, primarily physical evidence prompted Miller (1968, p. 18) to conclude that the Niobrara of Kansas was deposited in water only 40 m deep. The abundant occurrence of *Pycnodonte* specimens in the Fort Hays Limestone Member led Frey (1972, p. 48) to suggest that initial deposits of the member represent deposition in waters possibly less than 50 feet (15 m) deep with progressive deepening later resulting in deposition of the Smoky Hill Member at depths of 200 to 500 feet (61 to 153 m). These last figures are based largely on depth estimates made by Kauffman (1969, p. 238) who estimated bathymetric ranges of oysters by comparison with modern analogs.

These interpretations of relatively shallow depths lack agreement with depths estimated by Asquith (1970). Basing his interpretation on considerations of depositional topography and with data corrected for compaction, he determined depths exceeding 2000 feet (610 m) for deposition of submarine slope deposits of the lower Cody Shale in Wyoming, and, by implication, for the correlative Niobrara deposits of the adjacent basin.

For the Greenhorn Limestone, Kauffman (1969) has suggested depths of deposition ranging from 100 to 500 feet (31 to 153 m). Much greater depths were postulated by Eicher (1969a) who concluded from foraminiferal evidence that the central (eastern Colorado) part of the seaway during Greenhorn deposition was 1640 feet (500 m) or more in depth. From determinations of paleoslope he (Eicher, 1969a) postulated maximum depth of 2000 to 3000 feet (610 to 915 m). My own (Hattin, 1971, p. 421) estimation for maximum depth of Greenhorn deposition is founded on stratigraphic considerations. The terminal deposit of the Greenhorn Cyclothem (Codell Sandstone Member of Carlile Shale) is a thoroughly bioturbated shallow water deposit representing slow sedimentation prior to a period of sedimentary stillsand and sublevation. The stratigraphic interval from the top of the Greenhorn to the Codell is a maximum of 300 feet in west-central Kansas. Allowing a generous 50 percent compaction factor this interval was originally only 600 feet thick. If the minimum depth of Greenhorn deposition was near the 1640 feet (500 m) suggested by Eicher (1969a), then even after 600 feet of post-Greenhorn sediment was laid down, the entire western Kansas area would have had to be uplifted at least 1000 feet to bring the sea floor into shallow water depths by the inception of Codell deposition. We have no physical evidence for significant uplift of the area during Greenhorn deposition. Assuming that the Codell is a shallow water sand body, and that the pre-compactional thickness of Carlile Shale was about 600 feet, the maximum depth at the beginning of Carlile deposition would be about 600 feet (183 m). This figure makes no allowance for progressive compaction of the Greenhorn, or of continued subsidence, during Carlile deposition.

Whereas an abundance of fossil planktonic foraminifera may in general suggest deep water deposition, these organisms may be abundant also in shallow water habitats (Phleger, 1960, p. 242). The very high ratios of planktonic to benthonic foraminifera in the Greenhorn are not, in my opinion, an indication of the great depths suggested by Eicher, but are a reflection of bottom conditions unfavorable to the establishment of large numbers of benthonic foraminifera. In the absence or near absence of benthonic forms, the planktonic-benthonic ratio would be high for sediments deposited at *any* depth where planktonic foraminifer tests were settling to the bottom. As pointed out by Phleger (1960, p. 242) planktonic foraminifera can be found in abundance in inner shelf environments. Although an abundance of planktonic foraminifera may be an indication of open sea conditions, an abundance of these forms can also be an indication of *high organic production* (Bandy & Arnal, 1960, p. 1927). Certainly this last condition is indicated by the organically rich shaly chalk beds and the vast numbers of coccoliths in the Greenhorn. I see no compelling reason to assume that a high planktonic to benthonic foraminiferal ratio has any relationship to depth in an unusual environment such as that represented by the Kansas part of the Western Interior Sea during Greenhorn deposition.

In his comprehensive analysis of Late Cretaceous macroinvertebrate assemblages of the Western Interior region Kauffman (1967, p. 122) stated that small *Ostrea*, like *O. beloiti*, occur today in inner shelf waters at depths of 10 to 200 feet (3 to 61 m). In this assemblage small, inequivalve robust *Inoceramus*, *I. rutherfordi*, is a common associate. In Kansas this assemblage characterizes the upper part of the Graneros Shale and occurs locally in the basal part of the Lincoln Member of the Greenhorn. Kauffman (1969, p. 238) concluded that the forms occupied a depth range of 100 to 200 feet (31 to 61 m). At Locality 13 the lower part of the Hartland Member contains small assemblages consisting almost exclusively of the paper pecten, *Syncyclonema*?. Kauffman (1969, p. 240) stated that today such forms are found at mid- to outer-shelf depths of 200 to 500 feet (61 to 153 m). For the sort of assemblange preserved in the *Sciponoceras gracile* Assemblage Zone, Kauffman (1969, p. 239) postulated a depth range of 300 to 500 feet (92 to 153 m). Assemblages containing flat *Inoceramus* covered with small oysters and commonly having other epizoans such as stalked barnacles and serpulid worms, and also containing diverse ammonites were ascribed to depths ranging from 200 to 500 feet (61 to 153 m) by Kauffman (1969, p. 238). This assemblage is most typical of the Fairport Member, Carlile Shale, but a modified version of it occurs in the lower part of the Pfeifer Member. A small, squamous form of *Pycnodonte,* occurring on large, flat *Inoceramus,* occurs in the middle part of the Jetmore Member and is another version of the same assemblage. Kauffman's interpretations suggests depths of Greenhorn deposition ranging from 100 to 500 feet (31 to 153 m), with minimum range of 100 to 300 feet (31 to 92 m). The shallowest depths are for the upper Graneros and lowermost Lincoln. His estimates are entirely compatible with the physical evidence of decreasing levels of environmental energy upward from the basal Lincoln calcarenites, and with my own conclusions regarding maximum depth as determined from considerations of sedimentation and subsidence. The total absence in all thin sections of evidence of algal borings in valves of *Inoceramus,* oysters, etc., is accepted as reasonable evidence for minimum depth greater than 60 to 80 feet (18 to 24 m) (see Swinchatt, 1969, p. 1934; Halsey & Perkins, 1970, p. 565).

Bottom Conditions and Substrates.—Through much of Greenhorn deposition the sea floor consisted of impure carbonate mud that lithified eventually to form fairly homogeneous shaly chalk. This sort of mud bottom was an unfavorable habitat for most forms of benthonic life; on such muds the macroinvertebrate epifauna was restricted largely to inoceramid bivalves and the infauna was practically nonexistent. Benthonic foraminifera were mostly rare on such bottoms (Eicher & Worstell, 1970a, figs. 9, 10).

The preservation of thin laminae in many beds and paucity of current-formed structures such as lenses of skeletal debris are evidence that bottom currents were nil. Fagerstrom (1964, p. 1205) suggested that the mutual occurrence of pelagic and benthonic organisms may be evidence that a preserved assemblage has not been altered by action of bottom currents; such assemblages prevailed generally on Greenhorn chalk-producing substrates. I suggest that poor circulation of bottom waters, and resulting low levels of dissolved oxygen were the principal factors limiting the benthonic faunas in most shaly chalk units. Relatively high content of organic carbon in analyzed shaly chalk samples (average 3.3 percent for 20 nonweathered samples) and near absence of burrow traces in such rocks, suggesting oxygen deficiency in interstitial waters, were a consequence of poor circulation in this environment. A modern parallel has been reported by Calvert (1964) who determined that in the Guaymas Basin, Gulf of California, laminations are preserved where low levels of dissolved oxygen in bottom waters preclude development of a mobile infauna. If Greenhorn sediments had been well oxygenated, one would expect, in such a muddy substrate, a preponderance of deposit-feeding organisms (Purdy, 1964, p. 254) but evidence of any kind of deposit feeders is rare in shaly chalk strata. During deposition of these beds the surficial sediments probably were relatively stable and turbidity of overlying water was low owing (a) to lack of sediment resuspension by deposit-feeding organisms (see Rhoads & Young, 1970), and (b) to lack of mechanical agitation of the sea floor. In such an environment the broad-valved, suspension-feeding inoceramids thrived, apparently by virtue of tolerance to dissolved oxygen levels too low for most other macroinvertebrates. Low taxonomic diversity is characteristic of benthonic environments having low levels of dissolved oxygen (Rhoads & Morse, 1971, p. 419). Except in certain stratigraphic zones, described below, epizoans are rare on valves of inoceramids preserved in shaly chalk beds.

Carbonate muds that lithified to form chalky limestone beds of the Hartland and Jetmore Members, and equivalent parts of the Bridge Creek Member, differ from the shaly chalk-producing muds in two important respects. The former were much more pure than shaly chalk-producing muds and are extensively burrow mottled. The burrow-mottled chalky limestones represent periods of reduced influx of terrigenous detritus (Hattin, 1971, p. 427). Although these beds lack evidence of increased current activity, oxygen content in sediments apparently was greater so that an extensive, mobile infauna of sediment-ingesting organisms could be sustained. It is suggested that these purer sediments were more permeable than those containing greater quantities of fine-grained terrigenous detritus, and that the reduced rate of sedimentation also involved lesser incorporation of organic matter into the sediment. In sediments containing large quantities of organic matter, available oxygen is completely consumed; apparently this happened in the case of shaly chalk-forming substrates. Chalky limestones seem to record the opposite effect because organic carbon levels are low in analyzed samples (average 0.28 percent in 10 nonweathered samples), and the rocks are correspondingly lighter in color than the shaly chalks. Similar environments have been reported from the Santa Barbara Basin off California by Berger and Soutar, (1970, p. 275), who reported that below sill depth available oxygen is readily consumed and resulting sediments are dark colored and do not host burrowing organisms. Above sill depth, where the basin is well oxygenated, the sediments are lighter-colored and have been homogenized by the burrowing benthos. Although this recent example is not a true analog of the Greenhorn environment the influence of oxygen availability on composition and structure of the rock is parallel. I did not detect in the Greenhorn rocks the kinds of differences in skeletal composition and abundance reported from the contrasting environments studied by Berger and Soutar (1970, p. 279). My interpretation of the alternating burrow-mottled and non-burrowed beds of the Hartland and Jetmore Members is the same as that set forth by Hallam (1967, p. 210) for alternating red, mottled, and greenish laminated marls of the Jurassic Ammonitico Rosso of Italy and southern Switzerland.

In comparison with shaly chalk beds of the Greenhorn many of the chalky limestone beds contain a greater frequency of macroinvertebrates in addition to *Inoceramus*. This may be in part a result of reduced sedimentation rate and in part owing to the greater likelihood of finding specimens in chalky limestone. Nevertheless, a few beds, like HL-1 and HL-2, contain not only greater numbers of macroinvertebrates but also greater diversity of both pelagic and benthonic forms. That the added benthonic forms in these beds, especially including *Phelopteria* and *Cerithiella,* represent a real change in benthonic conditions is manifested by increase also in this stratigraphic position of calcareous benthonic foraminifera (Eicher and Worstell, 1970a, p. 276). Special local conditions were not responsible for the increased macroinvertebrate diversity recorded in beds HL-1 and HL-2 because these beds are part of the *Sciponoceras gracile* Assemblage Zone which shows similar increase of diversity across much of the Western Interior region. Eicher and Worstell (1970a, p. 278) attributed the increased diversity of benthonic foraminifera in this zone to widespread improvement of water circulation in the Western Interior sea.

Above the Shellrock limestone bed (JT-13) burrow structures are sparse in all beds of chalky limestone. Although these beds were probably initiated in the same way as Hartland and Jetmore chalky limestones, the chalky limestone-producing substrates of the Pfeifer did not support a diverse endobenthos nor did they support large endobenthonic forms. Sparse mineral-filled burrows were recorded in irregular discontinuous, shell-rich concretionary beds of the Pfeifer, and parts of these beds have an isotropic probably bioturbated fabric, but some of these beds contain good evidence of internal stratification. More continuous beds like PF-1 and the Fencepost limestone bed lack internal stratification and sparse burrows, consisting mostly of minute, calcite-filled structures, occur especially in the Fencepost bed. The isotropic fabric of these two beds as viewed in thin sections suggests that these units also have been bioturbated, but intensive weathering at all exposures studied apparently has eradicated evidence of extensive burrowing.

The general condition of poor bottom circulation during Greenhorn deposition has exceptions. The upper half of the Jetmore Member, from about the level of marker bed JT-8 to shortly above JT-12, and the lower two-thirds of the Pfeifer, from shortly above JT-13 nearly to the Sugar sand (PF-2), are characterized by a profusion of valves and valve fragments of inoceramids as well as by small, commonly poorly washed lenses of foraminiferal and/or inoceramid debris. The epizoal oysters *Pycnodonte* and *Pseudoperna,* locally in large clusters, scattered remains of pedunculate cirripeds, and anomiids are a conspicuous element of the macroinvertebrate fauna in shaly chalk and chalky limestone beds. These fossils are interpreted as the result of generally improved circulation that produced conditions favorable for proliferation of the macroinvertebrate epifauna, including the slowest rates of sedimentation during deposition of the Greenhorn Limestone. Impingement on the sea floor of gentle currents brought supplies of dissolved oxygen to the otherwise nearly stagnant bottom and served to sweep skeletal debris into small heaps through much of the designated intervals. These conditions prevailed during periods of slow as well as more rapid sedimentation because the increased numbers and diversity of macroinvertebrates occurs in both shaly chalk and chalky limestone beds of the two intervals. On an arbitrary energy scale of 1 to 4 these beds represent energy-level 2. Most of the Greenhorn represents energy level 1.

A still higher level of energy expenditure by sea floor currents is represented by the thin, discontinuous beds and zones of lenses of well-washed, commonly cross-laminated skeletal limestone that characterizes most Lincoln sections. The widespread bed of foraminifer- and calcisphere-rich limestone lying between Jetmore marker beds JT-1 and JT-2, and a few lenses in the lowermost Pfeifer also are in this category. Limestones of this sort represent more thorough washing of sediment during short-lived episodes of sea floor scour that set finer sediments in suspension and produced lag concentrates of skeletal debris as much as 0.4 foot thick. On the arbitrary energy scale mentioned above, these rocks represent energy level 3.

Units of crossbedded skeletal limestone as much as 1.5 foot thick and local lenses, possible pararipples, as much as 0.5 foot thick, lie at the base of the Lincoln Member at many Kansas localities, especially in the area extending from Ford County to Jewell County. At most places these thicker units of limestone rest with sharp contact on underlying Graneros strata.

These limestones consist largely of *Inoceramus* debris, especially isolated prisms, as well as shark teeth, bentonite pebbles, coprolites, bits of fossil wood, local intraclasts, and reworked Graneros fossils. Diachroneity of the Graneros-Greenhorn contact (Hattin, 1968; this paper) suggests that these prominent lag-concentrate limestones were produced as an offshore, high-energy belt (Shaw, 1964; Irwin, 1965, p. 450) swept progressively eastward or northeastward during the Greenhorn transgression. The attending environment supported a benthonic macroinvertebrate community consisting principally of *Inoceramus* but supporting also at least 3 species of oysters, a hamitid, and sparse cirripeds. The shifting substrate precluded all but local establishment of abundant macroinvertebrates and only locally do the numbers of *Inoceramus* or oysters compare with those of the upper Jetmore or lower and middle parts of the Pfeifer. On the arbitrary energy scale these beds represent energy level 4, the highest represented in the Greenhorn Limestone of Kansas.

Salinity.—The broad uniformity of fauna, flora, and lithology in Greenhorn rocks suggests that salinity remained essentially constant throughout the period of deposition. Most abundant of all identified organic remains are coccoliths which characterize shaly chalk units throughout the formation. In present-day seas most species of coccolithophores cannot tolerate seawater having a salinity that departs widely from that of the open ocean (Black, 1965, p. 136), and few species of coccoliths can flourish at salinities greater than 38‰ or less than 25‰. The extant species *Braarudosphaera bigelowi* (Gran & Braarud), known to be tolerant of salinities as low as 17‰ (Bukry, 1974, p. 358), and uncommon in waters of full marine salinity (ibid.), was reported only from the upper part of the Jetmore and the Pfeifer Member in a study of the Greenhorn section at Locality 3 (Russell County) by Cepek and Hay (1969, p. 327) and was not recorded in Greenhorn samples from any of the Colorado, Wyoming and South Dakota localities studied by Trexler (1967). Furthermore, the variety of coccoliths recorded in the Greenhorn (Trexler, 1967; Cepek & Hay, 1969) is comparable with that of equivalent rocks in the Gulf Coast section (Gartner, 1969) and suggests water of normal salinity.

Second in observed abundance in Greenhorn rocks are tests of planktonic foraminifera. Eicher and Worstell (1970a) reported a total of 22 planktonic species from the formation at Localities 3, 13, and 14, with as many as 15 of these species occurring in a single lithic unit. Recent planktonic foraminifers are found characteristically in marine waters of normal salinity (Smith, 1955, p. 147; Phleger, 1964, p. 34). Although diversity of these fossils differs from bed to bed within the Greenhorn, the foram assemblage is everywhere dominated by planktonic forms. This evidence is accepted as indicating water of normal or close-to-normal salinity. Stratigraphic variations in planktonic foraminifer diversity documented by Eicher and Worstell (1970a) may represent fluctuations in salinity but if so, these variations are judged to have been small. According to Douglas (1972, p. 26) the northern limit of oceanic conditions in the Western Interior is marked by the limit of keeled planktonic foraminifers. During Greenhorn deposition this boundary lay well to the northwest of central Kansas.

Virtually all parts of the Greenhorn contain ammonites, although these fossils are not distributed uniformly through the section. Largest concentrations appear in the lower part of the Lincoln, in the *Sciponoceras gracile* zone of the Hartland and Bridge Creek (twelve species), in the Jetmore Member, and in the Fencepost limestone bed. With few exceptions modern cephalopods are strictly marine organisms (MacGinitie & MacGinitie, 1949, p. 389) and inhabit marine water of normal salinity (Scott, 1940, p. 308). Kummel (1948, p. 64) noted that cephalopods apparently cannot endure decreased salinities but may be able to tolerate above-normal salinity. Cretaceous cephalopods, like nearly all modern ones, most probably inhabited waters of normal salinity; this conclusion is reinforced by the fact that in the Greenhorn cyclothem, beds believed on other evidence to represent brackish water environments are lacking in cephalopod remains. The upper part of the Dakota Formation (Hattin, 1967; Siemers, 1971) and the lower part of the Graneros Shale (Hattin, 1965a) have been lithologically and faunally linked with brackish water environments. Even where remains or molds of originally aragonitic skeletons are preserved abundantly in these units, the remains of cephalopods are lacking in Kansas.

Pycnodont oysters, such as characterize part of the Jetmore Member, are characteristic of normal marine environments according to Stenzel (written communication, 1972). This genus, and the small oysters of the Pfeifer Member are apparently ancient counterparts of the living *Ostrea equestris*, a similarly small, adnate form which is characteristic of high-salinity waters (Abbott, 1954, p. 373; Parker, 1955, p. 203).

The abundance of *Inoceramus* in most parts of the Greenhorn is also taken as evidence of normal or nearly normal marine salinity. In the Greenhorn cyclothem this genus has stratigraphic distribution nearly parallel with that of ammonites. Vokes (1947, p. 128) believed that *Inoceramus* was normally an inhabitant of water of normal salinity. *Inoceramids* have not been recorded in brackish water assemblages of the upper part of the Dakota Formation in Kansas and are very sparse in the lower part of the Graneros Shale. They are abundant in the upper part of the Graneros Shale where small oysters, ammonites, and planktonic foraminifera collectively indicate waters of normal or near normal salinity.

Temperature.—More than half a century ago knowledge of climatically controlled latitudinal differentiation of Cretaceous biotas was advanced sufficiently to be summarized in some detail by Dacqué, (1915, p. 423-426) in his classic textbook on paleogeography. At that time geologists recognized a warm water Tethyan or Mediterranean belt, characterized by rudists, corals, actaeonellids, nerineids and larger calcareous foraminifera, and a cool water boreal belt characterized by belemnites. Reeside (1957, p. 512) agreed that the Mediterranean realm had a warm or perhaps tropical climate but noted that the more northerly (boreal) realm had a temperate, possibly cold temperate, but not an arctic climate. Jeletzky (1971, p. 1647; 1971a, p. 12-13) also pointed out that the term "boreal" is misleading because paleontological evidence from the higher latitudes indicates at least a warm temperate climate "everywhere in the Cretaceous 'Boreal' Realm." Kauffman (1973, p. 367) has substituted the term "north temperate realm" for "boreal" because in this belt the fauna consists dominantly of warm to mid-temperate organisms. According to Sohl (1971, p. 1611) the Cretaceous of North America was characterized throughout its history by three main biotic provinces including (1) a Caribbean-Central American-Baja Californian province having a warm water (tropical-parentheses mine) fauna of Tethyan affinities, (2) a Coastal Plain-southern Western Interior province having a subtropical to warm temperate assemblage, and (3) a California-northern Western Interior province having a boreal fauna. In a review of biogeographic data on Cretaceous foraminifera, Bergquist (1971, p. 1567, 1568) recognized a climatic zonation comprising tropical, warm temperate, mild temperate, cool temperate, and cold zones. According to this scheme the warm temperate zone included the area of the present Gulf Coastal Plain, the mild temperate zone embraced the southern part of the Western Interior region (including Kansas), the cool temperate zone included the northern part of the U.S. Western Interior and all of western Canada, and the northern cold zone included the Arctic portion of Alaska and Canada. It is doubtful that the Western Interior region was as finely zoned climatically as Bergquist (1971) suggested. Indeed, Kauffman (1973, p. 367) has noted that the Cretaceous north temperate realm contains "no truly Arctic faunas and has few north-temperate bivalves." As Valentine (1967) has pointed out, the latitudinal range of individual species is narrow at times of increased climatic zonation. In the Western Interior region many Late Cenomanian and Early Turonian species have wide latitudinal distribution and the faunas include many European and cosmopolitan species. These observations suggest broad climatic zones of equable temperature. Despite contradictory statements regarding whether the so-called boreal region was cold temperate or warm temperate, pronounced south-to-north differences in Western Interior faunas have been documented extensively (e.g. Sohl, 1971; Kent, 1969; Bergquist, 1971; Eicher, 1969) and climate, i.e. temperature, is accepted generally as the controlling factor.

Certain taxa have been regarded as biogeographically diagnostic. In the southern part of the Western Interior region the Greenhorn Limestone includes endemic species like *Exogyra* aff. *E. boveyensis, Pycnodonte* sp. A, *Anomia* sp. A, and *Pseudoperna bentonensis* as well as cosmopolitan species like *Mytiloides labiatus, Mammites nodosoides,* and *Collignoniceras woollgari.* Some species are migrants from other parts of the same faunal province, for example *Acanthoceras wyomingense* and *Dunveganoceras* spp. which are characteristic of the northern Western Interior and western Canada. The occurrence of *A. wyomingense* only sparingly in the southern Western Interior and the discovery of only a few specimens of *Dunveganoceras* in the Greenhorn suggests that the Kansas area lay at the southernmost geographic limit of these forms. No belemnites have been recorded from the Kansas Greenhorn and only four specimens are known from the overlying Fairport Chalk Member of the Carlile Shale. This evidence suggests that Kansas lay at or below the southern limit of the northern Western Interior province (Sohl, 1971) in late Cenomanian and early Turonian times.

Although rudists have been recorded sparingly in the Niobrara Chalk of Kansas, none have been discovered in the Greenhorn. Likewise, no actaeonellids, corals, or nerineids are known from the Kansas Greenhorn, and only one coral specimen has been recorded from the Greenhorn farther to the north (Cobban, 1951, p. 2184). The Kansas area lay north of the influence of the Tethyan faunal realm. Jeletzky (1971, p. 1654; 1971a, p. 76) noted that the Western Interior south-to-north temperature gradient is expressed by gradual northward disappearance of the Tethyan elements. Studies of gastropod assemblages by Sohl (1971) and foraminiferal assemblages by Bergquist (1971) yield evidence that is in substantial agreement with this concept. During Greenhorn deposition Kansas lay near the southern limit of the north temperate realm; the faunas have a strong affinity with Gulf Coastal Plain assemblages rather than with those of the Arctic area which suggests a warm-temperate rather than a cool-temperate climate. This conclusion is borne out by the evidence of occasional incursions of warm water gastropods (Sohl, 1971, p. 1620) and planktonic foraminifera (Bergquist, 1971, p. 1602) farther northward than usual during the time of Greenhorn deposition.

Oxygen isotope studies of Late Cretaceous fossils, largely belemnites, have been used extensively in paleotemperature analysis. Data from many parts of the world confirm a pattern of poleward temperature decline throughout the Late Cretaceous of the Northern Hemisphere (Lowenstam, 1964, p. 244). A tabulation of North American analyses was presented by Lowenstam and Epstein (1954, p. 220-222) but most of their specimens are from Maastrichtian units of the Atlantic and Gulf Coastal Plains. These analyses yielded temperatures ranging from 16° to 23°C which suggests a marginally subtropical environment. Nonbelemnoid analyses, mostly from Coon Creek, Tennessee bivalves, yielded paleotemperatures ranging from 20° to 28°C which suggests a subtropical environment (ibid., 1954, p. 229). Later, Lowenstam and Epstein (1959, p. 67) reported a baculite analysis from the Coon Creek locality that indicated a paleotemperature of only 17°C.

Few belemnite analyses have been reported from the Western Interior region; however, Lowenstam and Epstein (1954) reported paleotemperatures ranging from 26° to 31°C for three specimens from the Colorado Group at Fort Benton, Montana and 23°C for belemnites from the Coniacian near Winnecook, Montana (Lowenstam & Epstein, 1959, p. 68). These temperatures suggest a marginally tropical environment and are in conflict with statements by those who concluded in favor of a warm to mild temperate climate for the Western Interior region. Similarly high paleotemperature values were recorded by Tourtelot and Rye (1969) for specimens of *Baculites* and belemnites of Campanian and Maastrichtian age from localities distributed between northern New Mexico and southern Canada. In this area they recorded temperatures averaging 21° to 33°, by state, the wide variation being interpreted as the result of isotopic variation within the sea that deposited the Pierre Shale. The generally higher temperature values for Western Interior localities as compared with localities peripheral to the continent was interpreted as resulting from isotopically lighter water owing to meteoric water influx (ibid., p. 1920). These authors believed that the paleotemperature data do not encourage use of oxygen isotopes for climatic analysis of the North American Late Cretaceous.

Despite discrepancies at individual localities for data derived from different organism groups, it is desirable to continue the gathering of data, especially from areas not previously sampled. The Fairport Chalk Member of the Carlile Shale represents deposition under apparently normal marine conditions, far from any shoreline. Belemnites from two localities in Ellis County, Kansas were processed for oxygen isotope analysis in order to compare the paleotemperature values with those of other Western Interior localities, farther west (Tourtelot & Rye, 1969) and with the Gulf Coast values (Lowenstam & Epstein, 1954; 1959). These specimens yielded paleotemperatures of 65°C and 48°C. These temperatures are impossibly high and suggest that the specimens submitted for analysis have suffered considerable alteration of the skeletal carbonate.

Paleoecology of Major Invertebrate Groups

Foraminifera.—Tests of foraminifera are detected readily in many Greenhorn beds and are commonly concentrated in laminae, lenses, and thin beds consisting principally of these fossils. Foraminifera were observed in all of the more than 300 thin sections examined in this study. The recent, excellently illustrated study of Greenhorn foraminifera by Eicher and Worstell (1970a) made detailed treatment of the group unnecessary. However, my petrographic study confirms the overwhelming preponderance of planktonic species as reported by Morrow (1934, p. 188) and by Eicher and Worstell *(ibid.)*, as well as the overwhelming predominance of forms belonging to the genera *Hedbergella* and *Heterohelix*.

The writer (Hattin, 1965a, p. 55) recorded within the Graneros Shale a stratigraphically upward change in foraminiferal assemblages from those consisting wholly of agglutinated forms to those containing a large proportion of planktonic forms. This change was interpreted as resulting from gradual establishment of normal salinity as open-sea conditions developed during the Cenomanian transgression. The predominance of planktonic species in all Greenhorn foraminiferal assemblages reflects approach to and attainment of the transgressional maximum during deposition of the formation. This conclusion is in substantial agreement with that of Eicher and Worstell (1970a, p. 270) who noted that the change to predominantly planktonic assemblages corresponds nearly with the Graneros-Greenhorn contact and coincides with "the opening of the western interior seaway to major open ocean currents." They recognized three major Greenhorn foraminiferal zones: (a) lower planktonic zone,

(b) benthonic zone, and (c) upper planktonic zone. The absence of calcareous benthonic species in (a) was judged by them to be a result of unfavorable bottom conditions, probably low levels of oxygenation. The appearance of diverse species but mostly small numbers of calcareous benthonic forms in (b) was ascribed to improved bottom conditions resulting from improved circulation (Eicher, 1969a, p. 1078; Eicher & Worstell, 1970a, p. 278). In Kansas (b) is only 5 to 7 feet thick and corresponds to the *Sciponoceras gracile* Assemblage Zone which is unique with regard also to the diverse macroinvertebrate fauna that it contains. In this zone the abrupt and widespread appearance of a diverse benthos on a bottom occupied earlier almost exclusively by *Inoceramus* suggests rapid response to improved physical conditions by opportunistic species (see Levinton, 1970). The upper planktonic zone reflects return to "limiting environmental circumstances" (Eicher & Worstell, 1970a, p. 280) similar to those of the lower planktonic zone. They note, however, that the disappearance of benthonic forms is not abrupt; calcareous benthonic species persist sparingly into the Fairport Member, Carlile Shale. Contradiction to their suggestion that increased circulation explains abrupt development of the benthonic zone is seen in skeletal limestones that characterize much of the Lincoln Member, and occur also in the upper part of the Jetmore and the lower part of the Pfeifer. These skeletal limestones imply as good or better circulation of bottom waters as during deposition of the *Sciponoceras gracile* zone, but the accompanying strata are deficient in or lacking benthonic foraminifera. It seems that the abrupt appearance of the *Sciponoceras gracile* assemblage, including its benthonic foraminifera, requires an explanation less general than "increased circulation" especially when one recalls the enormous geographic distribution of the zone.

On the basis of percentage of planktonic foraminifer specimens Eicher (1969a, p. 1079) concluded that the lower part of the Bridge Creek Member, i.e., the *Sciponoceras gracile* zone, was deposited at a minimum depth of 1640 feet (500 m). For Greenhorn beds below the *S. gracile* Assemblage Zone, which contain no benthonic foraminifers, Eicher (1969a, p. 1076) postulated a silled-basin environment and stated that for such a basin depth estimates based on proportion of planktonic foraminifera would be meaningless. Throughout the Graneros Shale and Greenhorn Limestone, assemblages of benthonic macro- and microinvertebrates lack the broad diversity that is characteristic of modern open-ocean floors. During Graneros and Greenhorn deposition bottom conditions obviously were not conducive to proliferation of a diverse benthos; this makes direct comparison with modern open-sea environments very tenuous. Whereas I agree with Eicher that foraminiferal ratios are of little utility when applied to the Greenhorn beds having no benthonic foraminifera, I do not believe that the mere presence of benthonic foraminifera in the overlying beds is in itself basis for valid application of foraminiferal ratios to the problem of paleobathymetry. Conditions may have improved sufficiently to foster growth of sparse benthonic foraminifera in the *S. gracile* Assemblage Zone and overlying beds, but macroinvertebrate and sedimentologic data suggest that the sea floor remained, for the most part, poorly oxygenated.

Ammonites.—On the basis of gross morphology, which may have significance with respect to mode of life, Greenhorn ammonites are classifiable into 7 major types. These are 1) partially uncoiled types like *Worthoceras* and *Scaphites*, 2) irregularly uncoiled forms like *Stomohamites* and *Allocrioceras*, 3) straight uncoiled forms like *Sciponoceras* and *Baculites*, 4) involute, nearly smooth, laterally compressed forms like *Borissjakoceras*, *Desmoceras*, and mature *Tragodesmoceras*, 5) robust, coarsely ribbed, horned or spined ammonites like *Acanthoceras*, *Mammites*, *Colligoniceras*, and *Kanabiceras*, 6) robust, densely ribbed, tuberculate forms like *Eucalycoceras*, *Calycoceras*, *Pseudocalycoceras*, and *Watinoceras*, and 7) involute, ribbed, laterally compressed forms like *Metoicoceras* and youthful *Tragodesmoceras*. This grouping differs somewhat from that of Scott (1940) and represents only 4 of the 7 groups he described. Opinion regarding life habits of the ammonites are diverse and no consensus has been reached; Arkell (1957, p. L120) stated that debate on the subject is at least 90 percent conjecture. Reyment (1958) summarized in considerable detail the contradictory conclusions reached by various cephalopod workers over a 68-year period beginning in 1890. An example of this diverse opinion is found in Birkelund (1965, p. 145) who recounted that different authors have interpreted the scaphites as benthonic, nektonic, or planktonic forms. Excepting certain uncoiled forms Scott (1940, p. 320) concluded from evidence of lithologic association that most Texas Cretaceous ammonites were nektobenthonic and that depth was a major factor controlling distribution. In agreement with Scott, both Arkell (1957, p. L122) and Ziegler (1967) believed that most ammonites were nektobenthonic. Ziegler (1967) believed that in the European Upper Jurassic ammonite distribution was strongly controlled by depth but he believed (p. 453) that the species and genera are generally independent of the substrate. Arkell (1957, p. L119) also noted that Scott's conclusions regarding relationship of shell form to lithology are not applicable generally. Reyment (1958) concluded that a majority of ammonite conchs floated after death and could be transported widely by marine currents, but Arkell (1957, p. L122) believed that current distribution of larvae was probably more important than post-mortem drifting as a means of effecting wide distribution of ammonite species.

Smooth-shelled, involute discoidal Greenhorn ammonites like *Desmoceras* and *Borissjakoceras* are not unlike modern *Nautilus* and like the last were probably excellent swimmers. Heavily ribbed, strongly tuberculate or horned ammonites like *Acanthoceras, Collignoniceras,* and *Pseudocalycoceras* lacked streamlining and apparently were not able to swim rapidly but moved about rather sluggishly, probably close to the sea floor. Modern heavy-shelled *Strombus gigas* which is both ribbed and horned bears a striking resemblance to certain acanthoceratid ammonites when viewed apically; *S. gigas* is well adapted to a foraging habit on the sea floor. The chambered acanthoceratids were certainly more buoyant than *Strombus,* and rather than crawling on the bottom probably utilized their buoyancy to hover above the sediment-water interface.

The baculitids probably swam in schools, somewhat like modern squids. The concentrations of huge numbers of baculitids locally in Hartland marker bed HL-2 and in the Shellrock limestone bespeak a gregarious existence during at least a part of the life cycle. The loosely uncoiled ammonites are among the most curious of all ammonites; why uncoiling occurred is not certain but the question has been reviewed recently by Wiedmann (1969) who concluded that the uncoiling has nothing whatever to do with evolutionary degeneracy. Modern uncoiled mollusks like *Vermicularia* are strictly benthonic, but lack the chambers possessed by ammonites. Chambers in *Stomohamites* and *Allocrioceras* suggest sufficient buoyancy to facilitate short swimming motions but I am inclined to believe that these were essentially benthonic forms. In the Greenhorn they occur almost exclusively in beds that contain benthonic bivalves in addition to *Inoceramus.* The genus *Worthoceras* is a most puzzling form as are the true scaphites. The change from regularly coiled to uncoiled and finally to recurved conch in the adult stage suggests that juvenile *Worthoceras* was a good swimmer and that adults were probably sluggish swimmers. Involute, ribbed, compressed forms like *Metoicoceras* and juvenile *Tragodesmoceras* probably were fair swimmers, intermediate in ability between smooth-walled involute forms and the heavily ribbed, horned forms.

Several Greenhorn ammonite species have broad geographic range, including such forms as *Acanthoceras wyomingense, Calycoceras? canitaurinum,* most species of the *Sciponoceras gracile* zone, *Mammites nodosoides, Watinoceras reesidei,* and *Collignoniceras woollgari.* Furthermore, these species have been recorded in rocks of differing lithology. These facts might be construed as positive evidence for a wholly nektonic existence well above the sediment-water interface and unaffected by bottom conditions. However, several of the accompanying strictly benthonic species, especially including *Ostrea beloiti, Inoceramus prefragilis, Mytiloides labiatus,* and *I. cuvieri* also have wide distribution. Therefore, the wide distribution of ammonite species is as easily explained by current spreading of larvae as by migrating swarms of adults.

The occurrence together in a single bed such as Hartland marker bed HL-2 of 6 out of the 7 ammonite forms mentioned above, each of which suggests at least minor difference in mode of life or adaptation to environment suggests some underlying control which influenced also the distribution of the gastropod *Cerithiella, Phelopteria* and probably also the introduction at or near this stratigraphic position of abundant benthonic foraminifera. The evidence is strong that this host of new forms resulted from rather abrupt improvement of bottom conditions and favors a nektobenthonic interpretation for the ammonites, as suggested by Scott (1940) and Ziegler (1967).

Other Greenhorn beds have less diversity of ammonites than marker bed HL-2. Basal Lincoln skeletal limestones locally contain several species, but the texture and structure of these rocks, as well as erratic distribution and fragmentary condition of many specimens shows that many of the basal Lincoln specimens were transported to the place of burial.

Isolated occurrences of abundant ammonites of small size, like those of *Eucalycoceras* sp. B in the middle Lincoln at Locality 26, may be explained as resulting from small-scale catastrophes, but it is also possible that such forms are also abundant elsewhere and have been overlooked because of small size and imperfect fissility of the shaly chalks that contain them. The nearly ubiquitous occurrence of mostly juvenile forms of *Watinoceras reesidei* in Jetmore marker bed JT-1 suggests that this species was distributed as consistently as certain species of the *Sciponoceras gracile* zone and that *W. reesidei* suffered high infant mortality. *Collignoniceras woollgari* is a ubiquitous form in the Fencepost limestone bed and like *W. reesidei* in JT-1, is mostly preserved as juveniles. If these two species had lived far above the bottom where waters were better circulated it seems likely that more adult specimens of each would be found. It is suggested that bottom conditions were only intermittently suitable for such forms, and that a majority of specimens never reached adulthood. The paucity of ammonite molds in most shaly chalk beds, as compared with the limestone beds, fits well with the conclusion stated above that the lowest energy levels and least favorable bottom environments are represented by shaly chalk beds.

Bivalves.—Greenhorn specimens of *Exogyra columbella* are all from skeletal or intraclastic limestone beds lying at or near the base of the formation. Unlike *E.* aff. *E. boveyensis, E. columbella* was attached originally by only a small area of the left valve, and lay with ventral margin upward and with plane of commissure lying at a usually steep angle to the horizontal (Hattin, 1965a, p. 58).

Exogyra columbella is common only at Locality 23, in the lower 1.5 feet of the Lincoln, and is preserved there in conglomeratic skeletal limestone containing pebbles of limestone, bone fragments and teeth, inoceramid and oyster shell debris, and coprolites. Textural evidence suggests a turbulent and probably shallow-water depositional environment such as Jourdy (1924, p. 35) postulated for small species of *Exogyra*. At Locality 23 excellent preservation of thin *Exogyra* valves indicates that most of these shells were not subjected to the environmental rigor that broke into pieces many of the ammonite conchs preserved in the same beds. Nonetheless, apparent absence of right-hand *Exogyra* valves, and nearly uniform convex-up orientation of the collected specimens are evidence that these oysters were transported to the site of burial. During early life the individuals were attached to a solid substrate (shell fragments, etc.) as shown by shell deformation in the beak and umbonal regions of some specimens. In many specimens, as the shells grew, the posterior part of the left valve came to lie directly on the substrate. As a result, some of the left valves are irregularly flattened, the flattened area merging with the rest of the valve along a deflection that essentially marks the sediment-water interface. Assuming originally horizontal orientation of flattened areas and/or areas of juvenile attachment, specimens of *E. columbella* at Locality 23 lay with planes of commissure inclined at angles 21° to 84° ($\bar{x}$=54°) from the horizontal in 6 specimens for which this measurement could be made.

Lincoln specimens of *E. columbella* lack totally the sponge and other borings that are so commonly observed in thicker shelled Late Cretaceous exogyras such as *E. ponderosa, E. costata, E. cancellata,* and *E. mesabiensis.* Absence of borings and possession of thin, small shells suggests for Greenhorn specimens of *E. columbella* rapid growth, a short life, and early burial. The last factor is consistent with the texture of rocks in which I have collected the species.

In the Lincoln Member of Kansas *Exogyra* aff. *E. boveyensis* is more common and widespread than *E. columbella.* The former species is characteristic of basal Lincoln skeletal grainstones across much of central Kansas, and ranges locally to above the middle of the Member. At Locality 55 (Hodgeman County) *E.* aff. *E. boveyensis* occurs well above the base of the Lincoln and at Localities 8 (Ford County) and 12 (Kearny County) it occurs in the upper few feet of the member. Occurrence of this oyster almost exclusively in parts of the section containing an abundance of skeletal grainstone indicates preference for habitats in which relatively strong bottom currents prevailed. *Exogyra* aff. *E. boveyensis* is broadly attached by the left valve to valves of *Inoceramus prefragilis,* and only rarely occurs as clusters in which more than one generation of individuals is represented. The shells are mostly less than 2.5 cm across, are thin, and lack epizoan borings. Collectively these features suggest a short life history for individuals and for clusters, occasioned perhaps by the frequent shifting of substrates by currents. Right valves are usually separated from the left valves, but in the cluster illustrated (Plate 3,D) several articulated specimens can be seen. Only rare specimens of *Ostrea beloiti* and even fewer specimens of *E. columbella* have been collected from beds containing *E.* aff. *E. boveyensis.*

The small oyster *Ostrea beloiti* forms a thin biostrome-like bed at the base of the Lincoln Member at Locality 8 (Ford County). Although these oysters are commonly well preserved, the valves are disarticulated, many are broken (Fig. 7,A) and the bed contains much quartz sand and rests sharply on the Graneros Shale. The species does not range above this bed, which may represent a lag deposit of shells derived locally from the upper Graneros by pre-Lincoln sea floor scour (Hattin 1965a, p. 44). The species occurs also as well-preserved valves scattered through the Graneros-Greenhorn transition beds at Locality 12 (Kearny County); the chalky matrix surrounding these oysters suggests low energy conditions and little transport of specimens. Here also the species does not range upward into more typical chalk units of the Lincoln. In central and northern Kansas the sharp contrast between Graneros and Lincoln lithology, the conglomeratic nature of basal Lincoln strata at many places, and the occurrence of sparse, disarticulated valves of *O. beloiti* only in basal Lincoln skeletal limestones suggests that here, too, the species has been reworked from the Graneros.

Ostrea beloiti is abundant in the upper half of the Graneros Shale (Hattin, 1965a, p. 40) in central

Kansas where it occurs mostly in calcareous quartzose sandstones and skeletal limestone beds, commonly as thin biostromal layers. The upper part of the Graneros is also rich in *O. beloiti*, including biostromal units, at Locality 12. On lithologic, stratigraphic and paleontologic grounds the writer (Hattin, 1965a, p. 67) concluded that the Graneros oyster-bearing beds were deposited relatively far from shore in waters of normal marine salinity and probably at a depth not exceeding 100 feet. Kauffman (1967, p. 122) stated that recent small *Ostrea* mostly inhabit the inner shelf regions in moderately quiet water at depths ranging from 10 to 200 feet, and suggested an inner to middle shelf environment for the *O. beloiti* biostromes of the Western Interior Sea. His conclusions are compatible with my own. The energy levels reflected in basal Lincoln skeletal limestones were unfavorably high for *O. beloiti* and the coccolith-rich muds that make up the bulk of the Lincoln apparently represent an environment in which energy levels were too low, or the substrate too soft, for colonization by *O. beloiti*.

Above the basal part of the Lincoln Member *Ostrea* is not represented, and *Exogyra* aff. *E. boveyensis* occurs high in the member only at Localities 6, 8, 12 and 55. Elsewhere all but the basal Lincoln and essentially all of the Hartland Member are devoid of oysters. General absence within this stratigraphic interval of all clearly benthonic forms save *Inoceramus*, and excepting the *Sciponoceras gracile* zone, suggests bottom conditions inimical to habitation by epizoal oysters and other epifaunal species. The probable nature of the environment has been discussed elsewhere.

Beginning at the base of the Jetmore Member small, fragile valves of oysters are preserved sparingly in chalky limestones and, rarely, in shaly chalk beds. In the interval extending from the top of marker bed JT-7 to shortly above JT-12, but most abundantly and consistently in the shaly chalk unit lying between marker beds JT-9 and JT-10, a small adnate oyster, *Pycnodonte* sp. A, is the only conspicuous benthonic form other than *Mytiloides*. The small fragile valves of these oysters are attached commonly as well preserved clusters (Pl. 8,E) of articulated valves, in growth position, on large inoceramid valves. Abundance of pycnodonts in this interval coincides with abundance of whole and fragmentary inoceramid valves. These oysters are less abundant above the base of JT-10 and apparently do not range to the top of the member. In the lower and middle parts of the Pfeifer Member, as high stratigraphically as the sugar sand unit (PF-2), a niche similar to that of *Pycnodonte* sp. A is occupied by *Pseudoperna bentonensis*. The latter species is also commonly well preserved as articulated valves in growth position on large inoceramid valves in a part of the section that is rich in inoceramid remains. The conditions that produced great numbers of inoceramids fostered also the development of the two groups of epizoal oysters. Ample hard substrates, more highly oxygenated bottom waters, and sedimentation rates sufficiently slow to prevent premature burial of oyster spat are believed to be the chief factors permitting development in the Jetmore and Pfeifer Members of abundant epizoal oysters. Common occurrence of perfectly preserved, articulated specimens of *Pycnodonte* and *Pseudoperna* is evidence of quiet, non-agitated or little-agitated bottom conditions. In the uppermost part of the Pfeifer and lowermost part of the overlying Fairport Chalk Member, Carlile Shale, where large oblate spheroidal concretions of chalky limestone are abundant, inoceramids are relatively sparse and epizoal oysters are rare, probably owing to reduced circulation and low levels of bottom-water oxygenation.

Kauffman (1967, p. 122) stated that on the modern Atlantic shelf *Pycnodonte* is the dominant or sole ostreid found in deeper water environments of 50 to 100 to 300 feet, and (1967, p. 124) indicated a quiet water, middle to outer shelf habitat for the genus. For gryphioid *Pycnodonte* assemblages of the Western Interior Cretaceous Kauffman (1969, p. 238) postulated a depth range of from 50 to 500 feet. For small Cretaceous pycnodonts, apparently including forms like those in the Jetmore Member, he (Kauffman, 1969, p. 238) postulated depths ranging from 200 to 500 feet. He regarded the most common Niobrara oyster, known generally as *Ostrea congesta*, as small pycnodonts, but Stenzel (1971, p. N1131) referred these to the genus *Pseudoperna*. The Pfeifer oysters are also *Pseudoperna*. If Kauffman's interpretation is correct, the small oysters in the Jetmore and Pfeifer Members represent a deepwater environment, probably the greatest represented in the Greenhorn.

Species of *Inoceramus* are common to abundant throughout the stratigraphic section extending from the upper half of the Graneros Shale to the middle part of the Blue Hill Shale Member of the Carlile Shale. This distribution is parallel with that of ammonites and is accepted as evidence that these species of inoceramids were inhabitants of marine waters of normal salinity. Many of the species recognized in the Greenhorn of Kansas are known also from distant parts of the globe. Examples include *Inoceramus flavus* Sornay, described originally from Madagascar, *Mytiloides labiatus* (Schlotheim), described originally from Europe but having essentially worldwide distribution, and *Inoceramus cuvieri* Woods, described originally from the British Chalk. Presence of these widespread species suggests free communication of the Western Interior Sea with the world ocean. This observation is supported by presence in the Greenhorn of several ammonite species that likewise are known from distant areas.

The only close living relative of the inoceramids is the byssate genus *Isognomon* which bears only general resemblance to the Greenhorn inoceramids and which has a mode of fixation to solid substrates that is not demonstrable in any Greenhorn species. Highly inequivalved, probably byssate inoceramids are represented by a few specimens of *Inoceramus rutherfordi?* at the base of the Lincoln Member at one locality, but other Greenhorn species apparently were not attached forms. Many of the latter are preserved in isolated positions within shaly chalk beds that afforded no apparent solid substrate for byssal attachment. Chalky limestone beds containing the same species do not represent former hardgrounds and thus offered no general attachment surface for these bivalves. Most Greenhorn inoceramids were neither semi-infaunal nestlers nor burrowers because none have been observed in a vertical position. Rather, all whole specimens are preserved lying concordant with stratification, suggesting that they merely lay on the carbonate muds with the plane of commissure parallel to the sediment-water interface. The three principle Greenhorn species *Inoceramus prefragilis, I. cuvieri,* and *Mytiloides labiatus* all have large, relatively flat or only moderately biconvex valves in the large adult stage of growth and thus were adapted well to a free existence on relatively soft substrates. Juvenile forms of these species were likewise adapted to the soft substrate, *I. cuvieri* by virtue of highly inflated valves, *I. prefragilis* and *M. labiatus* by virtue of moderate inflation and closely spaced, prominent concentric undulations. All three species served at times as hosts for small epizoans, *I. prefragilis* for *Exogyra* aff. *E. boveyensis, M. labiatus* for *Pycnodonte* sp. A., and *I. cuvieri* and *M. labiatus* for *Pseudoperna bentonensis* and small cirripeds. Presence of these epizoans seems to have been linked to energy conditions on the sea floor because in beds lacking current-accumulated concentrations of skeletal debris epizoans are rare or lacking.

The Greenhorn section in Kansas contains many shaly chalk beds in which inoceramids are the only conspicuous bottom-dwelling macroinvertebrates and these may be abundant where no other benthonic species are preserved. Among species of the Greenhorn benthos only inoceramids could tolerate the lowest oxygenation levels reached on the Kansas floor of the Western Interior Sea.

SUMMARY and CONCLUSIONS

1. The Greenhorn Limestone of Kansas is part of a widespread chalky carbonate unit that is similar lithologically, and related genetically, to the overlying Fairport Member, Carlile Shale. The Greenhorn ranges in thickness from 68.5 to 135.9 feet, averaging 94.8 feet for 11 measured sections. Thinnest in Mitchell County, the formation nearly doubles in thickness to the southwest.

2. Shaly chalk, a more or less laminated, impure, olive gray to olive black rock comprises most of the Greenhorn Limestone. The basal Lincoln Member is characterized by abundant beds and lenses of skeletal grainstone and by numerous thin to very thin seams of bentonite. The overlying Hartland Member contains little skeletal limestone, three regionally traceable beds of burrow-mottled chalky limestone, four equally widespread seams of bentonite, and a few beds of soft, usually burrow-mottled chalk. Above the Hartland Member the section is characterized by an abundance of chalky limestone. The Jetmore Member contains 13 regionally traceable beds of mostly burrow-mottled chalky limestone that are separated by thicker intervals of shaly chalk. A widespread bentonite seam lies on the twelfth limestone bed. The uppermost bed of limestone, called the Shellrock limestone bed, is usually concretionary in its upper part and is crowded with *Inoceramus* valves in the lower part. Shaly chalk directly beneath the Shellrock bed contains beds of lenses of concretionary chalky limestone. The Pfeifer Member is characterized by numerous irregular, discontinuous, shell-rich beds of concretionary chalky limestone and, especially in the upper half, by oblate spheroidal concretions of this rock. Widespread Pfeifer marker beds include a thin bed of chalky limestone lying an average of 6.1 feet above the base, a thin bentonite seam that is overlain in most of central Kansas by a bed of granular calcite known as the sugar sand, and the Fencepost limestone bed which lies at the top of the formation.

3. Across most of central Kansas the Greenhorn Limestone lies disconformably on the Graneros Shale; elsewhere the two formations are apparently conformable and lithologically gradational. The Graneros-Greenhorn contact is diachronous, ascending stratigraphically in a northeastward direction. The Lincoln-Hartland contact also is diachronous such that most of the type Hartland, and lower Hartland of Ford County, pass northeastward into the Lincoln Member. In western Kansas the Bridge Creek Member includes strata equivalent to the Pfeifer, Jetmore, and most of the Hartland of central Kansas. By northeastward disappearance of most chalky limestone beds the lower Bridge Creek passes into the main part of the central

Kansas Hartland. The Jetmore and Pfeifer Members of central Kansas are readily recognizable as being equivalent to the middle and upper parts of the type Bridge Creek.

4. Fossils are abundant throughout the Greenhorn, but with few exceptions diversity of macroinvertebrates is low in most beds. A sequence of assemblage zones is recognized including (ascending): *Acanthoceras wyomingense* Assemblage Zone, known in the Greenhorn only in Ford and Kearny Counties; *Calycoceras? canitaurinum-Exogyra* aff. *E. boveyensis* Assemblage Zone, occurring in the upper part of the Lincoln in Ford and Kearny Counties and in the lower Lincoln of most central Kansas localities; an undesignated assemblage zone, occurring in the type Hartland, in the lower half of the Hartland of Ford County, and in the middle and upper Lincoln and lower few feet of the Hartland across most of central Kansas; the *Sciponoceras gracile* Assemblage Zone, occurring in the lower few feet of the type Bridge Creek, near the middle of the Hartland of Ford and southern Hodgeman Counties, and in the lower half of the Hartland in most central Kansas localities; a second undesignated assemblage zone, occurring near the base of the type Bridge Creek and in the upper part of the central Kansas Hartland; the *Mytiloides labiatus - Watinoceras reesidei* Assemblage Zone, extending from near the top of the Hartland and an equivalent part of the Bridge Creek to the top of Jetmore marker bed JT-6; the *M. labiatus-Mammites nodosoides wingi* Assemblage Zone, extending from Jetmore marker bed JT-6 to the top of the Jetmore Member; a third undesignated assemblage zone, occupying the lower few feet of the Pfeifer Member and an equivalent part of the type Bridge Creek; and the *M. labiatus - Collignoniceras woollgari-Inoceramus cuvieri* Assemblage Zone, extending from the base of marker bed PF-1 through the lower part of the Fairport Member, Carlile Shale. Greenhorn assemblage zones up to and including that of *S. gracile* are of Late Cenomanian age; above this zone the Greenhorn is of Early Turonian age.

5. The Greenhorn limestone is composed of three major kinds of carbonate rock including skeletal limestones, laminated impure shaly chalk, and chalky limestone. Skeletal limestones, including biosparites and biosparrudites, are most abundant in the Lincoln Member and are common also in the upper half of the Jetmore member and lower one-half to two-thirds of the Pfeifer Member. The principal skeletal grain types are inoceramid debris and tests of planktonic foraminifera but calcispheres predominate locally. The skeletal limestones are mostly cemented by sparry calcite, and qualify as grainstones, but where incompletely washed such rocks include some micritic matrix. Shaly chalk is a poorly consolidated carbonate ooze composed primarily of coccolithophore skeletal debris. The main allochemical grains are inoceramid debris, tests of planktonic foraminifera, and fecal pellets. The last everywhere manifest the effects of sediment compaction. Organic matter, pyrite, and very fine grained terrigenous detritus are common in most shaly chalks. Chalky limestone includes rocks having micritic or microsparitic matrix and allochemical grains consisting of inoceramid bivalve debris, tests of planktonic foraminifera, fecal pellets and calcispheres. Soft beds of nonlaminated chalk have a predominantly micritic matrix. Depositional texture in the chalky limestones ranges from mudstone to packstone, with wackestones or wackestone-packstone transitional rocks predominating. Depending on allochem content, chalky limestone and chalk beds are classifiable mostly as biomicrite or biomicrosparite, biopelmicrite or biopelmicrosparite, and fossiliferous micrite or fossiliferous microsparite.

6. Greenhorn shaly chalk beds have been little altered by diagenesis. An inhospitable interstitial environment largely prevented development of a burrowing infauna so original stratification is well preserved. Compaction flattened most fecal pellets so they are now largely fusiform in vertical section; bivalves and sparse ammonites were also flattened. Diagenetic loss of skeletal aragonite, especially from bivalves and ammonites, may have furnished the $CaCO_3$ that now fills chambers of foraminifer tests. Pressure solution of skeletal grains was a possible source of late diagenetic cement. Diagenesis of skeletal grainstones consisted largely of cementation by void-filling sparry calcite cement. Sources of cement may have included interstitial pore water (early diagenesis), dissolution of aragonitic skeletal material (early to late? diagenesis), and pressure solution (late diagenesis). Large size of most crystals of sparry calcite, and general absence of centripetal increase in crystal size of void-filling calcite suggests slow development of sparry cement from relatively few growth centers, but present morphology of cement crystals may reflect diagenetic inversion to low-magnesium calcite. Chalky limestone and chalk beds have a generally homogeneous texture and most are extensively burrow mottled or have an isotropic fabric that suggests bioturbation. Exceptions are beds of soft, secondary granular chalk associated with bentonite seams, and laminae that are preserved locally in concretions or irregular, concretionary beds of chalky limestone. Burrow-mottled chalk beds usually have a micritic matrix and represent incompletely developed beds of chalky limestone. In these the original matrix of cocco-

lith-rich ooze has been partially cemented but only partly neomorphosed. The harder, usually thicker, chalky limestone beds have been largely converted to microsparite, a process that has obliterated many of the original nannoplankton skeletons. Textural differences associated with burrow structures suggest that burrowing organisms were a factor in facilitating neomorphism; bioturbation also may have helped bring into the sediment fresh supplies of seawater rich in $CaCO_3$ for early diagenetic cement. Early diagenetic dissolution of skeletal aragonite is implied by almost complete absence of void space where these skeletons lay. Early lithification of chalky limestone beds is demonstrated in beds having in-the-round or little-compacted specimens of macroinvertebrates and fecal pellets. The best-cemented rocks (Hartland marker bed HL-2, Jetmore marker beds JT-1, JT-6, and JT-10 to 12) also contain the greatest concentrations of fossils that had at least partially aragonitic skeletons.

7. The Greenhorn Limestone was deposited on a broad, flat, gently subsiding cratonic shelf that lay along the eastern side of the Western Interior Sea. The western side of the seaway was a deeply subsiding trough in which Late Cretaceous deposits locally reach thicknesses of nearly 20,000 feet. During Late Cretaceous time the interaction of subsidence and sediment supply from the Sevier orogenic belt imposed a broad pattern of cyclicity on deposits in and along the western margin of the seaway.

8. The Greenhorn Limestone represents deposition during the first Late Cretaceous transgression. The sea spread eastward or northeastward from Colorado, reaching Kansas in Late Cenomanian time. From the upper part of the Dakota Formation through the Greenhorn Limestone the vertical succession of lithofacies manifests upward change from fluviatile and marginal marine environments (Dakota), through open sea, brackish to normal or nearly normal marine environments in which very-fine-grained terrigenous mud was deposited (Graneros Shale), and culmination ultimately in far offshore carbonate-mud producing environments representing maximum transgression (Greenhorn Limestone).

9. Nearly everywhere in Kansas, Greenhorn deposition began with deposition of skeletal sands, silts, and conglomerates in a high-energy, far offshore zone of wave and/or current impingement on the sea floor. As the transgression approached its peak, and the sea floor reached its greatest depth, energy levels at the sediment-water interface decreased to minimum levels that were interrupted occasionally by impingement on the sea floor of weak to moderate currents. These produced zones of poorly to well-washed skeletal silt and sand. Shaly chalk beds reflect deposition under low-energy conditions on a nearly stagnant sea bottom that supported few benthonic macroinvertebrates other than inoceramid bivalves. Chalky limestones and nonlaminated chalk beds represent periods of slow sedimentation during which organic matter could not accumulate in sufficient quantities to produce interstitial reducing conditions. During most such times sediments were extensively bioturbated, particularly in the Hartland and Jetmore Members and equivalent parts of the Bridge Creek Member. Coincidence of reduced rates of sedimentation and improved circulation of bottom waters produced chalky limestones that are exceptionally rich in benthonic macroinvertebrates, including especially marker beds HL-2, JT-10 to JT-12, part of the Shellrock limestone bed, and many irregular, more or less concretionary beds of chalky limestone in the lower half to two thirds of the Pfeifer Member. In the upper Jetmore and through much of the Pfeifer, diagenetic segregation of calcium carbonate produced many early diagenetic concretions and concretionary beds of chalky limestone, possibly related to extremely slow rates of sedimentation.

10. The concensus of current European opinion is that the Cretaceous chalks of that continent are not deep sea deposits; most European authors interpret chalk as a deposit of seas less than 50 m to about 300 m in depth. Although depths greater than 500 m have been suggested for Greenhorn deposition, initial depths on the order of 30 m and maximum depths of perhaps 90 m at the height of transgression are more in line with paleoecologic, stratigraphic, and tectonic considerations. Diverse assemblages of coccoliths, planktonic foraminifera, ammonites, and certain bivalves indicate open-sea conditions and normal or nearly normal salinity during accumulation of Greenhorn sediments. During Greenhorn deposition the Kansas area lay near the southern edge of the north temperate realm and enjoyed a warm temperate climate. That the seaway was open to the world ocean is manifest in inclusion of several cosmopolitan species in Greenhorn fossil assemblages.

11. The major invertebrate groups represented in Greenhorn rocks are foraminifera (mostly specimens of planktonic species), ammonites, oysters, and inoceramid bivalves. The enormous imbalance between numbers of planktonic and benthonic specimens is believed owing to generally poor oxygenation at the sea floor. Despite a great diversity in shape and size, most of the Greenhorn ammonites seem best interpreted as nektobenthonic forms. Distribution of oysters in Greenhorn rocks essentially parallels that of lenses of skeletal limestone and seems related to episodes of current action when the sea floor was better

oxygenated than usual. Inoceramid valves are the almost exclusive hosts for these bivalves. Nearly all the inoceramids lay free on the sea floor, with plane of commissure parallel to the substrate. Inflated umbos prevented juveniles from sinking into soft sediment. Broad, nearly flat or only moderately biconvex valves enabled adult inoceramids to exist on the dominantly soft carbonate substrates. Inoceramids were remarkably well adapted to life on the muddy bottom and tolerated the low oxygenation levels on the floor of the Western Interior Sea.

References

ABBOTT, R. T., 1954, American seashells: Princeton, N.J., D. Van Nostrand, 541 p.

ADELSECK, C. G., JR., GEEHAN, G. W. and ROTH, P. H., 1973, Experimental evidence for the selective dissolution and overgrowth of calcareous nannofossils during diagenesis: Geol. Soc. America Bull., v. 84, p. 2755-2762.

ADKINS, W. S., 1931, Some Upper Cretaceous ammonites in western Texas: Univ. Texas Bull. 3101, p. 35-72.

AMERICAN COMMISSION ON STRATIGRAPHIC NOMENCLATURE, 1970, Code of stratigraphic nomenclature: Tulsa, Amer. Assoc. Petroleum Geologists, 22 p.

ARKELL, W. J., 1957, Introduction to Mesozoic Ammonoidea, *in* W. J. Arkell and others, Mollusca 4—Cephalopoda, Ammonoidea, Pt. L of Treatise on invertebrate paleontology, R. C. Moore, ed., p. L81—L129.

ARMSTRONG, R. L., 1968, Sevier orogenic belt in Nevada and Utah: Geol. Soc. America Bull., v. 79, p. 429-458.

ASQUITH, D. O., 1970, Depositional topography and major marine environments, Late Cretaceous, Wyoming: Amer. Assoc. Petroleum Geologists Bull., v. 54, p. 1184-1224.

BANDY, O. L., and ARNAL, R. E., 1960, Concepts of foraminiferal paleoecology: Amer. Assoc. Petroleum Geologists Bull., v. 44, p. 1921-1932.

BARR, F. T., 1961, Upper Cretaceous planktonic foraminifera from the Isle of Wright: Palaeontology, v. 4, p. 552-580.

BASS, N. W., 1926, Geologic investigations in western Kansas: Kansas Geol. Survey Bull. 11, parts 1 and 2, p. 1-83.

BASSE, ÉLIANE, 1959, Le Turonien, part II of E. Basse de-Menorval and P. Sornay, Generalites sur les faunes d'ammonites de Crétacé superieur Français, *in* Colloque sur le Crétacé supérieur Français, Comptes Rendus Cong. Soc. Savantes, Section des Sciences, Sous sect. géologie, p. 15-20.

BATHURST, R. G. C., 1970, Problems of lithification in carbonate muds: Proc. Geologists Assoc., v. 81, p. 429-440.

———, 1971, Carbonate sediments and their diagenesis: Developments in Sedimentology 12, Amsterdam, Elsevier, 620 p.

BAUSCH, W. M., 1968, Clay content and calcite crystal size of limestones: Sedimentology, v. 10, p. 71-75.

BAYNE, C. K., and WALTERS, K. L., 1959, Geology and groundwater resources of Cloud County, Kansas: Kansas Geol. Survey Bull. 139, 144 p.

BERGER, W. H. and SOUTER, ANDREW, 1970, Preservation of plankton shells in an anaerobic basin off California: Geol. Soc. America Bull., v. 81, p. 275-282.

BERGMAN, D. W., 1949, The Greenhorn Limestone in Kansas: Unpub. M.S. thesis, Kansas State University, 72 p.

BERGQUIST, H. R., 1971, Biogeographical review of Cretaceous foraminifera of the western hemisphere: Proc. North Amer. Paleontological Conv., Sept. 1969, pt. L, p. 1565-1609.

BERNER, R. A., 1968, Calcium carbonate concretions formed by the decomposition of organic matter: Science, n.s., v. 159, p. 195-197.

BILLINGS GEOLOGICAL SOCIETY, 1969, Eastern Montana Symposium: Billings Geol. Soc., 20th Ann. Conf. Guidebook, 256 p.

BIRKELUND, TOVE, 1965, Ammonites from the Upper Cretaceous of West Greenland: Medd. on Grønland, Bd. 179, no. 7, 192 p.

BISHOP, B. A., 1970, Stratigraphy of Sierra de Picachos and vicinity, Nuevo León, Mexico: Amer. Assoc. Petroleum Geologists Bull., v. 54, p. 1245-1270.

———, 1972, Petrography and origin of Cretaceous limestones, Sierra de Picachos and vicinity, Nuevo León, Mexico: Jour. Sed. Petrology, v. 42, p. 270-286.

BLACK, 1965, Coccoliths: Endeavour, v. 24, p. 131-137.

BONET, FEDERICO, 1956, Zonificación microfaunística de las calízas Cretácicas del este de México: Asoc. Mexicana Petroleros Bol., v. 8, p. 389-488.

BOSWELL, P. G. H., 1933, A piece of chalk: Science Progress, v. 28, p. 193-202.

BROMLEY, R. G., 1967, Marine phosphorites as depth indicators: Marine Geol., v. 5, p. 503-509.

BUKRY, DAVID, 1974, Coccoliths as paleosalinity indicators—evidence from Black Sea, *in* E. T. Degens and D. A. Ross, eds., The Black Sea—Geology, Chemistry and Biology: Amer. Assoc. Petroleum Geologists Mem. 20, p. 353-363.

BURNABY, T. P., 1961, The palaeoecology of the foraminifera of the Chalk Marl: Palaeontology, v. 4, p. 599-608.

BYRNE, F. E., HOUSTON, M. S., and MUDGE, M. R., 1948, Construction materials in Jewell County, Kansas: Washington, D.C., U.S. Geol. Survey Preliminary Rept., 47 p.

CALVERT, S. E., 1964, Factors affecting distribution of laminated diatomaceous sediments in Gulf of California, *in* T. H. van Andel and G. G. Shor, Jr., eds., Marine geology of the Gulf of California: Amer. Assoc. Petroleum Geologists Memoir 3, p. 311-330.

CAYEUX, LUCIEN, 1897, Contribution a l'étude micrographique des terrains sédimentaires, Part II. Craie du Bassin de Paris: Lille, Bigot Freres, 589 p.

CEPEK, PAVEL, and HAY, W. W., 1969, Calcareous nannoplankton and biostratigraphic subdivision of the Upper Cretaceous: Trans. Gulf Coast Assoc. Geol. Societies, v. 19, p. 323-336.

CHOQUETTE, P. W., and PRAY, L. C., 1970, Geologic nomenclature and classification of porosity in sedimentary carbonates: Amer. Assoc. Petroleum Geologists Bull., v. 54, p. 207-250.

CLARK, D. L., and BIRD, K. J., 1966, Foraminifera and paleoecology of the upper Austin and lower Taylor (Cretaceous) strata in north Texas: Jour. Paleontology, v. 40, p. 315-327.

COBBAN, W. A., 1951, Colorado Shale of central and northwestern Montana and equivalent rocks of Black Hills: Amer. Assoc. Petroleum Geologists Bull., v. 35, p. 2170-2198.

———, 1955, Some guide fossils from the Colorado Shale and Telegraph Creek Formation, northwestern Montana: Billings Geol. Soc., 6th Annual Field Conf. Guidebook, p. 198-207.

———, 1956, Cretaceous rocks along part of southeast boundary of Glacier National Park, Montana: Amer. Assoc. Petroleum Geologists Bull., v. 40, p. 1002-1023.

———, 1961, The ammonite family Binneyitidae Reeside in the Western Interior of the United States: Jour. Paleontology, v. 35, p. 737-758.

———, 1971, New and little known ammonites from the Upper Cretaceous (Cenomanian and Turonian) of the Western Interior of the United States: U.S. Geol. Survey Prof. Paper 699, 24 p.

——— and GRYC, GEORGE, 1961, Ammonites from the Seabee formation (Cretaceous) of northern Alaska: Jour. Paleontology, v. 35, p. 176-190.

——— and REESIDE, J. B. JR., 1952, Correlation of the Cretaceous formations of the Western Interior of the United States: Bull. Geol. Soc. America, v. 63, p. 1011-1044.

———, 1952a, Frontier Formation, Wyoming and adjacent areas: Amer. Assoc. Petroleum Geologists Bull., v. 36, p. 1913-1961.

———, ROHRER, W. L., and ERDMANN, C. E., 1956, Discovery of the Carlile (Turonian) ammonite *Collignoniceras woollgari* in northwestern Montana: Jour. Paleontology, v. 30, p. 1269-1272.

——— and SCOTT, G. R., 1972, Stratigraphy and ammonite fauna of the Graneros Shale and Greenhorn Limestone near Pueblo, Colorado: U.S. Geol. Survey Prof. Paper 645, 108 p.

CRAGIN, F. W., 1896, On the stratigraphy of the Platte Series, or Upper Cretaceous of the Plains: Colorado Coll. Studies, v. 6, p. 49-52.
DACQUÉ, EDGAR, 1915, Grundlagen und Methoden der Paläogeographie: Jena, Gustav Fischer, 499 p.
DANE, C. H., 1960, The Dakota Sandstone and Mancos Shale of the eastern side of San Juan basin, New Mexico: New Mexico Geological Soc., Eleventh Field Conference Guidebook, p. 63-74.
——— and BACHMAN, G. O., 1957, The Dakota Sandstone and Mancos Shale in the Gallup area: Four Corners Geol. Soc., Second Field Conf., Guidebook, p. 95-98.
———, PIERCE, W. G., and REESIDE, J. B., JR., 1937, The stratigraphy of the Upper Cretaceous rocks north of the Arkansas River in eastern Colorado: U.S. Geol. Survey Prof. Paper 186-K, p. 207-232.
DARTON, N. H., 1904, Comparison of the stratigraphy of the Black Hills, Bighorn Mountains, and Rocky Mountain front range: Geol. Soc. America Bull., v. 15, p. 379-448.
———, 1905, Preliminary report on the geology and underground water resources of the central Great Plains: U.S. Geol. Survey Prof. Paper 32, 433 p.
———, 1920, Description of the Syracuse and Lakin quadrangles: U.S. Geol. Survey, Geol. Atlas, Syracuse-Lakin folio (no. 212), 10 p.
DEGROOT, K., 1969, The chemistry of submarine cement formation at Dohat Hussain in the Persian Gulf: Sedimentology, v. 12, p. 63-68.
DOUGLAS, R. G., 1972, Paleozoogeography of Late Cretaceous planktonic foraminifera in North America: Jour. Foram. Research, v. 2, p. 14-34.
DUNHAM, R. J., 1962, Classification of carbonate rocks according to depositional textures, *in* W. E. Ham, ed., Classification of carbonate rocks—A symposium: Amer. Assoc. Petroleum Geologists Memoir 1, p. 108-121.
EARLAND, ARTHUR, 1939, Chalk: its riddles and some possible solutions: Trans. Hertfordshire Nat. Hist. Soc., v. 21, pt. 1, p. 6-37.
EICHER, D. L., 1969, Cenomanian and Turonian planktonic foraminifera from the western interior of the United States, *in* P. Brönniman and H. H. Renz, eds., Proc. First Int. Conf. Planktonic Microfossils, Geneva, 1967, v. 2, p. 163-174.
———, 1969a, Paleobathymetry of Cretaceous Greenhorn sea in eastern Colorado: Amer. Assoc. Petroleum Geologists Bull., v. 53, p. 1075-1090.
——— and WORSTELL, PAULA, 1970, *Lunatriella*, a Cretaceous heterohelicid foraminifer from the western interior of the United States: Micropaleontology, v. 16, p. 117-121.
——— and WORSTELL, PAULA, 1970a, Cenomanian and Turonian foraminifera from the Great Plains, United States: Micropaleontology, v. 16, p. 269-324.
FAGERSTROM, J. A., 1964, Fossil communities in paleoecology: their recognition and significance: Geol. Soc. America Bull., v. 75, p. 1197-1216.
FOLK, R. L., 1965, Some aspects of recrystallization in ancient limestones, *in* L. C. Pray and R. C. Murray, eds., Dolomitization and limestone diagenesis—A symposium: Soc. Econ. Paleontologists and Mineralogists Special Publ. No. 13, p. 14-48.
———, 1973, Carbonate petrography in the post-Sorbian age, *in* R. N. Ginsburg, ed., Evolving concepts in sedimentology: Baltimore: Johns Hopkins Univ. Press, p. 118-158.
FRANKS, P. C., COLEMAN, G. L., PLUMMER, NORMAN, and HAMBLIN, W. W., 1959, Cross-stratification, Dakota sandstone (Cretaceous), Ottawa County, Kansas: Kansas Geol. Survey Bull. 134, pt. 6, p. 223-238.
FREY, R. W., 1970, Trace fossils of Fort Hays Limestone Member of Niobrara Chalk (Upper Cretaceous), west-central Kansas: Univ. Kansas Paleont. Contr., Art. 53 (Cretaceous 2), 41 p.
———, 1972, Paleoecology and depositional environment of Fort Hays Limestone Member, Niobrara Chalk (Upper Cretaceous), west-central Kansas: Univ. Kansas Paleont. Contrib., Art. 58 (Cretaceous 3), 72 p.
FUCHS, THEODOR, 1883, Welche Ablagerungen haben wir als Tiefseebildungen zu betrachten?: Neues Jahrb. für Min. Geol. und Palaeontologie, Beilige Band, v. 2, p. 487-584.
GALIMOV, E. M., GIRIN, YU. P., and VERNADSKIY, V. I., 1968, Variation in the isotopic composition of carbon during the formation of carbonate concretions: Geochem. International, v. 5, p. 178-182.
GARTNER, STEPHAN, JR., 1969, Coccoliths and related calcareous nannofossils from Upper Cretaceous deposits of Texas and Arkansas: Univ. Kansas Paleont. Contrib., Ser. No. 48, Protista, Art. 1, 56 p.
GILBERT, G. K., 1896, The underground water of the Arkansas Valley in eastern Colorado: U.S. Geol. Survey Ann. Rept. 17, pt. 2, p. 551-601.
GILLULY, JAMES, 1963, The tectonic evolution of the western United States: Quart. Jour. Geol. Soc. London, v. 119, p. 133-174.
GODDARD, E. N., TRASK, P. D., DEFORD, R. K., ROVE, A. N., SINGEWALD, J. T., and OVERBECK, R. M., 1948, Rock-color chart, Wash. D.C., Nat. Res. Council, 6 p.
GOODMAN, A. J., 1951, White specks in Colorado shale: Amer. Assoc. Petroleum Geologist Bull., v. 35, p. 2427-2429.
GREGORY, H. E., 1950, Geology and geography of the Zion Park region, Utah and Arizona: U.S. Geol. Survey Prof. Paper 220, 200 p.
———, 1951, The geology and geography of the Paunsaugunt Region, Utah; U.S. Geol. Survey Prof. Paper 226, 116 p.
HAAS, OTTO, 1949, Acanthoceratid ammonoidea from near Greybull, Wyoming: Bull. Amer. Mus. Nat. History, v. 93, art. 1, 39 p.
———, 1963, *Paracanthoceras wyomingense* (Reagan) from the Western Interior of the United States and from Alberta (Ammonoidea): Amer. Mus. Novitates, no. 2151, 19 p.
HALL, JAMES, and MEEK, F. B., 1856, Descriptions of new species of fossils, from the Cretaceous formations of Nebraska, with observations upon *Baculites ovatus* and *B. compressus*, and the progressive development of the septa in *Baculites*, *Ammonites*, and *Scaphites:* Amer. Acad. Arts and Sciences Memoir, n.s., v. 5, p. 379-411.
HALLAM, ANTHONY, 1967, Sedimentology and palaeogeographic significance of certain red limestones and associated beds in the Lias of the Alpine region: Scottish Jour. Geology, v. 3, p. 195-220.
HALSEY, S. D., and PERKINS, R. D., 1970, Microborings in relict sediments: a possible key to Carolina shelf history (abst.): Geol. Soc. America, Abstracts with Programs, v. 2, no. 7. p. 565.
HANSEN, D. E., 1955, Subsurface correlations of the Cretaceous Greenhorn-Lakota interval in North Dakota: North Dakota Geol. Survey Bull. 29, 46 p.
HATCH, F. H., RASTALL, R. H., and BLACK, MAURICE, 1938, The petrology of the sedimentary rocks: London, Thomas Murby, 383 p.
HATTIN, D. E., 1962, Stratigraphy of the Carlile Shale (Upper Cretaceous) in Kansas: Kansas Geol. Survey Bull. 156, 155 p.
———, 1964, Cyclic sedimentation in the Colorado Group of west-central Kansas: Kansas Geol. Survey Bull. 169, p. 205-217.
———, 1965, Upper Cretaceous stratigraphy, paleontology, and paleoecology of western Kansas: Geol. Soc. America, Field Conf. Guidebook, Ann. Mtg., Kansas City, Mo., 66 p., with a section on the Pierre Shale by W. A. Cobban.
———, 1965a, Stratigraphy of the Graneros Shale (Upper Cretaceous) in central Kansas: Kansas Geol. Survey Bull. 178, 83 p.
———, 1967, Stratigraphic and paleoecologic significance of macroinvertebrate fossils in the Dakota Formation (Upper Cretaceous) of Kansas, *in* Curt Teichert and E. L. Yochelson, eds., Essays in paleontology and stratigraphy, R. C. Moore Commemorative Volume: Dept. Geology, Univ. Kansas, Spec. Publ. 2, p. 570-589.
———, 1968, *Plesiacanthoceras wyomingense* (Reagan) from Graneros Shale and Greenhorn Limestone (Upper Cretaceous) of central Kansas: Jour. Paleontology, v. 42, p. 1084-1090.
———, 1968a, Revision of stratigraphic classification of Greenhorn Limestone and Fairport Chalk Member of Carlile Shale (Upper Cretaceous) in Kansas (abst.): Geol. Soc. America Special Paper 115, p. 389.
———, 1969, Reference section for Lincoln Limestone Mem-

ber, Greenhorn Limestone (Upper Cretaceous), Lincoln County, Kansas: Kansas Geol. Survey Bull. 194, pt. 1, p. 29-33.

———, 1969a, Role of mobile endobenthos in forming marker beds in Greenhorn Limestone (Upper Cretaceous) of Kansas (abst.): Geol. Soc. America Special Paper 121, p. 659-660.

———, 1971, Widespread, synchronously deposited, burrow-mottled limestone beds in Greenhorn Limestone (Upper Cretaceous) of Kansas and southeastern Colorado: Amer. Assoc. Petroleum Geologists Bull., v. 55, p. 412-431.

——— and DARKO, D. A., 1971, Technique for determining coccolith abundance in shaly chalk of the Greenhorn Limestone (Upper Cretaceous) of Kansas: Kansas Geol. Survey Bull. 202, part 2, 11 p.

HAY, ROBERT, 1889, Northwest Kansas: its topography, geology, climate, and resources: Kansas State Board of Agriculture, 6th Biennial Rept., p. 92-116.

HAY, W. W., MOHLER, H. P., ROTH, P. H., SCHMIDT, R. R., and BOUDREAUX, J. E., 1967, Calcareous nannoplankton of the Cenozoic of the Gulf Coast and Caribbean-Antillean area, and transoceanic correlation: Trans. Gulf Coast Assoc. Geol. Societies, v. 17, p. 428-480.

HAYDEN, F. V., 1872, Sketch of the geological formations along the route of the Union Pacific Railway, Eastern Division, *in* Final report of the United States Geological Survey of Nebraska and portions of adjacent territories: U.S. 42nd Cong., 1st Sess., House Exec. Doc. 19, p. 66-69.

HUDSON, J. D., 1967, Speculations on the depth relations of calcium carbonate solution in recent and ancient seas: Marine Geol., v. 5, p. 473-480.

HUH, J. M., and SMITH, C. I., 1972, Coccoliths and related nannofossils from the Upper Cretaceous Fencepost Limestone of northwestern Kansas: Univ. Michigan, Mus. Paleo. Contrib., v. 24, p. 17-22.

HUME, W. FRASER, 1894, The genesis of the Chalk: Proc. Geologists Assoc., v. 13, p. 211-248.

HUXLEY, T. H., 1858, Chalk, ancient and modern: Saturday Review, v. 7, p. 500-502.

IRWIN, M. L., 1965, General theory of epeiric clear water sedimentation: Amer. Assoc. Petroleum Geologist Bull., v. 49, p. 445-459.

JEFFERIES, R. P. S., 1962, The palaeoecology of the *Actinocamax plenus* Subzone (Lowest Turonian) in the Anglo-Paris basin: Palaeontology, v. 4, p. 609-647.

JELETZKY, J. A., 1968, Macrofossil zones of the marine Cretaceous of the western interior of Canada and their correlation with the zones and stages of Europe and the western interior of the United States: Geol. Survey Canada Paper 67-72, 66 p.

———, 1971, Marine Cretaceous biotic provinces of western and Arctic Canada: Proc. North Amer. Paleontological Conv., Sept. 1969, pt. L, p. 1638-1659.

———, 1971a, Marine Cretaceous biotic provinces and paleogeography of western and Arctic Canada: illustrated by a detailed study of ammonites: Geol. Surv. Canada Paper 70-22, 92 p.

JEWETT, J. M., 1951, Geologic structures in Kansas: Kansas Geol. Survey Bull. 90, pt. 6, p. 105-172.

JICHA, H. L., JR., 1954, Geology and mineral deposits of Lake Valley quadrangle, Grant, Luna, and Sierra Counties, New Mexico: New Mexico Bur. Mines and Min. Resources Bull. 37, 93 p.

JOURDY, E., 1924, Histoire naturelle des Exogyres: Annales de Paléontologie, v. 13, p. 1-104.

JUKES-BROWNE, A. J., and HILL, WILLIAM, 1903, The Cretaceous rocks of Great Britain. Vol. II—The Lower and Middle Chalk of England: Mem. Great Britain Geological Survey, 559 p.

———, 1904, The Cretaceous rocks of Great Britain. Vol. III—The Upper Chalk of England: Mem. Great Britain Geological Survey, 556 p.

KATICH, P. J., 1956, Some notes on the Cretaceous faunas of eastern Utah and western Colorado: Intermountain Assoc. Petroleum Geologists, Seventh Annual Field Conf., Guidebook, p. 116-119.

KAUFFMAN, E. G., 1961, Mesozoic paleontology and stratigraphy, Huerfano Park, Colorado: Unpub. PhD thesis, Univ. of Michigan. Vol. 1, Stratigraphy, 501 p.

———, 1966, Notes on Cretaceous Inoceramidae (Bivalvia) of Jamaica: Jour. Geol. Soc. Jamaica, v. 8, p. 32-40.

———, 1967, Coloradoan macroinvertebrate assemblages, central Western Interior, *in* E. G. Kauffman and H. C. Kent, coch., Paleoenvironments of the Cretaceous seaway—a symposium, Colorado School of Mines, Golden, May, 1967—preprints of papers, p. 67-143.

———, 1969, Cretaceous marine cycles of the Western Interior: Mountain Geologist, v. 6, p. 227-245.

———, 1973, Cretaceous Bivalvia, *in* A. Hallam, ed., Atlas of Palaeobiogeography: Amsterdam, Elsevier, p. 353-383.

———, HATTIN, D. E., and POWELL, J. D., in preparation, Cenomanian-Lower Turonian (Upper Cretaceous) stratigraphy of Cimarron County, northwestern Oklahoma.

——— and KENT, H. C., Cochairmen, 1967, Paleoenvironments of the Cretaceous Seaway—a Symposium, Colorado School of Mines, Golden, May, 1967, 266 p.

KENNEDY, W. J., and HANCOCK, J. M., 1970, Ammonites of the genus *Acanthoceras* from the Cenomanian of Rouen, France: Palaeontology, v. 13, p. 462-490.

KENT, H. C., 1969, Distribution of keeled Globotruncanidae in Coniacian and Santonian strata of the Western Interior region of North America; *in* P. Brönniman and H. H. Renz, eds., Proc. First Int. Conf. Planktonic Microfossils, Geneva 1967, v. 2, p. 323-327.

KING, P. B., 1969, The tectonics of North America—a discussion to accompany the Tectonic Map of North America, scale 1:5,000,000: U.S. Geol. Survey Prof. Paper 628, 94 p.

KUMMEL, BERNHARD, 1948, Environmental significance of dwarfed cephalopods: Jour. Sedimentary Petrology, v. 18, p. 61-64.

LANDES, K. K., 1930, The geology of Mitchell and Osborne Counties, Kansas: Kansas Geol. Survey Bull. 16, 55 p.

LAWRENCE, J. C., HERMAN, GEORGE, and ELISON, J. H., 1966, North American distribution of the Turonian (Late Cretaceous) ammonite *Mammites nodosoides* (Schlotheim) (abst.): Geol. Soc. America Special Paper 87, p. 297.

LEVINTON, J. S., 1970, The paleoecological significance of opportunistic species: Lethaia, v. 3, p. 69-78.

LOGAN, W. N., 1897, The Upper Cretaceous of Kansas: Kansas Geol. Survey Vol. 2, p. 195-234.

———, 1898, The invertebrates of the Benton, Niobrara and Fort Pierre groups: Kansas Geol. Survey Vol. 4, p. 431-518.

———, 1899, A discussion and correlation of certain subdivisions of the Colorado formation: Jour Geology, v. 7, p. 83-91.

———, 1899a, Contributions to the paleontology of the Upper Cretaceous Series: Field Columbian Museum, Geol. Ser., v. 1, no. 6, p. 201-216.

LOWENSTAM, H. A., 1964, Palaeotemperatures of the Permian and Cretaceous Periods, *in* A. E. M. Nairn, ed., Problems in Paleoclimatology—NATO Palaeoclimates Conf., Univ. Newcastle upon Tyne, January 1963, London and New York, Interscience Publishers, p. 227-248.

——— and EPSTEIN, S., 1954, Paleotemperatures of the post-Aptian Cretaceous as determined by the oxygen isotope method: Jour. Geology, v. 62, p. 207-248.

———, 1959, Cretaceous paleotemperatures as determined by the oxygen isotope method, their relations to and the nature of rudistid reefs, *in* L. B. Kellum, Chm., El Sistemo Cretácico—un symposium sobre el Cretácico en el Hemisferio Occidental y su correlación mundial, Tomo 1, p. 65-76.

MACGINITIE, G. E., and MACGINITIE, NETTIE, 1949, Natural history of marine animals: New York, McGraw-Hill Book Co., 473 p.

MATSUMOTO, T., 1959, Upper Cretaceous ammonites of California, Part II: Mem. Fac. Science Kyushu Univ., Ser. D. Geology, Spec. Vol. 1, 172 p.

——— and MILLER, H. W., JR., 1958, Cretaceous ammonites from the spillway excavation of Cedar Bluff Dam, Trego County, Kansas: Jour. Paleontology, vol. 32, p. 351-356.

——— and OBATA, I., 1966, An acanthoceratid ammonite from Sakhalin: Bull. Nat. Sci. Museum, Tokyo, v. 9, p. 43-52.

MCCRAE, R. O., 1956, Subsurface stratigraphy of the pre-Niobrara formations in the Julesburg basin, southeastern Wyoming: Wyoming Geol. Assoc., Subsurface Stratigraphy of the pre-Niobrara Formations in Wyoming, pt. 1, p. 85-89.

MEEK, F. B. and HAYDEN, F. V., 1861, Descriptions of new Lower Silurian (Primordial), Jurassic, Cretaceous, and

Tertiary fossils, collected in Nebraska, etc.: Philadelphia Acad. Nat. Sciences Proc., v. 13, p. 415-447.

Merriam, D. F., 1957, Subsurface correlation and stratigraphic relation of rocks of Mesozoic age in Kansas: Kansas Geol. Survey Oil and Gas Inv. No. 14, 25 p.

———, 1957a, Preliminary regional structural contour map on top of the Dakota Formation (Cretaceous) in Kansas: Kansas Geol. Survey Oil and Gas Inv. No. 15, map.

———, 1958, Structure of the central part of the Great Plains: Kansas Geol. Soc. Guidebook, 22nd Ann. Field Conf., p. 89-99.

———, 1963, The geologic history of Kansas: Kansas Geol. Survey Bull. 162, 317 p.

Miller, H. W., 1968, Invertebrate fauna and environment of deposition of the Niobrara Formation (Cretaceous) of Kansas: Fort Hays Studies, n.s., Sci. Ser. no. 8, 90 p.

Moore, R. C., 1920, Oil and gas resources of Kansas; pt. 2, Geology of Kansas: Kansas Geol. Survey Bull. 6, pt. 2, 98 p.

——— and Haynes, W. P., 1917, Oil and gas resources of Kansas: Kansas Geol. Survey Bull. 3, 391 p.

——— and Landes, K. K., 1937, Geologic map of Kansas: Kansas Geol. Survey, map.

Moreman, W. L., 1942, Paleontology of the Eagle Ford Group of north and central Texas: Jour. Paleontology, v. 16, p. 192-220.

Morrow, A. L., 1934, Foraminifera and Ostracoda from the Upper Cretaceous of Kansas: Jour. Paleontology, vol. 8, p. 186-205.

———, 1935, Cephalopods from the Upper Cretaceous of Kansas: Jour. Paleontology, v. 9, p. 463-473.

———, 1941, The stratigraphy and invertebrate paleontology of the Colorado group in Kansas: Unpub. Ph.D. thesis, Yale Univ., 281 p.

Moss, R. G., 1932, The geology of Ness and Hodgeman Counties, Kansas: Kansas Geol. Survey Bull. 19, 48 p.

Mudge, B. F., 1866, First annual report on the geology of Kansas: Lawrence, 1866, 56 p.

———, 1875, Geology of Kansas: Kansas State Board of Agriculture, 4th Ann, Report, p. 107-127.

———, 1876, Notes on the Tertiary and Cretaceous Periods of Kansas: U.S. Geol. and Geog. Survey of the Territories, Bull. 2, p. 211-221.

———, 1877, Notes on the Tertiary and Cretaceous Periods of Kansas: U.S. Geol. and Geog. Survey of the Territories: Ann. Rept. 9, 277-294.

———, 1878, Geology of Kansas: Kansas State Board of Agriculture, 1st Biennial Rept., p. 46-88.

Muilenberg, Grace, 1958, The land of the post rock *or* Fencepost limestone country: Kansas Geol. Survey, pamphlet, 22 p.

Nestler, Helmut, 1965, Die Rekonstruktion des Lebensraumes der Rügener Schreibkreide-Fauna (Unter Maastricht) mit Hilfe der Pälaoökologie und Paläobiologie: Geologie, Jahrg. 14, Beiheft, 49, p. 1-147.

O'Boyle, C. C., 1955, The Cretaceous rocks of northwest Colorado: Intermountain Assoc. Petroleum Geologists, Sixth Ann. Field Conf., Guidebook, p. 32-35.

Page, H. G., and Repenning, C. A., 1958, Late Cretaceous stratigraphy of Black Mesa, Navajo, and Hopi Indian reservations, Arizona: New Mexico Geol. Soc. Ninth Field Conf. Guidebook, p. 115-122.

Parker, R. H., 1955, Changes in the invertebrate fauna, apparently attributable to salinity changes, in the bays of central Texas: Jour. Paleontology, v. 29, p. 193-211.

Phleger, F. B., 1960, Ecology and distribution of recent Foraminifera: Baltimore, Johns Hopkins Press, 297 p.

———, 1964, Foraminiferal ecology and marine geology: Marine Geology, v. 1, p. 16-43.

Pike, W. S., Jr., 1947, Intertonguing marine and nonmarine Upper Cretaceous deposits of New Mexico, Arizona, and southwestern Colorado: Geol. Soc. America Mem. 24, 103 p.

Plummer, Norman, 1937, Rockwool resources in Kansas: Kansas Geol. Survey Min. Res. Circ. 5, 74 p.

———, 1937a, Rock wool resources of Kansas, Appendix: Kansas Geol. Survey Min. Res. Circ. 8, 28 p.

——— and Romary, J. F., 1942, Stratigraphy of the pre-Greenhorn Cretaceous beds of Kansas: Kansas Geol. Survey Bull. 41, pt. 9, p. 373-348.

Porthault, B., Thomel, G., and Villoutreys, O. de, 1966, Étude biostratigraphique du Cénomanien de bassin supérieur de L'Estéron (Alpes Maritimes). Le problème de la limite de la Cénomanien-Turonien dans le Sud-Est de la France: Bull. Soc. Geol. France, ser. 7, v. 8, p. 423-439.

Powell, J. D., 1963, Turonian (Cretaceous) ammonites from northeastern Chihuahua, Mexico: Jour. Paleontology, v. 37, p. 1217-1232.

Purdy, E. G., 1964, Sediments as substrates, *in* John Imbrie and N. D. Newell, eds., Approaches to paleoecology: New York, John Wiley and Sons, p. 238-271.

Reeside, J. B., Jr., 1927, An *Acanthoceras rhotomagense* fauna in the Cretaceous of the Western Interior: Jour. Washington Acad. Sci., v. 17, p. 453-454.

———, 1944, Maps showing thickness and general character of the Cretaceous deposits in the western interior of the United States: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map no. 10.

———, 1957, Paleoecology of the Cretaceous seas of the Western Interior of the United States: Geol. Soc. Amer. Memoir 67, v. 2, p. 505-542.

Reid, R. E. H., 1962, Sponges and the Chalk Rock: Geol. Mag., v. 99, p. 273-278.

———, 1968, Bathymetric distributions of Calcarea and Hexactinellida in the present and the past: Geol. Magazine, v. 105, p. 546-559.

Reyment, R. A., 1958, Some factors in the distribution of fossil cephalopods: Stockholm Contr. Geology, v. 1, p. 97-184.

Rhoads, D. C., and Morse, J. W., 1971, Evolutionary and ecologic significance of oxygen-deficient marine basins: Lethaia, v. 4, p. 413-428.

——— and Young, D. K., 1970, The influence of deposit-feeding organisms on sediment stability and community trophic structure: Jour. Marine Res., v. 28, p. 150-178.

Richards, P. W., 1955, Geology of the Bighorn Canyon—Hardin area, Montana and Wyoming: U.S. Geol. Survey Bull. 1026, 93 p.

Riedl, R. J., Huang, N., and Machan, R., 1972, The subtidal pump: a mechanism of interstitial water exchange by wave action: Mar. Biology, v. 13, p. 210-221.

Risser, H. E., 1960, Kansas building stone: Kansas Geol. Survey Bull. 142, pt. 2, p. 53-122.

Rubey, W. W., and Bass, N. W., 1925, The Geology of Russell County, Kansas: Kansas Geol. Survey Bull. 10, pt. 1, p. 1-86.

Rupp, A. W., 1966, Origin, structure and environmental significance of Recent and fossil calcispheres (abst.): Geol. Soc. America, Spec. Paper 101, p. 186.

St. John, O. H., 1883, Sketch of the Geology of Kansas: Kansas State Board of Agriculture, 3rd Biennial Rept., p. 571-599.

———, 1887, Notes on the geology of southwestern Kansas: Kansas State Board of Agriculture, 5th Biennial Rept., pt. 2, p. 132-152.

Schoewe, W. H., 1949, The geography of Kansas: Trans. Kansas Acad. Science, v. 52, p. 261-333.

Scholle, P. A., and Kling, S. A., 1972, Southern British Honduras: lagoonal coccolith ooze: Jour. Sed. Petrology, v. 42, p. 195-204.

Scott, Gayle, 1940, Paleoecological factors controlling the distribution and mode of life of Cretaceous ammonoids in the Texas area: Jour. Paleontology, v. 14, p. 299-329.

Scott, G. R., 1962, Geology of the Littleton Quadrangle Jefferson, Douglas, and Arapahoe Counties, Colorado: U.S. Geol. Survey Bull. 1121-L, 53 p.

Seitz, O., 1959, Vergleichende Stratigraphie der Oberkreide in Deutschland und in Nordamerika mit hilfe der Inoceramen: International Geological Congress, 20th, Mexico, 1956, El Sistemo Creticico, v. 1, 113-129.

Shaw, A. B., 1964, Time in stratigraphy: New York, McGraw-Hill, 365 p.

Siemers, C. T., 1971, Stratigraphy, paleoecology, and environment analysis of upper part of Dakota Formation (Cretaceous), Central Kansas: unpub. Ph.D. thesis, Indiana, Univ., 287 p.

Smith, F. D., Jr., 1955, Planktonic Foraminifera as indicators of depositional environment: Micropaleontology, v. 1, p. 147-151.

SOHL, N. F., 1971, North American Cretaceous biotic provinces delineated by gastropods: Proc. North Amer. Paleontological Conv., Sept. 1969, pt. L, p. 1610-1638.
SORBY, H. C., 1861, On the organic origin of the so-called 'crystalloids' of the Chalk: Ann. Mag. Nat. History, ser. 3, v. 8, p. 193-200.
SPIEKER, E. M., 1949, Sedimentary facies and associated diastrophism in the Upper Cretaceous of central and eastern Utah: Geol. Soc. America Memoir 39, p. 55-82.
STARK, J. T., JOHNSON, J. H., BEHRE, C. H., JR., POWERS, W. E., HOWLAND, A. L., GOULD, D. B., and OTHERS, 1949, Geology and origin of South Park, Colorado: Geol. Soc. America Mem. 33, 188 p.
STEINECH, GERHARD, 1965, Die artikulaten Brachiopoden der Rügener Schreibkreide (Unter-Maastricht): Paläont. Abhandlungen, Abt. A, Paläozoologie, Band II, Heft 1, 220 p.
STELCK, C. R., and WALL, J. H., 1955, Foraminifera of the Cenomanian *Dunveganoceras* zone from Peace River area of western Canada: Res. Council Alberta, Report No. 70, 81 p.
STENZEL, H. B., 1971, Oysters, *in* R. C. Moore, ed., Treatise on Invertebrate Paleontology, Part N, Bivalvia, v. 3, p. N953-N1224.
STOTT, D. F., 1963, The Cretaceous Alberta Group and equivalent rocks, Rocky Mountain foothills, Alberta: Canada Geol. Survey Mem. 317, 306 p.
SWINCHATT, J. P., 1969, Algal boring: a possible depth indicator in carbonate rocks and sediments: Geol. Soc. America Bull., v. 80, p. 1391-1396.
TARR, W. A., 1925, Is the Chalk a chemical deposit?: Geol. Magazine, v. 62, p. 252-264.
THOMAS, H. D., 1931, Origin of spheres in the Georgetown Limestone: Jour. Paleontology, v. 6, p. 100-101.
TOURTELOT, H. A., and RYE, R. O., 1969, Distribution of oxygen and carbon isotopes in fossils of Late Cretaceous age, western interior region of North America: Geol. Soc. America Bull., v. 80, p. 1903-1922.
TREXLER, D. W., 1967, Stratigraphic distribution of Upper Cretaceous nannoplankton (coccoliths) in central and northern Colorado and the Black Hills region: Jour. Paleontology, v. 41, p. 1355-1364.
VALENTINE, J. W., 1967, The influence of climatic fluctuations on species diversity within the Tethyan provincial system, in C. G. Adams & D. V. Ager, eds., Aspects of Tethyan biogeography: Systematics Assoc. Publ. No. 7, p. 153-166.
VOIGT, EHRHARD, 1929, Die Lithogenese der Flach- und Tiefwassersedimente des jüngen Oberkreidemeeres: Jahr. Halleschen Verbandes N. F., 8, p. 3-162.
———, 1959, Die ökologische Bedeutung der Hartgründe ("Hardgrounds") in der oberen Kreide: Paläont. Zeitschrift, v. 33, p. 129-147.
VOKES, H. E., 1947, Cretaceous Mollusca from depths of 4875 to 4885 feet in the Maryland Esso well: Maryland Dept. Geol., Mines and Water Resources Bull. 2, p. 126-151.
WAAGÉ, K. M., 1959, Stratigraphy of the Dakota Group along the northern Front Range foothills, Colorado: U.S. Geol. Survey Oil and Gas Inv. Chart OC-60.
WARREN, P. S., 1930, New species of fossils from Smoky River and Dunvegan formations, Alberta: Research Council Alberta Rept. 21, p. 57-68.
———, 1947, Cretaceous fossil horizons in the Mackenzie River valley: Jour. Paleontology, v. 21, p. 118-123.
WEEKS, L. G., 1953, Environment and mode of origin and facies relationships of carbonate concretions in shales: Jour. Sed. Petrology, v. 23, p. 162-173.
WEIMER, R. J., 1960, Upper Cretaceous stratigraphy, Rocky Mountain area: Amer. Assoc. Petroleum Geologists Bull., v. 44, p. 1-20.
———, 1970, Rates of deltaic sedimentation and intrabasin deformation, Upper Cretaceous of Rocky Mountain region, *in* J. P. Morgan, ed., Deltaic sedimentation, modern and ancient: Soc. Econ. Paleontologists and Mineralogists Spec. Publ. No. 15, p. 270-292.
WHITE, C. A., 1878, Report on the geology of a portion of northwestern Colorado: U.S. Geol. and Geog. Surv. Territories, 10th Ann. Rept., p. 5-60.
WICKENDEN, R. T. D., 1945, Mesozoic stratigraphy of the eastern plains, Manitoba and Saskatchewan: Canada Geol. Survey Mem. 239, 87 p.
WIEDMANN, JOST, 1969, The heteromorphs and ammonoid extinction: Biol. Reviews, v. 44, p. 563-602.
WILBUR, K. M., 1964, Shell formation and regeneration, *in* K. M. Wilbur and C. M. Yonge, eds., Physiology of the mollusca: New York, Academic Press, p. 243-282.
WING, M. E., 1930, The geology of Cloud and Republic Counties, Kansas: Kansas Geol. Survey Bull. 15, 51 p.
WISE, S. W., JR., and KELTS, K. R., 1972, Inferred diagenetic history of a weakly silicified deep sea chalk: Trans. Gulf Coast Assoc. Geol. Societies, v. 22, p. 177-203.
WOLFE, M. J., 1968, Lithification of a carbonate mud: Senonian chalk in northern Ireland: Sedimentary Geology, v. 2, p. 263-290.
WOODS, HENRY, 1912, The evolution of *Inoceramus* in the Cretaceous Period: Quart. Jour. Geol. Soc. London, v. 68, p. 1-20.
WRIGHT, C. W., and WRIGHT, E. V., 1951, A survey of the fossil Cephalopoda of the Chalk of Great Britain: Palaeontographical Society, v. 104, 40 p.
ZANKL, H., 1969, Structural and textural evidence of early lithification in fine-grained carbonate rocks: Sedimentology, v. 12, p. 241-256.
ZIEGLER, BERNHARD, 1967, Ammoniten-Ökologie am Beispiel des Oberjura: Geologische Rundschau, Bd. 56, H. 2, p. 439-463.

APPENDIX A
Procedure

Field study of Greenhorn rocks in Kansas was accomplished during part of each summer from 1962 to 1968, and 1971. For comparative purposes, sections in Oklahoma, Colorado, and Iowa were examined during the field seasons of 1963, 1964, and 1968. In Kansas, exposures were located by reference to published work and by systematic traversing of the outcrop area. The latter was based on study of the Geologic Map of Kansas (Moore and Landes, 1937), maps accompanying bulletins of the Kansas Geological Survey, State Highway Commission county plat maps, maps in U.S. Geological Survey construction-materials circulars, and U.S. Geological Survey topographic maps.

Stratigraphic sections were measured with a hand level, steel tape, and stadia rod. Most measurements were made to the nearest hundredth foot because of small and relatively uniform thickness of many shaly chalk, bentonite, and chalky limestone beds. For beds having undulatory surfaces or non-uniform thickness a range of thickness was determined. In most measured sections the described units were defined on the basis of homogeneous lithology but some intervals comprising an alternating sequence of only two rock types were treated as a single unit. The limits of individual units, or homogeneous bundles of strata, are based on sharp changes in lithology or stratal characteristics that can be distinguished readily in the field. At many places poorly exposed or extensively weathered rocks were ditched with a trench pick so as to permit study of a continuous stratigraphic section.

Representative rock samples were collected from each measured section and at key sections, scattered across the entire outcrop, samples were collected from every lithic unit. Detailed descriptions of four key sections are included in the appendix. At all key sections each lithic unit was searched systematically for fossils. Beds of limestone were examined surficially and broken up with a hammer. Shaly chalk units were searched virtually on a lamina-by-lamina basis in each key section. In addition to the measured sections, 46 sections were examined, but not measured in detail. At these sections notes were made on bed continuity, variations in bed thickness and lithology, unusual stratigraphic features such as scour features and concretions, and fossil content. Many of the fossils illustrated in this report and much additional data on fossil distribution were taken from these supplementary sections.

Although few beds contained a sufficient number of fossils or were suitably exposed, quadrat and meter-long counts of specimens were made at several horizons. Data on orientation, articulation of bivalves, and degree of breakage were also gathered. Cross-bedded strata are not common in the Greenhorn of Kansas but a few measurements were made of cross-bed dip direction and dip angle.

Laboratory work consisted of fossil identification, thin section study, insoluble residue study, chemical analysis of representative rock specimens, X-ray determination of major mineral components, and scanning electron microscopy of shaly chalk and chalky limestones. Fossils were freed from matrix using hammer and chisel, a Gravermeister pneumatic chisel, and an S. S. White Airbrasive unit. Thin sections were cut normal to stratification and prepared by vacuum impregnation techniques. Many of the thin sections were X-rayed before being covered. Insoluble residues were prepared from the unweathered or little-weathered parts of four key sections including one in Pueblo County, Colorado. Samples weighing approximately 20 grams were digested in HCl, filtered through pieces of No. 40 filter paper, dried, and weighed to the nearest tenth gram. Most of the residues were examined microscopically and selected samples were analyzed with an X-ray unit. In addition to analyses of the thin sections and insoluble residues, powdered samples of shaly chalk, bentonite, and skeletal materials were analyzed by X-ray diffraction. Samples of shaly chalk and chalky limestone were subjected to partial chemical analysis in order to determine percentages of organic carbon, pyrite, and gypsum. Percentages of these components were used in interpreting the chemical environment below the depositional interface and as a rough index to amount of weathering. Scanning electron misroscopy of shaly chalk and chalky limestone samples was used to distinguish ultramicroscopic textures and structures that reflect primary and diagenetic-epigenetic differences between these major kinds of carbonate rock.

Results of insoluble residue study, thin section analysis, chemical analysis, electron microscopy, and trace fossil study of the Hartland and Jetmore Members has been reported, in part, by Hattin (1971).

APPENDIX B
Description of Measured Sections

Explanation.—This appendix includes descriptions of four measured sections that characterize the Greenhorn Limestone in the Kansas outcrop. The colors used are from the Rock Color Chart (Goddard et al., 1948) and are given for wetted rock unless specified otherwise. Alphanumeric color codes are used only with color names that appear more than once in the color chart and with color names that are not included in the chart.

Virtually all shaly chalk units are speckled by minute, nearly white, ellipsoidal fecal pellets; most shaly chalk units contain abundant calcareous silt and fine sand made up of foraminifer tests, *Inoceramus* prisms, etc.; most shaly chalk units are more or less laminated; shaly chalks are tough and blocky where freshly exposed and weather into small soft chips. Repetitious description of these features is deemed unnecessarily monotonous; therefore, mention of these fairly uniform characteristics is omitted from the descriptions that follow.

Nearly all Greenhorn rocks contain tests of planktonic foraminifera, but in the descriptions of key sections mention of these fossils is made only when they are especially conspicuous in the field.

Chalky limestones commonly contain evidence of burrowing by infaunal organisms. Except where otherwise specified the "burrow structures" or "burrow mottles" of the described sections are chalk-filled features that differ from the surrounding rocks chiefly in color or degree of staining by limonite.

Key Section 1.—Composite section in Republic and Washington Counties. Upper part of section is in road cut on north side of U.S. Hwy. 36, in SW¼ SW¼ sec. 4, T. 3 S., R. 1 W., Republic County, Kansas (Locality 7).

	Thickness, feet
GREENHORN LIMESTONE	
Pfeifer Member	
47. Chalky limestone, Fencepost limestone bed, weathered grayish orange to dark yellowish orange, resistant, ledge forming, weathers into three beds. FOSSILS: *Mytiloides labiatus*, *Inoceramus cuvieri*, *Collignoniceras woollgari*	0.55
46. Shaly chalk, very light gray in basal foot becoming grayish orange to dark yellowish orange in upper part; soft, breaks blocky but is apparently thinly and evenly laminated; several very thin chalk layers in upper foot project from	

	Thickness, feet
weathered surface; unit contains layer of chalky limestone concretions, light olive gray (5Y6/1) to yellowish gray (5Y8/1), speckled throughout, middle part thinly and evenly laminated, central part stained by limonite; bentonite seam 0.08 foot thick, slighty silty, light olive gray (5Y6/1) lies 0.5 foot below top; very thin bentonite seam, 0.01 foot thick, lies 0.65 foot below top of unit. FOSSILS: in shaly chalk, *Mytiloides labiatus*	2.8
45. Chalky limestone, very light gray to dark yellowish orange, resistant, ledge forming, thinly and evenly laminated, speckled throughout, lower half in part visibly crystalline, with conspicuous tests of planktonic foraminifera. FOSSILS: *Mytiloides labiatus*	0.2
44. Shaly chalk, weathered grayish orange to dark yellowish orange, soft, nonresistant; extremely thin seam of light bluish gray bentonite lies 0.6 foot above base. FOSSILS: *Mytiloides labiatus,* fish scales	2.0
43. Bentonite, "sugar sand" seam, bluish white, very slightly silty, with sparse flakes of biotite?	0.08
42. Shaly chalk, weathered yellowish gray (5Y8/1) to grayish orange, soft. FOSSILS: *Mytiloides labiatus,* fish scales	0.15
41. Chalky limestone, weathered pale dusky yellow (5Y7/4) to dark yellowish orange, concretionary, resistant, ledge forming, speckled; lower part of bed pinches and swells from 0.15 to 0.35 foot, upper 0.15 foot is thinly and evenly laminated, bed has two ferruginous bands parallel to bedding; contains scattered *Inoceramus* fragments and sparse, soft limonite nodules. FOSSILS: *Inoceramus cuvieri,* fish bones. Equivalent bed forms top of companion section (Loc. 6) and contains *Baculites* cf. *B. yokoyamai*	0.35
Road cut on north side of U.S. Hwy. 36, in SW¼ sec. 5, T. 3 S., R. 1 E., Washington County (Locality 6).	
40. Shaly chalk and chalky limestone; shaly chalk predominant, weathered yellowish gray (5Y7/2) to grayish orange, all but uppermost part filled with inoceramid valves and fragments that interrupt evenness of lamination, lower part contains very small lenses of brittle, dark yellowish brown, calcite-cemented skeletal limestone containing abundant inoceramid, prisms and/or tests of planktonic foraminifera; unit contains at least nine irregular, discontinuous beds of nodular chalky limestone, weathered yellowish gray to pale grayish orange, resistant, project from weathered slope, speckled, with abundant valves and fragments of *Mytiloides;* parts of some limestone nodules are cemented by visibly crystalline calcite and have a petroliferous odor; upper part of nodules in 6th bed is very thinly laminated and cemented by sparry calcite; bentonite, 0.08 foot thick, light gray, weathering dark yellowish orange, lies 0.1 foot below top of unit. FOSSILS, in shaly chalk, *Mytiloides labiatus;* in chalky limestone, *M. labiatus.* At Locality 7 the 3rd limestone bed contains *Baculites* cf. *B. yokoyamai*	5.7
39. Chalky limestone (PF-1) weathered light olive gray (5Y6/1) to grayish orange, with ferruginous stain along center of bed; unit resistant, ledge forming, speckled, well cemented, with very flat top and base; contains many very thin inoceramid valves and fragments, some of which are oblique to bedding. FOSSILS: *Mytiloides labiatus*	0.17
38. Shaly chalk and chalky limestone; shaly chalk predominates, lower 1.4 feet yellowish gray (5Y8/1), remainder light gray, yellowish gray (5Y8/1) or pale grayish orange owing to limonite staining; mostly contains abundant inoceramid valves and fragments that interrupt evenness of lamination or bedding and that in part are imbricated so as to form small limestone lenses; contains scattered small lenses of skeletal limestone consisting largely of *Inoceramus* prisms and/or tests of planktonic foraminifera; unit contains at least 7 irregular, discontinuous beds of nodular chalky limestone, weathered yellowish gray (5Y8/1) to dark yellowish orange, all relatively resistant, project from weathered slope, contain abundant inoceramid valves and fragments that are mostly parallel to bedding; limestone in uppermost bed in part cemented with visibly crystalline calcite and has petroliferous odor. FOSSILS: in shaly chalk, *Mytiloides labiatus,* fish scales, phosphatic coprolite; in chalky limestone, *M. labiatus*	6.3
Total thickness (composite) of Pfeifer Member	18.3
Jetmore Member	
37. Chalky limestone (Shellrock limestone bed), lower part pale grayish orange; upper part yellowish gray (5Y8/1) and slightly softer than lower part; resistant, ledge forming, upper part of unit concretionary; weathers to form several slabby beds, all speckled, inoceramid valves and fragments common throughout, especially in lower half, oriented parallel to bedding, base of lower part plastered with in-the-round *Mytiloides* valves. FOSSILS: *M. labiatus, Baculites* cf. *B. yokoyamai,* fish bones and scales	0.95
36. Shaly chalk and chalky limestone; shaly chalk predominant, yellowish gray (5Y7/2) to grayish orange, not visibly speckled; uppermost 0.3 foot very thin bedded soft chalk; all but upper 0.8 foot contains abundant inoceramid valves and valve fragments together with very thin irregular beds of soft nonshaly chalk; discontinuous layer of oblate spheroidal chalky limestone concretions up to 0.2 foot thick, yellowish gray (5Y8/1), at least in part thinly and evenly laminated, with few fossils, lies at center of unit; lower half of unit contains at least two irregular, discontinuous beds of concretionary chalky limestone, light olive gray (5Y6/1) to grayish orange, contain abundant inoceramid valves and fragments some of which are crinkled because of compaction; limestones are resistant, project from slope, speckled. FOSSILS: in shaly chalk, *Mytiloides labiatus,* fish scales, phosphatic coprolite; in chalky limestone, *M. labiatus, Baculites* cf. *B. yokoyamai,* fish scales	2.55
35. Limestone (three hard beds) and shaly chalk; limestone separated by shaly chalk intervals, weathered yellowish gray (5Y7/2) to light olive gray (5Y5/2), brittle, resistant, ledge forming, speckled, with abundant in-the-round valves and fragments of *Mytiloides,* most shells parallel to bedding, beds weathered into sharp contact with adjacent rock; shaly chalk weathered light gray to yellowish gray (5Y8/1, 5Y7/2), with abundant *Mytiloides* valves and fragments that project conspicuously from surface, also contains small lenses of imbricated inoceramid valves; bentonite seam, 0.01 foot thick, dark yellowish orange to light gray, lies on lowest limestone bed. FOSSILS, in shaly chalk, *Mytiloides labiatus,* fish scales; in limestone, *M. labiatus, Baculites* cf. *B. yokoyamai,* calcite and limonite cylindrical burrows, limestone-filled *Planolites*-like burrow structures	2.65
34. Shaly chalk and chalky limestone, shaly chalk predominates, medium olive gray (5Y5/1) where nearly fresh, mostly weathered yellowish gray (5Y7/2), in part not laminated, *Mytiloides* valves and fragments scattered throughout and very abundant in upper 1.5 feet; chalky lime-	

No.	Description	Thickness, feet
	stone all partly weathered light olive gray (5Y6/1) to light gray and partly stained dark yellowish orange by limonite, occurs as nine uneven, mostly continuous, subequally spaced beds separated by shaly chalk; limestone relatively resistant, ledge-forming, breaks blocky, most beds speckled and burrow mottled, with nearly homogeneous texture; burrow structures most evident in beds 1, 6, 7, 8, and 9; basal limestone bed contains small pyrite nodules; skeletal limestone, 0.02 foot thick, very pale yellowish brown, well cemented, thinly laminated to gently cross laminated, composed mostly of planktonic foraminiferal tests, lies 0.32 foot above JT-1; lenses of skeletal limestone composed of inoceramid fragments occur above JT-9. FOSSILS: in shaly chalk, *Mytiloides labiatus, Pycnodonte* sp. A (above JT-9); in chalky limestone: *M. labiatus, Watinoceras reesidei* (JT-1, JT-6, JT-8?), *Baculites* cf. *B. yokoyamai* (JT-8, JT-9), *Mammites nodosoides wingi* (JT-9 and as float), *Tragodesmoceras?* sp. (JT-8)	9.3
	Total thickness of Jetmore Member	15.5
33.	Bentonite and bentonitic shaly chalk; bentonite 0.12 foot thick, medium olive gray (5Y5/1) to light olive gray (5Y6/1), weathering dark yellowish orange, slighty silty, biotitic, grades up into bentonitic shaly chalk, weathered yellowish gray (5Y7/2)	0.25
32.	Shaly chalk, olive black, dries medium light gray, in part very tough; inoceramid fragments common throughout, lie parallel to bedding; planktonic foraminiferal tests abundant, stud weathered surfaces; yellowish brown (10Y5/2) zone 0.2 thick and lying 1.8 to 2.0 feet above base contains very thin (< 0.01 foot) seam of light olive gray bentonite; grayish orange to yellowish brown zone 0.35 foot thick (5Y6/1) bentonite seam	6.0
	and lying 1.9 feet below top contains 0.02 foot-thick medium light gray to light olive gray	
31.	Bentonite, medium gray, weathering dark yellowish orange, brittle, slightly silty	0.55
30.	Chalk (HL-3), weathered yellowish gray (5Y8/1) to very pale orange, highly fractured, soft, almost punky, speckled; moderately bioturbated, burrow structures weather to lighter color than rest of rock; tests of planktonic foraminifera common to abundant	0.3
29.	Shaly chalk, olive black, dries medium light gray, with abundant tests of planktonic foraminifera; contains thin, large valves of inoceramid bivalves, some valves and fragments project from weathered slope; unit contains a few very thin layers of soft olive gray chalk and a very thin lens of hard, thinly laminated, light olive gray (5Y5/2) calcisiltite. FOSSILS: *Inoceramus prefragilis*	2.2
28.	Ferruginous-bentonitic unit; partly soft, olive black shaly chalk, partly limonite, basal 0.02 foot is pale gray bentonite; unit forms reentrant. FOSSILS: *Allocrioceras annulatum* at extreme base of unit	0.4
27.	Chalky limestone (HL-2), olive gray (5Y4/1), dries light gray, very resistant, ledge forming, speckled, bioturbated throughout, *Inoceramus* valves and fragments common, thickness of bed ranges from 0.2 to 0.6 foot, base undulatory; FOSSILS: *Inoceramus prefragilis, Sciponoceras gracile, Metoicoceras whitei, Cerithiella* sp. A	0.35
26.	Chalky shale, medium gray, blotched with green, plastic when wet, slightly silty, speckled, bioturbated locally; burrow fill dark gray; basal 0.4 foot bentonitic; bentonite seam, 0.12 foot thick, pale grayish yellow, stained dark yellowish orange, moderately silty, lies 0.4 foot above base of unit	1.1
25.	Chalky limestone, (HL-1) light olive gray to dark olive gray (5Y6/1 to 5Y3/1), weathering yellowish gray (5Y8/1), not as hard as HL-2, not very resistant, crumbly, sparsely speckled, burrow mottled throughout, with scattered blebs of limonite; contains abundant tests of planktonic foraminifera, sparse *Inoceramus* fragments, and conspicuous limonite-filled *Trichichnus*	0.9
24.	Shaly chalk, olive black, dries medium light gray, poorly laminated; contains numerous small, very thin lenses of well-cemented, light olive gray (5Y6/1), fine-grained skeletal limestone. FOSSILS: *Inoceramus prefragilis,* fish scales	2.4
23.	Bentonite, yellowish gray (5Y8/1) to grayish orange with dark yellowish orange limonite stains, slightly silty, with sparse biotite flakes	0.12
	Total thickness of Hartland Member	14.6
22.	Shaly chalk, olive black, dries medium light gray, at least in part thinly and fairly evenly laminated; contains numerous small, very thin lenses of well-cemented, light olive gray (5Y6/1, 5Y5/2) fine-grained skeletal limestone consisting of planktonic foraminiferal tests, *Inoceramus* prisms and small fragments, and sparse fish remains. FOSSILS: *Inoceramus prefragilis,* fish bone fragments and scales	1.15
21.	Bentonite, grayish yellow, stained dark yellowish orange by limonite, locally up to 0.2 foot thick	0.15
20.	Shaly chalk, olive black, dries medium light gray, at least in part thinly laminated, hard where freshly exposed, breaks blocky but not along bedding; upper half contains numerous small thin to very thin irregular lenses of well-cemented, light olive gray (5Y6/1, 5Y5/2) fine grained skeletal limestone; some limestone almost wholly composed of planktonic foraminiferal tests, some is almost wholly *Inoceramus* prisms, and some is a mixture of these grain types; bottoms of limestone lenses marked by fecal casts; bentonite seams, 0.03, 0.03, 0.01 to 0.03 and 0.06 foot thick, respectively, pale olive to light olive gray (5Y5/2), weathering dark yellowish orange, lie 0.6, 1.0, 5.1, and 6.5 feet above base of unit, respectively. FOSSILS: *Inoceramus prefragilis*	6.7
19.	Bentonite, yellowish gray (5Y8/1), weathering dark yellowish orange, slightly silty, very slightly biotitic	0.07
18.	Shaly chalk, olive black, dries medium light to light gray, not well laminated, with numerous *Inoceramus* valves projecting from slope; contains sparse, very thin lenses of well-cemented, light olive gray (5Y6/1) fine grained skeletal limestone composed mostly of *Inoceramus* debris. FOSSILS: *Inoceramus prefragilis*	3.6
17.	Chalk, olive gray (5Y3/2), thinly laminated, soft, discontinuous, speckled, with fragments and valves of *Inoceramus.* FOSSILS: *Inoceramus* sp., fish scales	0.25
16.	Bentonite, yellowish gray (5Y8/1), slightly silty, stained by jarosite and limonite, weathers mealy, thins laterally to 0.05 foot	0.23
15.	Shaly chalk, olive black, dries medium light gray; contains scattered very thin, small lenses of skeletal limestone, light olive gray (5Y6/1), weather medium light gray. FOSSILS: in limestone, *Inoceramus* debris, fish scales, teeth and bones	0.5
14.	Chalk, olive gray, granular, soft, with limonite nodules near base. FOSSILS: Fish scales	0.2
13.	Bentonite, lower half light gray, weathering dark yellowish orange, mealy, biotitic; upper half light olive gray (5Y5/2), slightly silty	0.25
12.	Shaly chalk, olive black, dries medium light gray; contains numerous lenses of skeletal	

Thickness, feet

limestone, light olive gray (5Y6/1), generally lumpy on tops and bases, composed largely of inoceramid debris; also contains very thin, laminated layers of foraminiferal limestone, olive gray (5Y4/1). FOSSILS: *Inoceramus prefragilis*, fish scales and bones 5.0

11. Chalk, shaly chalk, and bentonite; chalk lies at top and base of unit, olive gray (5Y4/1), soft, granular, upper chalk bed with fresh to partially decomposed nodules of pyrite that weather to form masses of limonite, nodules surround large *Inoceramus* fragments; chalks are separated by 0.15 foot of olive black shaly chalk. FOSSILS: *Inoceramus* sp. 0.4
10. Bentonite, very light gray, weathering dark yellowish orange, slightly silty, very slightly biotitic 0.1
9. Shaly chalk, olive black, dries medium light gray, with many large thin valves of *Inoceramus* lying parallel to bedding and in part projecting from slope; contains numerous small very thin lenses of skeletal limestone, light olive gray (5Y6/1) to yellowish gray (5Y7/2), composed mostly of inoceramid debris, one lens contains abundant coprolites; bentonite, 0.02 foot thick, light olive gray, weathering dark yellowish gray, lies 2.5 foot above base; soft, granular chalk, maximum 0.15 foot thick and discontinuous, containing decomposed pyrite nodules, lies on bentonite seam. FOSSILS: *Inoceramus prefragilis, Exogyra* aff. *E. boveyensis* 3.8
8. Chalk, olive gray (5Y4/1), soft, nonresistant, crumbly, with a few faint laminae; lensing zone of soft limonite, 0.05 to 0.1 foot thick, lies in lower part of bed; upper part contains small fragments of *Inoceramus* 0.2
7. Bentonite, light gray, weathering dark yellowish orange, slightly silty, biotitic, lensing 0.06
6. Shaly chalk, olive black, dries medium light gray, with very thin laminae of skeletal calcisiltite; contains numerous very thin lenses of skeletal limestone, light olive gray (5Y6/1), composed largely of *Inoceramus* debris. FOSSILS: *Inoceramus prefragilis*, fish bones and scales 2.25
5. Bentonite, light gray, weathering grayish yellow to dark yellowish orange, moderately silty, biotitic 0.2
4. Shaly chalk, olive black, dries medium gray, only slightly speckled and with little calcareous silt; contains a lensing bed and numerous small, very thin lenses of skeletal limestone, light olive gray (5Y5/2) to olive gray (5Y4/1), well-cemented, brittle; one lens contains light brown phosphatic coprolite; lensing bed has fecal casts on underside. FOSSILS: *Inoceramus prefragilis*, fish scales and bones 1.7
3. Chalk, olive gray (5Y3/2), soft, discontinuous, slightly speckled, with local ferruginous staining along center of bed 0.25
2. Chalky shale, olive black, dries medium light gray, not well laminated, weathers flaky, not conspicuously speckled; unit transitional in lithology from typical Graneros shale to typical Lincoln shaly chalk; contains scattered small lenses of skeletal limestone, mostly well cemented, resistant, composed largely of *Inoceramus* debris, with most conspicuous lenses in upper part; limestones olive gray (5Y3/2) to light olive gray (5Y5/2), some lenses thinly laminated, some lenses have highly irregular cross sections; unit contains much ferruginous matter. FOSSILS: *Inoceramus* sp., *Squalicorax falcatus*, fish bones and scales 3.2
1. Chalky shale, olive black, dries medium gray, thinly and faintly laminated, weathers flaky, speckled, unit transitional in lithology from typical Graneros shale to typical Lincoln shaly chalk; unit contains numerous thin lenses of skeletal calcisiltite, medium gray to olive gray (5Y4/1), weathering grayish orange, very thinly laminated, gently cross laminated, weather papery, with maximum thickness of 0.03 foot 1.8

Total thickness of Lincoln Member 32.1
Total thickness of Greenhorn Limestone 80.5
Rests conformably on Graneros Shale

Key Section 2.—Cuts on east side of Bunker Hill-Luray Road along center, westline, sec. 18, T. 13 S., R. 12 W., Russell County, Kansas (Locality 3).

GREENHORN LIMESTONE

Pfeifer Member

36. Chalky limestone, weathered, mostly grayish orange; upper 0.4 foot slabby, weakly resistant; lower 0.7 foot is massive Fencepost limestone bed, resistant, ledge-forming, with dark yellowish orange limonite stain along nearly central plane and with undulatory base. FOSSILS: *Mytiloides labiatus, Inoceramus cuvieri, Baculites* cf. *B. yokoyamai, Collignoniceras woollgari*, scalpellid cirriped (rare), *Pseudoperna bentonensis*, fish scales 1.1
35. Shaly chalk, weathered, pale grayish orange; bedding fractures 0.04 foot apart in lower part, closer together above, mostly stained dark yellowish orange by limonite; 0.12-foot-thick very even bed of dark yellowish brown to grayish orange chalky limestone lies 0.8 foot above base of unit, base of bed criss crossed by linear burrow casts; weathered oblate spheroidal concretions of grayish orange to dark yellowish orange chalky limestone lie in two zones centering 2 and 4 feet above base, shaly chalk beds bend around concretions; concretions in lower zone are up to 0.2 foot thick, with thin strata of dark yellowish brown skeletal limestone passing through centers; bentonite seam, 0.03 foot thick, light gray, overlain by 0.02 foot of finely granular gypsum, lies beneath even bed of limestone. FOSSILS: in shaly chalk, molds of flattened *Mytiloides labiatus*, fish scales; in chalky limestone, *M. labiatus, Inoceramus cuvieri*, calcitic casts of juvenile hamitids, fish scales 5.1
34. Bentonite and granular calcite (sugar sand); bentonite lies at base and top of unit, 0.05 and 0.03 foot thick, respectively, weathered, nearly white; granular calcite dark yellowish orange, sandy texture 0.36
33. Shaly chalk and chalky limestone; shaly chalk dominant, olive black in lower part of unit where fresh, light olive gray (5Y6/1) to moderate yellowish brown to grayish orange where weathered, non-resistant, contains an abundance of chalky *Inoceramus*-fragment lenses that are mostly less than 0.01 foot thick and 0.2 foot across; chalky limestone nodules and concretions scattered throughout unit, arranged roughly in 11 zones, mostly resistant, forming discontinuous ledges, olive gray where fresh, weather light olive gray (5Y5/2) to yellowish gray (5Y7/2) to grayish orange and pale yellowish orange; limestone in zone 4 partly concretionary and in zones 9 and 11 entirely concretionary and poorly fossiliferous; remaining limestones mostly nodular, more brittle than concretions, with abundant whole and broken valves of *Mytiloides labiatus;* all limestones are white speckled; concretions in zone 9 are thinly laminated, laminae are contorted; shaly chalk beds bend around concretions and nodular limestones; bentonite, 0.12 foot thick, very light gray, weathering dark yellowish orange, slightly silty, lies 0.65 foot below top. FOSSILS: in shaly chalk, abundant scattered valves

	Thickness, feet
of *M. labiatus;* in chalky limestone, *M. labiatus, Pseudoperna bentonensis, Baculites* sp., fish scales	6.6
32. Chalky limestone (PF-1), olive gray, weathering grayish orange to pale grayish orange, white speckled, resistant, forms prominent thin ledge with very flat top and base. Fossils: *Mytiloides labiatus,* whole and broken, *Pseudoperna bentonensis*	0.25
31. Shaly chalk and chalky limestone; shaly chalk dominant, olive black where fresh, weathering light olive gray (5Y6/1) to medium yellowish brown, with abundant flattened valves of *Mytiloides* lying parallel to bedding; upper foot contains very thin lenses of pale yellowish brown skeletal limestone rich in *Mytiloides* debris and foraminifer tests; chalky limestone occurs as resistant nodular masses up to 0.2 foot thick and arranged roughly in 5 main layers, olive black speckled with white where fresh, weathering light gray to grayish- and pale grayish orange, very pale orange, and moderate- to dark yellowish brown with limonite-stained zones passing through centers of most nodules; fragments of *Mytiloides* valves are common in nearly all limestones, nodule surfaces are roughened by tests of foraminifera that weather into relief; bentonite, two seams, 0.01 to 0.02 foot thick, lie 0.6 and 0.1 foot below top of unit, respectively, dark yellowish orange, with upper bentonite separated from unit 32 by seam of dark yellowish orange granular calcite. FOSSILS: in shaly chalk, *Mytiloides labiatus;* in chalky limestone, *M. labiatus, Pseudoperna bentonensis,* fish scales	7.0
Total thickness of Pfeifer Member	20.4
Jetmore Member	
30. Chalky limestone, Shellrock limestone bed, olive gray, weathering dark yellowish brown to yellowish gray (5Y7/2) with dark yellowish orange limonite staining, white speckled throughout, resistant, forms prominent ledge, characterized by abundance of *Mytiloides* valves and valve fragments lying mostly parallel to bedding, with upper surface characterized by abundance of baculitid molds; upper half of unit tends to be concretionary. FOSSILS: *Mytiloides labiatus, Baculites* cf. *B. yokoyamai,* burrow structures, fecal? casts on upper surface	1.15
29. Shaly chalk, olive black, weathering yellowish gray, lowest foot shelly with many *Mytiloides* valves and valve fragments lying mostly parallel to bedding and with very thin lenses of dark yellowish brown skeletal limestone rich in *Mytiloides* debris; unit contains two layers of relatively resistant chalky limestone that form minor ledges; lower limestone is discontinuous, concretionary, softer than beds in unit 28, weathering light olive gray (5Y5/2) to pale grayish orange, and containing many nonflattened valves and valve fragments of *Mytiloides;* upper limestone is continuous flat bed, pale grayish orange, white speckled, and composed partly of hard, pale olive calcilutite. FOSSILS: in shaly chalk, *Mytiloides labiatus,* fish scales and bones; in lower limestone, *M. labiatus, Baculites* cf. *yokoyamai;* in upper limestone, *Anomia* sp. A, *Baculites* cf. *B. yokoyamai*	2.95
28. Limestone (three hard beds) and shaly chalk; limestones dark olive gray weathering light olive gray to pale grayish orange to pale grayish yellow, lowest two beds with limonite stained zones in upper half; all limestones hard, brittle, resistant, form prominent ledges separated by shaly chalk, punky on weathered edges, all with abundant disarticulated and many broken valves of *Mytiloides* most of which lie parallel to bedding and with some shell debris concentrated in thin lenses; burrow structures, some sediment-filled and some calcite or limonite filled, occur in all beds and especially in lowest bed; rock is white speckled and has slight petroliferous odor; shaly chalk is olive black where fresh, weathering to grayish orange, contains abundant flattened fragments and valves of *Mytiloides* and small, very thin lenses of dark yellowish brown skeletal limestone all of which project prominently from weathered exposures; shaly chalk relatively hard where filled with skeletal debris; bentonite, 0.01 foot thick, dark yellowish orange, lies on top of lowest limestone bed. FOSSILS: in limestone, *M. labiatus, Pycnodonte* sp. A, *Baculites* cf. *B. yokoyamai,* burrow structures (see species count in text); in shaly chalk, *M. labiatus, Ptychodus* (rare)	3.2
27. Shaly chalk and chalky limestone, shaly chalk predominant, olive black, locally dark olive gray, weathering light olive gray, weakly resistant, blocky, weathers to small chips, in part well laminated, with abundant fragments and valves of *Mytiloides* and very thin lenses of skeletal limestone in upper 2.5 feet; chalky limestone, 8 subequally spaced mostly continuous thin to medium beds, dark olive gray to light olive gray (5Y6/1) or medium gray, weathering very pale orange or pale grayish orange, usually having dark yellowish orange limonite stain near centers of beds, sparingly white speckled; limestones mostly brittle, resistant, ledge-forming, break into blocks, all more or less burrow mottled, some beds with calcite-filled burrows; thin bed of softer, almost nonresistant burrow-mottled chalk lying 4.5 feet above base of unit is equivalent to marker bed JT-4 of other localities; cross laminated skeletal limestone bed, composed mostly of foraminifer tests, mostly grayish orange, 0.2 to 0.3 foot thick, lies 0.8 foot above base. FOSSILS: in limestone, *M. labiatus, Baculites* cf. *B. yokoyamai, Watinoceras reesidei, Mammites* sp., *ostreid* sp. (lower part); in shale, *M. labiatus, Pycnodonte* sp. A (upper part)	13.5
Total thickness of Jetmore Member	20.8
Hartland Member	
26. Shaly chalk and chalk, shaly chalk predominant, mostly olive black, dries medium light gray, weakly resistant, blocky, weathers to small chips; chalk is olive gray (5Y4/1) to light olive gray (5Y6/1), all burrow mottled, relatively harder than shaly chalk, not ledge forming, uppermost bed contains pyrite nodules; basal foot contains starved ripples composed of gently cross laminated foraminiferal limestone; bentonite seam 0.01 foot thick, grayish orange lies 4.0 feet above base; bentonite seam 0.02 foot thick, dark yellowish orange, marked by line of pyrite nodules, lies 8.1 foot above base; chalky bentonite, 0.4 foot thick, olive gray to grayish orange with dark yellowish orange limonite stains, lies 8.5 foot above base; bentonite seam, 0.08 foot thick, light gray, weathering dark yellowish orange, lies 0.15 foot below top of member. FOSSILS: in shaly chalk, *Inoceramus prefragilis* (lower part), *Mytiloides labiatus* (in upper 3 feet), *Isurus* sp., fish scales and bones especially common in upper part	13.3
25. Bentonite, nearly white, stained dark yellowish orange, biotitic?, slightly silty	0.5
24. Chalk (marker bed HL-3), olive gray (5Y4/1) to light olive gray (5Y6/1), soft, crumbly, burrow-mottled throughout, weathers slabby, foraminifer tests stud weathered surface	0.35
23. Shaly chalk, olive black to olive gray (5Y4/1), soft, weathers to small chips, whole and frag-	

	Thickness, feet
mentary valves of *Inoceramus* scattered throughout; bed of chalk 0.1 foot thick, like unit 24, lies 1.6 foot above base. FOSSILS: in shaly chalk, *Inoceramus prefragilis,* fish bones and scales	2.25
22. Chalky limestone, olive gray (5Y4/1) to light olive gray (5Y6/1), much burrow mottled especially at base, speckled by nearly black fish? bone scraps, relatively resistant, not as hard as limestones in Jetmore Member; unit characterized by abundance of black stained molds of smooth slender baculitids; bed is in sharp contact with underlying unit. FOSSILS: *Inoceramus prefragilis, Phelopteria* sp. A., *Worthoceras vermiculum?, Baculites* sp., acrothoracian cirriped borings in *Inoceramus*	0.3
21. Shaly chalk, olive black, tough, well jointed, weathers to small chips, ferruginous in lower 0.6 foot, contains scattered very thin lenses of hard, pale yellowish brown skeletal limestone; bentonite seam, 0.02 foot thick, grayish yellow (5Y7/2), lies 0.5 foot above base; discontinuous lensing bed of chalky limestone, 0.2 foot thick, olive gray, dries to light gray, speckled with fine black grains of possible fish-bone fragments, lies 0.6 foot above base. FOSSILS: in shaly chalk, *Inoceramus prefragilis;* in chalky limestone, *Baculites* sp., *Worthoceras vermiculum, W. gibbosum, Inoceramus prefragilis, Cerithiella* sp. A	2.6
20. Chalky limestone (marker bed HL-2), olive gray, dries very light gray to yellowish gray (5Y8/1), hard, resistant, prominent ledge formed in weathered part of outcrop, speckled, bed contains abundant burrow structures some of which are weathered to low relief on weathered slabs, body fossils and small fragments of fish bones are conspicuously aligned parallel to bedding, bed swells downward locally to produce bed 0.6 foot thick. FOSSILS: *Inoceramus prefragilis, I.* cf. *I. tenuistriatus, I. flavus, Phelopteria* sp. A, *Metoicoceras whitei, Worthoceras vermiculum, Kanabiceras septemseriatum, Sciponoceras gracile, Allocrioceras annulatum, Baculites* sp., *Cerithiella* sp. A	0.2
19. Shaly chalk and bentonite, shaly chalk olive black, medium gray to dark olive gray (5Y3/1) at top and base, has ferruginous streak near top; bentonite seam, 0.3 foot thick, light brownish gray, weathers yellowish gray (5Y8/1), stained dark yellowish orange by limonite, lies 0.3 foot above base	2.0
18. Chalky limestone (marker bed HL-1), light olive gray (5Y6/1), to medium gray, moderately hard, resistant, highly fractured, with abundant burrow structures; burrow fill is both lighter and darker than surrounding rock; unit contains some open horizontal burrows that are lined with limonite; also sparse, vertical, cylindrical pyrite-filled burrows. FOSSILS: *Inoceramus prefragilis*	0.7
17. Shaly chalk, olive black, lower 2 feet contains very thin, small lenses of pale yellowish brown skeletal limestone; thin lenses of olive gray (5Y4/1) chalk, composed largely of foraminifer tests, lie 2.1 feet above base; upper half of unit contains two thin, nonshaly layers of olive gray (5Y4/1) to light olive gray (5Y6/1) chalk that are gradational with adjacent rock, upper layer is burrowed extensively. FOSSILS: *Inoceramus prefragilis, Plicatula?* sp. (near top)	4.9
16. Bentonite, yellowish gray (5Y8/1) weathering grayish yellow and stained dark yellowish orange	0.22
15. Shaly chalk, olive black, contains many valve fragments of *Inoceramus;* bentonite seam, less than 0.01 foot thick, yellowish gray (5Y7/2), stained dark yellowish orange, lies 0.4 foot below top; unit contains very thin scattered lenses of hard, brittle, pale yellowish brown skeletal limestone. FOSSILS: *Inoceramus prefragilis*	1.3
Total thickness of Hartland Member	28.6
Lincoln Member	
14. Shaly chalk and skeletal limestone, shaly chalk olive black, with numerous very thin, discontinuous laminae of limestone and fragments of *Inoceramus;* skeletal limestone, abundant but not predominant, mostly pale yellowish brown, hard, brittle, resistant, has petroliferous odor, occurs as thin to very thin mostly discontinuous beds and as lenses composed predominantly of *Inoceramus* debris and/or tests of planktonic foraminifera and lesser amounts of bone fragments; some of limestone is cross laminated; uppermost bed convoluted locally and with well preserved casts of thalassinoid burrows; layer of limonitized and gypsiferous pyrite nodules lies 0.5 foot above base. FOSSILS: *Inoceramus prefragilis, Calycoceras?* sp., *Squalicorax falcatus*	2.0
13. Shaly chalk and skeletal limestone, shaly chalk olive black, weathering dark yellowish brown to grayish orange; skeletal limestone as scattered lenses, olive gray, weathering moderate yellowish brown to grayish orange, hard, brittle, mostly with sand-sized grains, composed predominantly of *Inoceramus* prisms and/or tests of planktonic foraminifera; in lower 2.2 feet the unit contains 3 thin or very thin seams of dark yellowish orange bentonite and one seam of grayish olive bentonite that is overlain by 0.2 foot of olive gray granular chalk. FOSSILS: *Inoceramus* sp., vertebrate bone fragments	4.5
12. Shaly chalk, olive black, weathering dark yellowish brown, with some whole and fragmentary remains of *Inoceramus;* contains sparse, scattered very thin small lenses of hard, brittle, skeletal limestone, olive gray (5Y4/1), weathering pale yellowish brown, with bone fragments and local worm? castings; very thin dark yellowish orange bentonite seams lie 1.3 and 4.5 feet above base. FOSSILS: *Inoceramus* sp.	5.0
11. Bentonite, dark yellowish orange	0.2
10. Shaly chalk, olive black, dries medium light gray; unit contains very thin, small lenses of hard, brittle, skeletal limestone, pale yellowish brown, with petroliferous odor, composed largely of tests of planktonic foraminifera. FOSSILS: *Inoceramus* sp.	0.8
9. Bentonite, dark yellowish orange	0.27
8. Shaly chalk, olive black, dries medium light gray and weathers dark yellowish brown. FOSSILS: *Inoceramus prefragilis,* fish bones, one large fish skeleton	1.7
7. Bentonite, yellowish gray (5Y7/2), stained dark yellowish orange	0.15
6. Shaly chalk, olive black, weathering light gray to grayish orange, very soft where weathered; contains local lenses of skeletal limestone, pale yellowish brown, hard, brittle, petroliferous odor, composed mainly of *Inoceramus* debris together with oyster and bone fragments. FOSSILS: *Inoceramus prefragilis, Stramentum* sp. A, *ostreid,* sp., vertebrate bone fragments	1.2
5. Chalk, light brown (5YR5/6) to grayish orange, weathering to form thin layers. FOSSILS: *Inoceramus prefragilis, Eucalycoceras?* sp., fish bone fragments	0.3
4. Shaly chalk, olive black (part), mostly weathered dark yellowish brown to grayish orange, very soft where weathered, *Inoceramus* fragments common. FOSSILS: *Inoceramus prefragilis*	3.1
3. Chalk, light olive gray, weathering dark yel-	

	Thickness, feet
lowish orange, granular, discontinuous, with ferruginous band along center; underlain by 0.04 foot thick seam of nearly white bentonite that weathers dark yellowish brown; also very thin seam of bentonite at top of chalk. FOSSILS: fish bone fragments	0.5
2. Shaly chalk, weathered grayish orange; contains numerous very thin, small lenses of hard, brittle, skeletal limestone, pale yellowish brown, with abundant fish bone fragments	0.7
1. Skeletal limestone, medium dark gray, weathering light olive gray to pale yellowish brown with dark yellowish orange limonite staining, mostly hard, brittle, resistant, ledge former, medium to very thin bedded, in part thinly laminated to cross laminated, has petroliferous odor, composed mostly of *Inoceramus* prisms; basal 0.25 foot coarser, contains much quartz sand, oyster fragments, fish tooth and bone fragments, coprolites, fish scales and is crumbly where weathered. FOSSILS: *Inoceramus prefragilis, Calycoceras? canitaurinum* (float), *Stomohamites* cf. *S. simplex, Exogyra* aff. *E. boveyensis, Ostrea beloiti,* cirriped valves, shark teeth, fish bones	0.9
Total thickness of Lincoln Member	21.3
Total thickness of Greenhorn Limestone	91.1

Rests conformably on Graneros Shale.

Key Section 3.—Composite section in Hodgeman and northern Ford Counties. Pfeifer Member exposed in bluff and abandoned fencepost quarry on south side of Pawnee Creek, NE¼ SE¼ sec. 25, T. 21 S., R. 26 W., Hodgeman County, Kansas (Locality 10).

GREENHORN LIMESTONE

Pfeifer Member

	Thickness, feet
103. Chalky limestone, Fencepost limestone, weathered grayish orange to very pale orange, resistant, ledge-forming, speckled, with ferruginous zone along center of bed; contains abundant valves and fragments of inoceramids, including molds; lower 0.1 foot is softer, very thin bedded. FOSSILS: *Mytiloides labiatus, Collignoniceras woollgari*	0.9
102. Shaly chalk and chalky limestone; shaly chalk predominant, all weathered pale grayish orange; contains a few lenses of shelly foraminiferal chalk and soft grayish orange chalk that project from slope; chalky limestone is concretionary, weathered grayish orange to pale grayish orange, resistant, occurs as oblate spheroids in three layers centering 1.2, 1.8, and 2.1 feet above base, lowest group reach maximum thickness of 0.65 foot; one concretion is 23 feet long, up to 1.1 feet wide, 0.65 foot thick and encloses a log through most of its length; concretions contain relatively few fossils, including whole and fragmentary inoceramid valves, and commonly have ferruginous zone along central plane; bentonite seam, 0.01 foot thick, light olive gray, weathering dark yellowish orange, lies 0.5 foot below top of unit. FOSSILS: in shaly chalk, *Mytiloides labiatus;* in chalky limestone, *M. labiatus, Pseudoperna bentonensis*	3.6
101. Chalky limestone, weathered grayish orange to light brown (5YR5/6), moderately resistant, forms small ledge, speckled, contains lenses of pale yellowish brown, well cemented, brittle limestone; bed underlain by bentonite seam, 0.01 foot thick, olive gray, weathering dark yellowish orange, silty. FOSSILS: *Collignoniceras woollgari*	0.18
100. Shaly chalk, weathered pale grayish orange	0.6
99. Chalky limestone, weathered yellowish orange (5Y7/2) to dark yellowish orange, moderately resistant, forms small ledge, speckled, much stained by limonite, poorly fossiliferous, with many calcite-lined joints. FOSSILS: ammonite mold	0.15
98. Shaly chalk, dark yellowish orange	0.09
97. Bentonite and granular calcite (sugar sand), bentonite 0.09 foot thick, dark yellowish orange, very slightly silty, overlain by 0.32 foot of dark yellowish orange granular calcite	0.41
96. Shaly chalk, grayish orange to pale yellowish orange. FOSSILS: *Mytiloides labiatus*	0.4
95. Chalky limestone, yellowish gray to grayish orange, speckled, poorly fossiliferous	0.1
94. Bentonite, dark yellowish orange	0.12
93. Shaly chalk and chalky limestone; shaly chalk predominant, dark olive gray (5Y3/1), mostly weathered grayish orange to very pale orange, with inoceramid valves abundant in lower part becoming less common upward; lower 2.3 feet of shaly chalk contains abundant lenses of well cemented fine-grained skeletal limestone composed of foraminiferal tests and inoceramid debris and with some chalky matrix, lenses project from weathered slope; chalky limestone, light olive gray (5Y5/2), light brown (5YR5/6), grayish orange or dark yellowish orange, all speckled, resistant, ledge forming, most limestone (5 beds) occurs in irregular, continuous to discontinuous, subequally spaced concretionary beds that contain abundant fragments and valves of inoceramids, second bed from base has sparry calcite cemented laminated zone along center of bed; large chalky limestone concretions, flat on top, hemispheroidal below, poorly fossiliferous, with limonite stains along center, lie 2.9 feet below top. FOSSILS: in shaly chalk, *Mytiloides labiatus, Pseudoperna bentonensis,* scalpellid plates (lower 2.3 feet); in chalky limestone, *M. labiatus, P. bentonensis*	4.7
92. Chalky limestone (PF-1), grayish orange to very pale orange, resistant, ledge forming, speckled, valves and fragments of inoceramids common, top and base uneven. FOSSILS: *Mytiloides labiatus*	0.2
91. Shaly chalk and chalky limestone; shaly chalk predominant, olive black, weathering yellowish gray (5Y7/2) to grayish orange; in upper foot contains lenses of skeletal limestone composed of foraminifera and inoceramid fragments and prisms, with some chalky matrix, project conspicuously from slope; chalky limestone, olive gray (5Y4/1) to light olive gray (5Y6/1) weathering grayish orange to dark yellowish orange, resistant, ledge forming, speckled, in three irregular concretionary beds containing common to abundant fragments or valves of inoceramids, middle bed has ferruginous stain along center; bentonite seam, overlain by granular calcite, dark yellowish orange, 0.01 foot thick, lies at top of unit in contact with PF-1. FOSSILS: in shaly chalk: *Mytiloides labiatus,* fish scales; in chalky limestone, *M. labiatus, Baculites* cf. *B. yokoyamai* (lowest bed)	6.4
Total thickness of Pfeifer Member	17.9

Cut bank on intermittent stream, NW¼ sec. 13, T. 23 S., R. 24 W., Hodgeman County, Kansas (Locality 9).

Jetmore Member

	Thickness, feet
90. Chalky limestone, Shellrock limestone bed, weathered yellowish gray (5Y7/2) to light brown (5YR5/6) or grayish orange, resistant, major ledge former, speckled, in part composed of visibly crystalline calcite, valves and fragments of inoceramids abundant throughout, mostly preserved in-the-round. FOSSILS: *Mytiloides labiatus*	0.55
89. Chalk, yellowish gray (5Y7/2) to grayish orange, very thin beds project from weathered slope, brittle, represents lower part of Shellrock limestone bed of other localities	0.45
88. Shaly chalk, weathered yellowish gray (5Y7/2)	

Thickness, feet

to grayish orange, soft, poorly laminated, contains many small fragments and lenses of fragments of inoceramids; contains two beds of chalky limestone weathered yellowish gray to grayish orange; lower bed continuous, flat on bottom, irregular on top, maximum of 0.23 foot in thickness, highly speckled, contains abundant valves and scattered prisms and fragments of inoceramids; upper limestone bed consists of oblate spheroidal concretions, some coalesced, maximum of 0.3 foot in thickness, highly speckled, with liesegang banding along centers of concretions. FOSSILS: in shaly chalk, *Mytiloides labiatus;* in chalky limestone, *M. labiatus, ?Pseudoperna bentonensis* 2.65

87. Limestone (3 hard beds) and shaly chalk; limestone light olive gray (5Y6/1), weathering grayish orange, three subequally spaced beds separated by shaly chalk, resistant, ledge forming, sparingly speckled, composed in part of visibly crystalline calcite, with many whole and fragmentary valves of inoceramids; inoceramids preserved mostly in-the-round; bentonite seam, 0.01 foot thick, dark yellowish orange, lies on basal limestone bed; shaly chalk predominant, weathered yellowish gray (5Y7/2) and dark yellowish orange, irregularly laminated, soft, with many valves and fragments of inoceramids that project from weathered slope; contains a few lenses of gritty chalk; FOSSILS: in shaly chalk, *Mytiloides labiatus;* in chalky limestone, *M. labiatus, Baculites* cf. *B. yokoyamai* 3.3

86. Shaly chalk and chalky limestone; shaly chalk predominant, in part dark olive gray in lower 3.5 feet, remainder is weathered yellowish gray (5Y7/2) to grayish orange; in uppermost 2.5 feet the shaly chalk beds are crowded with inoceramid valves and fragments that project from weathered slope; chalky limestone, 8 uneven beds, subequally spaced, separated by shaly chalk intervals, relatively hard, resistant, form minor ledges, = JT-1 to JT-8, lowest bed in part olive gray (5Y4/1), remainder of chalky limestone is weathered yellowish gray (5Y7/2) and is dark yellowish orange where stained by limonite; most beds sparingly speckled by fecal pellets; all beds lack laminations, beds 1, 2, 4, 6, and 7 are conspicuously burrow mottled, beds 1, 3, 6, and 7 contain abundant slender, tubular, calcite and/or limonite-filled burrows; position of JT-9 is occupied by soft chalk bed; shaly chalk between JT-6 and JT-7 contains 0.3 foot thick bed of soft, nonresistant chalk; lens of chalk, 0.02 foot thick, thinly laminated, lies 0.5 foot above top of JT-1. FOSSILS: in shaly chalk, *Mytiloides labiatus, Pycnodonte* sp. A (above JT-8), fish bones and scales; in chalky limestone, *M. labiatus, Baculites* cf. *B. yokoyamai* (JT-3), ostreid, sp. (JT-1, JT-2) 15.6

Total thickness of Jetmore Member 22.6

Hartland Member

85. Shaly chalk, dark olive gray (5Y3/1), dries medium light gray; lens of soft chalk, up to 0.25 foot thick, lies 1.0 foot above base; bentonite seam, 0.06 foot thick, dark yellowish orange, lies 0.15 foot below top. FOSSILS: *Mytiloides labiatus* 2.25

84. Chalky limestone, weathered yellowish gray (5Y7/2), forms minor ledge, burrow mottled, with zone of limonite nodules near top 0.35

83. Shaly chalk, dark olive gray (5Y3/1), dries medium light gray, bedding fractures pitted 1.0

82. Chalky limestone, olive gray (5Y4/1), weathering yellowish gray (5Y7/2), forms minor ledge, burrow mottled, with tests of foraminifera studding weathered surface 0.4

Thickness, feet

81. Shaly chalk, dark olive gray (5Y3/1), dries medium light gray 1.3

80. Chalky limestone, olive gray (5Y4/1), weathering yellowish gray, swells locally to 0.3 foot, forms prominent minor ledge, burrow mottled 0.15

79. Shaly chalk, olive black, dries medium light gray; contains two seams of bentonite, dark yellowish orange, 0.05 and 0.01 foot thick, lying at base and 0.5 foot above base of unit, respectively 0.7

78. Chalky limestone, olive gray (5Y4/1), weathering very pale orange, forms minor ledge, weathered slabby, sparingly speckled, faintly burrow mottled, with conspicuous tests of foraminifera. FOSSILS: *Inoceramus prefragilis* 0.8

77. Shaly chalk, olive black, dries medium gray, weathering grayish orange; unit has zones of soft, laminated, weathered rock that alternate with harder, nonlaminated, little-weathered rock resulting in irregular profile on exposure; where least weathered this unit does not show alternation of harder and softer layers and is uniformly olive black. FOSSILS: *Inoceramus prefragilis, Syncyclonema?* sp., lignitized wood (fragment) 3.5

76. Chalky limestone, weathered yellowish gray (5Y7/2), weathers into very thin uneven beds, weakly resistant, with scattered valves and fragments of inoceramid bivalves. FOSSILS: *Inoceramus prefragilis* 0.4

75. Shaly chalk, olive black, in part weathered grayish orange. FOSSILS: *Inoceramus prefragilis* 1.1

74. Chalky limestone, weathered yellowish gray (5Y7/2), weathers to very thin beds, weakly resistant 0.23

73. Shaly chalk, olive black, dries medium light gray with bluish tinge, in part weathering to grayish orange; ferruginous zone, 0.02 foot thick, dark yellowish brown, lies 0.4 foot below top. FOSSILS: *Inoceramus prefragilis* 1.1

72. Chalky limestone, weathered pale yellowish brown to grayish orange, partly stained by limonite, speckled, moderately resistant, single bed of uneven thickness 0.5

71. Shaly chalk, dark olive gray, in part weathered to grayish orange. FOSSILS: *Inoceramus prefragilis* 1.1

70. Chalky limestone, weathered yellowish gray (5Y7/2) with dark yellowish orange limonite stains, moderately resistant, burrow mottled, white speckled. FOSSILS: fish scale 0.3

69. Shaly chalk, olive black, mostly weathered dark yellowish brown to pale yellowish brown. FOSSILS: fish scales and bones 0.8

68. Chalky limestone, olive gray (5Y4/1), weathering very pale orange, in part stained dark yellowish orange by limonite, very uniform texture, sparse inoceramid bivalve fragments, abundant foraminifera. FOSSILS: *Inoceramus* sp. 0.3

67. Shaly chalk, olive black, weathering grayish orange. FOSSILS: fish bones 1.85

Draw in south wall of Buckner Creek valley, NE¼ sec. 10, T. 23 S., R. 23 W., Hodgeman County (Locality 11)

66. Bentonite, weathered nearly white to dark yellowish orange 0.3

65. Chalky limestone (HL-3), weathered very pale orange (10YR8/2), relatively soft, weathers into very thin irregular beds, weakly resistant, sparsely burrow mottled, some laminae preserved. FOSSILS: *Inoceramus prefragilis,* fish vertebra 0.25

64. Shaly chalk, weathered light gray with dark yellowish orange limonite stains on bedding fractures and joints, with scattered whole and fragmentary inoceramid valves; contains very thin bed of soft, partially burrow mottled chalk

	Thickness, feet
1.6 feet above base. FOSSILS: *Inoceramus prefragilis,* fish scales	2.8
63. Chalky limestone, mostly weathered pale grayish orange (10YR8/4), locally almost white, brittle, weathers blocky and crumbly, minor ledge former, much burrow mottled, with abundant spheroidal to vermiform bodies of limonite that may be burrow fillings; contains whole and fragmentary inoceramid valves. FOSSILS: *Inoceramus prefragilis, Phelopteria* sp. A., *Baculites* sp. (smooth), *Worthoceras vermiculum*	0.3
62. Shaly chalk, olive black, weathering medium light gray, some bedding planes made very light gray by abundance of fecal pellets (white specks). FOSSILS: *Inoceramus prefragilis,* fish bones and scales	2.15
61. Chalky limestone (HL-2), weathered light gray to pale grayish orange (10YR8/4), hard, brittle, resistant, major ledge former, faintly burrow mottled, uppermost part very thinly laminated, fossils abundant relative to other Hartland beds, commonly preserved in-the-round; contains slender calcite-filled burrows: FOSSILS: *Inoceramus prefragilis, Cerithiella* sp. A., *Baculites* sp. (smooth), *Kanabiceras septemseriatum, Worthoceras vermiculum, W. gibbosum, Pseudocalycoceras dentonense, Allocrioceras annulatum, Hemiptychoceras reesidei,* articulated teleost skeleton	0.3
60. Shaly chalk, weathered light gray mottled with dark yellowish orange; bentonite seam, 0.07 foot thick, dark yellowish orange, lies 0.8 foot below top	1.45
59. Bentonite, yellowish gray (5Y8/1) to white with dark yellowish orange staining, very slightly silty	0.35
58. Shaly chalk, weathered light gray to grayish orange	0.7
57. Chalky limestone (HL-1), weathered very light olive gray (5Y7/1) to very pale orange (10YR8/1), brittle, resistant, ledge forming, weathers into very thin irregular beds, thoroughly burrow mottled; contains calcite-filled burrows and threadlike, limonite-filled burrows. FOSSILS: *Inoceramus* sp. (frags.), ostreid (indet.), *Trichichnus*	0.4
56. Shaly chalk and chalk, weathered pale orange (10YR7/2); lower part is tough chalk, fractures irregularly subparallel to bedding, burrow mottled, transitional upward from bed below, may grade laterally into upper part of bed below	0.7
55. Chalky limestone, very light gray to nearly white, very thinly bedded, thickens locally to 1.0 foot thickness, main part burrow mottled, upper part thinly and evenly laminated where bed is thicker than normal; brittle, moderately resistant. FOSSILS: ammonite mold (indet.), *Trichichnus*	0.5
54. Shaly chalk, dark olive gray (5Y3/1), dries light gray, in part weathered brown (10YR5/4), upper part weathered moderate grayish orange (10YR6/4), soft at top, remainder very tough and blocky; burrow mottled chalk, 0.2 foot thick, lies 1.5 foot below top; limonite seam, 0.01 foot thick, lies 3.1 foot below top	8.0
Cut bank and pasture on south side of Sawlog Creek, SW¼ sec. 5, T. 25 S., R. 24 W., Ford County (Locality 8).	
53. Bentonite, pale yellowish gray (5Y8/2) to dark yellowish orange, very slightly silty	0.32
52. Shaly chalk, weathered grayish orange	0.16
51. Skeletal limestone, yellowish brown (10YR5/2), weathering very pale orange, well cemented, brittle, mostly very fine grained with some coarse shell fragments, has strong petroliferous odor	0.05
50. Covered interval	2.1
49. Skeletal limestone, light brown (5YR6/4) to grayish orange pink, well cemented, brittle calcisiltite with sparse shell fragments	0.05
48. Shaly chalk, weathered grayish orange to very pale orange, with sparse inoceramid valves and fragments; with scattered very thin, small lenses of foraminiferal limestone, very pale yellowish brown, well cemented, brittle, project from weathered slope; *Inoceramus*-rich limestone, 0.15 foot thick, well cemented, brittle, forms local lens 0.5 foot above base; bentonite seam less than 0.01 foot thick, dark yellowish orange, lies 0.35 foot above base. FOSSILS: *Inoceramus prefraglis,* fish bones and scales	1.9
47. Chalky limestone, weathered grayish orange to pale grayish orange (10YR8/4), relatively resistant, faintly laminated, speckled, with inoceramid shell fragments on upper surface	0.12
46. Shaly chalk, weathered grayish orange to very pale orange, with scattered inoceramid valves and fragments and sparse small, very thin lenses of skeletal limestone composed of *Inoceramus* debris; bentonite seam, 0.02 foot thick, light olive gray (5Y6/1), slightly silty, lies 0.4 foot above base; bentonite seam, 0.06 foot thick, grayish orange, lies at top of unit. FOSSILS: *Inoceramus* sp., fish bones and scales	1.1
45. Bentonite, dark yellowish orange, slightly silty	0.17
44. Shaly chalk, weathered yellowish orange (10YR7/6) to very pale orange, unevenly laminated, filled with inoceramid valves and fragments; contains numerous small, very thin lenses of well cemented, brittle, skeletal limestone composed of *Inoceramus* debris	0.9
43. Skeletal limestone, pale yellowish brown, weathering grayish orange, well cemented, brittle, composed of very fine to coarse *Inoceramus* debris, has petroliferous odor. FOSSILS: *Inoceramus* sp.	0.05
42. Shaly chalk and bentonite; shaly chalk mostly weathered dark yellowish orange to very pale orange; weathered slope littered with *Inoceramus* valves and fragments and lenses of inoceramid debris; skeletal limestone, pale yellowish brown, as scattered small, very thin lenses, well cemented, brittle, has petroliferous odor; bentonite, 4 seams 0.06, 0.05, 0.05, and 0.15 foot thick, dark yellowish orange, lie 0.2, 1.0, 2.35, and 2.6 feet above base, respectively; unit contains sparse very thin, small lenses of relatively resistant chalk. FOSSILS: *Inoceramus prefragilis*	3.6
41. Chalky limestone, weathered grayish orange, moderately resistant, minor ledge former, faintly laminated, white speckled, lenticular, wedges out laterally. FOSSILS: fish bones and scales	0.17
40. Shaly chalk, weathered pale yellowish brown to very pale orange; slope littered with inoceramid valve fragments; unit contains sparse lenses of skeletal limestone, pale yellowish brown, well cemented, brittle, composed mainly of *Inoceramus* debris; bentonite, 0.03 foot maximum thickness, wedges out laterally beneath unit 41, lies at top of unit	1.2
39. Bentonite and limonite; limonite powdery, yellowish orange (10YR7/6), predominates; bentonite is light brown (5YR5/6)	0.13
38. Shaly chalk, weathered dark yellowish orange to very pale orange, with abundant *Inoceramus* valves and fragments; contains many small, very thin lenses of skeletal limestone, pale yellowish brown, well cemented, brittle, with petroliferous odor, composed largely of *Inoceramus* debris, very fine to coarse grained, project from weathered slope. FOSSILS: *Inoceramus prefragilis,* fish bones and scales	3.2
37. Bentonite, pale yellowish brown to very dark yellowish orange (10YR5/6)	0.15

	Thickness, feet
36. Shaly chalk, weathered grayish- to pale grayish orange (10YR8/4) to pinkish gray; contains small, very thin lenses of skeletal limestone, pale yellowish brown, well cemented, brittle, have petroliferous odor, composed predominantly of tests of foraminifera or *Inoceramus* debris, range from very fine to coarse grained. FOSSILS: *Inoceramus prefragilis,* fish bones and scales	0.9
35. Bentonite, weathered light brownish gray (5YR6/1) to very dark yellowish orange (10YR5/6)	0.15
34. Shaly chalk, weathered very pale orange to dark yellowish orange, in part harder than usual and projecting from slope; contains sparse very thin, small lenses of skeletal limestone. FOSSILS: *Inoceramus prefragilis,* fish bones and scales	0.4
33. Bentonite, very light olive gray (5Y7/1) to very dark yellowish orange (10YR5/6)	0.27
32. Shaly chalk, weathered grayish- to pale grayish orange (10YR8/4) and pinkish gray, with numerous *Inoceramus* valves and fragments that litter weathered slope; upper foot contains thin to very thin lenses of skeletal limestone, well cemented, brittle, project from slope, fine to coarse grained, composed largely of *Inoceramus* debris; local lens of chalky limestone, 0.01 foot thick, lies 1.7 feet above base; bentonite seam, 0.01 foot thick, lies 0.5 foot above base. FOSSILS: *Inoceramus prefragilis,* fish bones and scales	3.0
31. Bentonite, mostly weathered very dark yellowish orange (10YR5/6), limonitic	0.04
30. Shaly chalk, weathered grayish orange to very pale orange, very flat bedding planes, with abundant *Inoceramus* valves and fragments that litter weathered slope. FOSSILS: *Inoceramus prefragilis*	2.3
29. Chalky limestone, weathered pale orange (10YR7/2) to pale grayish orange (10YR8/4), relatively resistant, forms minor ledge, white speckled, basal part faintly laminated, weathers platy, with whole and fragmentary *Inoceramus* valves. FOSSILS: *Inoceramus prefragilis*	0.25
28. Shaly chalk, weathered grayish orange to pale orange (10YR7/2), with common *Inoceramus* valves and fragments; discontinuous bentonite seam, 0.03 foot thick, dark yellowish orange, lies 0.01 foot below top of unit. FOSSILS: *Inoceramus prefragilis,* fish bones and scales	4.3
27. Chalky limestone, weathered pale grayish orange, moderately resistant, forms prominent bench, weathers into three very thin beds, speckled. FOSSILS: *Inoceramus prefragilis*	0.3
26. Shaly chalk, weathered light brownish gray to pinkish gray and grayish orange, with many harder-than-usual laminae that project from weathered slope locally; discontinuous bentonite seam, dark yellowish orange, maximum 0.08 foot thick, lies at top of unit. FOSSILS: fish bones and scales	1.6
25. Bentonite, very light gray to dark yellowish orange, with associated coarsely granular gypsum; contains sparse limonite nodules	0.16
24. Shaly chalk, weathered pale orange (10YR7/2) to grayish orange, limonite stained, with much powdery gypsum on bedding planes; soft, nonlaminated chalk bed, 0.2 foot thick, pale yellowish brown to dark yellowish orange, lies 0.3 foot above base. FOSSILS: *Inoceramus prefragilis?,* fish scales and bones	3.25
Total thickness of Hartland Member	68.3
Lincoln Member	
23. Skeletal limestone, pale orange (10YR7/2), well cemented, brittle, very fine grained with some coarse and pebble size grains, resistant. FOSSILS: *Inoceramus prefragilis, Exogyra* aff. *E. boveyensis,* fish bones	0.1
22. Shaly chalk, weathered medium light gray to light brown (10YR6/4), with powdery gypsum on bedding planes; contains scattered small, very thin lenses of skeletal limestone, pale yellowish brown, well cemented, brittle, have petroliferous odor, mostly very fine grained, composed largely of *Inoceramus* prisms or foraminifer tests, some lenses composed of large fragments of *Inoceramus.* FOSSILS: *Inoceramus prefragilis, Exogyra* aff. *E. boveyensis*	0.9
21. Bentonite, moderate olive brown, calcareous	0.24
20. Shaly chalk, weathered grayish orange; contains many small, very thin lenses of skeletal limestone, well cemented, brittle, pale yellowish brown, weathering grayish orange, has petroliferous odor, mostly fine to very fine grained, composed of foraminiferal tests and/or *Inoceramus* debris, very fine to coarse grained; burrow casts occur on soles of some limestones; bentonite seam, 0.01 foot thick, moderate yellowish brown, lies at base. FOSSILS: *Inoceramus prefragilis, Exogyra* aff. *E. boveyensis,* scalpellid barnacle plates, *Calycoceras?* cf. *C? canitaurinum, Isurus,* fish bones and scales	2.4
19. Chalk, weathered dark yellowish orange with some manganese oxide staining, granular, probably secondary	0.32
18. Bentonite, grayish orange to dark yellowish orange	0.22
17. Shaly chalk, weathered light olive gray (5Y6/1) to grayish orange and dark yellowish orange; contains scattered very thin, small lenses and two very thin lensing beds of skeletal limestone, pale yellowish brown, very fine grained, well cemented, brittle, composed mainly of foraminifer tests or *Inoceramus* prisms; contains two bentonite seams, 0.05 and 0.04 foot thick, moderate olive brown and dark yellowish orange, lying 0.05 and 0.7 foot above base, respectively. FOSSILS: *Inoceramus prefragilis,* fish scales	1.2
16. Bentonite, medium light gray, weathering dark yellowish orange, very slightly silty	0.3
15. Shaly chalk, as in unit 17, with only sparse lenses of skeletal limestone	1.1
14. Bentonite, yellowish gray (5Y7/2), weathering dark yellowish orange	0.25
13. Shaly chalk, as in unit 15; bentonite seam, 0.05 foot thick, dark yellowish orange, lies 0.2 foot above base	1.53
12. Chalky limestone and shaly chalk; chalky limestone predominant, four thin to very thin lensing units, all very thin bedded, separated by shaly chalk beds, beds at base and top of unit are most conspicuous, resistant, form minor ledges, speckled, weathered grayish orange to dusky yellow, in part cemented or recrystallized to visibly crystalline calcite, in part laminated, in part burrowed; small, very thin lenses of skeletal limestone, pale yellowish brown, very fine grained, well cemented, occur in the two main limestone beds; uppermost chalky limestone bed contains fragments of *Inoceramus* valves; fecal castings on soles of some limestone beds; bentonite seam, 0.07 foot thick, light olive gray (5Y6/1), lies 0.35 foot below top. FOSSILS: *Inoceramus prefragilis, Exogyra* aff. *E. boveyensis, Eucalycoceras* sp. A	1.7
11. Shaly chalk and chalky limestone; shaly chalk predominant, weathered grayish orange to light brown (5YR6/4); chalky limestone, as scattered very thin beds, weathered grayish orange to dark yellowish orange, moderately resistant, contain abundant *Inoceramus* prisms and foraminifer tests, speckled, locally well cemented; lower part of unit contains small, very thin lenses of skeletal limestone, pale yellowish orange, cross laminated, very fine grained, well	

	Thickness, feet
cemented, brittle, with petroliferous odor. FOSSILS: *Inoceramus prefragilis*	1.2
10. Chalky limestone, weathered grayish orange, single lensing bed, moderately hard, forms prominent ledge. FOSSILS: *Inoceramus prefragilis,* fish scales	0.12
9. Bentonitic shaly chalk, all weathered dark yellowish orange to moderate yellowish brown; contains a layer of nodular chalky limestone masses, up to 0.8 foot thick, grayish orange, with contorted laminae, resulting from disruption of a single bed, exhibits ball and pillow structure. FOSSILS: *Inoceramus prefragilis*	0.8
8. Bentonite, light greenish gray, weathering dark yellowish orange, very slightly silty, grades upward into overlying unit	0.5
7. Shaly chalk, weathered dark yellowish orange, bentonitic in upper 0.75 foot; contains 0.15 foot thick lens of soft chalk, grayish orange, laminated, limonite streaked, with fragments of *Inoceramus* valves, lies 0.35 foot above base. FOSSILS: *Inoceramus prefragilis*	1.46
6. Bentonite, medium gray to nearly white, very slightly silty	0.14
5. Shaly chalk, weathered dark yellowish orange	1.65
4. Bentonitic chalk, weathered dark yellowish orange to moderate yellowish brown, thinly laminated, speckled, contains calcareous silt and some light gray streaks of bentonite. FOSSILS: fish bones	1.05
3. Chalk, mostly weathered to grayish orange, in part thinly laminated, all thin to very thin bedded, locally shaly; bentonite seam, 0.01 foot thick, light gray, lies 0.85 foot below top. FOSSILS: *Ostrea beloiti,* fish bones, teeth and scales	2.0
2. Bentonite, dark yellowish orange	0.02
1. Skeletal limestone, olive gray, weathering dark yellowish orange with much limonite staining, single well-cemented bed, composed of *Ostrea beloiti* valves set in "matrix" composed largely of *Inoceramus prisms,* has petroliferous odor, locally pyritic; uppermost 0.02 foot locally lacks *Ostrea* valves, is pale yellowish brown; unit forms conspicuous, projecting ledge. FOSSILS: *Ostrea beloiti,* ammonite mold (indet.), coprolites, bone pebbles, *Inoceramus* sp. (frags.), *Lispodesthes?* sp., *Ptychodus, Isurus*	0.25
Total Thickness of Lincoln Member	19.4
Total Thickness of Greenhorn Limestone	128.2
Rests disconformably on Graneros Shale	

Key Section 4.—Composite section in Hamilton and Kearny Counties. Upper part in cut banks along East Bridge Creek, SW¼ sec. 14, NE¼ sec. 22, T. 23 S., R. 42 W., Hamilton County, Kansas (Locality 14).

GREENHORN LIMESTONE

Bridge Creek Member (Pfeifer equivalent)

	Thickness, feet
116. Chalky limestone, weathered very pale yellowish brown to pale grayish orange, tough, less resistant than unit 114, breaks blocky; represents upper part of Fencepost limestone bed. FOSSILS: *Collignoniceras woollgari*	0.55
115. Shaly chalk, weathered pale grayish orange	0.22
114. Chalky limestone, olive gray (5Y4/1), mostly weathered grayish orange, stained dark yellowish orange locally by limonite, hard, brittle, resistant, ledge forming, in part thinly laminated, locally cross laminated, sparsely speckled, represents lower part of Fencepost limestone bed. FOSSILS: *Mytiloides labiatus, Collignoniceras woollgari, Baculites* cf. *B. yokoyamai, Pseudoperna bentonensis,* fish scales	0.55
113. Shaly chalk, olive black to dark olive gray (5Y3/1); bentonite, dark yellowish orange, 0.01 foot thick, lies 0.07 foot below top. FOSSILS: *Syncyclonema?* sp., baculitid mold, fish scales	2.75
112. Bentonite, dark yellowish orange, slightly silty	0.14
111. Shaly chalk, dark olive gray (5Y3/1); limestone, dark olive gray (5Y3/1), weathering grayish orange, hard brittle, resistant, massive, sparsely speckled, unfossiliferous, concretionary, breaks with smooth vertical fractures, passes laterally into shaly chalk, maximum thickness 0.35 foot, lies 0.15 foot above base; limonite and gypsum nodule, 0.15 foot thick, centers 0.7 foot above base. FOSSILS: *Syncyclonema?* sp., *Mytiloides labiatus,* fish scale	1.1
110. Bentonite, dark yellowish orange, gritty	0.14
109. Shaly chalk, olive gray (5Y4/1), crowded with whole and broken inoceramid valves; FOSSILS: *Mytiloides labiatus*	0.65
108. Chalky limestone, olive gray (5Y4/1) weathering yellowish gray (5Y7/2), tough, resistant, conspicuous on slope, homogeneous, partially cemented by visibly crystalline calcite, inoceramid valves and fragments abundant, weathered surfaces studded with foraminifera. FOSSILS: *Mytiloides labiatus*	0.15
107. Shaly chalk, dark olive gray (5Y3/1); limestone, olive gray (5Y4/1), speckled, homogeneous, concretionary, with abundant whole and fragmentary inoceramid valves, 0.35 foot thick, lies 1.4 foot above base; unit contains very thin discontinuous beds of well-cemented skeletal limestone, yellowish brown, laminated to gently cross laminated, composed of inoceramid prisms or a mixture of prisms and planktonic foraminiferal tests; selenite seam, 0.01 foot thick, marked by limonitized marcasite nodules, lies 3.2 feet above base, probably marks weathered seam of bentonite. FOSSILS: *Mytiloides labiatus, Syncyclonema?* sp.	4.5
106. Chalky limestone, olive gray (5Y4/1), weathering yellowish gray, tough, brittle, resistant, homogeneous, with abundant *Mytiloides* valves, surface studded with tests of planktonic foraminifera, base of unit contains concretionary masses up to 0.3 foot thick and 1.4 feet wide. FOSSILS: *Mytiloides labiatus*	0.3
105. Shaly chalk, dark olive gray (5Y3/1), laminae bend downward beneath overlying concretions; unit contains abundant very thin small lenses of skeletal limestone, fine grained, composed largely of inoceramid valve prisms	1.4
104. Chalky limestone, olive gray (5Y4/1) weathering pale grayish orange, discontinuous, ranges up to 0.35 foot thick, speckled, tough, resistant, partially cemented by sparry calcite, with very thin laminated zone in middle of bed and with sparse tests of planktonic forams studding surface; contains whole valves and fragments of *Mytiloides,* some valves with recrystallized nacreous layer preserved. FOSSILS: *Mytiloides labiatus,* fish scales	0.2
103. Shaly chalk, olive black (5Y4/1), laminae bend around concretions; limestone, olive gray (5Y4/1), concretionary, as oblate spheroidal masses up to 0.2 foot thick and 1.0 foot in breadth, lie in zone centering 0.25 foot below top; in lower foot unit contains very thin lenses of well-cemented skeletal limestone, dark yellowish brown, composed mainly of inoceramid valve prisms; bentonite, less than 0.01 foot thick, dark yellowish orange, lies 1.2 foot above base. FOSSILS: *Mytiloides labiatus, Pseudoperna bentonensis*	1.8
102. Chalky limestone, olive gray (5Y4/1), weathering grayish orange with dark yellowish orange limonite stains, tough, resistant, speckled, rock tightly cemented in lowest 0.02 foot, sole is load? casted, top of bed flat; contains whole and fragmentary valves of *Mytiloides.* FOSSILS: *Mytiloides labiatus, Pseudoperna bentonensis,* fish scale	0.14
101. Shaly chalk, olive black, like unit 103; abundant whole and broken *Mytiloides* valves and	

	Thickness, feet
very thin small lenses of pale yellowish brown skeletal limestone project conspicuously from slope. FOSSILS: *Mytiloides labiatus, Pseudoperna bentonensis*	1.45
100. Chalky limestone, olive gray (5Y4/1), weathering grayish orange, homogeneous, speckled, partially cemented by sparry calcite, tests of planktonic foraminifera stud surface, unit weathers into very thin beds, marcasite fills sparse tubular burrows: FOSSILS: *Pseudoperna bentonensis, Mytiloides labiatus*	0.35
99. Shaly chalk, olive black, like unit 103, with whole and broken valves of *Mytiloides.* FOSSILS: *Mytiloides labiatus,* fish scale	1.0
98. Chalky limestone, dark olive gray (5Y3/1), weathering yellowish gray (5Y8/1) to pale grayish orange, homogeneous texture, partially cemented by sparry calcite; *Mytiloides* valves in-the-round, many juveniles; contains sparse, large *Planolites*-type burrow structures. FOSSILS: *Mytiloides labiatus, Baculites* sp., *Stomohamites* sp. cf. *S. simplex*	0.4
97. Shaly chalk, dark olive gray (5Y3/1), partly weathered dark yellowish brown to medium yellowish brown, like unit 103; unit contains abundant very thin, small lenses of pale yellowish brown skeletal limestone composed mainly of *Mytiloides* fragments and isolated prisms. FOSSILS: *Mytiloides labiatus,* fish scales	2.5
96. Chalky limestone, dark olive gray, weathering yellowish gray (5Y8/1) to pale grayish orange, homogeneous, nonspeckled, partially cemented by visibly crystalline calcite, very fine grained, with sparse small limonitic nodules along center of bed; burrow structures not obvious, bed expands locally to 0.35 foot. FOSSILS: *Mytiloides labiatus,* fish scale	0.2
95. Shaly chalk, dark olive gray, partly weathered to slightly brownish olive gray (5Y4/1), with abundant valves of *Mytiloides* projecting from slope; unit contains very thin lenses of hard, brittle, very fine grained skeletal limestone scattered throughout but mostly near middle and reaching 0.05 foot in thickness. FOSSILS: *Mytiloides labiatus, Anomia* sp. A, oyster (fragment), fish scales	5.35
Total thickness of Pfeifer equivalent	25.8
Bridge Creek Member (Jetmore equivalent)	
94. Chalky limestone, Shellrock limestone bed, olive gray (5Y4/1), weathering grayish, resistant, ledge-forming, less brittle than three beds in unit 92, massive, with shaly weathering in lower 0.3 foot, at top and base gradational to adjacent units, contains faintly defined burrow structures some of which are limonite stained or lined with marcasite, surface of bed studded with foraminifera and inoceramid valve prisms, lower 0.3 foot rich in whole specimens of *Mytiloides.* FOSSILS: *Mytiloides labiatus,* fish scales	0.9
93. Shaly chalk, dark olive gray, laminae bend around concretions in lower part of unit; shaly chalk contains abundant *Mytiloides* valves, valve fragments, and lenses of fragments as well as numerous very thin, small lenses of chalky limestone; unit grades to very thin bedded chalk in upper 0.2 foot; at 0.9 foot above base unit contains layer of oblate spheroidal concretions of chalky limestone, olive gray, weathering grayish orange, brittle, resistant, in part cemented by visibly crystalline calcite, speckled, with abundant whole and fragmentary specimens of *Mytiloides* and with irregular masses of limonite scattered along middle part of concretion zone; individual concretions are as much as 0.3 foot thick and up to 1.2 feet in diameter but reach greater size where 2 such structures have coalesced. FOSSILS: in shaly chalk, *Mytiloides labiatus, Pycnodonte* sp. A; in chalky limestone, *Mytiloides labiatus*	3.9
92. Limestone (three hard beds) and shaly chalk; limestones, three beds, separated by shaly chalk intervals, olive gray (5Y4/1) to medium olive gray (5Y5/1) or light olive gray (5Y6/1), weathering grayish orange, partly stained dark yellowish orange by limonite; all limestones hard, brittle, resistant, highly fractured, more or less speckled; all beds with burrow mottling and/or burrow structures and crowded with noncrushed valves of *Mytiloides;* shaly chalk dark olive gray (5Y3/1), contains abundant whole and fragmentary valves of *Mytiloides* and very thin lenses of skeletal limestone; bentonite, 0.14 foot thick, grayish orange, selenitic, lies on lowest limestone bed. FOSSILS: in limestone, *M. labiatus, Baculites* cf. *B. yokoyamai, Pycnodonte* sp. A, fish scales, *Anomia* sp. A, marcasite- and calcite-filled cylindrical burrows; in shaly chalk, *M. labiatus*	4.0
91. Shaly chalk, dark olive gray (5Y3/1), partly weathered to dark yellowish brown, weathers more flaky than shaly chalks below, upper 0.5 foot rich in *Mytiloides* valves and fragments; 0.01-foot-thick seam of selenite and clay (bentonite?) lies 0.25 foot above base. FOSSILS: *Mytiloides labiatus,* fish scale	1.3
90. Chalky limestone, light olive gray (5Y6/1) to olive gray (5Y4/1), partly weathered to light olive gray (5Y5/2), brittle, resistant, ledge-forming, speckled, upper part locally weathers slabby, lensing bed mostly 0.2 to 0.4 foot thick, locally discontinuous, many disarticulated and broken valves of *Mytiloides,* weathered surface studded with tests of planktonic foraminifera. FOSSILS: *Mytiloides labiatus,* ammonite mold fragment, fish scale	0.35
89. Shaly chalk, dark olive gray (5Y3/1). FOSSILS: *Mytiloides labiatus,* fish scales	1.3
88. Chalky limestone, light olive gray (5Y6/1) to olive gray (5Y4/1), brittle, resistant, weathers shaly, speckled, burrow mottled, some burrow fill dark olive gray (5Y3/1), with many broken and disarticulated valves of *Mytiloides;* tests of planktonic foraminifera stud weathered surface; bed pinches and swells, forms discontinuous ledge. FOSSILS: *Mytiloides labiatus*	0.35
87. Shaly chalk, dark olive gray (5Y3/1); three thin beds forming reentrants 0.2, 0.45, and 0.75 foot above base are weathered light olive gray (5Y5/2) and are associated with very thin seams of gypsum. FOSSILS: *Mytiloides labiatus,* one phosphatic coprolite	1.45
86. Chalky limestone, light olive gray (5Y6/1) to olive gray (5Y4/1), in part weathered yellowish gray (5Y8/1) to pale grayish orange, brittle, resistant, forms prominent ledge, speckled, extensively burrow mottled, some burrow fill dark olive gray (5Y3/1), some burrows weathered into strong relief, many burrows limonite stained, some burrows marcasitized; bed thickens locally to 1.6 feet where base extends lower in section, tests of planktonic foraminifera stand in relief on surface. FOSSILS: *Discinisca sp.*	0.55
85. Shaly chalk, dark olive gray, in part weathered moderate yellowish brown; contains abundant *Mytiloides* valves and valve fragments; middle part with abundant planktonic foraminifer tests and less well speckled and laminated; limonitic and jarositic marcasite nodule 0.15 foot thick lies 0.8 foot above base. FOSSILS: *Mytiloides labiatus,* fish scales	3.15
84. Chalky limestone, light olive gray (5Y6/1) with olive gray (5Y4/1) to dark olive gray (5Y3/1) burrow mottles, brittle, resistant, ledge-forming, sparsely speckled, with abun-	

Thickness, feet

dant tests of planktonic foraminifera weathered out on surface; rock extensively burrowed and burrow mottled; contains some marcasite- or calcite-filled burrows; sparse marcasite nodules lie near center of bed. FOSSILS: *Mytiloides labiatus, Mammites* sp. (fragment), *Baculites* sp. 0.35

83. Shaly chalk, dark olive gray (5Y3/1), many tests of planktonic foraminifera, abundant whole and broken valves of *Mytiloides.* FOSSILS: *Mytiloides labiatus* 1.1

82. Chalky limestone, light olive gray with dark olive gray (5Y3/1) burrow fill, mostly weathered pale grayish orange, relatively brittle, resistant, ledge-forming, very sparsely speckled, faintly burrow mottled, some burrows stained dark yellowish orange by limonite. FOSSILS: *Mytiloides labiatus, Discinisca* sp., *Baculites* sp. 0.25

81. Shaly chalk, dark olive gray (5Y3/1), with prominent reentrants at levels of 3 very thin seams of bentonite. FOSSILS: *Mytiloides labiatus* 1.0

80. Chalky limestone, weathered very pale orange, brittle, resistant, ledge-forming, sparsely speckled, faintly burrow mottled, scattered valves and fragments of *Mytiloides,* many tests of planktonic foraminifera weathered out on surface; sparse calcite-filled burrows; pyrite nodules in zone along center of bed are mostly weathered to limonite which stains much of bed dark yellowish orange. FOSSILS: *Mytiloides labiatus, Baculites* sp., *Discinisca* sp. ... 0.44

79. Shaly chalk, all partially weathered to medium yellowish brown (10YR5/2); contains many whole and fragmentary valves of *Mytiloides,* abundant tests of planktonic foraminifera, unit weathers flaky. FOSSILS: *Mytiloides labiatus* 1.25

78. Chalky limestone, partially weathered to light olive gray (5Y6/1) to very pale orange, brittle, resistant, ledge-forming, large burrow structures throughout that are locally stained dark yellowish orange by limonite, weathered surface studded with tests of planktonic foraminifera; sparse calcite-filled burrows; sparse marcasite nodules occur locally in center of bed. FOSSILS: *Mytiloides labiatus, Discinisca* sp. 0.42

77. Shaly chalk, dark olive gray (5Y3/1), *Mytiloides* valves common throughout, abundant in upper 0.5 foot; dark yellowish orange bentonite seams, each less than 0.01 foot thick, lie 0.05 foot and 0.35 foot above base, respectively. FOSSILS: *Mytiloides labiatus* 1.35

76. Chalky limestone, medium light gray, mostly partially weathered to light olive gray (5Y6/1) and yellowish gray (5Y8/1), brittle, resistant, ledge-forming, speckled, burrow mottled, in part stained dark yellowish orange by limonite, with scattered tests of planktonic foraminifera weathered out on surface. FOSSILS: *Mytiloides labiatus,* oyster sp. 0.35

75. Shaly chalk, olive black, weathering locally to grayish orange, with many valves of *Mytiloides;* very thin (0.015 foot, maximum) lensing bed of foram-rich skeletal limestone lies 0.3 foot above base. FOSSILS: *Mytiloides labiatus* 1.25

74. Chalky limestone, light olive gray (5Y6/1), weathering grayish orange, with olive gray (5Y4/1) burrow structures, brittle, resistant, ledge forming, very sparsely speckled, with abundant noncrushed valves (some paired) of *Mytiloides.* FOSSILS: *Mytiloides labiatus, Watinoceras reesidei, Vasoceras birchbyi* 0.43

Total thickness of Jetmore equivalent 25.4

Bridge Creek Member (Hartland equivalent, part)

73. Shaly chalk, dark olive gray (5Y3/1); bentonite, 0.05 foot thick, grayish orange to dark yellowish orange, lies 0.11 below top of unit. FOSSILS: *Mytiloides labiatus* 2.4

Thickness, feet

72. Chalky limestone, weathered very pale orange, highly fractured, resistant, forms ledge, sparsely speckled, contains large limonite-stained burrow mottles and many slender burrows lined with limonite; unit in part laminated locally 0.4

71. Shaly chalk and chalky limestone, shaly chalk all weathered grayish orange, soft and rich in foraminifer tests in lower part, brittle in upper part; chalky limestone bed 0.4 foot thick, weathered pale grayish orange, moderately resistant, forms minor ledge near middle of unit, contains abundant tests of planktonic foraminifera. FOSSILS: fish scales 1.4

70. Bentonite, olive gray (5Y4/1), stained dark yellowish orange by limonite, gritty, not waxy like most bentonites 0.11

69. Shaly chalk, all partly weathered light olive gray (5Y6/1) to grayish orange 0.45

68. Chalky limestone, all weathered very pale orange to grayish orange, sparsely speckled, blotched with limonite that apparently reflects burrow mottling. FOSSILS: *Mytiloides labiatus* 0.5

67. Shaly chalk, dark olive gray (5Y3/1), weathering yellowish gray (5Y8/1) to grayish orange or moderate yellowish brown, with some beds not well laminated; 0.3-foot-thick bed of chalk, dark olive gray (5Y3/1), thin bedded, speckled, burrow mottled, with abundant tests of planktonic foraminifera, lies 0.6 foot above base. FOSSILS: *Mytiloides labiatus, Inoceramus prefragilis?* 2.2

66. Chalky limestone, light olive gray (5Y6/1), weathered grayish orange, brittle, resistant, ledge forming, highly fractured, speckled, extensively burrowed; burrows outlined by limonite 0.4

65. Shaly chalk, dark olive gray (5Y4/1), weathering light olive gray (5Y5/2) to grayish orange or dark yellowish orange, thinly laminated, contains abundant tests of planktonic foraminifera; one foot above base is conspicuous 0.15-foot-thick lensing zone of very thinly bedded chalky limestone, weathered light olive gray, gradational with adjacent chalk. FOSSILS: *Mytiloides labiatus* 2.05

64. Chalky limestone, olive gray (5Y4/1) to dark olive gray (5Y3/1), weathers grayish orange to very pale orange; speckled, extensively burrowed, burrow fill mostly darker than adjacent matrix, contains abundant tests of planktonic foraminifera; scattered nodules of limonite, some with marcasite centers, lie near center of bed. FOSSILS: *Mytiloides labiatus, Watinoceras reesidei?, Puebloites* sp., *Tragodesmoceras bassi?* 0.4

63. Shaly chalk, dark olive gray with some layers partly weathered to medium yellowish brown (10YR5/2); many tests of planktonic foraminifera visible on bedding planes; uppermost part poorly laminated, tougher than below, and burrow mottled; unit contains whole and fragmentary inoceramid valves. FOSSILS: *Inoceramus prefragilis, Mytiloides labiatus* 1.1

62. Chalky limestone, olive gray (5Y4/1), mostly weathered light olive gray (5Y7/2) to light olive gray (5Y6/1), brittle, highly fractured, resistant, ledge-forming, sparsely speckled, apparently burrow mottled, weathered surface studded with tests of planktonic foraminifera 0.3

61. Shaly chalk, dark olive gray (5Y3/1), very well laminated; local bed of chalk, 0.15 foot thick, pale grayish orange, lies 1.15 feet below top, forms conspicuous streak in unweathered exposures; scattered limonite nodules up to 0.05 foot thick and 0.4 foot wide occur in zone 0.3 foot above base. FOSSILS: *Inoceramus prefragilis, Mytiloides labiatus,* fish scale 3.1

	Thickness, feet
60. Bentonite, nearly white to grayish orange, in part stained dark yellowish orange by limonite; slightly silty; forms prominent reentrant	0.25
59. Chalky limestone (HL-3), olive gray (5Y4/1), mostly weathered yellowish gray (5Y8/1), brittle, resistant, ledge forming, ranges from 0.35 to 0.5 foot, not speckled, abundant tests of planktonic foraminifera stud surface, faintly burrow mottled, burrows stained by limonite. FOSSILS: fish vertebra	0.4
58. Shaly chalk, dark olive gray (5Y3/1), most is weathered yellowish gray (5Y7/2) to medium yellowish brown (10YR5/2); contains whole and fragmentary inoceramid valves. FOSSILS: *Inoceramus prefragilis*, *Phelopteria* sp. A.	1.75
57. Chalky limestone, mostly weathered grayish orange, sparsely speckled, brittle, resistant, ledge forming, extensively burrowed, chalky burrow fill is light olive gray (5Y5/2) to light olive gray (5Y6/1), some slender burrows outlined by limonite stains. FOSSILS: *Inoceramus prefragilis*, *Phelopteria* sp. A., *Worthoceras vermiculum*, *W. gibbosum*, *Baculites* sp. (smooth), fish vertebra	0.35-0.4
56. Shaly chalk, dark olive gray (5Y6/1), conspicuously laminated, contains sparse olive black burrow structures and whole and broken inoceramid valves; bentonite, 0.03 foot thick, dark yellowish orange, lies 0.7 foot below top. FOSSILS: *Inoceramus prefragilis*, fish scales, fish vertebra	1.5
55. Chalky limestone, olive gray (5Y4/1), weathers grayish orange to pale grayish orange, discontinuous lensing bed is brittle, ledge forming, locally contains oblate spheroidal chalky limestone concretions, limestone not speckled, contains whole and fragmentary inoceramid valves, basal 0.08 foot contains cylindrical chalk-filled burrow structures lying parallel to bedding, bed ranges from nothing to 0.55 foot in thickness. FOSSILS: *Inoceramus prefragilis*, *Worthoceras vermiculum*, *Baculites* sp. (smooth), ?*Allocrioceras* sp., fish scales	0.33
54. Shaly chalk, dark olive gray (5Y3/1), weathers dark yellowish orange; contains 5 limonitic selenite seams the upper 3 of which merge laterally, these may be weathered bentonites; unit contains much jarosite	0.85
53. Chalky limestone (HL-2), olive gray (5Y4/1) with weathered crust of dusky yellow, brittle, resistant, ledge forming, edge of ledge weathers rounded; part of bed contains faint laminae that contain visibly crystalline calcite; unit contains sparse, large, chalk-filled burrow structures. FOSSILS: *Inoceramus prefragilis*, *Cerithiella* sp. A, *Worthoceras vermiculum*, *Pseudocalycoceras dentonense*, fish scales, fish bone	0.34
52. Shaly chalk, dark olive gray (5Y3/1) in lower part, medium dark gray and burrow mottled in upper 0.25 foot, poorly laminated, darker part not speckled; contains oblate spheroidal concretion of chalky limestone, medium gray, speckled, 0.25 foot thick, lying 0.5 foot above base; bed of chalky limestone, medium gray, 0.08 foot thick, lies 0.25 foot below top	1.05
51. Bentonite, fresh color medium gray, most is weathered nearly white with dark yellowish orange limonite stains, gritty	0.6
50. Shaly chalk, medium gray, not conspicuously speckled, poorly laminated, apparently clayey, upper part contains streaks of limonite and jarosite, rock contains fine grained selenite crystals	0.4
49. Chalky limestone (HL-1), light olive gray (5Y6/1), brittle, extensively mottled by chalk-filled structures approximately 1 cm in average diameter, also contains calcite-filled burrows approximately 2 mm in diameter, rock speckled. FOSSILS: *Sciponoceras gracile*	0.4
48. Shaly chalk, olive gray (5Y4/1), faintly speckled, soft	0.13
47. Chalky limestone, dark olive gray (5Y3/1) mottled with light gray, crowded with chalk-filled burrow structures; equivalent to lower part of HL-1	0.8
Total thickness of Hartland equivalent of Bridge Creek member	24.0
Total thickness of Bridge Creek member	75.2

Road ditch and bluff on north side of county road in NE¼ sec. 32, T. 21 S., R. 38 W., approximately 2 miles east of Kendall, Kearny County. (Locality 13).

Hartland Member

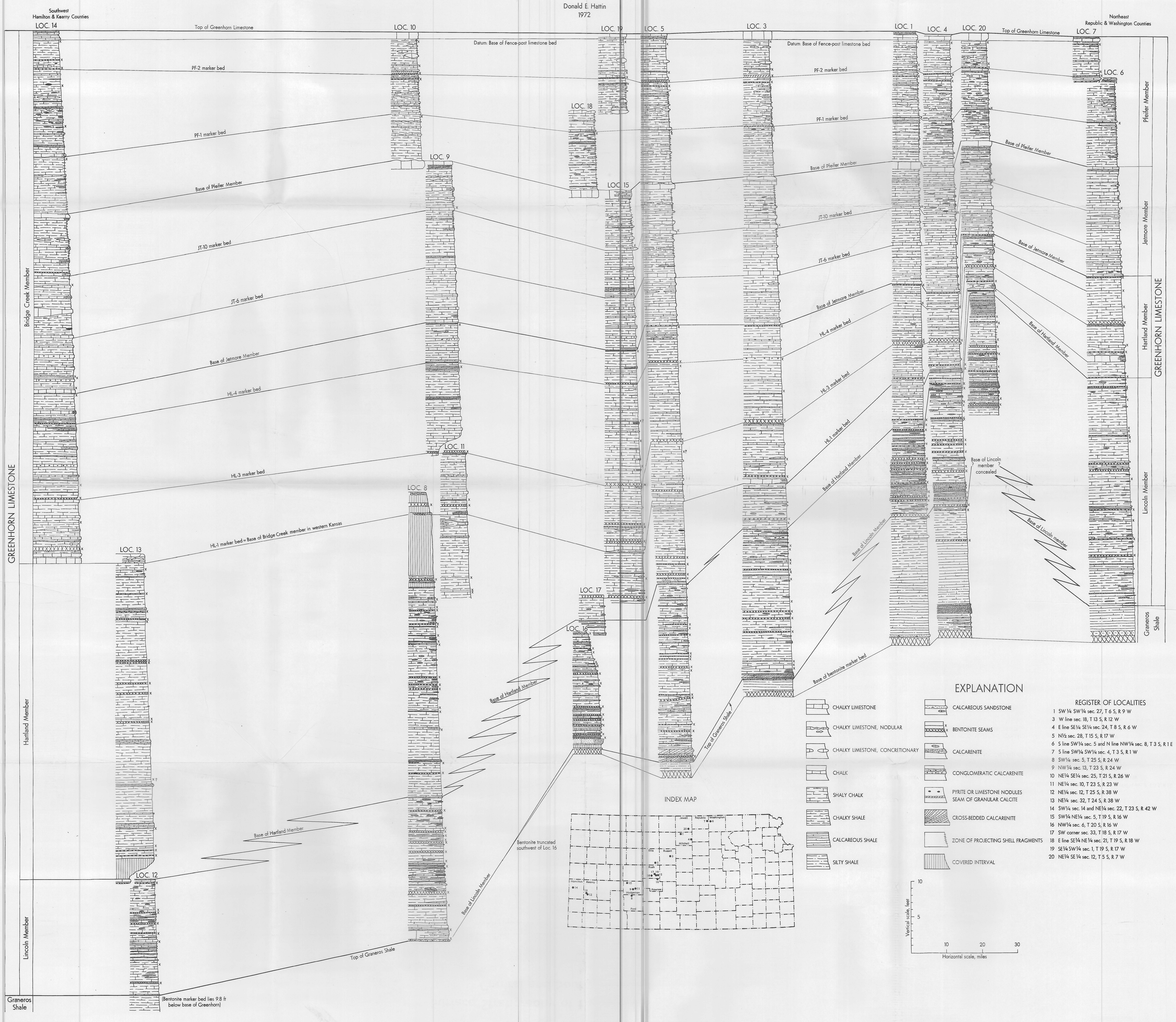
	Thickness, feet
46. Shaly chalk with some chalky limestone; shaly chalk mostly weathered to light olive gray (5Y6/1) to grayish orange; upper half contains scattered lenses and very thin beds of chalky limestone, light olive gray (5Y5/2) to grayish orange, that are rich in *Inoceramus* prisms; ferruginous streak lying 0.25 foot above base may be weathered bentonite; bentonite seam, dark yellowish orange, 0.06 foot thick, lies 0.8 foot above base. FOSSILS: *Inoceramus prefragilis*, fish bones and scales	1.8
45. Skeletal limestone, pale yellowish brown to grayish orange, with both chalky matrix and sparry calcite cement, brittle, litters slope with slabs, petroliferous odor; rich in *Inoceramus* shells, prisms and fragments; sole of bed preserves large burrow casts. FOSSILS: *Inoceramus prefragilis*, mold of large ammonite, fish bones	0.1
44. Shaly chalk, all partly weathered light olive gray (5Y6/1) to grayish orange or dark yellowish orange; skeletal limestone bed, pale yellowish brown, petroliferous odor, 0.02-foot-thick, lies 0.55 foot below top. FOSSILS: *Inoceramus prefragilis*, whole and as fragments, fish scales and bone fragments	2.3
43. Bentonite, dark yellowish orange to very light gray, silty	0.1
42. Shaly chalk, all partly weathered light olive gray (5Y6/1) to grayish orange or dark yellowish orange. FOSSILS: *Inoceramus prefragilis*, whole and as fragments, fish scales and bone fragments	1.95
41. Limestone, pale yellowish brown, weathering grayish orange, brittle, ledge forming, with 0.05-foot-thick shaly chalk parting near middle, unit litters slope with slabs. FOSSILS: *Inoceramus prefragilis*, whole and as fragments, fish scales and bones	0.22
40. Shaly chalk, mostly weathered grayish orange to yellowish gray (5Y8/1)	0.15
39. Bentonite, dark yellowish orange, with shaly chalk parting 0.1 foot above base and about 0.04 foot thick	0.25
38. Shaly chalk, mostly weathered grayish orange to yellowish gray (5Y8/1); lensing, skeletal limestone bed, 0.03 foot thick, pale yellowish brown, brittle, lies at top of unit. FOSSILS: *Inoceramus prefragilis*, whole and as fragments, fish scales and bones	0.9
37. Bentonite, nearly white, stained dark yellowish orange by limonite, silty, with some granular selenite	0.12
36. Shaly chalk, all weathered light olive gray (5Y6/1) to medium yellowish brown (10YR6/4) or grayish orange; selenite streaks, possibly representing weathered bentonite seams, lie 2.8 and 3.15 feet above base; bentonite seam, 0.02 foot thick, lies 0.04 foot below top. FOSSILS: *Inoceramus prefragilis*, whole and as fragments, fish scales and bones	5.7
35. Bentonite and gypsum, dark yellowish orange, silty, gypsum concentrated in upper half; 0.05-foot-thick shaly chalk parting lies near middle	0.45
34. Shaly chalk, all weathered light olive gray	

Unit	Description	Thickness, feet
	(5Y6/1) to dark yellowish orange, grayish orange, or pale grayish orange. FOSSILS: *Inoceramus prefragilis*, mostly whole, mold fragment of large, strongly ribbed ammonite, fish scales and bones	2.7
33.	Bentonite and gypsum, grayish orange, granular gypsum scattered throughout	0.22
32.	Shaly chalk, weathered light olive gray (5Y5/2) to grayish orange. FOSSILS: *Inoceramus prefragilis*, whole and as fragments, fish scales and bones	1.15
31.	Bentonite, dark yellowish orange, granular selenite prevalent in lower 0.1 foot	0.2
30.	Shaly chalk, partly weathered to light olive gray (5Y6/1, 5Y5/2)	3.85
29.	Bentonite, weathered dark yellowish orange, associated with granular selenite	0.3
28.	Shaly chalk, weathered light olive gray (5Y6/1) to grayish orange. FOSSILS: *Inoceramus prefragilis*, fish scales and bones	2.3
27.	Chalky limestone, all weathered grayish orange to dark yellowish orange, brittle, resistant, forms prominent bench, very thin bedded, speckled, crudely laminated. FOSSILS: *Inoceramus prefragilis*, whole and fragmentary, *Inoceramus flavus*, *Stomohamites?* sp. (molds), *Eucalycoceras* sp. B. (molds), *Desmoceras* (s.l.) sp. (molds)	0.6
26.	Shaly chalk, dark olive gray (5Y3/1), in upper half mostly weathered medium yellowish brown (10YR5/2) to grayish orange; 0.05-foot thick seam of granular gypsum lying 0.6 foot above base may represent weathered bentonite. FOSSILS: *Inoceramus prefragilis*, whole and fragmentary, *Eucalycoceras?* sp. (mold), *Stomohamites?* sp., *Syncyclonema?* sp., fish scales and bone fragments	5.7
25.	Chalky limestone, olive gray (5Y4/1), weathers grayish orange, thin to very thin bedded, brittle, resistant, forms small bench, speckled, specks aligned parallel to bedding. FOSSILS: molds of small ammonite, fish bone fragments	0.35
24.	Shaly chalk, dark olive gray (5Y3/1), in part weathered to medium yellowish brown (10YR5/2). FOSSILS: *Eucalycoceras* sp. B (molds), fish scales	3.7
23.	Chalky limestone, olive gray (5Y4/1), weathers grayish orange, brittle, resistant, forms small ledge, crudely laminated, speckled	0.14
22.	Shaly chalk, dark olive gray, mostly weathered moderate yellowish brown. FOSSILS: *Inoceramus* fragments, fish scales	1.3
21.	Chalky limestone, medium yellowish brown (10YR5/2), weathers pale yellowish orange, resistant, forms projecting ledge, all but middle bed are speckled, specks define crude laminae, unit thin to very thin bedded, grades into overlying shaly chalk; contains sparse limonite nodules scattered in band near middle of unit. FOSSILS: *Inoceramus prefragilis*, whole and fragmentary, mold of small ammonite, fish scales and bone fragments	0.65
20.	Shaly chalk, dark olive gray (5Y3/1), weathering medium yellowish brown (10YR5/2); bentonite seams, dark yellowish orange, 0.01 and 0.02 foot thick, lie 0.6 foot above base and 0.01 foot below top, respectively. FOSSILS: *Inoceramus prefragilis*, whole, *Inoceramus* fragments, mold of small ammonite, fish scales and bone	3.2
19.	Bentonite, dark yellowish orange, slightly silty	0.11
18.	Shaly chalk, dark olive gray, weathers dark yellowish brown; FOSSILS: *Inoceramus* sp. (juvenile), *Syncyclonema?* sp., fish scale	0.6
17.	Bentonite, dark yellowish orange, with associated granular gypsum	0.1
16.	Shaly chalk, dark olive gray (5Y3/1). FOSSILS: teleost vertebrae (articulated), *Syncyclonema?* sp.	0.35
15.	Covered interval, probably shaly chalk	2.9
	Total thickness of Hartland Member (type)	44.5
	Lincoln Member	
14.	Chalky limestone, dark olive gray (5Y3/1), weathering grayish orange to dark yellowish orange, brittle, resistant, ledge forming, speckled, has faint petroliferous odor; same unit lies at top of section at Locality 12. FOSSILS: *Inoceramus prefragilis*, *Eucalycoceras* sp. B. (juveniles); *Stomohamites* cf. *S. simplex*	0.5
	Cut bank on tributary to Arkansas River in NE¼ sec. 12, T. 25 S., R. 38 W., Kearny County (Locality 12).	
13.	Shaly chalk, all weathered grayish orange; filled with small very thin lenses of skeletal limestone, pale yellowish brown, sparry calcite cemented, composed mostly of *Inoceramus* debris; bentonite, 0.07 foot thick, grayish orange, lies at top (also seen beneath unit 14 at Locality 13); bentonite, 0.02 foot thick, nearly white to grayish orange, lies 0.4 foot above base. FOSSILS: *Inoceramus prefragilis*, whole and as fragments, *Syncyclonema?* sp., *Exogyra* aff. *E. boveyensis*	4.05
12.	Bentonite, nearly white to dark yellowish orange, flaky	0.18
11.	Shaly chalk, chalky limestone, and skeletal limestone; shaly chalk weathered yellowish gray (5Y8/1) to grayish orange with abundant very thin lenses of light olive gray (5Y6/1) skeletal limestone in upper part; chalky limestone, 0.17 to 0.25 foot thick, lies 0.5 foot below top; chalky limestone, maximum 0.3 foot thick, lenticular light olive gray (5Y5/2) and banded dark yellowish orange by limonite stains, lies 0.2 foot above base; skeletal limestone, light olive gray (5Y6/1) to grayish orange, 0.1 to 0.17 foot thick, arches above lower chalky limestone; 0.1 foot thick lens of similar skeletal limestone lies 0.1 foot above base. FOSSILS: *Inoceramus prefragilis*, fecal castings on sole of skeletal limestone bed	1.3
10.	Bentonite, grayish orange to dark yellowish orange, punky, with seams of coarsely granular calcite at top and base	0.26
9.	Shaly chalk, weathered grayish orange to dusky yellow; contains discontinuous seams of granular gypsum less than 0.02 foot thick; upper 0.4 foot contains very thin lenses of skeletal limestone. FOSSILS: *Inoceramus prefragilis*, whole and fragments	1.15
8.	Bentonite and gypsum, bentonite nearly white to dark yellowish orange, punky, with seams of selenite at top and base	0.1
7.	Shaly chalk, weathered grayish orange to dusky yellow; contains 3 seams of gypsum each about 0.01 foot thick; skeletal limestone bed, 0.15 foot thick, thinly cross laminated, well cemented, in part with chalky matrix, and with petroliferous odor, lies 0.2 foot above base. FOSSILS: *Inoceramus* fragments, fish bones and scales	0.85
6.	Chalky limestone, mostly weathered grayish orange but in part mottled with medium light gray, brittle, resistant, ledge-forming bed ranging from 0.17 to 0.35 foot thick, speckled, with *Inoceramus* fragments common; contains large (0.2 foot wide) elliptical masses of calcite that may be recrystallized fossils. FOSSILS: *Inoceramus prefragilis*, whole and as fragments, fish bones and scales	0.35
5.	Shaly chalk, chalk, chalky limestone, and bentonite, all weathered, mostly grayish orange; chalk bed 0.08 foot thick, 0.23 foot below top, is granular; contains numerous very thin, discontinuous beds and small lenses of chalky limestone, thinly laminated, brittle, speckled;	

	Thickness, feet
also contains lenses of brittle, thinly laminated to gently cross laminated skeletal limestone having petroliferous odor; chalky limestone, 0.2 foot thick, with undulating base, lies 0.55 foot below top and lies on 0.2-foot-thick bed of locally deformed, very thin bedded chalky limestone or skeletal limestone; bentonite, 0.02 foot thick, grayish orange, punky with thin layer of selenite at top, lies at top of unit. FOSSILS: *Inoceramus* fragments, fish scale, *Acanthoceras wyomingense*	2.55
4. Shaly chalk, olive black, mostly weathers medium yellowish brown (10YR5/2), dark part not much speckled, less calcareous than weathered part; bentonite, 0.02 foot thick, grayish orange, lies 0.65 foot below top, underlain by 0.02 foot thick gypsum seam; unit contains very thin beds of brittle, thinly laminated chalky limestone scattered throughout the unit. FOSSILS: *Inoceramus prefragilis*, whole and fragments, cirriped plate, *Ostrea beloiti* valve, *Camptonectes* sp., *Borissjakoceras?* sp. (mold), *Desmoceras* sp., *Pseudocalycoceras?* sp. (mold), fish scales and bones, coprolite, chunk of charcoal	3.05
3. Bentonite, nearly white to dark yellowish orange with 0.04-foot-thick seam of selenite and jarosite 0.05 foot below top	0.21
2. Chalky shale, olive black, mostly weathered medium yellowish brown (10YR6/4), specks less abundant than in typical shaly chalk; contains gritty, thinly laminated chalky limestone bed, 0.04 foot thick, 0.21 foot below top; also contains very thin lenses of laminated, gritty chalky limestone. FOSSILS: *Inoceramus* fragments, baculitid mold, *Inoceramus* sp. (juvenile), *Desmoceras* sp., ammonite fragment (mold), fish scales and bones, chunk of charcoal	1.6
1. Chalky limestone, weathered grayish orange, lensing bed, thinly laminated, much speckled, very gritty, passes laterally into chalky skeletal limestone bed. FOSSILS: scraps of vertebrate bones. Bed forms arbitrary base of Greenhorn. Rests on dark olive gray to olive black very impure chalky shale and calcareous shale that is only sparsely speckled and assigned to Graneros Shale	0.08
Total thickness of Lincoln Member	16.2
Total thickness of Greenhorn Limestone	135.9
Rests conformably and gradationally on Graneros Shale	

Surface Stratigraphy of the Greenhorn Limestone Central and Southwestern Kansas

By
Donald E. Hattin
1972



REGISTER OF LOCALITIES

1 SW 1/4 SW 1/4 sec. 27, T 6 S, R 9 W
3 W line sec. 18, T 13 S, R 12 W
4 E line SE1/4 SE1/4 sec. 24, T 8 S, R 6 W
5 N1/2 sec. 28, T 15 S, R 17 W
6 S line SW1/4 sec. 5 and N line NW1/4 sec. 8, T 3 S, R 1 E
7 S line SW1/4 SW1/4 sec. 4, T 3 S, R 1 W
8 SW1/4 sec. 5, T 25 S, R 24 W
9 NW1/4 sec. 13, T 23 S, R 24 W
10 NE1/4 SE1/4 sec. 25, T 21 S, R 26 W
11 NE1/4 sec. 10, T 23 S, R 23 W
12 NE1/4 sec. 12, T 25 S, R 38 W
13 NE1/4 sec. 32, T 24 S, R 38 W
14 SW1/4 sec. 14 and NE1/4 sec. 22, T 23 S, R 42 W
15 SW1/4 NE1/4 sec. 5, T 19 S, R 16 W
16 NW1/4 sec. 6, T 20 S, R 16 W
17 SW corner sec. 33, T 18 S, R 17 W
18 E line SE1/4 NE1/4 sec. 21, T 19 S, R 18 W
19 SE1/4 SW1/4 sec. 1, T 19 S, R 17 W
20 NE1/4 SE1/4 sec. 12, T 5 S, R 7 W