# STRATIGRAPHY OF THE CARLILE SHALE (UPPER CRETACEOUS) IN KANSAS

By

**DONALD E. HATTIN**

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## ABSTRACT

The Carlile Shale of Kansas was examined at numerous places, fossils were collected at 56 localities, and 47 sections were measured. Stratigraphic relations are depicted in graphic columns. The known ranges of macrofossils in the Kansas Carlile are tabulated graphically and characteristic species are figured.

From the standpoints of general lithology, chemistry, environment of deposition, mappability, and fauna, the Fairport Chalk Member should be accorded formational status, as should the combined Blue Hill Shale and Codell Sandstone Members.

Fairport marker beds include 13 layers of chalky limestone, marly chalk, and bentonite, and Blue Hill marker beds include 7 layers of clay-ironstone concretions, septarian concretions, and bentonite that provide a framework for more detailed studies.

The Greenhorn Limestone and Fairport Member of the Carlile are entirely conformable, the Fairport-Blue Hill contact is conformable, and the Blue Hill-Codell contact is gradational both vertically and laterally, but absence of the zones of *Scaphites nigricollensis* and *S. corvensis,* which characterize highest Carlile strata in the Black Hills region, in combination with stratigraphic and lithologic evidence, is proof that the Niobrara Chalk rests on the Carlile Shale with regional diastem.

Carbonate sediments of the Fairport were generated wholly within the depositional basin and consist of micro- and macrofossils, calcareous ooze, recrystallized calcite, sparry calcite, and fecal pellets of unknown organisms that fed upon coccolithophores. Terrigenous detritus, consisting mostly of clay and very fine silt, is nearly lacking in lower Fairport beds but is more abundant toward the top of the member. Sparseness of detritus, lamination of chalky shales, and paucity of structural features associated with turbulence are evidence that Fairport sediment was deposited under generally quiet conditions, far from shore, in relatively clear to very clear water, and below the depth of normal wave activity. Beds of chalky limestone and marly chalk represent sediment that was reworked by gentle turbulence; calcarenite lenses are the product of short intervals of severe stirring of bottom sediments by waves.

Blue Hill and Codell strata are composed chiefly of fine-grained terrigenous detritus deposited rapidly from turbid waters of a nearer-shore environment than that represented by the Fairport, but mostly deeper than that in which wave and current activity is normal. The upward coarsening of detritus in the Blue Hill-Codell section and local development of cross-laminated and ripple-marked beds near the top of the Carlile indicates the approach to the Kansas area of a regressive shoreline. Abundant septarian concretions and pyrite nodules of the Blue Hill Member are products of early diagenesis.

Slow sedimentation and general lack of turbidity during most of Fairport deposition favored development of an extensive benthonic fauna in well-oxygenated water. *Inoceramus cuvieri,* which commonly reached a breadth of 3 feet, provided the substratum for an extensive epizoal growth of *Ostrea congesta,* bryozoans, serpulids, and barnacles. Normal salinity is indicated by the fauna. Increased turbidity during Blue Hill deposition reduced the sessile benthos to a small number of *O. congesta;* salinity remained normal. The benthonic fauna is evidence of well-oxygenated water; the near absence of fossils at many exposures is the result of nonpreservation rather than inhospitable bottom conditions.

The Fairport Member lies wholly within the range of *Collignoniceras woollgari.* The Blue Hill Member coincides with the range of *Collignoniceras hyatti.* Codell strata of Kansas contain few macroinvertebrates, but *Prionocyclus wyomingensis* is abundant at one locality. The zone of *Scaphites warreni,* which normally lies between the zones of *C. hyatti* and *P. wyomingensis,* cannot be distinguished in Kansas, but strata in that part of the section are entirely conformable. Evidence is summarized for correlation of the Kansas Carlile with strata of the Western Interior and Gulf Coastal Plain and with the zone of *Terebratulina lata* and at least the lower part of the zone of *Holaster planus* of the English Middle Chalk on the basis of stratigraphic distribution of *C. woollgari, Inoceramus labiatus* (broad form), *I. latus,* and *Prionocyclus.*

Strata of the Carlile Shale of Kansas represent the regressive half of the first major Late Cretaceous cycle of sedimentation in the Western Interior region. Chief elements of the cycle are (1) siltstone or sandstone, (2) dark-gray silty and sandy clay shale, (3) dark-gray locally concretionary silty clay shale, (4) chalky shale and limestone, (5) dark-gray concretionary silty clay shale, (6) dark-gray silty and sandy shale, and (7) siltstone or sandstone. The first phase of deposition is represented by the Dakota Formation, the second and third by the lower and upper parts of the Graneros Shale, respectively. The fourth phase (maximum transgression) is represented by the Greenhorn and Fairport; regression began during Fairport sedimentation. The fifth and sixth phases are represented by the lower and upper parts of the Blue Hill, respectively, and the last phase by the Codell.

# INTRODUCTION

## Purpose and Scope of Investigation

Published information on the Carlile Shale in Kansas is limited to general summaries of lithology, descriptions of mostly incomplete measured sections, and incomplete paleontological studies. Although specific details of the Carlile section long have been known for some counties, particularly Russell County, no previous effort has been made to synthesize field and laboratory data from the outcrop belt as a whole. Despite the fact that many invertebrate species have been reported from the Carlile of Kansas, virtually nothing has been known of the vertical and lateral distribution of the fauna.

The present study is based chiefly on field work during the summers of 1959 and 1960 but the Carlile invertebrates are augmented by those collected in 1951. Foremost among the goals of the field investigation is to gain a complete and detailed knowledge of the section throughout the vertical and horizontal extent of the Carlile Shale in the Kansas outcrop area (Pl. 1). A second objective is definition of the macrofauna and determination of the stratigraphic distribution of species. Prior to this investigation no attempt had been made to interpret the depositional environment and conditions of origin of the sedimentary rocks of the formation; achievement of this end is a third objective. Finally, it is hoped that this work will provide a framework for future studies such as statistical analysis of invertebrate populations, additional geochemical studies of the sediments, and more quantitative treatment of sedimentation.

## Previous Work

Although Hawn (in Meek and Hayden, 1857, p. 130) and Leconte (1868, p. 8) gave the earliest brief descriptions of the Kansas Carlile, the first detailed description was by Hayden (1872, p. 67). During a trip on the Union Pacific Railroad, made for the purpose of examining the geology along the route, he observed a 60-foot section of "the dark clays of No. 2, of the Fort Benton Group. . . . It is bright-bluish-black slaty clay, covered with a thin coating of iron rust whenever the water or air can have access to it. It is full of arenaceous concretions of every size, which are lined inside with crystals of calc-spar. On the summit of the hills, resting directly on No. 2, are the massive layers of the yellow chalk No. 3". Hayden described clearly the section of the Blue Hill Shale Member of the Carlile Shale and the Fort Hays Limestone Member of the Niobrara Chalk that is still well exposed at Yocemento, Ellis County, Kansas.

Mudge (1876, p. 219) wrote an enlarged description of strata now assigned to the Blue Hill Member. He mentioned the abundant "concretions, or septaria, of all sizes from 1 inch to 6 feet in diameter", recorded the presence of selenite crystal clusters, and mentioned that the beds are noted in the Saline and Solomon River valleys for the variety of *Ammonites*. Occurrence of *Scaphites* near *S. larvaeformis* and several species of *Inoceramus* was recorded. He referred these strata to the Fort Hays division of the Niobrara.

One of the most definitive of early stratigraphic papers on the Carlile Shale of Kansas is that by W. N. Logan (1899). Good, though brief, lithologic descriptions of the upper and lower members and names and general stratigraphic position of some characteristic fossil species were presented. Logan (1899, p. 88) made definite correlation of the Fairport, then called "Ostrea shales", and the Blue Hill with the Carlile Shale of Colorado.

Most detailed and useful of all previous descriptions of the Carlile Shale in Kansas is that by Rubey and Bass (1925, p. 32-45) for Russell County. Considerable emphasis was placed by them on lithologic and paleontologic characters, and such features as topographic expression, means of recognition, and beds useful in mapping were treated at length. Much of their description is applicable to the Carlile outcrop in adjacent counties.

Other noteworthy contributions to general knowledge of the Kansas Carlile include county reports by Bass (1926), Landes (1930), and Moss (1932). In recent years, many ground-water bulletins issued by the Kansas Geological Survey have presented brief summaries of the general stratigraphy, and some include measured sections of part of the formation.

The only published comprehensive faunal study on invertebrates of the Carlile Shale of Kansas is that of Logan (1898). Many Carlile fossils were not listed or described by Logan, and unfortunately, most of his figures were copied from older works and illustrate specimens not from Kansas. Many species recorded by Logan are now known to be restricted to non-Carlile portions of the Western Interior Cretaceous. Unpublished theses on the Colorado Group fauna by Morrow (1941), Carlile Foraminifera by Griffith (1947), and Carlile macroinvertebrates by Hattin (1952) are the only other embracive studies of fossils from the Kansas Carlile. Important shorter contributions include published works on foraminifers by Morrow (1934), and ammonites by Morrow (1935), Cobban (1951a), and Matsumoto and Miller (1958).

## Location and Description of Area

*Geography.*—In Kansas, the Carlile Shale crops out in two areas of greatly different geographic extent. The larger area of outcrop is a belt that occupies part of 21 Kansas counties and that trends approximately southwest from the southernmost part of central Nebraska to Finney and Ford Counties in southwestern Kansas (Fig. 1). The maximum length of this area, hereafter referred to as the west-central Kansas outcrop, is more than 200 miles, and its maximum width in an east-west direction, parallel to major stream valleys, is about 100 miles. A very much smaller area of exposed Carlile is located in northwestern Hamilton County, near the Colorado-Kansas border, where the formation may be seen in 13 small outcrops north of the Arkansas River valley.

The best exposed sections of Carlile Shale in west-central Kansas are found along White Rock Creek in Jewell County, in the Blue Hills (*sensu stricto*) of Mitchell County and neighboring hills of eastern

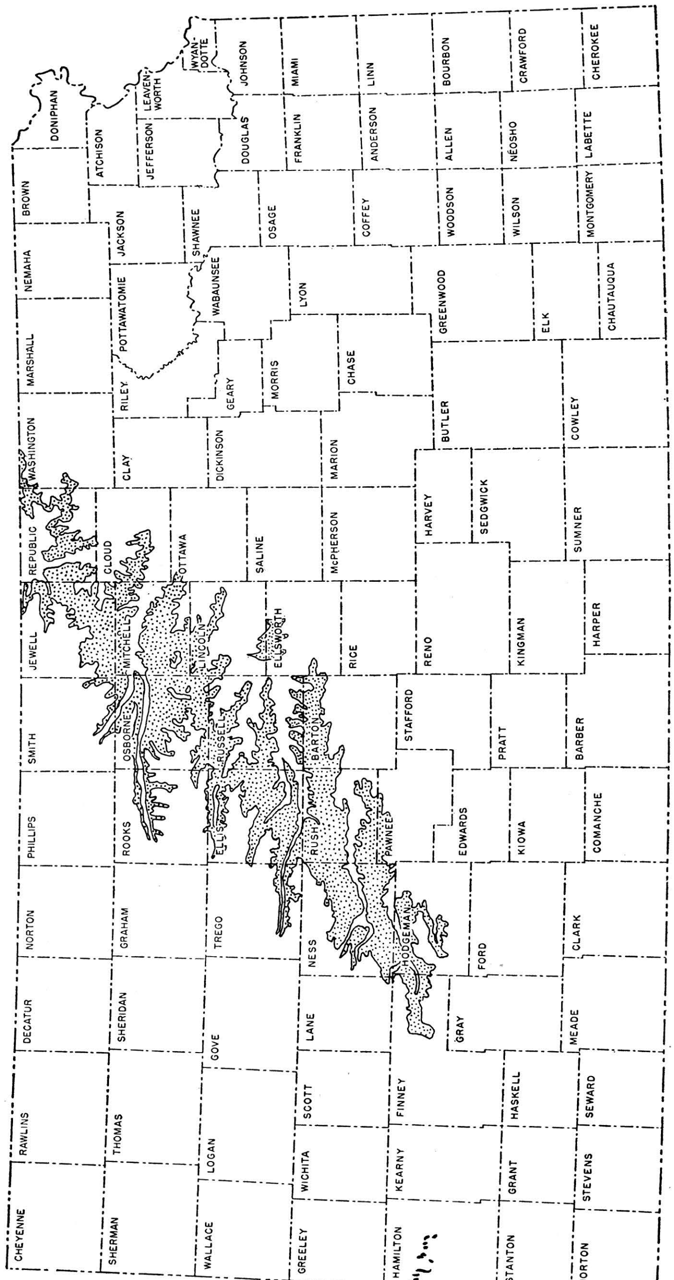



FIG. 1.—Map showing outcrop of Carlile Shale in Kansas.

Osborne County, along the north and south forks of Solomon River in Smith and Osborne Counties, along Saline River in northern Ellis County, along Smoky Hill River of southern Ellis and Trego Counties, along Walnut Creek in Ness and Rush Counties, and along Pawnee Creek in Finney and Hodgeman Counties. Some sections were measured in tributary valleys of these main streams, but nearly all the best exposures are close to major east-trending valleys. Most good exposures of the Fairport Member are located along streams or in gullies close to streams (Pl. 2A). The Blue Hill Member is generally exposed on washed slopes or in gullies along the Fort Hays escarpment (Pl. 2B). In most of the eastern counties of the west-central Kansas outcrop, the Carlile forms only a thin veneer on a rolling upland surface, and good exposures are rare (Pl. 2C).

Hamilton County exposures of the Carlile Shale are generally poor, and no complete section is known, excepting a composite one that includes a water-well log (Bass, 1926, p. 63). Nonetheless, a few excellent exposures of parts of the Carlile lie along small tributaries of Arkansas River. Topographic relief in this area is much less than relief farther east, and exposures nowhere show the full thickness of either the Fairport or Blue Hill Member.

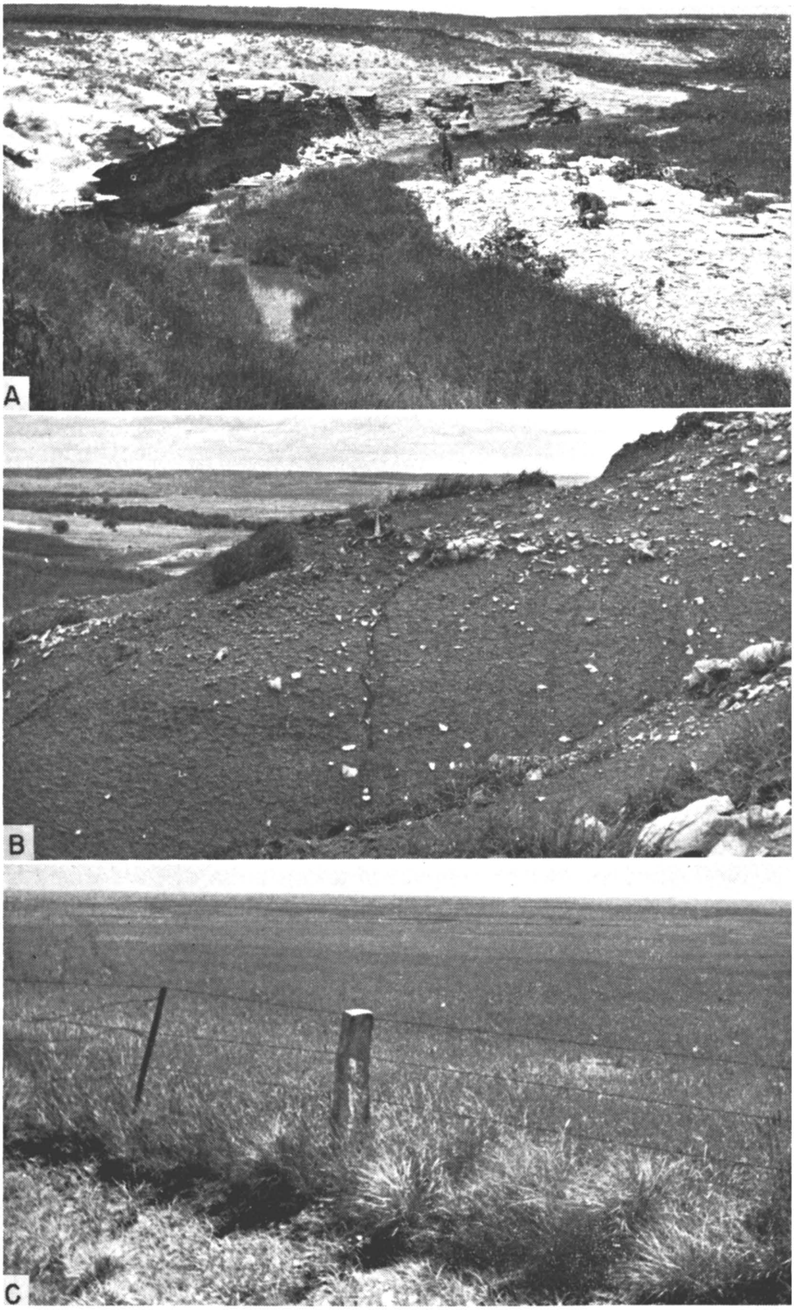
Upland surfaces throughout both outcrop areas are devoted mostly to the growing of wheat. The hilly walls of major stream valleys and the hills of escarpments on the east and west edges of the west-central outcrop are devoted almost exclusively to cattle ranching. Oil is produced locally in the west-central outcrop area, particularly in Ellis and Russell Counties.

Several bulletins of the Kansas Geological Survey describe groundwater conditions in counties in which the Carlile Shale crops out, although the Carlile itself is not an aquifer.

*General geology.*—Stratigraphic units under consideration are classed in the Colorado Group by Jewett (1959), who included therein the following formal units:

Colorado Group
  Niobrara Chalk
    Smoky Hill Chalk Member
    Fort Hays Limestone Member

PLATE 2.—Topographic expression of Fairport and Blue Hill Members. **A**, Typical exposure of lower Fairport strata, sec. 22, T. 19 S., R. 23 W., Ness County (Loc. 22). **B**, Typical exposure of Blue Hill Member in bluff of Fort Hays escarpment, sec. 29, T. 11 S., R. 16 W., Ellis County (Loc. 25). **C**, Upland developed on lower Fairport strata, sec. 16, T. 13 S., R. 15 W., Russell County.


A
B
C

Carlile Shale
- Codell Sandstone Member
- Blue Hill Shale Member
- Fairport Chalk Member

Greenhorn Limestone
- Pfeifer Shale Member, including Fencepost limestone bed at top
- Jetmore Chalk Member
- Hartland Shale Member
- Lincoln Limestone Member

Graneros Shale

In normal sequence, the Niobrara Chalk overlies the Carlile Shale, but locally, as in Finney, Hodgeman, and Republic Counties, the Ogallala Formation (Pliocene) rests disconformably on the Carlile. The northern part of the west-central outcrop is mantled locally by Pleistocene deposits.

Regional dip on top of the Dakota Formation is approximately 12 feet per mile toward the northeast from Hamilton County to Phillips County, Kansas (Merriam, 1957). In the west-central Kansas outcrop area of the Carlile, however, dip on top of the Dakota is generally northward at about 7 or 8 feet per mile. The regional dip at the base of the Niobrara from central Hamilton County to northeastern Phillips County is approximately 10 feet per mile as determined from a map prepared by Morrow (1941, fig. 7). The slope is far from uniform, however, because several major anticlines and synclines of the Kansas Great Plains involve Cretaceous strata (Merriam, 1958, p. 93), and many local flexures and small-scale normal faults are recorded. Two small normal faults not reported previously were discovered in the Fairport Member: one near locality 27 in the SE¼ sec. 18, T. 15 S., R. 19 W., Ellis County, and the other at locality 37, in Osborne County.

More resistant formations of the Colorado Group form prominent east-facing escarpments that dominate local topography of the west-central Kansas area. The Carlile Shale, which crops out in the western half of the Smoky Hills Section of the Great Plains, lies between two such escarpments. An intricately eroded escarpment in upper Greenhorn strata marks the eastern boundary of the Carlile belt, and a more conspicuous escarpment, capped by the relatively resistant Fort Hays Limestone Member of the Niobrara Chalk, forms the western edge (Pl. 3A).

Areas of greatest relief in the west-central Kansas Carlile outcrop are along the valley walls of major east-flowing streams, and at many such places Carlile strata are excellently exposed. Local relief along the Fort Hays escarpment is commonly 200 to 300 feet.

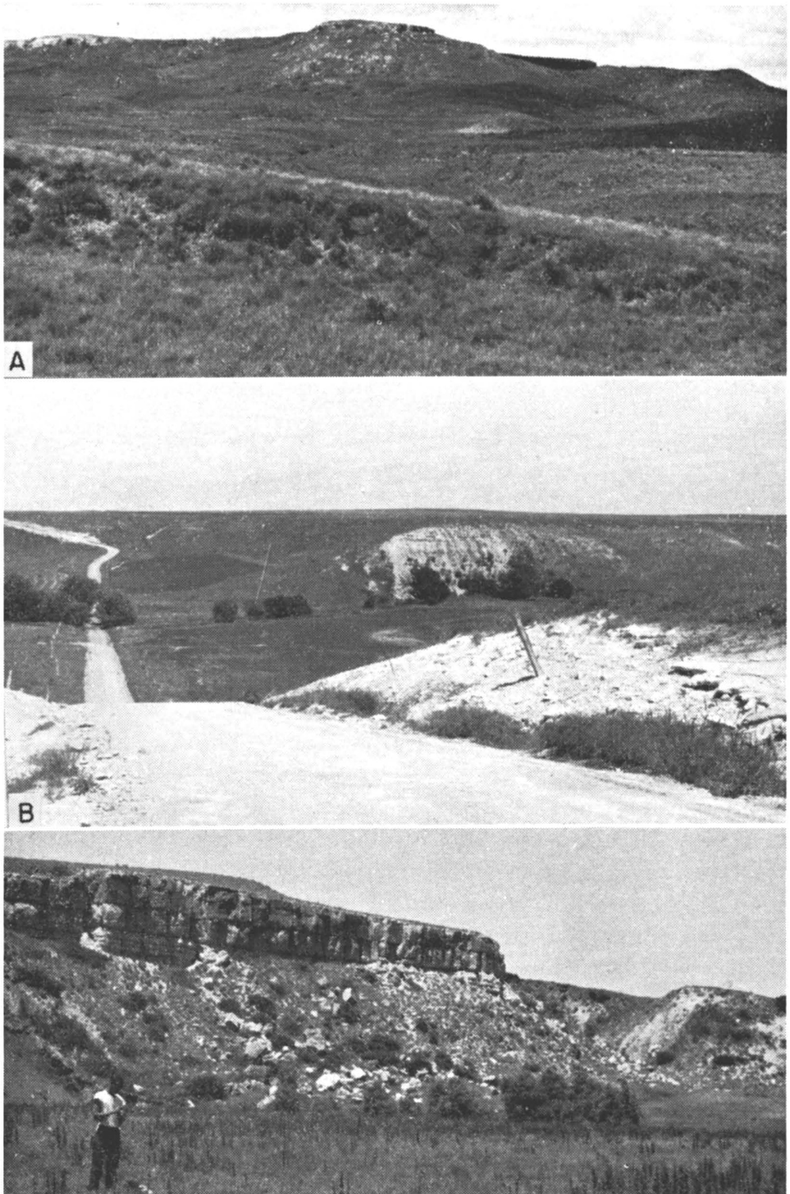
Breadth of outcrop in the west-central Kansas belt of Carlile Shale is governed almost wholly by topography rather than by differences in stratigraphic thickness or changes in dip. Thus, in areas of considerable relief, for example, in northeastern Ellis County along Saline River, the outcrop is as little as 1 mile wide. In contrast, interstream local relief is generally very small, and there the width of outcrop may be measured in tens of miles. Exposed sections in such areas are commonly small, difficult to locate, poorly exposed, and deeply weathered, and the surface on the Carlile Shale is a gently rolling upland plain. Except for thin chalky limestones near the base and layers of septarian concretions in the upper half, the Carlile offers little resistance to erosion. In many areas, the formation has been laid bare by slope-eroding processes, and miniature badlands may be observed locally in both the Fairport and Blue Hill Members.

## Procedure

Exposures of the Carlile Shale were located by reference to published works and by systematic traverse of the outcrop belt as shown on the Geologic Map of Kansas (Moore and Landes, 1937), geological maps in various county reports of the Kansas Geological Survey, maps in construction-materials circulars of the U. S. Geological Survey, and State Highway Commission county plat maps. The locations of a few exposures were acquired orally from persons familiar with the area.

Sections were measured with a hand level and stadia rod, and with a steel tape. Use of a rod with the hand level greatly increased the accuracy of measurements, especially on grass-covered slopes. Total thicknesses of vertically extensive sections were checked by means of alidade and stadia rod. Most measurements are given to the nearest tenth of a foot, but many thin to very thin units, such as chalky limestones, marly chalks, and bentonites, are measured to the nearest hundredth of a foot. Precise measurements of thin beds have proved very useful as an aid in tracing persistent layers of rock. Concretions in the Blue Hill Member are commonly poorly preserved or only partly exposed, and dimensions of these, either stated or depicted graphically, are given to the nearest half-foot. Each measured section is divided into sedimentation units of uniform lithology, limited vertically by changes that are detected readily in the field.

Units thus distinguished were described separately, and lithology, thickness, fresh and weathered color, degree of induration, calcareous nature, fossils, secondary minerals, and structures were recorded.


A
B
C

Colors were determined from the rock-color chart prepared by Goddard and others (1948). Sections were ditched with an ordinary trench pick wherever grass, soil, or slumped rock had covered otherwise continuous exposures. All contacts between members and between Carlile and adjacent formations were ditched so as to expose fresh rock.

Paleontological collections were made at nearly all places where invertebrate fossils are well preserved; however, the collections are only representative, because no attempt was made to collect all fossil materials available at any particular locality. Many fossils consist of fragile molds or partly weathered shells and must receive special field handling. Such specimens were dried briefly and then coated with a solution of alvar and acetone. All small specimens, including those not coated with preservative, were rolled in a thick wrapping of tissue paper, loosely bundled in more tissue paper, and placed in labelled sacks. Numerous representative hand specimens and shale samples were collected for laboratory analysis.

Laboratory study included examination of hand specimens and crushed samples under the binocular microscope, examination of micrograined and cryptograined constituents under very high magnification, and petrographic examination of thin sections. Representative thin sections were photographed. X-ray analyses were made of chalky shales, marly chalks, clay shales, bentonites, clay-ironstone concretions, a shaly chalk, and a sandstone. Chemical analyses of samples representing each of the major rock types of the three Carlile members followed standard procedure. For each of the three dominant rock varieties in the Fairport Member, insoluble residues were obtained by use of a 5-percent solution of technical grade HCl and distilled water for study of sand-size residue fractions and by use of a 20-percent solution for determination of total residue.

In the following text, some terms are used that could be misinterpreted, owing to wide range in usage by other workers, and these terms are explained below. Bedding terminology is that cited by Dunbar and Rodgers (1957, p. 97). Grain sizes mentioned in field and microscopic descriptions are based on the following scale: coarse grained, larger than 0.5 mm; medium grained, 0.25 to 0.5 mm; fine

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PLATE 3.—Topographic expression of Greenhorn, Carlile, and Niobrara Formations. **A**, Fort Hays escarpment, capped by limestone of Fort Hays and underlain by upper Carlile beds, sec. 29, T. 11 S., R. 16 W., Ellis County (Loc. 25). **B**, Typical exposures of upper part of Greenhorn Limestone and lower part of Fairport Member, sec. 15, T. 13 S., R. 15 W., Russell County. Note upland surface developed on lower Fairport beds. **C**, Slump block of limestone (Fort Hays), sec. 4, T. 11 S., R. 18 W., Ellis County (Loc. 18). Note sharp contact of very thick bedded Fort Hays on thinner beds of Codell Sandstone Member.

grained, 0.125 to 0.25 mm; very fine grained, 0.062 to 0.125 mm; micro-grained or microcrystalline, grains less than 0.125 mm but visible under a petrographic microscope at 100×; cryptograined, grains too small to be distinguished under a petrographic microscope. The term "biofragmental" is used to describe rocks composed chiefly of fossil fragments. Colors, for all descriptions, are given for wet samples. The color-code designation appears in parentheses after names for which two colors are shown in the National Research Council Color Chart.

## Acknowledgments

It is my pleasure to thank Dr. John Imbrie, Columbia University, under whose direction I completed a master's thesis on the Carlile invertebrates at The University of Kansas in 1952. I also thank Dr. T. Matsumoto, Kyushu University, Japan, for opportunity to discuss with him, in 1957, the identification of some of the Carlile species. I wish to express special appreciation to my wife, Marjorie, who accompanied me in the field in 1951, helped to gather a large part of the fossil collections, and has been of assistance in many ways during preparation of the manuscript. My appreciation is extended to Dr. W. A. Cobban, U. S. Geological Survey, for extensive discussion of the Carlile fauna and for permission to examine invertebrate fossils collected by him from Upper Cretaceous rocks of the Western Interior. Also acknowledged are Mr. George F. Sternberg and Mr. Myrl V. Walker, of the Fort Hays Kansas State College, for discussion of Carlile fossils with me and for directing me to several fine collecting localities, and Mr. Alex Richards, of Hays, who made known to and discussed with me the Osborne County locality where Blue Hill ripple marks and wall-like concretionary masses are exposed. Mr. James Pivonka, formerly a student at The University of Kansas, deserves much thanks for providing information regarding hard-to-find Fairport exposures in Rush County and for donating many excellent Fairport fossil specimens from his personal collection. I am deeply indebted to Indiana University students, Mr. Barry Haff and Mr. Richard Schumann, who accompanied me in the field in 1959; Mr. Craig Hatfield and Miss Judith Clark, who accompanied me in 1960; and Dr. Don Englehardt, who identified the plant remains. I am grateful to Dr. Carl Beck, Dr. John Droste, and Mr. S. Chaudhuri, all of Indiana University, for aid in x-ray determinations of Carlile minerals. Special thanks are due the following staff members of the Department of Geology, Indiana University: Mr. Maynard Coller, for preparation of chemical analyses; Mr. Leonard Neal, for preparation of most of the thin sections; Messrs. William Moran and Micky Love, for final drafting of line drawings; and Mrs. Joan Justus, for preparation of rough and final draft copies of the typescript. Photographs of fossils, hand specimens, and thin sections were prepared by Mr. George Ringer, Indiana Geological Survey, and to him I extend my gratitude. Lastly, but most of all, I extend sincerest appreciation to Dr. D. F. Merriam, State Geological Survey of Kansas, for advice in the field, laboratory, and office, for making many necessary arrangements with regard to the field work, and for the encouragement that has been, in large measure, responsible for the completion of this work.

## STRATIGRAPHY

### Upper Part of Greenhorn Limestone

Subjacent to the Carlile in west-central Kansas is the Pfeifer Shale Member of the Greenhorn Limestone. Typical exposures of the member consist predominantly of yellowish-gray chalky shale that is interbedded with a small volume of yellowish-gray chalky limestone in thin to medium, commonly pinching and swelling beds (Pl. 3B). Layers of oblate-spheroidal chalky limestone nodules are not uncommon in the Pfeifer. Fresh exposures of these strata are generally olive gray to medium gray. Most beds of the member are richly fossiliferous and contain an abundance of *Inoceramus labiatus.*

Highest stratum of the Greenhorn is a geographically and lithologically persistent bed of tough chalky limestone that Cragin (1896, p. 49) called the Downs limestone or Fencepost limestone. The informal term "Fencepost limestone bed" has become widely popular through extensive use of the rock for fence posts, attaining stature equal to that of names of adjacent members because the unit is an excellent marker bed. The Fencepost outcrop is marked over broad areas by abandoned shallow quarries from which the rock has been excavated.

In Hamilton County, Kansas, the top half of the Greenhorn, equivalent to the Jetmore Chalk and Pfeifer Shale Members of west-central Kansas, was named Bridge Creek Limestone Member by Bass (1926, p. 67). The topmost unit of this member consists of a thicker-than-usual layer of relatively hard chalky limestone that Bass (1926, p. 69) correlates with the Fencepost.

### Lower Part of Niobrara Chalk

Except where erosion has removed younger Cretaceous strata, the Carlile Shale is overlain by the Fort Hays Limestone Member of the Niobrara Chalk. The Fort Hays comprises 45 to 70 feet of yellowish-gray- to grayish-yellow-weathering tough chalky limestone. The rock breaks readily upon weathering and is well jointed, but the member offers much greater resistance to erosion than the underlying shale beds and caps a prominent escarpment at the western edge of the Carlile outcrop. In broad interstream areas, the Fort Hays escarpment is characterized by a gently rounded lip and poor exposure of the limestone. In contrast, the limestone is well exposed and forms cliffs that stand out in bold relief along valley walls of major streams. Along the Saline River valley in northern Ellis County, huge masses of the Fort Hays have become dislodged from the bluffs overlooking the river and many have slumped far downslope (Pl. 3C).

Recognition of the Fort Hays Member is not difficult, because topographic expression and general appearance of exposures suffice for identification in most areas. Innumerable small fragments of the weathered rock impart a whitish tinge to slopes in places where Fort Hays bedrock is not exposed; furthermore, color of unimproved roadways changes from drab brown to pale shades of yellow near the Carlile-Niobrara contact. Stratigraphic relations of this contact are discussed below.

Like most units in the Colorado Group, the Fort Hays Limestone is of remarkably uniform lithologic and paleontologic character throughout the area of the Fort Hays escarpment. A large and easily identified pelecypod, *Inoceramus deformis,* is ubiquitous in the Fort Hays Limestone and serves to identify the member wherever the unit crops out.

## Carlile Shale

*History of nomenclature.*—As early as 1857, Hayden depicted Cretaceous rocks of Kansas on colored geological maps of fairly large scale. First to present a complete classification of Cretaceous strata in the Western Interior, however, were Hall and Meek (1856, p. 405), who subdivided the Missouri River section of Nebraska into units numbered one through five, from the base upward. Geographic names based on places of typical exposure of these subdivisions were subsequently published by Meek and Hayden (1861, p. 419) in a comprehensive tabulation that included lithologic and paleontologic descriptions and thicknesses for each of the five formations. The name "Fort Benton Group" was introduced for their original "Formation No. 2", and this embraces strata now called Graneros, Greenhorn, and Carlile. In the same paper (1861, p. 421), they noted the existence of the Fort Benton in "northeastern" Kansas. In 1876, Hayden (p. 45) introduced the name "Colorado Group" for units 2 (Fort Benton), 3 (Niobrara), and

4 (Fort Pierre) of his Nebraska section. The group was restricted by White (1878, p. 21) to units 2 and 3 and has remained thus defined to the present. The term "Benton" has not been applied for many years in areas where the section is subdivided into formations, but its use has been continued informally for several decades by many geologists. In Kansas, "Benton Group" had formal status at least until 1920 (Moore, p. 83). The name Benton Shale or Benton Formation is in use today in parts of Colorado and Wyoming where the Graneros, Greenhorn, and Carlile formations cannot be differentiated.

Benton strata in Kansas were first subdivided by Cragin (1896, p. 49), who assigned rocks equivalent to the Graneros, Greenhorn, and Fairport to his "Russell Formation", and those equivalent to the Blue Hill Member to his "Victoria clays". A contrasting subdivision of the Benton Group, into a lower limestone group and an upper shale group, was made by Logan (1897, p. 215). Logan's lower limestone group included the Graneros Shale and Greenhorn Limestone of modern classification, and his upper shale group included the lower two-thirds of what is now known as the Carlile Shale. Logan (1897, p. 217) divided his upper shale group into two "horizons", the lower Ostrea shales, named for the abundance of *Ostrea congesta,* and the younger Blue Hill shales.

The name "Carlile Shale", for the uppermost of three lithologic subdivisions of the Benton Group along Arkansas River in eastern Colorado, was proposed by Gilbert (1896, p. 565). He gave the type locality as Carlile Spring and Carlile Station, 21 miles west of Pueblo, Colorado (1896, p. 570). In 1899, Logan (p. 88) correlated his upper shale group of the Fort Benton, consisting of the Ostrea shales and Blue Hill shales, with the lower and upper parts of the Carlile Shale of Colorado, respectively. The name "Carlile" was not used in Kansas until 1904 (Darton, pl. 36). No major change in nomenclature was made until Rubey and Bass (1925, p. 40) proposed the formal name "Fairport chalky shale member" to replace the nongeographic term "Ostrea shales". Bass (1926, p. 28) named the upper sandstone the "Codell sandstone bed". In 1933, the Codell Sandstone was elevated to member rank by Dane and Pierce, and in 1959, Jewett shortened "Fairport chalky shale member" to "Fairport Chalk Member".*

*Suggested reclassification.*—During the course of detailed lithostratigraphic study of the Carlile Shale in Kansas I have become aware of the academic inappropriateness of the present classification. The

* Because the Fairport is not composed primarily of true chalk, use of the name "Fairport Member" for this division of the Carlile is preferred until such time as recommended nomenclatural changes are adopted.

Fairport division of the Carlile is distinct genetically from the Blue Hill and Codell divisions. The upper two members, on the other hand, are completely transitional, both vertically through a considerable stratigraphic thickness, and laterally, and are the products of deposition in genetically related depositional environments. The following classificatory changes were suggested by me but have not been adopted by the Kansas Geological Survey, which prefers to retain Carlile Shale rather than elevate it to subgroup status, which the Survey regards as undesirable:

1. That the Fairport Chalk Member be elevated to formational status and bear the name "Fairport Formation".
2. That the Blue Hill Shale Member be redefined to include all beds between the Fairport and the Niobrara (Blue Hill of original usage), be elevated to formational status, and bear the name "Blue Hill Shale".
3. That the Codell Sandstone Member be retained as a member of the Blue Hill Shale.
4. That a new name, "Saline Valley Shale Member", be applied to the lower, or shale and concretion division, of the Blue Hill Shale, and locality 25, where the member is typically developed and completely exposed, be designated as type section.
5. That the Carlile be elevated to subgroup rank in Kansas. Subgroup, rather than group, is suggested in order that the widely accepted concept of the Colorado Group can be preserved.

As thus reclassified, the Blue Hill and Fairport conform to every requisite for definition of a formation, as prescribed by Ashley and others (1933, p. 430), Gray (1958, p. 451), and American Commission on Stratigraphic Nomenclature (1961, p. 650). Each of the two formations thus defined is lithologically (and faunally) distinct, geographically widespread, of practical thickness, and mappable on an even smaller scale than that adopted recently as standard by the U. S. Geological Survey (see maps by Rubey and Bass, 1925; Bass, 1926; and Landes, 1930). The contact between the Fairport and Blue Hill is detected readily in the field. Rocks below the contact are chiefly olive-gray, chalky, fossiliferous shale, whereas rocks above the contact are predominantly medium-dark-gray to dark-gray, noncalcareous, poorly fossiliferous, concretionary, flaky-weathering clayey shale. The color contrast, lithologic differences, and faunal differences are pronounced in every section where this contact is exposed.

Locally in the subsurface of western Kansas, dark-gray noncalcareous clayey shale a few feet thick lies between the Codell Sandstone Member and the Niobrara Chalk. Because the shale lies between

Fairport and Fort Hays beds, it can be included within the Blue Hill, as originally defined by Logan (1897), and may be classed as an unnamed member wherever encountered.

It is not suggested that this revision of classification should be extended outside of Kansas nor need it ever be so extended. As stated by the American Commission on Stratigraphic Nomenclature (1961, p. 654), "change in rank of a rock-stratigraphic unit does not require redefinition of its boundaries or alteration of the geographic part of its name. . . The Conasauga Shale is recognized as a formation in Georgia and as a group in eastern Tennessee". Thus, the Fairport and Blue Hill may be classed legitimately as members of the Carlile in one area, and as formations in another.

*Distribution of Carlile Shale outside of Kansas.*—The Carlile is recognized as a discrete lithostratigraphic unit in all of southeastern Colorado and as far southwestward as the Las Vegas, New Mexico, area (Griggs and Hendrickson, 1951, p. 31) (Fig. 2). According to Rankin (1944, p. 9), the Greenhorn can be traced as far southwestward as Benson, Cochise County, Arizona. In the same paper, Rankin (p. 12) states that the Fort Hays Limestone Member can be traced with certainty westward to Pagosa Springs, in south-central Colorado. The basis for recognition of the Carlile-Niobrara contact in northern New Mexico is change from sandy noncalcareous shale to less sandy, very calcareous shale. The boundary between the Niobrara and Carlile cannot be demonstrated adequately west of a line running from Las Vegas, New Mexico, to Pagosa Springs, Colorado, and use of the term Carlile west of that line seems to be unwarranted.

Along the Rocky Mountain Front in Colorado, the term "Benton Formation" is used, where the Greenhorn Limestone is not present, to embrace Graneros, Greenhorn, and Carlile equivalents. In the Golden Quadrangle, Colorado, the lower part of the Colorado Group is referred to as the Benton by Van Horn (1957), even though the Carlile equivalent is recognized clearly; in South Park, Colorado, Stark and others (1949, p. 52) do not subdivide the Benton. The Benton Group is subdivided south of Castle Rock, Colorado, where the Greenhorn Limestone appears within the Benton section (Lovering and Goddard, 1950, p. 39). The Carlile also is recognized in the subsurface in most of the Denver Basin of eastern Colorado, but where the Greenhorn is poorly developed, as in southeastern Wyoming (McCrae, 1956, p. 89), the term "Benton" is in general use. The term "Carlile" has been used extensively for noncalcareous clayey shale lying between the Frontier Formation and Niobrara Chalk in the area from the Laramie Basin, Wyoming, to the west flank of the Powder River Basin, Wyoming. Because these strata represent only the uppermost, or Sage Breaks, division of the Black Hills Carlile, the name "Sage Breaks Shale" is preferable in these places, according to Faulkner (1956, p. 41) and Berg (1956, p. 82).

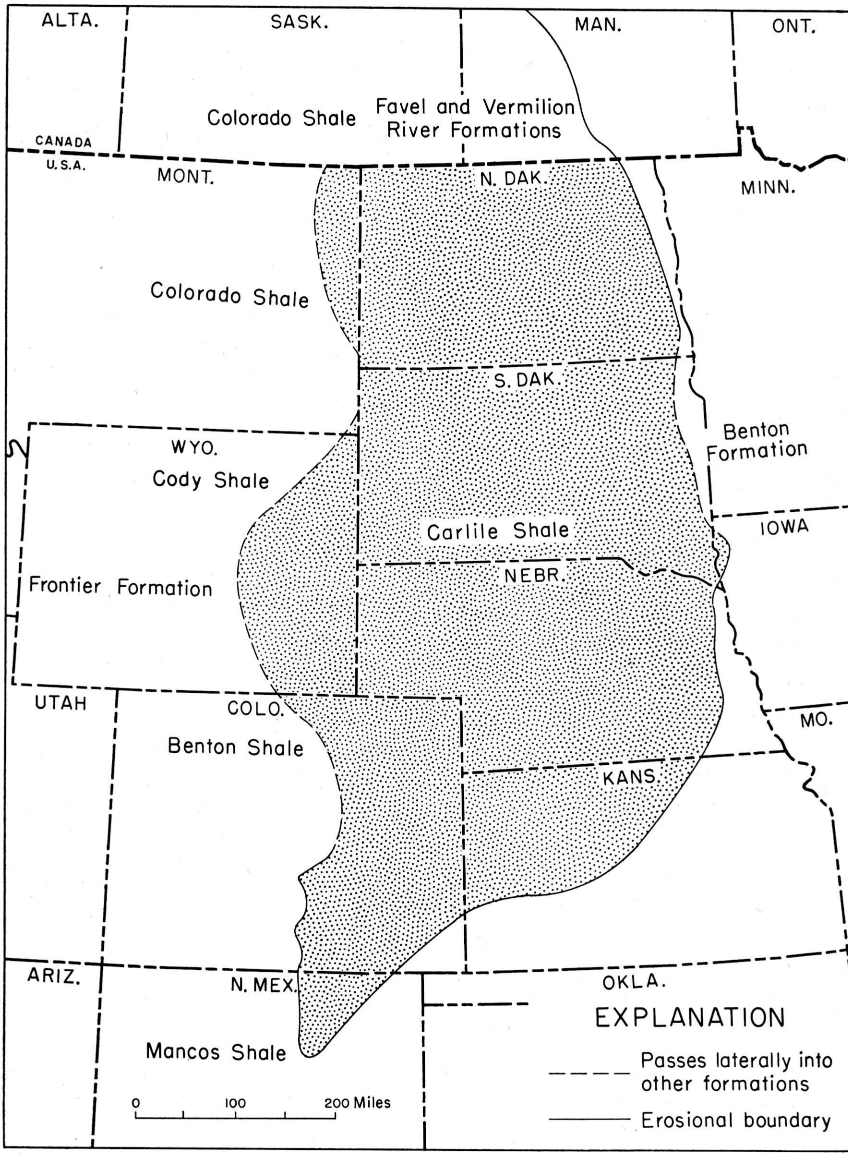



FIG. 2.—Map showing areal distribution of Carlile Shale and nomenclature of contiguous strata.

Northward from Kansas the Carlile Shale is known in Nebraska and South Dakota, where it is well developed in both surface and subsurface sections (Condra and Reed, 1959; Barkley, 1952, 1953; Baker, 1948, 1951), and it is exposed in a small area of northwesternmost Iowa, according to Todd (1908, p. 2). The thickest and most fossiliferous section of the Carlile Shale is exposed along the north flank of the Black Hills (Cobban, 1951; personal communication, 1959). Gries (1954, p. 449) recognized the Carlile Shale throughout the Williston Basin subsurface in North Dakota and easternmost Montana. Equivalent strata crop out only along Pembina and Little Pembina Rivers in northeasternmost North Dakota and have been referred to the Benton Group by Kline (1942, p. 351). Kline noted that the Benton there includes three distinct lithologic subdivisions, suggesting possible correlation with the Graneros, Greenhorn, and Carlile. Cobban and Reeside (1952, pl. 1) classified the Pembina section according to the nomenclature of Wickenden (1945) in Canada.

Nomenclature of rock units laterally adjacent to the Carlile Shale is shown in Figure 2. Toward the south, the Carlile was contiguous with part of the Eagle Ford Formation of Texas and southeastern New Mexico before erosion removed most Cretaceous rocks from the intervening area. Where the Carlile-Niobrara contact loses distinction westward across northern New Mexico, the Carlile Shale loses its identity in a thick section of the Mancos Shale. From Castle Rock, Colorado, to southeastern Wyoming, as noted above, the Carlile passes into the Benton Formation westward from the Rocky Mountain foothills. Still farther westward in Colorado, the Benton merges with part of the Mancos Shale. In southern and east-central Wyoming, the Carlile grades westward into sandy beds of the Frontier Formation, but farther north, along the west flank of the Powder River Basin, Carlile lithology can be detected in the lower part of the Cody Shale. Northwestward from the Black Hills, the Carlile loses identity in the thick Colorado Shale sequence, which is recognized as far to the north as south-central Saskatchewan. In southeastern Alberta and southwestern Saskatchewan, Carlile equivalents are classed as part of the Alberta Group.

Lithologic characteristics of the Manitoba and southeastern Saskatchewan sections (Wickenden, 1945) suggest that the Carlile passes northward and northeastward from the Williston Basin into the upper part of the Favel Formation and lower part of the Vermilion River Formation of those areas.

## Fairport Chalk Member

*Name and definition.*—Rubey and Bass (1925, p. 40) proposed the name "Fairport Chalky Shale Member" for the lower part of the Kansas Carlile in order to replace the nongeographic term "Ostrea shales" of Logan. No type section was selected, but four stratigraphic sections (Rubey and Bass, 1925, p. 44) in an area a short distance south and west of Fairport, Russell County, may be used to define the type area. So far as is known, in no place near the town of Fairport can the entire member be viewed in a single exposure.

Beds of chalky shale, calcareous shale, chalky limestone, and impure chalk that lie between the Fencepost limestone, below, and the noncalcareous Blue Hill Member, above, constitute the Fairport Member. Definition of the unit by Rubey and Bass corresponds exactly to that of Logan's Ostrea shales.

*Contacts.*—No break exists between the Greenhorn Limestone and the Carlile Shale; the Pfeifer Member of the Greenhorn and the lower few feet of the Fairport Member of the Carlile are lithologically indistinguishable in the field. An arbitrary boundary is placed at the top of the Fencepost limestone bed, mainly because the bed is geographically widespread and can be identified readily by the field geologist. Some difficulty in recognition may be encountered, however, where exposed sections include little of the Fairport, and where the post rock has not been quarried. The following criteria will be found useful to even the casual observer:

1. The Fencepost bed is almost uniformly 0.7 to 0.8 foot thick, and has a nearly central iron-stained layer.
2. Chalky limestones in the uppermost Pfeifer are crowded with molds and shells of characteristic *Inoceramus labiatus* at most exposures. Specimens of this fossil are less abundant in chalky limestones above the Fencepost bed, and those in lower Fairport beds mostly represent a broader variety of the species.
3. Chalky limestone layers are spaced closely in the uppermost Greenhorn. The lower 5 feet of Fairport lacks continuous layers of chalk at most exposures.
4. Nearly everywhere, the lower 5 feet of Fairport has three, or locally four, layers of widely spaced, fairly large chalky limestone nodules 0.2 to 0.3 foot thick (Pl. 4A).
5. A 0.2- to 0.3-foot layer of nearly white bentonite that weathers dark yellowish orange everywhere lies approximately 5 feet, locally as little as 3.8 feet, above the Fencepost bed (Pl. 4A).

In Hamilton County, as in west-central Kansas, the uppermost Greenhorn beds are crowded with typical specimens of *Inoceramus labiatus,* and a relatively greater volume of chalky limestone occurs below the Fencepost bed than in an equivalent thickness above. Seemingly, bentonite is lacking in the lower 30 feet of the Fairport, and recognition of the Greenhorn-Carlile boundary is somewhat more difficult in westernmost Kansas.

Locally, topmost beds of the Fairport Member lack the chalky character of beds below and can be described as calcareous clay shale. Specks of white calcium carbonate, which are so abundant throughout most of the section, diminish gradually in numbers in the upper 5 to 10 feet, so that the speckled character is commonly lacking entirely just below the Fairport-Blue Hill contact. Notwithstanding, the fresh rock is tinged with olive, much like the rest of the Fairport Member. The contact between the Fairport and Blue Hill Members can be recognized by the criteria enumerated below:

1. Beds below the contact usually react to dilute hydrochloric acid, whereas beds above do not. In most localities the change is abrupt, but no evidence of physical discontinuity is seen in the section. Locally, the change is gradational through a foot or so of section. Statement by Matsumoto and Miller (1958, p. 352) that the low calcium carbonate content of a single shale sample from Cedar Bluff Dam, Trego County, Kansas, is evidence that the rock is Blue Hill Shale is not necessarily correct. A supporting chemical analysis presented by these authors showed more calcium carbonate than usual for the member because the sample is from an exposure where the Blue Hill Member contains many calcareous fossils. The Fairport-Blue Hill contact is exposed at locality 17 (inset, Pl. 1) in the Smoky Hill River valley a few miles east of Cedar Bluff Dam. Below the contact one finds an abundance of typical Fairport fossils, including large *Collignoniceras woollgari* specimens, like that figured by Matsumoto and Miller (1958, pl. 44); preservation of the fossils is simliar to that at Cedar Bluff Dam. At locality 17, the uppermost 3 or 4 feet of Fairport is weakly calcareous, as at other localities; some of the most fossiliferous strata, well below the contact, are virtually noncalcareous; the overlying Blue Hill Shale is noncalcareous and contains only a sparse, poorly preserved fauna consisting of fish scales and diminutive molds of *Collignoniceras* sp. Thus, the Cedar Bluff Dam material came possibly from the upper part of the Fairport rather than from the Blue Hill Member.

2. A marked change of color at the Fairport-Blue Hill contact is visible in both natural exposures and in trenches. Shale below the contact shows various shades of olive gray, whereas that above is dark gray. Weathering produces an even more prominent change of color. Fairport strata weather to shades of yellow

or orange, whereas the Blue Hill Member generally weathers medium gray.

3. The Fairport Member has a dull earthy appearance where weathered, whereas the lower part of the Blue Hill Member weathers flaky, and light-reflection from flake-covered slopes imparts a distinctive sheen to the exposures (Pl. 4B).
4. Finally, in most exposures the lower part of the Blue Hill Member is filled with small well-formed crystals of selenite; the Fairport lacks this feature.

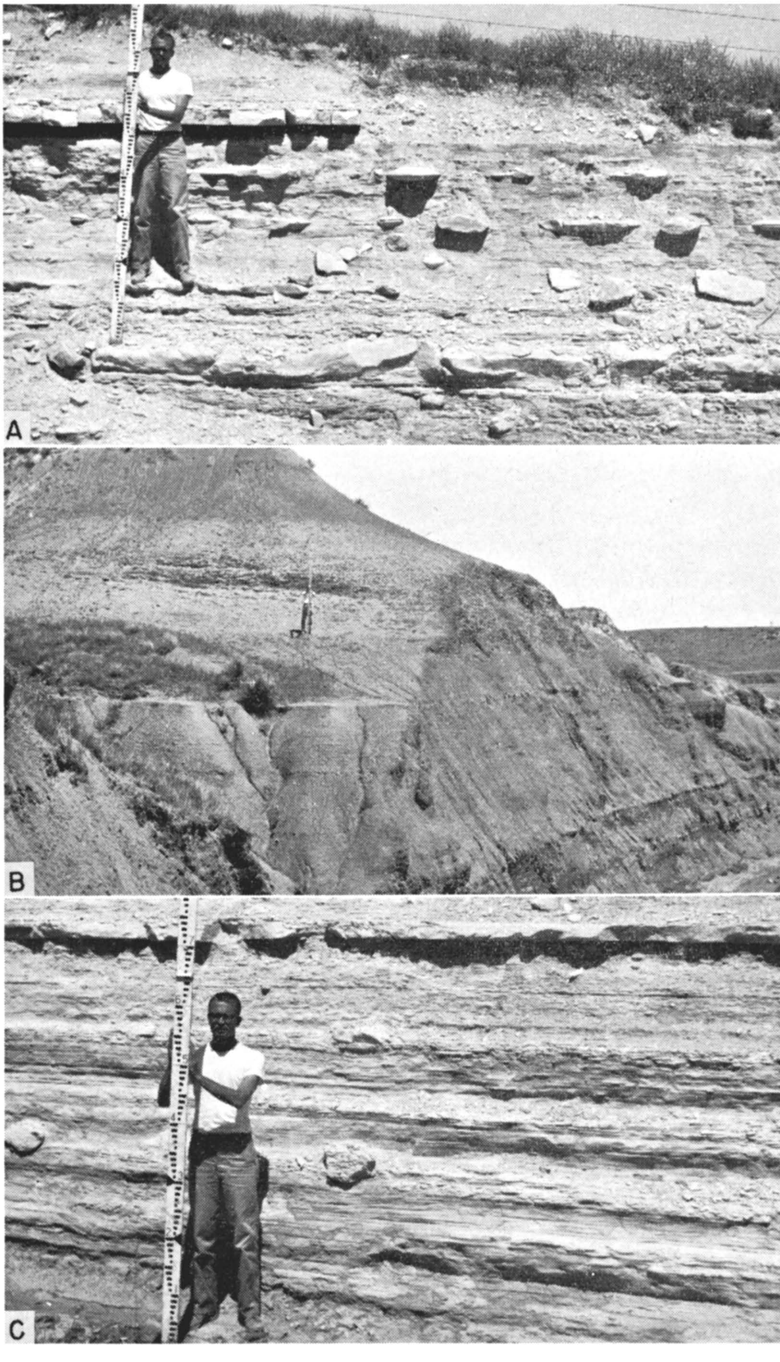
Throughout Kansas these criteria serve logically and definitively to differentiate the shale members of the Carlile.

*Lithology.*—Although the Fairport is mapped and discussed as a unit, its lithology is too diverse to be described adequately under a single rock name. The several genetically related and partly intergrading kinds of rock that make up most of the unit are therefore described separately, although they are not stratigraphically segregated. The minor bentonitic component is also described separately, because the thin layers are stratigraphically significant.

Chalky Shale.—Predominant lithology of the Fairport Member is represented by chalky shale* that has a characteristic speckled appearance, owing to nearly ubiquitous pellets of chalky calcium carbonate. Most of the rock is somewhat gritty because of minute particles of calcite and is generally fossiliferous. Nearly all of the speckled shale is hard, tough, irregularly jointed, and blocky, where freshly exposed by deep digging. Where partly weathered, the shale is soft and splits easily into very thin layers along generally uneven bedding planes. Development of minute selenite crystals along bedding planes enhances splitting qualities of the rock. At some localities, notably locality 30, partly weathered chalky shale has a melanterite taste. Layers of chalky shale subjacent to the lowest Fairport bentonite generally are less well jointed than elsewhere in the unit, and tend to break into platy slabs when split along the bedding. At localities 12, 14, 26,

* The term "chalky shale" is preferred to "shaly chalk" because most of the beds are harder, much darker, grittier, and much less pure than true chalk.

PLATE 4.—Exposures of Fairport Member. **A**, Lower Fairport beds including layers of chalky limestone nodules, bentonite marker bed 1 (reentrant), and chalky limestone marker bed 2 (above bentonite). Rod rests on Fencepost limestone, sec. 4, T. 13 S., R. 15 W., Russell County (Loc. 29). **B**, Fairport-Blue Hill contact (base of rod), sec. 21, T. 11 S., R. 17 W., Ellis County. Note marly chalk marker bed 13 near top of Fairport. **C**, Laminated shaly chalk near base of Fairport, sec. 4, T. 13 S., R. 15 W., Russell County (Loc. 29). Note concretionary nodules of chalky limestone near base of exposure and chalky limestone marker bed 3 near top.


A
B
C

and 29, the rock lying between the first and second bentonites is shaly chalk (Pl. 4C), which is less impure than the chalky shale and splits less easily along bedding planes. Beds of shale in the topmost few feet of the Fairport are, gradationally upward, less speckled and less calcareous than the underlying strata.

Where fresh, the chalky shale is olive gray (5Y4/1 and 5Y3/2) to dark olive gray (5Y3/1); medium gray, dark gray, and light olive gray prevail locally. Most exposures of fresh rock are along stream banks and draws; colors typical of deeply weathered rock can be seen only toward the top of such exposures. Partly weathered chalky shale is generally light olive gray (5Y6/1), medium light gray, or light gray. For more deeply weathered chalky shales, yellowish gray (5Y8/1) and grayish orange are the most common colors, but dark yellowish orange and very pale orange prevail locally.

Fossils in the shale, except for shark teeth, serpulas, and oysters, generally are flattened along the bedding planes. *Collignoniceras woollgari*, species of *Inoceramus*, and *Ostrea congesta* are by far the most abundant forms. The first is generally represented by external molds, and most specimens are smaller than 2 inches in diameter. *Inoceramus* is represented by generally fragile shells of prismatic calcite or as molds, and the oysters are well preserved as nearly white shells that litter the slopes locally, especially in the middle part of the member (Pl. 5A). In most exposures, teleost scales about an inch in breadth are common and are particularly well preserved in the lower 20 to 25 feet of the member. Barnacles, bryozoans, and worm tubes are common in the middle part of the member.

Thin sections of chalky shale specimens representative of the lower, middle, and upper parts of the member (Pl. 6A, C) reveal that the rock matrix is chiefly microcrystalline calcite ooze, microspar, and clay in combined quantities that range from 40 to 75 percent, increasing in abundance upward in the section. Coarser constituents include *Inoceramus* fragments and isolated prisms, 5 to 15 percent; spar-filled foraminifers, 1 to 15 percent; cryptograined calcite pellets, 10 to 25 percent; and amber-colored organic fragments, 1 to 2 percent. *Inoceramus* remains are sparse in the purer chalky shale near the base of the member, whereas foraminifers and pellets are most abundant there. Thin sections of chalky shale from the middle part of the Fairport at locality 4 consist dominantly (as much as 75 percent) of *Inoceramus* fragments of coarse silt and very fine sand size. Other constituents of these unusually gritty shales include the usual microcrystalline calcite, microspar, clay, foraminifers, and cryptograined calcite pellets. Pyrite and limonite are common secondary minerals in

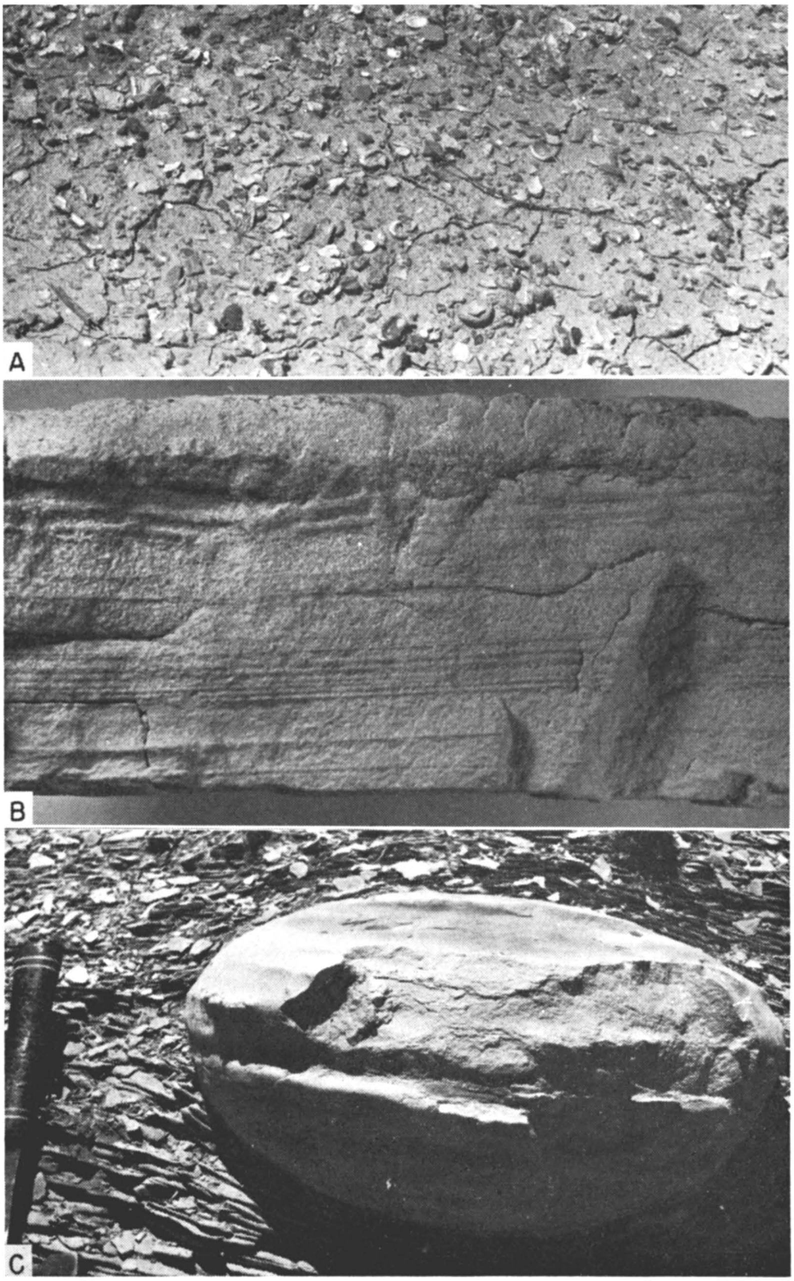



PLATE 5.—Features of Fairport Member. **A**, *Ostrea*-littered slope in lower half of Fairport, sec. 22, T. 19 S., R. 23 W., Ness County (Loc. 10). Largest specimen is about 1 inch long. **B**, Laminated chalky limestone in lower part of Fairport, sec. 7, T. 23 S., R. 42 W., Hamilton County (Loc. 21). **C**, Concretionary nodule of chalky limestone in lower part of Fairport, sec. 29, T. 11 S., R. 16 W., Ellis County (Loc. 26). Note manner in which shaly chalk layers bend around nodule.

chalky shales. Lamination of constituents is consistently more pronounced in chalky shales than in other rocks of the Carlile Shale of Kansas. In addition to thin-section study, several samples of chalky shale were crushed and examined under the binocular microscope. White specks in the rock are mostly oblate-spheroidal pellets of cryptograined calcium carbonate. The pellets lie parallel to bedding planes and commonly show, by great elongation, the effects of compaction in the shale (Pl. 6A, C). All crushed shale samples contain isolated prisms and fragments of *Inoceramus,* calcareous Foraminifera, and pellets. A few samples contain limonite, pyrite, gypsum, or all three. Fine powder from the crushed shale was examined under very high magnification, and all samples were found to contain coccoliths that range in abundance from sparse to abundant. Cryptograined pellets contain large numbers of coccoliths. The role of coccoliths in the formation of chalky shales and chalky limestones is discussed below.

Insoluble residues from several samples of chalky shale that represent the lower, middle, and upper parts of the Fairport Member range from 15.2 to 50.1 percent of the rocks, the amount increasing upward in the section. The largest residue is from a sample representing the topmost few feet of the Fairport at locality 9, where, as in similar sections, the chalky character diminishes gradually upward toward the top of the member. The sand-size fractions of the residues include such constituents as fine-silt aggregates, pyrite, clay-limonite aggregates, limonite, replacement silica, and organic matter. Fine to very fine quartz sand and coarse silt make up less than 0.1 percent of the sample from locality 9.

One sample of shaly chalk (Loc. 26) and two of chalky shale (Loc. 4 and 9) were examined by x-ray for clay-mineral content. In each of the samples, nonclay minerals are far more abundant than clay minerals. The shaly chalk is composed chiefly of calcite, a small quantity of quartz, and virtually no clay minerals. One chalky shale sample (Loc. 9) contains calcite, dolomite, and quartz in nearly equal amounts, and minor quantities of kaolinite, illite, and montmorillonite, in order of decreasing abundance. In the other chalky shale (Loc. 4), calcite is twice as abundant, and the only clay mineral, and that in small quantity, is montmorillonite.

Two of the x-rayed samples and an additional one from locality 27 were analyzed chemically. Analyses of samples from localities 26 and 27 are similar because both specimens are from the same depositional unit. This demonstrates the uniform depositional and later history of the unit over a considerable distance. The greater silica and smaller calcite contents of the sample from locality 9 are reflections of the change in environment toward that of Blue Hill deposition; the sample was taken from the topmost few feet of the Fairport Member. Results of analyses are tabulated below.

*Chemical analyses of chalky shale*

| Locality | Unit | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | $TiO_2$ | CaO | MgO | MnO | $P_2O_5$ | S | $CO_2$ | Loss 140°C | Total loss, as-rec'd basis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9 | A | 33.0 | 10.5 | 5.02 | 0.34 | 18.3 | 4.62 | | 0.16 | 0.60 | 18.5 | 2.37 | 26.2 |
| 26 | E | 7.91 | 2.55 | 0.93 | 0.13 | 45.1 | 0.44 | N.D. | 0.13 | 0.58 | 35.0 | 1.13 | 41.6 |
| 27 | A | 10.4 | 2.88 | 1.01 | 0.14 | 43.0 | 0.44 | N.D. | 0.11 | 0.67 | 33.3 | 1.10 | 39.9 |

N.D. Not detected.

Chalky limestone.—In the lower 20 to 25 feet of the Fairport Member, chalky shales are interstratified with thin to medium beds and layers of nodules of fine-grained chalky limestone (Pl. 4A, C). The limestone is fairly tough but pulverized easily beneath a hammer. Upper and lower surfaces of the chalky limestone beds are generally very even, and the beds range in thickness from 0.15 to 0.6 foot. In a few places, chalky limestone units consist of two or three very thin beds. Locally, chalky limestone is thinly laminated (Pl. 5B). Nodules of chalky limestone are restricted to the part of the section beneath the second bentonite seam of the member, and are most abundant and characteristic beneath the lowest bentonite (Pl. 4A). Chalky shale or, locally, shaly chalk layers commonly are depressed below and arched above the nodules, as at localities 26, 27, and 29 (Pl. 5C). The nodules usually lack stratification, but ferruginous zones pass horizontally through the middle of many. Locally the nodules are as much as 0.5 foot thick and 2 feet in diameter, and at locality 26 a nodule 0.9 foot thick was observed (Pl. 5C).

Limestone of the lower part of the Fairport is fine textured and porous but is much more coherent than true chalk; thus the name "chalky limestone" is most appropriate for these rocks. Most of the chalky limestone is somewhat gritty, owing to presence of Foraminifera and *Inoceramus* prisms, but at locality 21 a bed that lies 15 feet above the base of the member is very gritty, owing to concentration of Foraminifera.

Because most outcrops of the lower part of the Fairport Member are along the tops of bluffs that have undergone long weathering, exposures of fresh chalky limestone are uncommon. The fresh rock is olive gray (5Y4/1) or light olive gray (5Y5/2 or 5Y6/1) and characteristically is speckled with white calcareous pellets. Deeply weathered chalky limestone is generally yellowish gray (5Y8/1); dark yellowish orange, yellowish gray (5Y7/2), grayish orange, and very pale orange are the next most common colors, in that order. Rocks that can be termed "partly weathered" show great range in coloration, grayish orange and grayish yellow (5Y8/4) being most common. Several other shades of yellow, gray, orange, and brown prevail at some exposures. In western Russell County, a bed that lies about 19 feet above the base of the member has a conspicuous moderate reddish-orange color and has been called "pink lime" by some geologists (Rubey and Bass, 1925, p. 41).

Fossils in the chalky limestone are mostly *Collignoniceras woollgari,* preserved nearly everywhere as external molds and generally smaller than 3 inches in diameter, a broad variety of *Inoceramus labiatus,* and *I. cuvieri.* The last two are unusually well preserved, and structural details of the prismatic layer are readily detectable. Other fossils are like those in adjacent chalky shale but are much less abundant in the chalky limestone. A chalky limestone marker bed (Pl. 4A) that lies 4.0 to 6.2 feet above the base of the formation contains recrystallized remains of belemnites, some of which are more than 0.5 foot in length.

Thin-section studies show that the chief constituents of the chalky limestone are microcrystalline calcite ooze and microsparry recrystallized calcite, which make up 45 to 85 percent of the rock (Pl. 6B, 7A-D). One sample (Pl. 7A) contains 20 percent of more coarsely recrystallized calcite. Clay in minute streaks is present in a few thin sections. Coarser components include spar-filled calcareous foraminifers, 5 to 30 percent; oblate-spheroidal pellets of cryptograined calcium carbonate that lie parallel to the bedding and are 0.1 to 0.2 mm in maximum dimension, 10 to 40 percent; shell fragments and isolated prisms of *Inoceramus,* 2 to 10 percent; and amber-colored organic matter, less than 1 percent. Limonite and, in some thin sections, pyrite are common accessory minerals and range from a trace to perhaps as much as 10 percent of the rock. In some thin sections the borders of calcareous pellets are indefinite and irregular where marginal recrystallization has converted the outer part of the pellets to microsparry calcite. Coccoliths were identified in the microcrystalline calcite matrix of a few thin sections. Most of the white specks visible in hand specimens of chalky limestone are soft calcareous pellets of the type described above. Isolated pellets, dispersed in glycerine and viewed at very high magnification, have proved to consist almost entirely of coccoliths, as do pellets from chalky shale. Coccoliths were also identified in each of several bulk rock samples that were crushed, sieved, and examined under high magnification. At locality 3, in the bed that contains recrystallized belemnites, these fossils are sparse, but in the same bed at locality 29 they are more abundant than in any

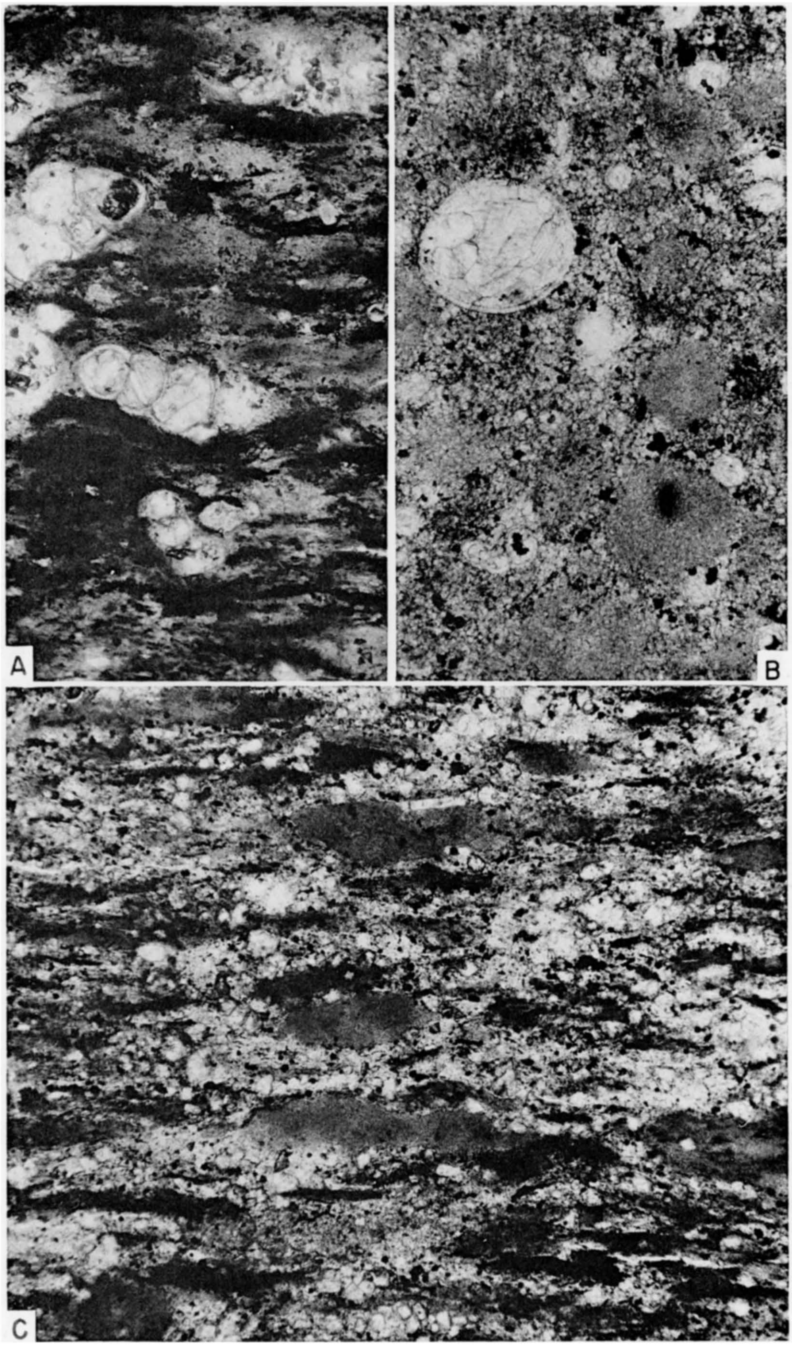



Plate 6. — Photomicrographs of Fairport rocks, plane polarized light. **A**, Chalky shale from lower part of Fairport showing spar-filled Foraminifera, compressed pellets (light gray), and microcrystalline-calcite-ooze matrix (dark), X150 (Loc. 5). **B**, Chalky limestone from lower part of Fairport showing spar-filled Foraminifera, numerous uncompressed pellets (gray ovoid areas), and matrix of microcrystalline calcite ooze and microspar, X100 (Loc. 27). **C**, Chalky shale from uppermost Fairport showing compressed pellets (medium-gray bodies), clay and pyrite lentils (black), and matrix of microcrystalline calcite ooze and microspar, X150 (Loc. 9).

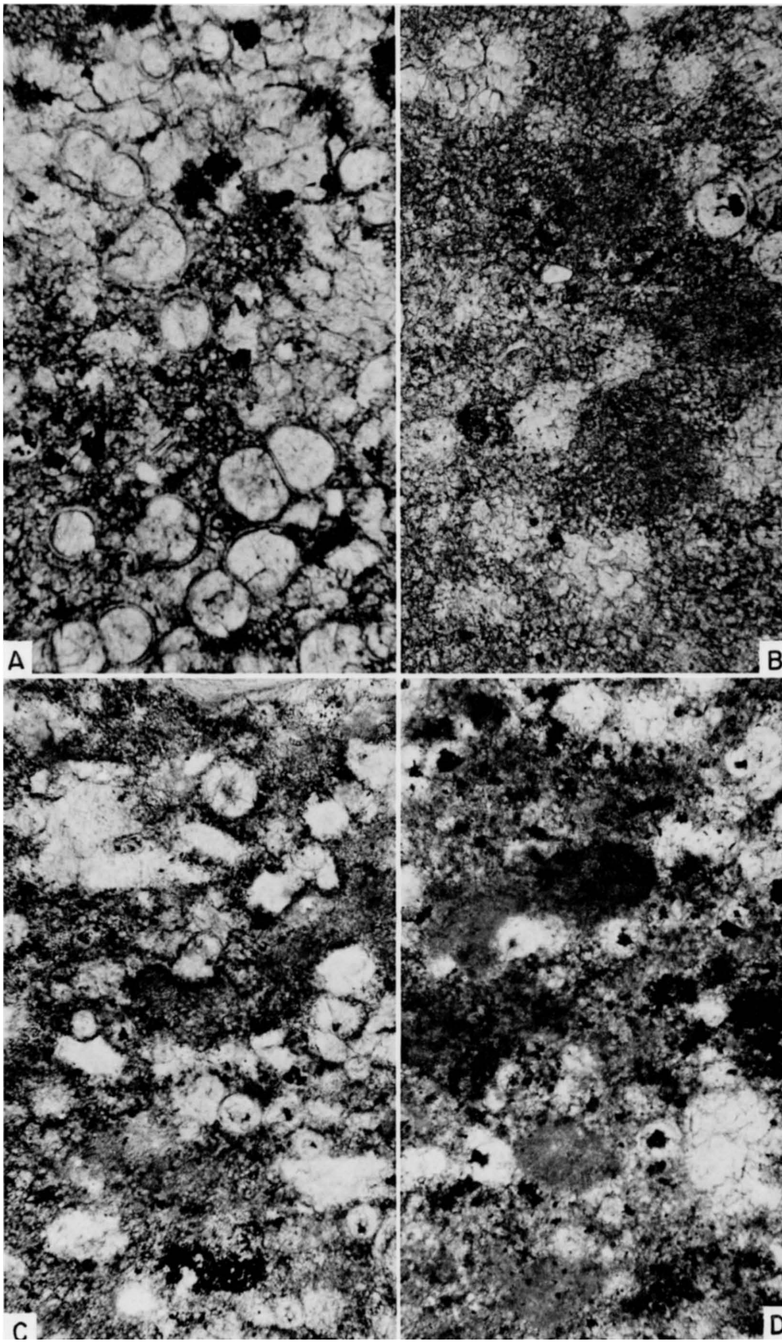



Plate 7. — Photomicrographs of chalky limestone from Fairport Member, plane polarized light. **A,** Chalky limestone showing spar-filled Foraminifera, recrystallized matrix of fine and coarse calcite spar, and limonite (black), X100 (Loc. 21). *B,* Chalky limestone nodule showing recrystallized Foraminifera (light areas), recrystallized pellets (gray ovoid bodies near center), and matrix of microsparry calcite, X150 (NE ¼ sec. 24, T. 12 S., R. 16 W., Russell County). **C,** Chalky limestone nodule showing spar-filled Foraminifera, fragments of *Inoceramus,* a pellet (center), pyrite (bottom center, black), and matrix of microcrystalline calcite ooze and microspar, X100 (Loc. 33). **D,** Chalky limestone nodule showing recrystallized spar-filled Foraminifera, pellets (dark ovoid bodies), pyrite (black), and matrix of microcrystalline calcite ooze and microspar, X100 (Loc. 5).

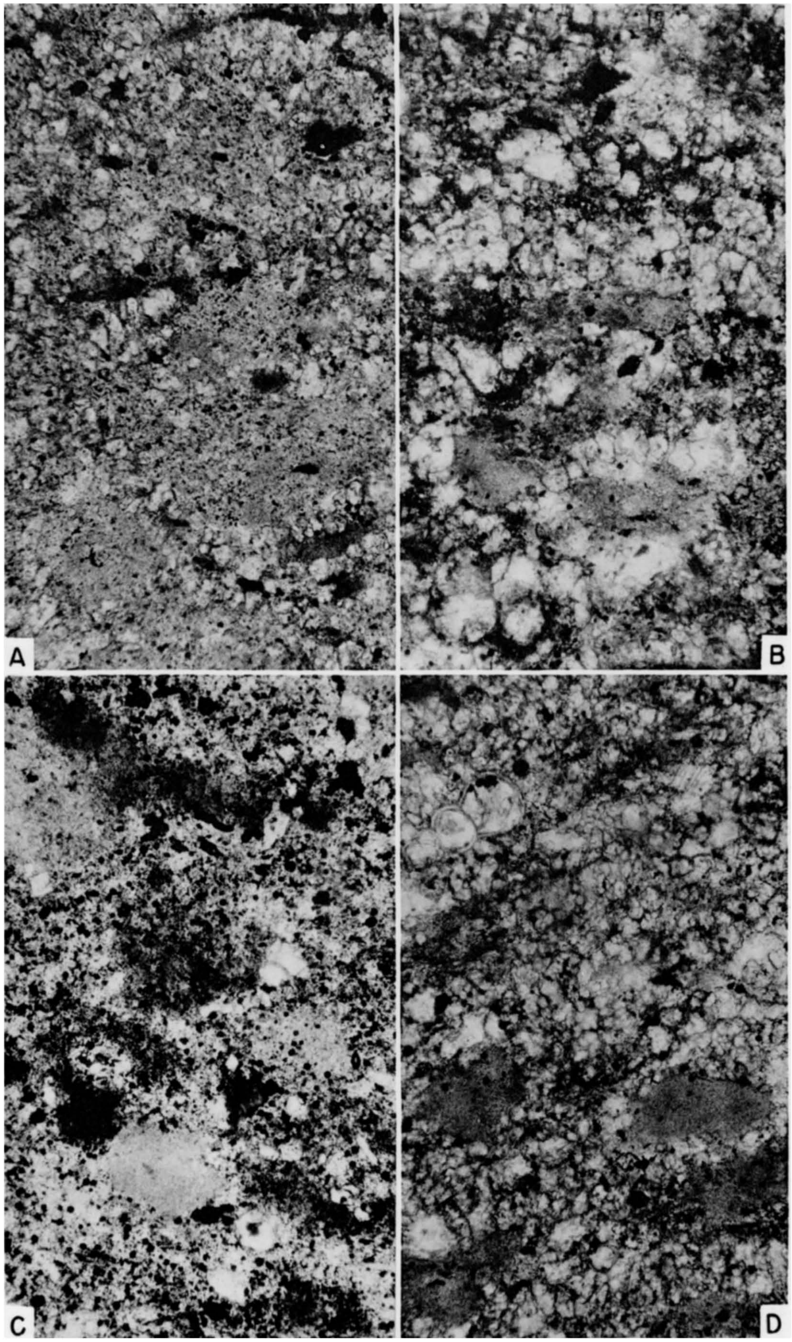



Plate 8. — Photomicrographs of marly chalk from Fairport Member, plane polarized light. **A**, Marly chalk showing pellets (finest-grained ovoid areas near base of photo), limonite (dark areas), and matrix of microsparry calcite, X150 (Loc. 16). **B**, Marly chalk showing spar-filled foraminifer (lower left), pellets (light-gray ovoid bodies near center), clay (dark-gray interstitial matter), pyrite (black), and matrix of microsparry calcite, X150 (Loc. 16). **C**, Marly chalk showing pellets (light-gray ovoid bodies), clay (dark-gray blotches), fossil fragments (clear), pyrite (black), and matrix of microcrystalline calcite ooze, X150 (Loc. 17). **D**, Marly chalk showing spar-filled foraminifer (upper left), pellets (dark-gray ovoid bodies), and matrix of microsparry calcite, X150 (Loc. 17).

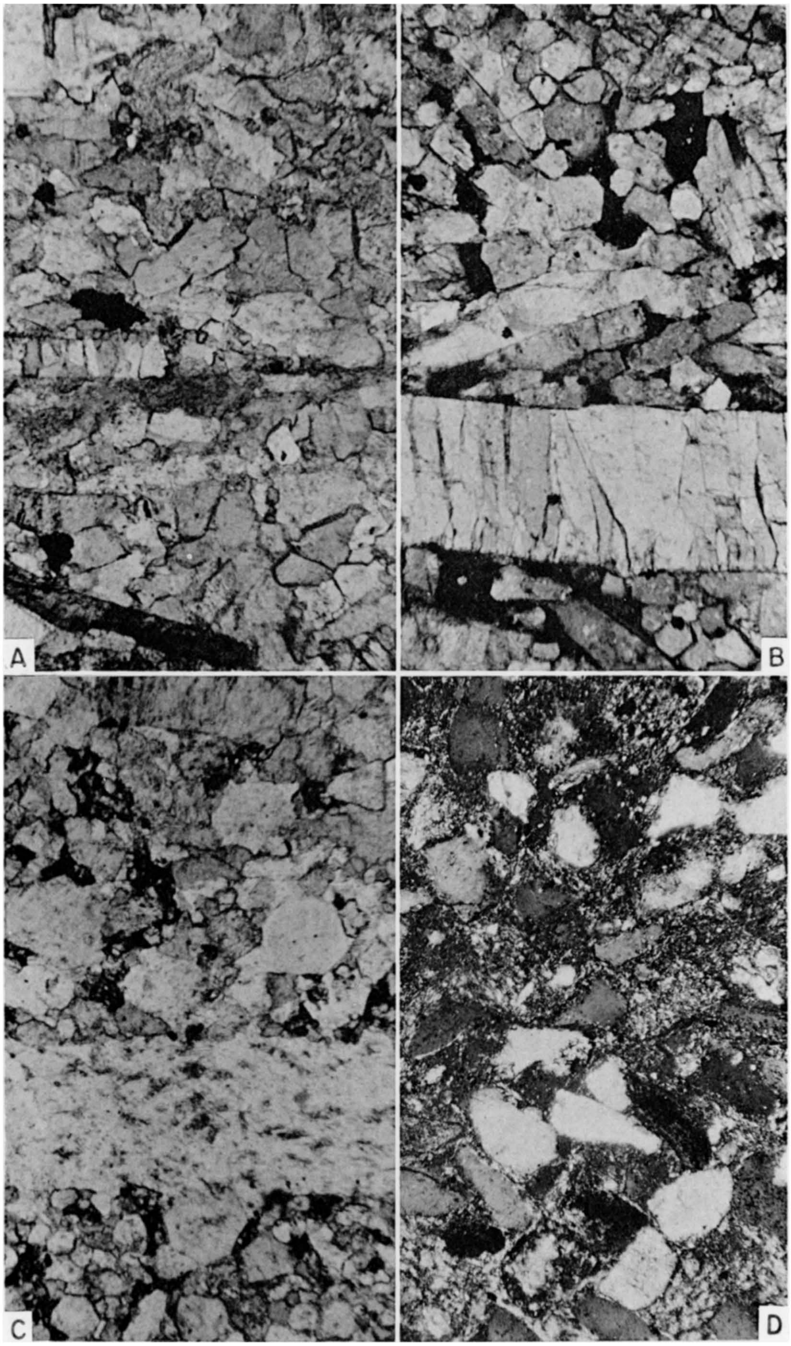



Plate 9. — Arenites from Carlile Shale, under crossed Nicols. **A,** Calcarenite from middle part of Fairport showing fragments and isolated prisms of *Inoceramus,* limonite (black), and coarse spar cement, X60 (Loc. 4). **B,** Calcarenite from upper part of Fairport showing fragments and isolated prisms of *Inoceramus,* and spar calcite cement that is uniformly at extinction position (black), X60 (Loc. 25). **C,** Calcarenite from topmost Codell showing recrystallized fragment and numerous prisms of *Inoceramus,* quartz (large rounded grain, right center), limonite (black), and spar calcite cement, X60 (Loc. 22). **D,** Siltstone from upper part of Codell at type locality showing dominance of quartz and chert grains, accessory biotite (elongate black grains, lower right and upper right), and matrix of fine silt and clay, X100 (Loc. 28).

of the other samples. No attempt was made to estimate the total percentage of coccoliths in the crushed rock samples. Frizzell (1933, p. 154) stated that coccoliths make up much of the fine-grained matrix of North American Cretaceous chalk. Bramlette (1958, p. 122), on the other hand, found that in two Upper Cretaceous chalks, one from the Danish Maastrichtian, the other from the Campanian of Texas, only about one-fifth of the rock consists of coccoliths. Bramlette (p. 123) suggested that the smaller percentage of coccoliths and large percentage of small calcite particles in English and German chalk samples may be attributed to recrystallization of the coccoliths.

Total insoluble residues in samples of chalky limestone range from 3.8 to 13.1 percent but only 0.31 percent or less of any sample is sand-size residue. Very fine silt and clay aggregates, clay pellets, limonite, or gypsum overwhelmingly dominate the sand-size residues, each of the first three being as much as 95 percent of some residues. Clay pellets in one sample resemble internal molds of Foraminifera. Other residue constituents, all in quantities less than 1 percent, are pyrite, quartz, asphaltic residue, muscovite, agglutinated Foraminifera?, and replacement silica. Residues differ greatly from one another, depending upon stratigraphic position and degree of weathering.

Chemical analyses of three chalky limestone samples show somewhat greater CaO content than any other Fairport specimens. The percentage of $CaCO_3$ in these three samples ranges from about 85 to 95 percent. The total possible organic matter is very small; thus, the gray color of the fresh rock can be only partly explained by the presence of finely divided organic matter. Clay and pyrite probably contribute to the rock color. Sample 3-J is a lighter-colored rock than the other two samples, owing chiefly to weathering, has the smallest possible organic content, and has the smallest alumina and sulfur content of the three. This tends to support the contention that organic matter, clay, and pyrite are chief sources of the color of the darker-gray chalky limestone.

Marly chalk.—Interbedded with chalky shale in the upper 75 feet of the Fairport Member in west-central Kansas are harder beds of generally impure, white-speckled, blocky limestone that are classed

*Chemical analyses of chalky limestone*

| Locality | Unit | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | $TiO_2$ | CaO | MgO | MnO | $P_2O_5$ | S | $CO_2$ | Loss 140°C | Total loss, as-rec'd basis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | J | 1.75 | 0.72 | 0.45 | ...... | 53.4 | 0.53 | 0.016 | 0.038 | 0.010 | 42.7 | 0.18 | 43.0 |
| 29 | F | 8.47 | 2.61 | 0.87 | 0.12 | 46.6 | 0.41 | 0.015 | 0.13 | 0.037 | 36.9 | 0.68 | 39.4 |
| 33 | D | 4.63 | 1.36 | 2.75 | 0.073 | 49.5 | 0.38 | 0.013 | 0.066 | 0.35 | 38.9 | 0.33 | 40.7 |

here as marly chalk (Pl. 10A). Too little clay is present for these rocks to be classed as marls. Some beds contain such an abundance of fine fossil debris that they are classed properly as silty chalks, and in the field such rocks easily could be misidentified as chalky siltstones. In fresh and weathered exposures, the marly chalks stand out as more resistant lithologic units and many, as indicated below, can be utilized as marker beds. The rock is ordinarily tough where fresh but soft and crumbly where weathered. Beds of chalk are 0.1 to 1.1 feet in thickness. Within the chalky shale at the base of section 17 is some marly chalk that is thoroughly permeated by pyrite, the presence of which results in a much harder rock than is usual for marly chalk. Fossils in the pyritized chalk are replaced by very finely crystalline pyrite. Beds of marly chalk at localities 19, 36, and 37 contain marcasite nodules, which are badly decomposed at the last two localities.

Fresh marly chalks are nearly everywhere olive gray (5Y4/1 or 5Y3/1). Partly weathered rock of this lithology is generally light olive gray (5Y6/1), commonly medium to very light gray, and, less commonly, medium to dark yellowish brown. The deeply weathered rock is mostly grayish orange, medium to dark yellowish orange, or yellowish gray, in that order of importance.

Fossils in the marly chalks are the same species that are found in the chalky shales. Most abundant are *Inoceramus latus* and *I. cuvieri*. In the latter, the calcareous shell is well preserved, but some valves are contorted or fractured, owing to compaction. *I. latus* is represented commonly by somewhat flattened shells retaining the prismatic layer only, but in the highest marly chalk of the member the species is usually preserved as molds of uncrushed shells. Other common fossils in the marly chalks are *Ostrea congesta* and *Collignoniceras woollgari*. Fossils are commonly more abundant in marly chalks than in adjacent chalky shales.

Thin sections of marly chalk have almost uniform composition, varying mostly in percentages of the several components (Pl. 8). The dominant constituents are microsparry calcite or, less commonly, microcrystalline calcite ooze, which make up 45 to 70 percent of the rock. A cryptograined portion of the matrix, consisting of clay-size particles, makes up 5 to 15 percent of the thin sections. Coarser constituents include isolated prisms and fragments of *Inoceramus*, 5 to 10

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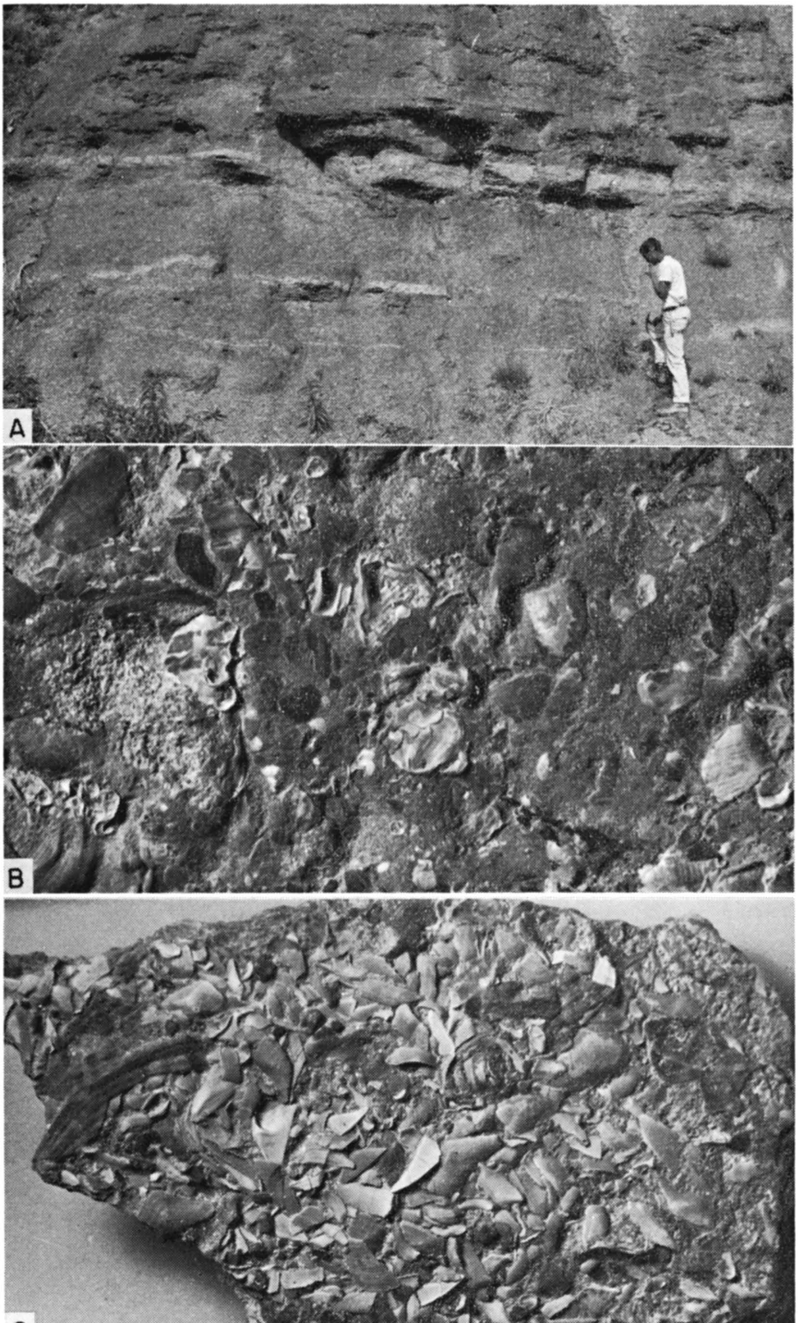
PLATE 10.—Lithology of middle part of Fairport. **A**, Exposure of chalky shale, sec. 2, T. 2 S., R. 5 W., Republic County (Loc. 41). Note bed of marly chalk above man's head. **B**, Biofragmental calcarenite, sec. 6, T. 22 S., R. 24 W., Hodgeman County (Loc. 4). Note fragments of *Inoceramus* and *Ostrea*. **C**, Biofragmental calcarenite, same locality. Note disarticulated barnacle plates.


A
B
C

percent; calcite-spar-filled calcareous foraminifers, about 5 percent, except in one sample that is 20 percent spar-filled foraminifers; and amber-colored organic matter, less than 1 percent. Oblate-spheroidal pellets of cryptograined calcium carbonate are common, as in other chalky rocks of the Fairport Member, and make up 10 to 25 percent of the thin sections. As in the chalky limestone, many pellets have ragged edges where recrystallized to microsparry calcite. Disaggregated pellets from some samples were examined under very high magnification and found to consist chiefly of coccoliths. These minute fossils can be seen also in the microsparry calcite matrix of some thin sections but in smaller numbers than in the pellets. The white speckling that is characteristic of the marly chalk is attributable to large numbers of calcareous pellets in the rock. At locality 17, marly chalk at the base of the section has been extensively recrystallized and pyritized, as noted above. A thin section of this rock consists of nearly 50 percent very finely crystalline to microcrystalline pyrite and nearly 50 percent sparry calcite, which is in optical continuity throughout large areas of the thin section. Shell fragments, organic matter, and gypsum make up the rest of this recrystallized rock. A thin marly chalk bed in the lower part of the section at locality 19 contains about 15 percent coarse-silt-size angular shards of quartz and feldspar, quite unlike any other rock in the Fairport Member. Both the shape of the shards and the fact that the chalk rests on a bentonite suggest a volcanic origin for the quartz and feldspar.

Total insoluble residues of samples of marly chalk range from 9.4 to 21.5 percent. The largest percentage is in a sample from the highest bed of marly chalk in the Fairport. Sand-size residues constitute 0.11 to 1.64 percent of the rock, although particles of true sand size are very rare in the marly chalk. Sand-size residues are mostly about 99 percent quartz-silt aggregates, but one sample contains 50 percent quartz-silt aggregate, 30 percent bentonite-like clay aggregates that are seemingly pyrimoldic, and 20 percent pyrite. Organic matter and limonite are minor accessories, and one residue contains beekite.

Two marly chalk samples, one from the middle of the member and one from near the top, were analyzed chemically. Results of analyses are tabulated below. The larger quantity of silica and smaller amount

*Chemical analyses of marly chalk*

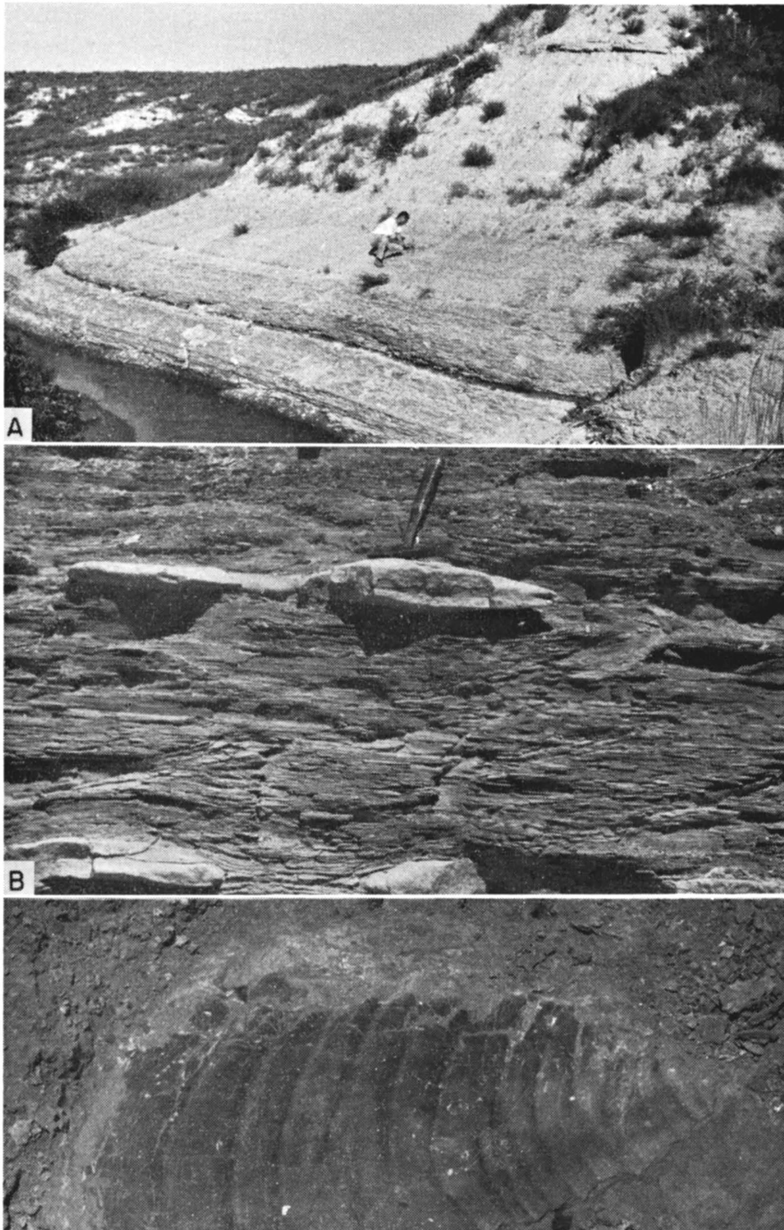
| Locality | Unit | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | $TiO_2$ | CaO | MgO | MnO | $P_2O_5$ | S | $CO_2$ | Loss 140°C | Total loss, as-rec'd basis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | J | 8.82 | 2.90 | 1.18 | 0.10 | 46.5 | 0.55 | 0.027 | 0.071 | 0.65 | 37.0 | 0.62 | 39.2 |
| 17 | B | 16.3 | 5.06 | 2.94 | 0.19 | 35.1 | 4.65 | 0.040 | 0.101 | 0.62 | 32.0 | 1.01 | 34.5 |

of CaO in sample 17-B reflect changing environmental conditions near the top of the Fairport Member. The sulfur in 16-J is from pyrite, which was noted also in an insoluble residue from the same bed. The sulfur in 17-B is probably in gypsum, because this mineral is very common in the lower part of section 17.

Calcarenite.—Scattered at random through the middle and upper parts of the Fairport Member, from 17 feet above the base to the top, are thin to very thin discontinuous layers of hard calcarenite composed chiefly of prisms and fragments of *Inoceramus* (Pl. 10B). Fragments of *Ostrea,* disassociated and broken plates of barnacles, and molds of immature *Collignoniceras* are common rudaceous constituents of these rocks (Pl. 10C). Locally, the shell debris provided a substratum for the growth of *Ostrea.* Because *Inoceramus* fragments so dominate the rock, the informal term "inoceramite" is suggested for this rock type and used in the same manner as Kansas geologists employ "osagite" for Pennsylvanian limestone composed chiefly of the presumed alga *Osagia.* Most of the inoceramites are grayish orange.

Several thin sections of this rock were examined, two of which are illustrated (Pl. 9A, B). Coarser grains in the rock are dominantly pieces of *Inoceramus*, as fragments, many of which show both nacreous and prismatic layers, and as isolated prisms. Small pieces of amber-colored organic matter, possibly fish scales, are common in two sections. Larger grains are generally well oriented parallel to the bedding. In most thin sections sparry calcite cement occupies the interstices locally (Pl. 9B). Such calcite is commonly in optical continuity through much of a thin section. Some sections have a sparse matrix of microcrystalline ooze. Locally, inoceramite beds are extensively recrystallized, and much of the distinction between clasts and ooze or cement is lost. Orange coloration of most inoceramite layers is attributable to limonite scattered throughout the rock.

Bentonite.—Bentonite beds make up a minor but stratigraphically significant part of the Fairport Member (Pl. 4A, 11A). The bentonite is nearly white, less commonly yellowish gray (5Y8/1) where fresh, and weathers dark yellowish orange or, in some places, grayish yellow (5Y8/4). Because the bentonite is readily susceptible to iron staining during weathering, the beds can be recognized as yellowish-orange streaks that cross the face of an exposure. The thickest observed bentonite, 0.4 foot, lies about 30 feet above the base of the Fairport Member at locality 21, Hamilton County. In the west-central Kansas area, the lowest bentonite is generally the thickest in the member, ranging from 0.2 to 0.3 foot. Other widespread bentonite seams are as little as 0.01 foot thick. The highest bentonite in the Fairport is gener-


A
B
C

ally 0.01 foot thick, nearly white, and harder than other bentonites in the member. Bentonite in the Fairport Member breaks into small chips or flakes upon drying, or when dug from fresh exposures. At several localities, including 34, 37, and 41, nodules of pyrite are associated with some bentonite seams. At many exposures the bentonite contains considerable limonite and finely granular gypsum. Weathering of pyrite has probably produced the limonite by oxidation and the gypsum by weak sulfuric acid reactions with adjacent calcareous strata. At only one exposure (Loc. 37) were fossils found in the bentonite; furthermore, there is no positive evidence that any ash fall killed large numbers of benthonic invertebrates.

Clay minerals predominate in two samples of lower Fairport bentonite from localities 14 and 29. X-ray study shows montmorillonite to be the dominant mineral and kaolinite second in importance but present only in small to moderate amount. A small quantity of illite occurs in the sample from locality 14, and a very minor amount of chlorite in the sample from locality 29. The nonclay minerals in both samples are quartz and feldspar, each in only small quantity. In addition, biotite was detected in the sample from locality 14. The clay mineralogy of the two samples establishes the rocks as true bentonites. The sample from locality 29 was analyzed chemically with the results shown below. The large amounts of silica and alumina reflect the dominance of clay minerals in the sample.

*Chemical analysis of a Fairport bentonite*

| Locality | Unit | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | $TiO_2$ | CaO | MgO | $P_2O_5$ | S | $CO_2$ | Loss 140°C | Total loss, as-rec'd basis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 29 | B | 53.2 | 20.5 | 0.28 | 0.19 | 2.93 | 4.67 | 0.009 | 0.003 | 0.19 | 7.34 | 14.74 |

*Marker beds.*—Plate 1 shows graphically the almost incredible lateral persistence of nodule layers, bentonite, chalky limestone, and marly chalk beds that occur in the Fairport Member of west-central Kansas. With detailed knowledge of the section, one can use many such units as structural or stratigraphic datum planes, although in small

PLATE 11.—Features of Fairport Member. **A**, Typical exposure of middle Fairport beds showing bentonite (reentrant) near base of exposure, sec. 33, T. 16 S., R. 19 W., Rush County (Loc. 11). **B**, Exposure of lowermost Fairport beds, sec. 29, T. 11 S., R. 16 W., Ellis County (Loc. 26). Note coalesced chalky limestone nodules enclosed in shaly chalk. **C**, Well-preserved specimen of *Inoceramus cuvieri* in middle Fairport strata, sec. 21, T. 11 S., R. 17 W., Ellis County (Loc. 19). Quarter-dollar used for scale.

exposures it may be difficult to recognize their exact position in the section without reference to adjacent exposures. Nonetheless, several key beds can be recognized very readily and these are described below. The first four marker beds have been recognized in the area extending from northwestern Hodgeman County (Loc. 5) to southeastern Jewell County (Loc. 42).

1. Bentonite, nearly white and weathering dark yellowish orange, 0.2 to 0.3 foot thick, lies 3.8 to 5.8 feet above the Fencepost bed (Pl. 4A). Underlying chalky shale contains three, uncommonly four, distinctive layers of oblate-spheroidal nodules of chalky limestone that range to 0.5 foot in thickness and 1.0 foot in diameter. Some nodules are interconnected and present a variety of curiously shaped limestone bodies (Pl. 11B). At all measured sections except at localities 14 and 42, the bentonite bed is overlain by about 0.2 foot of coarsely granular gypsum.

2. Chalky limestone, 0.45 to 0.60 foot thick, lies 4.0 to 6.2 feet above the Fencepost bed (Pl. 4A). At localities 14 and 42 the limestone rests on marker bed 1, but elsewhere the limestone lies on the granular gypsum layer. In many sections, the upper 0.1 foot is separated from the main bed by a thin shaly parting. The top of the marker bed contains recrystallized belemnites? at many exposures. This bed is nearly as prominent in west-central Kansas as the Fencepost bed but is especially distinct because of its association with marker bed 1.

3. Chalky limestone, 0.15 to 0.5 foot thick, lies 11.2 to 15.8 feet above the Fencepost bed and is underlain by 6.0 to 9.0 feet of chalky shale or shaly chalk that generally contains one to three layers of oblate-spheroidal nodules of chalky limestone (Pl. 4C). The nodules in the shale range to 0.8 foot thick and 1.5 feet in diameter. A fossil log (Pl. 12F) with *Teredo* borings was collected from this bed at locality 5.

4. Bentonite, weathered dark yellowish orange, 0.01 to 0.05 foot thick, lies 0.85 to 3.1 feet above marker bed 3.

5. Gritty chalky limestone, 0.35 to 0.7 foot thick, lies 20.4 to 30.2 feet above the Fencepost bed. The interval between the Fencepost and

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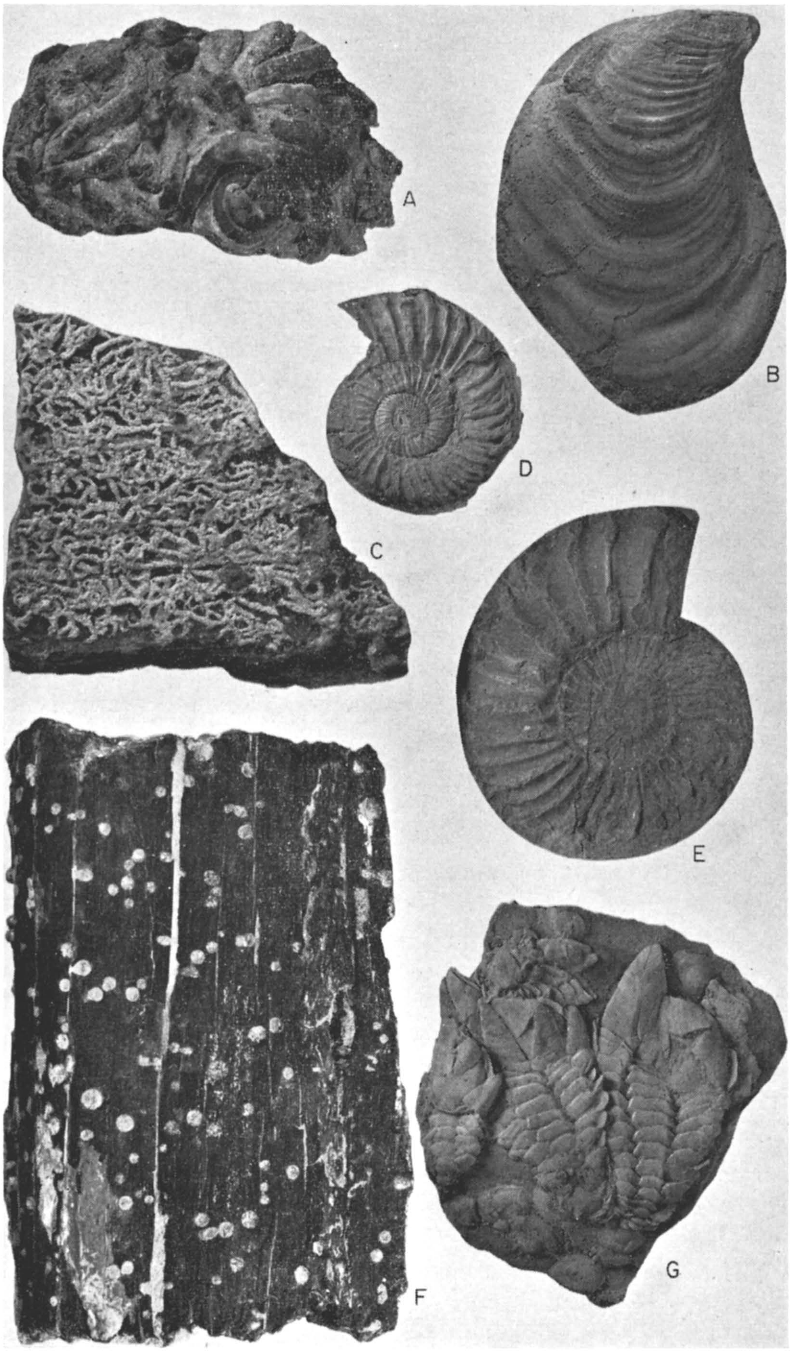
PLATE 12.—Fairport fossils. **A**, *Conopeum* n. sp., encrusted upon *Serpula,* middle part of Fairport (Loc. 11), X1, KU12053. **B**, *Inoceramus* n. sp.?, internal mold, right valve, upper part of Fairport (Loc. 17), X1, KU12056. **C**, *Proboscina* n. sp., encrusted upon fragment of *Inoceramus cuvieri,* middle part of Fairport (Loc. 53), X2, KU10536. **D**, **E**, *Collignoniceras woollgari* (Mantell). **D**, Internal mold, juvenile, uppermost Fairport (Loc. 9), X1, hypotype, KU12052A1. **E**, Internal mold, youthful individual, upper part of Fairport (Loc. 17), X1, hypotype, KU12056A1. **F**, Calcite-filled *Teredo* borings in carbonized *Cedroxylon* sp., lower part of Fairport (Loc. 5), X½, KU12051. **G**, *Stramentum?* n. sp., attached to fragment of *Inoceramus cuvieri,* middle part of Fairport (Loc. 34), X1, KU12086.


A
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F

marker bed 5 decreases generally northeastward. Marker bed 5 has been traced from Hodgeman County (Loc. 5) to Osborne County (Loc. 33). A dark-yellowish-orange-weathering bentonite layer, 0.01 foot thick, lies 0.45 to 1.0 foot below the gritty limestone and is an aid to identification of the marker bed. The bed contains fossil wood at locality 27. Chalky shale between marker beds 4 and 5 contains two thin chalky limestone beds at all localities in Ellis and Osborne Counties.

6. Three bentonite seams, all weathering dark yellowish orange and separated by chalky shale, lie in a stratigraphic sequence 3.0 to 3.8 feet thick that rests 2.8 to 5.6 feet above marker bed 5 and 24.5 to 36.4 feet above the Fencepost bed. The lowest bentonite ranges from 0.15 to 0.3 foot thick, the second from less than 0.01 to 0.05 foot thick, and the highest from 0.05 to 0.2 foot thick. All three bentonite seams can be traced from Rush County (Loc. 11) to eastern Osborne County (Loc. 33), and they probably extend farther northward, but I have not seen this part of the Fairport in the northern tier of Kansas counties. The lower two bentonite seams are also exposed at locality 5 in northwestern Hodgeman County. The greatest thickness between marker bed 5 and the lowest bentonite of marker unit 6 is at locality 5. Intervals between the first five marker beds are generally greater at locality 5 than elsewhere in west-central Kansas, thus attesting the greater rate of sedimentation here than farther northeast. In the upper 1.5 feet of the chalky shale unit that lies below marker unit 6 is a very thin seam of bentonite, less than 0.005 foot thick, which was seen only at localities 5, 30, and 33.

7. Two nearly white bentonite layers, weathering dark yellowish orange, are the most conspicuous marker beds in the middle part of the Fairport Member and can be traced from northern Rush County (Loc. 11) to eastern Osborne County (Loc. 36 and 37). The lower bentonite seam ranges from 0.05 to 0.07 foot in thickness, the upper from 0.08 to 0.15 foot. They are separated by 0.15 to 0.25 foot of chalky shale, and a silty chalk rests on the upper bentonite layer throughout Ellis County.

The lower bentonite bed lies 37.2 feet (Loc. 26) to 44.8 feet (Loc. 36) above the Fencepost bed. Marker unit 7 lies 9.4 (Loc. 26) to 13.5 feet (Loc. 36) above the top bentonite layer of marker unit 6.

8. Gritty marly chalk, 0.5 to 1.1 feet thick and 6.8 (Loc. 26) to 9.4 (Loc. 37) feet above marker unit 7, lies 44.5 to 54.5 feet above the Fencepost bed in the region between northern Rush County (Loc. 11) and western Republic County (Loc. 41). Criteria for recognition of this bed include (a) greater thickness than most marly chalk layers in this part of the Fairport, (b) more gritty character than adjacent marly

chalk beds, and (c) a very thin seam of bentonite, 0.01 foot thick or less, that lies 0.3 foot above the chalk in Ellis County, 0.5 foot above in Osborne County, and 1.8 feet above in western Republic County. The bentonite is associated with limonite in Osborne and Republic Counties. A thinner, less gritty, marly chalk bed lies 1 to 1.5 feet below the chalk in the northeastern Ellis—western Russell—eastern Osborne County area.

9. Two thin marly chalk beds and an associated very thin bentonite seam occupy a stratigraphic sequence ranging from 1.1 to 1.7 feet in thickness and lying 51.5 (Loc. 26) to 62.7 feet (Loc. 37) above the Fencepost bed. In parts of northwestern Ellis County and eastern Osborne County, the bentonite is beneath or within the lower marly chalk. At localities 11, 16, and 19, the bentonite lies in chalky shale that separates the two marly chalk beds. Marker unit 9 lies 5.4 to 7.6 feet above marker unit 8 and can be traced definitely from northern Rush County (Loc. 11) to eastern Osborne County (Loc. 37). At locality 41 in Republic County, a bentonite seam that lies 8.2 feet above marker bed 8 is probably the same as that in marker unit 9. At the base of the section at locality 4 in Hodgeman County, a bentonite, chalky shale, and gritty chalk sequence 0.5 foot thick is judged tentatively to be contiguous with marker unit 9.

10. Bentonite, nearly white and weathering dark yellowish orange, 0.06 to 0.16 foot thick, lies 5.7 to 8.1 feet above marker unit 9. The vertical distance of marker bed 10 above the Fencepost bed ranges from 59 (Loc. 25) to 71.2 feet (Loc. 35) in the four composite sections where the interval can be measured. The bentonite can be traced from northwestern Hodgeman County (Loc. 5) to western Republic County. In all measured sections, except that at locality 5, a 0.3- to 0.6-foot marly chalk bed occurs 2.5 to 3.0 feet above the bentonite.

11. Bentonite, nearly white and weathering dark yellowish orange, 0.05 to 0.1 foot thick, lies 7.1 (Loc. 19) to 11.7 feet (Loc. 16) above marker bed 10 and has the same distribution as marker bed 10. In four composite sections where the distance above the Fencepost bed can be determined, marker bed 11 lies between 67.3 (Loc. 19) and 79 feet above the base of the Fairport Member. The bentonite is at a minimum of 19.1 feet below the top of the Fairport (Loc. 38) and a maximum of 41.4 feet below the top (Loc. 16). From northeastern Ellis County to western Republic County a 0.4- to 0.55-foot marly chalk layer rests 0.65 to 0.9 foot above the bentonite.

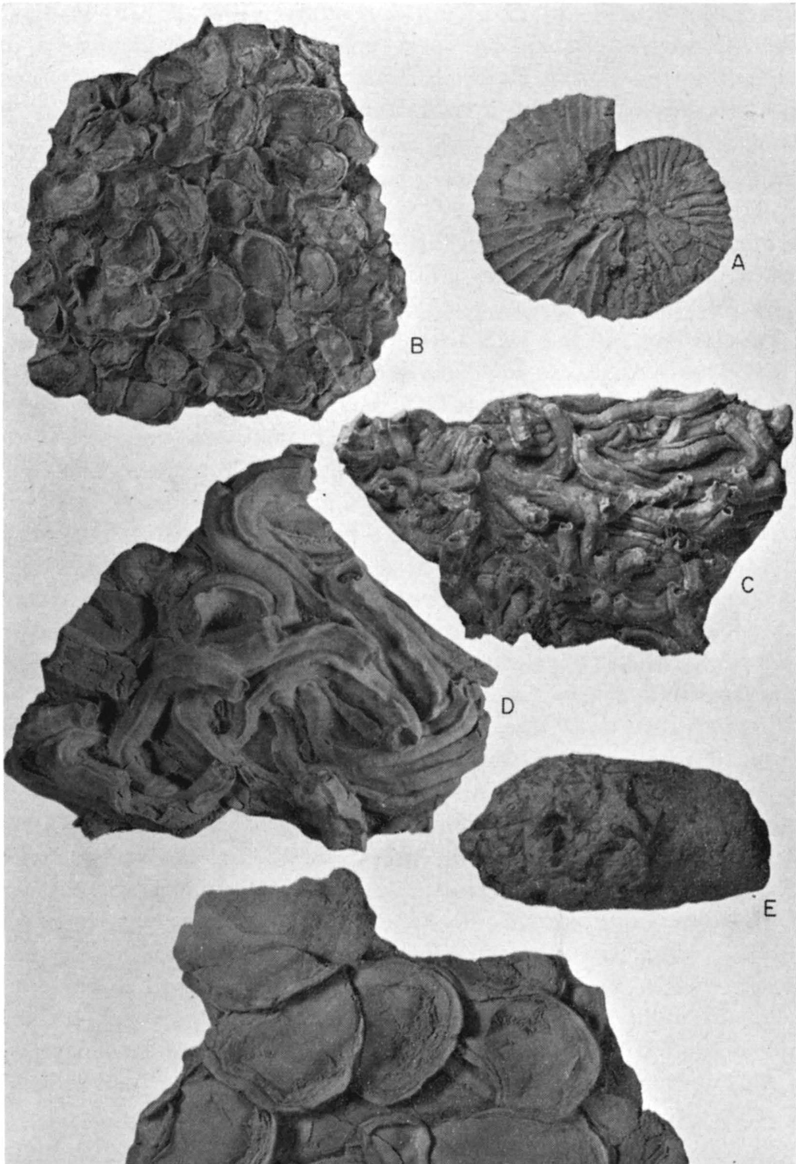
12. Bentonite, nearly white but locally weathering dark yellowish orange, 0.01 foot thick and harder than most Fairport bentonite, lies 9.2 (Loc. 38) to 28.8 feet (Loc. 16) above marker bed 11, 83.7 (Loc. 19)

to 105.2 feet (Loc. 16) above the Fencepost bed, and 6.8 (Loc. 25) to 14.3 feet (Loc. 41) below the Fairport-Blue Hill contact. Marker bed 12 can be traced from southwestern Ellis County to western Republic County and may be represented as far southwestward as locality 9 in Finney County. This bed can be recognized most readily by its association with the next higher marker bed or nearness to the top of the Fairport Member.

13. Marly chalk, 0.4 to 0.8 foot thick and 1.85 to 3.1 feet above marker bed 12, can be traced from southwestern Ellis County to eastern Osborne County, and may be represented by nodular marly chalk at locality 9 in Finney County. The chalk lies 4.4 (Loc. 25) to 8.9 feet (Loc. 17) below the top of the Fairport Member. In Ellis County, marker bed 13 contains an abundance of well-preserved molds of *Inoceramus*.

*Thickness and distribution.*—At no single exposure is it possible to measure the total thickness of the Fairport Member. Composite thicknesses have been compiled as follows: (1) Pawnee River valley, Finney and Hodgeman Counties, estimated minimum 121.6 feet; (2) along Smoky Hill River, Ellis County, 117.9 feet; (3) along Saline River, Ellis County, 89.9 feet; and (4) along the Solomon River valley, Osborne County, 98.9 feet. An estimated total of approximately 100 feet along White Rock River in eastern Jewell County and western Republic County is based on comparison of two partial sections with complete sections farther south. Thus, the section is thicker toward the southern end of the west-central Kansas outcrop belt and thinnest in the Saline River valley. In Hamilton County, 147 feet of Fairport was penetrated in a water well, according to Bass (1926, p. 65). In Colorado, the Fairport is recognized as a distinct subdivision of the Carlile from Baca and Prowers Counties, in the southeastern corner of the state, to the foothills areas of Fremont and El Paso Counties. North of Arkansas River in eastern Colorado, Dane and others (1937, p. 215) reported an estimated 75 to 125 feet of the Fairport Member. Mann (1958, p. 158) reported an average thickness of 70 feet locally in the

PLATE 13.—Fairport fossils. **A**, **F**, *Ostrea congesta* Conrad. **A**, Specimens from middle part of Fairport (Loc. 5), X½, hypotypes, KU12051P1. **F**, Large individuals attached to fragment of *Inoceramus cuvieri*, middle part of Fairport (Loc. 14), X1, hypotypes, KU12054P1. **B**, *Scaphites patulus* Cobban, lower(?) part of Fairport, Horsethief Canyon, Hodgeman County, X1, hypotype, KU 11273A1. **C**, *Serpula tenuicarinata* Meek and Hayden, encrusted upon fragment of *Inoceramus cuvieri*, middle part of Fairport (Loc. 57), Russell County, X1, hypotypes, KU12063J1. **D**, *Serpula semicoalita* Whiteaves, encrusted upon fragment of *Inoceramus cuvieri*, middle part of Fairport (Loc. 37), X½, hypotypes, KU12062J1. **E**, Coprolite containing numerous fragments of undigested bone, middle part of Fairport (Loc. 53), X2, KU11279.


A
B
C
D
E
F

Cañon City Embayment, and Dane and others (1937, p. 215) measured 55 feet of gray limy shale between typical Greenhorn Limestone and Blue Hill strata west of Colorado Springs. The Fairport is not recognized formally along the Front Range north of El Paso County, Colorado.

In Colfax County, northeastern New Mexico, the little-known lower half of the Carlile is a dark-gray shale that is calcareous, at least locally, according to Griggs (1948, p. 28). This is the southwestern limit of known lithologic equivalents of the Fairport Member.

Condra and Reed (1959, p. 17) reported a general thickness range of 60 to 80 feet for the Nebraska Fairport. No formal recognition of the Fairport is made in northeastern Nebraska, and calcareous beds are limited to two zones, probably tongues, within the Carlile section (Condra, 1908, p. 12). In addition, beds transitional between Greenhorn Limestone and Carlile Shale are possibly representative of the Fairport in this area. Among common Carlile fossils listed by Condra are *Serpula* sp., *Ostrea congesta,* and a large flat species of *Inoceramus,* all common in the Kansas Fairport. With exception of the Codell Sandstone Member, Carlile strata are not subdivided in the subsurface of most of South Dakota, but in some wells limestone beds like those of the Greenhorn lie above the base of the Carlile, and locally the base of the Carlile is marly (Baker, 1951).

The Fairport and Blue Hill are not recognized as formal stratigraphic divisions in the Black Hills of Wyoming, South Dakota, and Montana, but an unnamed shale making up the lower part of the Carlile in this region is divisible into two parts, according to Cobban (1951, p. 2187). The lower unit consists of 13 feet of dark-gray, soft, papery shale that contains thin calcareous shale partings and some lenses of *Inoceramus*-prism limestone. A concretionary zone marks the top of this unit. The somewhat calcareous nature of this lower shale suggests that it is the northwesternmost lithologic equivalent of the Fairport Member. Little attempt has been made to subdivide the Carlile Shale in the Williston Basin (Gries, 1954, p. 449). At least a part of the Assiniboine Member of the Favel Formation of Manitoba and

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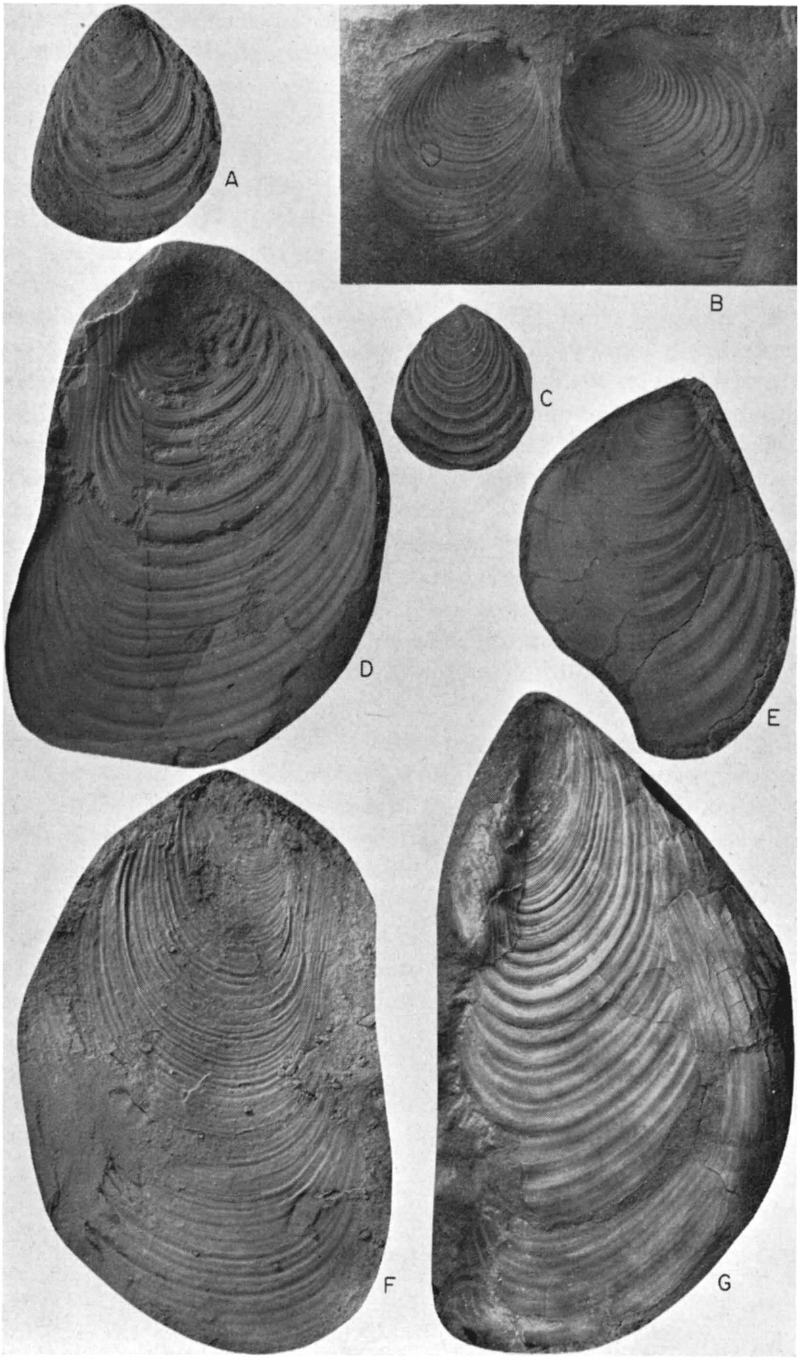
PLATE 14.—Fairport fossils. **A**, **C**, **E**, *Inoceramus latus* Sowerby. **A**, Internal mold, right valve, uppermost Fairport (Loc. 9), X1, hypotype, KU12052P1. **C**, Internal mold, right valve, middle part of Fairport (Loc. 51), X1, hypotype, KU-10546P1. **E**, Internal mold, right valve, upper part of Fairport (Loc. 16), X1, hypotype, KU12055P1. **B**, **D**, **F**, **G**, *Inoceramus labiatus* Schlotheim. **B**, Form transitional to *I. latus*, interior of paired valves, lower part of Fairport (Loc. 58), X½, hypotype, KU12064P1. **D**, Broad form, interior of left valve, lower part of Fairport (Loc. 12), X½, hypotype, KU10534P1. **F**, Broad form, interior of right valve, lower part of Fairport (Loc. 5), X1, hypotype, KU12051P2. **G**, Typical form, interior of left valve, lower part of Fairport (Loc. 33), X½, hypotype, KU12061P1.


A
B
C
D
E
F
G

Saskatchewan is laterally contiguous with lower Carlile strata farther south, but the Assiniboine cannot be distinguished in the subsurface (Wickenden, 1945, p. 23) and bears only superficial resemblance to the Fairport Member.

*Fossils and correlation.*—All Fairport exposures contain an abundance of well-preserved fossils, among which mollusks are by far the best represented in numbers of individuals. Fairport fossil localities are less well known than those of the overlying Blue Hill Member, perhaps because the specimens are less spectacular, but more probably because Fairport sections (1) are less numerous, (2) are generally less accessible, (3) expose smaller thicknesses of strata, and (4) are generally more deeply weathered than sections of the Blue Hill Member. Most invertebrate fossils consist of calcium carbonate in which original structure is preserved. The usual color of shell matter is nearly white, but shades of brown and gray are common among specimens of *Ostrea congesta* and all species of *Inoceramus*. External molds of *I. labiatus* and *I. latus* are common throughout the ranges of these two species in the Fairport, and molds, both external and internal, are the most common mode of preservation of *Collignoniceras* in the member. *Inoceramus* and *Ostrea,* replaced by very finely crystalline pyrite, were collected at locality 17 and in the SW¼ sec. 11, T. 11 S., R. 17 W., respectively.

Three stratigraphically well defined assemblages of invertebrate fossils occur in the Kansas Fairport. The lowest, restricted to the basal 6 to 12 feet, is marked by a broad variety of *Inoceramus labiatus*. The middle assemblage is characterized by abundance of bryozoans, barnacles, and worm tubes, together with large numbers of *I. latus* and *Ostrea congesta*. The highest of the three assemblages is similar to that in the middle beds, but bryozoans, barnacles, and worm tubes are absent or very sparse. Many species range throughout the formation but, although abundant, are not characteristic of any one of the three assemblages.

Listed below are macrofossils collected during the present investigation. The most abundant and characteristic fossils are preceded by an asterisk. Guide fossils are indicated by a dagger. Rare forms are

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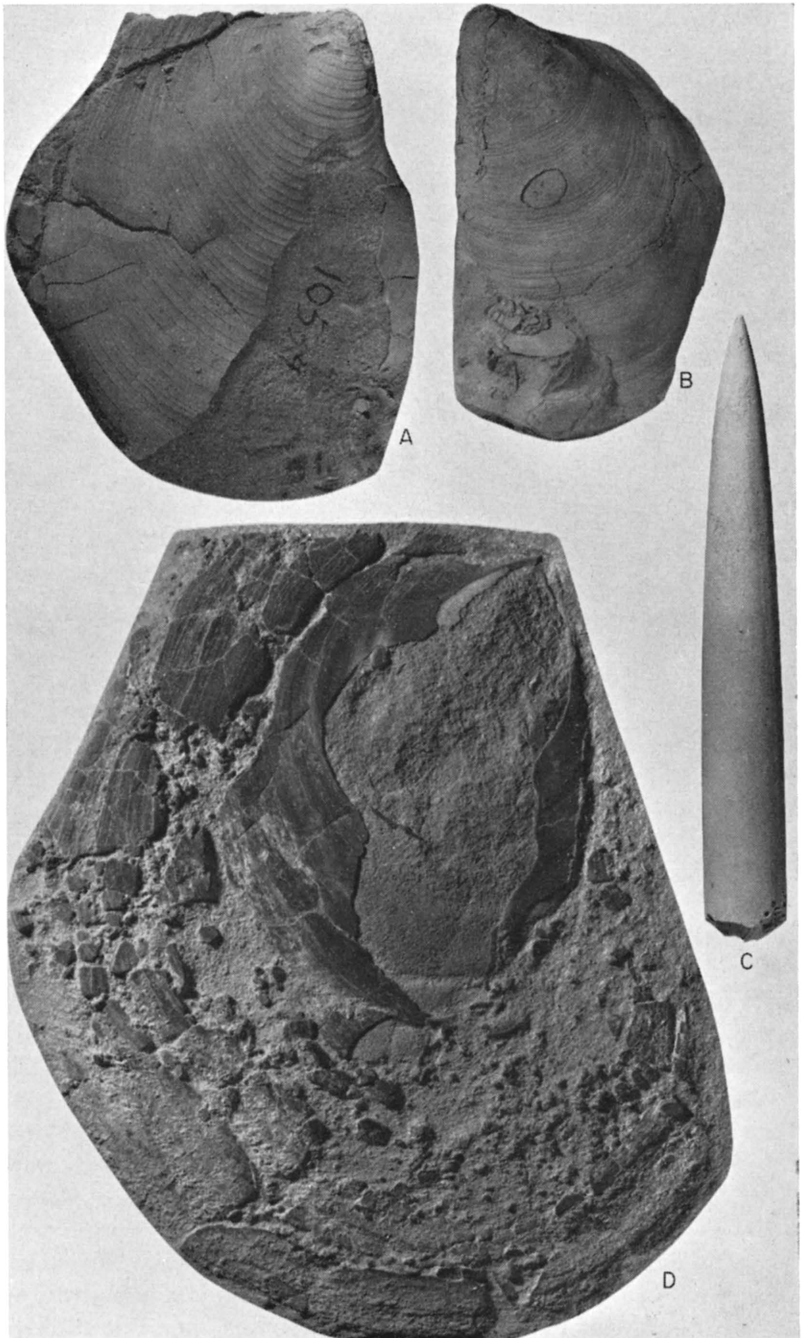
PLATE 15.—Fairport fossils. **A**, **B**, **D**, *Inoceramus cuvieri* Sowerby. **A**, Exterior, right valve, immature specimen, lower part of Fairport (Loc. 12), X1, hypotype, KU10534P2. **B**, Exterior, left valve, immature specimen, lower part of Fairport (Loc. 12), X½, hypotype, KU10534P3. **D**, Exterior, right valve, nearly mature individual, lower part of Fairport (Loc. 14), X½, hypotype, KU12054P2. **C**, *Actinocamax manitobensis* (Whiteaves), guard, middle part of Fairport (Loc. 19), X1, hypotype, KU12057L1.


A
B
C
D

followed by an asterisk. The ranges are plotted in Table 1, and the more common forms are illustrated in Plates 12 through 15.

*Fossils observed in the Fairport Member*

Tracheophyta
- Gymnospermae
  - *Cedroxylon* sp.*, with *Teredo?* borings
  - *Pinuxylon* sp.*

Bryozoa
- *Conopeum* n. sp.
- **Proboscina* n. sp.

Annelida
- *Hamulus* sp.*
- **Serpula semicoalita* Whiteaves
- **Serpula tenuicarinata* Meek & Hayden

Mollusca
- Pelecypoda
  - *Exogyra* sp.*
  - **Inoceramus cuvieri* Sowerby
  - **Inoceramus labiatus* Schlotheim, broad form
  - **Inoceramus latus* Sowerby
  - *Inoceramus* n. sp.?
  - **Ostrea congesta* Conrad
  - *Ostrea lugubris* Conrad*
- Cephalopoda
  - *Actinocamax manitobensis* (Whiteaves)*
  - Belemnites, recrystallized
  - †**Collignoniceras woollgari* (Mantell)
  - †*Scaphites patulus* Cobban*

Arthropoda
- Crustacea
  - **Stramentum?* n. sp.

Vertebrata
- Chondrichthyes
  - *Isurus appendiculata* (Agassiz)
  - *Isurus desorii* (Agassiz)*
  - *Isurus mantelli* (Agassiz)
  - *Ptychodus anonymus* Williston
  - *Ptychodus martini* Williston*
  - *Ptychodus whipplei* Marcou
  - *Scapanorhynchus raphiodon* (Agassiz)*
  - *Squalicorax falcatus* (Agassiz)
- Osteichthyes
  - Teleost bones, scales
- Reptilia
  - Mosasaur remains
- Incertae sedis
  - Coprolites

*Collignoniceras woollgari* has been selected by Cobban and Reeside (1952, p. 1018) as a zonal index for rocks of Fairport age in the Western Interior region of the United States. The species includes many named varieties but no attempt is made herein to make varietal identifications. Geographically, *C. woollgari* ranges from Texas, New Mexico and northern Arizona northward to northwestern Montana and southern Alberta, and from Kansas westward to California and Oregon. The stratigraphic distribution includes the Mancos Shale of Utah, New Mexico, and Arizona; Arcadia Park Formation of the Eagle Ford Group of Texas; lower part of the Carlile of the Great Plains and Black Hills; Frontier Formation of northern Utah and western and southwestern Wyoming; Colorado Shale of Montana; the Blackstone Formation of southern Alberta; and Turonian of California and Oregon. *C. woollgari* is found in the middle part of the European Turonian (Matsumoto, 1959, p. 108) and is also found in the zone of *Terebratulina lata* of the English Middle Chalk. To Western Interior beds containing *C. woollgari*, Reeside (1957) assigned an age of early middle Turonian.

Only one other described species, *Scaphites patulus*, is known to be restricted to rocks of Fairport age. *S. patulus* has been found only in the lower part of the Carlile Shale of South Dakota, Wyoming, and

Kansas; the Colorado Shale of Montana; and the upper part of the Blackstone Formation of Alberta. Apparently, it is known only from the zone of *Collignoniceras woollgari*. Present identification of this species is based on two specimens collected by me and especially one in The University of Kansas collections that was identified by T. Matsumoto. Two additional specimens from the "Blue Hill Shale" at Cedar Bluff Dam, Trego County, Kansas, were described by Matsumoto and Miller (1958, p. 355). The Cedar Bluff fossils probably should be regarded as Fairport fauna for reasons discussed above. Two additional molds of *Scaphites,* collected by me, cannot be identified specifically.

*Actinocamax manitobensis* is a fairly short-ranging species that has scattered regional distribution. A single well-preserved specimen was collected from the middle part of the Fairport at locality 19. Three other specimens, described by Jeletzky (1961), and now in the collection at Fort Hays Kansas State College, are of uncertain stratigraphic horizon but are probably from the Fairport. The species is known elsewhere in the Cardium Formation of Alberta, the Tuskoola sandstones (sic) of British Columbia, and the Assiniboine Member of the Favel Formation of Manitoba and Saskatchewan (Jeletzky, 1950, 1961). The Assiniboine Member lies above the zone of *Inoceramus labiatus,* this species being confined to the Keld Member of the Favel (Wickenden, 1945, p. 32), and below rocks the lithology of which suggests homotaxial equivalence with the Blue Hill Shale Member. Correlation of the Fairport with at least a part of the Assiniboine thus seems logical. Other Favel species, including a large flat *Inoceramus, Serpula* cf. *S. semicoalita, Ostrea congesta,* and *Stramentum canadensis,* make up an assemblage similar to that occurring in the Fairport.

Two short-ranged species of intercontinental distribution are *Inoceramus labiatus* and *I. latus.* The former species has nearly worldwide distribution and is characteristic of lower Turonian rocks. It occurs in the zones of *Rhynchonella cuvieri* and *Terebratulina lata* of the English Middle Chalk. Most forms in the *T. lata* zone are broader and less high than the typical forms (Woods, 1912, p. 13). The species is characteristic of the Greenhorn Limestone but ranges into the lower few feet of the Fairport, where typical high, narrow forms are subordinate in numbers to the broader, less high forms. A gradation stratigraphically upward is observed from *I. labiatus* to its descendant, *I. latus,* the latter being abundant in middle and upper Fairport beds and seemingly ranging also throughout the Blue Hill Member. *I. latus* is widespread in upper Turonian strata of Europe and is most characteristic of the zone of *Holaster planus* of the English Middle Chalk.

Long-ranging invertebrate species in the Fairport Member include *Ostrea congesta, Inoceramus cuvieri, Serpula tenuicarinata,* and *S. semicoalita. O. congesta,* one of the commonest oysters in Cretaceous rocks of the Western Interior region, has a known geographic range that extends from Mexico northward to the southern plains provinces of Canada, and from Kansas westward to Utah. It has been reported also from Texas, Arkansas, and New Jersey. Most reported occurrences are in beds of the Fairport through the Niobrara; however, Morrow (1941, p. 129) recorded *O. congesta* in the Greenhorn of Kansas, Fisher and others (1960, p. 29) reported the species in the Eagle equivalent of the Mancos Shale of Utah, and Stott (1961, p. 29) recorded its occurrence in the middle part of the Wapiabi Formation of Alberta. *I. cuvieri* (Pl. 11C) has been reported in the Kansas Carlile by Hattin (1952, p. 45) and by Matsumoto and Miller (1958, p. 354). The species has been discovered also in the upper part of the Seabee Formation (Turonian) of Alaska by Jones and Gryc (1960). These authors stated erroneously (1960, p. 152) that the lower limit of the range of *I. cuvieri* in North America is the zone of *Collignoniceras hyatti* (Blue Hill). Stott (1961) reported *Inoceramus* cf. *I. cuvieri* in the Cardium and Wapiabi Formations of Alberta. Most Kansas specimens are from the Fairport Member or from the Fencepost bed (uppermost Greenhorn Limestone). Fragments of a large, flat, thick-shelled *Inoceramus* that have been reported in other areas from beds correlative with the Fairport may prove to be of this species. *I. cuvieri* is widespread in Europe and ranges from the zone of *Terebratulina lata* to that of *Micraster coranguinum* of the English Middle and Upper Chalk. *S. tenuicarinata* is known from the Fairport and Niobrara of Kansas, from the "Fort Benton Group" of South Dakota, and from the lower Carlile equivalent of the Mancos Shale of Utah. The apparent stratigraphic range of this species is Fairport through Niobrara. *S. semicoalita* is known only from Manitoba and Kansas. In Canada it has been collected from the Favel Formation, and in Kansas from the Fairport and Niobrara.

The range of *Ostrea lugubris* is extended to somewhat older strata than reported previously by discovery of two specimens in the middle part of the Fairport at locality 4.* The range shown by Cobban and Reeside (1952) includes the zones of *Scaphites warreni* and *Prionocyclus wyomingensis* of the middle part of the Carlile Shale, or Turner Sandy Member, equivalents. Stott (1961, fig. 2) shows the range of *O. lugubris* in western Canada as extending from the top of the zone

* Dr. Erle Kauffman, U.S. National Museum, has examined these Fairport oysters and believes that they are not *O. lugubris.*

of *Collignoniceras woollgari* upward to the base of the zone of *Inoceramus deformis* and *Scaphites preventricosus.* This range includes strata equivalent to the Blue Hill, Turner, and Sage Breaks Members of the American Carlile. Morrow (1941) described a single specimen from the Blue Hill Member in Mitchell County, Kansas, that was collected and identified by J. B. Reeside, Jr. This is, so far as I am aware, the only other specimen known from the Carlile of Kansas. *O. lugubris* has a geographic distribution that includes Mexico, Texas, New Mexico, Colorado, Utah, Kansas, and Alberta.

Calcite-filled holes in a fossil log of the genus *Cedroxylon* are ascribed to the genus *Teredo,* wholly on the basis of size and relationship of borings to wood fragments. A single *Exogyra* is so contorted by attachment as to preclude adequate comparison with named species of the genus. Previously undescribed species of the bryozoans *Conopeum* and *Proboscina* and the barnacle *Stramentum?* will be treated fully in a separate paper. Identification of the genus *Hamulus* in the Fairport is based on a single cross section in a thin section of chalky limestone from locality 29. Bass (1926, p. 66) reported *Baculites* from the Fairport of Hamilton County, and I discovered a few molds at locality 21 that may belong to this genus. Matsumoto and Miller (1958, p. 355) reported *Proplacenticeras pseudoplacenta* from the spillway at Cedar Bluff Dam, Trego County (Loc. 56). If these strata are, as I believe, part of the Fairport Member, then this species also should be added to the list of Fairport invertebrates.

Shark teeth are common in the Fairport and have been collected at many localities. Eight named species have been identified by me, none restricted to the Fairport Member. Five species are long ranging and of intercontinental distribution, namely: *Scapanorhynchus raphiodon, Squalicorax falcatus, Isurus appendiculata, I. desorii,* and *I. mantelli. Pytchodus martini* has been reported hitherto only from the Niobrara of Kansas. *P. anonymus* has been reported from the Niobrara and Benton? of Kansas. *P. whipplei* is known from Mexico, New Mexico, Colorado, Wyoming, South Dakota, and Kansas; the range is Fairport through Niobrara.

Foraminifera of the Fairport Member of Kansas have been treated by Morrow (1934) and Griffith (1947). Three species described by Morrow and seven additional species reported by Griffith, including one previously undescribed species, are all long-ranging forms. All are calcareous. Fox (1954) listed three species from the Fairport equivalent of the unnamed member of the Carlile Shale near Belle Fourche, South Dakota, two of which were also reported from Kansas by Griffith; all three of Fox' species are long-ranging forms. Known

Foraminifera of the Fairport Member of Kansas are not restricted stratigraphically and are not useful for precise correlation of these strata.

Blue Hill Shale Member

*Name and definition.*—The name "Blue Hill" was first applied to upper Carlile strata by Logan (1897, p. 217). A type section has never been designated, but the term was probably derived from the Blue Hills of western Mitchell County, Kansas (Pl. 16A). Curiously, Logan (1897, p. 219) included in the Niobrara a sequence of concretion-bearing shale that he (Logan) called "Septaria"; yet farther on in the same paper Logan (1897, p. 234) clearly included the concretionary beds in the Benton Group. This part of the section was classed as Benton by all subsequent workers including Williston (1897, p. 237), whose paper appeared in the same volume as that of Logan. The name "Blue Hill" replaced Cragin's name "Victoria", which was preoccupied. Rubey and Bass (1925, p. 33) defined the Blue Hill as gray fissile concretionary clay shale lying between the chalky shale of the Fairport, below, and the Fort Hays Member of the Niobrara Chalk, above. These authors subdivided the unit into an upper sandstone division and a lower shale and concretion division.

When the sandstone division, later named Codell, was elevated to member status, the term Blue Hill was thus restricted to the lower shale and concretion division. This change was adopted temporarily by the Kansas Geological Survey (Moore and others, 1944, p. 152); however, Moore and others (1951, p. 24) reverted to the original definition of the Blue Hill Member and included the Codell as a zone within the Blue Hill. Still more recently, Merriam (1957a, p. 8) and Jewett (1959) ranked the Codell as a member and used the term Blue Hill in the restricted sense, and that usage is followed in this report.

As reference section of the member I herewith designate the beds exposed at locality 25 (inset, Pl. 1; Pl. 16B), where the full thickness of the Blue Hill Shale Member is exposed in a linear distance of about 0.5 mile.

*Contacts.*—The contact of the Blue Hill Shale Member with the underlying Fairport Member is easy to determine in the field, and criteria for recognizing it have been outlined above. The boundary

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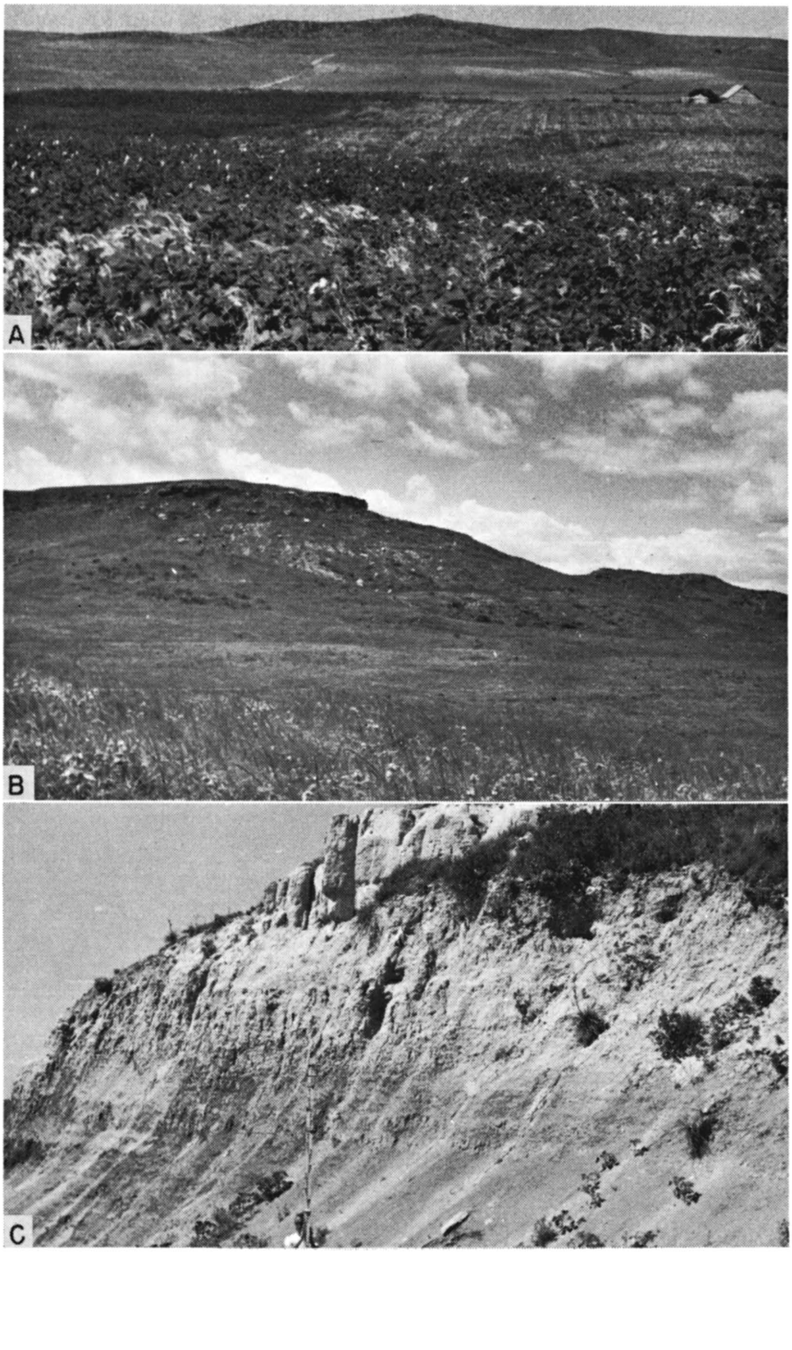
PLATE 16.—Topography and exposures in Blue Hill outcrop belt. **A**, Niobrara-capped butte in southwestern Blue Hills, sec. 21, T. 9 S., R. 10 W., Mitchell County. Measured section 31 is located on north (left) side of butte. **B**, Reference section of Blue Hill Member exposed on Fort Hays escarpment, sec. 29, T. 11 S., R. 16 W., Ellis County (Loc. 25). **C**, Blue Hill-Codell contact (top of rod) at type locality of Codell Member, sec. 3, T. 11 S., R. 17 W., Ellis County (Loc. 28). Note sandy beds in uppermost Blue Hill and very thick ledge of Codell near top of photograph.


A
B
C

between the Blue Hill and Codell, on the other hand, offers some problems in recognition because of the commonly transitional junction of these units. In many exposures, including the reference section of the Blue Hill Shale Member (Loc. 25) and the type section of the Codell Sandstone Member (Loc. 28), a sharp change in slope or road-cut color, from gray to grayish yellow or dusky yellow, is observed where the section changes upward from chiefly silty shale to chiefly sandstone or siltstone. Where marked in this way, the contact between the members can be recognized with little difficulty (Pl. 16C). At many places, however, as at localities 15, 17, 22, and others, the proportion of sand and silt below the Codell is great enough to impart a grayish-yellow color to the slope, even though the rock is predominantly argillaceous shale and is clearly assignable to the Blue Hill Shale Member. Naturally, in some sections the boundary must be placed somewhat arbitrarily because transitional strata are thick. As much as 17 feet of such rock is exposed at locality 47 in Trego County. Before one can attempt to determine the contact, the section must be ditched so as to expose fresh strata. In such a ditch, the transitional strata show a color that is generally either predominantly medium to medium dark gray or predominantly light olive gray (5Y6/1). The former colors indicate a chiefly argillaceous rock, the latter, chiefly siltstone or sandstone. I have followed the practice of placing the contact where the fresh-rock color changes upward from mostly gray to predominantly light olive gray.

*Lithology.*—Most of the Blue Hill Shale Member is blocky to fissile, slightly silty, clayey shale that weathers into small brittle flakes (Pl. 17A). Bedding planes are poorly defined in most fresh exposures. Very fine carbonaceous matter is scattered throughout the shale. The predominant color of the shale is dark gray, but locally the rock is light to dark olive gray. In most exposures, deeply weathered rock is uncommon, but many flakes of partly weathered shale are medium gray. In the lowermost 20 to 25 feet of the member, the shale weathers to light olive gray (5Y6/1) at some places. Concretionary nodules of finely to very coarsely crystalline pyrite are common in some exposures, notably at localities 18 and 32. The nodules are generally an inch or two in greatest dimension. At locality 18, many fossils, particularly *Scaphites,* are filled with finely crystalline pyrite and even

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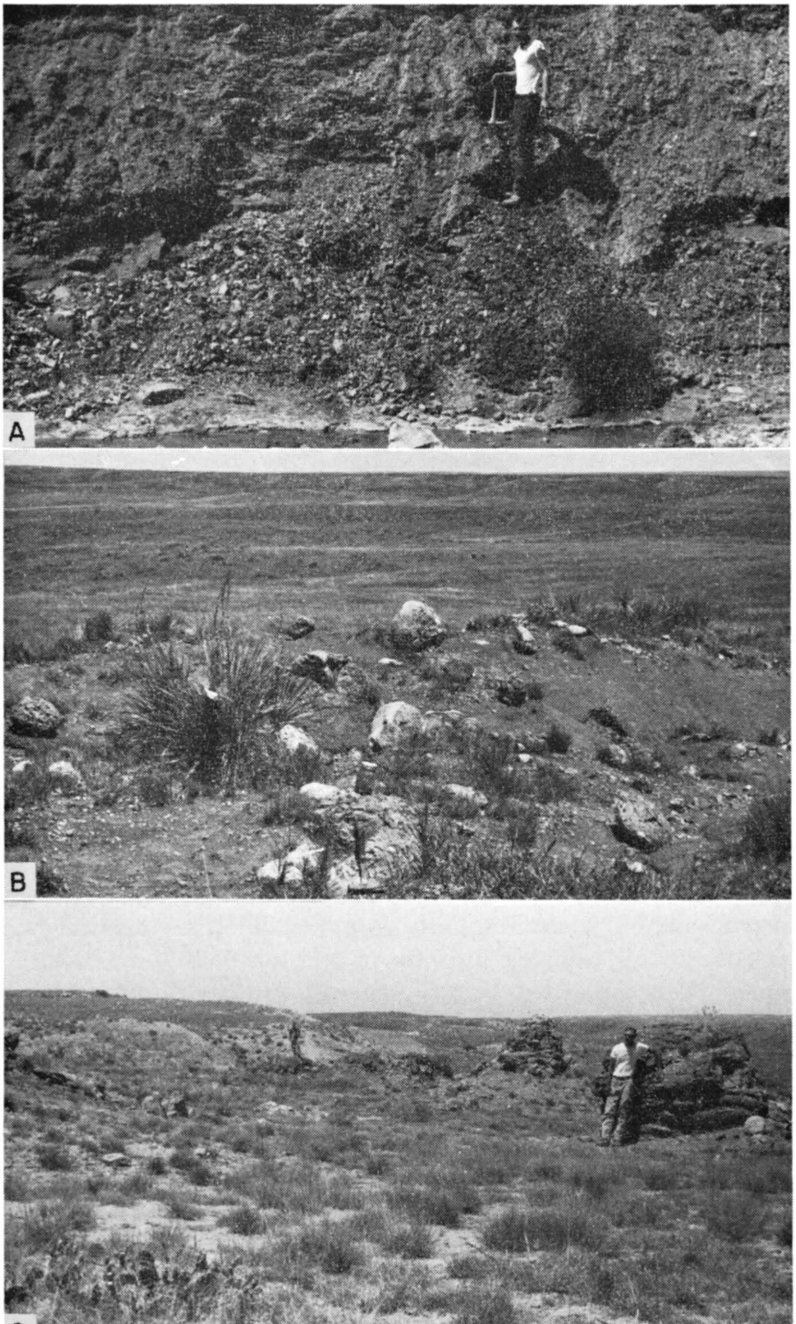
PLATE 17.—Exposures of Blue Hill Member. **A**, Typical exposure of unweathered Blue Hill beds, sec. 4, T. 11 S., R. 18 W., Ellis County (Loc. 18). **B**, Septarian-concretion-studded exposure of Blue Hill Member, sec. 22, T. 15 S., R. 20 W., Ellis County (Loc. 17). **C**, Gigantic concretions in upper part of Blue Hill Member, sec. 25, T. 22 S., R. 42 W., Hamilton County (Loc. 22).


A
B
C

partly or wholly surrounded by this mineral. Very small grains of crystalline pyrite are disseminated in the shale locally. At nearly all exposures the shale is stained along joints and bedding planes by pale-yellow, powdery iron sulfate. Limonitic staining along joints and bedding planes is common also, and is generally concomitant with the iron sulfate stains; indeed, the limonite undoubtedly originated by oxidation of the iron sulfate. At a few places, especially at locality 32, a strong melanterite taste can be detected locally in the gray shale. Calcium sulfate in the form of selenite is especially abundant at many exposures, occurring as minute aggregates along planes of fissility, as coarsely crystalline platy masses in partly weathered shells of *Inoceramus,* and as large individual or fishtail-twinned crystals several inches in length. At a few places, slopes of the shale glitter by reflection of sunlight from thousands of large selenite crystals. Gypsum and barite occur locally as fossil-replacement minerals.

X-ray study was made of five representative samples of the Blue Hill Shale Member from selected exposures along the Saline River valley. Two additional samples from Jewell County were studied because the field appearance of the rock is not "typical" for the member. Despite the different appearance of the last two samples, the mineral content is harmonious with other analyzed samples. In all samples, quartz is the dominant mineral, and in all but two samples nonclay constituents exceed the total clay-mineral content. In the field, all of the samples were described as being very slightly to slightly silty clayey shale, except sample 28-L, which is very sandy. Thus, most of the quartz is seemingly of very fine silt size or smaller. Kaolinite is the dominant clay mineral in five of the samples and is present in the other two. Montmorillonite, or illite and montmorillonite are dominant in the two samples where kaolinite is not, and occur in nearly equal quantities in all samples. Results of x-ray study of the Blue Hill samples are summarized below. According to Swineford and others (1954, p. 163), minerals in the upper part of the Blue Hill of Ness County are, "in rough order of abundance, montmorillonite, quartz, kaolinite, illite, feldspar, muscovite, and traces of chlorite and gypsum". Except for dominance of montmorillonite, rather than quartz, the Ness County analysis is in accord with those of the present report. The upper part of the Blue Hill is seemingly more bentonitic in Ness County than where the tabulated samples were collected.

Beginning as much as 75 feet or as little as 15 feet below the Niobrara, the Blue Hill Member becomes, progressively upward, more silty and finally very sandy at the top. In the lower part of this transition to the overlying Codell Sandstone Member, the quantity of silt

*Clay mineral analyses of clayey shale*

| Sample | Clay minerals | | | Nonclay | | Dominant mineral assemblage | Dominant mineral |
|---|---|---|---|---|---|---|---|
| | Dominant | Moderate | Minor | Dominant | Minor | | |
| 18-B | Kaolinite | Montmorillonite<br>Illite | Chlorite | Quartz | Dolomite | Nonclay | Quartz |
| 19-Y | Kaolinite | Illite<br>Montmorillonite | Chlorite | Quartz | Feldspar<br>Gypsum | Nonclay | Quartz |
| 25-O | Montmorillonite | Illite<br>Chlorite | Kaolinite | Quartz | Mica | Clay | Quartz |
| 28-F | Illite<br>Montmorillonite | Kaolinite | Chlorite | Quartz | Mica | Nonclay | Quartz |
| 28-L | Kaolinite | Illite<br>Montmorillonite | | Quartz | Feldspar | Nonclay | Quartz |
| 40-P | Kaolinite | Illite<br>Montmorillonite | | Quartz | | Clay | Quartz |
| 43-A | Kaolinite | Illite<br>Montmorillonite | | Quartz | Calcite | Nonclay | Quartz |

grains disseminated in the shale gradually increases. Upward, the shale is interbedded with thin to thick laminae and lenses of light-olive-gray (5Y6/1), very fine grained quartz sand and silt. The small lenses of sand commonly impart a mottled appearance to this part of the shale. Still higher, thin to very thin beds of very fine grained quartz sand or silt alternate with thicker layers of silty or very fine sandy shale. As the quantity of sand increases, the blocky structure of the shale is less prominent, and the weathered rock is only partly flaky. The predominant color of this part of the section is medium dark gray on fresh surfaces, medium gray where weathered. The thickness range of the sandy upper part of the Blue Hill Member in part reflects intergrading facies at the Codell-Blue Hill boundary. Rocks in stratal continuity are assigned to one member or the other, depending on the percentage of coarse silt and sand content. Where the Codell is thickest, the part of the Blue Hill Member that is sandy is generally much thinner than at places where the Codell is poorly developed. X-ray analysis of a sandy shale sample (28-L) is given above.

At several localities in Finney, Ness, Ellis, Hamilton, Osborne, and Mitchell Counties one or two thin beds of hard, resistant sandstone or sandy siltstone lie just above or just below the base of the sandy upper portion of the Blue Hill Member. The beds are generally no more than

0.3 foot thick, are gently cross laminated locally, and commonly contain worm? trails or worm castings. Calcareous sandstone or sandy siltstone is exposed in the upper part of the Blue Hill at localities 1, 6, 15, 17, 31, 32, and 39; the calcite may maintain optical continuity through several cubic centimeters of the rock. Most of the sandstone is light gray to medium light gray or light olive gray and weathers to grayish orange, dark yellowish orange, or moderate yellowish brown. Large concretionary masses of gently cross laminated sandstone lie about 35 feet below the top of the Carlile Shale in the sandy part of the Blue Hill Member at locality 39. A layer of sandy calcareous concretions lies in calcareous sandy siltstone about 24 feet below the top of the Carlile at locality 32. Similar concretions, some as much as 8 feet in diameter and mostly of irregular shape, are exposed at several localities in southern Osborne County and lie about 25 feet below the top of the Carlile. At the same horizon in the SW¼ sec. 3, T. 10 S., R. 13 W., Osborne County, a 1.2-foot bed of calcareous siltstone is gently cross laminated and oscillation ripple marked. The ripples have a spacing of approximately 0.2 foot and amplitude of 0.02 foot.

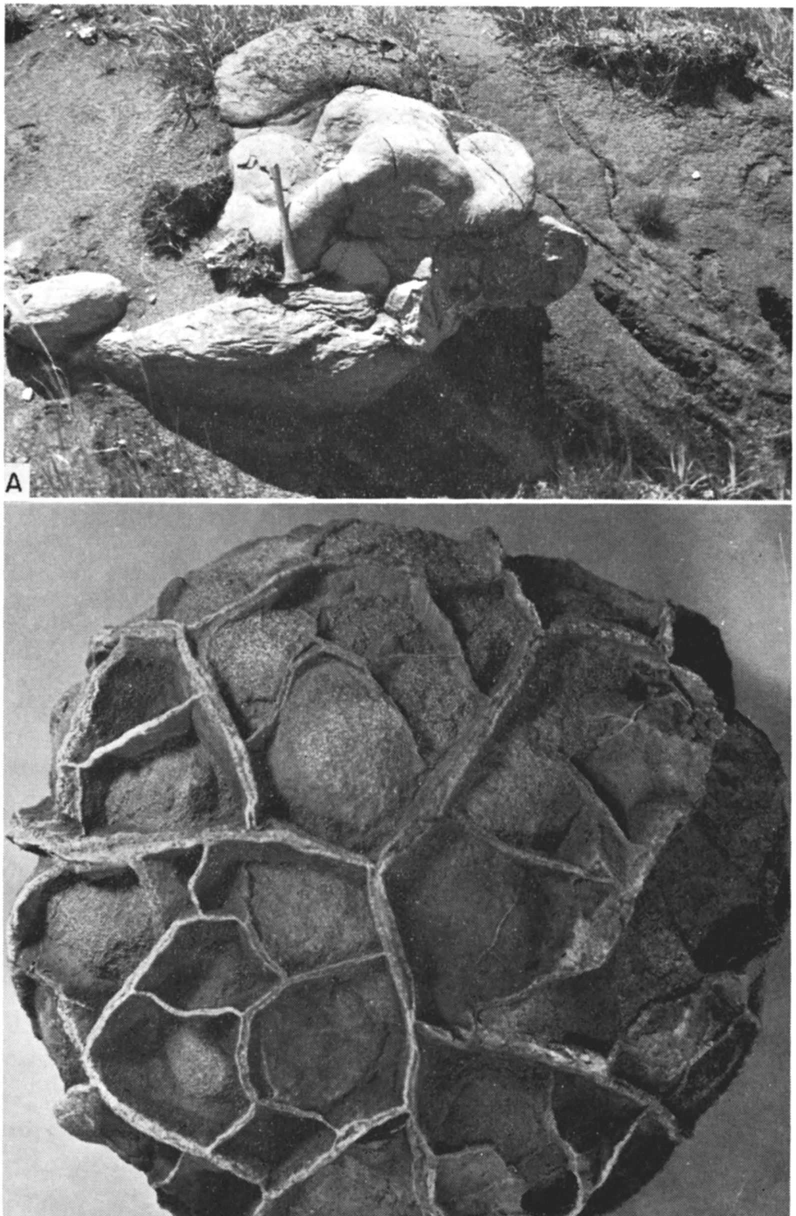
Thin sections were prepared of a calcareous, very fine sandy siltstone (Loc. 17), a noncalcareous siltstone (Loc. 17), and a sandy calcareous concretion (Loc. 32). The first of these contains the following minerals, listed in approximate order of abundance: quartz, feldspar, chert, limonite, and biotite. The cement consists of a small quantity of calcite. The second thin section contains quartz, feldspar, chert, biotite, glauconite, and tourmaline. The rock is cemented by a very fine grained silt and clay matrix, which is dark under crossed nicols. The sandy concretion consists of finely crystalline calcite through which are scattered abundant fine grains of subangular quartz.

Even the most casual observer cannot fail to be impressed by the number and size of the concretions that stud the slopes of every large exposure of Blue Hill Shale (Pl. 17B). Three kinds occur: calcareous septarian concretions (most abundant), noncalcareous clay-ironstone concretions, and sandstone concretions (least common). The concretions are arranged mostly in zones, some of which are useful as marker beds because they can be traced for many miles.

Calcareous septarian concretions are found through a greater stratigraphic range than the other kinds. The position of the lowest septarian-concretion zone of the member ranges from 30 feet above the base, in Osborne County, to about 70 feet above the base, in Finney County. In sections located geographically between, the distance of the lowest concretion zone above the base increases from north to south. Generally, the highest septarian concretions are in the lowest few feet of the fine sandy shale that makes up the upper part of the Blue Hill Shale Member and are correspondingly sandier than other septaria; but concretions lie high in the sandy zone in Osborne, Mitchell, and Hamilton Counties. The vertical interval between the base of the Fort Hays Limestone Member and the highest concretion zone ranges from 22 feet at locality 31, in Mitchell County, to 40 feet at several other localities. Despite the fact that many of the concretions lie in widespread zones, a great number are distributed randomly throughout the shale, and some are arranged in local zones that cannot be traced even to nearby exposures. North of Mitchell and Osborne Counties, the number and size of calcareous septarian concretions decreases considerably.

The largest septarian concretions are in Hamilton County, where unbroken specimens as large as 12 feet in diameter and 6 feet in thickness are exposed at locality 20 and at locality 22 (Pl. 17C); some may have been even larger, although most are now partly broken by weathering. In west-central Kansas, the largest concretions seen are at locality 2 in Ness County, where one specimen is 8 feet in diameter and 5 feet in thickness. Complete gradation in size between such gigantic concretions and those only an inch or two in diameter is observed. Many septarian concretions less than 0.5 foot in diameter are nearly spherical, but most larger ones are more or less oblate spheroidal. Many have a smooth, unbroken exterior and some are oddly shaped because of wartlike or ridgelike tuberosities (Pl. 18A). In other specimens, calcite septa project conspicuously from the weathered surface, thus imparting a coarse honeycomb appearance to the concretion, but these are sparse (Pl. 18B). At many places, notably locality 28, adjacent septarian concretions coalesce into irregular rock masses. In southern Osborne County and southwestern Mitchell County, sandy septarian concretions that lie in a zone approximately 40 feet below the top of the Carlile are smooth, nearly spherical, as much as 3.5 feet in diameter, and, because septa are not so extensively developed as in typical septaria, weather concentrically in the outer part.

The unweathered matrix of the concretions is olive gray, dark gray, or medium dark gray or less commonly olive black or medium gray. The weathered surface is yellowish gray (5Y8/1), dark yellowish orange, or grayish orange and less commonly grayish yellow, light gray, or shades of brown. At many exposures one or two zones of vivid dark-yellowish-orange-weathering concretions stand out conspicuously on the slopes. Some of these concretions are stained grayish red, moderate reddish brown, or light brown (5YR5/6). The matrix is very hard,


A
B

brittle, and calcareous, and ranges in texture from very fine grained to micrograined. Many concretions have an outer "crust" with cone-in-cone structure. Where weathered, such a crust breaks into large numbers of tapered, pencil-like fragments. In other concretions, the outer surface becomes coarsely granular upon weathering.

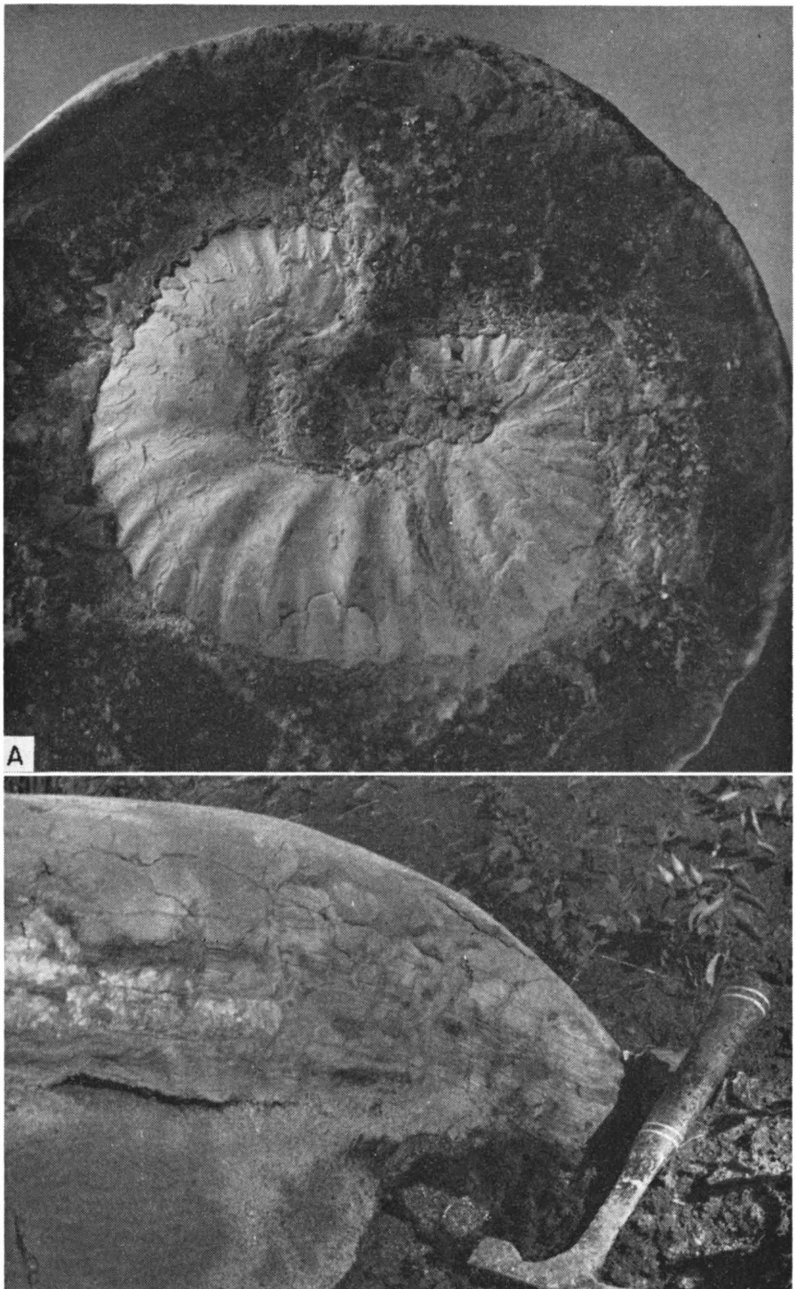
The septa are mostly grayish brown or moderate brown, less commonly dusky brown, dark yellowish brown, or various shades of yellow and orange. They may be as much as an inch thick and consist of slender fibers of calcite oriented perpendicular to the enclosing walls of concretionary matrix. From the centers of the concretions outward, the septa taper gradually to a wedge edge. Most concretions contain interior-shrinkage cavities lined with the same prismatic calcite that forms septa. Second-generation calcite of white, grayish yellow, or pale yellow generally encrusts the walls of the cavities. This calcite has assumed various crystal habits. Under the effects of long mechanical weathering, the concretions break along septal planes and form heaps of angular fragments.

Pyrite has been described in septarian concretions from northeastern Ness County by Swineford and others (1954, p. 161) but I did not find this to be a usual constituent of septaria.

Fossils are common in septarian concretions at some localities and are preserved little damaged in the smaller concretions (Pl. 19A), which break along laminae of the nacreous layers so that the fossils show an iridescence where freshly exposed. Internal shrinkage of larger concretions has shattered most of the contained fossils, but at locality 25 I broke open a large concretion that contained a fairly complete specimen of *Collignoniceras hyatti* about 1.5 feet in diameter. The most common species preserved in the concretions are *C. hyatti*, *Inoceramus flaccidus*, and *Scaphites carlilensis*.

Shale bordering the concretions laterally is commonly sandy or silty. A thin layer of very fine grained sandstone passes through concretions in the sandy upper part of the Blue Hill Shale Member at localities 15, 25, and 31. The sand layer bends downward in the concretion margins at the last two localities, probably as a result of upward expansion of the concretions during growth (Pl. 19B). At several places, including localities 13, 18, 25, and 31, the surrounding shale arches over and is depressed beneath some of the concretions.

Swineford and others (1954) described nodules of hydrated halloysite and alunite from three localities in Ness and Trego Counties, Kansas. The nodules are peripheral to the septarian concretions at the concretion-shale contact, and are associated with gypsum.


A
B

The second major group of concretions is the noncalcareous clay-ironstone type. These are known from Osborne County, northern Ellis County, and southeastern Smith County. Along the south side of the Saline River valley a zone of such concretions, 1.4 to 1.9 feet thick, caps a low but prominent bench (Pl. 20A). The zone lies 27 to 33 feet above the base of the member. At localities 32 and 45 in Osborne and Smith Counties, respectively, clay-ironstone concretions lie in a discontinuous zone of nonuniform thickness approximately 45 to 55 feet above the base of the member. The concretions occupy part of a 10-foot section of shale beneath a marker zone of conspicuous, warty, dark-yellowish-orange-weathering septarian concretions. Presumably the same clay-ironstone zone is exposed at locality 18, in northern Ellis County, where it lies approximately 85 feet above the base. At locality 45, the clay-ironstone concretions are abundant (Pl. 20B) and contain numerous well-preserved fossils.

The clay-ironstone concretions are very flat oblate spheroids and have a narrowly elliptical vertical cross section. Most of the concretions are less than 1.5 feet in diameter and less than 0.25 foot thick, but at locality 18, in northern Ellis County, there is a continuous bed of such concretionary rock. The prevailing color is olive gray; the prevalent weathered colors are grayish red (10R4/2), moderate reddish brown, light brown (5YR5/6), and dark yellowish orange. Most of the concretions are very hard, brittle, resistant to weathering, and fossiliferous. Most common of the fossils are *Inoceramus flaccidus, Collignoniceras hyatti,* and small gastropods. A few concretions contain thin calcite-filled fractures quite unlike those of the septarian concretions.

In thin section, a typical clay-ironstone concretion consists of uniformly microgranular matrix containing abundant disseminated pyrite, some crystalline aggregates of pyrite, a few very small grains of angular quartz, and limonite. X-ray analysis of a concretion from locality 45 shows a dominance of nonclay minerals, chiefly siderite, and a subordinate quantity of quartz. Clay minerals constitute a maximum of 15 percent of the entire sample and include illite, montmorillonite,

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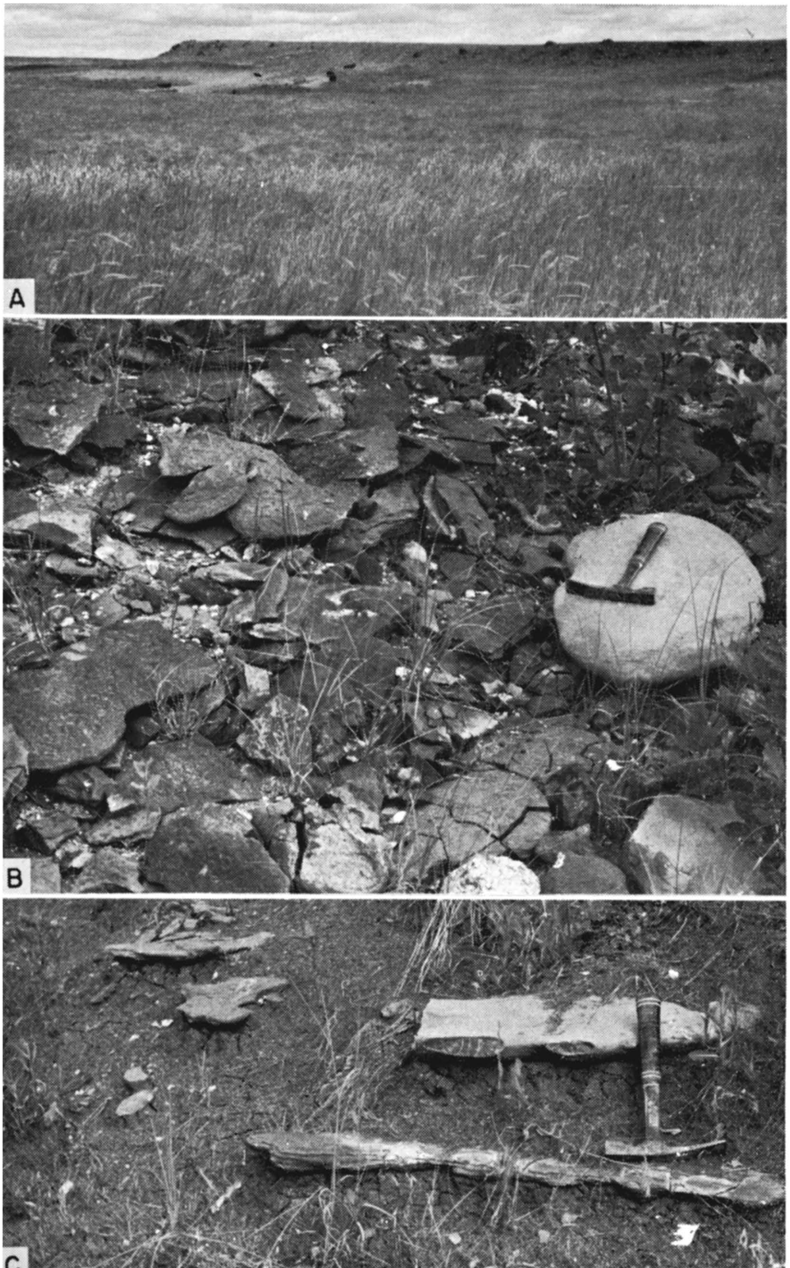
PLATE 19.—Blue Hill concretions. **A**, Small septarian concretion that contains well-preserved *Scaphites*, X2, from middle part of Blue Hill, sec. 24, T. 7 S., R. 14 W., Osborne County (Loc. 49). **B**, Laminated sandstone layer in septarian concretion in middle part of Blue Hill, sec. 20, T. 9 S., R. 10 W., Mitchell County (Loc. 31). Note uparched condition of sand in center of photograph.



and chlorite in almost equal amounts. The same specimen was analyzed chemically and the following percentages were determined:

*Chemical analysis of a clay-ironstone concretion*

| Locality | Unit | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | $TiO_2$ | CaO | MgO | $P_2O_5$ | S | $CO_2$ | Loss 140°C | Total loss, as-rec'd basis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 45 | D | 11.9 | 5.08 | 37.4 | 0.094 | 5.70 | 7.36 | 0.095 | 0.12 | 31.4 | 1.11 | 31.4 |

Small sandy concretions can be observed at a few localities in Mitchell, Osborne, and Smith Counties, where they occur in close association with clay-ironstone concretions. The sandy concretions are mostly olive gray and weather to moderate yellowish brown, pale to dark reddish brown, or, where very limonitic, dark yellowish orange. Most of the specimens are less than 1 foot in diameter and less than 0.3 foot thick. The rock is composed chiefly of fine quartz sand, silt, and clay, is softer than the ironstone concretions, and generally is weakly calcareous. A few fossil fragments are preserved locally. Such concretions are surrounded by soft, very argillaceous, fine-grained quartz sandstone in some sections and by silty argillaceous shale in others. Sandy concretions that lie near the top of the Blue Hill Member in Osborne County have been noted above.

Probably also of concretionary origin are wall-like masses of calcareous siltstone that lie 23 to 35 feet below the top of the Carlile Shale in sec. 3 and 10, T. 10 S., R. 13 W., Osborne County. Individual structures are as much as 12 feet high, 5 to 6 feet wide, and several hundred feet long. Study of these structures has not been completed.

Bentonite is uncommon in the Blue Hill Member and has been observed at only a few localities. Two varieties are evident, biotitic and nonbiotitic. The former is known from a single horizon in Osborne, Mitchell, and Ellis Counties and is light olive gray (5Y6/1), medium gray, or medium olive gray; weathers dark yellowish orange; and contains pyrite nodules as much as 0.4 foot in diameter and 0.15 foot thick at locality 38. Very fine flakes of biotite are scattered throughout, and the bentonite at localities 31 and 38 is gritty. The greatest thickness of

PLATE 20.—Blue Hill concretion zones. **A**, Bench capped by clay-ironstone marker bed 1, lower part of Blue Hill Member, sec. 29, T. 11 S., R. 16 W., Ellis County (Loc. 25). Black spots are cattle. **B**, Clay-ironstone concretions from marker zone 4, middle part of Blue Hill, sec. 27, T. 5 S., R. 13 W., Smith County (Loc. 45). Hammer lies on septarian concretion from top of zone. **C**, Calcareous concretion (hammer handle) and clay-ironstone concretion (hammer head) in marker zone 4, middle part of Blue Hill, sec. 27, T. 5 S., R. 13 W., Smith County (Loc. 45).

the biotitic bentonite seam is 0.15 foot. The nonbiotitic bentonite is like that in the Fairport Member and has been observed at two horizons, the lower of which seems to be widespread in north-central Kansas (Pl. 1). The color ranges from light olive gray (5Y6/1) to yellowish gray (5Y8/1) or very pale orange, and the weathered bentonite is dark yellowish orange. The higher of the two seams of this kind of bentonite is known only at locality 32, where it contains small nodules of pyrite. Seemingly, neither seam of nonbiotitic bentonite reaches a greater thickness than 0.04 foot. At most localities, the bentonite seams are not exposed on weathered slopes but must be located by trenching the section.

Chemical analysis of a bentonite sample from the lower part of the Blue Hill Member is shown below. The large weight loss is due to the expulsion of water from clay minerals that dominate the sample.

*Chemical analysis of a Blue Hill bentonite*

| Locality | Unit | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | $TiO_2$ | CaO | MgO | $P_2O_5$ | S | $CO_2$ | Loss 140°C | Total loss, as-rec'd basis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 31 | B | 46.9 | 21.8 | 5.20 | 0.56 | 2.66 | 3.92 | 0.29 | 0.68 | 0.10 | 0.28 | 18.5 |

X-ray analysis was made on samples of biotitic bentonite from localities 25 and 31. In both samples the dominant mineral is montmorillonite; very small quantities of illite and kaolinite are present. Among the nonclay minerals biotite is dominant; small quantities of quartz and possibly feldspar were recorded. The sample from locality 31 also contains some gypsum. Both samples are bentonite in the strict sense of the word.

*Marker beds.*—The large number of septarian-concretion zones and monotonous aspect of most Blue Hill strata make especially desirable the description of key beds that can be used as stratigraphic markers. Fortunately, concretions in all zones are not alike, and two bentonite seams can be traced for a considerable distance. Beds that serve as markers are described below in numbered order, upward from the base of the section (Pl. 1).

1. Clay-ironstone concretions. Lowest of usable marker beds in the Blue Hill Shale Member is a 1.4- to 1.9-foot zone of clay-ironstone concretions that lies 27 to 33 feet above the base of the member along the Saline River valley in northern Ellis County (Loc. 19, 23, and 25). The zone can be recognized by the conspicuous topographic bench that it upholds (Pl. 20A). *Inoceramus flaccidus,* a finely ribbed *Collignoniceras,* and a small gastropod are common fossils in the zone.

2. Septarian concretions. A few feet above the clay-ironstone concretions lies a 4.0- to 8.6-foot zone of small, oblate-spheroidal septarian concretions that weather dark yellowish orange to yellowish gray (5Y8/1). The zone lies about 38 feet above the base in sections along the Saline River valley in northern Ellis County (Loc. 19, 23, and 25). A large *Inoceramus* and a small finely ribbed ammonite, like those in the clay-ironstone-concretion zone, are characteristic fossils, together with minute gastropods and the small thick-shelled clam *Lucina*. Most of the concretions are less than 0.5 foot thick by 1.5 feet in diameter, but a few reach 3.5 feet in diameter. At locality 38, in eastern Osborne County, a single 0.15-foot layer of similar concretions lies 18.4 feet above the base of the Blue Hill Member. Proximity of both this layer and the calcareous concretion zone of Ellis County to the next higher marker bed, a biotitic bentonite layer, suggests that the Osborne County concretions represent marker bed 2 of Ellis County.

3. Bentonite. The third major marker bed in the Blue Hill Member lies 4.0 feet to 10.8 feet above the calcareous concretion zone and is a 0.1- to 0.15-foot medium-gray to light-olive-gray biotitic bentonite. This layer has been observed in Mitchell and Osborne Counties and northern Ellis County at localities 23, 25, 31, and 38. At locality 38 it rests 22.4 feet above the base of the Blue Hill and at locality 25 is 54.0 feet above the base. A conspicuous layer of nearly spherical, dark-yellowish-orange-weathering calcareous septarian concretions lies at or near the bentonite level along the Saline River valley in northern Ellis County. The concretion zone is the 47- to 50-foot zone reported by Rubey and Bass (1925, p. 35).

4. Concretions. The fourth useful marker zone has been identified in Osborne and Mitchell Counties (Loc. 31, 32, 38, and 45) and possibly in northern Ellis County (Loc. 18). Small oblate-spheroidal concretions of varied composition form a zone that ranges from 2.3 (Loc. 31) to 10.4 feet thick (Loc. 45, Pl. 20C) and lies 29.5 (Loc. 38) to 43.6 feet (Loc. 31) above the biotite-bearing bentonite seam. At locality 38, the zone lies 52 feet above the base of the member. Three kinds of concretions are included: (1) clay ironstone (Loc. 18 and 45), (2) calcareous septarian concretions (Loc. 45 and 38), and (3) moderately calcareous, ferruginous, sandy concretions (Loc. 31, 32, 38, and 45). Most of the concretions are not more than 0.3 foot thick and 2 feet in diameter. One layer at locality 18 is continuous throughout its exposure.

5. Septarian concretions. The fifth useful marker bed above the base of the Blue Hill Shale Member is a zone of calcareous septarian concretions that can be traced from locality 17 in southwestern Ellis

County to locality 44 in northeastern Jewell County, a distance of approximately 110 miles along the trend of outcrop. Chief characteristic of the unit is the extremely irregular shape of most of the concretions. Except at locality 17, the concretions have large wartlike or rounded ridgelike tuberosities that are especially prominent and serve to set this zone apart from others stratigraphically near it (Pl. 18A). The concretions are predominantly olive gray and weather yellowish gray or a very conspicuous dark yellowish orange. The zone ranges from 1.0 foot thick at locality 44 to 4.8 feet thick at localities 23 and 25 in northeastern Ellis County. The zone lies 55 feet above the base of the member, at locality 38 in eastern Osborne County, to 101.6 feet above the base, at locality 23 in northeastern Ellis County.

6. Bentonite. A very thin bentonite seam that can be traced from locality 44 in northeastern Jewell County to locality 38 in southeastern Osborne County lies 4.1 to 7.2 feet above the zone of warty concretions. The seam ranges in thickness from 0.02 to 0.04 foot, is light olive gray to yellowish gray, and weathers dark yellowish orange. A bentonite that is 0.01 foot thick and that lies at or near the base of the warty concretion zone (marker bed 5) at localities 23 and 28 in northeastern Ellis County may be equivalent. If so, the warty concretions in Jewell, Mitchell, and Osborne Counties are somewhat older than those in Ellis County (see Pl. 1).

7. Septarian concretions. In the upper 50 feet of the Blue Hill, seemingly only one lithologic zone can be recognized with ease over a broad area. A zone of very large oblate-spheroidal calcareous septarian concretions lies at or near the base of the silty and fine sandy upper part of the member in Finney, Ness, and Trego Counties, and southwestern Ellis County. The zone can be recognized by its proximity to the transitional beds, and by the large size and vivid dark-yellowish-orange weathering of the concretions that permits field recognition of the zone even from long distances. The largest concretions are at locality 2, Ness County, and are as much as 8 feet in diameter and 5 feet high. Thickness of the zone ranges from 3.5 feet at locality 6 in Finney County to 10.5 feet at locality 1 in northeastern Ness County. The vertical distance below the Fort Hays Limestone Member of the Niobrara Chalk ranges from 33.1 feet at locality 48 to 46.1 feet at locality 15. Near the base of the transition between the lower clayey shales and upper sandy beds of the Blue Hill Member in Hamilton County a zone of gigantic calcareous septarian concretions lies about 25 feet below base of the Niobrara (Pl. 17C). These concretions are oblate spheroids, weather grayish orange to dark yellowish orange, and are as much as 12 feet in diameter by 6 feet in thickness. Stratal continuity of this zone with that

just described from Finney, Ness, Trego, and Ellis Counties seems probable. A similar zone of giant concretions, lying in nearly the same stratigraphic position in Baca County, Colorado (McLaughlin, 1954, p. 121), is probably the same as that in Hamilton County. Dane and others (1937, p. 216) reported a zone of septarian concretions, individually as much as 10 feet in diameter, from near the top of the Blue Hill equivalent in Prowers and Bent Counties in easternmost Colorado. This zone averages 10 feet in thickness and terminates vertically at the transition between dark-gray clayey shale and gray sandy shale. At least a part of the zone is equivalent to that in Hamilton County.

From locality 13 in west-central Ellis County to locality 39 in north-central Osborne County a layer of septarian concretions lying approximately 40 feet below the Fort Hays Limestone is probably the northern equivalent of the widespread zone described above, but the conspicuous coloration is lacking. At most localities the layer is only one concretion in thickness, and the concretions are not so numerous as southwestward. The layer may be recognized by the larger average size of the concretions than those in adjacent zones, position with respect to the Fort Hays Limestone and base of the sandy upper part of the Blue Hill Shale Member, and the smoothly ellipsoidal or even cannonball-like appearance of the unbroken concretions.

*Thickness and distribution.*—There are few places in Kansas where the entire thickness of the Blue Hill Member is exposed and can be measured accurately. The minimum thickness is 72 feet at localities 20 and 22 in Hamilton County, and at locality 44 in Jewell County the thickness of the member is estimated to be 215 feet, of which 192 feet is exposed. Generally, the member thins gradually southwestward across Kansas.

According to Condra and Reed (1959, p. 17), the Blue Hill Shale Member in Nebraska is about 80 feet thick in the east, 100 feet in the southwest, and 400 to 500 feet thick in the northwest. Well records published as Reports of Investigations of the South Dakota Geological Survey are, for the most part, insufficiently detailed to permit widespread recognition of the Blue Hill in that state. In a few South Dakota sections the Carlile sequence includes, in upward order, chalky or calcareous shale, gray shale, and sandstone, which probably can be classed as Fairport, Blue Hill, and Codell equivalents, respectively. In these few sections the calcareous strata are only 10 to 20 feet thick. In other sections, however, calcareous strata lie between sandstone of the Codell above and noncalcareous shale below. Furthermore, the sub-Codell section contains prominent sandstone locally. In general, dark-gray clay and silty shale make up part of the section below the Codell in every South Dakota subsurface section, but relation of these shales to the Blue Hill is obscure. Despite the difficulties attending recognition of a Blue Hill equivalent in the South Dakota subsurface, gray noncalcareous concretionary shale lies between fine-grained sandstone above and calcareous strata below, as far north as southwestern Manitoba. Here the shale is the lower part of the Vermilion River Formation. This shale is homotaxial with the Blue Hill Member and is undoubtedly its lithogenetic equivalent.

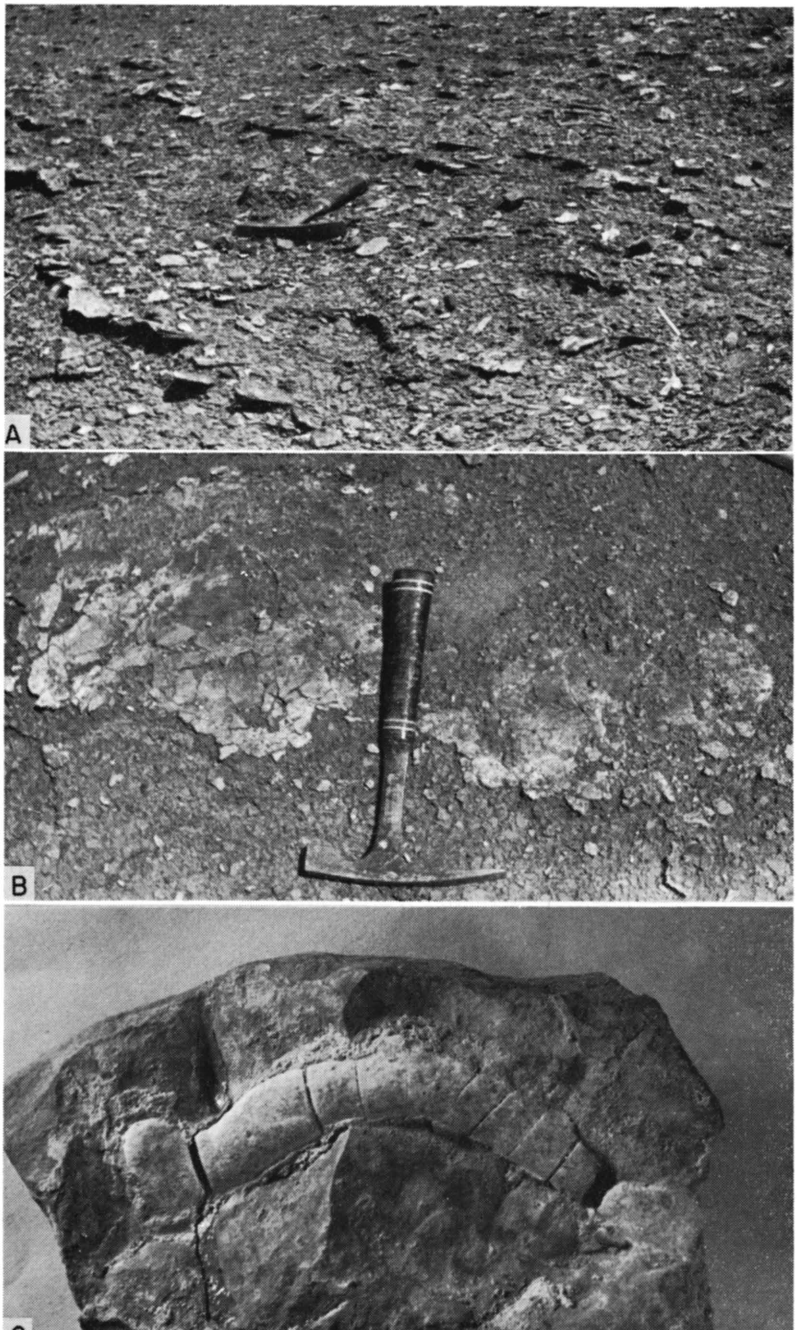
On the north flank of the Black Hills (Cobban, 1951, p. 2187) the Blue Hill equivalent consists of as much as 140 feet of dark-gray shale, including two bentonite layers near the base of the shale, and clay-ironstone and calcareous septarian concretions in the upper part. The shale is bounded below by 13 feet of gray shale with calcareous partings and above by sandstone of the Turner Sandy Member of the Carlile. Southwestward, these lithologic units pass laterally into the Colorado Shale of the Powder River Basin (Haun, 1958). Farther northwest, in central Montana, the Blue Hill Member is probably represented by two lithologic units within the Colorado Shale, (1) a lower dark-bluish-gray fissile shale, and (2) an upper dark-gray shale containing clay-ironstone and some calcareous concretions (Cobban, 1951, p. 2190). Concretion-bearing shale lies in a similar stratigraphic position in the Sweetgrass Arch of north-central Montana, but the shale can be compared with the Blue Hill Member better by its fossils than by specific lithologic characters.

In southeastern Wyoming, divisions of the Carlile are not generally recognized, but septarian-concretion-bearing gray shale continuous with the Blue Hill is known as far west as Carbon County (Cobban and Reeside, 1952a, p. 1942), where it intertongues with sandstone of the Frontier Formation. Essentially the same relations at the south end of the Powder River Basin of Wyoming are shown graphically by Haun (1958).

According to Merriam (1957a), the Blue Hill Shale Member can be traced throughout the western Kansas subsurface, but the concretion zones are not recognizable. Westward through northeastern Colorado, the divisions of the Carlile are lost, and in the Golden Quadrangle, Colorado (Van Horn, 1957), the Carlile equivalent consists wholly of siltstone and sandstone. Farther south, however, along the north side of Arkansas River in southeastern Colorado, the Blue Hill equivalent has been described by Dane and others (1937, p. 215). No complete section was measured by them, but at one locality, 56 feet of the member was exposed. South of Arkansas River, more than half of the 85 feet of Carlile in Baca County (McLaughlin, 1954, p. 121) is lithologically and stratigraphically equivalent to the Blue Hill Shale Member. Mann (1958, p. 158) reported 93 feet of dark to black, platy, clayey shale between the Fairport and Codell Members in Fremont County, Colorado, but he made no mention of concretions or lack of them. In the Model Anticline of Las Animas County, Colorado, Bass and others (1947) reported 70 to 100 feet of dark-gray fissile shale, the upper half of which contains septarian concretions, between limy and chalky shale below (Fairport) and sandstone (Codell) above.

In northeastern New Mexico, dark-gray concretionary shale forms the middle part of the Carlile in Colfax County (Griggs, 1948, p. 29) and makes up most of the Carlile in San Miguel County (Griggs and Hendrickson, 1951, p. 31). Westward from the longitude of Las Vegas, New Mexico, the Carlile contains the Juana Lopez Sandstone, which Cobban and Reeside (1952) correlated with the Codell. The section beneath the Juana Lopez and above the Greenhorn is nearly all black, fissile, sandy shale that generally contains calcareous concretions in the upper half (Rankin, 1944). At least the upper half of this shale is laterally continuous with the Blue Hill Member, but the lower part probably grades eastward into the Fairport. In the San Juan Basin of northwestern New Mexico, the Blue Hill Member is represented by dark-gray, fissile, sandy and concretionary shale within the Mancos Shale.

*Fossils and correlation.*—At most exposures, the Blue Hill Member is poorly fossiliferous, but at a few places in Ellis, Osborne, Mitchell, and Smith Counties, fossils are not only abundant but also exceptionally well preserved. The best fossils come from part of the section adjacent to the marker zone of warty concretions, described above. Well-known localities are those here numbered 18, 31, 45, 49, and 50. Other good fossil-collecting areas include localities 9, 19, 23, 25 (Pl. 21A, B), 32, 38, 40, and 48. At some localities, such as 31, 32, and 38, the best-preserved fossils are in small septarian concretions (Pl. 19A); at locality 45, most of the fossils are in ferruginous claystone concretions (Pl. 21C); at locality 18, some fossils are enclosed in nodules of pyrite; elsewhere most of the fossils are enclosed in the shale. Most are preserved as original material, are nearly white, and have a dull luster, but iridescence of the nacreous layers is common in many ammonites and pelecypods. In such fossils purple, green, red, and gold colors predominate and some specimens are truly objects of great beauty. Locally, as at localities 19 and 23, specimens of *Inoceramus flaccidus* are replaced by gypsum. At locality 44 and elsewhere in Jewell County, fragments of *I. cuvieri* have been replaced by barite. Internal molds of *I. flaccidus, Scaphites,* and *Collignoniceras* are com-


A
B
C

mon where fossils have lain exposed to weathering, because the shell matter is fragile and flakes off readily.

Chief among the Blue Hill fossils are mollusks, especially pelecypods and ammonites. The following list includes the macrofossils collected during the present investigation. The most abundant and characteristic fossils are preceded by an asterisk. Guide fossils are preceded by a dagger. Rare forms are followed by an asterisk. The ranges are plotted in Table 2 and the more common forms are illustrated in Plates 22 through 25.

*Fossils observed in the Blue Hill Member*

Mollusca
- Pelecypoda
  - **Inoceramus flaccidus* White
  - *Inoceramus latus* Sowerby
  - *Inoceramus cuvieri* Sowerby
  - †*Lucina juvenis* Stanton
  - *Ostrea congesta* Conrad
  - *Yoldia subelliptica* Stanton
  - *Yoldia* n. sp.
- Gastropoda
  - †*Bellifusus willistoni* (Logan)
  - Gastropods, gen. et sp. indet.
  - *Gyrodes* sp.
  - *Oligoptycha* n. sp.*
  - *Tessarolax* n. sp.
- Cephalopoda
  - †*Binneyites aplatus* (Morrow)*
  - †**Collignoniceras hyatti* (Stanton)
  - *Collignoniceras (Selwynoceras)?* sp.*
  - *Proplacenticeras pseudoplacenta* (Hyatt)
  - †**Scaphites carlilensis* Morrow

Arthropoda
- Crustacea
  - *Linuparus canadensis* (Whiteeaves)*
  - *Raninella?* sp.*

Vertebrata
- Chondrichthyes
  - *Isurus appendiculata* (Agassiz)
  - *Ptychodus whipplei* Marcou*
  - *Scapanorhynchus raphiodon* (Agassiz)
  - *Scapanorhynchus* sp. cf. *S. raphiodon* (Agassiz)
  - *Squalicorax falcatus* (Agassiz)
- Osteichthyes
  - Teleost bones, teeth, scales
- Incertae sedis
  - Coprolites

The ammonite *Collignoniceras hyatti* has been suggested by Cobban and Reeside (1952, p. 1018) as a zonal index for strata here referred to the Blue Hill Member. They stated, "This zone is widely distributed in the Great Plains and in eastern Utah." To Western Interior strata containing *C. hyatti,* Reeside (1957) assigned a late middle Turonian age. The species is known generally throughout the area where the Carlile is recognized as a formal subdivision of the Upper Cretaceous sequence. Westward, the zone can be traced into the Mancos Shale of eastern Utah. In Wyoming and northern Utah, *C. hyatti* is distributed widely in the Frontier Formation (Cobban and Reeside, 1952a). Northwest of the Black Hills, *C. hyatti* has been collected from

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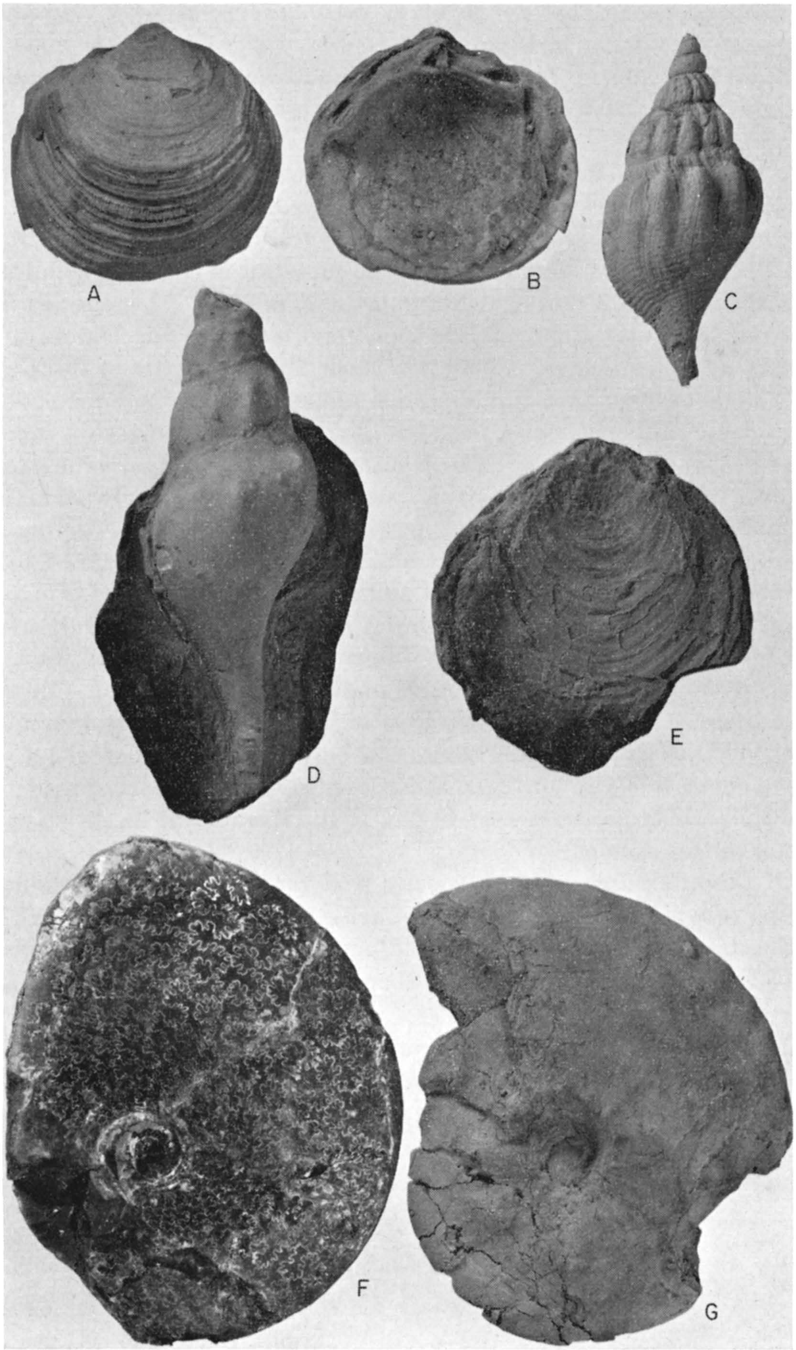
PLATE 21.—Blue Hill fossils. **A**, Fragments of *Inoceramus cuvieri* in lower part of Blue Hill, sec. 29, T. 11 S., R. 16 W., Ellis County (Loc. 25). **B**, Close view of large *I. cuvieri* showing typical preservation, same locality. **C**, Clay-ironstone concretion that contains cylindrical phosphatic structure of probable organic origin, X1, middle part of Blue Hill, sec. 27, T. 5 S., R. 13 W., Smith County (Loc. 45).

the Colorado Shale on the Sweetgrass Arch of northwestern Montana (Cobban, 1951, p. 2191). In Canada, *C. hyatti* is known as far north as northwestern Alberta, where it has been collected from the Kaskapau Formation (McLearn, 1937, p. 115). Moreman (1942, p. 213) reported this species from the Arcadia Park Formation of the Eagle Ford Group of Texas. Several authors have reported its occurrence in the Mancos Shale of New Mexico. In Kansas, a specimen of *C. hyatti* was collected from the basal 3.5 feet of the Blue Hill Member at locality 20, and at locality 9 a specimen was found in the basal 10 feet of the member. Juvenile specimens of *Collignoniceras,* probably *C. hyatti,* have been observed in the lower 25 to 30 feet of the member at localities 9, 17, 19, 25, and 38. At locality 40, poorly preserved specimens probably referable to this species were collected from shale less than 20 feet below the top of the member. The species ranges seemingly throughout the Blue Hill Member but is most abundant and best preserved in beds adjacent to the warty concretion marker zone at localities in northern Ellis County, southwestern Mitchell County, Osborne County, and southeastern Smith County.

Most abundant of all Blue Hill species in my collections is *Scaphites carlilensis,* which was thought by Cobban and Reeside (1952) to be restricted to the zone of *Collignoniceras hyatti.* The type specimen is from the Blue Hill Member in southeastern Mitchell County (Loc. 50). This species has a much smaller reported geographic distribution than *C. hyatti,* and according to Cobban (1951a, p. 21), is known outside of Kansas only from the north flank of the Black Hills, on the Cat Creek Anticline of central Montana, and on the Sweetgrass Arch of north-central Montana. *Scaphites morrowi* (= *S. pygmaeus*), described originally from the same locality as *S. carlilensis,* differs from the latter mostly in size. I have compared the types of these species and have examined, from the same stratigraphic horizon, specimens ranging in size from less than half the length of *S. morrowi* to considerably larger than the holotype of *S. carlilensis.* The two are undoubtedly conspecific. On this basis, recognition of *S. pygmaeus* in the Arcadia Park Formation of the Texas Eagle Ford Group by Moreman (1942, p. 216)

PLATE 22.—Blue Hill fossils. **A, B,** *Lucina juvenis* Stanton, both X2. **A,** Exterior, left valve; **B,** Interior, same valve, middle part of Blue Hill (Loc. 45), hypotype, KU10542P1. **C, D,** *Bellifusus willistoni* (Logan). **C,** Well-preserved conch of young individual, middle part of Blue Hill (Loc. 45), X2, hypotype, KU10542G1. **D,** Somewhat weathered conch of mature individual, partly embedded in concretion, middle part of Blue Hill (Loc. 45), X1, hypotype, KU10542G2. **E,** *Inoceramus latus* Sowerby, interior view (Loc. 52), X1, hypotype, KU10544P1. **F, G,** *Proplacenticeras pseudoplacenta* (Hyatt). **F,** Internal mold, middle part of Blue Hill (Loc. 49), X1, hypotype, KU10538A1; **G,** Exterior view of specimen from middle part of Blue Hill (Loc. 18), X½, hypotype, KU10533A1.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extends the geographic range of *S. carlilensis* considerably. Kansas specimens are from beds adjacent to the warty concretion zone in northern Ellis County, Osborne County, southwestern Mitchell County, and southeastern Smith County. Poorly preserved scraps of *Scaphites* from sandstone 10 feet below the top of the member at locality 22 and from the basal 10 feet of the member at locality 9 may belong to this species.

Only one other species, *Inoceramus flaccidus,* is truly abundant in the Blue Hill Shale Member. The type material is from the Niobrara beds near Pueblo, Colorado (Stanton, 1899, p. 634). This species has received little attention but has been reported from the Niobrara of Kansas by Logan (1898, p. 485) and from the upper part of the Colorado Shale of Wyoming and Montana. Matsumoto has examined many of the Blue Hill specimens and identified several as *I. flaccidus* and a few as *I.* sp. cf. *I. flaccidus.* The Kansas species exhibits a wide range of form, showing gradation from coarsely and irregularly wrinkled specimens with a well-defined posterolaterally directed furrow to others with quite smooth shells in which the furrow is only faintly depressed. The latter form is very similar in appearance to *I. howelli. I. flaccidus* is abundant adjacent to the warty concretion zone (marker bed 5) at most exposures in northern Ellis County, southwestern Mitchell County, Osborne County, and southeastern Smith County. In addition, it is common in the zone of ferruginous claystone concretions that lies 27 to 33 feet above the base of the member along the Saline River valley in northern Ellis County. A single poorly-preserved internal mold from the lowest 10 feet of the member at locality 9 may belong to this species.

Of the other invertebrate species that range beyond Kansas, only *Lucina juvenis* is restricted to the Carlile. It was described originally by Stanton (1893, p. 98) from the "Pugnellus sandstone" in the upper part of the Colorado Carlile and seemingly has a narrow geographic distribution.

Widespread, long-ranging invertebrate species in the Blue Hill Shale Member include *Ostrea congesta, Inoceramus cuvieri, Proplacenticeras pseudoplacenta, Yoldia subelliptica,* and *Linuparus canadensis.* The first two of these have been discussed with the Fairport fauna. *P. pseudoplacenta* ranges geographically from Kansas to Utah

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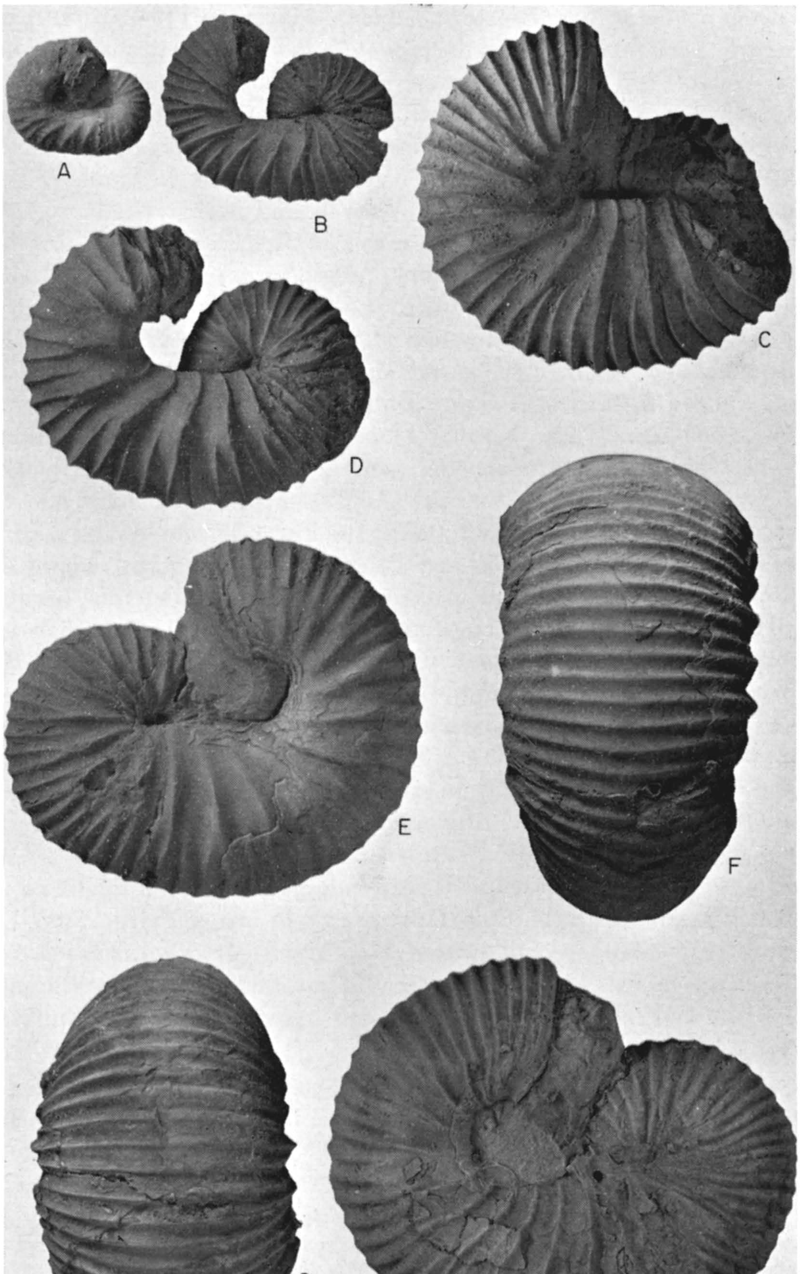
PLATE 23.—Fossils from middle part of Blue Hill. **A-H**, *Scaphites carlilensis* Morrow, all X1. **A**, Internal mold (Loc. 48), hypotype, KU10537A1. **B**, Locality 18, hypotype, KU10533A2. **C**, Locality 18, hypotype, KU10533A3. **D**, Locality 18, hypotype, KU10533A4. **E**, Locality 50, holotype, KU7802-3. **F-H**, Ventral, end, and side views of specimen (Loc. 31), hypotype, KU10540A1.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and from Texas to northwestern Alberta. Moreman (1942, p. 219) described *P. pseudoplacenta* var. *occidentale* from the Britton Formation of the Eagle Ford Group of Texas. These beds are of Greenhorn age. The species ranges upward to beds of Niobrara age in the Cody Shale (Reeside, 1927, p. 2). *Y. subelliptica* ranges geographically from New Mexico to Alberta and has been reported from beds as old as Cenomanian in the latter area by Warren and Stelck (1940, p. 145). *L. canadensis* is known from Tennessee to British Columbia and has been collected from several horizons, ranging from as low as the Eagle Ford of Louisiana and the Carlile of the Black Hills area to as high as the Ripley Formation of Tennessee (Rathbun, 1935, p. 36).

Species not reported from outside of Kansas include *Binneyites aplatus* and *Bellifusus willistoni.* Blue Hill invertebrates that cannot be identified specifically, because of poor or incomplete preservation, include *Gyrodes* sp., gastropods, gen. et sp. indet., *Collignoniceras (Selwynoceras)?* sp., and *Raninella?* sp. Specimens of *Selwynoceras* have hitherto been reported only from the lower Turonian, and accordingly the discovery of a specimen in the zone of *C. hyatti* would extend considerably the known geologic range of the subgenus, because the Blue Hill Member has been assigned a late middle Turonian age by Reeside (1957). Previously undescribed species of the Blue Hill fauna assignable to the genera *Tessarolax, Oligoptycha,* and *Yoldia* will be treated fully in a separate paper.

Apparently only one Blue Hill invertebrate species is both short ranged and intercontinental in geographic distribution. This form, *Inoceramus latus,* has been discussed in connection with the Fairport fauna, of which it is more typical. The abundance of *I. latus* in the lowermost 10 feet of the Blue Hill Member at locality 9 might be interpreted as an indication that the strata there are of Fairport age but of Blue Hill lithology, but presence of imperfect specimens of *Collignoniceras hyatti, I. flaccidus,* and unidentified gastropods (molds), as well as lack of reaction by the shale to acid, show that the beds are correctly classed as Blue Hill.

To the above list of macrofossils may be added *Ostrea lugubris.* A single specimen of this species from Mitchell County, Kansas, was collected and identified by J. B. Reeside, Jr.

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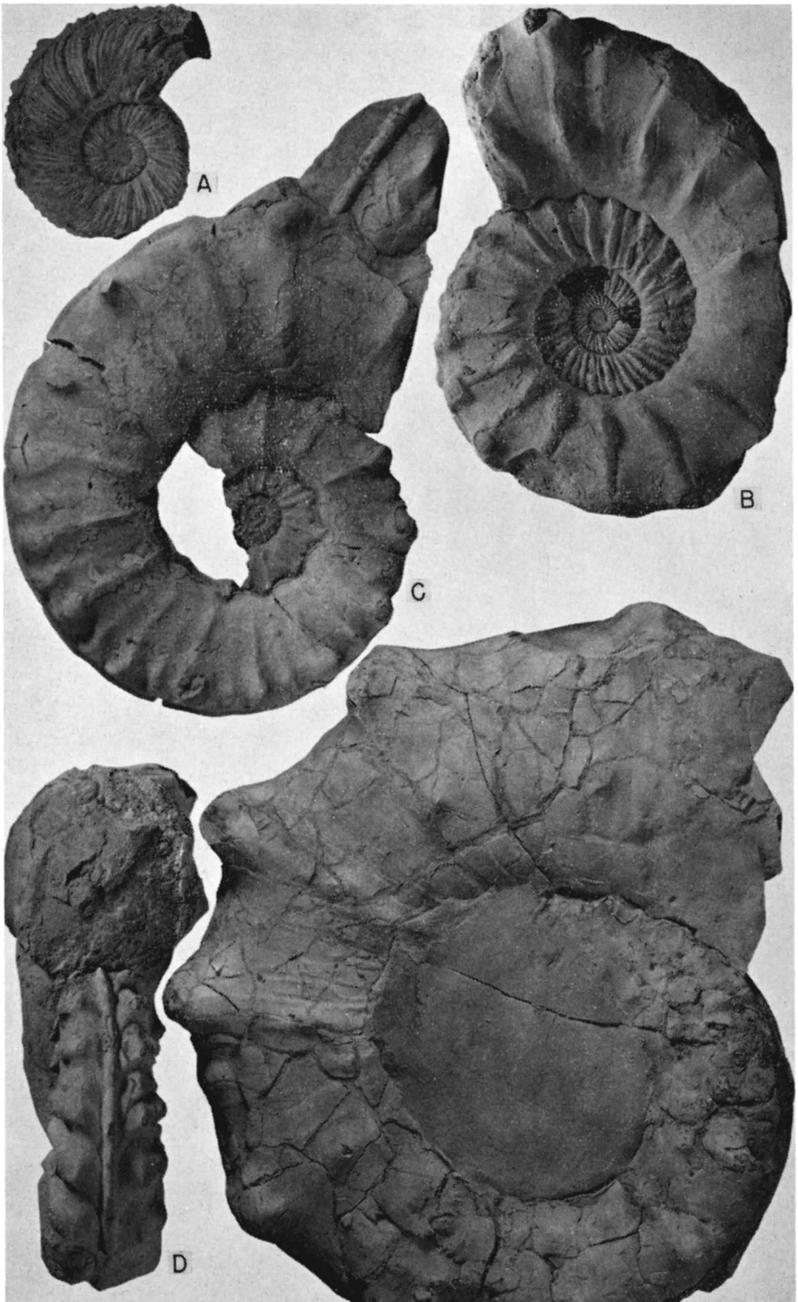
PLATE 24.—Fossils from middle part of Blue Hill. **A-E**, *Collignoniceras hyatti* (Stanton). **A**, Internal mold (small amount of shell material adhering) of juvenile specimen (Loc. 31), X1, hypotype, KU10540A2. **B**, **D**, Well-preserved immature specimen (Loc. 18), X1, hypotype, KU10533A5. **C**, Internal mold (some shell material adhering) of nearly mature individual (Loc. 49), X½, hypotype, KU-10538A2. **E**, Mature individual (Loc. 45), X⅜, hypotype, KU10542A1.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Among shark teeth found in the Blue Hill Member, all but *Ptychodus whipplei* have intercontinental geographic distribution and great geologic range. *P. whipplei* has been reported only from South Dakota, Wyoming, Colorado, Kansas, New Mexico, and Mexico and is seemingly restricted to beds of Carlile and Niobrara age.

Morrow (1934) discovered no Foraminifera in the strata here referred to the Blue Hill Member. Griffith (1947, p. 20), in an unpublished master's thesis, listed 36 species (eight undescribed previously) from the Blue Hill strata of the Republican River valley of Kansas and Nebraska. Five of the species are known also from the Fairport, and four of the five are known in the Niobrara. A total of eight Blue Hill species range into the Niobrara. Griffith (1947) noted that 23 Blue Hill species are known from the Texas Upper Cretaceous, but most of these come from formations younger than Eagle Ford, the upper part of which is correlative with the Blue Hill Member of Kansas. Of stratigraphic and paleoecological significance is the fact that the Blue Hill Member is marked by the presence of arenaceous Foraminifera, whereas the Fairport is known only to contain calcareous species (Griffith, 1947, p. 22). The part of the unnamed member of the Carlile Shale near Belle Fourche, South Dakota, that contains the *C. hyatti* fauna contains eight species of Foraminifera, according to Fox (1954, p. 101). Although several forms have been reported by Griffith and Fox, none of the published species is restricted to strata equivalent to the Blue Hill. Other papers in which Carlile species are listed are insufficiently detailed stratigraphically to warrant discussion here. Knowledge of Upper Cretaceous Foraminifera from the Western Interior region is not yet extensive enough to permit correlation of the Blue Hill Shale Member by its microfauna.

### Codell Sandstone Member

*Name and definition.*—Bass (1926, p. 28) gave the name "Codell sandstone bed" to sandstone lying at the top of the Blue Hill Shale "in the bluffs along the Saline Valley in Ellis County, 5 miles south and a little west of Codell" (Pl. 16C). The original description characterizes the Codell as consisting of two very thick beds of sandstone separated

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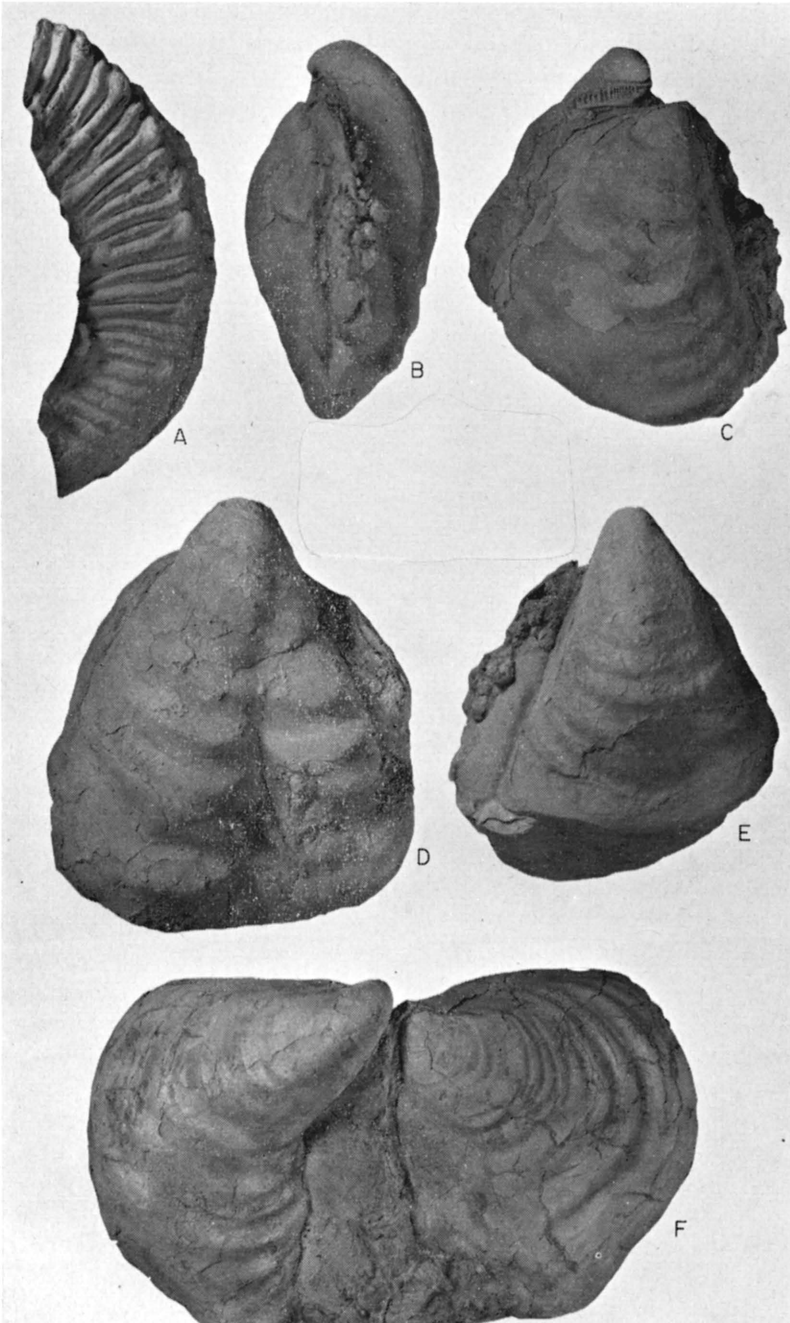
PLATE 25.—Blue Hill and Codell fossils. **A**, *Prionocyclus wyomingensis* Meek, rubber cast of external mold, topmost Codell (Loc. 22), X½, KU12058. **B-F**, *Inoceramus flaccidus* White. **B**, **C**, **E**, Views of anterior, right valve, and left valve, respectively, of specimen that has only faint concentric folds, middle part of Blue Hill (Loc. 18), X½, hypotype, KU10533P1. **D**, Left valve of specimen that has pronounced concentric folds, middle part of Blue Hill (Loc. 48), X½, hypotype, KU10537P1. **F**, Paired valves of specimen that has moderately developed concentric folds, middle part of Blue Hill (Loc. 18), X½, hypotype, KU10533P2.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by a foot of shaly sandstone and including at the top a few inches of clayey rock that weathers to produce a notch below the Fort Hays Member. The lower sandstone bed grades downward into the shale below. A thickness of sandstone that ranges from 3.5 to 22 feet was recorded in Ellis County by Bass (1926, p. 28), and he included in the Codell a few feet of sandy shale that lies below the sandstone at Yocemento (locality 13 of this report) and in southwestern Ellis County (vicinity of locality 17 of this report). In Hamilton County, likewise, about 23 feet of gritty shale beneath 2 feet of sandstone was included in the Codell by Bass (1926, p. 63).

In 1933, Dane and Pierce elevated the Codell to member status, but this change in rank did not appear in publications of the Kansas Geological Survey until 1943 (McLaughlin, 1943, p. 133). This use was continued until 1951 when Moore and others (p. 24) relegated the Codell to the informal rank of zone within the Blue Hill Shale Member of the Carlile. This usage prevailed until recently, when Merriam (1957a, p. 8) and Jewett (1959) re-elevated the Codell to member status. As presently conceived, the Codell consists of sandstone, silty sandstone, or sandy siltstone lying above the Blue Hill Member. A boundary between the Blue Hill and Codell is difficult to select because of the completely gradational nature of the contact at many localities. Criteria for recognition of this contact have been described above under the heading "Blue Hill Shale Member".

*Contacts.*—The contact of the Codell and Blue Hill Members is generally abrupt in Smith and Jewell Counties, where the Codell is less than 1 foot thick, and is fairly sharp at localities 25 and 28 (Pl. 16C), where the Codell is well developed. In most other areas, however, the contact is gradational, and the boundary between chiefly shaly strata of the Blue Hill and chiefly sandy strata of the Codell is best marked by a change in slope color, as described above.

The contact between the Codell Member and overlying Fort Hays Member of the Niobrara Chalk is generally very even and knife-edge in sharpness; chalky limestone of the Fort Hays rests on noncalcareous sandstone (Pl. 26A) or argillaceous shaly sandstone of the Codell (Pl. 26B). At locality 25, the contact, though abrupt, is distinctly and irregularly undulatory. Locally, the topmost part of the Codell is calcareous, as at locality 24, probably because of local downward perco-

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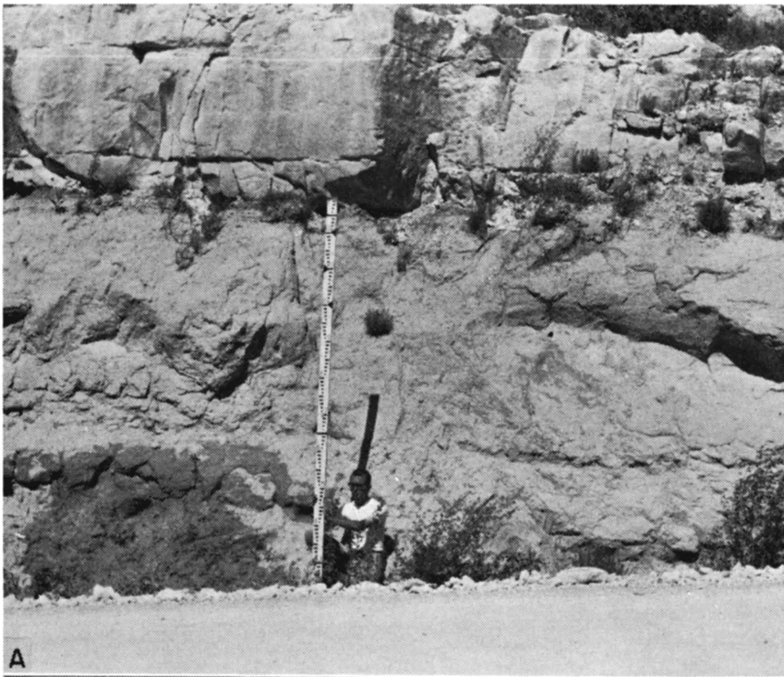
PLATE 26.—Exposures of Codell Member. **A,** Upper part of Codell at type locality, sec. 3, T. 11 S., R. 17 W., Ellis County (Loc. 28). Note sharp contact (top of rod) with Niobrara Chalk. **B,** Codell Member on W line sec. 21, T. 15 S., R. 20 W., Ellis County. Lower part of Codell (hammer) very sandy; upper part very argillaceous, shaly, and in sharp contact with Niobrara Chalk (top of photo).



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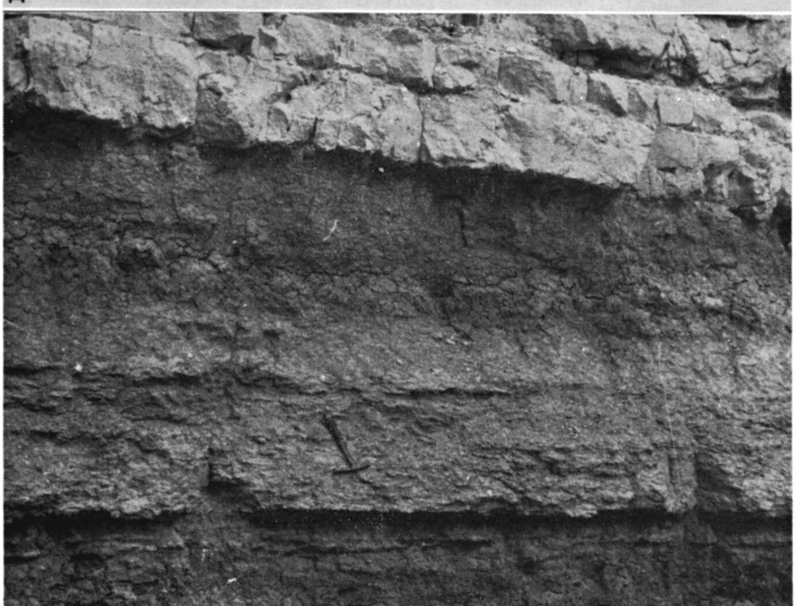

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lation of lime-rich water from the Fort Hays. At some localities, the bottommost inch or two of the Fort Hays is sandy, undoubtedly consisting in part of reworked Codell, but the sandiness diminishes upward abruptly. At locality 40, the base of the Fort Hays is so sandy that the contact between Carlile and Niobrara seems to be transitional. Locality 22, in Hamilton County, displays the most puzzling conditions. Here, typical sandstone of the Codell is overlain by 0.1 foot of silty and sandy chalk that resembles Fort Hays in lithology. The sandy chalk, in turn, is overlain by a discontinuous bed of hard, *Inoceramus*-prism-limestone lenses that contain molds of *Prionocyclus wyomingensis,* a typical Carlile species. Above the hard limestone is sandy and chalky limestone that contains polished, black phosphate pebbles 0.2 foot above the base. The lenses of hard limestone seemingly lie within the Niobrara, but the ammonite *P. wyomingensis,* which is typical of the Codell in eastern Colorado, bespeaks a Carlile age for them. The sand in the limestone above the lenses is undoubtedly reworked Codell.

If the hard limestone lenses containing *Prionocyclus wyomingensis* are a part of the Codell Sandstone Member or have been derived from the Codell, then at least the upper part of the Codell Member in Kansas is obviously equivalent to part of the zone of *P. wyomingensis,* a zone that is widespread in the Great Plains. In the Black Hills, the *P. wyomingensis* zone is separated from the zone of *Collignoniceras hyatti* by the zone of *Scaphites warreni,* which occurs in the Codell Member at Colorado City, Colorado, in association with *P. wyomingensis* (Dane and others, 1937, p. 218); the zone of *S. warreni* is not altogether lacking in the southern Great Plains region. *S. warreni* has not been identified in Kansas, perhaps owing to poor preservation; a scrap of *Scaphites* from the hard brownish-gray limestone at locality 22 is unidentifiable specifically. Despite the lack of evidence of the *S. warreni* zone in Kansas, the stratigraphic sequence from the Blue Hill Member through the Codell Sandstone Member is unquestionably conformable.

Much more significant is the total absence in the southern Great Plains region of the zones of *Scaphites nigricollensis* and *S. corvensis,* which lie, respectively, in the upper part of the Turner Member and in the Sage Breaks Member of the Carlile in the Black Hills area. Absence of these zones in the southern Great Plains was interpreted as evidence of a widespread disconformity in the region by Cobban and Reeside (1952, p. 1029). Johnson (1930) cited textural, lithologic, stratigraphic, ecologic, and paleontologic evidence for a disconformity between the Carlile and Niobrara in parts of eastern Colorado that border the Rocky Mountains. Chief among these are (1) conglomerate at the base of the Niobrara, (2) sharp change in lithology across the contact between the two formations, (3) considerable variation in thickness and character of the topmost beds of the Carlile, and (4) faunal differences above and below the contact that are too markedly different to be caused solely by change in environment of deposition. Dane and others (1937, p. 219) did not observe a conglomerate in lower beds of the Niobrara between La Junta, Colorado, and the Kansas state line. Indeed, these authors stated (1937, p. 219), "The hard brown limestone assigned to the Codell by the writers appears to grade upward into the overlying gray or white limestone, and locally lenses of hard brown limestone like the underlying rock also appear in the basal Niobrara." Variation in thickness of strata of Benton age in the La Junta area is greater than the maximum thickness of the Codell and was explained by Dane and others (1937, p. 220) as the result of differential sedimentation, rather than erosion of the uppermost Carlile strata. The improbability of significant erosion is demonstrated by the fact that the septarian concretion zone in the Blue Hill Shale Member of eastern Colorado persistently occurs at approximately the same distance below the Niobrara, even where there is no Codell sand. Dane and others (1937, p. 220) stated that the most convincing evidence of an unconformity between the Codell and Niobrara is faunal discontinuity, which they believed to be the result of nonaccumulation of sediments, rather than subaerial erosion of the upper part of the Carlile.

In Kansas, the evidence for a hiatus between the Codell and Niobrara comprises (1) a sharp lithologic break at most localities, (2) hard, brownish-gray limestone nodules of reworked Carlile in the basal Niobrara at locality 22, (3) variation in thickness between the highest Blue Hill marker bed (Pl. 1) and the base of the Niobrara, (4) irregularity of the Codell-Niobrara contact locally, (5) presence of phosphatic pebbles nearly at the base of the Niobrara at locality 22, and (6) faunal discontinuity at the contact between the Codell and Niobrara. At a few Kansas localities, as noted above, the contact between the Codell and Fort Hays is transitional through a small thickness of strata, but this has explanation in reworking of the topmost Codell during inception of Niobrara sedimentation. Hard, brownish-gray lenses of reworked Codell limestone in the basal Niobrara at locality 22 may be remnants of a once much more extensive bed, eroded fragments of which lay on the sea floor during a long interval of sedimentary stillstand or period of slight sublevation. Thus, the nodules could have been incorporated into the Fort Hays during early Niobrara sedimentation. Thickness differences of Carlile strata between the highest concretion marker zone and the base of the Niobrara may have been produced by erosion, but thickness differences occur also between marker beds throughout the Blue Hill Member. Such variations as the latter were produced by differential sedimentation on an unevenly subsiding sea floor. Thus, all factors considered, thickness variations in the uppermost Carlile may be explained by (a) subaerial erosion, (b) sublevation, or (c) differential sedimentation. Positive evidence for (a) is wholly lacking; evidence for (b) is good at locality 22, provided that the supposition regarding origin of the hard limestone lenses is correct. In my opinion, explanation (c) is most logical for the west-central Kansas area, where evidence for (b) is negative, because differential sedimentation can be demonstrated elsewhere in the Carlile Shale. Differences in stratal thickness between pairs of marker beds in some places is greater than the variation in thickness of the Carlile beds above the highest marker bed. Local, small-scale irregularities at the Codell-Fort Hays contact may be evidence of erosion, but are also explainable as load phenomena in unconsolidated sediments and thus not proof of a hiatus. Phosphatic pebbles that lie a few inches above the base of the Fort Hays Member at locality 22 may indicate intermittent sedimentation during an early stage of Niobrara sedimentation, but do not constitute concrete evidence of a prolonged pre-Fort Hays break in sedimentation. I agree with Dane, Pierce, and Reeside (1937, p. 220) that faunal discontinuity is the strongest evidence of a stratigraphic hiatus between the Codell and Fort Hays. The best supporting evidence is sharpness of the lithologic break at most localities and inclusion in the basal Niobrara, at locality 22, of eroded remnants of limestone from the Codell Member.

*Lithology.*—Considerable range in lithology is characteristic of the Codell in Kansas. Essentially, the member consists of fine to very fine grained silty sandstone or sandy, commonly argillaceous, siltstone. Of several samples disaggregated in the laboratory, more than half consist chiefly of silt- and clay-size particles. At locality 22, a layer of calcarenite nodules that contain typical Carlile fossils and a few phosphate pebbles forms the top of the Codell Member.

Predominant color of the fresh rock is light olive gray (5Y6/1), and weathering produces colors ranging from dark yellowish orange, dusky yellow, and yellowish gray (5Y8/1, 5Y7/2) to light gray. Specks of disseminated limonite cause the dark-yellowish-orange coloration that is common at many exposures.

Bedding thickness in the Codell ranges from very thin (Pl. 26B) to very thick (Pl. 26A), the latter condition prevailing in the upper part of the section, especially along the Saline River valley in northern Ellis County, where the member reaches maximum thickness. In places, as at locality 25, the basal siltstone of the Codell is in part thinly interlaminated with gray silty clay shale. Codell bedding is everywhere even and seemingly lacks such structures as ripple marks and cross-bedding, but the rock contains angular clay pellets in the top 0.4 foot at locality 47, Trego County, and numerous burrows, probably of worms, at localities 25 and 28, Ellis County. Much of the Codell is poorly cemented and very friable. At a few localities, including 15 and 17, the Codell is well cemented by calcite. Hardness of the rock is, of course, dependent upon the degree of cementation and the composition of the cement. Most of the Codell, though coherent, is soft and breaks readily under the hammer into blocky fragments.

The Codell is usually well exposed at the base of cliffs capped by the Fort Hays Member of the Niobrara (Pl. 3C). Where softest, the Codell is a slope former, and such slopes are sparsely vegetated; where the rock is coherent, it is exposed in vertical faces. The latter condition is especially well displayed along the Saline River valley in northern Ellis County, where the member is exposed prominently in the lower part of a cliff capped by the Fort Hays. In this area, individual beds of the Codell become rounded by weathering, and a conspicuous notch in the uppermost 0.5 foot of the sandstone commonly marks the contact between the Fort Hays and Codell.

Several Codell samples were disaggregated and passed through a sieve series. Coarse-sand fractions make up only 0.05 to 0.55 percent of the samples and part of this amount is aggregates of finer grains. The coarse grains are mostly quartz and are generally subrounded and frosted, but a few are subhedral. A single quartz grain of granule size was observed in a sample from the type Codell. Fossils in coarse fractions include fragments of *Inoceramus,* shark teeth and dermal denticles, fecal pellets, and vertebrae. The vertebrate remains show effects of considerable transport and are polished, possibly by solutional effects of ground water. Fossils make up 30 percent of the coarse-sand fraction in a sample from Hamilton County (Loc. 22) but are virtually lacking in two samples. Medium-sand fractions make up 0.075 to 1.85 percent of the samples and consist of subangular to subrounded grains and in one sample, some subhedral grains. Fossils of medium-sand size include agglutinated and calcareous foraminifers, fragments of *Inoceramus,* bone fragments and vertebrae, teeth, and fecal pellets. Most samples contain only 1 percent or less fossils of medium-sand size, but the sample from locality 22 is 5 percent fossil matter. Fine-sand fractions make up 0.1 to 30 percent of the samples and consist chiefly of subangular grains, but angular grains occur in some samples, and subrounded grains are common in one sample. Fossils make up 2 percent or less of the fine-sand fraction and include calcareous and agglutinated Foraminifera, fecal pellets, spores, and fragments of teeth and bones. Very fine sand fractions make up 6.75 to 50.7 percent of the samples and consist chiefly of angular to subangular grains. In one sample some grains are subhedral, and in another sample some grains are shardlike. Fossils are very sparse or lacking in the very fine sand fraction but include calcareous and agglutinated foraminifers and fragments of bones and teeth.

Several thin sections were cut from representative samples of the Codell Member and one of these is illustrated (Pl. 9D). Strongly dominant among minerals in these sections is quartz, some grains of which show wavy extinction. Second in importance is feldspar; orthoclase, microcline, and plagioclase were identified in one or another of the thin sections. Chert grains are common in all thin sections. Biotite is seemingly the only other ubiquitous mineral but is present in quantities less than 5 percent. Less common minerals include pyrite, tourmaline, zircon, limonite, and glauconite. Some specimens have a cryptograined matrix, probably consisting of very fine silt and clay, which is dominant in one sample from the lower part of the member at the type locality. X-ray analysis of one sample showed a very high quartz peak, a moderate plagioclase peak, which may mask an orthoclase peak, and a series of low peaks that represent iron-bearing minerals. Quartz makes up 60 to 80 percent of the Codell sandstone and siltstone, and various feldspars constitute another 15 to 25 percent. About 5 to 10 percent of the samples is chert grains. Quantities of biotite, pyrite, and limonite are smaller than 5 percent. Tourmaline, zircon, and glauconite probably each make up less than 1 percent of a given sample.

A thin section of the calcarenite from the top of the Codell at locality 22 in Hamilton County consists of recrystallized "inoceramite" containing a few rounded quartz grains and a small amount of microcrystalline-calcite-ooze matrix (Pl. 9C).

A representative sample of sandstone from near the middle of the member at the type locality was analyzed chemically and results of this analysis are shown below. The second sample is from a very silty

*Chemical analyses of Codell sandstone and Blue Hill silty shale*

| Locality | Unit | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | $TiO_2$ | CaO | MgO | $P_2O_5$ | S | $CO_2$ | Loss 140°C | Total loss, as-rec'd basis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 28 | N | 78.8 | 11.4 | 1.56 | 0.45 | 0.40 | 0.85 | 0.16 | 0.023 | N.D. | 1.12 | 3.63 |
| 28 | M | 72.2 | 13.5 | 2.40 | 0.52 | 0.27 | 1.08 | 0.11 | 0.094 | 0.09 | 1.61 | 5.63 |

N.D. Not detected.

shale unit at the top of the Blue Hill Member at the same locality and is included for comparison.

*Thickness and distribution.*—At the type locality I measured 25 feet of Codell, including an upper silty sandstone and a basal argillaceous sandy siltstone. Below the Codell lie argillaceous blocky sandstone and sandy clay shale transitional beds 5.1 feet thick. These are included in the Blue Hill Shale Member because a sharp color change above them reflects a distinctive difference in rock composition, that is, chiefly clayey beds below, and predominantly quartz silt and sand above. Maximum development of the Codell exposed in Kansas is along the Saline River valley in northern Ellis County. From this area, the Codell thins in all directions. The greatest thickness is at locality 25, where 19 feet of thick and very thick beds of sandstone is underlain by 12 feet of thin to very thin bedded siltstone that contains some partings of slightly silty to very silty clay shale. At localities 18 and 24, the member is 18.2 and 19.7 feet thick, respectively. The four localities described above are along the Saline River valley (Pl. 1). Southwestward, the member is about 5 feet thick at locality 13, 5.7 feet at locality 17, 4.2 feet at locality 47, and 6.2 feet at locality 15. At localities 2 and 6, in Hodgeman and Finney Counties, sandy shale constitutes the upper part of the Blue Hill Member, but such strata should not, in my opinion, be assigned to the Codell Sandstone Member. Northeastward from Ellis County the following thicknesses have been measured: locality 32, 2.4 feet; SW¼ sec. 25, T. 8 S., R. 10 W., 3.7 feet; locality 39, 0.6 foot; locality 46, 0.6 foot; locality 40, 0.55 foot; and locality 43, 1.6 feet. In Hamilton County, at locality 22, I have assigned 13.4 feet of sandstone to the Codell (Pl. 1).

In Nebraska, the Codell ranges from 5 to 10 feet in thickness (Condra and Reed, 1959, p. 17) and "underlies southwestern, western, and northern Nebraska a few feet below the Niobrara formation." Numerous wells in southeastern South Dakota have penetrated sandstone at or just below the top of the Carlile, according to well logs published in Reports of Investigations of the South Dakota Geological Survey. Exposures of Codell are distributed widely over this area, according to Barkley (1952, p. 8), and the Codell is recognized as far east as the Sioux Quartzite ridge area of South Dakota. In wells where the Codell has been reported, the range in thickness is about 10 feet to at least 100 feet, but Barkley (1952, p. 8) reported the usual range to be 30 to 50 feet in southeastern South Dakota. Locally, as in Charles Mix, Brule, and Buffalo Counties, the Codell grades into clay (Barkley, 1952, p. 8; 1953, p. 18). Generally, a dark-gray shale separates the Niobrara and Codell throughout the state. In westernmost South Dakota, similar stratigraphic relations prevail, the upper shale being laterally contiguous with the Sage Breaks Member of the Carlile.

Northward from Beadle County, South Dakota, the Carlile subdivisions seemingly are not recognized, and Gries (1954, p. 449) stated that the Carlile is not subdivided in the subsurface in the Williston Basin. Kerr (1949, p. 27) reported 10 feet of "fine sand and silt beds interbedded with the shale" at the top of the Morden Member of the Vermilion River Formation. Because most of the Morden Member is lithologically similar to the Blue Hill Member and occupies a stratigraphically analogous position in the section, and because fossils in the underlying Favel Formation (Wickenden, 1945, p. 32) are typical Greenhorn and Fairport species, the Morden is seemingly equivalent to the Blue Hill, at least in part. Thus, the sandstone at the top of the Morden may be stratigraphically equivalent to the Codell.

In the Black Hills area, the name "Turner Sandy Member" of the Carlile is used for sands that are homotaxial, but only partly correlative, with the Codell, but the Turner is thicker and generally more shaly than the Codell. Westward from the Black Hills, the Turner Sandy Member passes into the Wall Creek Sandstone Member of the Frontier Formation (Haun, 1958, p. 87). Lee (1927, p. 23) stated that in most stratigraphic sections south of Douglas, Wyoming, sandstone a few feet thick lies at the top or just below the top of the Benton Shale. Near Douglas, 75 to 100 feet of such sandstone is separated from the Niobrara by about 375 feet of shale that probably is equivalent to the Sage Breaks Member of the Carlile. The sandstone, which is equivalent to the Turner Sandy Member and probably contiguous with at least part of the Codell in the subsurface of western Nebraska, was believed by Lee to represent the Wall Creek Sandstone of the Frontier Formation.

Westward from the outcrop in Kansas, the Codell Sandstone Member has been traced throughout the subsurface of western Kansas by Merriam (1957a), who recorded a thickness in this area of 2 to 40 feet. The Codell is as much as 20 feet thick in wells penetrating the Upper Cretaceous section on the west flank of the Denver Basin of Colorado (Clair, 1955, p. 35), but the unit is discontinuous. According to Mather and others (1928, p. 81), the Codell is recognized generally in the Front Range foothills region of northern Colorado, where it ranges from 3 to 20 feet in thickness and consists of soft shaly sandstone and uniformly fine grained sandstone. In south-central and southeastern Colorado, the Codell Sandstone Member ranges from 2.5 feet thick in Baca County, (McLaughlin, 1954, p. 121) to 40 feet in Fremont County (Mann, 1958, p. 158). The lithology in these areas ranges from quartzose sandstone to hard bituminous limestone that contains only a few grains of quartz sand. Where limestone and sandstone occur in the same section, the limestone forms the top of the Codell Member. Kauffman and Pope (1961, p. 1009) state that the Codell sequence in Huerfano Park, Colorado, includes a lower sandstone unit and an upper limestone and calcareous shale unit. Contrary to their belief, such a sequence is typical neither of the western Kansas Codell generally nor of the type section specifically. In Baca County (McLaughlin, 1954) and near La Junta (Dane and others, 1937, p. 217), the Codell is represented entirely by the hard limestone. A layer of hard, brownish-gray limestone nodules composed chiefly of *Inoceramus* prisms lies at the top of the Codell at locality 22 in Hamilton County, Kansas. This layer is probably lithogenetically related to the limestone in the Codell of southeastern Colorado and occupies an analogous stratigraphic position. Lenticular beds of dark-brownish-gray fine- to medium-grained bituminous limestone are interbedded with dark-gray shale in a zone 5 to 10 feet thick and occurring 10 to 20 feet below the top of the Carlile in Colfax County, New Mexico (Griggs, 1948, p. 28). These beds are the undoubted equivalent of the Codell; however, the Codell is not recognized farther west or south than Colfax County.

*Fossils and correlation.*—Macrofossils are scarce at most Kansas exposures of the Codell Member but microfossils are common, consisting mostly of broken and abraded tooth and bone fragments, calcareous and agglutinated foraminifers, and fecal pellets. The bones and teeth are generally orange. At locality 22, molds of *Prionocyclus* are common, and scraps of *Inoceramus* are abundant in the hard calcarenite that forms the top of the member. Flattened molds of clams are sparse in silty clay shale near locality 17. Worm? burrows are abundant in the type area. Macrofossils collected during the present investigation are listed below. Index fossils are preceded by a dagger. Ranges of identified species are depicted in Table 2, and *Prionocyclus* is illustrated in Plate 25.

*Fossils observed in the Codell Member*

Annelida
- Worm burrows

Mollusca
- Pelecypods
  - *Inoceramus* sp. cf. *I. dimidius* White
  - *Inoceramus* sp. cf. *I. flaccidus* White
  - *Inoceramus* sp.
  - Clam molds
- Cephalopoda
  - *Baculites?* sp.
  - †*Prionocyclus wyomingensis* Meek
  - *Scaphites* sp.

Vertebrata
- Chondrichthyes
  - *Isurus appendiculata* (Agassiz)
  - *Ptychodus whipplei* Marcou
- Osteichthyes
  - Teleost bones and scales

Cobban and Reeside (1952, p. 1018) have selected *Prionocyclus wyomingensis* as a zonal index for the "middle part of the Turner Member [Black Hills, brackets mine] of the Carlile Shale." They stated that "the zone is widely but irregularly distributed." *P. wyomingensis* has a geographic range from Kansas to Utah and from South Dakota to New Mexico. The stratigraphic distribution includes the upper limestone of the Codell Member in Hamilton County, Kansas; the calcareous upper part of the Codell in Colorado; part of the Mancos Shale of Utah, southwestern Colorado, and New Mexico; the Frontier Formation of Wyoming and northern Utah; and the Turner Member of the Carlile in South Dakota. Codell beds containing *P. wyomingensis* are assigned an early late Turonian age by Kauffman and Pope (1961, p. 1009). Species of *Prionocyclus* are common in the zone of *Holaster planus* of the English Middle Chalk. Finely ribbed ammonites from ironstone concretions in the lower part of the Blue Hill Member were recorded as *P. wyomingensis* by Rubey and Bass (1925, p. 36) but are probably juvenile *Collignoniceras hyatti.*

The zone of *Scaphites warreni,* which lies between the zones of *Collignoniceras hyatti* and *Prionocyclus wyomingensis,* is not represented discernibly in the Carlile Shale of Kansas. Absence of the zone cannot be taken as evidence of hiatus, because the Blue Hill and Codell Members are gradational. It must be remembered that *P. wyomingensis* has been discovered only in calcarenite at the top of the Codell in a single section. Whether the sandstones and siltstones, that is, the main part of the Kansas Codell, are equivalent to some part of the *P. wyomingensis* zone or to the zone of *S. warreni* remains to be proved. Indeed, the sandstone unit in the lower part of the Codell in Huerfano Park, Colorado, which is contiguous with the typical Codell of Kansas, has been included by Kauffman and Pope (1961, p. 1009) in the zone of *C. hyatti.* The lack of calcareous invertebrate macrofossils in most of the Codell Member may be due to solution by ground water. The polished condition of vertebrate fossils in the sandstone and siltstone certainly tends to support such a conclusion.

*Inoceramus* sp. cf. *I. dimidius* is associated with *Prionocyclus wyomingensis* in calcarenite at the top of the Codell in Hamilton County. Internal molds reflect the geniculate shell structure and coarse sculpture that are characteristic of the species. *I. dimidius* has been reported in the area from Kansas to Utah and from South Dakota to Texas. It is known from limestone in the upper part of the Codell Member in Hamilton County, Kansas, and Huerfano Park, Colorado; Arcadia Park Formation of Texas; lower beds of the Turner Member of the Carlile in South Dakota; and Mancos Shale of Utah, New Mexico, and southwestern Colorado. Cobban and Reeside (1952) recorded the range as coincident with the zone of *Scaphites warreni,* but Fisher and others (1960, p. 28) reported *I. dimidius* also from the zone of *P. wyomingensis* in the Mancos Shale of eastern Utah and western Colorado. *I. dimidius* is associated with *P. wyomingensis* in northwestern New Mexico and southwestern Colorado, according to Pike (1947). Cobban (personal communication, 1959) has noted that a seemingly identical species is known from the Upper Cretaceous of the U.S.S.R. The nongeniculate portion of *I. dimidius* is morphologically very similar to the English *I. costellatus* from the lower part of the *Holaster planus* zone of the British Middle Chalk (Woods, 1912, p .6). The *H. planus* zone is of late Turonian age.

The only other identifiable invertebrate macrofossil in the Codell is *Inoceramus* sp. cf. *I. flaccidus,* which occurs with *Prionocyclus wyomingensis* in the calcarenite at locality 22. The species is identified from two internal molds of immature specimens.

Identified shark teeth have been discussed above. Other macrofossils are so fragmentary or poorly preserved that specific or even generic identification is not warranted. *Inoceramus* sp. is represented at locality 22 by scraps of shells; *Baculites*? sp., *Scaphites* sp., and pelecypod remains are represented by a few molds.

Agglutinated and calcareous Foraminifera, spores, and well-preserved fecal pellets are the chief microfaunal elements in the Codell Sandstone Member. I have identified *Globigerina, Gümbelina, Ammobaculites,* and *Haplophragmoides* in disaggregated Codell samples. No published work on Codell Foraminifera exists, but Fox (1954, p. 101) has reported several species from the Turner Member of the Carlile in the Black Hills area, some of which could be expected to occur in Kansas.

## DEPOSITIONAL ENVIRONMENT

### General Statement

Dacqué (1915, p. 423) has noted that during Cretaceous time the Northern Hemisphere included two climatic provinces, a northern, or boreal, and a southern, or Mediterranean. Sediments of the boreal province are characterized by belemnites, the pelecypod *Aucella,* and several ammonite genera that are foreign to the Mediterranean region. Large foraminifers, corals, thick-shelled reef-building rudists, and nerineids and actaeonellids (thick-shelled gastropods) are characteristic of the Mediterranean belt and lacking in the boreal region. Dacqué (1915) interpreted the enormous quantity of limestone that extends from Central America eastward to the East Indies as reflecting warm-water conditions, in contrast to cold water of boreal regions. Fossils of the kind restricted to the Mediterranean belt are wholly lacking in the Kansas Carlile, and the only truly boreal elements (belemnites) are not abundant. The sea in Kansas occupied an area between regions where the two climatic provinces were developed typically. Distribution of sediments and fossils is proof that during Carlile deposition the sea in Kansas was connected with waters of both boreal and Mediterranean provinces.

Concerning the Western Interior Cretaceous sea, Reeside (1957, p. 505) wrote, "Two biotic realms contributed to the life in this sea—northern temperate, perhaps cold temperate, and southern warm, perhaps tropical." In addition to nektonic or planktonic forms, such as ammonites and foraminifers, respectively, four invertebrate species found in the Kansas Carlile are known also in the Eagle Ford Group of Texas. On the other hand, four species of *Inoceramus* in the Carlile are known also in Europe or northern Asia, and only one of these has been reported in Texas. The conclusion may be drawn that elements of the fauna common to Europe and Kansas migrated across an Arctic route.

Explicit data concerning depth, temperature, and salinity are difficult to gather for a sea as ancient as that represented by the Carlile fauna. None of the species is extant, and, except for Foraminifera, most of the genera are extinct, hence conclusions regarding paleoecology can be based only to a slight extent on comparison with ecologic analogues of modern seas.

*Depth.*—The paucity of structural features characteristic of a turbulent environment, the fragility of many well-preserved bottom-dwelling invertebrates, the preservation of paired pelecypod valves (Pl. 27A), the unworn condition of most fossils, and the preservation of thin laminae in some Carlile beds suggest deposition in quiet water, generally below the depth of frequent vigorous wave action. Common features of a shallow-water environment, such as prominent cross-bedding, ripple marks, intraformational conglomerates, and tetrapod foot prints, are rare or lacking in the Carlile sediments of Kansas.

In the middle and upper parts of the Fairport Member are numerous thin discontinuous beds of hard limestone composed chiefly of *Inoceramus* prisms. Most of the limestone beds include fragments of *Inoceramus,* and some contain an abundance of comminuted shell

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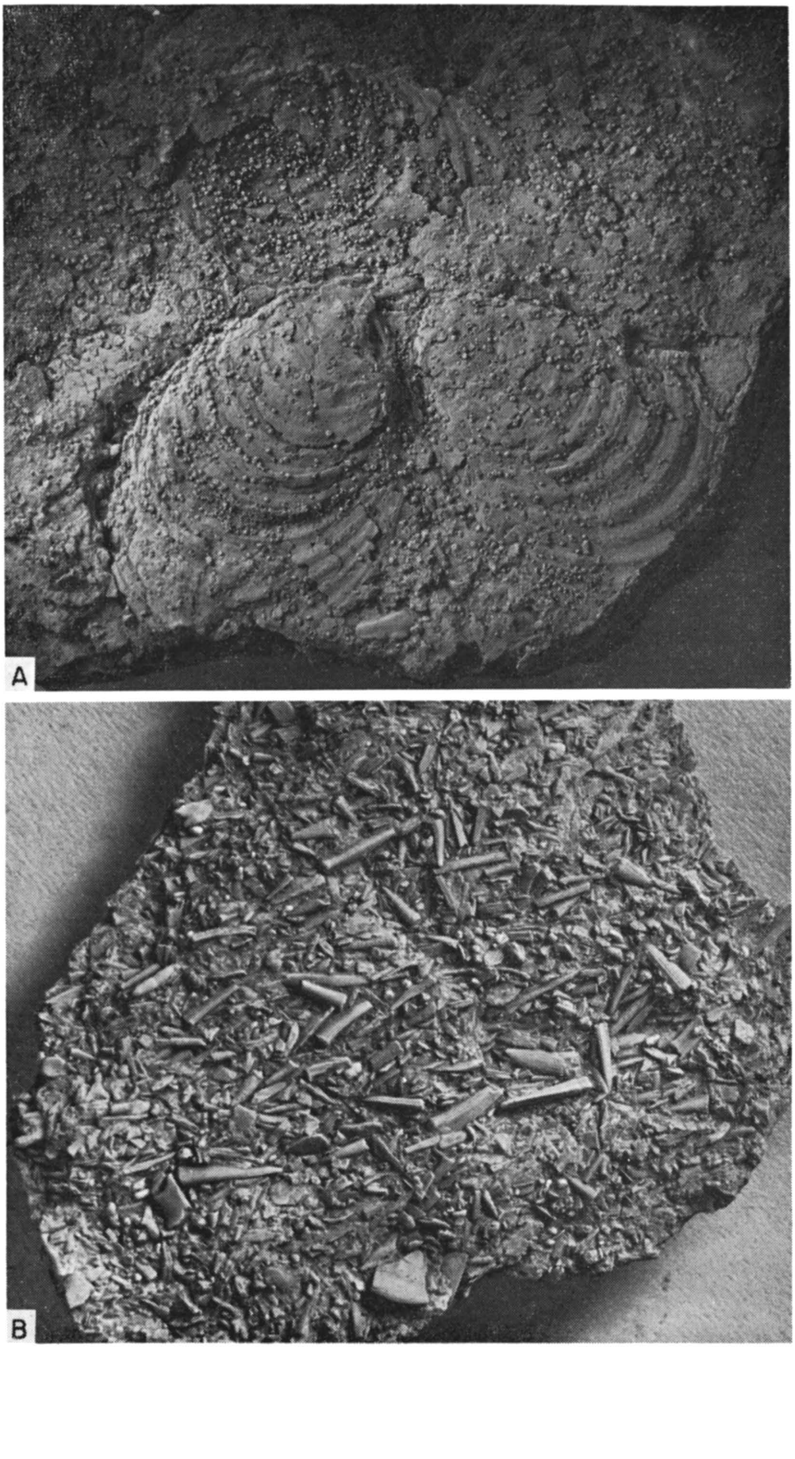
PLATE 27.—Carlile fossils. **A**, Paired valves of *Inoceramus* from middle part of Fairport, sec. 22, T. 15 S., R. 20 W., Ellis County (Loc. 17). **B**, Fish-tooth conglomerate from upper part of Blue Hill, sec. 18, T. 2 S., R. 6 W., Jewell County (Loc. 40).


A
B

debris, including fragments of barnacles and oysters, in addition to *Inoceramus* (Pl. 10B, C). Such lenses are the consequence of bottom disturbance by deep-reaching waves during occasional storms. Imbrication of large shell fragments of *I. cuvieri* and presence of smaller shell fragments that are oriented both parallel and oblique to bedding can be interpreted as effects of occasional destructive wave action. Oysters attached to the outside of both valves of *I. cuvieri* prove that the large shells were overturned at times, for these animals lived on the sea floor with both valves parallel to the bottom, as shown below. Layers of marly chalk in the Fairport Member contain, in greater abundance, the same species as intervening chalky shales, and contain also a large quantity of *Inoceramus* fragments and prisms. The suggestion is made here that waves occasionally stirred the limy mud of the sea floor, setting finer material in suspension, while larger particles, such as fossils and fossil fragments, were concentrated into thin layers that later became marly chalks. Modified, the same interpretation explains the chalky limestone layers in the lower part of the Fairport.

Evidence of wave activity in sediments of the Blue Hill Member is not nearly so abundant, but in a few places the effects of wave or current activity are obvious. At locality 18, valves of the pelecypod *Yoldia* are concentrated in thin lenses and many of the valves are parallel to one another. In many of the lenses, however, the valves are paired, so it seems that current or wave action was not strong. In a very thin and discontinuous bed of fish-tooth conglomerate at locality 40 (Pl. 27B), many teeth are in parallel alignment and most are fragmentary. A thin sandstone bed in the upper part of the Blue Hill at locality 15 is gently cross laminated; calcareous siltstone in the upper part of the Blue Hill in section 3, T. 10 S., R. 13 W., Osborne County, is gently cross laminated and has small oscillation ripple marks; and calcareous siltstone in the upper part of the Blue Hill at locality 31 is gently cross laminated. At locality 47, Trego County, the Codell contains a few angular clay pellets, which can be interpreted as indication of slight local turbulence. Elsewhere, the Codell Member contains rounded bone and tooth fragments, and the hard brown limestone nodules at the top of the member at locality 22 contain abundant shell fragments that suggest considerable agitation of the sea bottom.

Various authors have summarized the evidence for maximum depth of vigorous wave activity. Weller (1960, p. 356) stated that final deposition of sediment on open coast most likely takes place at depths not much greater than 300 feet. Dunbar and Rodgers (1957, p. 130) gave a similar figure for depth of wave action during heavy storms in the neritic zone. These depths relate to unprotected seas, however, not to nearly landlocked bodies of water. Irregularly distributed shoal areas in the Late Cretaceous sea of the Western Interior, such as those indicated by ripple-marked and cross bedded Codell sandstone of eastern Colorado and by ripple-marked and cross laminated calcareous siltstone in the upper part of the Blue Hill of Osborne County, Kansas, would limit the size of waves and thus would impose a narrower limit on the depth to which wave action could be effective. During Carlile deposition the maximum depth of the sea in Kansas was probably much less than 300 feet.

The absence of remains of other than planktonic algae may signify depths greater than those at which light penetration would have been sufficient to promote algal growth, but the sea in Kansas probably contained enough suspended matter to prohibit a categorical statement as to specific depths that might be indicated by lack of benthonic algae. Bathymetric ranges of extant genera of Carlile invertebrates are much too wide to permit specific depth interpretations.

*Temperature.*—Sverdrup and others (1942, p. 853) have noted that the rate of calcium carbonate precipitation by marine animals is governed chiefly by temperature. Animals that build shells of calcium carbonate are more abundant in warm than in cold water, and the shells of warm-water animals are more strongly constructed than shells of the colder-water animals (Sverdrup and others, 1942, p. 853). The large percentage of carbonate in the Fairport Member and the fact that it is chiefly organic suggest a warm, rather than cool or cold, environment of deposition. This conclusion is borne out by the enormous number of calcium carbonate shells in the Fairport and the large size to which some of the animals grew, especially benthonic forms such as *Inoceramus.*

*Chemistry.*—The number of benthonic invertebrates in the Kansas Carlile is suggestive of well-oxygenated bottom environments, because such populations could hardly endure long a habitat impoverished of oxygen. Pyrite in sediments of both formations is the product of a reducing environment beneath the sediment-water interface, as explained below, and is not an indication of reducing conditions in the densely populated bottom waters.

In contrast to the Fairport Member, the Blue Hill Member is not generally fossiliferous, but in most places where Blue Hill fossils are preserved, the fauna is diverse. It has been noted that locally a considerable quantity of gypsum has been produced in fossiliferous beds of the Blue Hill Member; the fossils in such places are poorly preserved and are encrusted with gypsum. At localities where large gypsum crystals litter exposed slopes of seemingly unfossiliferous shale, the alteration of $CaCO_3$ to gypsum by the action of weak sulfuric acid may have eradicated all traces of shells. Thus, the absence of fossils in gypsiferous parts of the Blue Hill may be due to post-depositional solution rather than to sparseness of life in a generally hostile environment during deposition.

Any tendency toward extreme environmental factors in the sea results in some kind of faunal restriction. Thus, if waters are too turbid, corals will not survive; if dissolved oxygen becomes sparse, drastic reduction in the fauna results; and if salinity is far from normal, the fauna is likely to include large numbers of individuals of but a few species. I believe that neither the Fairport nor Blue Hill fauna can be regarded as the product of environmental extremes. The number of benthonic genera in the two units is not large, but probably many other forms of life existed, which have left no record or have not been discovered. Remoteness of the open ocean and dilution by large streams carrying fine detritus to the sea from adjacent land areas may have resulted in water of lower salinity than normal in nearshore areas of the Western Interior sea. During Carlile deposition, however, most of the area that is now Kansas was far from shore, and the water was probably not much diluted by stream discharge. Paleoecological evidence for water of normal, or nearly normal, salinity is discussed below.

*Bottom conditions.*—Both Fairport and Blue Hill environments provided a chiefly soft-mud bottom for the benthonic animals to dwell upon. No indication is found that chalky limestone in the lower part of the Fairport hardened before burial; indeed, sessile species are virtually absent in these beds. The substratum to which most epizoans attached themselves consisted of whole or broken valves of *Inoceramus cuvieri*. Locally, comminuted shell fragments and *Inoceramus*-prism sand provided a firm base for attachment of sessile species. Despite occasional wave disturbance of the sea floor, a general quietness is indicated by such features as lack of wear of the fossils (except in the Codell Member), common occurrence of paired pelecypod valves (Pl. 27A), and preservation of stalked barnacles *in situ* on shells to which they were attached. The entire assemblage of Carlile benthonic invertebrates, except for fragmental fossils in thin local lenses, reflects preservation of individuals at or nearly in their respective places of growth. Fossils preserved on a given bedding plane are thus the remains of a community of organisms.

*Rate of sedimentation.*—That Fairport deposition was considerably slower than Blue Hill deposition is supported by several lines of evidence. (1) Fairport sediments are well bedded and mostly laminated, whereas Blue Hill rocks are poorly bedded. Compaction undoubtedly influenced alignment of fossils, fossil fragments, and pellets in the Fairport, and hence served to emphasize bedding developed during sedimentation (Pl. 6A, C). Lack of well-developed lamination in the Blue Hill could be due to activities of a mobile infauna, but seemingly no vestige remains of such a fauna. The preservation of laminae in chalky shale and shaly chalk of the Fairport, in beds that contain abundant remains of an epifauna, suggests that activities of any infauna that may have existed were negligible. (2) Extensive development of a sessile benthos during Fairport deposition could have occurred only under conditions of slow sedimentation, because *Inoceramus cuvieri* (the substratum to which the benthos became attached) was itself barely above the sediment-water interface. (3) The concentration of both microfossils and macrofossils vertically through the Fairport is suggestive of far slower rates of sedimentation than for the Blue Hill, where the volumetric concentration of fossils is much smaller.

Differential sedimentation within the Carlile can be demonstrated by comparison, at several localities, of the vertical distance between pairs of marker beds (Pl. 1). Fairport sedimentation, in areas now exposed, consistently was fastest at the south end of the west-central Kansas outcrop and slowest in northeastern Ellis County (Loc. 26). During early Blue Hill deposition, sedimentation was slowest in southeastern Osborne County (Loc. 38). That the thickness differences of parts of the Fairport and parts of the Blue Hill do not indicate the earlier beginning of Blue Hill deposition in some areas than in others is shown by the nearly uniform distance between the base of the Blue Hill and the highest Fairport bentonite marker bed 12 (Pl. 1).

## Fairport Chalk Member

*Origin of sediments.*—Most sediment in the Fairport Member is nonterrigenous and was laid down as calcareous mud that contained much clastic material in the form of calcareous fossils and fossil fragments. Five modes of occurrence of calcium carbonate in the Fairport can be discriminated, namely: interstitial spar calcite, recrystallized calcite, microcrystalline-calcite-ooze matrix, pellets, and fossils. Spar calcite is the least common and occurs as interstitial cement, particularly in biofragmental calcarenite beds, and fills the chambers in nearly all foraminifers. Such calcite is formed by precipitation from interstitial fluids. Recrystallized calcite is common in calcarenite beds, where the crystals are comparatively coarse, and in chalky limestone and marly chalk, where most grains are microsparry. Microcrystalline-calcite-ooze matrix, like that dominant in some Fairport rocks, has been interpreted by Folk (1959, p. 8) as the product of chemical or biochemical precipitation. In Fairport rocks, where pellets and foraminiferal tests are essentially intact, the matrix commonly contains microcrystallite calcite ooze that includes some coccoliths. But where pellets have ragged or fuzzy borders and foraminiferal tests have been recrystallized, as in many chalky limestone nodules, much of the ooze matrix has been recrystallized also. The Fairport microsparry calcite has formed by recrystallization of cryptograined calcareous pellets, calcareous foraminifers, and precipitated microcrystalline calcite ooze. Among features that serve to distinguish the finest-grained recrystallized calcite from microcrystalline calcite ooze are greater range in grain size, sparry appearance, and clearly interlocking grains of the former, as well as the usual association of microsparry calcite with partly recrystallized pellets and foraminifers.

Other calcium carbonate in the Fairport Member is biogenic and includes calcareous foraminifers, whole and fragmentary macrofossils, and cryptograined calcareous pellets. The foraminifers are mostly, perhaps wholly, of planktonic origin and, except for those that have been recrystallized, have undergone little post-depositional change. Most abundant among foraminiferal remains are minute tests of juveniles. Among the macrofossils, *Inoceramus* is most abundant. Destructive action by waves has so broken many of these fossils that fragments and isolated prisms are commonly the dominant macro-organic element in the chalky strata. The cryptograined calcareous pellets are here interpreted as fecal pellets of unknown organisms, chief in the diet of which were minute algae whose skeletons consisted of coccoliths. Pellets that impart a speckled appearance to most Fairport rocks thus accumulated continuously on the sea floor. Change in marine environment during the closing part of Fairport deposition caused disappearance from the scene of the pellet-producing organisms. This conclusion is based on the gradational upward decrease in number of pellets in the highest Fairport beds and the absence of pellets in the Blue Hill Member.

Fairport strata are most calcareous near the base of the member and least calcareous at the top. Basal strata represent an environment comparable to that of the upper part of the Greenhorn, whereas topmost beds reflect change in environment toward that of Blue Hill deposition. The basal 20 to 25 feet of the Fairport is characterized by very calcareous chalky shale, local shaly chalk, and chalky limestone. In general, these strata contain the largest percentages of calcareous foraminifers and cryptograined calcareous pellets and the smallest quantity of insoluble residue of any beds in the member. Deposition of these beds at greater distances from shore than higher Fairport strata would account for the virtual lack of terrigenous detritus in the basal Fairport section. Beds and nodular layers of chalky limestone contain a larger total percentage of microsparry calcite, foraminifers, and pellets than adjacent shaly strata. The relatively greater hardness of such beds is due partly to cementation by small quantities of spar calcite but mostly to partial or nearly complete recrystallization of foraminifer tests, calcareous pellets, and especially microcrystalline ooze (Pl. 7). I conclude that accumulating muds were occasionally stirred gently by deep-reaching waves that reworked the fine sediment, destroyed lamination, and produced layers susceptible to the recrystallization process. That recrystallization and lithification occurred during early diagenesis is shown by the uncompressed condition of pellets in chalky limestone, as contrasted to those in adjacent chalky shale. Obviously, laminated chalky shale was not disturbed by wave activity after deposition, hence contains correspondingly small quantities of recrystallized calcite. The nodular character of some chalky limestone layers resulted seemingly from more patchy distribution of reworked sediment, perhaps in hollows on a sea floor made undulatory by very gentle oscillatory movements of the water. The resulting lenses of sediment acted as nuclei for recrystallization that ultimately affected some of the surrounding shaly chalk or chalky shale, as is evident in the concretionary shape of many chalky limestone nodules. More widely scattered nodules in shaly chalk between marker beds 2 and 3 seem to be mainly concretionary (Pl. 5C). Some of the latter at locality 29 are nearly spherical.

Marly chalk layers of the middle and upper parts of the Fairport Member are similar to the chalky limestone in thickness and distribution, and are also the product of wave stirring of bottom sediments. In these rocks, too, matrix recrystallization has been extensive (Pl. 8). Grittiness of most marly chalk is attributable to concentration of fine fossils and fossil debris, including foraminifers and *Inoceramus* prisms particularly. Furthermore, such beds commonly contain greater concentrations of macrofossils than does adjacent chalky shale. The greater impurity of some marly chalk, contrasted to chalky limestone, is due to the greater quantity of terrigenous detritus deposited in the higher parts of the Fairport section.

Thin biofragmental calcarenite lenses in the member represent short periods of severe wave agitation of the bottom sediments. During such activity, the shell materials scattered through bottom muds were concentrated, while finer materials were temporarily suspended. Some microcrystalline ooze sifted down into the calcarenites as the turbulence subsided. Calcite spar that cements some calcarenite lenses is most likely a precipitate from interstitial water. Locally the calcarenites are tightly cemented because of recrystallization of all constituents.

Quartz, feldspar, and clay minerals in Fairport chalky strata are of terrigenous origin. The quartz, as determined from insoluble-residue and x-ray studies, is nearly all of silt size or finer, except in the uppermost part of the member; the fineness of grain size reflects remoteness of the land source. Clay minerals are present in only small quantity in calcareous rocks of the Fairport Member; therefore the origin of Carlile clay minerals, except in bentonite, is treated below in a discussion of the Blue Hill Shale Member.

Bentonite in the Fairport is seemingly bentonite in the restricted sense, because it is composed chiefly of montmorillonite. The exceedingly widespread distribution of some such layers, having almost uniform thickness, is explained by the uniform fall of volcanic ash on broad areas of the sea floor. Absence of lensing in the bentonite layers and paucity in most adjacent strata of structures or textures resulting from turbulence suggest that the sea into which the ash fell was generally calm. Under such conditions the ash probably underwent little or no sea-bottom transport and thus became devitrified at the original site of deposition. Small quantities of feldspar, quartz, and biotite in the bentonite may be unaltered mineral grains that fell with the ash. Fossils are no more abundant directly beneath the bentonites than elsewhere, indicating that the ash falls had no apparent effect on the benthonic population. Because of known Cretaceous orogenesis in the Cordilleran region and because Upper Cretaceous bentonite layers are generally much thicker in the Rocky Mountain region than in Kansas, a western source is postulated for ash that produced the Fairport bentonite layers. Distribution of bentonite so far to the east of the volcanic area suggests prevailing westerly winds during Late Cretaceous time.

Pyrite in Fairport rocks occurs mostly as minute crystalline aggregates but is found locally as nodules or as replacement of fossils. The richness of the Fairport benthos precludes the possibility of reducing conditions above the sediment-water interface. Thus, the pyrite is probably a product of precipitation from interstitial waters in which reducing conditions prevailed.

*Invertebrate paleoecology.*—Calcareous Foraminifera abound in the Fairport Member in Kansas, and most or all are planktonic species. Miller (1958, p. 102) regarded the small size of Niobrara foraminifers, compared to measurements of the same species from the Gulf Coast Upper Cretaceous, as the consequence of unfavorable sea-water chemistry. Griffith (1947) gave measurements of specimens representing several species of calcareous forms from the Fairport of Kansas and Nebraska, which are known also from the Gulf Coast, Mexico, and Carribean areas. Except for one species, his measurements fall within the size range of the forms found farther south. A few measurements made by me accord with the observations of Griffith. On this limited basis, seemingly no significant size difference distinguishes foraminifers of the two regions. Genera included for comparison are *Gümbelina*, *Globotruncana*, *Globigerina*, and *Gümbelitria*; all but the last are usually regarded as planktonic. The wide geographic range of modern globigerinas prohibits any categorical assumptions as to surface temperature of the sea in which the Fairport was laid down. The other genera, with possible exception of *Gümbelitria*, are extinct.

Several students of Foraminifera have noted the general increase in percentage of planktonic species with increasing distance from shore (Bandy, 1956, p. 186). That such a relationship pertains to fossils in the Carlile Shale of Kansas is manifest in the fact that Fairport sedimentation, as elaborated below, occurred early in a major marine regression. The Blue Hill and Codell, in which agglutinated foraminifers predominate, were deposited later in the same regression and, hence, closer to shore.

Depth of Fairport sedimentation cannot be determined on the basis of comparison of Cretaceous planktonic species with modern forms. Parker (1948, p. 235) has stated that planktonic foraminiferal species are negligible in water less than 50 meters in depth south of Cape Cod, Massachusetts. Phleger (1951, p. 35) found many of the same species to be most abundant in the upper 50 meters in the Gulf of Mexico. Therefore, distribution of these modern species seems to be controlled not by depth or temperature but by some other factor, probably salinity. Both Parker (1948, p. 237) and Bandy (1956, p. 187) indicated that modern planktonic Foraminifera are inhabitants of water of normal salinity. The offshore waters that were inhabited by Fairport planktonic foraminifers most likely were of normal salinity.

Foraminifera are abundant in nearly all Fairport rocks examined in thin section or after crushing. In some samples, spar-filled foraminifers make up as much as 30 percent of the rock. The largest volume of foraminifers is in chalky limestone near the base of the member. Slow sedimentation, in combination with periodic stirring of bottom sediments, could have concentrated such large numbers of these fossils. The only seemingly clear-cut instance of catastrophe is recorded in a sandy chalk layer that lies on a bentonite seam at locality 19. The chalk contains abundant splintery grains of quartz and feldspar, probably of volcanic origin, and numerous foraminifers that may have been killed during the ash fall.

The bryozoans *Conopeum* and *Proboscina* are usually found together and commonly occur in abundance in the middle part of the Fairport Member. The bryozoans are attached to the valves of *Inoceramus cuvieri* or to the other epizoans, including *Ostrea, Serpula,* and *Stramentum?*, which, in turn, are attached to large pelecypods. On a few barnacles, *Proboscina* is restricted to the capitular plates, but the fact that the bryozoan colonies are oriented upward on some barnacles and downward on others seems to preclude any sort of symbiotic relationship. It is probable, however, that the bryozoans oriented with apertures downward were attached after death of the barnacle.

Bryozoans generally inhabit clear water, and their absence from the Blue Hill Member is explained by the greater amount of suspended matter present during deposition of this shale. Bryozoa are abundant in Cretaceous strata of Europe and are more common in the Gulf Coast region of the United States than in the Western Interior. The paucity of these invertebrates in the Western Interior may reflect cooler water than farther south, but the problem of Cretaceous bryozoan distribution needs further study.

Data on modern proboscinas are scattered, but data from several dredging expeditions show that the genus is geographically widespread in modern seas, has a wide bathymetric range, and is probably most common in latitudes within 30° of the equator. Data for *Conopeum* are even more sparse, but specimens have been dredged from as deep as 1600 feet. Other members of the family Membraniporidae, including the very common genus *Membranipora*, range from low to high latitudes and are known from waters 100 to 9,000 feet deep. The bryozoans in Fairport rocks have seemingly little depth or temperature significance.

The annelid genus *Serpula* is represented abundantly throughout the middle part of the Fairport Member. Two species are recognized, of nearly identical structure, habitat, and mode of growth. Where one is numerous, the other is generally absent. Presence of a few specimens of intermediate structure is evidence that the two forms are probably varieties of a single species. Like other epizoans in the Carlile fauna, the serpulas preferred the clearer-water environment that prevailed during Fairport deposition, because no specimens are known from Blue Hill or Codell beds. The chief attachment is to valves of large *Inoceramus cuvieri*, or to other epizoans, which, in turn, are attached to the big pelecypod. Thus, *Serpula* may be attached to *Ostrea congesta*, other serpulas, or even to zoaria of encrusting bryozoans. Orientation of the worm tubes is generally random, the apertures being commonly but not invariably turned toward a perpendicular from the substratum. Parallel orientation of all tubes on a pelecypod valve would be evidence that the pelecypod was standing upright on the sea floor, but all evidence is to the contrary; the substratum for these annelids lay parallel to the sea floor. Attachment to shells of dead *I. cuvieri* is shown where serpulas are fixed to valve interiors or to valves that had been fragmented by wave activity before the worm tubes were constructed.

Modern serpulas range from tropical to polar latitudes and have been collected in water ranging in depth from a few feet to several thousand feet. Depositional influences such as depth and temperature cannot be determined by simple comparison of ancient and living species of such adaptable invertebrates, but the solid calcite walls of fossil forms may be suitable for oxygen-isotope-ratio studies to measure the ancient temperature.

Barnacles are common in the middle part of the Fairport Member and nearly everywhere are associated with *Serpula* and bryozoans. Maximum development of the epizoal element during deposition of these strata probably coincides with optimum growth conditions for *Inoceramus cuvieri*. The pedunculate barnacles are attached generally to valve exteriors of *I. cuvieri*, but at least one specimen in my collections is attached to *Ostrea congesta*. A few specimens, each measuring less than 4 mm in height, are attached to the interior of one *I. cuvieri*. Suggestion is offered that the opened valve of the dead pelecypod was buried too soon to permit growth to maturity of these small barnacles.

The genus *Stramentum*, to which the Fairport forms are tentatively assigned, is extinct, but modern pedunculate barnacles having an armored stalk are known at depths ranging from the littoral zone to 17,000 feet, from very low to high latitudes, and in water ranging from warm to nearly freezing. The Cretaceous forms cannot be used alone, therefore, as indices of temperature and depth of ancient seas.

Relative depths at which various ammonites lived have been discussed by many authors, and widely differing opinions have been expressed concerning most forms. Perhaps the classic American paper on this subject is that of Scott (1940), who concluded that most ammonites in Cretaceous rocks of Texas were nektobenthonic and that form and sculpture of the shell are of bathymetric significance. He (Scott, 1940, p. 313, 322) noted the association of ammonites having sculptured shells and quadrate whorl sections with uncoiled forms in the Eagle Ford Group of Texas, the same association seen generally in the Carlile Shale of Kansas. For this association, Scott (1940, p.

322) postulated a depth range of 120 to 600 feet, which embraces the probable greatest depth of the Carlile sea.

Modern cephalopods are restricted to marine environments and, as Scott (1940, p. 308) pointed out, inhabit waters of normal salinity. He noted the lack of evidence that ammonites ever lived in fresh or even brackish water. Abundance of ammonites in Fairport strata is strong evidence of deposition in waters of normal salinity.

Large numbers of immature *Collignoniceras woollgari* on bedding planes in the middle part of the Fairport Member might be explained by some sort of catastrophic event, but the number, geographic extent, and proximity to one another of such bedding planes would require almost continuous "catastrophe". Furthermore, on most of these bedding planes are almost numberless specimens of *Inoceramus latus* and locally abundant *I. cuvieri*, barnacles, oysters, bryozoans, and serpulas. The general uniformity of stratigraphic distribution of this faunal association tends to support a nektobenthonic or vagrant-benthonic mode of life for *C. woollgari*. Such a conclusion is supported by the imprint in chalky limestone, at locality 14, of the ventral impression of a fairly large ammonite, almost certainly *C. woollgari*.

The greatest numbers of *Collignoniceras woollgari* are juveniles less than 2 inches in diameter. The cause of death is unknown but may have been overproduction and consequent lack of sufficient food. These animals, like modern *Nautilus*, were probably carnivorous, and the habitat of *C. woollgari*, like many modern habitats, could not support large numbers of preying carnivores. The wide distribution of *C. woollgari* in beds that lack structures indicative of wave or current action seemingly precludes interpretation of the immature forms as a phenomenon of sedimentary sorting.

Scaphites are so sparse in the Fairport Member that the ecology of this group will be treated with that of other species in the Blue Hill Shale Member.

In a very detailed study of Canadian *Actinocamax*, Jeletzky (1950, p. 21) has pointed out that nearly all Late Cretaceous belemnitids dwelt in boreal seas. Belemnites generally have been regarded as inhabitants of cool waters; thus their abundance in the Favel Formation of Canada and rarity in the coeval Fairport Member may constitute evidence of slightly warmer seas in Kansas than in Manitoba and Saskatchewan. A southward decrease in numbers of *Belemnitella* along the Atlantic Coastal Plain in the United States (Jeletzky, 1950, p. 22) is analogous to the distribution of *Actinocamax* in the Western Interior. Paleotemperature studies of Late Cretaceous belemnites by Urey and others (1951) and Lowenstam and Epstein (1954) support the conclusion that the belemnites preferred cool-water habitats. Average temperatures of growth of all belemnite guards range from 16°C, in the Cenomanian, to 20°C, in the Coniacian and Santonian (Lowenstam and Epstein, 1954); Turonian temperatures were 17° to 19°C.

Large specimens of *Inoceramus cuvieri* everywhere lie parallel to planes of bedding and they undoubtedly assumed this position during life. Had this large species been a burrowing form, perpendicular orientation of at least some specimens could be expected, but no such occurrence has been observed. An upright position, with byssal attachment, is also unlikely, because of the lack of a solid substratum. Epizoans are encrusted heavily on many specimens in the middle and upper parts of the Fairport Member. Oysters are the commonest epizoans, worms next in abundance, then barnacles and bryozoans. The random orientation of the oysters, serpulas, and bryozoans is proof that the valves of *I. cuvieri* lay horizontal during epizoal growth. *Ostrea congesta* is commonly attached to both the exterior and interior of the valves and to both exterior surfaces of paired closed valves. Oysters on the interior of *I. cuvieri* are obviously postmortem epizoans. Where *O. congesta* is attached to the exterior of both valves, one must conclude that the specimen of *I. cuvieri* was overturned, perhaps during storms when wave activity reached deeper than usual. I postulate that some epizoal growth occurred during the lifetime of *I. cuvieri,* because some specimens of the large pelecypod are encrusted with oysters overgrown by worms, which, in turn, are overgrown by bryozoans. It seems unlikely that the valves of a dead *I. cuvieri* would have remained unburied on the sea bottom long enough for these successive phases of epizoal growth to have been completed.

No specimens of *Inoceramus latus* bear epizoans. Furthermore, no evidence is found that this species was a burrower. All specimens of *I. latus* are found lying parallel to planes of stratification. This species must have lain flat on the sea floor, partly or almost wholly covered with mud, and thus did not afford a substratum suitable for epizoal growth.

*Ostrea congesta* is the most abundant of all pelecypods in the Fairport. Most of these oysters are attached to large flat valves of *Inoceramus cuvieri.* As noted above, the random orientation of *O. congesta* proves a position parallel to the sea floor for valves of *I. cuvieri,* to which the oysters became attached. Like modern oysters, the shape of *O. congesta* individuals is extremely variable as a result of crowding; upward growth dominated after the specimens could no longer expand laterally. A few of the epizoal oysters not affected by crowding display smoothly rounded outlines, and commonly these reached a length exceeding 1 inch. Paucity of oysters in the lower few feet of the Fairport is related to sparseness of *I. cuvieri* in these beds. The small number of *O. congesta* in the topmost part of the member reflects increased turbidity during deposition of this part of the section.

Modern oysters occupy a wide range of habitats. Some live in relatively deep, quiet waters of normal salinity, whereas others inhabit the littoral zone, where they are commonly exposed to the atmosphere for several hours between tides. As Stenzel (1945, p. 37) and many other authors have noted, oysters are regarded generally as brackish-water dwellers. Modern shallow- and brackish-water oysters are mostly large and thick shelled, and locally they construct thick banks or so-called oyster "reefs". Similar thick-shelled oysters are common in near-shore sandy facies of the Western Interior Upper Cretaceous. Obviously, the thin-shelled, small *Ostrea congesta* of the Fairport Member represents an altogether different sort of environment. Among modern American oysters, the form most similar to *O. congesta* is *O. equestris*, distributed from North Carolina to the Gulf Coast and West Indies. According to Abbott (1954, p. 373), *O. equestris* is an inch or two in length, oval, and has a raised vertical margin on the attached valve. Parker (1955, p. 203) has stated that *O. equestris* is normally found in waters of high salinity, noting (1956, p. 371) that related forms date back to the Triassic. On the basis of morphological similarity of *O. congesta* and *O. equestris*, I suggest that the Fairport Member was deposited in waters of normal or nearly normal salinity.

The habitat of *Ostrea congesta* is determined best by study of its morphology, faunal associates, and substratum, and the texture, structure, and composition of the enclosing strata. Countless excellently preserved, fragile shells of this oyster, commonly in the life position on large *Inoceramus* or other firm substratum, such as calcareous sand, clearly indicate a quiet environment, below normal depth of wave activity. In the Weches Formation of the Gulf Coast, Stenzel (1945, p. 45) noted thick-shelled *O. lisbonensis* in the wave-worked lower part of the formation, but higher in the section a thin-shelled variety is preserved in sediments that lack evidence of wave action and contain other delicate fossils; he concluded similarly that the thin-shelled oysters reflect quiet-water deposition. Other delicate fossils in Fairport strata, such as Bryozoa and pedunculate barnacles attached to *O. congesta*, support the concept of a generally quiet environment of deposition. The paucity of terrigenous detritus in most Fairport strata suggests that the oysters preferred the far-offshore environment of clear water.

Local lenticular calcarenites contain shell fragments of *Ostrea congesta* and other fossil debris, all of which indicates the severity of occasional sediment agitation by deep-reaching waves. But these same calcareous sands, after turbulence had ceased, provided support for new generations of *O. congesta.*

On some shells of *Inoceramus cuvieri* are enormous numbers of juvenile oysters. Seemingly, these were killed by accumulating sediment before they had a chance to mature. The upper size limit of this species seems to have been less than 2 inches in length and might be a result of premature burial.

Also of interest with respect to *Ostrea congesta* is the retention of color pattern in one specimen and my discovery of a pearl in another specimen.

In summation, the animal paleoecology of the Fairport Member suggests a well-oxygenated environment far from shore, in waters of normal or near-normal salinity, and below the depth of normal wave activity.

### Blue Hill Shale and Codell Sandstone Members

*Origin of sediments.*—Quartz is the dominant mineral in shale samples of the Blue Hill Member. Much of this is very fine silt or even smaller, but the average grain size is considerably larger in the upper part of the member. Such fine quartz detritus is most likely the product of rock abrasion during weathering in, and transport from, the source area. In studied samples kaolinite is second in abundance and next, in nearly equal quantity and locally more abundant than kaolinite, are illite and montmorillonite. Grim (1953, p. 352) pointed out that marine environments are not favorable for the preservation of kaolinite, and later (1958, p. 252) stated that kaolinite persists in ancient rocks but that some is seemingly lost through diagenetic alteration. Weaver (1958) reasoned that most clay minerals in sedimentary rocks are of detrital origin and reflect conditions in the source area, rather than, as generally thought, diagenesis in the place of deposition. Weaver (1958) noted that kaolinite is abundant in all sedimentary environments but is most common in continental and near-shore sediments. Kaolinite can be produced by thorough leaching, probably under humid climatic conditions. That humid, rather than arid, conditions prevailed during the Late Cretaceous in Kansas is indicated by the diverse, well-known flora of the Dakota Formation, leaves and abundant carbonaceous matter in the Graneros Shale, and petrified logs in the Greenhorn Limestone and Fairport Member. In view of the paleogeography of Late Cretaceous time in the United States, the most likely source for large quantities of kaolinite might be the soils of the Wisconsin Highlands or southern Canadian Shield. Because illite forms under conditions of aridity, and because widespread fossil floras tend to rule out an arid climate in the eastern part of the Western Interior region during Late Cretaceous time, the Blue Hill illite probably did not originate during Late Cretaceous weathering. Illite is the commonest clay constituent of sedimentary rocks (Weaver, 1958, p. 259) and thus could have been eroded from Paleozoic sediments that in Cretaceous time were exposed around the eastern border of the Western Interior sea. Because kaolinite is not abundant in Paleozoic sediments, such rocks are not likely to have been the chief source of Blue Hill kaolinite. There is general agreement that montmorillonite in ancient rocks results from alteration of volcanic material, and Grim (1953, p. 357) has expressed judgment that much of the montmorillonite in Upper Cretaceous rocks of the central and southern United States had such an origin. Blue Hill bentonite, like that in the Fairport, is dominantly composed of montmorillonite and thus is true bentonite. The small quantity of chlorite found in shale samples of the Blue Hill accords with a statement by Weaver (1958, p. 258) that chlorite is least abundant in marine shales. The Blue Hill chlorite is most likely detrital. Small quantities of feldspar in some Blue Hill samples could be volcanic, but in my opinion a detrital origin is more probable. As Pettijohn (1957, p. 125) has pointed out, feldspar can survive long transport in large streams, although the rate of disintegration is much more rapid in turbulent streams, such as those having steep gradient. The very large quantity of fine to very fine grained terrigenous detritus in the highest beds of the Dakota Formation and in the near-shore deposits of the lower part of the Graneros Shale bespeaks transport by large, low-gradient streams that traversed the land bordering the Late Cretaceous sea of west-central Kansas. Transport by similar streams during the time of Carlile deposition could account for detrital feldspar in the Blue Hill Member.

The flood of coarse silt and fine-grained sand that characterizes uppermost Blue Hill beds and especially the Codell Member reflects approach of the shore of the Late Cretaceous sea to west-central Kansas during a general regression. Siltstone and sandstone of the Codell Member are composed chiefly of quartz but contain smaller quantities of chert, feldspar, and several minor accessories; sorting is fairly good, but most of the grains are subangular; hence, the sediment may be classed as nearly mature. Source areas for the three dominant minerals—quartz, feldspar, and chert—can only be postulated. Each mineral could have been eroded from Paleozoic sediments that bordered the Late Cretaceous sea in the north-central United States, and each could have been derived from Precambrian terrains of the Wisconsin area or southern Canadian Shield. A multiple source is quite possible, in fact, very likely.

Insufficient evidence is available to warrant firm conclusions as to relief in the source region of Blue Hill and Codell detritus. Obviously, this region was not extremely low in relief, because under such conditions any feldspar would have been thoroughly decomposed in the humid climate postulated above. Had the source region been one of high relief, mechanical erosion would have been dominant, and the thorough leaching necessary to produce Blue Hill kaolinites would have been less likely. Furthermore, high relief would result in steep stream gradients, but the grain size of terrigenous detritus is small in most marine and nonmarine Late Cretaceous sandstones of Kansas. Thus, the source area is postulated to have had moderate relief, because in such an environment mechanical erosion and chemical decomposition would achieve the balance capable of producing sediment having the character of Blue Hill and Codell deposits.

Calcareous septarian concretions are seemingly a product of early diagenesis of the Blue Hill shale. Fossils are inferred to be the usual nuclei around which calcareous matter was precipitated, because fragments of fossils are in evidence in nearly all of the larger concretions, and complete fossil specimens are preserved in numerous smaller concretions at certain horizons (Pl. 19A). That the concretions were at least partly lithified before significant compaction occurred is manifest in the uncompressed fossils of the concretions, in contrast to the more or less flattened condition of most fossils preserved in surrounding shale. Bedding in the shale bends beneath and arches over septarian concretions at some localities, thus providing additional evidence of rigidity of the concretions during later stages of shale compaction.

Accumulation of calcium carbonate as concretions in strata otherwise nearly devoid of calcareous rocks needs explanation. The noncalcareous nature of the Blue Hill shale reflects physical and chemical conditions of the sea water during sedimentation, whereas concretion development occurred within the sediments after their deposition. Two different environments are involved. An inverse relationship is indicated between turbidity and carbonate sedimentation in the Carlile sea of Kansas. Virtually no calcium carbonate accumulated on the sea floor during deposition of the clayey Blue Hill shale. Yet, much calcite was precipitated within the sediments to form the septarian concretions. Weeks (1953) concluded that local increase in alkalinity of fluids surrounding decaying organic matter in sediments would cause local precipitation of carbonate and formation of carbonate concretions around the organic nucleus. The lack of concretions around most fossils at some Blue Hill horizons, and the seeming absence of fossil remains in many concretions leaves the problem open for further study. However precipitated, calcareous matter was derived from interstitial fluids that migrated toward centers of precipitation during initial phases of diagenesis, when flow of fluids through the sediments would have been greatest. As pore space in an increasingly greater volume of sediment around the nuclei became charged with mineral matter, clay surrounding the nuclei became incorporated in the concretions. For this reason the concretions have the same color as the surrounding shale. According to Pettijohn (1957, p. 209), the formation of an aluminous gel is involved in the development of septarian concretions. He noted that the manner by which such a gel forms is not understood but that the process involves some expansion, as shown by the marginal cone-in-cone structure. At locality 31 (Pl. 19B) a thin sandstone bed passes through a concretion, arching upward through the center of the mass. This is evidence of the possibility of expansion during growth of septarian concretions. Desiccation, seemingly greatest near the concretion centers, produced the cracks, which later become filled with second- and, still later, third-generation calcite. Greater shrinkage in the larger concretions caused extensive fracturing of the contained fossils.

I cannot agree with the implication of Weeks (1953) that Cretaceous concretion-bearing shales were laid down in stagnant environments. Wherever preserved, the Blue Hill fauna contains numerous benthonic organic remains that do not show signs of transport. The environment was evidently well oxygenated.

Pyrite nodules, common locally in the Blue Hill Member, are products of diagenetic processes, as are the concretions. The character of the bottom fauna of the member precludes possibility of direct iron sulfide precipitation on the sea floor, because such precipitation demands reducing conditions. Preservation of finely divided carbonaceous matter generally throughout the Blue Hill beds suggests that reducing conditions prevailed within unconsolidated mud on the sea floor. Hydrogen sulfide, generated through decomposition of the organic matter by action of anaerobic bacteria, could have combined with iron in interstitial waters to precipitate the pyrite, probably as a colloid. Fluid movements during initial phases of compaction doubtless concentrated the finely divided pyrite, which then formed nodules, usually around buried shells of *Scaphites, Inoceramus,* or *Collignoniceras.*

*Invertebrate paleoecology.*—Environmental conditions in the Western Interior sea changed markedly as Blue Hill deposition began. The composition of the benthonic fauna mirrors particularly the change to more turbid waters. Epizoal elements virtually disappeared from the west-central Kansas area, and the total population of bottom-dwelling macroinvertebrates diminished considerably. Many species in the Blue Hill Member are represented sparsely and add little to understanding of the environment of deposition. Owing to the paucity of fossils in the Codell Member, the paleoecology of this unit is poorly known in Kansas.

Many species of calcareous and agglutinated foraminifers have been collected from the Blue Hill shale along the Republican River valley of Kansas and Nebraska (Griffith, 1947). Washed samples of the Blue Hill and Codell Members examined by me contain a preponderance of agglutinated species. In contrast, neither Morrow (1934) nor Griffith (1947) discovered agglutinated forms in the Fairport Member, and I discovered only a few questionable specimens in Fairport insoluble residues. Many Carlile calcareous species are known from both the Blue Hill and Fairport Members. Most of the calcareous foraminifers, perhaps all, were planktonic and thus were not affected by the contrasting bottom conditions that prevailed during deposition of the Blue Hill and Fairport shales. The abrupt appearance of agglutinated, and thus benthonic, Foraminifera in the Blue Hill Shale Member is a direct reflection of environmental change. Although the water was probably shallower during Blue Hill deposition, owing to regressional movement of the sea at that time, change in depth alone would not account for abrupt appearance of the agglutinated species, because such change in depth would be very gradual. On the other hand, during Blue Hill deposition there was an influx of terrigenous silt and very fine sand, of the size used by these species; such material is lacking in most Fairport strata. The availability of material for construction of their tests undoubtedly was one factor in restricting arenaceous foraminifers to the Blue Hill and Codell Members. Stainforth (1952, p. 43) concluded that turbidity was a main factor controlling some faunas consisting solely of arenaceous foraminifers but that turbidity was unimportant in normal marine facies where arenaceous and calcareous foraminifers coexist.

Dominance of arenaceous Foraminifera in the Lower Cretaceous Kiowa Shale of Kansas was interpreted as evidence of a brackish environment by Loeblich and Tappan (1950, p. 4). Lowman (1949, p. 1956) has noted the predominance of *Haplophragmoides* and *Trochammina*, both of which are well represented in the Blue Hill, in a brackish-water environment, but Bandy (1956, p. 187) noted that these genera are found in waters ranging from weakly brackish to normally saline. Furthermore, presence of several species of planktonic calcareous foraminifers and the taxonomic diversity of the Blue Hill fauna seemingly is evidence contrary to any major departure from normal salinity.

Unlike the Fairport Member, the Blue Hill contains very few specimens of *Ostrea congesta*. The greater quantity of fine terrigenous detritus in the Blue Hill Member suggests that waters were too turbid for development of an extensive oyster population. Nearly all of the few oysters collected from the Blue Hill are attached to valves of *Inoceramus flaccidus*, generally near the hinge, the oyster beak being directed toward the beak of *I. flaccidus*. The position of the oysters indicates that *I. flaccidus* must have lain partly buried in sea-floor mud in an upright position, the posteroventral margin of the valves directed downward. The preferred orientation of the oysters is proof that epizoal growth occurred during the lifetime of *I. flaccidus*.

No observed specimen of *Inoceramus cuvieri* in the Blue Hill has epizoans attached to the valves, probably because the few oysters that did survive in the turbid environment preferred *I. flaccidus* as a host, because it projected higher above the sea bottom than did *I. cuvieri*. Specimens of *I. latus* in the Blue Hill Member add little to knowledge of their ecology except that the species was tolerant of turbid as well as clear-water environments.

Specimens of *Yoldia* and *Lucina, Bellifusus, Gyrodes, Tessarolax,* and *Oligoptycha,* are elements of a near-shore assemblage of generally thick-shelled mollusks and reflect the regression in progress during deposition of the Blue Hill and Codell Members. That such mollusks are only the vanguard of the near-shore fauna is indicated by the relative sparsity of these fossils. The common preservation of paired valves of such pelecypods as *Inoceramus flaccidus, Yoldia,* and *Lucina* and the lack of shells showing signs of wear are evidence that these fossils were not transported far after death and that the species were indigenous to the environment of Blue Hill deposition.

Extant genera of Blue Hill pelecypods provide some evidence of ancient salinity. That *Ostrea congesta* may be indicative of normal salinity has been noted in discussion of Fairport paleoecology. Modern American species of *Lucina* are distributed from the intertidal zone to a zone beyond the continental shelf, and, except for one species reported from low-salinity bays by Ladd (1951), most individuals inhabit water of normal or nearly normal salinity. *Yoldia* is widely distributed in shallow to deep water of the North American shelf, and the genus seemingly favors water of normal salinity.

Except for some specimens of *Inoceramus* in the limestone nodules at the top of the section at locality 22, pelecypods are almost nonexistent in the Codell Member. As indicated elsewhere in this paper, the most plausible explanation seems to be removal of them by groundwater solution. Near locality 17, however, fragmentary molds of three clams were collected in a sandy shale bed near the top of the Codell. Sculpture preserved in the molds is suggestive of thick-shelled pelecypods of the kind that characterize a near-shore environment. Most pelecypods at locality 22 are fragmentary and are preserved in lenses of "inoceramite". The fossils are part of a lag concentrate produced by considerable agitation of bottom sediments as a result of wave action.

The ammonite *Collignoniceras hyatti* can be collected at virtually every locality where fossils are preserved in the Blue Hill Member. This fact seemingly supports the concept of a benthonic habitat that is concluded for *C. woollgari* of the Fairport Member. If these ammonites were surface nekton it would be necessary, in order to account for such distribution, to postulate ubiquitous surface distribution and wide-scale mortality at the precise times when bottom faunas that were destined for preservation were being entombed in the accumulating sediment. More probably, *C. hyatti* occupied the same habitat as the bottom fauna.

*Scaphites* was almost certainly a bottom-dwelling ammonite, by reason of the same evidence given for *C. hyatti*, but the distribution of *Scaphites* was seemingly controlled more closely by the environment of deposition. *Scaphites* is very sparse in the Fairport beds and is virtually lacking in the Niobrara Chalk of Kansas (Miller, 1958). So far as I am aware, none have been discovered in the Greenhorn Limestone of Kansas. Thus, *Scaphites* seems to have preferred the turbid waters that prevailed during Blue Hill deposition to the clearer waters of Fairport sedimentation.

Smooth, discoidal ammonites such as *Proplacenticeras* have been judged by several authors (see Bergquist and Cobban, 1957, p. 873) to be swimmers or floaters in the open ocean. The sparseness of *Proplacenticeras* in the Blue Hill Member is in harmony with such a conclusion; indeed, at most fossil localities the genus is sparse and at many others is absent.

The available fossil evidence indicates that Blue Hill and Codell deposition was marked by increased turbidity, shallower water, and introduction of the first elements of a near-shore invertebrate fauna. Such conclusions support the concept of a general regression that began early in Carlile history. Fossils such as planktonic Foraminifera, ammonites, *Ostrea congesta, Lucina,* and *Yoldia* suggest that the water during Blue Hill deposition was probably of normal or nearly normal salinity.

## Paleogeography and General Sedimentary History

Carlile strata of Kansas represent only a small portion of the sedimentary complex that was laid down in the Rocky Mountain trough during Late Cretaceous time. This trough is conceived as a vast, differentially subsiding area that extended from the Arctic region to the Gulf of Mexico. Locally, as in southwestern Wyoming, Upper Cretaceous sediments nearly 20,000 feet thick were laid down (Reeside, 1944). In the western United States, Late Cretaceous deposits along the western border of the trough are strikingly intertongued strata of marine and nonmarine origin. The oscillatory character of the ancient shoreline in this part of the trough is well documented in several detailed stratigraphic reports, which already have become classics. Westward gradation of nonmarine facies from coastal-plain to piedmont sediments reflects proximity to an extensive range of mountains (Spieker, 1946) that was elevated during the Nevadan Orogeny. Upper Cretaceous marine strata in the Rocky Mountain states generally contain more coarse-grained detritus than equivalent beds in the Great Plains (Reeside, 1957, fig. 7-21), thus providing testimony of the importance of the Nevadan mountains as a source area for Late Cretaceous sediments.

On the eastern edge of the interior sea, one can only speculate as to the position of the shoreline after the beginning of Late Cretaceous marine deposition. Above the lower part of the Graneros Shale of Kansas the section is mostly lacking in sediments, structures, or faunas of obviously near-shore shallow-water origin. In the Carlile, specifically, I have seen no evidence, physical or paleontological, that suggests unequivocally such an environment. The total thickness of Carlile beds in west-central Kansas is greater than in westernmost Kansas or eastern Colorado. The general uniformity of lithology and faunas of the major Carlile divisions throughout Kansas is not characteristic of near-shore sedimentation. Rock textures and structures characteristic of sedimentation in very shallow water are all but lacking in Carlile sediments of Kansas. Thick-shelled mollusks are sparse, and the most conspicuous element of a near-shore Late Cretaceous fauna—thick-shelled oysters—is absent from the Kansas Carlile, except for a single specimen of *Exogyra.* This evidence is taken collectively to indicate that the Cretaceous shoreline lay scores of miles to the east of the present west-central Kansas outcrop through most of the time of Carlile deposition.

Lower Upper Cretaceous strata in Kansas make up a markedly cyclical succession. The sequence commences with the Dakota Formation, an essentially nonmarine formation comprising chiefly fluviatile and paludal deposits. Dakota sediments grade upward into the Graneros Shale, in which ripple-marked and crossbedded sandstone, fauna, and thin conglomerate layers signify marine deposition in near-shore shallow water. Graneros deposition in Kansas reflects a broadening of the area of Late Cretaceous subsidence and an eastward marine transgression along the border of the Western Interior sea. Uppermost strata of the Graneros are commonly calcareous, contain ammonites and calcareous foraminifers, and contain smaller quantities of sand-size terrigenous detritus than beds below. Overlying beds of the Greenhorn Limestone are dominantly of nonterrigenous origin. Lower Fairport strata represent a cyclical phase nearly identical with that of the upper Greenhorn strata. In both units the calcareous sediment was generated chiefly within the sedimentary basin. The area of carbonate deposition extended across the trough from an area east of the present Kansas outcrop westward to central Colorado, northeastern New Mexico, and the Black Hills region. Farther west the calcareous sediments grade into mainly noncalcareous detrital rocks. The body of carbonate rock represents accumulation during a transgressional maximum, mostly beyond the range of deposition of terrigenous detritus. Increased quantities of land-derived detritus in the middle and upper parts of the Fairport herald regression of the sea in the Kansas area. During Blue Hill deposition, influx of fine-grained terrigenous sediment increased rapidly and brought a halt to carbonate sedimentation in the Kansas part of the Western Interior sea. As the regression neared its maximum, the Kansas area gradually came within range of sand deposition. The Codell Sandstone Member represents maximum influx of land-derived detritus during deposition of the Carlile Shale in Kansas, and also the maximum phase of regression in the first Upper Cretaceous cyclothem.

The source area for most of the terrigenous detritus of the Blue Hill and Codell was probably to the east. The nonmarine Dakota is believed to have had a northerly or northeasterly source in the type area, according to Tester (1929, p. 280), by reason of the direction of fore-set-bed inclination. An easterly source for the Dakota in the Williston Basin has been implied by Gries (1954, p. 447). Westward thinning of the Blue Hill and Codell in Kansas likewise suggests an easterly source for these beds. The sandy nature of the Carlile in southeastern South Dakota, where it lies on the Sioux Quartzite (Bolin and

Petsch, 1954, p. 85), testifies to the importance of eastern source areas for Carlile terrigenous detritus.

In many parts of the Western Interior region the cyclic phase represented by the Codell or its equivalent is overlain by dark-gray shale that records renewed transgression. In the Black Hills these sediments are termed the Sage Breaks Member of the Carlile Shale. Reeside (1957, fig. 13) depicted Kansas as an area of erosion during post-Codell—pre-Niobrara time but, as noted above, cited no concrete evidence to indicate that this was subaerial erosion. According to Merriam (personal communication, 1960), dark-gray shale locally occurs between the Codell and Fort Hays in the subsurface of western Kansas. This shale is homotaxial with similar shale in New Mexico and the Black Hills and is proof that the sea remained in Kansas during post-Codell—pre-Niobrara time, in the middle of the area that Reeside (1957, fig. 13) judged to be undergoing erosion. I interpret the lack of equivalents to upper Turner and Sage Breaks strata along the Kansas Carlile outcrop as evidence that the sea floor during this time was above the marine base level, resulting in nondeposition or even sublevation.

Niobrara sediments were deposited during the second Late Cretaceous transgressional maximum, and, like the Greenhorn, mostly beyond the range of terrigenous detrital deposition. The overstep relationship of the Niobrara to the Kansas Codell is the result of rising marine base level. By the time base level had risen to the position at which sediments could again accumulate, the transgression was already at a maximum and thus carbonates were laid down. The resulting hiatus is a regional diastem at which transgressive gray shale is unrepresented.

The marine cyclical succession, of which the Carlile is the regressive part, is here named the Greenhorn cyclothem, because this formation represents the phase of maximum transgression. The asymmetrical cycle comprises seven phases, defined as follows: (1) noncalcareous siltstone or sandstone, commonly clayey, nonmarine or marine, poorly developed macrofauna but much carbonaceous matter, represented by the uppermost Dakota and locally, the lowermost Graneros; (2) dark-gray noncalcareous silty or sandy clay shale and numerous beds of sandstone, poorly developed macrofauna, represented by the lower part of the Graneros Shale; (3) dark-gray noncalcareous silty clayey shale and beds of calcareous sandstone, local septarian concretions, and a normal marine fauna, represented by the upper part of the Graneros Shale; (4) chalky shale and limestone, sparse terrigenous detritus, a normal marine fauna, represented by the Greenhorn and Fairport; local calcareous strata at the top of the Graneros are included in this phase and are analogous to middle and upper Fairport beds; (5) dark-gray noncalcareous silty clayey shale containing septarian concretions, similar to phase 3, represented by most of the Blue Hill Member; (6) dark-gray noncalcareous silty or sandy shale, locally concretionary, similar to phase 2, represented by the upper part of the Blue Hill; (7) siltstone and sandstone, commonly clayey, poorly developed macrofauna, represented by the Codell Member. Carbonaceous matter of sand phase (1) was derived from vegetated lands or swamps over which the sea was transgressing. The lack of plant debris in sand phase (7) in an expectable condition of regression during which incorporation of vegetational litter was at a minimum. The cyclical succession that is outlined here provides a master framework for future interpretive studies of the stratigraphy, paleontology, and sedimentology of Cretaceous strata in Kansas.

## CONCLUSIONS

1. The Fairport Member is a mappable stratigraphic entity of wide geographic extent that differs from the rest of the Kansas Carlile in lithologic, sedimentological, and paleontological characters. Although the Fairport is treated as a member of the Carlile in this report, in my opinion the Fairport is more appropriately ranked as a formation.

2. The Blue Hill and Codell Members are related genetically, through both vertical and lateral lithologic gradation, and together are a mappable stratigraphic unit. I suggest return to the original definition of the term "Blue Hill Shale" and elevation of the unit to formational rank.

3. Although the Fairport and Blue Hill consist mainly of monotonous successions of chalky strata and concretionary gray shale, respectively, numerous marker beds provide a framework useful for understanding the lithostratigraphic and biostratigraphic relationships and differential sedimentation in the formation. The framework provided by the marker beds will aid future investigators in more detailed studies of the Carlile.

4. The contact between the Greenhorn Limestone and Carlile Shale is conformable and gradational, hence arbitrary, and is time parallel throughout the west-central Kansas area. The Fairport-Blue Hill contact is usually sharp but conformable, and at least in west-central Kansas, nearly time parallel. The Blue Hill-Codell contact is gradational laterally and vertically. Where the Codell is thickest, the upper sandy beds of the Blue Hill are thinnest. The Niobrara Chalk rests on the Codell or Blue Hill with regional diastem in the Kansas outcrop area.

5. Carbonate sediments of the Fairport Member were generated chiefly within the sedimentary basin and most were composed originally of microcrystalline calcite ooze, fossils, and calcareous fecal pellets of an unknown eater of coccolithophores. In chalky limestone and marly chalk much of the ooze has been recrystallized to microsparry calcite. Coarse spar is common inside foraminifers and as cement in lenses of calcarenite. Terrigenous detritus, mostly clay, is more abundant toward the top of the Fairport Member and reflects change in depositional environment toward that of Blue Hill sedimentation.

6. Blue Hill and Codell sediments are composed chiefly of quartz-dominant terrigenous detritus and resulted from erosion of Paleozoic and Precambrian terrains that were exposed to the east and northeast of the west-central Kansas area. Upward coarsening of grain size in the Blue Hill-Codell sequence indicates that the regressive shore of the Western Interior sea was approaching the west-central Kansas area.

7. The Carlile Shale of Kansas contains distinctive faunas that can be traced widely beyond the region where the names Fairport, Blue Hill, and Codell are applicable. Westward into western Colorado and Utah, and southwestward into western New Mexico, the Carlile faunas are recognized in the Mancos Shale. Zonal index species of the Fairport, Blue Hill, and Codell have been identified in the middle part of the Frontier Formation of southern Wyoming. Two of the zones can likewise be traced northwestward into the Colorado Shale of Montana. The Arcadia Park Formation of the Eagle Ford Group of Texas is at least partly equivalent to the Carlile Shale of Kansas. Fossils in the Assiniboine Member of the Favel Formation of Manitoba and Saskatchewan suggest at least partial correlation with the Fairport Member of Kansas. Seemingly, at least part of the Morden Member of the Vermilion River Formation of Manitoba is correlative with the Blue Hill, because the Morden is lithologically similar to the Blue Hill and conformably overlies the Assiniboine, or Fairport equivalent. Thus, the Carlile of Kansas can be correlated with all contiguous or formerly contiguous strata to the south, southwest, west, northwest, and north.

*Collignoniceras* marks the Carlile fauna as Turonian in age, and *C. woollgari* is characteristic of the zone of *Terebratulina lata* of the English Middle Chalk and of the middle part of the Turonian of continental western Europe. *Inoceramus labiatus*, which is characteristic of the lower part of the European Turonian, occurs in the *Rhynchonella cuvieri* and *T. lata* zones of the English Middle Chalk. Specimens of *I. labiatus* from the zone of *T. lata* are broader than those from the zone of *R. cuvieri*. The broad *I. labiatus* is transitional to *I. latus*. *I. latus* is characteristic of the *Holaster planus* zone of the English Middle Chalk. In Kansas the forms of *I. labiatus* transitional to *I. latus* lie in the lower few feet of the Fairport; therefore, one can infer equivalence of these strata to the zone of *T. lata. I. latus* ranges upward through the rest of the Fairport Member and through the Blue Hill Member of the Carlile. These strata can probably be correlated with at least the lower part of the *H. planus* zone of the Middle Chalk. Local limestone at the top of the Codell in Hamilton County is judged to be of early late Turonian age and is correlative with some part of the *H. planus* zone of the English Middle Chalk in which species of *Prionocyclus* are common. Because *C. woollgari* is found throughout the Fairport of Kansas, including the lower part of the range of *I. latus*, its stratigraphic distribution is seemingly greater than in England, where *C. woollgari* is restricted to the *T. lata* zone, as pointed out above.

8. The Fairport sediments accumulated slowly in clear water of normal salinity, far from shore, and mostly below the depth of normal wave activity. Lenses of calcarenite and overturned specimens of *Inoceramus cuvieri* attest to sporadic, severe wave agitation of the bottom sediments. Blue Hill and Codell sediments were laid down more rapidly than the Fairport, in turbid waters of normal or nearly normal salinity, closer to shore than the Fairport, and mostly below the depth of normal turbulence. Local gently cross laminated sandstone and siltstone, a few lenses of pelecypod valves, a fish-tooth conglomerate, and a few clay pebbles are evidence of occasional current or wave activity. Ripple marks at a single locality indicate that the water was very shallow locally.

9. The Carlile Shale of Kansas is mostly the regressional part of a sequence of strata deposited during the first cycle of Late Cretaceous sedimentation in the Western Interior region. The cycle comprises seven phases, the first and the last being sandstone, chalky strata representing the phase of maximum transgression. Lowermost Fairport beds are identical to those of the upper part of the Greenhorn and were deposited during maximum transgression of the sea. Higher Fairport strata reflect the beginning of widespread regression. Increased turbidity during Blue Hill deposition brought carbonate sedimentation to a close and caused virtual disappearance of the epizoal benthos. Continued regression brought a flood of coarse silt and fine sand to the Kansas area as upper beds of the Blue Hill and the Codell were laid down.

10. The diastem that separates Carlile from Niobrara strata resulted from a prolonged interval of nondeposition, probably accompanied by at least some sublevation. The second Late Cretaceous sedimentary cycle had reached the phase of maximum transgression before sediments again began to accumulate on the sea floor.

# APPENDIX

## Descriptions of Key Sections

Key section A. Composite of sections exposed at localities 4, 5, 6, and 9 along Pawnee River valley and tributary valleys in eastern Finney County and northwestern Hodgeman County (Pl. 1).

Locality 6; N½ sec. 2, T. 22 S., R. 29 W.

NIOBRARA CHALK

Fort Hays Limestone Member, rests with sharp contact on:

CARLILE SHALE

Codell Sandstone Member (not recognized)

Blue Hill Shale Member

| | Thickness, feet |
|---|---|
| 51. Shale, arenaceous, light olive gray (5Y6/1), weathers yellowish gray (5Y8/1), much terrigenous silt and very fine grained sand, especially at top; poorly exposed | 5.8 |
| 50. Shale, clayey, silty to arenaceous, medium dark gray, weathers light gray and blocky to flaky, numerous very thin sandy layers and some ferruginous streaks; transitional to unit above | 20.3 |
| 49. Shale, clayey, silty, dark gray, weathers medium gray, numerous streaks of very fine sand and several very thin irregular layers of dark-yellowish-orange very fine quartz sandstone; sandstone very gently cross laminated, ?worm castings in some layers; widely spaced calcareous septarian concretions at several horizons | 13.5 |
| 48. Concretions, calcareous, septarian, all partly weathered, matrix generally yellowish gray, septa grayish orange; concretions in lower part of zone weather conspicuous dark yellowish orange or pale reddish brown and have cone-in-cone "crust"; sandstone, 0.2 foot, hard, calcareous, weathered moderate yellowish brown, very fine grained, lies 1.5 feet below top of unit; shale in zone dark gray, weathers medium gray, silty, blocky, weathers flaky | 3.5 |
| 47. Shale, clayey, dark gray, weathers medium gray, blocky to fissile, weathers flaky, moderately silty, contains layer of widely scattered calcareous septarian concretions about 4 feet above base | 25.0 |
| 46. Concretions, calcareous, septarian, most are partly weathered, matrix yellowish gray (5Y8/1), septa grayish orange; uppermost concretions weather to conspicuous dark yellowish orange to pale reddish brown and have cone-in-cone "crust" that disintegrates to pencil-like fragments; shale in zone like that below | 4.2 |
| 45. Shale, clayey, dark gray, weathers medium gray, blocky to fissile, weathers flaky, mostly slightly silty, abundant crystals of selenite on slope; widely spaced calcareous septarian concretions at 4 and 14 feet above base | 29.5 |

Locality 9; SW¼ sec. 11, T. 22 S., R. 28 W.

| | |
|---|---|
| 44. Concretions, calcareous, septarian, matrix medium dark gray, weathers pale yellowish orange, septa weather dark yellowish orange; some concretions have cone-in-cone "crust" that disintegrates to splintery rubble, many concretions have smooth exterior except for large wartlike protuberances that are strongly septate; same zone is exposed at base of section at locality 6 but is there about 5 feet thick and has many concretions that are weathered a conspicuous moderate reddish brown; clay shale in zone like that below | 4.0 |
| 43. Shale, clayey, medium light gray to light olive gray (5Y6/1), weathers yellowish gray (5Y8/1) with dark-yellowish-orange fer- | |

Thickness, feet

ruginous staining, blocky to fissile, weathers flaky, slightly silty throughout; thin layer of dark-yellowish-orange oxidized iron near base ........ 15.4

42. Shale, clayey, medium light gray to light gray, weathers medium light gray with dark-yellowish-orange ferruginous staining, very thinly and irregularly fissile, very slightly silty, gradational with underlying shale ........ 6.1

41. Shale, clayey, olive gray (5Y4/1) in lower 10 feet to medium dark gray in rest of unit, mostly weathers medium dark gray, blocky to thinly and irregularly fissile, weathers flaky, very slightly silty throughout, selenite crystals common on weathered slope; streaked with iron oxide, very fossiliferous; FOSSILS, *Inoceramus latus, I. flaccidus, Scaphites* sp., *Collignoniceras hyatti,* gastropod molds, lobster? ........ 47.7

Total thickness of Blue Hill Shale Member 175.0

Fairport Chalk Member

40. Shale, chalky, olive gray (5Y4/1), weathers medium light gray, speckled throughout, tough, fissile, gypsiferous, streaked locally with yellow ferruginous matter, grades to weakly calcareous shale at top; limestone, marly, olive gray (5Y4/1), weathers yellowish gray (5Y7/2), medium hard, tough, very fine grained, speckled, as nodular lenses widely spaced in layers, mostly 4 to 5 feet below top of unit; biofragmental calcarenite, lenticular, medium gray, weathers dark yellowish orange, very hard, brittle, with petroliferous odor, locally at top of unit; FOSSILS, in shale, *Inoceramus latus, Collignoniceras woollgari,* fish scales; in marly limestone, mosasaur bones; in calcarenite, *Inoceramus* scraps and prisms, *C. woollgari,* fish bones ........ 11.0

39. Bentonite, dark yellowish orange, biotitic, associated with much granular gypsum ........ 0.02

38. Shale, chalky, light olive gray (5Y5/2), weathers dark yellowish orange to pale yellowish brown, blocky to fissile, splits best along fossiliferous bedding planes, slightly silty throughout, speckled throughout, chalkiest at top, thin limonite film around fossils; FOSSILS, *Inoceramus latus, Collignoniceras woollgari* ........ 1.7

37. Bentonite, dark yellowish orange, slightly silty ........ 0.15

36. Shale, calcareous, medium dark gray, weathers dusky yellow, fissile, weathers flaky, speckled throughout, slightly silty, locally streaked with very thin laminae of light-olive-gray quartz silt; shale partly chalky, especially in basal 3 feet; FOSSILS, *Inoceramus latus, I. cuvieri, Ostrea congesta, Collignoniceras woollgari,* remains of a large vertebrate ........ 17.3

35. Bentonite, pale grayish pink, nonsilty, very gypsiferous ........ 0.04

Locality 4; NE¼ NW¼ sec. 6, T. 22 S., R. 24 W., and SW¼ SE¼ sec. 31, T. 21 S., R. 24 W.

34. Shale, chalky, light gray, weathers dusky yellow to dark yellowish orange, soft, laminated, speckled throughout, several thin to very thin layers of white microgranular caliche; 0.01-foot nearly white bentonite layer 0.1 foot above base; a few very thin layers of biofragmental calcarenite, light olive gray (5Y6/2); FOSSILS, *Inoceramus latus, I. cuvieri, Ostrea congesta, Collignoniceras woollgari,* shark tooth, and fish vertebra ........ 10.5

33. Bentonite, very light gray ........ 0.02

32. Shale, chalky, light gray, weathers dusky yellow to dark yellowish orange, soft, laminated, speckled throughout, two very thin layers of grayish-orange biofragmental calcarenite; FOSSILS, *Inoceramus latus, Ostrea congesta, Serpula* ........ 3.7

| | Thickness, feet |
|---|---|
| 31. Bentonite, white, weathers dark yellowish orange | 0.1 |
| 30. Shale, chalky, light gray, weathers dusky yellow to dark yellowish orange mottled light gray, soft, laminated, speckled throughout, abundant fossils flattened along bedding planes, very thin lenses of grayish-orange biofragmental calcarenite; FOSSILS, *Inoceramus latus, I. cuvieri, Ostrea congesta, Collignoniceras woollgari, Serpula tenuicarinata, S. semicoalita,* fish vertebrae | 7.9 |
| 29. Shale, chalky, biofragmental calcarenite, silty chalk, and bentonite, interbedded; shale as above, calcarenite light olive gray (5Y5/2) and composed chiefly of *Inoceramus,* bentonite 0.02 foot thick and white, chalk weathered dark yellowish orange; FOSSILS, *Inoceramus cuvieri, Ostrea congesta, Collignoniceras woollgari, Serpula tenuicarinata* | 0.8 |
| 28. Bentonite, nearly white, weathers dark yellowish orange | 0.05 |
| 27. Shale, chalky, light gray to light olive gray (5Y5/2), weathers medium yellowish orange, mottled, soft, laminated, speckled throughout, abundant fossils flattened along bedding planes, thin layer of silty chalk near top; FOSSILS, *Inoceramus latus, Scaphites* sp., *Collignoniceras woollgari,* fish scales | 1.7 |
| 26. Chalk, silty, light olive gray (5Y6/1), weathers dark yellowish orange, speckled throughout; silt is calcareous; some light-gray bentonitic clay | 0.35 |
| 25. Shale, chalky, light olive gray (5Y6/1), weathers dark yellowish orange, mottled, soft, laminated, speckled throughout; FOSSILS, *Inoceramus latus, Collignoniceras woollgari* | 2.1 |
| 24. Shale, chalky, light olive gray (5Y6/1), weathers moderate yellowish brown, soft, laminated, speckled throughout; FOSSILS, *Inoceramus latus, I. cuvieri, Ostrea congesta, O. lugubris, Collignoniceras woollgari, Stramentum?* n. sp., *Serpula semicoalita* | 3.9 |
| 23. Chalk, silty, and shale, chalky, medium light gray, weathers dark yellowish orange; chalk lenticular, blocky, containing calcareous silt; shale soft, very thin bedded; all rocks speckled throughout; FOSSILS, *Inoceramus latus, Collignoniceras woollgari* | 0.5 |
| 22. Bentonite, moderate yellowish brown | 0.03 |
| 21. Shale, chalky, medium light gray, weathers dark yellowish orange, soft, laminated, speckled throughout, gypsiferous; FOSSILS, *Inoceramus latus, Collignoniceras woollgari,* fish scales | 2.8 |
| 20. Chalk, silty, medium gray, weathers dark yellowish orange, soft, blocky, speckled throughout; silt calcareous; FOSSILS, fish scale | 0.15 |
| 19. Shale, chalky, light gray, weathers dark yellowish orange, soft, laminated, speckled throughout, gypsiferous; FOSSILS, *Inoceramus latus* | 1.5 |
| 18. Unmeasured, not exposed in vicinity of sections at localities 4 and 5, estimated minimum thickness | 8.5 |

Locality 5; SE¼ sec. 36, T. 21 S., R. 26 W., and NW¼ sec. 6, T. 22 S., R. 25 W.

| | |
|---|---|
| 17. Shale, chalky, greenish gray (5GY6/1), weathers dark yellowish orange, soft, laminated, speckled throughout, with thin dark-yellowish-orange-weathering biofragmental calcarenite lenses near base; FOSSILS, *Inoceramus latus, I. cuvieri, Ostrea congesta,* fish scales | 5.6 |
| 16. Chalk, silty, all weathered dark yellowish orange, medium hard, tough, speckled throughout; silt is calcareous; FOSSILS, *Inoceramus latus, Ostrea congesta* | 0.3 |
| 15. Shale, chalky; base olive gray (5Y4/1), weathers light gray, tough, laminated, with dark-yellowish-orange bentonite 0.02 foot thick lying 0.7 foot above base; top of unit yellowish gray (5Y7/2) | |

| | | Thickness, feet |
|---|---|---|
| | weathering dark yellowish orange, soft, clayey; all rocks speckled throughout, abundant fossils flattened along bedding planes; FOSSILS, *Inoceramus latus, Ostrea congesta,* fish scales | 4.3 |
| 14. | Bentonite, yellowish gray (5Y7/2), weathers light brown (5YR5/6) | 0.03 |
| 13. | Shale, chalky, olive gray, weathers moderate yellowish brown, tough, laminated, speckled throughout; FOSSILS, *Ostrea congesta, Collignoniceras woollgari* | 1.4 |
| 12. | Chalk, silty, all weathered grayish orange, medium hard, speckled throughout; silt is calcareous, lies on very thin seam of dark-yellowish-orange bentonite; FOSSILS, *Inoceramus cuvieri, Ostrea congesta* | 0.1 |
| 11. | Shale, chalky, olive gray (5Y4/1), weathers moderate yellowish brown, tough, laminated, speckled throughout, very fossiliferous throughout, thin lenticular silty chalk bed 2 feet above base; FOSSILS, *Inoceramus cuvieri, Collignoniceras woollgari* | 4.1 |
| 10. | Limestone, chalky, dark yellowish brown, weathers dark yellowish orange and crumbly, speckled throughout, soft, less resistant than chalky limestone below, ranging in thickness from 0.2 to | 0.6 |
| 9. | Shale, chalky, olive gray (5Y4/1), dark yellowish brown toward top, weathers light gray, tough, laminated, speckled throughout; FOSSILS, *Inoceramus cuvieri, Ostrea congesta, Collignoniceras woollgari,* shark tooth | 7.4 |
| 8. | Limestone, chalky, all weathered grayish orange to dark yellowish orange, medium hard, tough, speckled throughout, moderately resistant, forms bench locally; FOSSILS, teleost scale | 0.4 |
| 7. | Shale, chalky, olive gray (5Y4/1), weathers light gray, upper beds all weathered grayish orange, tough, laminated, speckled throughout, becoming shaly chalk near top with a few thin yellowish-gray (5Y8/1) chalk layers in upper 0.5 foot; dark-yellowish-orange gypsiferous bentonite 0.1 foot thick lies 1.0 foot above base; FOSSILS, *Inoceramus cuvieri, Ostrea congesta* | 6.8 |
| 6. | Limestone, chalky, all weathered grayish orange to dark yellowish orange, medium hard, tough, speckled throughout, base of bed undulatory; locally weathers to three thin beds; FOSSILS, carbonized and partly calcified log perforated by *Teredo* borings | 0.4 |
| 5. | Shale, chalky, olive gray (5Y4/1) or light olive gray (5Y5/2), weathers light gray, yellowish gray (5Y7/2), or grayish orange, tough, laminated, abundantly speckled; unit very chalky at top, containing three layers of widely spaced oblate-spheroidal nodules of limestone, chalky, olive gray (5Y4/1) weathering yellowish gray (5Y8/1); FOSSILS, in shale, *Inoceramus cuvieri, Ostrea congesta, Serpula semicoalita, Collignoniceras woollgari;* in limestone, *I. cuvieri* | 8.6 |
| 4. | Limestone, chalky, all partly weathered grayish yellow (5Y8/4) with moderate-yellowish-brown ferruginous stain, hard, speckled throughout, thin to medium bedded, resistant, poorly fossiliferous; FOSSILS, recrystallized belemnites, fish scales, *Inoceramus* sp. | 0.6 |
| 3. | Gypsum, dark yellowish orange owing to ferruginous staining, soft, granular, some calcareous cement | 0.2 |
| 2. | Bentonite, dark yellowish orange | 0.2 |
| 1. | Shale, chalky, or chalk, shaly, olive gray (5Y4/1), weathers light gray to yellowish gray (5Y7/2), tough, very evenly laminated, abundantly speckled throughout, many fossils flattened along bedding planes, one thin bed and three nodular layers of limestone, chalky, light olive gray (5Y5/2), weathers yellowish gray (5Y7/2) or (5Y8/1), hard, tough, abundantly speckled throughout, | |

| | Thickness, feet |
|---|---|
| nodules oblate spheroidal; FOSSILS, in shale, *Inoceramus labiatus* (broad form), *Ostrea congesta, Collignoniceras woollgari,* teleost scales, and vertebrae; in nodules, *Inoceramus labiatus* (broad form) | 5.8 |
| Estimated minimum total thickness of Fairport Chalk Member | 121.6 |
| Estimated minimum total thickness of Carlile Shale | 296.6 |

GREENHORN LIMESTONE (not measured)

Key section B. Composite of sections exposed at localities 12, 16, 17, and 27 along Smoky Hill River valley in southwestern Ellis County.

Locality 17; N½ sec. 22 and NE¼ sec. 21, T. 15 S., R. 20 W.

NIOBRARA CHALK

Fort Hays Limestone Member, rests with sharp contact on:

CARLILE SHALE

Codell Sandstone Member

| | |
|---|---|
| 64. Sandstone, argillaceous, light olive gray (5Y6/1), weathers very light gray, or dark yellowish orange where iron stained, medium hard, very fine grained, very thin shaly bedding; FOSSILS, ?worm castings, fish scales | 2.2 |
| 63. Sandstone, calcareous, light olive gray (5Y6/1), weathers dark yellowish orange, hard, very fine grained, thin to very thin irregular bedding, much oxidized iron | 3.5 |
| Total thickness of Codell Sandstone Member | 5.7 |

Blue Hill Shale Member

| | |
|---|---|
| 62. Shale, arenaceous, and sandstone, argillaceous; shale dark gray, weathers medium gray, blocky to fissile, weathers blocky to flaky, streaks and patches of light-olive-gray (5Y6/1) very fine grained terrigenous sand throughout; sandstone light olive gray (5Y6/1), as thin to very thin layers interbedded with sandy shale, mostly soft, very fine grained, a few medium-hard layers near base of unit; pronounced color change on slope between this unit and one above | 10.1 |
| 61. Shale, clayey, finely arenaceous, dark gray, weathers medium gray, blocky to fissile, weathers mostly blocky or flaky; unit moderately silty at base becoming sandy upward, mottled by laminae and minute lentils of very fine terrigenous sand; unit very selenitic toward base, stained throughout by ferruginous matter; 0.3-foot hard sandstone, calcareous, light olive gray (5Y6/1), weathers dark yellowish orange, containing worm? or gastropod? trails lies 3 feet above base | 23.1 |
| 60. Concretions, calcareous, septarian, matrix olive gray (5Y4/1) weathering conspicuous dark yellowish orange to light brown (5YR5/6), septa grayish orange, maximum size of concretions is 8 feet wide by 3 feet thick, large concretions have cone-in-cone "crust"; shale in zone dark gray, weathers medium gray, blocky to fissile, weathers flaky, moderately silty to very fine sandy throughout; unit contains three thin layers of hard, calcareous fine-grained sandstone, light olive gray (5Y6/1), weathers yellowish gray (5Y8/1), containing worm? or gastropod? trails | 8.3 |
| 59. Shale, clayey, dark gray, weathers medium gray, blocky to fissile, weathers flaky, slightly silty throughout; FOSSILS, fragmentary remains of fish | 4.9 |
| 58. Concretions, calcareous, septarian, matrix olive gray (5Y4/1), weathers light gray, septa dusky brown where exposed; shale in zone like that in 57 | 2.0 |

| | Thickness, feet |
|---|---|
| 57. Shale, clayey, dark gray, weathers medium gray, blocky to fissile, weathers flaky; layer of widely scattered calcareous septarian concretions lies 7.6 feet above base | 18.1 |
| 56. Concretions, calcareous, septarian, matrix olive gray (5Y4/1), weathers grayish orange to light gray, lowest concretions weather conspicuous dark yellowish orange, septa moderate brown; shale in zone like that in unit 54 | 7.5 |
| 55. Shale, clayey, dark gray, weathers medium gray, blocky to fissile, weathers flaky, very slightly silty throughout, stained throughout by grayish-yellow ferruginous matter | 6.1 |
| 54. Concretions, calcareous, septarian, matrix olive gray (5Y4/1), weathers yellowish orange, septa moderate brown, outer surface very smooth; shale in zone like that in unit 52; FOSSILS, *Collignoniceras hyatti, Proplacenticeras?* sp., *Scaphites* sp., *Inoceramus* sp. | 3.0 |
| 53. Shale, clayey, dark gray, weathers medium gray, blocky to fissile, weathers flaky, very slightly silty; FOSSILS, *Inoceramus* sp. | 21.4 |
| 52. Concretions, calcareous, septarian, matrix olive gray (5Y4/1), weathers yellowish orange to dark yellowish orange, septa grayish brown, weather moderate yellowish brown; uppermost concretions have orbicular weathering and cone-in-cone "crust"; shale in zone like that in unit 51; zone forms distinct topographic bench | 9.0 |
| 51. Shale, clayey, dark gray, weathers medium gray, blocky to fissile, weathers flaky, very slightly silty, abundant small selenite crystals, stained throughout by yellowish-gray and dark-yellowish-orange ferruginous matter; thin layer of very fine grained sandstone, dusky red to dark yellowish orange, lies 5.5 feet below top | 37.2 |
| 50. Covered; small exposure 8 feet from top is clayey shale like that in unit 51; FOSSILS, *Collignoniceras* sp., teleost scales and vertebrae | 15.3 |
| 49. Shale, clayey, dark gray, weathers medium gray to pale yellowish brown, fissile, very slightly silty, iron stained, selenitic; FOSSILS, *Collignoniceras* sp., teleost scales | 1.6 |
| Total thickness of Blue Hill Shale Member | 167.6 |
| Fairport Chalk Member | |
| 48. Shale, chalky to calcareous, olive gray (5Y4/1), weathers medium gray, fissile, blocky and harder in lower 2 feet, sparsely speckled in lower part grading upward to nonspeckled and only slightly calcareous shale, slightly silty throughout; FOSSILS, *Inoceramus latus, Collignoniceras woollgari, Scaphites* sp., teleost scales | 8.9 |
| 47. Chalk, marly, silty, olive gray (5Y4/1), weathers grayish orange, medium hard, tough, blocky, speckled throughout; silt is calcareous; FOSSILS, *Inoceramus latus, Inoceramus* n. sp.?, *Collignoniceras woollgari, Scaphites patulus* | 0.8 |
| 46. Shale, chalky, silty, olive gray (5Y3/2), weathers medium light gray, medium hard, tough, irregularly laminated, blocky at top, grades into unit 47, mostly speckled throughout; some thin layers virtually noncalcareous, silt is calcareous; FOSSILS, *Inoceramus latus, Ostrea congesta, Collignoniceras woollgari* | 3.1 |
| 45. Bentonite, nearly white, medium hard | 0.01 |

Locality 16; SW¼ SE¼ sec. 10 and NW¼ NE¼ sec. 15, T. 15 S., R. 20 W.

| | |
|---|---|
| 44. Shale, chalky, olive gray (5Y3/2), weathers light olive gray (5Y6/1) to medium light gray, fissile, speckled throughout but much less so than most units lower in section; unit locally gypsiferous; very thin discontinuous silty chalk layer lies 1.4 feet above base; biofragmental calcarenite lenses common at several horizons; FOSSILS, *Inoceramus cuvieri, Ostrea congesta* | 28.7 |

| | Thickness, feet |
|---|---|
| 43. Bentonite, yellowish gray (5Y8/1), weathers dark yellowish orange | 0.08 |
| 42. Shale, chalky, silty, olive gray (5Y3/2), weathers medium light gray, fissile, tough, very sparse speckling; silt calcareous; several very thin layers of biofragmental calcarenite, light olive gray (5Y4/2), weathers grayish orange; FOSSILS, *Inoceramus latus, I. cuvieri, Ostrea congesta, Collignoniceras woollgari,* shark tooth | 8.5 |
| 41. Chalk, marly, silty, olive gray (5Y4/1), weathers light olive gray (5Y6/1), very thin bedded, blocky, tough, speckled, very fossiliferous; silt calcareous; FOSSILS, *Inoceramus latus* | 0.3 |
| 40. Shale, chalky, olive gray (5Y3/2), weathers medium light gray, irregularly laminated, speckled throughout, calcareous silt; very thin bentonite, yellowish gray (5Y7/2), lies 0.6 foot below top; ferruginous layer containing weathered pyrite nodules lies 0.9 foot above base; FOSSILS, *Inoceramus latus* | 2.9 |
| 39. Bentonite, nearly white, weathers dark yellowish orange, ranges from 0.07 to | 0.12 |
| 38. Shale, chalky, as in unit 40 | 1.4 |
| 37. Chalk, marly, silty, olive gray (5Y4/1), weathers light gray, medium hard, tough, thin irregular bedding, speckled throughout; silt calcareous; unit very fossiliferous; FOSSILS, *Inoceramus latus* | 0.15 |
| 36. Shale, chalky, olive gray (5Y4/1), weathers light gray, tough, irregularly laminated, speckled throughout, small amount of calcareous silt; thin pale-yellowish-brown very silty chalk layer 2.0 feet below top; FOSSILS, *Inoceramus cuvieri, Ostrea congesta, Stramentum?* n. sp. | 4.1 |
| 35. Chalk, marly, silty, olive gray (5Y4/1), weathers light gray, medium hard, tough, thin irregular bedding, speckled throughout; FOSSILS, *Inoceramus latus* | 0.4 |
| 34. Shale, chalky, olive gray (5Y3/2), weathers medium light gray, tough, irregularly laminated, speckled throughout, gypsiferous, some calcareous silt; bentonite 0.05 foot thick, very pale orange, weathers dark yellowish orange, lies 0.5 foot above base; very thin biofragmental calcarenite layer just below top; FOSSILS, *Inoceramus cuvieri, Ostrea congesta, Stramentum?* n. sp., *Serpula tenuicarinata* | 1.2 |
| 33. Chalk, marly, silty, olive gray (5Y4/1), weathers light gray, medium hard, tough, speckled throughout, weathered part greatly fractured; FOSSILS, *Inoceramus* sp. | 0.2 |
| 32. Shale, chalky, like unit 34, containing small selenite crystals along bedding planes; two 0.01-foot bentonite seams, dark yellowish orange, lie 0.3 and 2.4 feet above base respectively; FOSSILS, *Inoceramus latus, I. cuvieri* | 5.4 |
| 31. Chalk, marly, silty, olive gray (5Y4/1), weathers light gray, medium hard, tough, irregularly laminated, speckled throughout; FOSSILS, *Inoceramus cuvieri, Ostrea congesta, Collignoniceras woollgari* | 1.0 |
| 30. Shale, chalky, like unit 34; FOSSILS, *Inoceramus latus, I. cuvieri* | 7.3 |
| 29. Chalk, marly, silty, olive gray (5Y4/1), weathers light olive gray (5Y6/1), medium hard, tough, speckled; sparry gypsum layer at base | 0.1 |
| 28. Bentonite, yellowish gray (5Y8/1), weathers dark yellowish orange | 0.1 |
| 27. Shale, chalky, olive gray (5Y3/2), weathers medium light gray, tough, laminated, speckled, contains some calcareous silt | 0.15 |
| 26. Bentonite, nearly white, weathers dark yellowish orange | 0.05 |

| Locality 27; NE¼ SE¼ sec. 18, T. 15 S., R. 19 W. | Thickness, feet |
|---|---|
| 25. Shale, chalky, all partly weathered, pale yellowish brown to yellowish gray, soft, laminated, some calcareous silt | 3.1 |
| 24. Chalk, marly, silty, olive gray (5Y4/1), weathers light olive gray (5Y6/1) to grayish orange, soft, very thin irregular bedding, weathers blocky to platy, some calcareous silt | 0.3 |
| 23. Shale, chalky, all partly weathered, moderate yellowish brown to yellowish gray (5Y7/2), tough, laminated, speckled throughout, some calcareous silt, very fossiliferous; FOSSILS, *Inoceramus cuvieri, Ostrea congesta,* shark tooth, teleost vertebra | 1.6 |
| 22. Chalk, marly, silty, olive gray (5Y3/2), weathers light olive gray (5Y6/1) to dark yellowish orange, medium hard, thin to very thin bedded, weathers blocky, speckled; ferruginous layer near top; fossils sparse and fragmentary; FOSSILS, *Inoceramus cuvieri, Ostrea congesta* | 0.9 |
| 21. Shale, chalky, olive gray (5Y3/2), weathers light gray to moderate yellowish brown, tough, laminated, speckled throughout, some calcareous silt; FOSSILS, *Ostrea congesta, Serpula tenuicarinata,* shark tooth | 4.2 |
| 20. Bentonite, dark yellowish orange to grayish yellow, gypsiferous | 0.1 |
| 19. Shale, chalky, like unit 21 | 2.5 |
| 18. Bentonite, dark yellowish orange | 0.02 |
| 17. Shale, chalky, olive gray (5Y3/2), weathers light gray, tough, laminated, speckled throughout, some calcareous silt | 0.6 |
| 16. Bentonite, yellowish gray, weathers grayish yellow, dark yellowish orange, or nearly white | 0.15 |
| 15. Shale, chalky, olive gray (5Y3/2), weathers light gray, tough, laminated, speckled throughout, some calcareous silt; FOSSILS, *Inoceramus cuvieri, Ostrea congesta* | 3.7 |
| 14. Limestone, chalky, silty, all partly weathered, light olive gray (5Y5/2) to medium light gray, dark yellowish orange, or grayish orange, soft, thin bedded, weathers blocky to crumbly, not as resistant as chalky limestone beds below, speckled throughout; FOSSILS, *Inoceramus cuvieri, Ostrea congesta, Collignoniceras woollgari,* carbonized-calcified wood | 0.7 |
| 13. Shale, chalky, olive gray (5Y4/1), weathers medium light gray to light gray, tough, laminated, speckled throughout, minor calcareous silt; bentonite, 0.01 foot thick, dark yellowish orange, lies 0.5 foot below top; FOSSILS, *Inoceramus cuvieri, Ostrea congesta* | 2.2 |
| 12. Limestone, chalky, all partly weathered, moderate yellowish brown, grayish orange, or yellowish gray (5Y8/1), medium hard, tough, upper surface rough, speckled throughout, forms prominent ledge | 0.15 |
| 11. Shale, chalky, olive gray (5Y4/1), weathers medium light gray to pale yellowish brown, tough, laminated, speckled throughout, very fossiliferous, minor calcareous silt; FOSSILS, *Inoceramus cuvieri, Ostrea congesta,* shark teeth, teleost scales | 2.6 |
| 10. Limestone, chalky, all partly weathered, grayish orange to dark yellowish orange, soft but tough, forms prominent ledge, speckled throughout; FOSSILS, *Inoceramus cuvieri, Ostrea congesta* | 0.3 |
| 9. Shale, chalky, dark olive gray, weathers medium light gray to light gray, tough, evenly laminated, speckled throughout; top 0.5 foot is very pale orange silty shaly chalk; thin layer of light-olive-gray (5Y5/2) silty chalky limestone lies about 1.3 feet above base; unit very fossiliferous; FOSSILS, *Inoceramus cuvieri, Ostrea congesta,* fish remains | 5.3 |
| 8. Bentonite, pale yellowish brown, weathers dark yellowish orange | 0.05 |

| | Thickness, feet |
|---|---|
| 7. Shale, chalky, olive gray (5Y6/1), weathers medium light gray to light gray or yellowish gray (5Y8/1), medium hard, tough, evenly laminated, speckled throughout, poorly fossiliferous; FOSSILS, *Inoceramus* fragments, teleost scales | 1.1 |
| 6. Limestone, chalky, olive gray, weathers light gray to yellowish gray (5Y8/1), medium hard, tough, thin bedded, forms resistant ledge, speckled; FOSSILS, *Inoceramus cuvieri, Ostrea congesta,* shark tooth | 0.6 |
| Locality 12; NE¼ sec. 27, T. 15 S., R. 18 W. | |
| 5. Shale, chalky, and chalk, shaly, all partly to deeply weathered, very pale orange to dark yellowish orange or nearly white, soft but tough, evenly laminated to very thin bedded, speckled throughout; layers of irregular oblate-spheroidal nodules of chalky limestone, grayish orange to very pale orange, at three horizons in unit; nodules in top layer have ferruginous zone through centers and parallel to bedding; nodules of lowest zone contain calcified wood locally; FOSSILS, in shale, *Inoceramus latus, I. cuvieri, Ostrea congesta* | 7.2 |
| 4. Limestone, chalky, all partly to deeply weathered, grayish orange to pale yellowish orange, medium hard, tough, speckled, forms resistant ledge, two ferruginous zones near base; FOSSILS, *Inoceramus cuvieri, I. latus,* belemnite | 0.45 |
| 3. Gypsum, dark yellowish orange owing to ferruginous staining, loose, granular | 0.2 |
| 2. Bentonite, nearly white, weathers dark yellowish orange | 0.2 |
| 1. Shale, chalky, all partly to deeply weathered, yellowish gray (5Y8/1) to very pale orange, soft but tough, evenly laminated, speckled throughout, three layers of lenticular to irregularly oblate spheroidal nodules of limestone, chalky, yellowish gray (5Y7/2) to grayish yellow, medium hard, tough, speckled, some having ferruginous zone through center parallel to bedding; FOSSILS, in shale, *Inoceramus labiatus* (broad form), *I. cuvieri, Ostrea congesta, Collignoniceras woollgari* | 4.7 |
| Total thickness of Fairport Chalk Member | 117.9 |
| Total thickness of Carlile Shale | 291.20 |

GREENHORN LIMESTONE (not measured)

Key section C. Composite of sections exposed at localities 25 and 26 in gullies and bluffs along south wall of Saline River valley in northeastern Ellis County.

Locality 25; SW¼ sec. 29 and SE¼ SE¼ sec. 30, T. 11 S., R. 16 W.

NIOBRARA CHALK

Fort Hays Limestone Member, rests with sharp slightly uneven contact on:

CARLILE SHALE

Codell Sandstone Member

| | |
|---|---|
| 66. Sandstone, silty, light olive gray (5Y7/2), weathers dusky yellow, limonite stained, thick to very thick bedded, beds weather rounded and somewhat pitted, cavernous weathering near top, medium hard, friable, noncalcareous, moderately resistant, many cylindrical worm? burrows that are especially numerous near top; dominantly quartzose, chiefly very fine grained sand and coarse silt | 19.0 |
| 65. Siltstone, argillaceous and very finely arenaceous, light olive gray (5Y6/1), weathers yellowish gray (5Y7/2) to dusky yellow, thin | |

| | Thickness, feet |
|---|---|
| to very thin bedded, thinly laminated except for basal few feet, soft to medium hard, friable, much speckled with limonite, interbedded and locally interlaminated with slightly silty to very arenaceous shale, medium dark gray, fissile, weathers flaky, more abundant in lower half of unit; FOSSILS, one vertical worm? burrow | 12.0 |
| Total thickness of Codell Sandstone Member | 31.0 |
| Blue Hill Shale Member | |
| 64. Shale, clayey, silty to very finely arenaceous, medium dark gray, weathers same to somewhat brownish, blocky, weathers flaky, some yellowish ferruginous staining, moderately silty at base becoming progressively siltier upward; silt locally as streaks and small lentils less than 0.05 foot thick, some of which are thinly laminated, light olive gray (5Y5/2) | 10.5 |
| 63. Concretions, calcareous, septarian, (matrix olive gray (5Y3/2), weathers yellowish gray (5Y8/1) to light gray, septa gray brown to moderate brown), as much as 5 feet in diameter, granular texture on outer surface; shale like that in unit 62 but sandier; very soft, olive-gray, argillaceous shaly sandstone layer, 0.3 foot thick, lies near base of zone; one thin bed of dark-yellowish-orange-weathering, hard, calcareous, thinly laminated, very fine grained silty sandstone near middle of unit | 2.2 |
| 62. Shale, clayey, very finely arenaceous and silty, olive gray (5Y4/1), weathers medium gray, blocky to fissile, weathers flaky, numerous very small lenses and a few very thin layers of light-olive-gray (5Y6/1) very fine grained sandstone | 3.9 |
| 61. Shale, clayey, silty, dark gray, dark olive gray (5Y3/1) at top, weathers medium gray, blocky and fissile, weathers flaky, very slightly silty at base grading to very silty at top, numerous very small lenses of silt or very fine sand in upper part, transitional to unit 62 | 10.1 |
| 60. Concretions, calcareous, septarian, matrix olive gray (5Y3/2), weathers yellowish gray (5Y8/1) to light gray, outer surface granular, septa gray brown to moderate brown; shale in zone like that in unit 59 | 1.5 |
| 59. Shale, clayey, dark gray, weathers medium gray, blocky to fissile, weathers flaky, very slightly silty, limonitic staining along joints and bedding planes | 17.3 |
| 58. Concretions, calcareous, septarian, like those in unit 60 | 1.2 |
| 57. Shale, clayey, medium dark gray to dark gray, weathers light olive gray (5Y6/1) to medium gray, blocky to fissile, weathers flaky to platy, very slightly silty; limonitic staining along joints and bedding planes | 33.5 |
| 56. Concretions, calcareous, septarian, matrix olive gray (5Y3/2, 5Y4/1), weathers dark yellowish orange to moderate reddish brown, septa yellowish brown; concretions range from 0.3 to 7 feet in diameter, largest concretions have irregular to wartlike tuberosities at least one of which is formed by accretion around a very large ammonite; shale in zone like that in unit 55; FOSSILS, *Collignoniceras hyatti* | 4.8 |
| 55. Shale, clayey, dark olive gray (5Y3/1) to dark gray, weathers olive gray (5Y4/1) to medium gray, blocky to fissile, weathers flaky, slightly silty; limonitic staining on joints and bedding planes, small selenite crystals common locally, strongly oxidized pyrite nodules common | 4.9 |
| 54. Shale, clayey, dark gray, locally olive gray (5Y4/1) near base, weathers medium gray, blocky to fissile, weathers flaky, slightly silty; especially in top 12 feet contains several layers of small widely scattered calcareous septarian concretions, none larger | |

| | Thickness, feet |
|---|---|
| than 2.5 feet in diameter; concretions have olive-gray (5Y4/1) matrix that weathers yellowish gray (5Y8/1), exterior of concretions nearly smooth, many are somewhat irregularly spheroidal | 24.7 |
| 53. Concretions, calcareous, septarian, broadly oblate spheroidal, matrix olive gray, weathers yellowish gray (5Y8/1), zone somewhat more conspicuous than those in unit 54; shale in zone like that in unit 54 | 0.8 |
| 52. Shale, clayey, dark gray to dark olive gray (5Y3/1), weathers medium gray, blocky to fissile, weathers flaky, slightly silty; bentonite, 0.1 foot thick, light olive gray (5Y6/1), lies 1 foot above base of unit; first foot of shale above bentonite is light olive gray (5Y5/2), bentonitic, and much stained by limonite | 17.9 |
| 51. Concretions, calcareous, septarian, nearly spherical, widely scattered in a single layer, hold up prominent bench, weather conspicuous dark yellowish orange | 2.0 |
| 50. Shale, clayey, like that in unit 52 | 6.9 |
| 49. Concretions, calcareous, septarian, broadly discoidal, most are much smaller than 1.5 feet in diameter, but some in top layer are 3.5 feet wide by 0.5 foot thick, matrix generally olive gray (5Y4/1), weathers yellowish gray (5Y8/1), septa white to yellowish gray; shale in zone dark gray to olive gray (5Y4/1), blocky to fissile, weathers flaky, very slightly silty; FOSSILS, *Inoceramus flaccidus, Proplacenticeras?* sp., *Collignoniceras hyatti, Scaphites carlilensis, Yoldia* sp., gastropod mold | 5.5 |
| 48. Shale, poorly exposed | 7.5 |
| 47. Concretions, clay ironstone, discoidal, matrix olive gray (5Y4/1), weathers dark yellowish orange or, more commonly, grayish and dusky red; concretions very hard, brittle, very fine grained, do not react to dilute HCl, contain thin veins of nearly white calcite; FOSSILS, *Inoceramus* cf. *I. flaccidus*, gastropod molds | 1.4 |
| 46. Shale, clayey, dark gray, olive gray (5Y3/2, 5Y4/1), weathers medium gray to light olive gray (5Y6/1), blocky to fissile, weathers flaky, very selenitic, middle part fossiliferous; FOSSILS, *Inoceramus cuvieri, Ostrea congesta, Collignoniceras* sp. (juvenile), teleost bones, one coprolite, remains of a large reptile? | 28.6 |
| Total thickness of Blue Hill Shale Member | 185.2 |
| Fairport Chalk Member | |
| 45. Shale, chalky, olive gray (5Y4/1), weathers medium yellowish brown, soft, tough, laminated, slightly silty, speckled throughout, very fossiliferous; FOSSILS, *Inoceramus latus, I. cuvieri* | 4.4 |
| 44. Chalk, silty, all partly to deeply weathered, light gray to grayish orange, soft, tough, blocky, weathers crumbly, very fossiliferous; silt is calcareous; FOSSILS, *Inoceramus latus, I.* n. sp.? *Collignoniceras woollgari* | 0.55 |
| 43. Shale, chalky, olive gray (5Y3/2), weathers medium yellowish brown (10YR5/2), soft, tough, laminated, contains some calcareous silt, speckled throughout, very fossiliferous; bentonite seam, 0.02 foot thick, nearly white, weathers dark yellowish orange, lies 1.85 feet below top of unit; biofragmental calcarenite, dark yellowish orange, very fossiliferous, common as very thin lenses in middle part; FOSSILS, *Conopeum* n. sp., *Proboscina* n. sp., *Serpula semicoalita, Stramentum?* n. sp., *Inoceramus cuvieri, I. latus, Ostrea congesta, Collignoniceras woollgari*, teleost bones, shark teeth, coprolites | 16.3 |
| 42. Chalk, silty, all partly weathered, moderate yellowish brown, soft, tough, weathers blocky, speckled throughout; silt is calcareous; FOSSILS, *Inoceramus latus* | 0.55 |

| | Thickness, feet |
|---|---|
| 41. Shale, chalky, olive black, weathers medium gray to dark yellowish brown, soft, tough, laminated, speckled throughout, much fine granular gypsum throughout, contains some calcareous silt; bentonite seam, 0.08 foot thick, light brownish gray, weathers dark yellowish orange, underlain by fine granular gypsum, lies 0.9 foot below top of unit; FOSSILS, *Inoceramus latus* | 6.1 |
| 40. Chalk, marly, silty, olive gray (5Y4/1), weathers medium yellowish brown (10YR5/2), soft, tough, weathers blocky, speckled throughout; silt is calcareous; FOSSILS, *Inoceramus latus* | 0.4 |
| 39. Shale, chalky, olive black, weathers dark yellowish brown, soft, tough, laminated, contains much fine granular gypsum throughout, speckled throughout; FOSSILS, *Inoceramus latus, Ostrea congesta, Stramentum?* n. sp. | 2.6 |
| 38. Bentonite, very pale orange, weathers dark yellowish orange | 0.16 |
| 37. Shale, chalky, olive gray (5Y4/1), weathers pale yellowish brown, soft, tough, laminated, speckled throughout, contains much fine granular gypsum throughout; FOSSILS, *Inoceramus cuvieri, Ostrea congesta, Collignoniceras woollgari, Serpula tenuicarinata* | 5.9 |
| 36. Chalk, marly, silty, all partly weathered, moderate yellowish brown, weathers crumbly; FOSSILS, *Inoceramus cuvieri, Ostrea congesta* | 0.5 |
| 35. Shale, chalky, all partly weathered, pale yellowish brown, soft, laminated, speckled throughout; FOSSILS, *Inoceramus cuvieri, Ostrea congesta* | 0.95 |
| 34. Chalk, marly, silty, all partly weathered, moderate yellowish brown, weathers blocky | 0.2 |
| 33. Shale, like that in unit 35 | 1.2 |
| 32. Chalk, like that in unit 34 | 0.2 |
| 31. Shale, like that in unit 35, three partings of dark-yellowish-orange bentonite in lower 2.5 feet; FOSSILS, *Inoceramus cuvieri, Ostrea congesta, Stramentum?* n. sp., *Serpula* sp. | 4.8 |
| Locality 26; SE¼ sec. 29, T. 11 S., R. 16 W. | |
| 30. Chalk, marly, silty, all partly weathered, grayish orange to dark yellowish orange, soft, tough, weathers blocky to crumbly, speckled throughout; silt is calcareous | 0.8 |
| 29. Shale, chalky, all partly weathered, dark yellowish orange to grayish orange, soft, laminated, contains some calcareous silt, speckled throughout; FOSSILS, *Inoceramus cuvieri, Stramentum?* n. sp., *Proboscina* n. sp. | 6.6 |
| 28. Chalk, marly, silty, all partly weathered, dark yellowish orange, soft, blocky, speckled throughout | 0.15 |
| 27. Gypsum, all stained dark yellowish orange, granular | 0.05 |
| 26. Bentonite, two seams; upper is 0.1 foot thick and light gray to light olive gray (5Y6/1); lower is 0.07 foot thick, pale yellowish brown, weathers dark yellowish orange; bentonite seams separated by a 0.05-foot layer of prismatic gypsum and 0.13 foot of chalky shale | 0.35 |
| 25. Shale, chalky, olive gray, weathers light olive gray (5Y6/1) to medium light gray, soft, tough, laminated, contains some calcareous silt; bentonite seam, 0.07 foot thick, pale yellowish brown, weathers dark yellowish orange, lies 0.13 foot below top; FOSSILS, *Inoceramus cuvieri, Ostrea congesta, Proboscina* n. sp., shark tooth | 2.9 |
| 24. Chalk, marly, silty, olive gray (5Y4/1), weathers light olive gray (5Y6/1), soft, tough, weathers blocky to crumbly, speckled throughout; silt is calcareous | 0.5 |
| 23. Shale, chalky, olive gray (5Y3/2), weathers light gray to yellowish gray (5Y8/1), soft, tough, laminated, speckled throughout, virtually nonsilty | 0.9 |

| | Thickness, feet |
|---|---|
| 22. Chalk, marly, silty, light olive gray (5Y5/2), weathers yellowish gray (5Y8/1), very soft, very thinly layered to blocky, speckled throughout | 0.6 |
| 21. Shale, like that in unit 23; FOSSILS, *Inoceramus cuvieri, Ostrea congesta, Serpula semicoalita, Proboscina* n. sp. | 4.3 |
| 20. Gypsum and bentonite; bentonite, 0.02 foot thick, weathers moderate yellowish brown, overlain by 0.18-foot gypsum seam stained dark yellowish orange by iron oxide | 0.2 |
| 19. Shale, chalky, olive gray (5Y4/1), weathers light gray, soft, laminated, contains some calcareous silt | 2.4 |
| 18. Bentonite, weathers dark yellowish orange | 0.05 |
| 17. Shale, chalky, olive gray (5Y3/2), weathers light gray to medium light gray, soft, laminated, speckled throughout, contains a small amount of calcareous silt | 0.55 |
| 16. Bentonite, light olive gray (5Y6/1), weathers dark yellowish orange to light brown (5Y6/4) | 0.2 |
| 15. Shale, chalky, olive gray (5Y3/2), weathers light gray to medium gray, soft, tough, laminated, speckled throughout, contains a small amount of calcareous silt; FOSSILS, *Inoceramus cuvieri, Ostrea congesta* | 2.8 |
| 14. Limestone, chalky, silty, all partly weathered, dark yellowish brown to pale yellowish brown, softer than chalky limestone below, tough, speckled throughout; silt is calcareous | 0.35 |
| 13. Shale, chalky, olive gray (5Y3/2), weathers light gray, soft, tough, laminated, speckled throughout, 0.1-foot seam of dark-yellowish-orange bentonite 0.6 foot below top; FOSSILS, *Inoceramus cuvieri, Ostrea congesta, Serpula semicoalita* | 1.6 |
| 12. Limestone, chalky, all partly weathered, dark yellowish brown, yellowish gray (5Y8/1), or grayish orange, medium hard, tough, speckled throughout; FOSSILS, *Inoceramus cuvieri* | 0.2 |
| 11. Shale, like that in unit 13; FOSSILS, *Inoceramus cuvieri, Ostrea congesta, Serpula semicoalita* | 1.8 |
| 10. Limestone, like that in unit 12; FOSSILS, *Inoceramus cuvieri* | 0.2 |
| 9. Shale, chalky, olive gray (5Y6/1), weathers light gray, soft, very tough, laminated, speckled throughout, contains very small amount of calcareous silt, very thin lenses of hard, pale-brown to grayish-orange biofragmental limestone near top; FOSSILS, *Inoceramus cuvieri, Ostrea congesta, Collignoniceras woollgari* | 4.2 |
| 8. Bentonite, light olive gray (5Y5/2), weathers dark yellowish orange | 0.05 |
| 7. Shale, like that in unit 9 | 0.85 |
| 6. Limestone, chalky, olive gray (5Y4/1) to light olive gray (5Y5/2), weathers yellowish gray (5Y8/1), medium hard, tough, speckled throughout; FOSSILS, *Inoceramus cuvieri?, Collignoniceras woollgari* | 0.5 |
| 5. Shale, chalky, to chalk, shaly, olive gray (5Y4/1), weathers light gray, medium hard, very tough, laminated, weathering platy, speckled throughout, one layer of closely spaced and two layers of widely spaced oblate-spheroidal to discoidal nodules of limestone, chalky, olive gray, weathering yellowish gray, medium hard, speckled throughout; FOSSILS, in nodules, *Inoceramus latus?*, one gastropod mold | 6.0 |
| 4. Limestone, chalky, all partly weathered, yellowish gray (5Y8/1) to dark yellowish orange, medium hard, tough, speckled, top .08 foot separated from main bed by very thin layer of dark-yellowish-orange bentonitic? gypsum; FOSSILS, in top layer, recrystallized belemnites | 0.55 |

| | Thickness, feet |
|---|---|
| 3. Gypsum, nearly white, stained dark yellowish orange, granular, of coarse-sand size, bentonitic | 0.25 |
| 2. Bentonite, nearly white, weathers dark yellowish orange | 0.3 |
| 1. Shale, chalky, and limestone, chalky; shale olive gray (5Y4/1), weathers medium light gray to light gray, soft to medium hard, very tough, laminated, weathering platy, speckled throughout; limestone as three or four layers of widely to closely spaced oblate-spheroidal to discoidal nodules, olive gray (5Y4/1), weathering yellowish gray (5Y8/1), medium hard, speckled throughout, commonly having zone of limonitized chalk in middle parallel to bedding; FOSSILS, in nodules, *Inoceramus labiatus;* in shale, *Collignoniceras woollgari,* teleost scales | 4.9 |
| Total thickness of Fairport Chalk Member | 89.9 |
| Total thickness of Carlile Shale | 306.1 |

GREENHORN LIMESTONE (top of Fencepost limestone bed)

Key section D. Composite of sections exposed at localities 32, 33, 34, 35, 36, 37, and 38 along North Fork of Solomon River and tributaries in eastern Osborne County.

Locality 32; SW¼ sec. 24, T. 8 S., R. 12 W.

NIOBRARA CHALK

Fort Hays Limestone Member, lies with poorly exposed contact on:

CARLILE SHALE

Codell Sandstone Member

| | |
|---|---|
| 78. Clay, arenaceous, and sandstone, argillaceous, silty; clay, light olive gray (5Y5/2), dominates unit; sandstone, light olive gray (5Y6/1), weathers dark yellowish orange, soft, sparse cement, nonresistant | 2.4 |
| Total thickness of Codell Sandstone Member | 2.4 |

Blue Hill Shale Member

| | |
|---|---|
| 77. Shale, clayey, dark gray, weathers medium gray, blocky to fissile, weathers flaky, much powdery iron sulfate and limonite along joints and bedding planes, base of unit finely arenaceous grading upward to very slightly silty beds | 8.4 |
| 76. Sandstone, argillaceous, silty, and shale, silty, medium dark gray to light olive gray (5Y6/1), medium hard, blocky; sand fine to very fine grained; shale at top and base transitional with adjacent units | 5.8 |
| 75. Shale and mudstone, silty and arenaceous, dark gray to light olive gray (5Y6/1), soft, nonresistant; sand grains fine to very fine; unit transitional to adjacent units | 7.1 |
| 74. Sandstone, light olive gray, weathers pale yellowish orange, medium hard, fine to very fine grained, blocky, streaked with dark-gray mudstone, locally harder, more pure, and calcareous, bedding thin, irregular; contains sparse concretions, calcareous, sandy, as much as 3.5 feet thick, matrix light olive gray (5Y6/1), weathers same or stained dark yellowish orange by limonite, very hard, granular to smooth surface, septarian but unlike any septarian concretions below | 1.4 |
| 73. Sandstone, argillaceous, and shale, arenaceous, medium dark gray to light olive gray (5Y6/1), soft to medium hard, blocky, nonresistant; sandstone streaked with clay; shale streaked with sandstone | 10.5 |

| | Thickness, feet |
|---|---|
| 72. Concretions, calcareous, septarian, matrix olive gray (5Y8/1), weathers grayish orange, dark yellowish orange, or yellowish gray (5Y8/1), outer 0.5 foot of concretions weathers granular and crumbles readily; adjacent rock in zone is sandstone, argillaceous, silty, light olive gray (5Y5/2), weathers yellowish gray (5Y7/2), soft, friable, blocky, fine to very fine grained | 7.3 |
| 71. Shale, arenaceous, and sandstone, argillaceous, light olive gray (5Y5/2), weathers grayish orange, soft, nonresistant, noncalcareous | 3.2 |
| 70. Shale, clayey, dark olive gray (5Y3/1) to dark gray, weathers medium gray, blocky to fissile, weathers flaky, with abundant disseminated grains and very thin discontinuous laminae of very fine grained noncalcareous sand; unit has some thin beds of soft to medium-hard, fine-grained, noncalcareous sandstone that weathers dark yellowish orange owing to abundant limonite | 18.4 |
| 69. Concretions, calcareous, septarian, matrix dark gray, weathers yellowish gray (5Y8/1), outer surface granular and broadly bulbous, septa dark yellowish brown to dusky yellowish brown; shale in zone dark gray, weathers medium gray, blocky to poorly fissile; very thin discontinuous laminae of very fine grained sand | 3.9 |
| 68. Shale, clayey, silty, and very finely arenaceous, dark gray, weathers medium gray, blocky to poorly fissile, weathers flaky; silt and sand in very thin discontinuous laminae | 8.0 |
| 67. Concretions, like those in unit 69; shale in zone dark gray, weathers medium gray, blocky to poorly fissile; abundant disseminated silt and very fine sand | 3.2 |
| 66. Shale, clayey, dark gray, weathers medium gray, blocky to fissile, weathers flaky, very slightly silty throughout, abundant limonite and iron sulfate staining along joints and bedding planes, melanterite taste, pyrite concretions locally, small selenite crystals scattered throughout; unit contains a few isolated calcareous septarian concretions; FOSSILS, fish scales | 18.0 |
| 65. Concretions, calcareous, moderately septarian, matrix dark olive gray (5Y3/2), weathers yellowish gray (5Y8/1), septa dark yellowish orange; shale closest to sides of concretions weathers light brown (5YR5/6); rest of shale in zone dark gray, weathers medium gray, blocky to fissile, weathers flaky, slightly silty; limonite and iron sulfate stains on joints and bedding planes | 1.1 |
| 64. Shale, clayey, like that in unit 65, selenite crystals abundant, pyrite concretions locally; bentonite seam, 0.01 foot thick, lies about 0.4 foot below top; sandy shale, 0.5 foot thick, limonitic, lies about 2 feet above base | 4.5 |
| 63. Concretions, calcareous, septarian, widely scattered, matrix dark gray, weathers yellowish gray (5Y8/1); septa dusky brown, weather grayish orange; shale in zone like that in unit 65 | 2.3 |
| 62. Shale, clayey, like that in unit 65; FOSSILS, bone fragment | 11.0 |
| 61. Concretions, calcareous, septarian, matrix dark olive gray (5Y3/1), weathers dark yellowish orange, septa dark yellowish orange, concretions more irregular than those above; shale in zone olive gray (5Y4/1), weathers medium gray, blocky to fissile, weathers flaky | 2.2 |
| 60. Shale, clayey, dark gray, weathers medium gray, blocky to fissile, weathers flaky, limonite and iron sulfate stains on joints and bedding planes, melanterite taste; bentonite seam 0.04 foot thick, light olive gray (5Y6/1), weathers dark yellowish orange, lies 7.5 feet above base; concretions, calcareous, moderately septate, matrix olive gray (5Y4/2), weathers light gray to yellowish gray (5Y7/2), small, very hard, very fossiliferous, lie in lower 2 feet of | |

| | Thickness, feet |
|---|---|
| unit; FOSSILS, *Inoceramus flaccidus, I. cuvieri, Ostrea congesta, Bellifusus willistoni, Collignoniceras hyatti, Scaphites carlilensis, Proplacenticeras pseudoplacenta* | 8.2 |
| 59. Concretions, calcareous, septarian, matrix dark olive gray (5Y3/1), weathers conspicuous dark yellowish orange, very hard, wartlike or ridgelike tuberosities characterize larger concretions, smaller concretions smoothly oblate spheroidal, septa dark yellowish orange; shale in zone olive gray (5Y4/1), weathers medium gray, blocky to fissile, weathers flaky, slightly silty, limonitic staining along joints and bedding planes; FOSSILS, same as in unit 60 | 3.3 |
| Locality 38; NE¼ sec. 14, T. 8 S., R. 12 W. | |
| 58. Shale, clayey, dark gray, weathers medium gray, blocky to fissile, weathers flaky, very slightly silty, some ferruginous staining on joints and bedding planes; unit contains numerous small calcareous septarian concretions at top and moderately calcareous, ferruginous, finely sandy concretions in upper 3 to 4 feet; matrix of ferruginous concretions olive gray (5Y4/1), weathers dark yellowish orange or pale reddish brown | 10.5 |
| 57. Concretions, calcareous, septarian, matrix olive gray (5Y4/1), weathers dark yellowish orange, septa weather dark yellowish orange, lowest concretions underlain and bordered laterally by grayish-brown sandy shale or argillaceous fine-grained sandstone; shale in zone like that in unit 58 | 4.5 |
| 56. Shale, like that in unit 58, contains a few calcareous septarian concretions | 10.5 |
| 55. Shale, like that in unit 58; top of unit marked by zone of widely spaced concretions, calcareous, septarian, matrix olive gray (5Y4/1), weathers grayish orange | 7.0 |
| 54. Bentonite, finely arenaceous, medium gray, weathers very light gray, biotitic; unit contains pyrite nodules as much as 0.4 foot wide and 0.15 foot thick, very hard, calcitic | 0.15 |
| 53. Shale, clayey, dark gray, weathers medium gray to light olive gray (5Y6/1), blocky to fissile, weathers flaky, very slightly silty, limonite and iron sulfate staining along joints and bedding planes, small selenite crystals common throughout, large twinned selenite crystals common in lower half; concretions, very hard, brittle, calcite veined, oblate spheroidal to discoidal, in zone 0.15 foot thick and 4 feet below top; FOSSILS, in shale, *Inoceramus cuvieri*, juvenile *Collignoniceras*, shark tooth, teleost bones and scales; in concretions, *Inoceramus* cf. *I. flaccidus* | 22.4 |
| Total thickness of Blue Hill Shale Member | 182.9 |
| Fairport Chalk Member | |
| 52. Shale, chalky, dark gray, weathers grayish orange, soft, laminated, contains some calcareous silt, speckled in lower part grading upward to progressively less calcareous clay shale; FOSSILS, *Inoceramus latus* | 8.0 |
| 51. Chalk, marly, silty, light olive gray, weathers yellowish gray (5Y7/2), soft, nonresistant, blocky, speckled throughout; silt is calcareous | 0.7 |
| 50. Shale, chalky, olive gray (5Y4/1), soft, tough, laminated, slightly speckled throughout, contains some calcareous silt; FOSSILS, *Inoceramus latus* | 2.0 |
| 49. Bentonite, yellowish gray (5Y8/1), weathers nearly white | 0.01 |
| 48. Shale, chalky, dark gray, weathers medium light gray to grayish orange, soft, tough, laminated, speckled throughout, contains some calcareous silt and abundant organic remains; FOSSILS, *Inoceramus cuvieri, I. latus, Ostrea congesta, Collignoniceras woollgari* | 8.0 |

Locality 34; SW¼ sec. 1, T. 8 S., R. 12 W.

| | Thickness, feet |
|---|---|
| 47. Chalk, marly, very silty, olive gray (5Y4/1), weathers medium gray, medium hard but not very resistant, weathers blocky, speckled throughout; FOSSILS, *Inoceramus latus* | 0.55 |
| 46. Shale, chalky, dark olive gray (5Y3/1), weathers medium gray, soft, laminated, speckled throughout, contains small amount of calcareous silt | 0.8 |
| 45. Bentonite, nearly white, weathers dark yellowish orange | 0.06 |
| 44. Shale, like that in unit 46; FOSSILS, *Inoceramus cuvieri, I. latus, Ostrea congesta, Collignoniceras woollgari* | 4.5 |

Locality 35; NW¼ NW¼ sec. 31, T. 7 S., R. 11 W.

| | |
|---|---|
| 43. Chalk, marly, silty, moderate yellowish brown, weathers grayish orange to yellowish gray (5Y8/1), soft, tough, blocky, speckled throughout; FOSSILS, *Inoceramus cuvieri, I. latus, Collignoniceras woollgari* | 0.4 |
| 42. Shale, chalky, light olive gray (5Y5/2), weathers yellowish gray to medium light gray, soft, laminated, speckled throughout, contains some calcareous silt; 0.05-foot dark-yellowish-orange ferruginous zone 1.2 feet above base; 0.02-foot dark-yellowish-orange bentonite seam 0.4 foot below top; FOSSILS, *Inoceramus cuvieri, I. latus, Ostrea congesta, Collignoniceras woollgari* | 2.8 |
| 41. Bentonite, pale grayish orange, weathers dark yellowish orange | 0.13 |
| 40. Shale, chalky, olive gray (5Y4/1, 5Y3/1), weathers medium light gray to light gray, soft, tough, laminated, speckled throughout, contains some calcareous silt; FOSSILS, *Inoceramus cuvieri, Ostrea congesta* | 1.7 |
| 39. Chalk, marly, silty, dark olive gray (5Y3/1), weathers light olive gray, soft, blocky, nonresistant, speckled throughout; silt is calcareous | 0.15 |
| 38. Shale, like that in unit 40, gypsiferous and ferruginous layers in lower part; FOSSILS, *Conopeum* n. sp., *Serpula tenuicarinata, Inoceramus cuvieri, I. latus, Ostrea congesta, Stramentum?* n. sp. | 5.1 |
| 37. Chalk, marly, silty, dark olive gray (5Y3/1), weathers light olive gray (5Y6/1) to light gray, soft, blocky, speckled throughout, ferruginous layer 0.15 foot above base; FOSSILS, *Serpula tenuicarinata, Inoceramus cuvieri* | 0.5 |
| 36. Shale, chalky, olive gray (5Y3/1), weathers medium light gray to light gray, soft, laminated, speckled throughout, contains some calcareous silt; contains local lenses of silty marly chalk at base; FOSSILS, *Inoceramus cuvieri, I. latus, Ostrea congesta* | 0.75 |
| 35. Bentonite, nearly white, weathers dark yellowish orange | 0.08 |
| 34. Chalk, marly, silty, olive gray (5Y4/1), weathers light olive gray (5Y6/1) to light gray, soft, tough, blocky, locally shaly, speckled throughout; silt is calcareous; unit pinches and swells | 0.25 |
| 33. Shale, like that in unit 36; 0.05-foot ferruginous layer, dark yellowish orange, containing deeply weathered pyrite nodules in center, bentonitic and gypsiferous, lies 0.45 foot above base; FOSSILS, *Serpula tenuicarinata, Inoceramus cuvieri, Ostrea congesta, Stramentum?* n. sp. | 7.1 |
| 32. Chalk, marly, silty, olive gray (5Y4/1), weathers light olive gray (5Y6/1), soft to medium hard, weathers blocky, speckled throughout; silt is calcareous; FOSSILS, *Inoceramus cuvieri,* coprolite | 0.6 |
| 31. Shale, chalky, olive gray (5Y4/1), weathers medium gray, medium hard, tough, laminated, speckled throughout; FOSSILS, *Inoceramus cuvieri, Ostrea congesta* | 1.8 |
| 30. Chalk, marly, silty, olive gray (5Y4/1), weathers light olive gray (5Y6/1), soft to medium hard, weathers blocky, locally shaly, | |

Thickness, feet

speckled throughout; silt is calcareous; FOSSILS, *Inoceramus cuvieri* .......... 0.4

Locality 37; NE¼ sec. 1, T. 8 S., R. 12 W.

29\. Shale, chalky, dark olive gray (5Y3/1), weathers medium light gray, soft, tough, laminated, speckled throughout, contains very small amount of calcareous silt and scattered limonite nodules; persistent zone of limonite nodules lies about 1.9 feet below top; FOSSILS, *Inoceramus cuvieri, Ostrea congesta* .......... 7.4

Locality 36; SE¼ NE¼ sec. 21, T. 7 S., R. 11 W.

28\. Bentonite, light olive gray (5Y6/1), weathers dark yellowish orange, limonite and iron sulfate staining .......... 0.11

27\. Shale, like that in unit 25 .......... 0.25

26\. Bentonite, nearly white, weathers dark yellowish orange .......... 0.05

25\. Shale, chalky, dark olive gray (5Y3/1), weathers medium light gray, soft, tough, laminated, speckled throughout, contains calcareous silt, locally limonitic at top; FOSSILS, *Inoceramus cuvieri, I. latus, Ostrea congesta, Collignoniceras woollgari* .......... 4.6

24\. Chalk, marly, silty, olive gray (5Y4/1), weathers light gray, medium hard, tough, shaly at top and base, speckled throughout; silt is calcareous; layer of limonitized pyrite nodules lies 0.25 foot above base .......... 0.6

23\. Shale, chalky, olive gray (5Y4/1), weathers light gray, soft, tough, laminated, contains some calcareous silt; unit has several very thin layers of shaly chalk; 0.25-foot ferruginous zone that contains limonite nodules lies 1.3 feet above base; scattered limonite nodules about 1 foot below top; FOSSILS, *Inoceramus cuvieri, I. latus, Ostrea congesta, Collignoniceras woollgari* .......... 7.4

22\. Chalk, marly, silty, olive gray (5Y4/1), weathers yellowish gray (5Y8/1), soft, shaly to blocky, nonresistant, speckled throughout; FOSSILS, *Inoceramus cuvieri, Ostrea congesta* .......... 0.25

21\. Shale, chalky, dark olive gray (5Y3/1), weathers light gray to yellowish gray (5Y8/1), medium hard, tough, laminated, weathers platy, speckled throughout, contains some calcareous silt; FOSSILS, *Inoceramus cuvieri, Ostrea congesta* .......... 0.6

20\. Bentonite, light olive gray (5Y6/1), weathers dark yellowish orange .......... 0.07

19\. Shale, like that in unit 21; FOSSILS, *Ostrea congesta* .......... 2.9

Locality 33; NW¼ sec. 25, T. 7 S., R. 11 W.

18\. Bentonite, weathers dark yellowish orange, lies on 0.05-foot seam of nearly white powdery gypsum .......... 0.06

17\. Shale, chalky, light olive gray (5Y5/2), weathers yellowish gray, soft, tough, laminated, speckled throughout, contains small amount of calcareous silt; FOSSILS, *Inoceramus cuvieri, Ostrea congesta* .......... 0.5

16\. Bentonite, weathers dark yellowish orange, contains nearly white powdery gypsum .......... 0.2

15\. Shale, chalky, olive gray (5Y4/1), weathers light gray, soft, tough, laminated, weathers platy, speckled throughout, contains small amount of calcareous silt; 0.01-foot bentonite seam, dark yellowish orange, lies 0.95 foot below top; FOSSILS, *Inoceramus cuvieri, Ostrea congesta* .......... 3.5

14\. Limestone, chalky, very silty, olive gray (5Y4/1), weathers light gray, soft, nonresistant, blocky, weathers crumbly, speckled throughout, local veins of calcite; FOSSILS, *Inoceramus cuvieri, Ostrea congesta, Collignoniceras woollgari* .......... 0.7

| | Thickness, feet |
|---|---|
| 13. Shale, like that in unit 15; 0.01-foot bentonite seam, dark yellowish orange, lies 0.5 foot below top; FOSSILS, *Inoceramus cuvieri*, *Ostrea congesta* | 2.0 |
| 12. Limestone, chalky, all weathered dark yellowish orange, gently undulatory top and base, medium hard, speckled throughout, moderately resistant | 0.23 |
| 11. Shale, chalky, olive gray (5Y4/1), weathers pale grayish orange, soft, tough, laminated, speckled throughout, contains very small amount of calcareous silt; FOSSILS, *Inoceramus cuvieri*, *Ostrea congesta*, teleost remains | 2.3 |
| 10. Limestone, chalky, olive gray (5Y4/1), weathers dark yellowish orange, undulatory top and base, medium hard, resistant, speckled throughout; FOSSILS, *Inoceramus cuvieri*, *Ostrea congesta* | 0.25 |
| 9. Shale, chalky, olive gray (5Y4/1), weathers light gray to very light gray, soft, tough, laminated, speckled throughout, contains small amount of calcareous silt; abundant powdery gypsum along bedding planes; 0.01-foot silty chalk layer about 0.7 foot below top; FOSSILS, *Ostrea congesta*, teleost vertebra | 4.6 |
| 8. Bentonite, dark yellowish orange, locally a central layer of powdery gypsum, maximum thickness | 0.03 |
| 7. Shale, like that in unit 9; FOSSILS, *Ostrea congesta*, teleost scales | 0.9 |
| 6. Limestone, chalky, all partly weathered grayish orange to pale yellowish orange, medium hard, moderately resistant, speckled throughout, bed undulatory at top and base, maximum thickness 0.5 foot; FOSSILS, *Inoceramus cuvieri* | 0.15 |
| 5. Shale, chalky, olive gray (5Y4/1), weathers very light gray, light gray, and grayish orange, soft, tough, laminated, weathers platy, speckled throughout, few thin layers of dark-yellowish-orange chalky limestone; unit is shaly chalk near base; layer of widely spaced oblate-spheroidal chalky limestone nodules lies 3.3 feet above base, limestone light olive gray (5Y5/2), weathers yellowish gray (5Y8/1); FOSSILS, *Inoceramus cuvieri*, *I. labiatus* (broad form), *Ostrea congesta*, teleost scales | 7.5 |
| 4. Limestone, chalky, light olive gray (5Y5/2), weathers yellowish gray (5Y8/1), medium hard, tough, evenly bedded, resistant, speckled throughout; top 0.07-foot layer has belemnite? molds and is separated from rest of unit by 0.05-foot layer of bentonitic ferruginous granular gypsum; FOSSILS, *Inoceramus* sp., belemnite? molds, *Collignoniceras woollgari* | 0.5 |
| 3. Gypsum, nearly white, stained dark yellowish orange by limonite, coarse grained to granular, soft, bentonitic | 0.23 |
| 2. Bentonite, nearly white, weathers dark yellowish orange | 0.25 |
| 1. Shale, chalky, olive gray (5Y4/1), weathers medium light gray to light gray, soft, tough, laminated, speckled throughout, contains small amount of calcareous silt; unit contains three discontinuous nodular layers of limestone, chalky, light olive gray (5Y5/2), weathering yellowish gray (5Y8/1), medium hard, tough, resistant, speckled throughout; FOSSILS, *Inoceramus labiatus*, *Collignoniceras woollgari*, fish remains | 4.4 |
| Total thickness of Fairport Chalk Member | 98.9 |
| Total thickness of Carlile Shale | 284.2 |

GREENHORN LIMESTONE (not measured)

## List of Localities

Measured sections are plotted on Plate 1, and their localities are shown in the inset map thereon.

1. NW¼ sec. 19, T. 17 S., R. 22 W., Ness County. Draw in bluff of tributary to Walnut Creek, 9½ miles northeast of Ness City. Upper part of Blue Hill Member.
2. Center sec. 30, T. 20 S., R. 26 W., Ness County. South bluff of Hackberry Creek, 11 miles south and 2 miles west of Beeler. Upper part of Blue Hill Member.
3. SW¼ SE¼ sec. 3, T. 19 S., R. 22 W., Ness County. Abandoned quarry and ditch on north side of road, 3 miles west-southwest of Bazine. Lower part of Fairport Member.
4. NE¼ NW¼ sec. 6, T. 22 S., R. 24 W., and SW¼ SE¼ sec. 31, T. 21 S., R. 24 W., Hodgeman County. Bluff and road bank along east-west county road, approximately 8½ miles northwest of Jetmore. Middle part of Fairport Member.
5. SE¼ sec. 36, T. 21 S., R. 26 W., and NW¼ sec. 6, T. 22 S., R. 25 W., Hodgeman County. Bluffs along tributary to Pawnee River, approximately 14 miles west-northwest of Jetmore. Lower part of Fairport Member.
6. N½ sec. 2, T. 22 S., R. 29 W., Finney County. Gullies and bluffs on north wall of valley of Pawnee River, 12 miles northwest of Kalvesta. Upper part of Blue Hill Member.
7. NE¼ sec. 11, T. 23 S., R. 24 W., Hodgeman County. Bluff on south wall of Buckner Creek valley, approximately 1½ miles southwest of Jetmore. Lower part of Fairport Member.
8. SW¼ SE¼ sec. 27, T. 22 S., R. 26 W., Hodgeman County. Ditch on north side of county road, 14 miles west and 1 mile north of northwest corner of Jetmore. Middle part of Fairport Member.
9. SW¼ sec. 11, T. 22 S., R. 26 W., Finney County. Bluffs and cut banks along south side of Pawnee River, 7 miles north-northwest of Kalvesta. Upper part of Fairport Member and lower part of Blue Hill Member.
10. Sec. 22 and NE¼ sec. 27, T. 19 S., R. 23 W., Ness County. Banks of intermittent tributary to Walnut Creek and cut on south side of east-west county road, approximately 5½ miles south-southeast of Ness City. Lower part of Fairport Member.
11. SW¼ SW¼ sec. 33, T. 16 S., R. 19 W., Rush County. Cut bank and bluffs on south side of Big Timber Creek, 4 miles north of Hargrave. Middle part of Fairport Member.
12. NE¼ sec. 27, T. 15 S., R. 18 W., Ellis County. Road cut on east side of U.S. Highway 183, approximately 1 mile northeast of Schoenchen. Lower part of Fairport Member.
13. NE¼ SE¼ sec. 21, T. 13 S., R. 19 W., Ellis County. South bluff of Big Creek valley, 6 miles west-northwest of Hays. Upper part of Blue Hill Member and Codell Member.
14. S½ sec. 25, T. 19 S., R. 19 W., Rush County. Stream banks and bluffs of a western tributary to Otter Creek, approximately 8 miles south-southwest of Rush Center. Lower part of Fairport Member.
15. NE¼ sec. 8, T. 17 S., R. 21 W., Ness County. Bluffs in headwaters region of Black Stub Gulch, 10 miles north and 1 mile east of Bazine. Upper part of Blue Hill Member and Codell Member.
16. SW¼ SE¼ sec. 10 and NW¼ NE¼ sec. 15, T. 15 S., R. 20 W., Ellis County. Cut bank on south side of Smoky Hill River, approximately 13½ miles southwest of Hays. Upper part of Fairport Member.
17. NE¼ sec. 21 and N½ sec. 22, T. 15 S., R. 20 W., Ellis County. Stream bank and bluffs on south wall of Smoky Hill River valley, approximately 15 miles southwest of Hays. Upper part of Fairport Member and Blue Hill and Codell Members.
18. SE¼ SE¼ sec. 4, T. 11 S., R. 18 W., Ellis County. Cut bank and bluff of northern tributary to Saline River, 17 miles north of Hays. Upper part of Blue Hill Member and Codell Member.

19. E½ sec. 21, T. 11 S., R. 17 W., Ellis County. Cut banks of southern tributary to Saline River, approximately 16 miles north-northeast of Hays. Upper part of Fairport Member and lower part of Blue Hill Member.
20. NW¼ sec. 32, T. 22 S., R. 42 W., Hamilton County. Bank of intermittent stream and tributary draw, 5 miles north-northeast of Coolidge. Upper part of Fairport Member and lower part of Blue Hill Member.
21. NE¼ sec. 7, T. 23 S., R. 42 W., Hamilton County. Cut bank and bluff of intermittent northern tributary of Arkansas River, 3 miles northeast of Coolidge. Lower part of Fairport Member.
22. SW¼ SW¼ sec. 25, T. 22 S., R. 42 W., Hamilton County. Bluffs on west side of intermittent-stream valley, 8 miles northeast of Coolidge. Upper part of Blue Hill Member and Codell Member.
23. W½ SW¼ sec. 21, T. 11 S., R. 17 W., Ellis County. Gully and bluff on south wall of Saline River valley, approximately 15 miles north-northeast of Hays. Upper part of Blue Hill Member and lower part of Codell Member.
24. SW¼ SE¼ sec. 22, T. 11 S., R. 17 W., Ellis County. Bluff on south wall of Saline River valley, 16 miles north-northeast of Hays. Upper part of Blue Hill Member and Codell Member.
25. SW¼ sec. 29 and SE¼ SE¼ sec. 30, T. 11 S., R. 16 W., Ellis County. Intermittent-stream banks, gullies, and bluffs in south wall of Saline River valley, approximately 5 miles west and 1 mile north of Fairport. Upper part of Fairport Member and Blue Hill and Codell Members.
26. SE¼ sec. 29, T. 11 S., R. 16 W., Ellis County. Banks and bluff of intermittent southern tributary to Saline River, 4½ miles west and 1 mile north of Fairport. Lower part of Fairport Member.
27. NE¼ SE¼ sec. 18, T. 15 S., R. 19 W., Ellis County. Cut bank and tributary draw on south side of Smoky Hill River, 7½ miles west-northwest of Schoenchen. Middle part of Fairport Member.
28. NE¼ sec. 3, T. 11 S., R. 17 W., Ellis County. Gullies and road cut on west side of north-south county road, approximately 4 miles south and ½ mile west of Codell. Upper part of Blue Hill Member and Codell Member.
29. NE¼ sec. 5, T. 13 S., R. 15 W., Russell County. Road cut on Fairport-Gorham road, 5 miles north of Gorham. Lower part of Fairport Member.
30. NE¼ sec. 1, T. 13 S., R. 16 W., Ellis County. Cut bank on south side of small creek, 6 miles north and 2 miles east of Walker. Middle part of Fairport Member.
31. NE¼ sec. 20 and NW¼ sec. 21, T. 9 S., R. 10 W., Mitchell County. Gullies in north face of conspicuous butte in Blue Hills, 5½ miles south and 1 mile east of Tipton. Middle part of Blue Hill Member.
32. SW¼ sec. 24, T. 8 S., R. 12 W., Osborne County. Gullies on south end of prominent mesa, 8 miles south-southeast of Osborne. Upper part of Blue Hill Member and Codell Member.
33. NW¼ sec. 25, T. 7 S., R. 11 W., Osborne County. Cut banks of South Fork of Solomon River and southern tributary, 6 miles south-southeast of Downs. Lower part of Fairport Member.
34. SW¼ sec. 1, T. 8 S., R. 12 W., Osborne County. Cut bank on Twin Creek, approximately 6 miles southeast of Osborne. Middle part of Fairport Member.
35. NW¼ NW¼ sec. 31, T. 7 S., R. 11 W., Osborne County. Cut bank on Twin Creek, 5½ miles east-southeast of Osborne. Middle part of Fairport Member.
36. SE¼ NE¼ sec. 21, T. 7 S., R. 11 W., Osborne County. Cut bank on north side of South Fork of Solomon River, approximately 5 miles south of Downs. Middle part of Fairport Member.
37. NE¼ sec. 1, T. 8 S., R. 12 W., Osborne County. Cut bank on Twin Creek, approximately 6 miles southeast of Osborne. Middle part of Fairport Member.
38. NE¼ sec. 14, T. 8 S., R. 12 W., Osborne County. Cut banks on Twin Creek and intermittent easterly tributary, 6½ miles south-southeast of Osborne. Upper part of Fairport Member and lower part of Blue Hill Member.
39. SE¼ SE¼ sec. 3 and NE¼ NE¼ sec. 10, T. 7 S., R. 13 W., Osborne County. Bluff on north valley wall of South Fork of Solomon River, approximately 3½

miles west-northwest of Osborne. Upper part of Blue Hill Member and Codell Member.

40. NE¼ sec. 18, T. 2 S., R. 6 W., Jewell County. Bluff at south end of dam on Lovewell Lake, approximately 3 miles west-northwest of Lovewell. Upper part of Blue Hill Member and Codell Member.
41. SW¼ sec. 2, T. 2 S., R. 5 W., Republic County. Artificial cut and gulley in south bluff of Republican River valley, approximately 8½ miles north and 2½ miles east of Courtland. Upper part of Fairport Member and lower part of Blue Hill Member.
42. SW¼ SE¼ sec. 9, T. 5 S., R. 7 W., Jewell County. Cut bank and bluff on south side of Buffalo Creek, approximately 4 miles southeast of Jewell. Lower part of Fairport Member.
43. SE¼ SE¼ sec. 16, T. 3 S., R. 7 W., Jewell County. Road cut on north side of U.S. Highway 36, ¾ mile west of Montrose. Upper part of Blue Hill Member and Codell Member.
44. E½ sec. 14, T. 2 S., R. 6 W., Jewell County. Gullies and bluff in south valley wall of White Rock Creek, approximately 1½ miles northeast of Lovewell. Upper part of Blue Hill Member.
45. NE¼ SE¼ sec. 27, T. 5 S., R. 13 W., Smith County. Cut bank on south side of North Fork of Solomon River, 1 mile south of Harlan. Middle part of Blue Hill Member.
46. SW¼ SE¼ sec. 34, T. 4 S., R. 11 W., Smith County. Bluff of west valley wall of Oak Creek, approximately 10½ miles south of Lebanon. Upper part of Blue Hill Member and Codell Member.
47. SW¼ SW¼ sec. 4, T. 15 S., R. 21 W., Trego County. Bluff on south valley wall of Smoky Hill River, approximately 14½ miles southeast of Trego Center. Upper part of Blue Hill Member and Codell Member.
48. N½ SW¼ sec. 25, T. 8 S., R. 12 W., Osborne County. Gullies near base of bluffs on north side of county road, approximately 8½ miles south-southwest of Osborne. Collecting locality in middle part of Blue Hill Member.
49. NW¼ NW¼ sec. 24, T. 7 S., R. 14 W., Osborne County. Cut bank on southern tributary to Medicine Creek, 3 miles west-southwest of Bloomington. Collecting locality in middle part of Blue Hill Member.
50. SE¼ sec. 4, T. 9 S., R. 10 W., Mitchell County. Gullies in slopes of Blue Hills, approximately 3½ miles south-southeast of Tipton. Upper part of Blue Hill Member. This is Morrow's collecting locality for holotypes of *Scaphites carlilensis,* and *Binneyites aplatus.*
51. NE¼ sec. 36, T. 4 S., R. 8 W., Jewell County. Cut bank on Buffalo Creek near southwest corner of Jewell. Collecting locality in middle part of Fairport Member.
52. NW¼ NW¼ sec. 13, T. 2 S., R. 7 W., Jewell County. Exposures on hillside, approximately 4 miles west-northwest of Lovewell. Collecting locality in upper part of Blue Hill Member.
53. NE¼ NE¼ sec. 30, T. 11 S., R. 16 W., Ellis County. Bluff of small tributary to Saline River, approximately 5½ miles west-northwest of Fairport. Collecting locality in upper part of Fairport Member.
54. NW¼ sec. 32, T. 11 S., R. 15 W., Russell County. Exposure at top of bluff overlooking Saline River, approximately 1 mile northeast of Fairport. Collecting locality in lower part of Fairport Member.
55. SE¼ sec. 6, T. 12 S., R. 15 W., Russell County. Exposures along Saline River, 1 mile southeast of Fairport. Collecting locality in lower part of Fairport Member.
56. W½ sec. 36, T. 14 S., R. 22 W., Trego County. Excavation for Cedar Bluff Dam. Collecting locality in upper part of Fairport Member? that is cited by Matsumoto and Miller (1958).
57. SW¼ sec. 31, T. 12 S., R. 15 W., Russell County. Ditch on east side of county road, 6 miles north of U.S. Highway 40. Collecting locality in middle part of Fairport Member.
58. SE¼ sec. 18, T. 12 S., R. 15 W., Russell County. Ditch on east side of county road, 3 miles south of Fairport. Collecting locality in lower part of Fairport Member.

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