The Red Bird Section of the Upper Cretaceous Pierre Shale in Wyoming

GEOLOGICAL SURVEY PROFESSIONAL PAPER 393-A

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By JAMES R. GILL *and* WILLIAM A. COBBAN

With a section on A New Echinoid from the Cretaceous Pierre Shale of Eastern Wyoming

By PORTER M. KIER

STRATIGRAPHY, PALEONTOLOGY, AND SEDIMENTATION OF A CLASSIC REFERENCE LOCALITY OF THE PIERRE SHALE

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Description, environmental interpretation, and correlation of a 3,100-foot-thick sequence of marine shale

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CONTENTS

ILLUSTRATIONS

[Plates 1–4 are in pocket, plates 5–12 follow index]

TABLES

STRATIGRAPHY, PALEONTOLOGY, AND SEDIMENTATION OF A CLASSIC REFERENCE LOCALITY OF THE PIERRE SHALE

THE RED BIRD SECTION OF THE UPPER CRETACEOUS PIERRE SHALE IN WYOMING

By JAMES R. GILL and WILLIAM A. COBBAN

ABSTRACT

The Pierre Shale of Late Cretaceous age (Campanian and Maestrichtian) is well exposed and very fossiliferous in the vicinity of Red Bird in Niobrara County, Wyo. A section measured on the northwest flank of Old Woman anticline, a large fold en echelon to structures of the Black Hills, is here presented as a reference locality for the Pierre Shale of the northern Great Plains. The Pierre Shale is about 3,100 feet thick at Red Bird and consists of dark- to light-gray-weathering noncalcareous clayey to silty shale that is entirely of marine origin. It rests on the chalky Niobrara Formation and is overlain by the Fox Hills Sandstone; both contacts are conformable and gradational. Seven lithologic members compose the Pierre Shale, from oldest to youngest: Gammon Ferruginous Member, Sharon Springs Member, Mitten Black Shale Member, Red Bird Silty Member, a lower unnamed shale member, Kara Bentonitic Member, and an upper unnamed shale member. These members are correlated with named and unnamed members of the Pierre Shale of eastern Colorado, western Kansas, central South Dakota, eastern North Dakota, and southeastern Montana, and with equivalent formations in southwestern Colorado, central Wyoming, Montana, southwestern Alberta, and east-central Texas.

The Gammon Ferruginous Member, which is unusually thin (30 ft) at Red Bird, consists of hard platy-weathering gray shale that contains a few layers of red-weathering siderite concretions and several thin beds of nonswelling bentonite.

The Sharon Springs Member, about 130 feet thick, consists of harder shale than that of the contiguous members. It is dark gray and fissile and forms buttresses and steep-sided gullies. The lower part is rich in organic material and contains many beds of nonswelling bentonite. The thickest bed (3.3 ft), the Ardmore Bentonite Bed, lies at the base. The upper part of the Sharon Springs Member is a little softer than the lower part and contains very little bentonite. There is a layer of gray limestone concretions 35 feet below the top.

The Mitten Black Shale Member differs from the underlying Sharon Springs Member in that it is softer and has many beds of concretions. The Mitten is 938 feet thick at Red Bird and is divisible into three parts. The lowest part, 408 feet thick, is a moderately hard to soft black-gray platy to flaky shale that is locally stained with limonite; it contains numerous dusky-red-weathering ironstone concretions and grayish-orange-weathering septarian limestone concretions, some having cone-in-cone structure. The middle part of the Mitten consists of 184 feet of brownish-gray to gray bentonitic shale that weathers to a gumbo soil bare of vegetation and stained by patches of white alkali. Dusky-red-weathering platy ironstone concretions are common throughout, and a few tan-weathering limestone concretions are present, especially in the upper part. The upper part of the Mitten consists of 346 feet of dark-gray soft flaky shale that has a few ironstone concretions in the lower part and numerous fossiliferous yellowish-brown-weathering limestone concretions throughout.

The Red Bird Silty Member, 607 feet thick, is almost entirely a soft silty shale that weathers a much lighter gray than the adjoining dark-gray members. Yellow-, orange-, and tan-weathering fossiliferous limestone concretions are common. At the top of the member and 284 feet below the top, limestone concretions are so closely spaced that they are nearly continuous in layers.

The lower unnamed shale member, 720 feet thick, consists of thick alternating units of dark-, medium-, and light-gray-weathering shale that give a banded appearance to the outcrop. Fossiliferous limestone concretions are abundant throughout the member. Most weather gray, yellowish gray, or brown, but one conspicuous bed 306 feet below the top weathers bright orange brown. Dusky-red-weathering ferruginous concretions are present at places and are especially noticeable at 140, 205, and 470 feet below the top. About 10 thin layers of bentonite are scattered in the upper two-thirds of the member.

The Kara Bentonitic Member, 36 feet thick, consists mostly of light-olive-gray-weathering silty bentonitic shale. It includes a 6-foot-thick bed of bentonite at the base and thinner beds of bentonite near the top. The bentonite has a high swelling capacity, and it weathers to gumbo soil bare of vegetation. Fossiliferous gray- and brown-weathering limestone concretions are present; a bed of closely spaced concretions at the top of the member forms a ridge.

The upper unnamed shale member, 680 feet thick, is chiefly alternating clay shale, silty shale, and sandy shale that weather different shades of gray. Brown-weathering fossiliferous limestone concretions are common and form well-defined beds. Several beds of bentonite and bentonitic shale are present below the middle of the member. The most conspicuous bed consists of 8 feet of calcareous yellowish-gray highly swelling bentonite and bentonitic shale that weathers to a bare gumbo soil.

Megafossils are abundant in much of the Pierre Shale above the Sharon Springs Member; 158 collections were made from 118 levels. Most of the fossils are mollusks, chiefly ammonites and inoceramids. The order of abundance, according to percentage of collections in which the various groups occur, is baculites, scaphites, and other heteromorph ammonites (32 percent), Mytilacea pelecypods (18 percent), all other pelecypods (17 percent), bryozoans (11 percent), gastropods (10 percent), and all other fossil groups (12 percent). The greatest diversity is in the lower and upper unnamed shale members.

The fossils are ordinarily well preserved, and those in limestone concretions are mostly uncrushed. Most of the cephalopod shells and the inner nacreous layer of *Inoceramus* are aragonitic, especially specimens from above the Red Bird Silty Member. Shell material in specimens from the Red Bird Member and the upper 50 feet of the underlying Mitten Member is partly or entirely transformed to calcite. Two ammonites from the middle

part of the upper third of the Mitten Member are composed entirely of aragonite, whereas shell material in all specimens from the underlying part of the Pierre is completely transformed to calcite. Air chambers of most of the cephalopods are partly or wholly filled with calcite crystals that are white, pale yellow to deep yellow, or light brown to dark brown. Colorless crystals of analcite or colorless, light-brown, or dark-brown crystals of barite encrust calcite crystals in some of the cephalopods; rarely, analcite and barite crystals are attached directly to the chamber walls.

Of the nonmolluscan megafossils, the bryozoans are the most numerous. Nearly all were a pyriporoid type that inhabited the interior of abandoned cephalopod and inoceramid shells. The fact that most of the bryozoans lived attached in only one quadrant of the interior of empty living chambers of the cephalopods suggests that most of the empty shells did not float but lay on the sea floor. The bryozoans grew on the ceiling of the living chamber while mud gradually accumulated on the floor.

Trace fossils are represented by trails in siltstone and by burrows, siltstone tubes, fecal pellets, and raspings on the interior of cephalopod living chambers. Some of these are probably the work of marine worms. Fecal pellets are abundant and usually well preserved in the living chambers of cephalopods. Most are simple ovoids probably produced by sediment-eating polychaetes.

The excellent ammonite record at Red Bird provides a rare opportunity to evaluate the range zones of certain key species. Beginning at the base of the Sharon Springs, 18 zones of ammonites can be recognized. The total footage of strata at Red Bird in which each species has been found is measured, and the total footage in which the species should be found is estimated. The thinnest range zone is that of *Didymoceras stevensoni* (30 ft), and the thickest is that of the early form of *Baculites perplexus* (525 ft). An analysis of published potassium-argon dates for rocks that can be correlated with the Pierre Shale at Red Bird suggests that the Pierre Shale spans about 12 million years (69½ to 81½ million years ago), and that each ammonite zone spans about ½ million years.

The position of the western strandline of the Upper Cretaceous epeiric sea changed considerably from time to time during the deposition of the Pierre Shale at Red Bird. It was as far away as 200 miles during Gammon time and as near as 60 miles during the deposition of the upper part of the Red Bird Silty Member and the upper part of the upper unnamed shale member.

The sea at Red Bird was probably never deep. Evidence of current or wave activity and indications that the distance to land to the west was fairly short suggest depths of less than 200 feet during deposition of all the Pierre Shale younger than the Sharon Springs Member. Depths greater than 200 feet seem likely during the deposition of the Gammon and Sharon Springs Members because the distance from shore was greater, there are many thin pure layers of bentonite, and oriented or fragmented shells are lacking.

Fossils from most of the Pierre Shale at Red Bird show effects of dissolution. The dissolution probably occurred in the sea before burial of the fossils, as indicated by differential etching of protected and unprotected parts of the shells. A low pH value for the sea water seemingly caused the dissolution. Attached organisms (chiefly bryozoans) protected molluscan shells from as much as 0.1 mm of corrosion. Data presented suggest that a young adult baculite shell probably would dissolve completely within 4.5 years if it were not buried; thus, deposition of the shale must have been moderately rapid to prevent complete dissolution of the shells. The rate of sedimentation required to bury the shells is much faster than the rate of only 0.10485 mm of rock per year that has been calculated by dividing the thickness of the Pierre by its age span.

Abstract of section "A New Echinoid from the Cretaceous Pierre Shale of Eastern Wyoming," by Porter M. Kier.—A new genus, *Eurysalenia*, of the family Acrosaleniidae is here described from the Pierre Shale of Wyoming. Hundreds of specimens of the type species, *Eurysalenia minima* Kier, new species, occur in a limestone concretion. The concentration of specimens may have been caused by the crowding of the echinoids to spawn or to feed upon a large dead animal.

INTRODUCTION

The Pierre Shale is well exposed and very fossiliferous near the Red Bird store in Niobrara County, Wyo. It is the only known stratigraphic section in the Montana–Wyoming–South Dakota part of the Great Plains province in which all the Pierre Shale can be seen within a distance of 1 mile. Because of its excellent exposures, its remarkable fossil record, and its ready accessibility, the section near Red Bird is here selected for measurement as a reference locality for the Pierre Shale of the northern Great Plains. The section is located 1½–2½ miles northeast of the Red Bird store and 1–2½ miles east of U.S. Highway 85 (fig. 1). The Red Bird store and filling station is on the old highway that extends from the present U.S. Highway 85 northeastward to U.S. Highway 18. Red Bird is shown on many road maps and is on the U.S. Army Map Service 2° sheet (NK 13-2, Newcastle). Although the old highway has been abandoned for many years by the Wyoming State Highway Commission, it still serves (1964) as a shortcut for travel to the south side of the Black Hills.

The excellent exposures of the Pierre Shale near Red Bird were noticed by H. A. Tourtelot and J. R. Gill in 1957 during a study of aerial photographs. In May 1958, two planetable traverses, about half a mile apart, were made across the outcrop of the Pierre Shale by Tourtelot and Gill accompanied by C. S. Robinson and W. J. Mapel. Later in the summer the section was measured in more detail with a Jacob's staff by W. A. Cobban. Many of the original wood stakes marking instrument stations, turns, and rod shots were replaced by numbered brass-capped steel stakes in 1962; the locations of these are shown in figure 4, and their stratigraphic positions are indicated in the "Detailed Measured Section."

In 1958, 88 samples were collected for thin sections, standard rock analyses, and X-ray analyses, and for the determination of heavy minerals, FeO, and Ca : Mg ratios. An additional 30 samples were collected for palynological determinations. Megafossils were collected by Tourtelot and Gill in 1957, and by Tourtelot, Gill, Robinson, Mapel, and Cobban in 1958. Two

FIGURE 1.—The Red Bird area, Niobrara County, Wyo., showing color contrasts between units in the Pierre Shale, and the location of plane-table traverses and a subsurface control point, the Texas Eastern Transmission Co. 1 Federal oil and gas test well. The area of figure 4 is enclosed by hachures. Aerial photograph by U.S. Army Map Service.

beds (units 46 and 54 of the "Detailed Measured Section") were searched extensively for heteromorphic ammonites later in 1958 by Cobban and G. R. Scott. Many collections were made by Gill and Cobban in 1959, and in 1960 fossils were collected by Gill and Cobban and L. G. Schultz from certain beds that had not yielded many fossils previously. In 1962 the section was sampled approximately every 10 feet for the foraminiferal content by J. R. Mello, assisted by R. E. Burkholder, and during this time additional megafossil collections were made by Gill and Cobban. In all, there are 158 megafossil collections, representing 118 levels.

Photographs of fossils were made by R. E. Burkholder and E. P. Krier of the U.S. Geological Survey. Photographed specimens are in the U.S. National Museum in Washington, D.C. H. A. Tourtelot made all the calcite and aragonite X-ray determinations and greatly aided the authors in many other aspects of the study.

EARLIER WORK

The Red Bird section was measured on the northwest flank of the Old Woman anticline (fig. 2), a large fold lying southwest of the Black Hills and trending north to slightly east of north en echelon to other folds along the south and southwest flanks of the Black Hills uplift. The geology of the Old Woman anticline was first described by Darton (1901, p. 552–554, pl. 91), who presented a small colored geologic and topographic map of the fold and showed its relation to the Black Hills uplift by a structure contour map. Darton noted that "The area is one in which the exposures are extensive and the steep dips on the west side of the flexure afford an excellent opportunity to obtain measurements of all of the Cretaceous formations from Lakota to Fox Hills." In a later report, Darton (1918, p. 24, 25) again described the Old Woman anticline and showed a simplified geologic map and cross section. Horton (1953) mapped the structure in more detail. Later Dobbin, Kramer, and Horn (1957) mapped the anticline and the surrounding region at a scale of 1:125,000 (½ inch=1 mile). In 1962 Gill and Cobban gave the name Red Bird Silty Member to the middle part of the Pierre Shale of the Black Hills region and designated and described the type stratigraphic locality, which is 2¼ miles northeast of the Red Bird store.

GEOGRAPHIC AND GEOLOGIC SETTING

REGIONAL SETTING

During the Late Cretaceous a broad north-south-trending epicontinental sea covered much of the Western Interior of the United States. This sea extended from the Gulf of Mexico to the Arctic Ocean (Reeside, 1957, p. 505). Three facies belts have been recognized in rocks deposited in this sea in the northern part of the Western Interior (Tourtelot, 1962, p. 3, 9). They are (1) an eastern facies belt consisting of shale and marlstone; (2) a central facies belt of marine shale and minor amounts of marine sandstone; and (3) a western facies belt consisting of alternate units of marine and nonmarine rocks. The Red Bird area, on the southeast flank of the Powder River Basin in east-central Wyoming (fig. 2), lies in the central facies belt, and the rocks exposed there are representative of the Pierre Shale throughout the central part of the Western Interior.

LOCAL SETTING

The Old Woman anticline (fig. 2) forms a north-trending wooded ridge that is conspicuous in the plains area southwest of the Black Hills. This ridge, earlier known as Old Woman Butte, rises some 500 feet above the valley of Old Woman Creek, an intermittent stream that bounds it on the west. Sandstone beds in the Inyan Kara Group of Early Cretaceous age crop out extensively along the axis of the anticline, and the resistance of these sandstones to erosion has produced the "butte."

Old Woman anticline is an asymmetric fold that dips steeply on the west flank and gently on the east. Nearly horizontal Tertiary strata mask the south end of the fold. Upper Cretaceous rocks exposed along the west, north, and east flanks are chiefly soft shales that tend to form subdued topography. Two harder units, the Greenhorn Limestone and the Turner Sandy Member of the Carlile Shale (upper Cenomanian–upper Turonian), form low ridges that outline the anticline. The area enclosed by the ridge of Greenhorn is about 3 or 4 miles wide and about 11 miles long. All the Pierre Shale and much of the overlying Fox Hills Sandstone are exposed on the steep-dipping west flank. The axis of the fold trends largely northward in the higher and main part that lies to the south, but farther north the axis curves and plunges gently northeastward. The Pierre Shale was measured on the west side of the northeastward-plunging nose of the anticline, where it is well exposed in gullies that drain southwestward into Old Woman Creek. The strike of the beds is about N. 30° E. in most of the area of the section, and the dip ranges from about 30° in the lower part of the Pierre to as much as 60° in the upper part. Part of the map of Dobbin, Kramer, and Horn (1957) is reproduced in this report (fig. 2) to show the local geologic setting of the Red Bird area.

CONTIGUOUS FORMATIONS

The Pierre Shale at Red Bird rests conformably on the marine Niobrara Formation, which in the Black Hills area is a soft white-weathering chalky shale. According to Horton (1953, p. 66), the Niobrara Formation is 264 feet thick on the west side of the Old Woman anticline in the E½ sec. 8, T. 36 N., R. 62 W., 9½ miles south of Red Bird. Only the upper 65 feet of the Niobrara was measured by the authors of this report in the Red Bird section. The rocks are well exposed in a steep-sided ravine in the NW¼SE¼ sec. 13, T. 38 N., R. 62 W. Most of the Niobrara measured is chalky, but the upper 14 feet is darker than the underlying part and consists of beds of slightly calcareous shale alternating with beds of very calcareous shale. The more calcareous beds contain abundant white calcareous specks. A thin layer of bentonite appears at the base of this shale unit, and there are several thin layers in the underlying chalky part of the formation.

The Pierre Shale grades upward into the Fox Hills Sandstone, a shallow-water marine sandy unit. Stanton (1910, p. 184, 186) measured a thickness of 505 feet near Buck Creek, 15 miles southwest of Red Bird; and 400 feet at the mouth of Lance Creek, 9 miles north of Red Bird. The figure for the thickness of the formation at the mouth of Lance Creek was altered to 357 feet by Dobbin and Reeside (1929, p. 19–20) and reduced further to about 300 feet by Dorf (1942, p. 90–91). Near Buck Creek the Fox Hills consists of a lower yellow massive sandstone containing brown fossiliferous sandstone concretions, a middle unit of sandy shale and thin-bedded sandstone, and an upper unit of yellow and white massive sandstone. At Red Bird the lower massive sandstone forms a conspicuous ridge, and the "Detailed Measured Section" includes measurements up to the top of this ridge. Transition beds underlying the massive sandstone were included in the Pierre Shale by Stanton (1910), Dobbin and Reeside (1929), and Dorf (1942). The transition beds are assigned to the Fox Hills in this report.

RÉSUMÉ OF THE PIERRE REFERENCE LOCALITY AT RED BIRD

When the reference locality of the Pierre Shale at Red Bird was originally measured by Tourtelot, Gill, Mapel, and Robinson, two planetable traverses using the double-rod method were made across the outcrop perpendicular to the strike of the beds (fig. 1 and pl. 1). The instrument stations (except 9 and 10) are now marked with numbered brass-capped iron stakes or pipe to facilitate future recovery of the section, and principal turn points are marked with wood stakes as shown on the map (pl. 1). The position of samples collected for chemical analyses and mineralogic study was noted, and collections of fossils were located during planetabling. Originally two sections were compiled from the two transects across the outcrop. The southern transect, herein called the A traverse, started with instrument station 1 in the lower part of the Mitten Black Shale Member of the Pierre Shale and extended westward across the N½ sec. 23 to instrument station 4 near the Pierre–Fox Hills contact. The northern, or B traverse, started at instrument station 6, located on the upper unnamed member of the Pierre Shale in about the center of sec. 14, and continued eastward to about the center of sec. 13.

The main purpose of the planetable traverse was to establish the position of the larger distinctive lithologic units within the Pierre Shale and to determine their gross thickness. Dips were taken with a Brunton compass on concretion layers and in some places on the bedding planes of the shale. Rubey (1930, p. 39) drew attention to the difficulties of obtaining true dip measurements in the Upper Cretaceous shales of the Black Hills region. The general tendency is to record dips several degrees greater than true dip. Dips shown on the map (pl. 1) are generally an average of several readings. Thicknesses of units shown on the columnar reference section (pl. 2) and in the text were determined by the authors from calculated thicknesses along the A and B planetable traverses and from supplemental Jacob's-staff measurements of many of the more distinctive units. The U.S. Geological Survey Mesozoic localities at which megafossils were collected during the period 1958–62 are located on the map (pl. 1) in reference to the original 1958 planetable survey. Thicknesses of the Niobrara Formation, the Gammon, and Sharon Springs Members of the Pierre, and the lower part of the Mitten Member were determined solely by Jacob's-staff measurements.

In July 1958, Texas Eastern Transmission Co. drilled its 1 Federal oil and gas test well in the center SW¼NW¼ sec. 15, T. 38 N., R. 62 W., Niobrara County, Wyo. This test hole, about a mile west of the Red Bird section (fig. 1), started in virtually horizontal beds of the Fox Hills Sandstone and penetrated about 3,050 feet of beds that are assigned in this report to the Pierre Shale (pl. 2). This thickness is 87 feet less than was measured for the Pierre Shale on the surface.

The following summary gives the location of the members of the Pierre in the Red Bird section and the

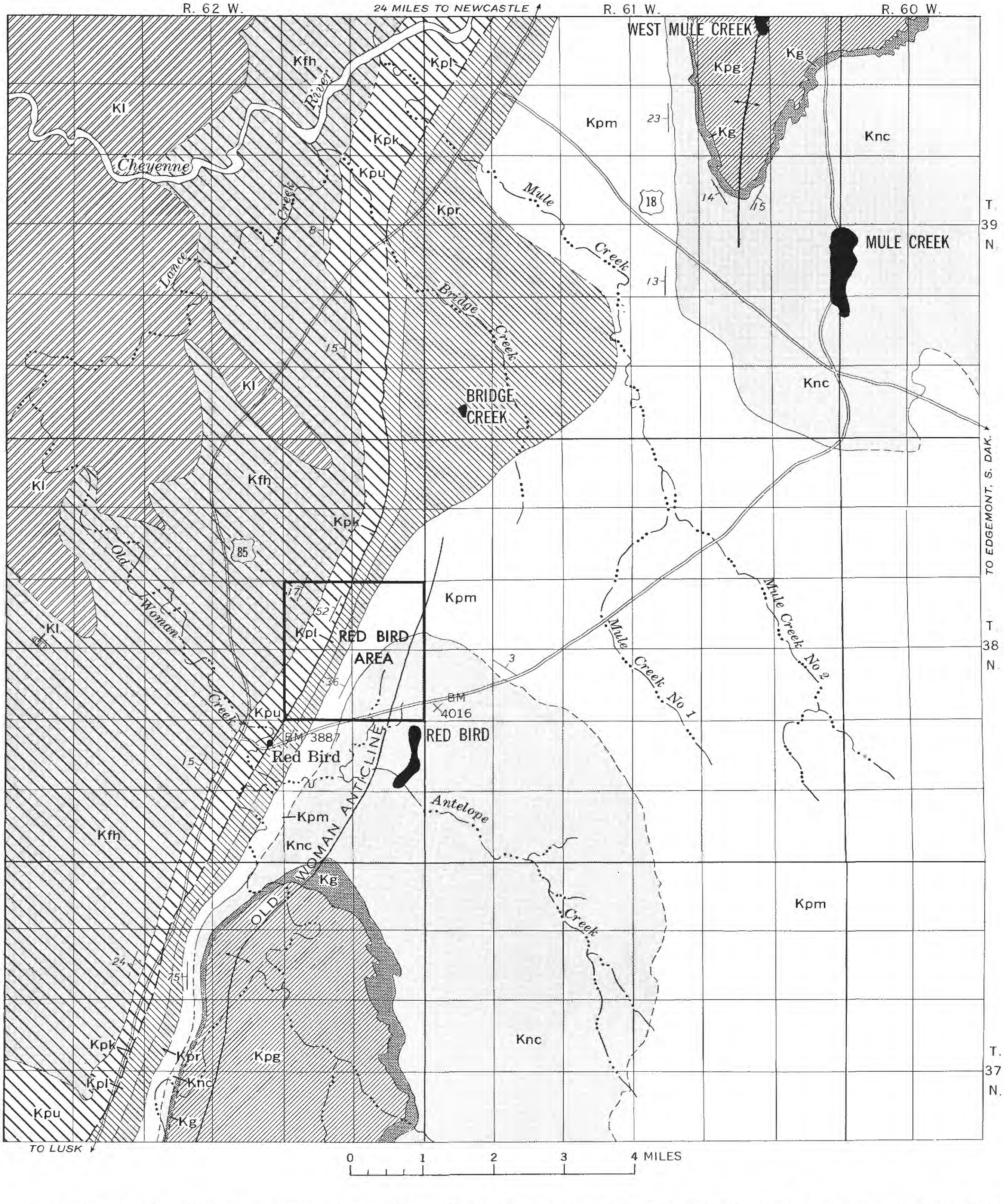
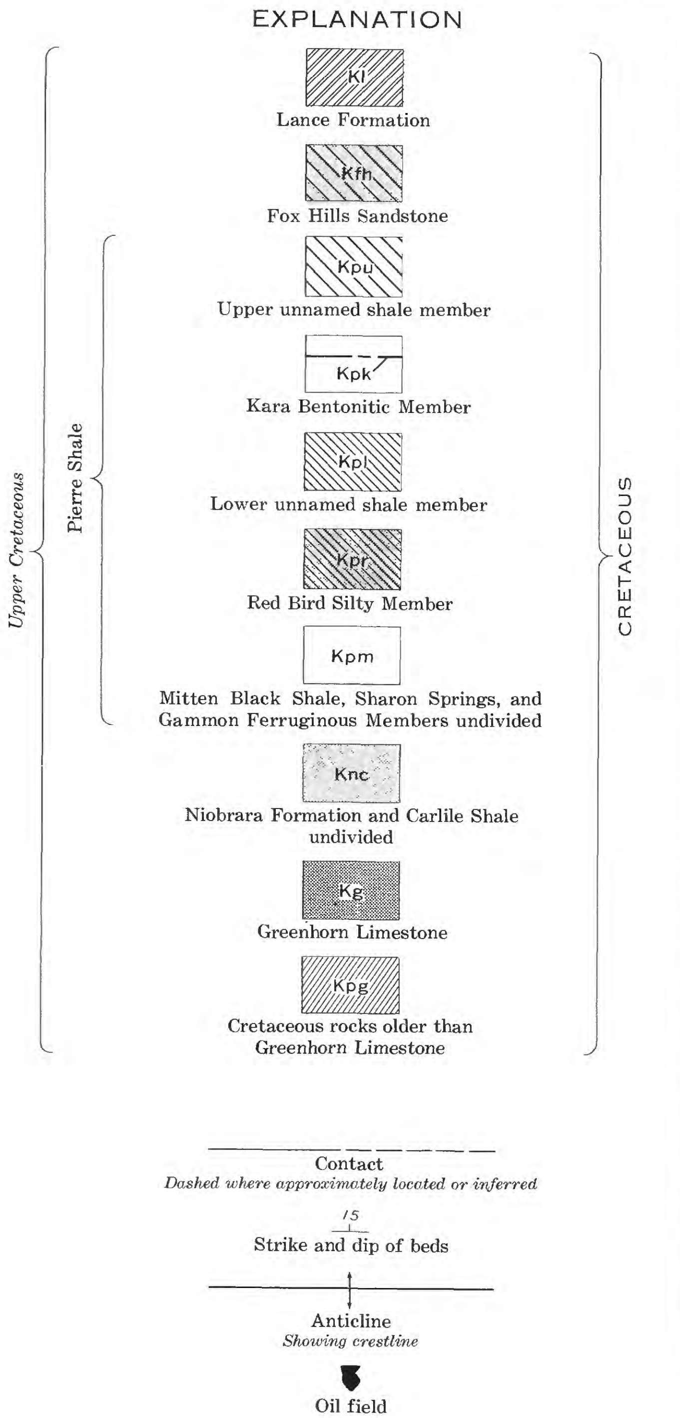


FIGURE 2.—Location of Red Bird area, Niobrara County, Wyo. Distribution of the subdivisions of the Pierre Shale is based on the authors' from Dobbin, Kramer, and Horn (1957).



interpretation of aerial photographs; other geologic data are modified

method used in determining their thicknesses. The upper part of the Niobrara Formation was measured by Jacob's staff in the NE¼NW¼SE¼ sec. 13; the lower part of the Fox Hills Sandstone was measured by planetable on A traverse.

Member	*Thickness (feet)*	*Location*	*Method of measurement*
Upper unnamed shale.	680	B traverse	Planetable and Jacob's staff.
Kara Bentonitic Member.	36	A traverse	Jacob's staff.
Lower unnamed shale.	720	A and B traverse.	Planetable and Jacob's staff; lower 330 ft by Jacob's staff on B traverse; upper 390 ft by Jacob's staff on A traverse.
Red Bird Silty Member.	607	B traverse	Planetable and Jacob's staff.
Mitten Black Shale Member:			
Upper part	346	do	Do.
Middle part	274	A traverse	Do.
Lower part	318	do	Do.
Total Mitten Black Shale Member	938	A traverse	Planetable.
Sharon Springs Member.	127	NE¼NW¼ SE¼ sec. 13.	Jacob's staff.
Gammon Ferruginous Member.	30	NE¼NW¼ SE¼ sec. 13.	Do.
Total Pierre Shale.	3, 138		

GAMMON FERRUGINOUS MEMBER

The Gammon Ferruginous Member of the Pierre Shale was named by Rubey (1930, p. 4) for exposures of dark-gray mudstone and bentonitic claystone containing abundant red-weathering siderite concretions. These exposures form the basal 800 feet of the Pierre along Gammon Creek on the northwest flank of the Black Hills in T. 57 N., Rs. 67 and 68 W., Crook County, Wyo. In that area, the Gammon contains in its upper part a 50- to 150-foot-thick sequence of sandstone, sandy shale, and siltstone named by Rubey (1930, p. 4) the Groat Sandstone Bed. The Groat is restricted to the northern and northwestern parts of the Black Hills. The Gammon thins southwestward from the type locality by interfingering with the Niobrara Formation, as well as locally by truncation by the overlying Sharon Springs or Mitten Black Shale Members. At the south end of the Black Hills, the Gammon ranges in thickness from a maximum of about 110 feet along the Cheyenne River near Hot Springs, S. Dak., to about 30 feet at Red Bird.

In the Red Bird map area (pl. 1), the Sharon Springs and Gammon Members and the upper part of the Niobrara Formation are well exposed in the SE¼ sec. 13, as shown in figure 3, and nearby in the S½ sec. 18, T. 38 N., R. 61 W.

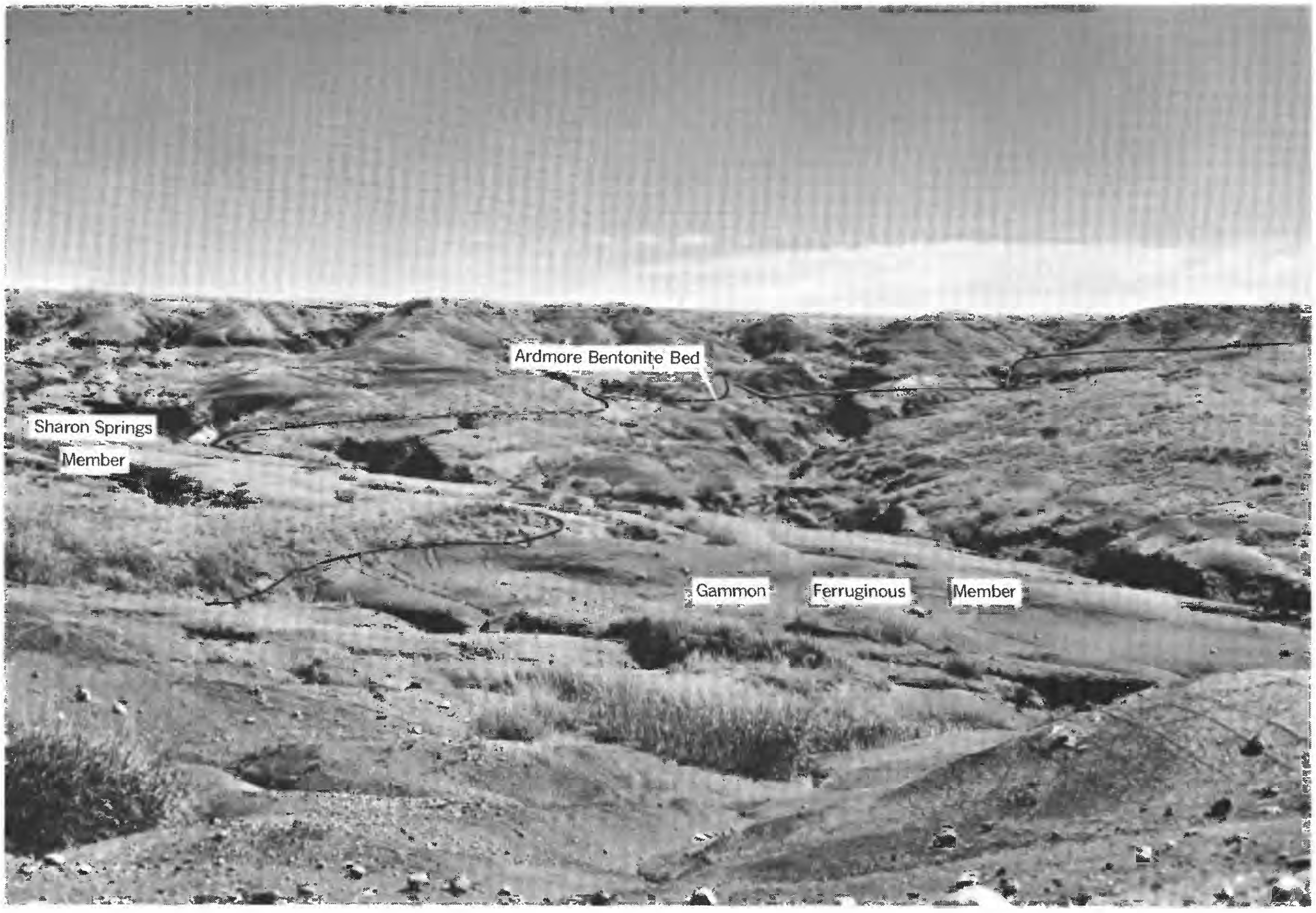


FIGURE 3.—Gammon Ferruginous and Sharon Springs Members of the Pierre Shale exposed on the northward-plunging nose of the Old Woman anticline at the Red Bird section. View is northeast from instrument station 9 in the center sec. 13, T. 38 N., R. 62 W., Niobrara County, Wyo.

At Red Bird, the Gammon consists of dark hard platy-weathering noncalcareous shale that contains a few layers of widely separated red-weathering siderite concretions and several thin beds of pale-yellow nonswelling bentonite. The member generally weathers to a smooth, rounded bald outcrop. The shale is considerably harder than the soft bentonitic claystones and mudstones typical of the Gammon of the northern Black Hills. The greater hardness at Red Bird is probably due to the slower rate of deposition prevailing at a greater distance from the western source of the Gammon sediments. At Red Bird, where the Gammon is thin and siderite concretions are rare, the unit is similar in gross appearance to the overlying Sharon Springs, but the Gammon is slightly softer, is lighter in color, and contains somewhat less organic material. There appears to be a gradual increase in hardness in the upper few feet of the Gammon at some localities, a condition that makes the contact with the overlying Sharon Springs difficult to determine.

Locally, the Gammon has a banded appearance due to rusty-weathering shale beds containing siderite concretions. The concretions weather to thin plates and angular fragments (fig. 4), and where these are particularly abundant the outcrop has the red tinge that led Rubey (1930, p. 3) to apply the adjective "ferruginous" to his description of the Gammon.

The Gammon Member has not been formally recognized in outcrops along the Missouri River in South Dakota, although it is probably represented in part, by beds assigned to the lower part of the Sharon Springs and by chalky beds in the upper part of the Niobrara Formation in this area. Westward from Red Bird the Gammon thickens at a rate of about 18 feet per mile across the Powder River Basin, and it is over 1,800 feet thick in the Salt Creek oil field. The westward thickening is accompanied by a decrease in hardness and an increase in abundance of siderite concretions, changes that also occur between Red Bird and the northern Black Hills.

SHARON SPRINGS MEMBER

Distinctive rocks that represent the Sharon Springs Member of the Pierre Shale were first recognized in the southern part of the Black Hills by Darton (1902, p. 4),

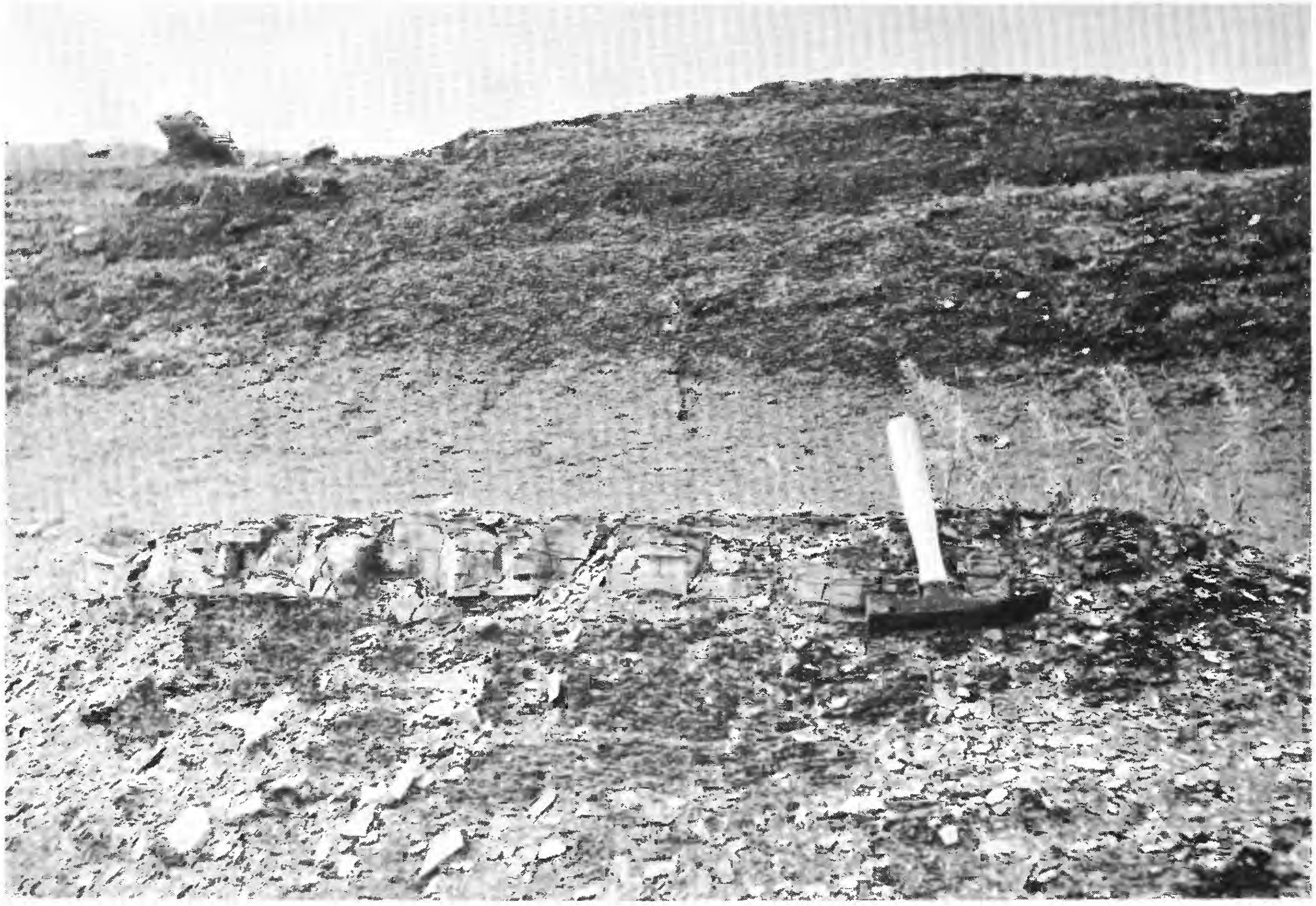


FIGURE 4.—Slabby red-weathering siderite concretions typical of the Gammon Ferruginous Member of the Pierre Shale. View is westward in about the center of sec. 13, T. 38 N., R. 62 W., Niobrara County, Wyo.

who described them as follows: "At the base of the formation, overlying the Niobrara chalk, there is always a very distinct black, splintery, fissile shale about 150 feet thick * * *." Darton described the septarian limestone and cone-in-cone concretions that are common in this shale in the South Dakota part of the Black Hills, but he did not mention the numerous beds of nonswelling bentonite. Wherry (1917) described these bentonite beds as clay derived from volcanic dust and presented columnar sections showing correlation of the beds around the south end of the Black Hills in South Dakota and Wyoming.

In 1931 Elias named the Sharon Springs Member of the Pierre Shale for exposures of hard buttress-forming shale, rich in organic material, in the lower part of the Pierre Shale in Wallace and Logan Counties, Kans. In 1938 Searight (p. 137) introduced the name into central South Dakota. Later, Moxon, Olson, and Searight (1939, p. 20–21) applied the name Sharon Springs to the basal sequence of hard dark shale that had been observed by Darton in the southern part of the Black Hills, and they described it as follows:

The lower Sharon Springs consists of dark nearly black beds of bituminous fissile shale which weather to dark brown. This part of the member weathers back less rapidly than the upper zone and forms relatively steep valley walls and escarpments of buttresslike appearance * * *. Thin beds of bentonite occur along the Missouri River and eastward but around the Black Hills they reach thicknesses up to three feet. The thickest bentonite bed occurs near the top in the Black Hills region * * *.

The upper Sharon Springs is somewhat similar to the lower zone but is much less fissile. Concretions, uncommon in the lower zone, are abundant in the upper zone * * *.

At Provo, Fall River County, the lower zone is about 95 feet thick * * *. The upper zone is at least this thick, around the southern Black Hills.

In the above account the Gammon Ferruginous and the Mitten Black Shale Members of the Pierre, as described in the present report, seem to be designated as lower and upper parts, respectively, of the Sharon Springs.

Spivey's study (1940) of bentonite in the lower part of the Pierre Shale in southwestern South Dakota was confined largely to the evaluation of a group of bentonite beds occurring in a zone 15–20 feet thick, beginning some 60–70 feet above the base of the Pierre. He made no attempt to subdivide the Pierre into members as had been proposed by previous geologists, but he did formally name the bentonite bed then being quarried at Ardmore, S. Dak. (sec. 8, T. 12 S., R. 4 E., Fall River County). Spivey (1940, p. 3) stated:

> In Fall River County the bentonite zone has eight to twelve beds separated by shale. The lowest bed of the zone is about eight inches thick on the average and is almost invariably brown in color. The next overlying bentonite bed averages a little over 3 feet in thickness and since this bed is the one being quarried on a commercial scale at Ardmore, it is designated the Ardmore bed in this report.

The present authors have recognized this bentonite over a wide area in western South Dakota, central and eastern Montana, and eastern Wyoming and Colorado, and the name Ardmore Bentonite Bed of the Sharon Springs Member of the Pierre Shale is here used for the bed at Red Bird. Spivey's definition is amended here to include as a part of the Ardmore the underlying thin shale parting and the 8-inch-thick bentonite in Fall River County with its equivalents elsewhere. In addition, the Ardmore Bentonite Bed is designated the basal unit of the Sharon Springs Member of the Pierre Shale where the member has been recognized in South Dakota, Wyoming, and Montana; in the area near Chadron in northwestern Nebraska; and along the Front Range in northern Colorado. This usage agrees with that implied by Tourtelot (1956, p. 65, fig. 2) and adopted by Connor (1963, p. 115), and the contact chosen is reasonably close to that of Kepferle (1959, p. 580, fig. 85).

Figure 5 shows the Sharon Springs outcrop near Ardmore, S. Dak., the type locality of the Ardmore Bentonite Bed of the Sharon Springs Member. This outcrop is typical for the Black Hills area and illustrates the subtle differences between the Gammon, Sharon Springs, and Mitten Members of the Pierre. A concretion layer in the lower part of the Ardmore Bentonite Bed at the type locality at Ardmore is moderately fossiliferous and contains well-preserved specimens of

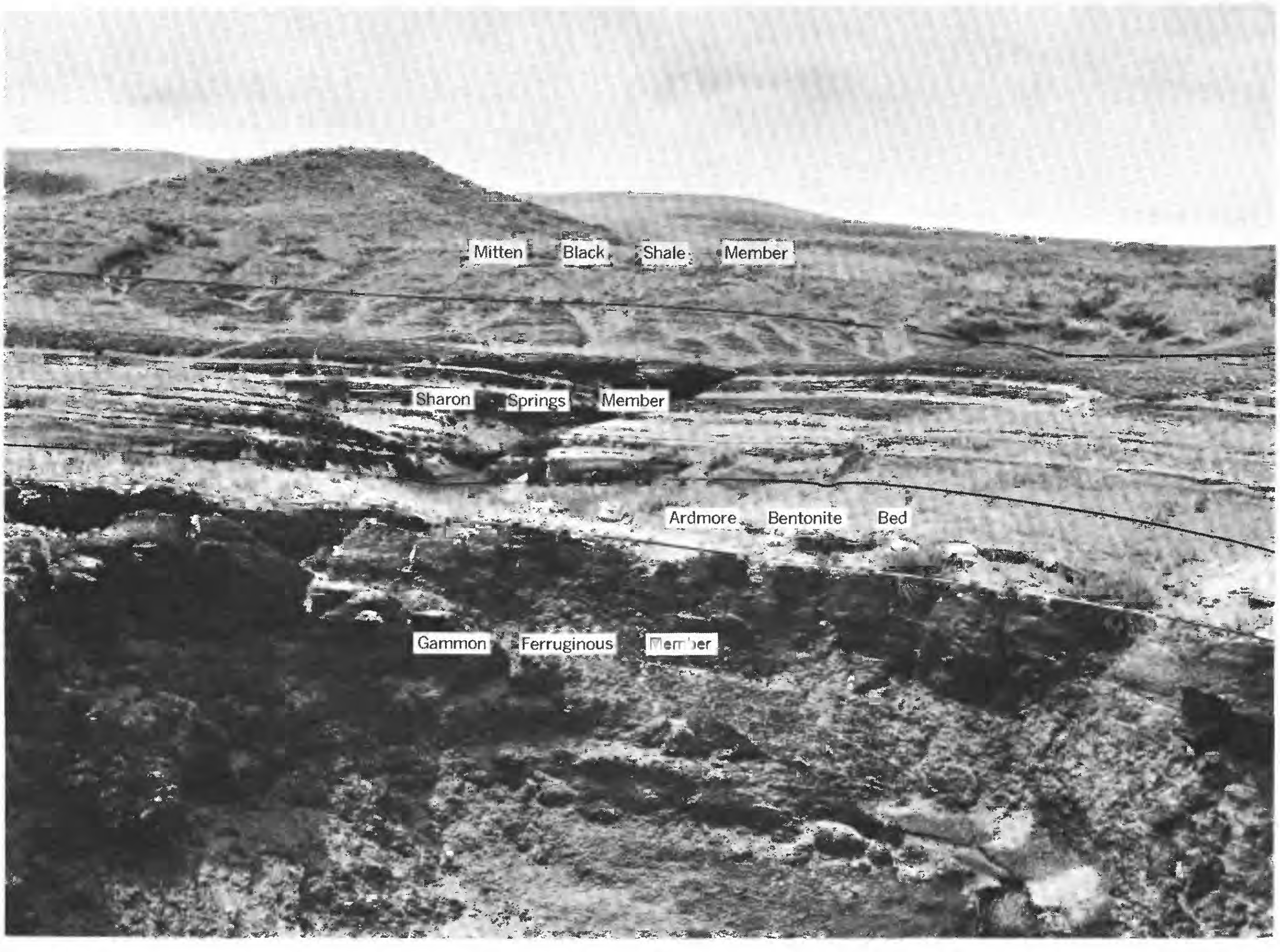


FIGURE 5.—Type locality of the Ardmore Bentonite Bed of the Sharon Springs Member of the Pierre Shale. The Ardmore Bentonite Bed marks the contact between the hard fissile shale of the Sharon Springs and the dark platy shale of the Gammon; the thin shale parting in the lower part of the Ardmore contains light-gray-weathering black limestone concretions from which *Baculites obtusus* was collected (USGS Mesozoic loc. D1851). Contact between the Sharon Springs and Mitten Black Shale Members is at the change from hard fissile shale to softer rusty-weathering shale. View is southwestward in the NW¼ sec. 8, T. 12 S., R. 4 E., Fall River County, S. Dak.

Baculites obtusus. This guide fossil is rarely well preserved elsewhere in the Sharon Springs, but it is abundant in time-equivalent but less organic-rich beds in areas on the west side of the Powder River Basin. At Red Bird, the Ardmore Bentonite Bed is 3.3 feet thick, and as at Ardmore, it is overlain by hard buttress-forming dark shale. Figure 6 shows the basal part of the Sharon Springs at Red Bird.

In the Red Bird area the Sharon Springs Member is well exposed and is typical of the unit throughout the Black Hills region except that the large white-weathering limestone concretions so common in the unit on the southeast side of the Black Hills are lacking. Where the Sharon Springs is moderately to steeply tilted, it weathers into striking stairsteps, the risers of which are formed by beds of soft bentonite (fig. 5). This characteristic is particularly well shown about 7 miles east of Red Bird (fig. 7). Where the beds are horizontal, the lower buttress-forming, more organic-rich shale forms steep-walled gullies, and the overlying softer part of the member weathers back in gentle slopes. At this locality and at many others, the shale disintegrates into a mantle of papery flakes that are blown about by the wind to form extensive dunes. Shale dunes are the only part of the Sharon Springs bedrock or residuum that supports much vegetation. This lack of soil is fortunate from an agricultural standpoint, because, as Moxon, Olson, and Searight (1939, p. 91) pointed out, the Sharon Springs Member is consistently highly seleniferous, and if it readily formed soil, the vegetation growing on it would be poisonous.

The upper part of the Sharon Springs consists of dark-gray to grayish-black shale that weathers silvery gray and papery. It forms a smooth, flake-littered, bald outcrop. This shale is somewhat softer than that in the lower part of the member but is slightly harder than the shales of the overlying Mitten Black Shale Member. Concretions are scarce in the Sharon Springs in the Red Bird area, but a layer of small gray limestone concretions crops out 35 feet below the top of the member, and there is a thin layer of grayish-orange phosphate nodules about 50 feet above the base. Vertebrate fossil remains are abundant in the Sharon Springs, and rocks of this unit have yielded several museum specimens.

The Sharon Springs Member and its lateral equivalents can be readily recognized on electric and gamma-

FIGURE 6.—Black shale and bentonite (light bands) in the basal part of the Sharon Springs Member of the Pierre Shale at the Red Bird section. The man is standing on the contact between the Ardmore Bentonite Bed at the base of the Sharon Springs and the underlying Gammon Ferruginous Member. View is northeastward in the NW¼NW¼SE¼ sec. 13, T. 38 N., R. 62 W., Niobrara County, Wyo.

ray logs of oil and gas test holes throughout much of eastern Colorado, western Kansas, Nebraska, North and South Dakota, and eastern Wyoming and Montana. The abnormal radioactivity of the shales rich in organic material in the Sharon Springs has been described by Tourtelot (1956), Kepferle (1959), and Landis (1959), and seems to be closely related to the organic content of the shale. Kepferle's data (1959, p. 592) indicate that the radioactivity of the Sharon Springs increases eastward from eastern Wyoming to central South Dakota, a change he attributed to an increase in organic matter for a given volume of shale.

On electric and gamma-ray logs the position of the Ardmore Bentonite Bed and the adjacent overlying shales and interbedded bentonites is shown by a marked decrease in radioactivity and resistivity (fig. 8). The contrast is most striking in the areas in which the organic content of the Sharon Springs is high. Induction or conductivity logs (fig. 8) are similar to resistivity logs in their response but indicate more precisely the presence of highly conductive beds of bentonite. In areas west of Red Bird, where organic-rich shales of the Sharon Springs are absent, induction and resistivity logs are useful in determining the position of the Ardmore and associated beds of bentonite.

MITTEN BLACK SHALE MEMBER

The Mitten Black Shale Member of the Pierre was named by Rubey (1930, p. 3) for exposures along Driscoll Creek, known locally as Mitten Prong, in sec. 22,

FIGURE 7.—Flat-lying beds of the Sharon Springs Member and the lower part of the Mitten Black Shale Member of the Pierre Shale in the Red Bird area. Bentonite beds in the lower part of the Sharon Springs are largely covered by a talus of papery shale flakes that are blown about by the wind, ultimately accumulating in grass-covered dunes as shown in the foreground. Veiw is eastward in sec. 1, T. 38 N., R. 61 W., Niobrara County, Wyo.

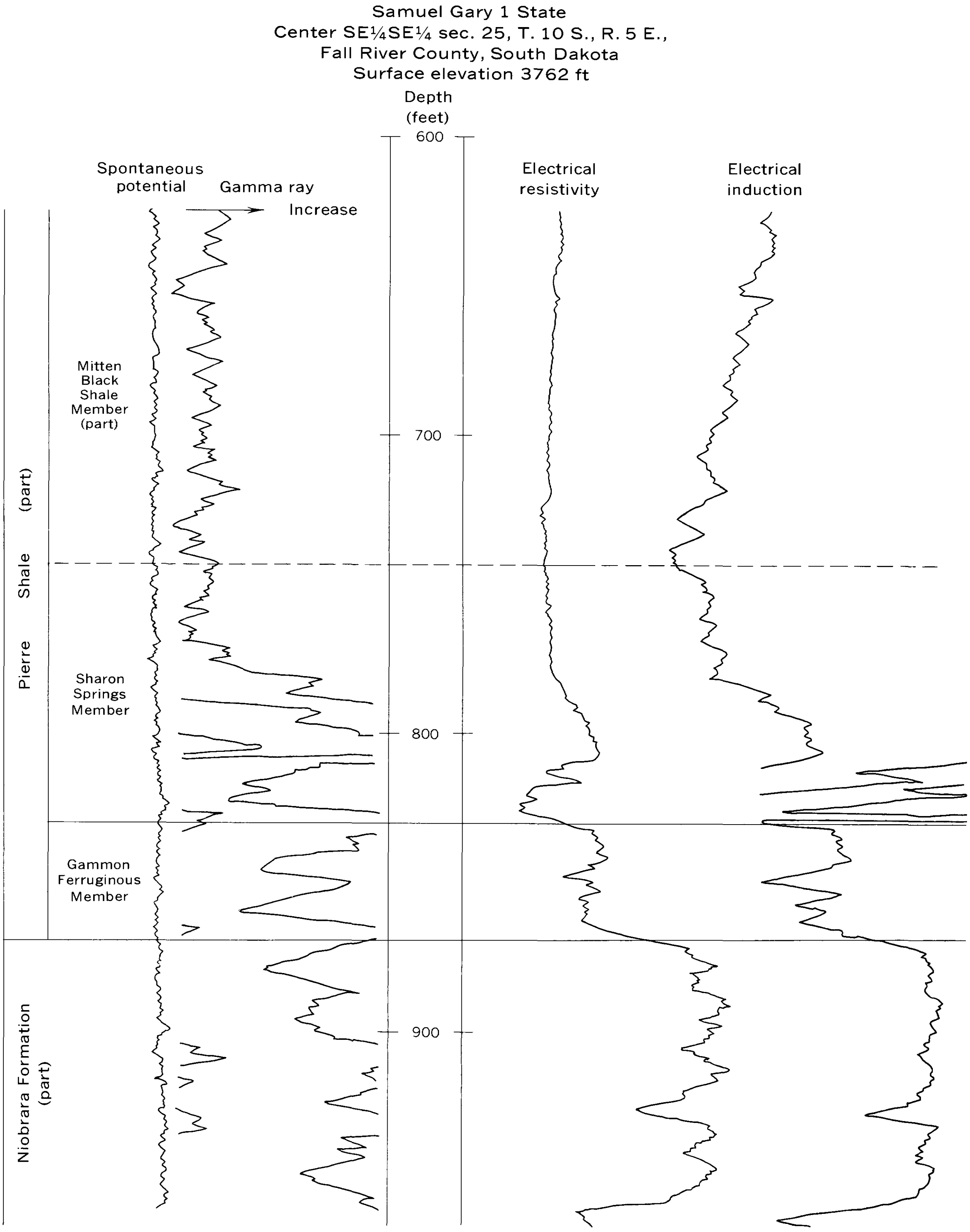


FIGURE 8.—Electric and gamma-ray log of Samual Gary 1 State oil and gas test well that penetrated the Sharon Springs and Gammon Ferruginous Members of the Pierre Shale and the upper part of the Niobrara Formation. Marked increase in radioactivity and resistivity is characteristic of the organic-rich shales overlying the Ardmore Bentonite Bed. The Ardmore and associated beds of bentonite and shale (depth interval 810–825 ft) show low radioactivity and resistivity.

T. 56 N., R. 68 W., Crook County, Wyo. (Robinson and others, 1959, p. 107). At the type locality, the Mitten is about 145 feet thick and is divisible into two parts (Robinson and others, 1964, p. 81). The lower part consists of about 80 feet of moderately hard dark-gray brownish-weathering shale that contains at its base a thin bed of polished black phosphate pebbles and rounded bone fragments. Rocks of the Sharon Springs are missing and the pebble bed rests disconformably on the Gammon Ferruginous Member of the Pierre. The upper part of the Mitten is about 65 feet thick and consists of black flaky shale containing numerous rusty-weathering limestone concretions in the upper part and siderite concretions in the lower part. A thin bed of rounded phosphatized casts of baculites occurs at the base of the upper part of the Mitten and, like the pebble bed, marks a disconformity.

Shales of the upper part of the Sharon Springs are conformable and gradational with the overlying Mitten Black Shale Member. The two members are differentiated by the change from silver-gray papery weathering shale to black-gray hackly limonite-stained shale that contains numerous siderite and grayish-orange-weathering septarian limestone concretions. Concretions in which the rinds of limestone have cone-in-cone structure are characteristic of the shale overlying the Sharon Springs throughout the southern Black Hills area.

From the type locality, the Mitten thickens southward along the west side of the Black Hills from about 145 feet to 938 feet at the Red Bird section. At Red Bird, the Mitten conformably overlies the Sharon Springs and can be separated into three parts (pl. 1). The basal part consists of 211 feet of moderately hard black-gray platy rusty-weathering shale (unit 20)[1] having a hackly fracture and containing many layers of dusky-red-weathering ironstone and grayish-orange-weathering septarian limestone concretions. A distinctive type of concretion common in this part of the section has a dusky-red-weathering core of siderite enclosed by a crust of grayish-orange limestone showing pronounced cone-in-cone structure (fig. 9). Above this is the rest of the lower part of the Mitten—197 feet of dark-gray to black-gray soft flaky shale (units 21–25). This sequence contains, 60 feet below its top, a 2.5-foot-thick bed of soft bentonitic dark-gray shale that weathers to a bare surface of frothy gumbo showing patches of alkali (unit 24).

A rare form of limestone concretion crops out about 6 feet above the base of the Mitten and is shown in figures 10 and 11. The concretion is a somewhat hardened tabular mass a few inches thick and several feet long, cut by shaly partings. Figure 10 shows the platy shale in the basal part of the member and the tabular, somewhat more resistant concretion in the shale. Figure 11 is a closeup view of the same concretion, showing the shaly partings in the concretion and the enclosing shale. Apparently, the concretion resulted from lime cementation of the shale at some time late in the diagenesis of the rock. A few specimens of crushed *Baculites mclearni* were present in the concretion, and these shells may have formed the nucleus for lime accumulation.

The middle part of the Mitten consists of 184 feet of brownish-gray to gray bentonitic shale that weathers to a grayish-brown gumbo soil bare of vegetation and stained with patches of white alkali. At the top is a 2-foot-thick bed of dark-gray highly swelling bentonite that weathers to a soft powder beneath a hard-crusted bare surface. This bed contains a 0.1-foot-thick layer of gray fibrous calcite at the base. The middle part of the Mitten contains many dusky-red-weathering platy ironstone concretions, 0.1 foot thick, and a few thicker tan-weathering limestone concretions. In weathering characteristics, this part of the Mitten resembles the Gammon in the northern part of the Black Hills; corresponding rocks are not present in the Mitten in that area.

The upper part of the Mitten (units 28–33) is represented by 346 feet of dark-gray soft flaky shale that contains a few ironstone concretions in the lower part and a great abundance of fossiliferous limestone concretions throughout. The limestone concretions weather yellowish brown and locally are septariate with veins of pale-yellow calcite. Irregular masses of rough-weathering limestone (tepee-butte limestone) occur very sparsely in the shale about 50 feet above the base and 60 feet below the top of the upper part of the member. A 2-foot-thick bed of bentonitic shale crops out 94 feet below the top of the Mitten. This bed makes a distinctive band of gumbo soil and contains abundant concretions.

The thinning of the Mitten from 938 feet at Red Bird to about 145 feet at the type locality on the northwest flank of the Black Hills is due to the pinching out of the middle bentonitic shale unit and thinning of the upper and lower dark shale units. The Mitten thins to the east, and on the Cheyenne River near Hot Springs, S. Dak., it consists of about 80 feet of dark-gray soft flaky shale that represents only the upper part of the Mitten at Red Bird. The Mitten cannot be identified by its lithology on the west side of the Powder River Basin, although time-equivalent rocks can be identified by their fossils in the upper part of the Cody Shale at the Salt Creek oil field.

[1] Unit numbers given in the following discussion refer to units listed on the "Detailed Measured Section," pages 49–62.

FIGURE 9.—Hard platy rusty-weathering shale and concretion in the lower part of the Mitten Black Shale Member. The area shown is 48 feet above base of unit 20 near instrument station 9.

The electric log of the Texas Eastern Transmission 1 Federal well at Red Bird (pl. 2) does not show any distinctive inflections that might be useful in correlating beds within the Mitten. The base of the member can be determined approximately at the change in resistivity from the more highly resistant shale of the Sharon Springs to the less resistant shale of the Mitten (pl. 2, depth 3,260 ft). For this report, the upper contact is selected at a point of increased resistivity that appears to indicate a change from the nonsilty shale of the Mitten to the silty shale of the Red Bird Silty Member (pl. 2, depth 2,390 ft).

RED BIRD SILTY MEMBER

The Red Bird Silty Member (units 34–54) of the Pierre Shale was named by the authors (Gill and Cobban, 1962) for light- to medium-gray soft silty shale exposed along the B planetable traverse of the Red Bird section (fig. 1, pl. 1).

The Red Bird Silty Member occupies an elongate north-south-trending area that covers east-central Colorado, eastern Wyoming, western South Dakota, eastern Montana, and western North Dakota. The member was deposited marginal to nearshore marine sandstones such as the Hygiene Sandstone Member of the Pierre Shale in Colorado, the Parkman Sandstone Member of the Mesaverde Formation of Wyoming, and the Judith River Formation of Montana. It is extensively exposed along the west flank of the Black Hills, where it ranges in thickness from about 600 feet at Red Bird to about 200 feet at the north end of the Black Hills. The unit thins and becomes less silty eastward, grading into the calcareous beds of the Gregory Member of the Pierre Shale of the Missouri River valley of South Dakota.

FIGURE 10.—Hard platy rusty-weathering shales in the basal part of the Mitten Black Shale Member. View southwestward from about the center of sec. 13, T. 38 N., R. 62 W.

In the original description of the unit, the authors stated that the member had a thickness of 725 feet as measured on the outcrop at Red Bird, but remeasurements indicate that the true thickness in the Red Bird area is about 607 feet. The member conformably overlies the Mitten Black Shale Member, and the contact is placed at a gradational change from dark flaky shale (unit 33) to lighter colored silty shale (unit 34). The upper contact, which is also somewhat gradational, is placed at the change from light-weathering silty shale (unit 54) to dark-weathering shale (unit 55). The color changes, which probably reflect the silt and fine-sand content of the rock, are strikingly shown on the aerial photograph of the Red Bird area (fig. 1).

Silty limestone concretions are very common in the Red Bird Silty Member; they are so abundant in some layers that they form an almost solid bed of limestone. The concretions, which range mostly from 1 to 2 feet in diameter and from 6 to 12 inches in thickness, weather various shades of yellow, orange, or brown, and many contain numerous invertebrate fossils. Many are septarian, with veins of yellow calcite, and some also contain vein fillings of white barite.

Throughout most of eastern Wyoming the Red Bird Silty Member is characterized on electric logs by a variable but sharp increase in the resistivity curve, whereas the resistivity is uniformly low in the overlying and underlying shale units. The Texas Eastern Transmission 1 Federal well (pl. 2) reached the top of the Red Bird Silty Member at a depth of about 1,790 feet and the base of the unit at about 2,390 feet. A thickness of about 600 feet is assigned to the unit in the subsurface. The sharp inflections on the resistivity log at 1,855 and 2,185 feet are interpreted as thick masses of limestone concretions.

LOWER UNNAMED SHALE MEMBER

The lower unnamed shale member (units 55–81) is 720 feet thick in the reference section at Red Bird. It consists of thick alternating units of dark-, medium-, and light-gray-weathering shale that give a banded appearance to the outcrop, in sharp contrast to the brighter and more uniform colors of the adjacent members. Figure 12 is a closeup view of a banded outcrop in the lower part of the lower unnamed shale member. The member appears as a distinct dark band on aerial photographs (fig. 1). The unnamed shale member is conformable with both the underlying Red Bird Silty Member and the overlying Kara Bentonitic Member.

Fossiliferous limestone concretions are abundant throughout the member, and many ironstone concretions occur in the interval from 250 to 630 feet above the base of the member (units 59–79). Moderately to highly swelling beds of bentonite and bentonitic shale that weather light gray occur in the upper two-thirds of the member (units 60–80.) The bentonitic rocks weather deeply and are poorly exposed, but their approximate position is ordinarily marked by light-gray to pale-yellow fibrous calcite fragments that weather out of the bentonite and accumulate on the outcrop. Calcite of this type seems to be largely restricted to the swelling variety of bentonite and has not been seen in nonswelling bentonites lower in the section. Septarian limestone concretions containing white or brown barite crystals and yellow calcite veins are not uncommon in this member. Barite-bearing septarian concretions occur in units 69, 71, 75, and 81; they appear to be restricted largely to the part of the member that contains beds of bentonitic shale or bentonite. (For illustrations of barite crystals from septarian limestone concretions in the Pierre Shale, see Barbour, 1898; Ziegler, 1914.)

FIGURE 11.—Limestone concretion shown in figure 10. The platy weathering of the rock probably represents the original bedding of the shale prior to lime cementation.

Small clear crystals of analcite have been found encrusting the empty chambers of baculites in the upper part of unit 81, which underlies the Kara Bentonitic Member (pl. 12, fig. 4). Analcite is also moderately common in rocks containing appreciable quantities of bentonite higher in the Pierre Shale.

The lower unnamed shale member is an easily recognized stratigraphic unit in the area in which the overlying Kara Bentonitic Member is present. Both members extend northward in outcrops along the west side of the Black Hills to a point near Oshoto, Wyo., about 25 miles south of the Montana-Wyoming line. At about Oshoto, a bentonitic unit similar in appearance to the Kara, but stratigraphically beneath it, appears in the upper part of the lower unnamed shale. This unit was called the Monument Hill Bentonitic Member by Rubey (1930, p. 3), who at that time did not recognize the Kara Bentonitic Member. North of Oshoto, the Kara disappears, and at the north end of the Black Hills, in Carter County, Mont., it is represented by dark nonbentonitic shale in the shale unit that overlies the Monument Hill, or by the basal part of the Fox Hills Sandstone (Robinson and others, 1959, p. 111).

In the Pierre reference section, at Red Bird rocks identifiable lithologically as belonging to the Monument Hill Bentonitic Member are not present. Time-equivalent beds containing the ammonite *Exiteloceras jenneyi* (an index fossil to the Monument Hill in the northern Black Hills) crop out 252–356 feet above the base of the lower unnamed shale member (units 60–65).

KARA BENTONITIC MEMBER

The Kara Bentonitic Member (Robinson and others, 1959, p. 111–113) was named for exposures on the northwest flank of the Black Hills in sec. 2, T. 48 N., R. 67 W., Weston County, Wyo., where the unit consists of about 100 feet of gray shale, gray bentonitic shale, and impure beds of highly swelling bentonite. At the type locality the Kara is conformably overlain and underlain by unnamed units of dark-gray to black shale. The member can be traced for about 100 miles along the west side of the Black Hills in Wyoming, but it has not been

FIGURE 12.—Dark-banded shales of the lower part of the lower unnamed member (units 58–59). View northward from planetable traverse in the SE¼NE¼ sec. 14, T. 38 N., R. 62 W., Niobrara County, Wyo.

recognized at the north end of the Black Hills in southeastern Montana. Robinson, Mapel, and Cobban (1959, p. 111) suggested that in southeastern Montana "rocks of the same age as the Kara bentonitic member apparently are represented either by the upper part of the black shale unit that overlies the Monument Hill bentonitic member, or possibly by the Fox Hills sandstone."

At the Red Bird section the Kara is 36 feet thick and contains a basal 6-foot-thick bed of light-olive-gray highly swelling bentonite that weathers to a soft "popcorn" surface (fig. 13). When bentonite is wet it flows over its outcrop and obscures the contact of the member with the underlying beds. Although it is difficult to determine their true thickness, beds of this type provide an excellent stratigraphic datum for mapping, inasmuch as they weather to distinctive bands of gumbo almost devoid of vegetation. The middle part of the Kara (unit 83) consists of light-olive-gray-weathering silty to sandy shale containing gray- and brown-weathering concretions. The upper part of the Kara is a light-olive-gray bentonite and bentonitic shale that weathers to a deep gumbo soil, which is bare of vegetation. The shale is capped by a persistent bed of ridge-forming concretionary limestone (unit 85) containing abundant invertebrate fossils. This distinctive concretionary bed weathers moderate brown; it contains, on fracture surfaces, colorless transparent crystals of quartz. Figure 14 shows the weathering characteristics of the Kara Bentonitic Member and the adjacent unnamed shale members.

In electric logs, the response of the spontaneous-potential and resistivity curves does not seem as pronounced for beds of highly swelling bentonite as for nonswelling bentonite. In the log of the Texas Eastern Transmission 1 Federal well (pl. 2), the depth interval 958–990 feet is tentatively assigned by the authors to the Kara. This measurement gives a subsurface thickness of 32 feet, compared with a surface measurement of 36 feet. The total interval from the top of the Red Bird Silty Member to the base of the Fox Hills Sandstone is 1,450 feet on the electric log, and 1,436 feet measured on the surface. Despite this close agreement, the position of the Kara Bentonitic Member within the interval is about 65 feet higher on the electric log than in the surface section. The reason for this discrepancy has not been resolved, but compensating errors have possibly been made in measuring the thickness of the overlying and underlying members of the Pierre.

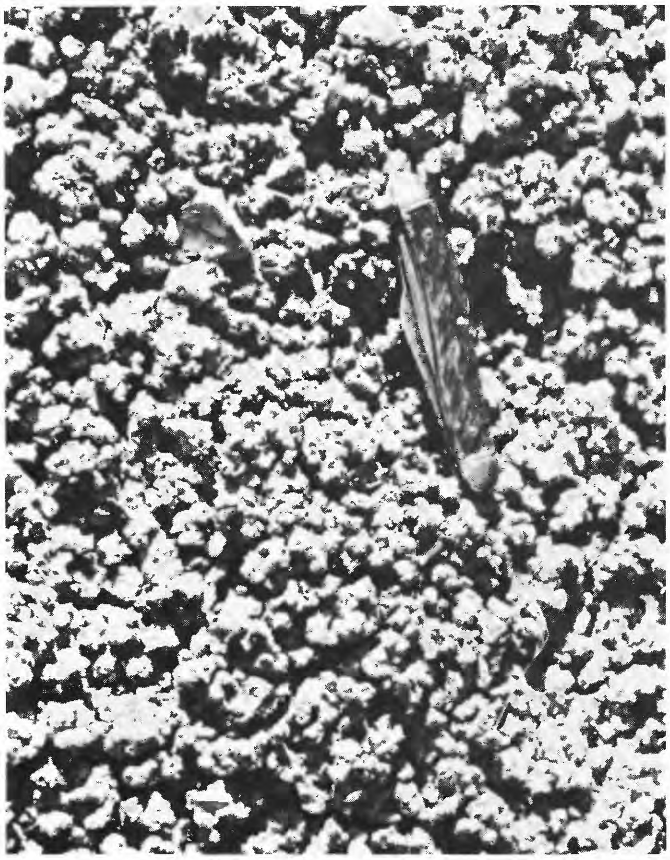


FIGURE 13.—Closeup view of the weathered surface of the basal bentonite bed in the Kara Bentonitic Member of the Pierre Shale, NW¼SE¼ sec. 14, T. 38 N., R. 62 W., Niobrara County, Wyo.

UPPER UNNAMED SHALE MEMBER

The upper unnamed shale member in the Red Bird area is 680 feet thick according to the surface measurement, and consists of variably sandy and silty shale that weathers to alternating dark and light-gray bands. There are many layers of brown-weathering fossiliferous limestone concretions.

The member appears to be 615 feet thick in the subsurface as determined from the log of the Texas Eastern Transmission 1 Federal oil and gas test (pl. 2), and the unit thins gradually northward along the west side of the Black Hills. It conformably overlies the Kara Bentonitic Member and is gradational with the overlying Fox Hills Sandstone. There is a notable increase of sand and silt in the upper part of the member; the contact with the Fox Hills is arbitrarily placed at the base of a 1.2-foot-thick bentonite that is overlain by a 13-foot-thick bed of medium-greenish-gray glauconitic sandstone. A few phosphate nodules and numerous scattered limy nodules that weather to hard orange-brown limonitic masses occur in the basal beds of the Fox Hills.

Several beds of dark-weathering bentonite and bentonitic shale crop out in about the middle of the member (pl. 2). The most prominent of these is unit 97, consisting of 8 feet of calcareous yellowish-gray bentonite and bentonitic shale that weathers to a medium- to dark-gray bare gumbo soil. This bentonitic unit, 327 feet above the base of the unnamed member, forms a useful stratigraphic marker in this part of the section and is shown on the geologic map (pl. 1). The bentonites of this unit are similar to those in the Kara Bentonitic Member (fig. 14) in their weathering aspects and in their tendency to flow downslope and cover adjacent units; however, they are different from bentonites in the Kara in that they weather much darker, are noticeably calcareous, and contain soft brown-weathering clayey limestone concretions.

In bentonitic parts of the upper unnamed member, there is abundant fibrous calcite in the bentonite layers, and analcite and barite crystals line the unfilled air chambers of ammonite shells. Chalcedony and crystalline quartz locally coat fracture surfaces of limestone concretions within or adjacent to the swelling bentonitic rocks.

MEGAFOSSILS

RELATIVE ABUNDANCE OF FOSSIL FORMS

Megafossils are abundant and well preserved in much of the Pierre Shale at Red Bird, as was first noticed by Newton (1880, p. 31) many years ago. He described the rocks now assigned to the Pierre Shale in the vicinity of Old Woman Creek (Red Bird area) as "Dark gray Cretaceous clays (No. 4 of Meek and Hayden), with many nodules filled with beautifully preserved forms—*Baculites ovatus*, *B. compressus*, *Inoceramus*, *Ammonites placenta*, &c". He stated further, "The Cretaceous in this vicinity is very fossiliferous, yielding to our hasty examination many beautiful and some new forms, and it will undoubtedly afford an abundant harvest to a thorough and systematic collector."

During the present study, 158 collections of megafossils were made from 118 levels in the Pierre Shale. The fossils are dominantly mollusks. Algae, sponges, crinoids, asteroids, and chitons are not present in the collections, and corals, echinoderms, and brachiopods

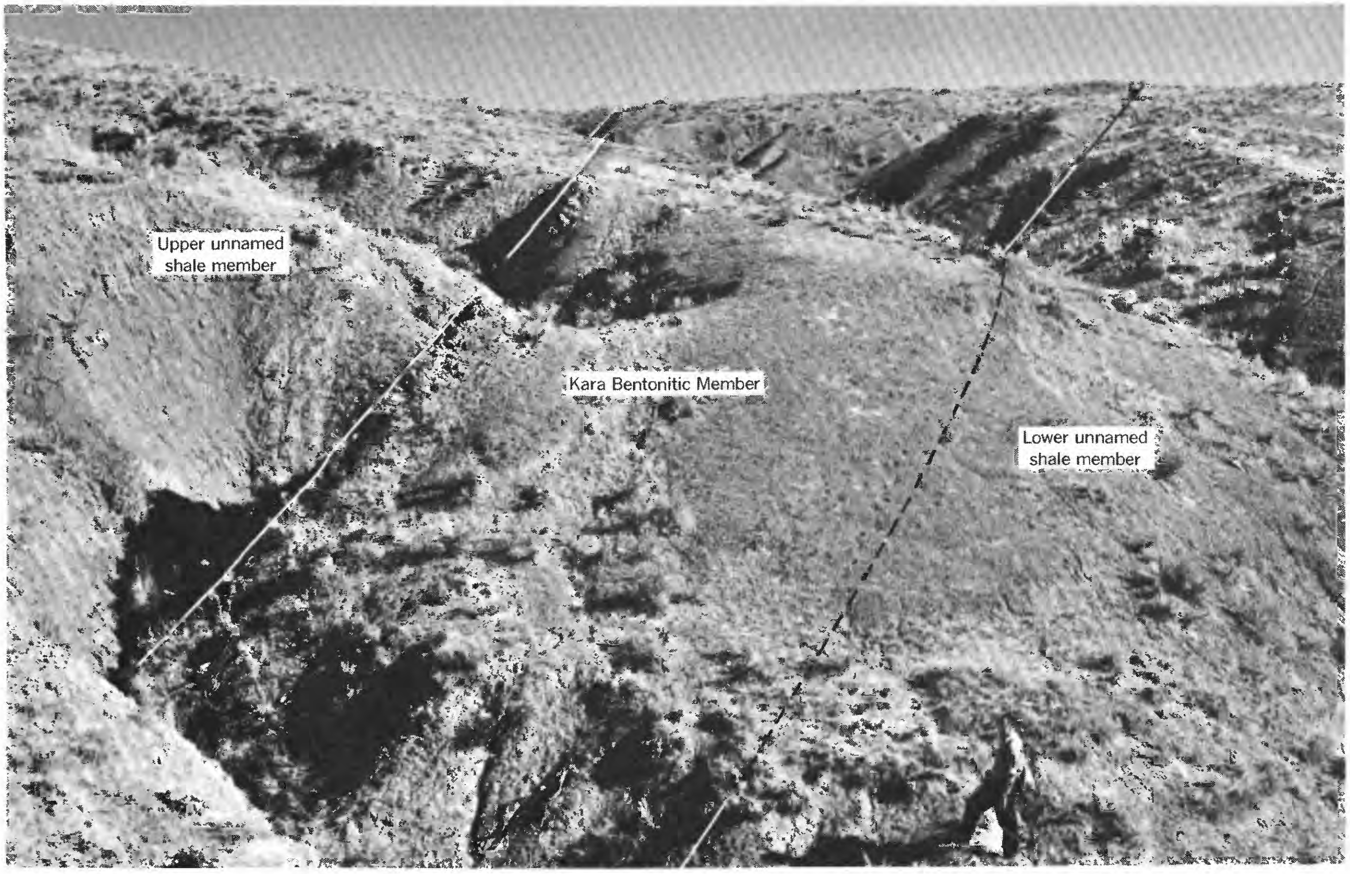


FIGURE 14.—Kara Bentonitic Member of the Pierre Shale in the Red Bird area, Niobrara County, Wyo. The contact between the Kara and the lower unnamed shale member is masked by bentonite that has flowed downslope. View is northeastward in the SW¼NE¼ sec. 14, T. 38 N., R. 62 W.

are scarce. The absence or scarcity of most of these fossils is normal for the Cretaceous rocks of the Western Interior (Reeside, 1957, p. 512). The absence of sponges is due in part to the muddy bottom of the Pierre sea; sponges need a firm substrate and clear water.

Among the megafossils from unit 32, D1875, of the Mitten Black Shale Member is in unidentified rounded object showing what appears to be an attachment scar. It most resembles the possible fossil gall described by Mickelson (1963) from the Mobridge Member (Maestrichtian) of the Pierre Shale of north-central South Dakota.

It is interesting to compare the megafossil record at Red Bird with the tallies of certain taxonomic groups of Western Interior Upper Cretaceous fossils compiled from the literature by Sloss (1958, p. 725). Sloss placed the fossils in groups (some as large as phyla and some as small as orders) and gave their frequency of occurrence as percentages for sandstone and shale environments. For shale he found the following percentages (estimated from his bar graph, text fig. 8).

Fossil group	*Percent frequency of occurrence in shale*
Echinodermata	1
Bryozoa	<1
Gastropoda	13
Scaphopoda	<1
Pelecypods:	
Pectenacea	<1
Ostracea	9
Mytilacea	22
Teleodesmacea (and other clams)	17
Cephalopods:	
Nautiloidea	<1
Ammonoidea:	
Compressed	3
Inflated	22
Aberrant	9
Arthropoda	<1

A tally of the number of collections in which most of the same groups of fossils were found at Red Bird shows fairly close agreement with the figures compiled by Sloss except for a few groups, such as Bryozoa and inflated and aberrant ammonites. The fossil groups at Red Bird are arranged below in the order given by Sloss (1958), with the addition of corals, worms, and brachiopods.

Fossil group	*Percentage of collections in which fossil was found*
Coelenterata	<1
Worms	2
Echinodermata	<1
Bryozoa	11
Brachiopoda	<1
Gastropoda	10
Scaphopoda	1
Pelecypoda:	
Pectenacea	2
Ostracea	2
Mytilacea	18
Other pelecypods	17
Cephalopoda:	
Nautiloidea	<1
Ammonoidea:	
Compressed	2
Inflated	1
Aberrant	32
Arthropoda	<1

MINERALOGY OF MOLLUSK SHELLS

Many of the ammonites, especially those in rocks above the Red Bird Silty Member, have iridescent shells; however, all the shells were at least slightly dissolved by sea water, and none of the original outer surfaces are left. Reyment (1957, p. 347) described what he believed to be the original outer surface of an ammonite identified as *Baculites compressus* Say from an unknown locality in the United States. He described this surface as grayish and the inner layers as iridescent. At Red Bird, most of the cephalopod shells and the inner nacreous layer of *Inoceramus* are aragonitic. Analyses by H. A. Tourtelot, of the U.S. Geological Survey, for selected specimens from various levels in the Pierre Shale are given in table 1. Mr. Tourtelot has contributed the following discussion of his findings.

In 1879, Sorby (1879, p. 60) reported that the shell material of *Nautilus pompileus* has a specific gravity of 2.95 and thus is aragonite, calcite having a specific gravity of 2.71. This is the first recorded determination of the mineralogy of a cephalopod shell. Later, Cornish and Kendall (1888) determined that ammonite shells are also made of aragonite. Meigen (1903, p. 54), using the reaction that bears his name, determined that the shells of *Nautilus* and *Spirula*, and the "cuttlebone" of *Sepia*, all living cephalopods, are made of aragonite. Cayeux (1916, p. 492) found original aragonitic structure in Liassic ammonites. Bøggild (1930, p. 323) found that the shells of some Mesozoic ammonites showed original laminated structure and consisted of aragonite, which he identified by its refractive index. The shells of all the Paleozoic and many Mesozoic ammonites he examined consisted of fine-grained calcite. He inferred that these had originally been aragonite, and his generalization was accepted by Arkell (1957, p. L82). Mayer (1932, p. 349) apparently was the first to use X-ray methods to identify aragonite in ammonite shells as old as Jurassic. Reyment reported an X-ray analysis by Mellis (Reyment, 1956, p. 101) of an aragonitic Cretaceous ammonite, and Reyment and Eckstrand (1957) reported on aragonitic ammonites from the Jurassic and Cretaceous, including a specimen of *Baculites compressus* from the Bearpaw Shale of Canada. Turekian and Armstrong (1961, p. 1820) determined that several coiled ammonites and a nautiloid from the Pierre Shale and Fox Hills Formation in South Dakota still are chiefly aragonite.

The ammonites and pelecypods from the Red Bird section were analyzed to provide data on the mineralogy of the shells of *Baculites* (a genus of ammonites for which only one other analysis is known to exist) and to determine the suitability of baculites and contemporaneous pelecypods for paleotemperatures studies.

The shells of *Baculites scotti* and all younger baculites consist almost entirely of aragonite. Diffraction traces for 4 of 10 species show no indications of calcite. Traces for the remaining 6 show faint to clear peaks for calcite in amounts estimated to be less than 5 percent. The broken edges of aragonitic shell fragments containing small amounts of calcite show a finely laminated structure and no calcite can be seen that originated by the alteration of aragonite. The small amount of calcite indicated by the X-ray traces is believed to be secondary, either adhering to the surfaces of the shell fragments or filling small fractures.

The shell fragments of *Baculites gregoryensis*, in which aragonite and calcite are present in about equal amounts (table 1), consist of finely laminated aragonite replaced by patches of finely crystalline calcite. In thin section, the calcite is seen to retain none of the laminated structure, but consists of a calcite mosaic having vague and irregular boundaries.

All specimens of *Baculites gilberti* except one from collection D2114 consist almost entirely of calcite in a finely to coarsely crystalline mosaic that seems clearly to have originated as an alteration or replacement of aragonite. The calcite was not deposited in voids left by the solution of aragonite shells, and thus is not secondary, that is, it is not analogous to the calcite deposited in the cracks of septarian concretions. A small

TABLE 1.—*X-ray determinations of aragonite and calcite in shells of fossil mollusks*

[Symbols: D, dominant; E, present in approximately equal amounts. H. A. Tourtelot, analyst]

Species	Distance below top of Pierre Shale (feet)	Locality	Aragonite	Calcite
Baculites clinolobatus	130	D1987	D	
grandis	190	D1986	D	Trace.
grandis	365	D2118	D	Trace.
grandis	405	D2117	D	
eliasi	650	D1966	D	Trace.
eliasi	745	D1963	D	
eliasi	865	D1636	D	Trace.
reesidei	1,050	D4008	D	
rugosus	1,165	D1941	D	Trace.
scotti	1,415	D1926	D	Trace.
gregoryensis	1,675	D1908	E	E.
gilberti	2,055	D1878	Trace	D.
gilberti	2,065	D1877	Trace	D
gilberti	2,075	D1876	Trace	D
gilberti	2,110	D2910		D.
gilberti	2,170	D2114	D	Trace.
perplexus (early form)	2,220	D1872	D	Trace.
perplexus (early form)	2,260	D1870	D	
perplexus (early form)	2,320	D1865	E	E.
perplexus (early form)	2,675	D1861	Trace	D.
sp. (smooth)	2,770	D2905	Trace	D.
asperiformis	2,935	D1855		D.
asperiformis	2,975	D1856		D.
mclearni	2,990	D4009		D.
Hoploscaphites plenus	455	D1984	E	E.
quadrangularis	620	D1970	D	
Inoceramus subcircularis (inner nacreous layer)	455	D1983	D	Trace.
typicus (inner nacreous layer)	620	D1970	D	Trace.

percentage of aragonite remains in some specimens according to the X-ray analyses, but the aragonite could not be recognized in thin sections. The specimen from collection D2114 (table 1) shows the typical finely laminated structure of aragonite, and the trace of calcite reported probably is secondary. The two collections of *B. perplexus* (early form) from the upper 50 feet or so of the range zone of this fossil (collections D1872, D1870, table 1) also are virtually pure aragonite. The specimens in other collections of *B. perplexus* (early form), and in collections from the underlying range zones, are partly or entirely transformed to calcite.

The specimens of *Hoploscaphites plenus* and *Inoceramus subcircularis* come from collections at the same level near the top of the *Baculites baculus* Range Zone (table 1, D1983, D1984), whereas the specimens of *H. quadrangularis* and *I. typicus* occur together (D1970) at the bottom of this range zone. The inner nacreous layer of the *Inoceramus* specimens and the shell of *H. plenus* are partly transformed to calcite; this may indicate that the aragonite formed by these biologic groups differs from that formed by the baculites in its susceptibility to transformation.

The transformation of aragonite to calcite can be very rapid in inorganically precipitated aragonite (Wray and Daniels, 1957). Nevertheless, Cloud reported aragonitic Bahamas sediments thousands of years old (1962, p. 124). He stated "Present and other geological evidence implies that aragonite at relatively low temperature and pressure will remain aragonite indefinitely [when it is] in contact with solutions similar to those from which [it] precipitated (or [if it is] dry sealed) * * *." Coleman and Lee (1962) reported metamorphic aragonite in glaucophane schists of the Franciscan Formation in California, which was formed in Late Jurassic or Early Cretaceous time (Lee and others, 1964). Brown, Fyfe, and Turner (1962, p. 579–580) discussed the survival of this metamorphic aragonite during the unloading that brought the aragonite from a depth of 20–30 km to the present surface and explained it as a function of a temperature gradient of 10°C per km. They also pointed out that aragonite in wet rocks with an open-pore system could survive near the surface for only 100,000 years at 50°C, but could survive for a few million years at 10°C. Aragonite in a cephalopod shell of Pennsylvanian age was reported by Switzer and Boucot (1955, p. 528; see Stehli, 1956, for data on additional fossils from the same locality), who supposed that the stability of the aragonite is related to its entombment in asphalt.

At Red Bird, stratigraphic intervals between some of the collecting horizons are large, and most specimens were selected for analysis because they appeared to consist of aragonite. Therefore, the data are incomplete, and some bias may have been introduced in the collecting. Nevertheless some speculations seem warranted. Fossils preserved in carbonate concretions or sealed in impermeable shale are partially isolated from diagenetic changes; this would seem to be the best explanation for the survival of abundant biogenic aragonite in the Pierre Shale at Red Bird and at many other localities throughout the Western Interior region.

The distribution of aragonitic shell material at Red Bird has a rough relation to the age of the fossils. Fossils found above the Red Bird Silty Member consist almost entirely of aragonite; specimens from the Red Bird Silty Member and the underlying 50 feet or so of the Mitten Black Shale Member are partly or entirely transformed to calcite; two specimens from the middle part of the upper third of the Mitten are entirely aragonite; and all the specimens from the underlying part of the Pierre near Red Bird are entirely transformed to calcite.

The transformation of aragonite to calcite probably is not due to any large extent to weathering; if it is were, the transformation should be roughly the same everywhere in the section.

The part of the Mitten Black Shale Member that contains calcite baculites contains many more siderite concretions than other parts of the Pierre Shale at Red Bird; limestone concretions are also present. Calcitic baculites come from both kinds of concretions (D1855, limestone: D1856, siderite). Siderite is formed at a lower pH than calcite (Krumbein and Garrels, 1952, fig. 8). The alternation of zones of siderite and limestone concretions indicates alternation of pH conditions; the changes in pH may not have been large, however. Aragonite is most soluble in solutions of low pH, and thus an environment favoring deposition of siderite may also have favored transformation of aragonite to calcite. Aragonite is the predominant mineral in shells from the uppermost part of the Mitten, where siderite is not abundant.

Inasmuch as a very small difference in pH may be sufficient to influence the transformation of aragonite to calcite, a mineralogical record of the change would not necessarily appear. The Red Bird Silty Member is inferred to have been deposited under the shallowest water conditions that existed throughout Pierre time in the Red Bird area.

CHAMBER FILLINGS

The air chambers of the ammonites that are not filled with sediment are wholly or partly filled with calcite crystals that line the chamber walls (pl. 12, figs. 4, 6). The calcite is mostly pale yellow in the specimens from the Mitten Black Shale Member, white to yellowish white in those from the Red Bird Silty Member, and pale yellow to deep yellow or pale brown to dark brown in ammonites from younger parts of the Pierre Shale. Colorless trapezohedrons of analcite line the walls of some otherwise empty cephalopod chambers in unit 95 in the lower unnamed shale member. Colorless crystals of analcite also occur on top of earlier formed calcite crystals in the air chambers of a few ammonites in units 80, 85, 86, and 95, and on the surface of sediment that partly filled the chambers of ammonites in units 86 and 95 in the lower unnamed shale member (pl. 12, fig. 4). Barite, in the form of colorless, light-brown, or dark-brown crystals, is present in the chambers of a few baculites in units 20, 21, and 23 of the Mitten Black Shale Member and in uits 81 and 96 of the lower unnamed shale member. The crystals of barite are usually on previously formed calcite crystals that line the chamber walls much like the crystals illustrated by Weaver (1931, pl. 55, fig. 349) in the interior of a Lower Cretaceous ammonite from Argentina. Rarely, the barite is attached directly to the chamber walls (unit 96). In unit 78 in the lower unnamed shale member, small reddish hematite crystals rest on the calcite crystals lining the chamber walls, and at places hematite crystals grow directly on the walls.

CORALS

Corals are present in only one collection (D2118, unit 96). The specimens are scarce, and only fragments are visible in a piece of a limestone concretion. The corals are a small solitary type that resembles well-preserved *Trochocyathus* from the Pierre Shale at a locality on the northwest flank of the Black Hills (Robinson and others, 1959, p. 117, loc. D440). The lack of corals in all but one level at Red Bird is probably due to rapid sedimentation and lack of a firm substratum for attachment. Aside from *Trochocyathus*, the only form recorded from the Pierre Shale is the small solitary species *Micrabacia americana* Meek and Hayden (Stephenson, 1916, p. 118, pl. 20, figs. 4–6; Robinson and others, 1959, p. 119) from the Range Zones of *Baculites baculus* and *B. grandis* along the west side of the Black Hills and on the Cedar Creek anticline in eastern Montana.

WORMS

The work of marine worms is preserved in the Pierre Shale at Red Bird by trails, burrows, fecal pellets, and tubes of siltstone and calcareous material. Only the calcareous tubes are listed in the "Detailed Measured Section." Burrows and fecal pellets are common in the rock that fills the living chambers of cephalopods, and some of these features are probably the work of free-living polychaetes.

Calcareous worm tubes are present in nine collections (D1899, D1911, D1917, D1919, D1960, D1983, D2117, D1985, D2118). They are represented by three forms: (1) gradually tapering tubes attached along one side to mollusks, (2) tubes wound in spiral whorls, and (3) gently curved to nearly straight unattached tubes.

The tubes attached along one side are very rare, and all such specimens are cemented to the interior surface of living chambers of baculites (pl. 8, figs. 1, 7). The tubes are sinuous, and the taper is small, the larger end of the tube attaining a diameter of about 3 mm. Growth is toward the aperture of the ammonite. In longitudinal cross section, the wall is composed of very thin layers set at an angle to the axis, a characteristic of the genus *Diplochoncha*. The apertural end is filled with the same limy matrix that fills the living chamber of the baculite; the remaining greater part of the tube is filled with brown calcite. In its degree of taper and sinuosity and in its habit of attachment all along one of its sides to the interior surface of the shell of a mollusk, this worm tube shows some resemblance to a specimen illustrated by Stephenson (1936, p. 371, pl. 1, fig. 1) as *Serpula* sp. from the Upper Cretaceous of the Atlantic Coast. Stephenson's form lived attached to the inner surface of valves of the pelecypod *Glycymeris subcrenata* Wade. Illustrations of Cretaceous worm tubes that grew on the inside of empty mollusk shells are few. Wade (1926, p. 31, pl. 3, fig. 1) observed that his *Serpula adnata* from the Ripley Formation of Tennessee was usually attached to the smooth inner surfaces of large pelecypods, and in a report by Stephenson (1952, p. 52, pl. 9, fig. 1) there is figured a mass of tubes of *Serpula* sp. on the interior of a pelecypod valve from the Woodbine Formation of Texas.

The tubes wound in spiral whorls are nearly smooth and have very little taper, if any. They apparently were unattached. Very minute fecal pellets can be seen in one of the tubes. These worm tubes (D1899) seem assignable to the sedentary polychaete *Omasaria* Regenhardt (1961, p. 45), a genus based on spiral tubes from the Maestrichtian of Germany and France. A spirally coiled worm tube that was attached to the interior wall of the living chamber of a Lower Cretaceous ammonite is visible on an illustration of an internal mold presented by Casey (1964, pl. 64, fig. 6a); the *Serpula* cf. *adnata* recorded by Casey (1961, p. 552) from a locality in the Folkestone Beds (Aptian) of England was attached to the inner wall of an empty ammonite living chamber (Raymond Casey, written commun., 1964).

The nearly straight tubes are very abundant in limestone concretions in the upper unnamed member of the Pierre Shale (units 93–96). The worms that secreted these tubes formed colonies on the mud floor of the sea. The tubes are 1–2 mm in diameter and are smooth except near the aperture, where conspicuous encircling ridges are present. Of the described species, perhaps, the nearest is *Diploconcha harbisonae* Howell (1943, p. 159, pl. 20, figs. 6–8) from the Upper Cretaceous Wenonah and Black Creek Formations of the East Coast. The apertural ends of the tubes at Red Bird are filled with the same silty, limy matrix as the enclosing concretions; the rest of the tubes are either hollow or filled with pale-brown calcite.

ECHINODERMS

Echinoderms are represented at Red Bird by only one collection (D1954 in unit 75 of the lower unnamed shale member). Hundreds of specimens of a very small echinoid with spines attached were found in a single limestone concretion where they occurred together with the arms of a starfish. The echinoids are described in the section by Porter M. Kier as the new genus and species *Eurysalenia minima*. Kier postulates that the echinoids crowded together for spawning or for feeding on a dead animal.

Echinoderms are extremely rare in the Cretaceous rocks of the Western Interior. The only echinoid species recorded previously from the Pierre Shale of the Northern Great Plains area is *Hemiaster humphrey-*

sanus Meek and Hayden (1857, p. 147) from the Range Zone of *Baculites baculus* on the Cedar Creek anticline in eastern Montana. Starfish are still more rare: only two specimens have been recorded from the Upper Cretaceous of the Western Interior (Weller, Stuart, 1905; Branson, 1947; Griffitts, 1949, p. 2025), and only two from Pierre equivalents in Texas (Clark, 1959). The fragments of starfish arms in unit 75 belong to an ophiuroid and closely resemble the arm of *Amphiura? senonensis* (Valette) figured by Rasmussen (1950, p. 118, pl. 15, figs. 6–8) from the upper Senonian of England.

BRYOZOANS

Bryozoans occur at Red Bird only as encrustations. Almost all such encrustations are on the inner surface of cephalopod living chambers (pls. 8, 9), but a few are on the inner surface of *Inoceramus* valves (pl. 8, figs. 2, 3). Rarely, a specimen is on the outer shell of a cephalopod. Only the attachment area is visible, but this is sufficient to classify the bryozoans into two groups. Most specimens represent a uniserial form that has pyriform zooecia resembling the common Cretaceous genus *Pyripora* d'Orbigny; the rest of the specimens are membranous and probably belong in the family Membraniporidae.

The pyriporoid bryozoans are present in 66 collections representing 52 different levels, beginning in unit 28 (D1865) in the upper part of the Mitten and ending in unit 108 (D2121) near the top of the Pierre. One hundred and ninety baculites from 54 collections have these bryozoans, and on all but two specimens the bryozoans are on internal molds of living chambers. This great preponderance of bryozoans on the inner surface of living chambers may be partly due to the manner in which the fossils are preserved; most of the baculites collected are internal molds. The majority of the bryozoans lived in the larger living chambers 20–50 mm in diameter. Only eight specimens were seen in living chambers less than 20 mm in diameter. The smallest baculite containing pyriporoid bryozoans was 13 mm in diameter. Apparently the smooth interior wall of large empty living chambers made an ideal home for the bryozoans. Thomas and Larwood (1960, p. 370) observed that the European Cretaceous specimens of *Pyripora* "encrust comparatively smooth substrates. Commonly these are fragments of *Inoceramus* shell (40%), pieces of echinoid test (40%), or fragments of *Ostrea* valve (10%). Less frequently zoaria are also found encrusting belemnite guards (5%) and occasionally the remains of other organisms (5%), e.g. brachiopod shell fragments, corals, crinoid plates, and other polyzoa (percentages approximate)." However, bryozoans and other organisms encrusting the inner walls of ammonite living chambers seem to be rare outside of the Western Interior. Casey (1961, p. 552) recorded the bryozoan *Heteropora michelini* (d'Orbigny) as encrusting both the outside and the inner walls of living chambers from a locality in the Lower Greensand (Lower Cretaceous) of England. Dunbar (1928, p. 165) mentioned that oysters, bryozoans, and worm tubes were known on both the outside and inside of living chambers, but specific examples were not given. Kobayashi and Kamada (1959, p. 120, pl. 10, fig. 1b), noting the growth of an oyster on the interior wall of the living chamber of an Eocene nautiloid from Japan, concluded that the empty shell lay on the sea floor for some time after the death of the animal. Hamada (1964, p. 264–268, pl. 4, figs. 1c, 2; pl. 5, figs. 1–5) described and illustrated excellent examples of bryozoans, oysters, calcareous worm tubes, and barnacles that were attached to the inner walls of the body chambers of modern drifted nautiloid shells.

Most of the pyriporoid bryozoans were attached in only one quadrant of the interior of empty living chambers. Of the 190 baculites that housed these bryozoans, 103 had bryozoans on one side only, 51 had them on two sides (adjacent), 20 had them on three sides, and 16 had them on all four sides. This distribution suggests that most of the empty baculite shells did not float but lay on the sea floor. The bryozoans grew on the ceiling of the living chamber, and in many baculites, on the walls as well, while mud gradually accumulated on the floor. The few baculites that had bryozoans entirely around the interior may have floated for a while or may have lain on the sea floor at an angle. The large proportion of baculites showing bryozoans on only one or two sides suggests that the empty shells of baculites may not have floated to the extent suggested by Reyment (1958, p. 129–131).

Pyriporoid bryozoans are not common on other fossils at Red Bird, and each occurrence is on the interior surface of a shell. These bryozoans are present on 19 specimens of *Inoceramus* from 18 levels, 3 specimens of *Hoploscaphites* from 3 levels, 2 specimens of *Placenticeras* from 2 levels, and 1 individual of *Anapachydiscus*.

Membraniporoid bryozoans are present in only five of the fossil collections from the lower and upper unnamed shale members (D1942, D1945, D1946, D1962, D2119), and they represent only four levels. These few specimens grew on the inner walls of empty living chambers of *Baculites* and *Placenticeras*. Similar bryozoans in the Western Interior have been referred to the genus *Conopeum* (Sanderson, in Allan and Sanderson, 1945, p. 89, pl. 7; Toots and Cutler, 1962, p. 84, pl. 18, figs. 1–4).

The scarcity and lack of diversity of the bryozoan faunas are probably due in part to the muddy bottom conditions that prevailed during Pierre time. Living bryozoans prefer a firm substratum for attachment and clear water with adequate circulation. Bassler (1953, p. G24) noted that bryozoans are not common in the Cretaceous rocks of North America, although they are abundant in Europe, and Butler and Cheetham (1958, p. 127) reinforced this observation by comparing the large number of genera known in Europe with the small number known in North America.

BRACHIOPODS

Brachiopods are represented in the fossil collections from Red Bird only by specimens of *Lingula* from one concretion in the lower unnamed shale member (unit 75, D1953). The numerous specimens consist of thin brown shells in a light-gray limy matrix that contains fragments of *Inoceramus*, a few fish bones and scales, and abundant pelagic Foraminifera. A close examination of fresh pieces of shale would probably reveal *Lingula* at several levels in the Pierre, judging from the occurrences in a well core in west-central South Dakota (Stanton, 1925, p. 10–13). Craig (1952, p. 111–115) summarized the ecology of living *Lingula*, noting that these brachiopods are confined to shallow tropical or subtropical seas, and that they inhabit all types of littoral sediments but prefer muddy types.

MOLLUSKS

Mollusks are common in much of the Red Bird section, although the diversity is not great. Two genera dominate—the pelecypod *Inoceramus* and the ammonite *Baculites*. Mollusks were not observed in the Gammon Ferruginous Member. Farther north in the Black Hills area, the Gammon contains many fossils (Robinson and others, 1959, p. 113, 114). Probably, mollusks are absent in the Gammon at Red Bird because the member is thin there, whereas it is thick farther north; also, the limestone or thick ironstone concretions suitable for preservation of the fossils are lacking. The Sharon Springs Member yielded only one species of pelecypod and two species of ammonites.

The mollusk record for the Mitten Black Shale Member is relatively poor in variety. Although the unit is over 900 feet thick, only six species of pelecypods, two species of gastropods, and eight species of ammonites were found. This record is comparable to that of the member farther north (Robinson and others, 1959, p. 114, 115).

The Red Bird Silty Member has a more diversified molluscan fauna—in this member, 14 species (11 genera) of pelecypods, 9 species (7 genera) of gastropods, and 13 species (8 genera) of ammonites were collected.

The fauna of the lower unnamed shale member is still more diversified; from it were collected 18 species (12 genera) of pelecypods, 1 species of scaphopod, 15 species (12 genera) of gastropods, and 22 species (9 genera) of ammonites. In contrast, only three species of pelecypods and gastropods and two species of ammonites are recorded from the Kara Bentonitic Member. Again, the lack of diversification may be due in part to the thinness of the member, although farther north where the Kara is thicker there is no great increase in the variety of the fauna (Robinson and others, 1959, p. 113, 118).

The upper unnamed shale member has the largest pelecypod fauna of any of the members of the Pierre Shale, and in addition, it contains many gastropods and cephalopods. Twenty-four species (18 genera) of pelecypods, 1 species of scaphopod, 14 species (12 genera) of gastropods, and 11 species (6 genera) of cephalopods were collected. This part of the Pierre Shale is also rich in fossils farther north along the Black Hills uplift (Robinson and others, 1959, p. 112–113, 118–119; Dobbin and Reeside, 1929, p. 19).

Inoceramus is the most common and conspicuous of the pelecypods. This genus is present in 95 collections, which represent all the members of the Pierre Shale except the Gammon. Specimens are especially abundant in the middle of the Red Bird Silty Member (unit 41) and in the unnamed shale member above the Kara Bentonitic Member (units 87–91). The limestone concretions in unit 91 in the Range Zone of *Baculites baculus* are crowded with *Inoceramus typicus* (Whitfield), which is characteristic of concretions in this zone in a belt that extends from the vicinity of Denver, Colo., northward 600 miles to the Poplar anticline in northeastern Montana. The types of *Endocostea* [*Inoceramus*] *typica* Whitfield (1877, p. 32; 1880, p. 403, pl. 9, figs. 1–7) came from this zone in the Red Bird area ("at Old Woman Fork of the Cheyenne River, Black Hills, where they occur very abundantly, densely packed together in the rock").

Gastropods are common only in some of the concretions in the upper part of the Pierre Shale above the Red Bird Silty Member (units 59, 93, 95). They are treated in the next chapter of this volume, by N. F. Sohl (in preparation).

Cephalopods are abundant in all the members except the Gammon. Baculites are easily the most common form, and at places, they make up the major part of some of the limestone concretions, particularly in the Mitten Shale Member (unit 29) and in the Red Bird Silty Member (units 39 and 41) (pl. 11, fig. 3). Scaphites are present in many of the collections from all the members above the Sharon Springs. They are common in limestone concretions in the upper unnamed shale member (units 89, 93, 95, and 96). Heteromorphs other than baculites and scaphites are represented by the genera *Didymoceras*, *Anaklinoceras*, *Exiteloceras*, and *Solenoceras*, and these are found from the middle of the Red Bird Silty Member to the middle of the overlying unnamed shale member (units 45–67). Pachydiscid ammonites, represented by the genera *Anapachydiscus* and *Menuites*, are confined to the Range Zone of *Baculites scotti* in the uppermost part of the Red Bird Silty Member and the basal part of the overlying unnamed shale member (units 52–56). The remaining groups of ammonites are represented by the genera *Placenticeras* and *Sphenodiscus*. *Placenticeras* occurs in the Mitten, Red Bird, and lower half of the overlying unnamed shale member, whereas *Sphenodiscus* occurs only near the top of the Pierre. The only aptychus noted was a very small dark-brown corneous specimen in unit 33 (D1878) at the top of the Mitten. It represents the type found with scaphites (Meek, 1876, p. 438–439, pl. 35, fig. 3i) and presumably came from one of the *Hoploscaphites*. Nautiloids, represented by the genus *Eutrephoceras*, are rare; they are present only in collections from the upper part of the Pierre Shale (units 59, 93, 96).

ARTHROPODS

Arthropods are represented by a single crab *Raninella* n. sp. (identified by Henry B. Roberts) in the Mitten Member (unit 28). The scarcity of arthropods is unusual. A few specimens or fragments are usually present in large collections of fossils from the Pierre Shale, especially from the Front Range area of Colorado, and crabs are locally so abundant in the Pierre Shale of north-central South Dakota that they form the well-known "crab zone" (Rathbun, 1917; Rothrock, 1947, p. 8–10). However, arthropods are not recorded in the long lists of fossils from the Pierre Shale of the western and northern parts of the Black Hills uplift (Robinson and others, 1959, p. 112–123).

VERTEBRATES

With the exception of fossils from the Sharon Springs Member, vertebrates are very rare in the Red Bird section. In the lower unnamed shale member, scattered fish bones and scales were observed in a limestone concretion in unit 75 (D1953), and a few fragments of large ribs, presumably mosasaurian, were noted in unit 58. Vertebrate fossils are common in the Sharon Springs Member, and the Red Bird area is a rich collecting ground (fig. 7). Loomis (1915) described a new species of mosasaur, *Platecarpus brachycephalus*, from the Sharon Springs outcrops in this area ("at the head of Mule Creek"), and listed representatives of the fishes *Corax*, *Portheus*, *Pachyrhizodus*, *Ichthyodectes*, *Saurocephalus*, and *Empo*, as well as another mosasaur *Elasmosaurus*. The numerous pelecypods and gastropods, and the ammonite listed by Loomis, are not from the Sharon Springs but from some higher level, probably from the upper half of the Red Bird Silty Member. In 1948, Dr. David H. Dunkle, U.S. National Museum (written commun., 1962), collected the following species in T. 38 N., R. 61 W. (Red Bird is in T. 38 N., R. 62 W.): The cartilaginous fishes *Isurus* sp., *Corax* sp., and *Ptychodus* sp.; the bony fishes *Pachyrhizodus* sp., *Elopopsis* sp., *Gillicus* sp., *Ichthyodectes* sp., *Ananogmius* sp., *Cimolichthys* sp., and *Enchodus* sp.; the primitive sea turtle *Porthochelys browni* Hay; and the flying reptile *Pteranodon* sp. A mosasaur, "an exceptionally complete *Clidastes*," was collected from the Pierre Shale near Mule Creek Junction by a University of Wyoming field party, according to the Society of Vertebrate Paleontology News Bull. 65, 1962.

TRACE FOSSILS

Trace fossils are represented in the Red Bird section by trails, burrows, siltstone tubes, fecal pellets, and various scratchings and other marks on the interior surface of cephalopod living chambers. Some of these features are probably the work of marine worms.

Trails were observed in only one bed, a thin layer of siltstone in the Mitten Member (unit 24) low in the Range Zone of the early form of *Baculites perplexus* (pl. 6, fig. 1). The trails are about one-fourth inch wide and consist of a poorly defined median furrow bounded by oblique tracks. They seem to be the same as the tracks shown by Hall and Meek (1855, pl. 7, figs. 3, 4) from Nebraska or South Dakota. Except for their much smaller size, they resemble the trail shown by Abel (1924, p. 101) from the Upper Cretaceous flysch of Upper Austria. Somewhat similar trails have been described and illustrated from rocks as old as the Devonian (Richter, 1941, p. 229–231, text figs. 4–7).

Burrows are common in the rock filling the living chambers of ammonites. They are especially numerous in the baculites in the Mitten Member and in baculites at many other levels, such as the major part of the Red Bird Member and unit 72 in the lower unnamed shale member. The sinuous burrows are 2 mm or less in diameter, and most have smooth interior walls, but a few have hummocky walls. Many burrows are hollow, and some are filled with fecal pellets. In some baculites, the burrows are filled with dark-brown calcite, which contrasts conspicuously with the lighter gray matrix filling the living chamber (pl. 6, fig. 3; pl. 7, fig. 1). On weathered baculites the calcareous material in some of the borings stands out in relief. The burrows in some of the living chambers of baculites from unit 72 in the lower unnamed member are filled with a moderate-brown noncalcareous ferruginous material, whereas the matrix filling the living chamber is light yellowish gray and calcareous and contains clusters of fecal pellets (pl. 10, fig. 13). On a few living chambers (pl. 7, fig. 1) the sinuosity of the burrows and their range in size recall the markings on the dark slate from the Upper Cretaceous (?) Yakutat Group of Alaska described by Ulrich (1904, p. 137, pl. 15) as a plant. An internal mold of the living chamber of a Lower Cretaceous ammonite from Colombia shown by Haas (1960, text fig. 106) contains many burrows like those at Red Bird.

Tubes composed of the same calcareous silty material as that filling the baculite living chambers occur sparsely (pl. 10, fig. 10). They are 3–4 mm in diameter and have a smooth hollow interior 1 mm in diameter. The animal that made them lived in empty baculite living chambers. The tubes do not seem to have been cemented to the wall.

Fecal pellets are abundant and usually well preserved in the living chambers of baculites; they occur in clusters, in the filling of burrows, or scattered throughout the rock. Most are simple ovoids (pl. 7, figs. 4–6, 8–9) as much as 3.5 mm long, like those illustrated by Moore (1939, text fig. 1f). Some are rod shaped (pl. 7, fig. 2), like those from the Raritan Formation (Stephenson, 1954, p. 40, pl. 8, fig. 28), and a few are sinuous. In some baculites the pellets are softer than the matrix, and in others they are harder and weather in relief. Actually, the pellets are much more abundant than is readily apparent. Polished sections of baculite living chambers reveal numerous pellets of the same hardness as the matrix and of almost the same color. Moore (1939, p. 516, 521–522) summarized data concerning fecal pellets in marine sediments and noted that "carnivorous animals tend to produce faeces of loose consistency, vegetable eaters firmer ones, and deposit eaters the most resistant of all," and that "the ovoid type produced by mud-eating polychaetes are certainly to be classed among the more resistant." Moore pointed out further that the simple ovoid is the most abundant type, and that it is produced by a large number of animals. He noted the occurrence of simple ovoids with a polychaete worm in the Clyde Sea of Scotland where pellets have retained their shape in the mud for over a hundred years. Schwarz (1932, text figs. 26–28) illustrated masses of ovoid fecal pellets of a worm and a gastropod from the North Sea; the Red Bird pellets most resemble those of the worm.

On the surface of the internal molds of a few baculites, there are small arcuate parallel ridges and (or) clusters of irregular protuberances, all with a relief of less than 0.1 mm (pl. 8, fig. 6). These are fillings of various cuts and scrapings made by unknown organisms on the inner wall of empty living chambers.

Very well preserved internal molds of living chambers of baculites may have on one or two sides numerous minute scratchlike marks, each of which consists of from four to six parallel bars (pl. 11, figs. 1, 2). The groups of bars occur in areas that range in width from 28 to 90 microns. They seem to be places where some organism rasped bits of shell off the interior of the empty living chambers. Each group of bars tends to lie at a slight angle to the group alongside it, resulting in a somewhat arcuate pattern for rows of scratches. These scratches are most common on the living chamber at its junction with the last septum of the chambered part of the baculite. On some individuals, enough of the shell has been removed by this rasping action to cause the scraped area to stand out in conspicuous relief on the internal mold (pl. 10, figs. 5, 11; pl. 11, fig. 2). The raspings are not unlike those illustrated by Ankel (1938, text fig. 3) for one of the modern gastropods, although the raspings at Red Bird are much smaller.

In a few internal molds of living chambers of baculites from the Red Bird Silty Member, the surfaces are pitted, most extensively near the apertures (pl. 10, figs. 1–4, 6–9). These pits, which are crudely elliptical, are 0.3–0.8 mm in diameter and 0.1 mm or less in depth, and tend to be oriented at right angles to the axis of the living chamber. They are most common on one or two (adjacent) sides of the living chambers, but they may be all around the circumference. They represent the attachment area of some small organism that lived near the open end of empty baculite shells. Each of these very small attachment areas on the baculite shells was shielded from dissolution by sea water. Inasmuch as the surface of the shell not covered by these organisms was dissolved to some extent, the attachment areas now appear as pits on the internal molds of living chambers. Somewhat similar attachment areas were observed on the living chambers of two specimens of an Eocene nautiloid from Japan by Kobayashi and Kamada (1959, p. 119, pl. 10, figs. 2, 3a, 3b), who described them as "numerous light coloured minute spots on the two shells which are all rounded and mostly similar in size. They appear to be traces of anchoring of unknown minor organisms."

RANGE ZONES OF AMMONITES

Range zone, as defined in the "Code of Stratigraphic Nomenclature" (Am. Assoc. Petroleum Geologists Bull., v. 45, no. 5, 1961, p. 656), is "a body of strata comprising the total horizontal and vertical range of occurrence of a specified taxon." Weller (1960, p. 438) noted further, "A range zone also may be considered to consist of all strata deposited during the existence of the zonal organism, whether or not fossils are present in the strata." Although the horizontal range of specific fossils will not be considered here, an attempt will be made to estimate the vertical range of certain ammonites at Red Bird including strata that do not contain fossils (pl. 2). To do this, the authors are drawing upon unpublished data from stratigraphic sections and fossil collections at other localities, such as the Salt Creek oil field north of Casper, Wyo.

***Range Zone of* Baculites obtusus.**—*Baculites obtusus* Meek (1876, p. 406, text figs. 57–60; Cobban, 1962a, p. 706, pl. 105, figs. 1–4) is characterized by its strongly sculptured flanks with closely spaced arcuate nodelike ribs on specimens ¼–1 inch in diameter, and by the weakening and loss of this ribbing on larger specimens.

Shale in the middle of the Sharon Springs Member contains badly crushed, very fragile baculites preserved as a mixture of selenite and rusty limonite. Most specimens ½–1 inch in diameter have strong closely spaced lateral ribs suggesting either *Baculites obtusus* or *B. mclearni.* These very poorly preserved baculites are interpreted as *B. obtusus* because (1) juveniles with widely spaced lateral nodes, a character of *B. mclearni*, were not observed, and (2) the specimens lie well within a bentonite-bearing part of the Sharon Springs that is equivalent to beds in the Salt Creek oil field farther west, and these Salt Creek beds contain several levels of well-preserved *B. obtusus.*

The gypsiferous limonitic baculites are not common where the Sharon Springs was measured at Red Bird and none were collected there, but 2 miles farther east numerous specimens were seen in the excellent outcrops north of the road at locality D2908 in the NW¼ sec. 20, T. 38 N., R. 61 W. Fossils from this locality are listed in the measured section.

In the Red Bird section, the poorly preserved baculites, interpreted as *B. obtusus*, are found scattered through unit 16, which comprises the interval from 36 to 57 feet above the base of the Sharon Springs Member, or a known range of 21 feet. In the Salt Creek oil field, *B. obtusus* occurs throughout a bentonite-bearing part of the Cody Shale down to the top of a thick bed of bentonite correlated with the Ardmore Bentonite Bed. Accordingly, the base of the inferred Range Zone of *B. obtusus* at Red Bird is placed at the top of the Ardmore Bed, which is 36 feet below the base of the lowest specimens observed in the Red Bird section. The upper 10 feet of the Sharon Springs Member contains *B. mclearni*, and, hence, the top of the Range Zone of *B. obtusus* lies somewhere between the top of unit 16 (60 ft above the base of the Sharon Springs) and the lowest occurrence of *B. mclearni* (116 ft above the base). The boundary is arbitrarily drawn in the middle of the undated interval that falls approximately at the contact between units 18 and 19. The Range Zone of *B. obtusus* in the Red Bird section is probably in the order of 88 feet (rounded to 90 ft).

***Range Zone of* Baculites mclearni.**—*Baculites mclearni* Landes (1940, p. 165, pl. 7, figs. 1–3; Cobban, 1962a, p. 712, pl. 105, fig. 15; pl. 107, figs. 17–19; text figs. 1g, h) resembles *B. obtusus* at diameters of ½–1 inch, but the strong lateral ribs persist in larger specimens of *B. mclearni*, and most juveniles ¼–½ inch in diameter have widely spaced nodelike lateral ribs.

The oldest examples of this species at Red Bird are crushed fragile specimens composed of a mixture of selenite and rusty limonite; they are much like specimens of *B. obtusus* lower in the section. The specimens of *B. mclearni* occur sparsely in the uppermost 10 feet of the Sharon Springs Member (D2101, D1858). Better preserved specimens, although crushed, were collected from a gray limestone concretion 6 feet above the top of the Sharon Springs (D4009). Specimens of *B. asperiformis*, more or less transitional from *B. mclearni*, occur only 13 feet higher (D1856) in the section; the top of the Range Zone of *B. mclearni* is placed at the base of this collection. The base of the range zone is arbitrarily placed at the bottom of unit 19 (35 ft below the top of the Sharon Springs) for the reasons given in the discussion of the Range Zone of *B. obtusus*. *Baculites mclearni* has been collected from only 16 feet of beds, but its range zone is probably about 54 feet (rounded to 55 ft).

Crushed baculites preserved as a mixture of limonite and selenite like those in the Sharon Springs Member at Red Bird are present in the Sharon Springs Member 340 miles south of Red Bird at Pueblo, Colo. (Scott and Cobban, 1963, p. B100), and in Logan County, Kans., some 330 miles southeast of Red Bird.

***Range Zone of* Baculites asperiformis.**—*Baculites asperiformis* Meek (1876, p. 405, pl. 39, figs. 10a, 10d; Cobban, 1962a, p. 708, pl. 106, figs. 1–16) is characterized by strong arcuate widely spaced lateral nodes on specimens ¼–1 inch in diameter; larger specimens tend to be smooth.

This zone at Red Bird is represented by very few specimens of *Baculites asperiformis*. The fossils were found in dusky-red shaly ironstone concretions and buff-weathering septarian limestone concretions 19–60 feet above the base of the Mitten Black Shale Member (unit 21). The specimens in the shaly ironstone concretions are crushed, whereas those in the limestone concretions, although commonly broken and distorted, are much better preserved. The chambered parts lacking the shell material are light brownish yellow to moderate brown, and in most the chambers are partly filled with pale-yellow calcite crystals. Most of the baculites are large (50–60 mm in diameter) and the shells are smooth; these represent senile individuals. Weak but distinct lateral ribbing persists on many of the younger adults, reflecting their well-ribbed *B. mclearni* ancestry. Inasmuch as typical young adults of *B. asperiformis* are smooth, the Red Bird specimens suggest a low position in the range zone. The lower boundary of the *B. asperiformis* Range Zone is placed 19 feet above the base of the Mitten Member, because the D1856 collection is transitional to *B. mclearni.* Other collections have been made in the overlying 41 feet, and the general aspect of these lots indicates a low level in the range zone. Above the highest collection (D1859), an interval of about 150 feet has not yielded diagnostic fossils, whereas concretions just above this interval contain a smooth species of *Baculites.* The top of the *B. asperiformis* Range Zone must lie in the undated 150-foot interval. Almost nothing is known about the Range Zone of *B. asperiformis* in the Salt Creek oil field, but in the northern Front Range area of Colorado, the zone is several hundred feet thick. Judging from the great thickness of the zone to the south, and from the old appearance of the *B. asperiformis* collections at Red Bird, it seems logical to assume that the top of the range zone lies high in the undated 150-foot interval. Accordingly, three-fourths of this unit (112 ft) is arbitrarily assigned to the *B. asperiformis* Range Zone; with the known 41 feet, this layer gives a total inferred thickness of about 153 feet (rounded to 155 ft).

Range Zone of* Baculites *smooth species.—A zone of smooth baculites lies above the Range Zone of *B. asperiformis.* Medium- and large-sized adults are smooth, like similar-sized specimens of typical *B. asperiformis.* Juveniles are also smooth, whereas similar-sized individuals of *B. asperiformis* have widely spaced conspicuous lateral nodes. Two examples from D2102 in unit 21 have been depicted (Cobban, 1962a, p. 714, pl. 108, figs. 1–4, text figs. 1i, j).

This smooth species is represented by many specimens from orange- and gray-weathering limestone concretions in unit 21, 217–233 feet above the base of the Mitten Member (D2102, D2904, D2905). The baculites are very well preserved and commonly consist of uncrushed specimens 50–60 mm in diameter. Chambered parts, lacking the shell material, are moderate brown to lighter yellowish brown and grayish orange, and many of the chambers are partly filled with pale-yellow calcite crystals.

The smooth species has been found through only 13 feet of beds. The base of the inferred range zone is arbitrarily drawn 38 feet below the top of unit 20 (173 ft above the base of the Mitten Member). *Baculites perplexus*, which marks the next zone above the smooth species, first appears in unit 22 only 42 feet above the top of the collection of smooth baculties. Collections (D2122, D2906) from unit 22 are small, but they suggest that the earliest *B. perplexus* are transitional from the smooth species, and a few individuals in unit 22 could be interpreted as the older species. Owing to the transitional nature of the collections from unit 22, the range zone of the smooth baculite is extended to the base of this unit. The thickness of strata assigned to the range zone of the smooth species is all of unit 21 (60 ft) and 38 feet of unit 20, or a total of 98 feet (rounded to 100 ft).

Range Zone of* Baculites perplexus *(early form).—*Baculites perplexus* Cobban (1962a, p. 714, pl. 107, figs. 1–16; text figs. 1a–c) is characterized by its strongly ribbed venter and more weakly ribbed flank. The oldest baculites that seem assignable to *B. perplexus* are in two collections (D2122, D2906) from small iron-stained limestone concretions in unit 22, 271–283 feet above the base of the Mitten Member. The specimens are few, but most of them have ribbed flanks and smooth or nearly smooth venters. They are clearly transitional from the slightly older smooth species, and a few individuals are smooth.

At a little higher level in the Red Bird section, 308–318 feet above the base of the Mitten Member, baculites are moderately common and very well preserved in small gray- and orange-weathering limestone concretions in unit 23 (D1861, D1862, D2907). The chambers of septate specimens are partly or entirely filled with pale-yellow calcite crystals, and on specimens lacking the outer shell material, the outside walls of adjacent chambers are commonly of different colors, such as light yellowish brown, medium brown, dark brown, or, more rarely, black. On most specimens both the flank and venter are strongly ribbed. Specimens 15–35 mm in diameter are the most suitable for rib counts. Smaller specimens are juveniles that are smooth or just beginning to attain ribbing; larger specimens are either in the senile stage or approaching it, and their ribbing becomes erratic in strength and spacing or disappears. Of the specimens 15–35 mm in diameter, the two largest collections (D1861, D1862) show an average spacing of

3.2 ribs on the venter in a distance equal to the diameter of the shell. This ribbing is coarser than that of the type lot of *B. perplexus* from the Cody Shale farther west near Glenrock, Wyo., where 150 specimens, 15–35 mm in diameter, average 3.7 ventral ribs for the shell diameter.

Units 23–27 and the lower 44 feet of unit 28, which total 318 feet, unfortunately did not yield megafossils. The overlying part of the Mitten Member is very fossiliferous although the fossils are chiefly baculites and inoceramids. The baculites are well preserved, most are uncrushed, and many retain their shell material, which is white to nacreous on specimens 635–915 feet above the base of the Mitten Member, and ivory colored on those 915–938 feet above the base (uppermost 23 ft of Mitten).

The lowest collection of baculites (D1864 in unit 28) above the thick unfossiliferous sequence contains specimens that have more finely ribbed venters (average 5.2 ribs per diameter) than those immediately below the unfossiliferous beds where they average 3.2 ribs per diameter. Beginning with the 5.2 average of D1864 (636–651 ft above the base of the Mitten), each successively higher collection of baculites seems to show slightly coarser ventral ribbing until a maximum coarseness of 3.1 ribs per diameter is attained in D1873 in unit 29, 781–783 feet above the base of the Mitten. Above this level, the baculites abruptly become finer ribbed, and the name *B. gilberti* Cobban (1962a, p. 716) is applicable to them. The lowest collection (D1874) of these finer-ribbed baculites is only 12 feet above D1873, and the top of the Range Zone of the early form of *B. perplexus* is placed at the base of the D1874 collection, which is 795 feet above the base of the Mitten. Inasmuch as the lower limit of the Range Zone of *B. perplexus*, is 271 feet above the base of the Mitten, the total thickness of the Range Zone of the early form is about 524 feet (rounded to 525 ft).

***Range Zone of* Baculites gilberti.**—*Baculites gilberti* Cobban (1962a, p. 716, pl. 108, figs. 5–13; text figs. 1d–f) resembles *B. perplexus* in having lateral ribs and a well-ribbed venter, but the ventral ribs are not as strong and their spacing is closer. The type lot of *B. gilberti* from the Pierre Shale near Boulder, Colo., contains 28 specimens 15–35 mm in diameter that have ventral ribbing, and these average 6.6 ribs per diameter of shell.

The upper 142 feet of the Mitten Member and the lower 108 feet of the Red Bird Silty Member at Red Bird contain baculites that seem referable to *B. gilberti*, although none of the collections have ventral rib averages as high as that of the type lot. *Baculites gilberti* descended rapidly from the early form on *B. perplexus*, and almost as rapidly gave rise to the coarse-ribbed late form of *B. perplexus*. The base of the Range Zone of *B. gilberti* is the level of D1874 (795 ft above the base of the Mitten Member), and the top is the position of D1891 in unit 37 (1,046 ft above the base of the Mitten) where the specimens change rapidly to the coarse-ribbed form. A thickness of 251 feet (rounded to 250 ft) is assigned to the Range Zone.

The baculites in the Range Zone of *B. gilberti* are abundant, well preserved, and largely uncrushed. Septate specimens from the upper part of the Mitten are usually partly filled with pale-yellow calcite crystals, and the outer surface of internal molds are several shades of brown. Specimens from the lower part of the Red Bird Silty Member are not so well preserved, and most consist of dark-yellowish-orange internal molds of living chambers.

***Range Zone of* Baculites perplexus (*late form*).**—Collections of baculites assigned to this zone have average ventral rib counts of less than five for the diameter. In this feature and in the presence of lateral ribs and the *perplexus*-like suture, these baculites resemble the early form of *B. perplexus*.

The lowest collections of the late form of *B. perplexus* are D1892 and D1893 at the base of unit 38 (124 ft above the base of the Red Bird Silty Member), and the highest collections are D1898 and D1899 at the top of unit 39 (218 ft above the base of the Red Bird Member). The known range for this baculite is therefore 94 feet. The base of its range zone is placed 16 feet lower at the level of the D1891 collection in unit 37 because the baculites in that collection, although assigned to *B. gilberti*, are transitional to the late form of *B. perplexus*. The upper limit of the range zone is placed at the base of unit 41 (13 ft above the highest collections of *B. perplexus*) because the baculites in that unit, although assigned to *B. gregoryensis*, are clearly transitional from *B. perplexus*. This gives a total thickness of 123 feet (rounded to 125 ft) for the Range Zone of the late form of *B. perplexus*.

The baculites representing the late form of *B. perplexus* are more numerous and better preserved than the *B. gilberti* lower in the Red Bird Silty Member. The chambers are usually filled with white to yellowish-white calcite, and many specimens have a white outer shell. Baculites are especially abundant in unit 39 near the top of the range zone of the species.

***Range Zone of* Baculites gregoryensis.**—*Baculites gregoryensis* Cobban (1951a, p. 820, pl. 118, figs. 1–5; text figs. 8–13) differs from its ancestor *B. perplexus* by having smooth flanks on most specimens and a more complex suture in which the first lateral lobe is constricted just above its major lateral branches. The earliest specimens resemble *B. perplexus* in having conspicuous coarse ventral ribbing, but later specimens are much more finely ribbed.

Baculites gregoryensis is common and very well preserved in much of the upper half of the Red Bird Member. This baculite is abundant in the gray limestone concretions in unit 41: from these, 300 uncrushed specimens were collected for measurements of size, angle of taper, and density of ventral ribbing. The chambers are partly or wholly filled with white to yellowish-white calcite crystals, and the shell material forming the outside of the baculites is white. Specimens from brown- and orange-weathering limestone concretions higher in the Red Bird Member, such as D1915 in unit 48, have nacreous shells.

The lower limit of the Range Zone of *B. gregoryensis* lies at the base of unit 41, 231 feet above the base of the Red Bird Member. A collection (D1900) from this unit contains 183 baculites 15–35 mm in diameter (suitable for ventral rib counts), and these average 4.4 ribs per shell diameter. The coarseness of ribbing is thus comparable to that of *B. perplexus*. Above the level of unit 41, ventral ribbing rapidly becomes finer and weaker, foreshadowing the smooth or nearly smooth venter of *B. scotti*, the descendant of *B. gregoryensis*. The highest collection is D1921 in the lower part of unit 51, about 518 feet above the base of the Red Bird. The next fossiliferous bed above D1921 is about 42 feet higher, where D1922 and D1923 at the top of unit 52 contain *B. scotti*. The top of the Range Zone of *B. gregoryensis* is arbitrarily placed midway in this 42-foot unfossiliferous interval, thus giving an inferred total thickness of 308 feet (rounded to 310 ft) for the range zone.

***Range Zone of* Baculites scotti.**—*Baculites scotti* Cobban (1958, p. 660, pl. 90, figs. 1–9; text figs. 1a–e, h) differs from *B. gregoryensis* by having less taper and a nearly smooth venter. Both species have the same suture pattern.

Baculites scotti occurs in the uppermost part of the Red Bird Silty Member and in the lowest part of the overlying unnamed dark shale member. It is not a common fossil. Specimens from concretions in the Red Bird Member have white shells, and those from concretions in the overlying shale have nacreous shells.

The lowest specimens of *B. scotti* were collected at the top of unit 52 (D1922, D1923), 48 feet below the top of the Red Bird, and the highest specimens were collected at D1932, 91 feet above the member; the total known range is therefore 139 feet. The lowest diagnostic fossil found above D1932 is *Didymoceras nebrascense* at D1934 in unit 58, 59 feet above D1932. The top of the Range Zone of *B. scotti* is arbitrarily placed at the midpoint of this 59-foot interval (121 ft above the Red Bird Member). Inasmuch as the base of the range zone was drawn 69 feet below the top of the Red Bird, the total thickness of the inferred range zone is 190 feet.

***Range Zone of* Didymoceras nebrascense.**—*Didymoceras nebrascense* (Meek and Hayden) was originally described as *Ancyloceras? nebrascensis* by Meek and Hayden (1856, p. 71) but was not illustrated. Later Meek (1876, p. 480, pl. 22, figs. 1a–c) described the type specimen more fully and illustrated it. This specimen consists of only a small fragment. The best illustrations of the species are those of Whitfield (1902), who showed several specimens under the name of *Heteroceras simplicostatum*.

Didymoceras nebrascense is an aberrant ammonite that has early whorls consisting of straight limbs connected by semicircular bends, later whorls in an open helicoid spire, and the final whorl bent at first away from the spire and then curved back toward it. There are closely spaced ribs and a row of small nodes on each side of the venter on the early straight limbs as well as on the later spiral part. Coarse ribs and strong nodes characterize the final recurved whorl.

Didymoceras nebrascense is not common in the Red Bird section, and the specimens collected are very fragmentary. However, the fragments are readily identifiable as to species by the dense ribbing and by the absence of any impressed area to indicate that adjacent whorls were in contact. The fossils have nacreous shells in which purple is conspicuous in unweathered specimens; white or ivory is characteristic of weathered ones.

Didymoceras nebrascense is found in concretions in unit 58 from 150 feet (D1934) to 223 feet (D1938) above the Red Bird Silty Member, a known range of 73 feet. *Didymoceras stevensoni*, which characterizes the next younger ammonite zone, is found only 13 feet above the highest collection of *D. nebrascense*. These 13 feet are assigned to the Range Zone of *D. stevensoni*, inasmuch as that species extends through a thickness of strata about equal to that containing *D. nebrascense* in areas farther west. The base of the Range Zone of *D. nebrascense* is inferred to lie about 121 feet above the top of the Red Bird, and the total thickness of the inferred range zone is 102 feet (rounded to 100 ft).

***Range Zone of* Didymoceras stevensoni.**—The original description of *Didymoceras stevensoni* (Whitfield) was based on the helicoid spiral part of a well-preserved aberrant ammonite from the Beaver Creek area southwest of Newcastle and about 40 miles north of Red Bird. The species was described by Whitfield (1877, p. 39; 1880, p. 447, pl. 14, figs. 5–8) as *Helicoceras stevensoni*. A more complete specimen was later illustrated by Whitfield (1901).

Didymoceras stevensoni is characterized by coarse ribbing and by the larger whorls of the helicoid spire, which are either in contact with the next earlier whorl or almost touching it. As a result of this close coiling, most of the larger whorls have an impresed area on the side adjacent to the next older whorl.

Didymoceras stevensoni has been found only in the red- and brown-weathering concretions in unit 59 in the lower unnamed shale member, where specimens are common but very fragmentary. The fragments are easily identified by the coarse ribbing and the impressed area. Most have slightly nacreous shells.

The known range of the species is only the 16 feet of unit 59. Fossils were not found in the overlying 17 feet (unit 60), but *Baculites rugosus*, a guide fossil to the next younger zone of *Exiteloceras jenneyi*, was found at the base of unit 61. A bed of bentonite is present 7 feet above the base of unit 60. Bentonite is abundant in rocks of *E. jenneyi* age on the north flank of the Black Hills uplift (Monument Hill Bentonitic Member), whereas bentonite is absent in the underying rocks of *Didymoceras stevensoni* age. Accordingly, the 17 feet of unit 60 are assigned to the Range Zone of *E. jenneyi*. The thickness of strata assumed to represent the Range Zone of *D. stevensoni* is the 16 feet of unit 59 plus the uppermost undated 13 feet of unit 58, a total of only 29 feet (rounded to 30 ft), all in the lower unnamed shale member.

***Range Zone of* Exiteloceras jenneyi.**—*Exiteloceras jenneyi* (Whitfield) was described as *Ancyloceras jenneyi* by Whitfield (1877, p. 42; 1880, p. 452, pl. 16, figs. 7–9) from specimens collected from the Pierre Shale in the Beaver Creek area about 40 miles north of Red Bird. Whitfield's illustrations have recently been reproduced by Arkell, Kummel, and Wright (1957, fig. 251, 7a–c).

Exiteloceras jenneyi is an aberrant ammonite that has juvenile whorls as straight limbs connected by semicircular bends, and later whorls loosely coiled in a plane without contact between adjacent whorls. Ornamentation consists of moderately coarse ribs, each of which terminates in a node at the margin of the venter. The species is easily identified from small fragments.

Exiteloceras jenneyi is common in units 61, 64, and 65 in the lower unnamed shale member, a total known range of 87 feet. Fossils were not found in unit 66 (6 ft), but unit 67 (3 ft), which is bentonitic, contains a small aberrant ammonite (*Solenoceras*) like that found with *E. jenneyi* in unit 65. Unit 69, which is only 6 feet above unit 67, yielded a coarse-ribbed scaphite of a type unknown in rocks as old as *E. jenneyi*, and a single baculite that seems assignable to *Baculites reesidei*. Accordingly, the upper boundary of the Range Zone of *E. jenneyi* is placed in the lower unnamed shale member at the top of unit 67 (366 ft above the top of the Red Bird Member). The lower boundary is assumed to lie at the base of unit 60 (252 ft above the Red Bird Member), and the inferred total thickness for the range zone is therefore 114 feet (rounded to 115 ft).

***Range Zones of* Didymoceras cheyennense, Baculites compressus *and* Baculites cuneatus.**—Fossils representing these three zones are unknown at Red Bird, where only 6 feet of shale in the upper part of the lower unnamed shale member (unit 68) seems to be assignable to these zones. Unit 67 is assigned to the Range Zone of *Exiteloceras jenneyi*, and unit 69 to the Range Zone of *Baculites reesidei*. Nothing unusual was noticed about the 6 feet of shale of unit 68. Phosphatic nodules or other features suggesting slow deposition were not observed. The time equivalent of the Range Zone of *Didymoceras cheyennense*, *B. compressus*, and *B. cuneatus* farther west and southwest is the nonmarine Teapot Sandstone Member of the Mesaverde Formation of the Casper area, and the Pine Ridge Sandstone Member of the Mesaverde Formation of the Laramie Basin. Straigraphic studies in progress in central and western Wyoming indicate a widespread unconformity at the base of the Teapot Sandstone Member of the Mesaverde Formation throughout much of the State. The thinness of strata at Red Bird appears to be related to this unconformity and is probably the result of submarine erosion (Gill and Cobban, 1966). Farther east, on the east flank of the Black Hills uplift, there are fossils representing each of the three ammonite zones.

***Range Zone of* Baculites reesidei.**—*Baculites reesidei* Elias (1933, p. 302, pl. 32, figs. 2a–c) was described by Elias as *B. compressus* Say var. *reesidei*. The holotype is a specimen from the Bearpaw Shale of Montana shown as *B. compressus* by Reeside (1927, p. 10, pl. 9, figs. 1–5). Elias' form is regarded as a distinct species because of its well-ribbed venter and its ventrolateral depression, features usually absent on *B. compressus* (Cobban, 1962b, p. 131).

Baculites reesidei is represented best at Red Bird by well-preserved specimens in limestone concretions in unit 75 and by phosphatic internal molds in unit 72. The specimens from the limestone concretions in unit 75 have white shells. The chambers are nearly or completely filled with calcite crystals that are pale brown to almost colorless. The outer surface of internal molds is various shades of brown. The phosphatic specimens in unit 72 are brown; they are chiefly fragments of adult living chambers and contain extensive burrows and fecal pellets.

The known range of the species is from the base of unit 69 (D1949) to 10 feet below the top of unit 75 (D1954), a total of 126 feet in the lower unnamed shale member. Unit 76 contains baculites of post-*reesidei* age. The upper undated 10 feet of unit 75 is assigned to the Range Zone of *Baculites reesidei* simply as a matter of convenience; the total assumed thickness is therefore 136 feet (rounded to 135 ft).

***Range Zone* of Baculites jenseni.**—*Baculties jenseni* Cobban (1962b, p. 129, pl. 26, figs. 1–12; text fig. 1a) is characterized by its very small amount of taper, stout ovate cross section, smooth flank, ventrolateral depression, and suture in which the terminal branches of the first lateral lobe are constricted at their base. The venter is well ribbed on young adults but tends to become smooth on older individuals.

Fossils are scarce in the 60 feet of shale overlying unit 75. Units 76 and 77 each yielded two fragments of baculites. The specimens from unit 76 (D1955) are poorly preserved phosphatic internal molds of adult living chambers that have very little taper, stout ovate cross sections, and smooth flanks. They could be assigned to either *Baculites jenseni* or the closely related *B. eliasi.* The two fragments from unit 77 (D1956) are parts of young adults that have a more slender cross section and a well-ribbed venter; they may well be *B. jenseni.*

The thickness of the beds containing baculites that are probably *B. jenseni* is only 15 feet (unit 76 and 6 ft of unit 77). *Baculites eliasi* is found 14 feet above the base of unit 78, and its range extends more than 200 feet upward. If the 14-foot section of unit 78 and all of units 77 and 76 lie in the Range Zone of *B. jenseni*, the total thickness of that zone can hardly exceed 63 feet. This figure (rounded to 65 ft) is used as a possible thickness of the inferred range zone.

***Range Zone of* Baculites eliasi.**—*Baculites eliasi* Cobban (1958, p. 663, pl. 91, figs. 1–11; text figs. 1f, 1g, 1i, 1j) resembles its immediate ancestor *B. jenseni* in its smooth flank, suture pattern, and almost complete lack of taper, but it differs by having a more elliptical cross section and a smooth or nearly smooth venter.

Baculites eliasi is common and very well preserved in units 78 (D1636), 80 (D1961), 81 (D1962, D2903, D1963), 85 (D1967), and 86 (D1968, D1966, D1969). Uncrushed specimens of both the chambered and unchambered parts can be readily collected, and many have nacreous shells. The chambers are usually partly filled with pale-yellow to deep-yellow calcite crystals, and a few have, in addition, light-brown crystals of barite.

The range of *Baculites eliasi* extends through 231 feet of beds, beginning 11 feet below the top of unit 78 (149 ft below the base of the Kara Bentonitic Member), and continuing up through 46 feet of unit 86 (82 ft above the base of the Kara). Unit 87, 15 feet above the highest collection of *B. eliasi* (D1969), contains abundant *Inoceramus typicus*, a pelecypod characteristic of the Range Zone of *Baculites baculus*. This 15-foot interval is arbitrarily divided between the two zones; the inferred total thickness of the Range Zone of *B. eliasi* is therefore 239 feet (rounded to 240 ft.)

***Range Zone of* Baculites baculus.**—*Baculites baculus* Meek and Hayden (1861, p. 445; Meek, 1876, p. 397, figs. 51, 52) is characterized by its large size, broad arcuate lateral ribs, moderately simple suture in which the opposite branches of the first lateral lobe are widely separated, and cross section that is nearly circular in juveniles and young adults but broadly ovate in older adults. This species seems to be a migrant into the Western Interior; it may have had its origin in *B. undatus* Stephenson (1941, p. 405, pl. 79, figs. 5–10) from the Navarro Group of Texas. A few baculites that resemble *B. baculus* first appear below the Kara Member low in the Range Zone of *B. eliasi* (D1636 in unit 78), but *B. baculus* does not appear in large numbers until well above the Kara.

In the Red Bird section, *Baculites baculus* has been identified with certainty only in the limestone concretions in unit 93. The specimens are well preserved, most are uncrushed, and they have brown to white shells. The chambers are partly or completely filled with pale-yellow to pale-brown calcite crystals.

The known range of *Baculites baculus* at Red Bird is the 17 feet of unit 93. Units 87 and 91 contain limestone concretions crowded with *Inoceramus typicus*. Similar concretions are widely distributed in the Western Interior from eastern Montana south into Colorado. The only baculite known from the *Inoceramus typicus* concretions is *B. baculus*. Because these inoceramids are abundant in unit 87 (61 ft above the top of the Kara Member), that unit is considered as the base of the Range Zone of *B. baculus*. The top of the Range Zone is placed at the base of unit 95 (275 ft above the Kara), which contains baculites assigned to the next younger zone of *B. grandis* but clearly transitional from *B. baculus*. The total thickness of the inferred Range Zone of *B. baculus* is 214 feet (rounded to 215 ft).

***Range Zone of* Baculites grandis.**—*Baculites grandis* Hall and Meek (1855, p. 402, pl. 6, fig. 10; pl. 7, figs. 1, 2; pl. 8, figs. 1, 2) resembles *B. baculus* in its large size, suture, and ornamentation, but differs by the more ovate cross section of juveniles and the narrower venter of adults.

Baculites grandis is common and very well preserved in units 95–104, 257–482 feet above the top of the Kara Bentonitic Member. The shells are nacreous where fresh, and brown and white where weathered. Pale-yellow to dark-brown calcite crystals usually line the chambers. The known range of 225 feet is probably also the total thickness of the range zone, inasmuch as the lowest collection (D2117) is transitional from *B. baculus* and the highest collection (D1986) is transitional to *B. clinolobatus*.

***Range Zone of* Baculites clinolobatus.**—*Baculites clinolobatus* Elias (1933, p. 310, pl. 30, figs. 1, 2; pl. 34, figs. 1, 2a, 2b) differs from its immediate ancestor *B. grandis* by its narrower venter, more compressed cross section in juveniles and young adults, more trigonal cross section in older adults, and more widely spaced broad lateral ribs. In addition, many young adults (1–1½ in. in diameter) have a dorsolateral depression.

Baculites clinolobatus is common in units 106 and 108, where the specimens have nacreous shells like those in the underlying Range Zone of *B. grandis*. Units 106–108 total 63 feet. The base of the Range Zone of *B. clinolobatus* is placed 35 feet lower at the top of unit 104, because of the transitional nature of the baculites in that unit. Units 109–111, which form the uppermost 77 feet of the Pierre Shale, are included also in the Range Zone of *B. clinolobatus* because of the presence of *Inoceramus*? *fibrosus* in the basal bed (unit 112) of the Fox Hills Sandstone. *Inoceramus*? *fibrosus* is not known in the Western Interior above the Range Zone of *B. clinolobatus*. The thickness of the Range Zone of *B. clinolobatus* in the Pierre Shale at Red Bird is inferred to be 175 feet.

AGE SPAN

The age span of the Pierre Shale at Red Bird can be evaluated by relating the known megafossil zones of the Pierre Shale and adjacent rocks to potassium-argon age determinations. In table 2, the fossil zones for the Pierre Shale follow the general usage of Scott and Cobban (1959) and Zapp and Cobban (1962). A few other important mollusks are added, and *Baculites perplexus*, treated as a single zone by Zapp and Cobban (1962, p. D54), is herein considered as representing three ammonite zones. The oldest zone is marked by an early form of *B. perplexus*, the middle by *B. gilberti*, and the youngest by a late form of *B. perplexus* (Cobban, 1962a, p. 705). This distinction has been made in an attempt to equate progressive changes in the forms of baculites in various zones. In other words, the sculptural and suture changes observable between *B. gilberti* and the late form of *B. perplexus* are roughly comparable in magnitude to the changes observable between *B. gregoryensis* and *B. scotti*, or between any other two baculites of adjoining zones. The megafossil zones representing the time span of the Niobrara Formation follow the previous usage of Cobban (1951b, p. 2194–2197; 1964, p. 15) and Scott and Cobban (1964, p. L24). The marine zones for the post-Pierre rocks are based on the fossil content of the Fox Hills Sandstone at Red Bird and in the type area of the Fox Hills. The Fox Hills Sandstone is at least 400 feet thick in the Red Bird area (Stanton, 1910, p. 184; Kramer and others, 1943), but only the basal 100-foot ridge-forming sandstone can be closely dated. This basal sandstone contains species of *Sphenodiscus* (*Coahuilites*), *Discoscaphites*, and *Hoploscaphites*, which suggest an age younger than the *Baculites clinolobatus* Range Zone and older than the oldest zone (*Hoploscaphites nicolletii*) of the Fox Hills Sandstone in its type locality in north-central South Dakota.

In table 2, the subdivision of the Coniacian and Santonian Stages into lower, middle, and upper parts follows broadly the recent works of Seitz (for example, 1953, p. 150; 1956, p. 4; 1959, p. 120). The divisions of the Campanian and Maestrichtian Stages into lower and upper parts are accepted by most stratigraphers in Europe and elsewhere. The boundary between the lower and upper parts of the Maestrichtian is questionable, and its position at the top of the *Discoscaphites nebrascensis* Range Zone is taken from Jeletzky (1962, p. 1008).

Most of the potassium-argon dates shown in table 2 are those that Kulp (1961) believed to be most reliable for the latest part of the Cretaceous. The original source of the 87±3 million years for the Coniacian, 83±3 million years for the lower Santonian, and the 81±3 million years for the lower Campanian is from an investigation by Evernden, Curtis, Obradovich, and Kistler (1961, p. 81, 95–97). Their samples came from glauconitic sandstone beds near Hannover, Germany. Data on the stratigraphic positions of these sandstones within the Conician and lower Campanian were not presented and are not available according to Evernden (written commun., June 1963). Presumably, the Coniacian sample came from rocks representing the middle or lower part of the stage (possibly Range Zone of *Inoceramus involutus*), inasmuch as strata of this age are widespread in Germany according to the literature. The early Campanian sample presumably came from rocks lying in the *Scaphites hippocrepis* Range Zone, which seems to be prominent in Germany. In the table the 81±3 million years is placed at the top of the *S. hippocrepis* Range Zone; there *S. hippocrepis* is represented by fine-ribbed forms much like those illustrated as *S. cuvieri* from Germany by Schlüter (1876, pl. 42, figs. 1–3).

The late Campanian date of 75±2 million years and most of the Maestrichtian dates are from papers by

TABLE 2.—*Time relation of the Pierre Shale at Red Bird to the standard stages of the Upper Cretaceous, to potassium-argon dates, and to the Western Interior ammonite sequence.*

[Asterisk indicates that fossil is present in Pierre Shale at Red Bird, Wyo.]

Upper Cretaceous stages and substages		Stratigraphic section at Red Bird and vicinity		Potassium-argon dates (Millions of years)	Estimated dates (Millions of years)	Western Interior ammonite sequence
				63[1]	63	
				64±2[2]	64	
	upper	Lance Formation			65	
				66±2[3]	66	
Maestrichtian	?				67	
					68	*Discoscaphites nebrascensis, Discoscaphites cheyennensis*
						Hoploscaphites nicolletii, Discoscaphites roanensis
	lower	Fox Hills Sandstone			69	*Sphenodiscus (Coahuilites), Discoscaphites* n. sp.
						**Baculites clinolobatus*
			upper unnamed shale member	70[4]	70	**Baculites grandis*
						**Baculites baculus, Ponteixites*
			Kara Bentonitic Member		71	**Baculites eliasi*
						**Baculites jenseni, Rhaeboceras*
					72	**Baculites reesidei, Rhaeboceras*
						Baculites cuneatus
				75±2[5]	73	*Baculites compressus*
			lower unnamed shale member			*Didymoceras cheyennense*
					74	**Exiteloceras jenneyi,* **Baculites rugosus*
						**Didymoceras stevensoni, Baculites crickmayi*
	upper				75	**Didymoceras nebrascense, Baculites pseudovatus*
		Pierre Shale				**Baculites scotti,* **Menuites,* **Anapachydiscus*
					76	**Baculites gregoryensis,* **Trachyscaphites redbirdensis*
Campanian			Red Bird Silty Member			**Baculites perplexus* (late form)
					77	**Baculites gilberti*
						**Baculites perplexus* (early form)
			Mitten Black Shale Member		78	**Baculites* sp. (smooth)
						**Baculites asperiformis, Hoplitoplacenticeras, Trachyscaphites spiniger porchi*
			Sharon Springs Member		79	**Baculites mclearni, Trachyscaphites spiniger porchi*
						**Baculites obtusus, Trachyscaphites praespiniger*
					80	*Baculites* sp. (weak flank ribs), *Trachyscaphites praespiniger*
			Gammon Ferruginous Member			*Baculites* sp. (smooth), *"Indoscaphites"*
	lower			81±2[6]	81	*Haresiceras natronense, Scaphites hippocrepis* (fine ribbed)
		?				*Haresiceras placentiforme, Scaphites hippocrepis* (coarse ribbed)
					82	*Haresiceras montanaense, Scaphites hippocrepis* (coarse ribbed)
	upper					*Desmoscaphites bassleri, Haresiceras manocosense*
					83	*Desmoscaphites erdmanni, Clioscaphites novimexicanus*
Santonian	middle					*Clioscaphites choteauensis, Baculites* sp. (smooth)
					84	*Clioscaphites vermiformis, Clioscaphites montanensis*
?	lower	Niobrara Formation		83±3[7]		*Clioscaphites saxitonianus*
	upper				85	*Scaphites depressus, Protexanites shoshonensis*
Coniacian	middle			87±3[8]		*Scaphites ventricosus*
					86	*Scaphites preventricosus, Baculites mariasensis*
	lower					*Barroisiceras, Peroniceras*

[1] "Big Dirty" coal seam at base of Fort Union Formation near Fort Peck, Mont. Folinsbee, Baadsgaard, and Cumming (1963, p. 77–78).
[2] Pembina coal bed near top of Edmonton Formation near Whitecourt, Alberta. Folinsbee, Baadsgaard, and Lipson (1961, p. 353–356) ; Kulp (1961, p. 1107).
[3] Kneehills tuff zone in upper part of Edmonton Formation southwest of Edmonton, Alberta. Folinsbee, Baadsgaard, and Lipson (1961, p. 353–356) ; Kulp (1961, p. 1107).
[4] Bentonite bed 100 ft below Fox Hills Sandstone north of Jordan, Mont. Nascimbene (1963, p. 78).
[5] Bentonite bed 45 ft above base of Bearpaw Shale near Lethbridge, Alberta. Folinsbee, Baadsgaard, and Lipson (1961, p. 353–356) ; Kulp (1961, p. 1107).
[6] Lower Campanian glauconitic sandstone near Hannover, Germany. Evernden, Curtis, Obradovich, and Kistler (1961, p. 96) ; Kulp (1961, p. 1107).
[7] Lower Santonian glauconitic sandstone near Salzgitter, Germany. Evernden, Curtis, Obradovich, and Kistler (1961, p. 97) ; Kulp (1961, p. 1108).
[8] Coniacian glauconitic sandstone near Hannover, Germany. Evernden, Curtis, Obradovich, and Kistler (1961, p. 95) ; Kulp (1961, p. 1108).

Follinsbee, Baadsgaard, and Lipson (1961, p. 353–356) and by Follinsbee, Baadsgaard, and Cumming (1963), p. 77–78). The late Campanian sample came from a bed of bentonite 45 feet above the base of the Bearpaw Shale near Lethbridge, Alberta. The bed of bentonite sampled for the Late Campanian date was designated ash bed A by Link and Childerhose (1931, A on text figs. 3 and 4) and bentonite No. 1 by Russell (1932, p. 30B). Fossil collections made during the present study from the lower part of the Bearpaw Shale at the locality described by Link and Childerhose and by Russell show that this bed of bentonite lies in the Range Zone of *Baculites compressus.* Nascimbene (1963, fig. 3) arrived at a figure of 73 million years for this bed of bentonite. Nascimbene (1963, table 6) also determined the age of 70 million years for a bed of bentonite 100 feet below the top of the Bearpaw Shale along the Missouri River north of Jordan in eastern Montana. *Baculites grandis* is present in this part of the Bearpaw Shale at Nascimbene's locality.

The age 66±2 million years was determined by Folinsbee and his coworkers for the Kneehills tuff zone in the upper part of the largely nonmarine Edmonton Formation on Strawberry Creek, about 30 miles southwest of Edmonton, Alberta. The Kneehills tuff zone was originally described and named by Sanderson (1931, p. 65), who noted its stratigraphic position as about 240 feet below the Ardley coal seam, near the top of the Edmonton Formation. The Kneehills was first dated as 53 million years by Ritchie (1958, p. 1), who used the lead-alpha method for the radioactive dating of the zircons. Using the potassium-argon method, Ritchie also dated a bentonitic ash layer in the Ardley coal seam as 52 million years.

The age 64±2 million years was determined by Folinsbee and coworkers by the potassium-argon dating of bentonite interbedded with the Pembina coal seam near the top of the Edmonton Formation near Whitecourt, Alberta, about 90 miles west-northwest of Edmonton. The Pembina coal seam is believed to be equivalent to the Ardley coal bed farther southwest (Ower, 1958, p. 6). According to Sanderson (in Allan and Sanderson, 1945, p. 62) about 100 feet of "freshwater beds and coaly layers and considerable bentonitic clay is found lying conformably above the big coal seam [Ardley]." Sanderson assigned these beds to the uppermost part of the Edmonton Formation, pointing out that they were overlain disconformably by the Paskapoo Formation of Paleocene age. From the position of the Ardley-Pembina coal horizon so near the Cretaceous-Paleocene boundary, Folinsbee, Baadsgaard, and Lipson (1961, p. 358) concluded that the Cretaceous Period ended about 63 million years ago, a figure accepted by Kulp (1961, p. 1109, 1111). This conclusion was verified recently by Folinsbee, Baadsgaard, and Cumming (1963, p. 77–78), who dated a bentonite in a coal bed at the base of the Fort Union Formation (Paleocene) in northeastern Montana as 63 million years old. The Fort Union Formation rests conformably on the dinosaur-bearing Hell Creek Formation.

Sanderson (1931, p. 66) noted the widespread occurrence of the Kneehills tuff and mentioned its possible presence near the top of what is now called the Battle Formation in the Cypress Hills area of southeastern Alberta. In both areas the overlying beds contain the latest Cretaceous *Triceratops* fauna. The Kneehills tuff has not been recorded from Montana or North Dakota, but volcanic ash, possibly related to the tuff, occurs in southern North Dakota in the Fox Hills Sandstone (Stanton, 1917; Fisher, 1952, p. 14–16; Manz, 1962) and in the basal part of the *Triceratops*-bearing Lance Formation (Laird and Mitchell, 1942, p. 10; Fisher, 1952, p. 19). As shown in table 2 these occurrences lie in the *Discoscaphites nebrascensis* Range Zone and in slightly younger levels, probably within the 66±2 million-year age of the Kneehills tuff. Ritchie (1960, p. 339), however, pointed out that caution should be used in correlating the Kneehills, inasmuch as similar tuff zones lie 68, 180, and 280 feet above the Kneehills in the Red Deer Valley of Alberta.

The Geological Survey of Canada has collected fossils from the upper part of the Bearpaw Shale of the Cypress Hills area. The youngest of these fossils, as noted by Cobban, probably represent the *Baculites grandis* Range Zone. The level of these fossils is separated from the level that is probably equivalent to the Kneehills tuff by a little of the Bearpaw Shale, all of the Eastend and Whitemud Formations, and most of the Battle Formation. Therefore, the time span probably represents several ammonite zones. Presumably, the Kneehills tuff is as young as the Fox Hills Sandstone in its type area in north-central South Dakota; the tuff may even be a little younger.

In estimates based on the potassium-argon ages shown in table 2 and on the potassium-argon dates and fossil zones for the older Turonian and Cenomanian, the time span per fossil zone ranges from a little less than half a million years to a little more than half a million years. In table 2 a time span of half a million years for each fossil zone was arbitrarily used. The resulting chronology seems to be in close agreement with potassium-argon dates if it is keyed on the date of 81 million years for the early Campanian (presumably the zone of the fine-ribbed or late form of *Scaphites hippocrepis*). The age span of the Pierre Shale at Red Bird thus seems to be about 12 million years (about 69½–81½ million years ago). Measured against the standard stages of the Cretaceous, the Pierre ranges in age from some part of the early Campanian into the early Maestrichtian. The Campanian Stage was vastly longer than either the Santonian or Coniacian Stage (table 2). The Maestrichtian is also a long stage, but more than half of it is represented by the nonmarine Lance Formation.

DEPOSITIONAL ENVIRONMENT

PROXIMITY TO STRANDLINES

The Pierre Shale at Red Bird is a gray clayey to silty shale. It lacks the intertonguing sandstone beds that are present farther west in Wyoming and the marly intercalations that appear farther east in South Dakota. Regional studies reveal that the nearest strandlines during Pierre time were west or northwest of Red Bird. The approximate positions of the strandlines in south-central Wyoming during the time of deposition of the middle and upper parts of the Gammon Ferruginous Member and the lower and upper parts of the Mitten Black Shale Member have been indicated by Zapp and Cobban (1962, fig. 134.1 on p. D53), and the position of the strandlines for the younger parts of the Pierre, discussed below, have been worked out during the present study. During middle and late Gammon time the strandline was about 185–205 miles west of Red Bird. During Mitten time the strandline was 135–160 miles west of Red Bird. It was much nearer during the deposition of the Red Bird Silty Member and probably was no more than 60 miles away during late Red Bird time (Gill and Cobban, 1961, fig. 352.3B; 1962, fig. 8.1; Zapp and Cobban, 1962, R_3 on fig. 134.1). Immediately after the deposition of the Red Bird Silty Member, a transgression in Wyoming moved the strandline to a point about 110 miles west of Red Bird (Zapp and Cobban, 1962, T_3 on fig. 134.1), and during this time the lower third of the lower unnamed shale member was deposited. Late in the period of deposition of this part of the unnamed shale member, and prior to deposition of the Teapot Sandstone Member of the Mesaverde Formation of areas farther west, central and western Wyoming underwent uplift and erosion (Gill and Cobban, 1966). The orogeny was more intense in the western part of the State, where great thicknesses of nonmarine rocks of the Mesaverde Formation were eroded (Reynolds, 1966; Gill and Cobban, 1966). In eastern Wyoming, broad areas of former sea bottom were exposed to subaerial erosion, and adjacent areas that remained below sea level underwent varying amounts of submarine planation. Physical evidence of an unconformity was not observed at Red Bird, but in the authors' opinion, the missing ammonite zones of *Didymoceras cheyennense*, *Baculites compressus*, and *B. cuneatus* (p. A32), are absent because of erosion. After uplift and erosion, a regression followed in which the Teapot Sandstone Member of the Mesaverde Formation, with its coal beds, was formed over much of the western two-thirds of the Powder River Basin. The eastern edge of the Teapot Sandstone Member is exposed in the Lance Creek oil field 21 miles southwest of Red Bird, where it was referred to as the Shannon(?) Sandstone by Hancock (1920, p. 101). There it consists of soft glauconitic sandstone containing at the top phosphatic nodules and phosphatic internal molds of *Baculites reesidei*. Unpublished subsurface studies suggest that a westward change in the Teapot Sandstone Member from marine glauconitic sandstone to white nonmarine sandstone occurs about 40 miles west of Red Bird. At Red Bird the middle third of the lower unnamed shale member is the time equivalent of the Teapot Sandstone Member. This part of the shale is dark, clayey, and nonsandy, and lacks phosphatized fossils; the proximity of the Teapot strandline is not apparent. After the deposition of the Teapot Sandstone Member, a major transgression in Wyoming resulted in a shift of the strandline to a point 150 miles west of Red Bird. During this period of transgression, the upper third of the lower unnamed shale member, the Kara Bentonitic Member, and the basal part of the upper unnamed shale member were formed. The sea then gradually withdrew eastward and southeastward across the eastern half of Wyoming. By the time the lower third of the upper unnamed shale member was formed, the strandline was about 130 miles west and 100 miles north of Red Bird. While the middle third of this member was being formed, the strandline moved to a point about 100 miles west and 80 miles north of Red Bird. During the deposition of the upper third of this member, the strike of the strandline shifted, so that marine waters still extended 100 miles west of Red Bird but no more than 60 miles northward. In summary, the western shore of the Pierre sea was probably never nearer to Red Bird than about 40 miles, and it was often 100 miles or more away (fig. 16, p. A46).

DEPTH OF THE PIERRE SEA

In his thorough discussion of the fine-grained marine Upper Cretaceous rocks of the Black Hills area, Rubey (1930, p. 13) pointed out the great similarity of these rocks, including the Pierre Shale, to the present-day blue muds accumulating in both shallow and deep water in partly enclosed seas and in water several hundred miles from oceanic coasts. Owing to its geographic position near the center of the Cretaceous seaway, the site of the Black Hills was probably in the deepest part of the sea (Rubey, 1930, p. 43). Most of the 30 thin sections of the marine shales of the Black Hills area examined by Rubey (1930, p. 40) showed bedding laminations that were largely light and dark layers or silt and clay layers. Because these laminations had not been destroyed by waves or currents, Rubey believed that the laminated shales accumulated in relatively deep water below effective wave base. Barrell (1917, p. 779, 782) concluded that present-day effective wave base is about 300 feet, although it probably was less in ancient times (such as the Cretaceous) when the more uniform climate would have been characterized by less intense winds. However, the bedding laminations described by Rubey may not be very meaningful, in discussion of most of the Pierre Shale, to indicate the depth of the sea. In numerous thin sections of Pierre Shale examined by H. A. Tourtelot (oral commun., 1964), laminations were scarce. Rubey did not state how many of his thin sections of laminae are from the Pierre, but presumably most are from older rocks. His one illustration (Rubey, 1930, p. 5, pl. 4, fig. 2) from the Pierre Shale is from the lower part of the Gammon Ferruginous Member. Fine laminations are visible in a limestone concretion (D4009) low in unit 20, which is almost at the base of the Mitten. Laminations are lacking in polished sections across baculite living chambers from other parts of the Pierre Shale, but these sections invariably reveal fecal pellets and burrows suggesting that laminations, if present originally, have been destroyed by sediment eaters.

The ancient epeiric seas are thought to have been rather shallow. Schuchert (1910, p. 438) believed that the seas probably "rarely exceeded 200 to 300 feet in depth," and Barrell (1917, p. 782) concluded that almost everywhere the seas were not more than 100 feet deep. According to calculations by Barrell (1917, p. 780), wave action in a quiet epeiric sea is effective to a depth of 35 feet at a distance of 5 miles from shore, 50 feet at 10 miles, 70 feet at 20 miles, and 90 feet at 80–90 miles. Recently Shaw (1964, p. 5) also concluded that the epeiric seas were very shallow and were probably "no more than about 15 fathoms deep over thousands of square miles."

The kinds and conditions of fossils found in the Pierre Shale at Red Bird suggest that the bottom water of the sea was in motion much of the time. The abundant inoceramids and bryozoans must have required an aerated bottom, and in nearly all the inoceramid shells the valves are separated and have drifted a little. Present-day pelecypods comparable in size to *Inoceramus* are not found in deep water. The presence of bryozoans throughout most of the Pierre could be construed to indicate shallow waters. In his summary of modern bryozoans, Osburn (1957, p. 1109) noted that the great majority live in water at depths from low tide of 100 or 200 fathoms. Most of the bryozoans at Red Bird are on the interior walls of unfilled ammonite living chambers that probably lay on the sea floor. The fact that fecal pellets in the Pierre Shale are unglauconitized suggests shallow water, for, as Moore (1939, p. 521) mentioned, glauconitization of fecal pellets progresses with depth. Unit 75 in the upper part of the lower unnamed member especially suggests shallow-water deposition; this unit was perhaps deposited close to the strandline of the Teapot Sandstone Member. Numerous specimens of *Lingula* were found in one of the limestone concretions (D1953). Craig (1952, p. 114, 115) noted that living specimens of *Lingula* are shallow-water brachiopods most common in water less than 10 fathoms deep and only rarely found in water as much as 60 fathoms deep.

Bottom turbulence is indicated by the paucity of distinct layers of pure bentonite in some parts of the section although the time equivalents elsewhere have many discrete beds. For example, only one bed could be distinguished in the Kara Bentonitic Member, and this one only because of its considerable thickness. Other bentonite is disseminated in the shale. Farther east in the Missouri River valley of central South Dakota, where rocks of Kara (*Baculites eliasi*) age are represented in the Pierre Shale by the Lower Virgin Creek Member of Searight (1937, p. 36), many thin layers of pure bentonite are conspicuous. In parts of the Pierre Shale at Red Bird (the Gammon and Sharon Springs Members, for example), where numerous thin discrete layers of bentonite are present, the nearest strandline was far to the west.

In summary, no information is available that gives the depth of water directly, but several indirect lines of evidence, including the distance to shore, suggest that the Mitten Black Shale and younger members of the Pierre were deposited at depths less than 200 feet, and that the Gammon and Sharon Springs Members were deposited at depths greater than 200 feet.

EFFECTS OF CURRENTS

Fossils in the Pierre Shale at Red Bird reveal times of very quiet water as well as times of pronounced activity by currents. The presence of spines still attached to echinoids (D1954) in the middle of unit 75 suggests very quiet water. In contrast, specimens of *Lingula* (D1953) lower in the same unit consist of single valves arranged parallel to the bedding and mixed with broken shells of *Inoceramus* and scattered fish remains, all of which point to the work of currents. Some of the *Lingula* and other fossil debris are in the living chambers of baculites, where they were apparently swept by the currents. A variety of fossils within the living chambers of cephalopods is more common higher in the Pierre, especially in units 93 and 95. Visible on the surface of an internal mold of the living chamber of a nautiloid from D1983, less than 4 inches in diameter, are six gastropods, one scaphite, one baculite, numerous calcareous worm tubes and broken *Inoceramus* shells, and one each of the pelecypods *Nucula*, *Pteria*, and *Cuspidaria*. Packing of baculite shells within the living chambers of larger baculites was observed in units 29, 32, 36, 38, 48, and 86.

Similar accumulations of fossils in the living chambers of Cretaceous cephalopods have been recorded by several authors. Casey (1961, p. 552), in his comprehensive stratigraphic and paleontologic summary of the Lower Cretaceous Lower Greensand of England, noted that at one locality the living chambers of ammonites were "the repository of smaller shells, sponges, pieces of drift-wood, and other sweepings of the sea-floor." Haas (1943, p. 3) observed that at one locality in Angola "almost every body chamber of ammonites, be they large or small, is filled with other fossils which most frequently, contain still smaller ones, and so forth." Wright (1935) ascribed the occurrence of clusters of mollusks and other fossils in a Turonian chalk bed in England as due to their preservation inside the living chambers of large ammonites which protected them from further current action and dissolution. Such packing of shells in cephalopod living chambers suggests accumulation by currents, as does the general appearance of the fossils in the limestone concretions. Steady current action in one direction is revealed in some beds by the accumulations of the shells of baculites and by their somewhat linear arrangement (pl. 11, fig. 3). Such accumulations are most conspicuous in units 29, 30, 33, 36, and 41. In their abundance and linear orientation, they are reminiscent of an unusual occurrence of Ordovician nautiloids in the Maquoketa Shale in Dubuque County, Iowa (Miller and Youngquist, 1949, p. 199, pl. 40, fig. 1). In many concretions the baculites are not noticeably alined, but tend to lie in a plane at various angles to one another, much like the specimens illustrated by Wetzel (1930, pl. 10, fig. 4) from the "Baculitenknolle" in the Maestrichtian rocks of Chile. In units 93 and 95 the shells lie at all angles and are commonly crowded together, the valves of *Inoceramus* are disassociated, and the baculites and scaphites are usually broken.

DISSOLUTION OF MOLLUSCAN SHELLS

Fossils from most of the Pierre Shale at Red Bird show the effects of dissolution by sea water before the shells were buried. That this action occurred before burial is revealed by parts of the shells protected by bryozoans and worm tubes from further dissolution, by the etched interiors of ammonite living chambers that contrast with unaffected air chambers (pl. 7, fig. 7), and by the disappearance of parts of the last septa in some specimens. According to Revelle and Fairbridge (1957, p. 281), the interior of molluscan shells can be etched by (1) catabolic acids produced by the mollusks in response to an unfavorable environment such as long exposure above tide level or lack of oxygen; (2) action of decay bacteria after the death of the mollusk; and (3) regional acidification of the water. The presence of bryozoans and worm tubes on the interior of cephalopod living chambers during dissolution of the shell rules out the first two of these three processes as the cause of etched shells at Red Bird. A low pH value for the sea water, therefore, seems to be the cause of this feature. That the low pH was not restricted to the Pierre sea at Red Bird, but rather was common to much of the Western Interior, is indicated by etched cephalopod shells in the U.S. Geological Survey's collections from several levels in the Pierre Shale in northeastern New Mexico, eastern Colorado, northwestern Nebraska, central South Dakota, and southeastern Montana, and from the Bearpaw Shale of Montana, Alberta, and Saskatchewan.

The amount of dissolution of the molluscan shells at Red Bird can be determined approximately by examination of attachment areas of organisms that lived on the interior walls of empty cephalopod living chambers and on the interior surface of the empty valves of *Inoceramus*. These organisms were bryozoans, worms, and some small unidentified organism having a somewhat elliptical attachment base. Most of the attached organisms were bryozoans, and nearly all represent a genus characterized by zooecia whose attachment bases are oval or teardrop shaped and arranged linearly with narrow tubular connections (caudae). They are probably representatives of *Pyripora* d'Orbigny, a genus that is widely distributed geographically and stratigraphically in the Upper Cretaceous and still exists in present seas. Only the shape of the attachment bases and the connecting caudae are visible on the Red Bird specimens—the zooecia, if still preserved, are buried in the rock composing the internal mold of the cephalopod or *Inoceramus* shell. The physical relations of these bryozoans to their hosts reveal the events following the death of a mollusk. They show that the mollusk was not buried in its shell, but was eaten or rotted away, and that the empty shell either floated awhile or lay on the sea floor, where it underwent varying degrees of dissolution from sea water. Later, the free-swimming larva of a bryozoan attached itself to the interior wall of the molluscan shell, and, by repeated budding, a colony (zoarium) was formed which spread out in all directions (pl. 9, fig. 7). During the time of growth of the colony, the interior of the molluscan shell continued to undergo dissolution by the sea water. As each zooecium of the colony was formed, its attachment area immediately protected that part of the shell from further corrosion. Hence, the first-formed zooecium preserved a greater thickness of the shell than the last-formed zooecium. Growth of the colony continued until the zooarium was engulfed by the sediment that filled the shell. On internal molds of cephalopod living chambers and *Inoceramus* valves, the attachment areas of bryozoans that encrusted the interior surface now appear as pits, and the depth of each pit (as much as 0.1 mm) represents the amount of shell dissolved between the time that the zooecium was formed and the time that it was covered by sediment. The floor of the pits on internal molds of some of the ammonites is lined with nacreous shell, which also shows that the shell was once thicker.

Areas of small disconnected pits on the internal molds of the living chambers of some baculites mark the attachment places of an unidentified organism (pl. 10, figs. 1–4, 6–9). Like the bryozoans, this organism protected the attached area of the baculite shell from further corrosion. The depth of the pits is about the same as that of the bryozoans. The pits are deepest nearer the aperture, which indicates that the animals that made them first appeared on that end of the shell.

Calcareous worm tubes attached to the interior wall of baculite living chambers also reveal the amount of dissolution of the shell. The larvae of the worms attached themselves far back in the empty living chambers, and most subsequent growth was in the general direction of the aperture. On internal molds of the living chambers the early or small end of the worm tube appears trenched to a depth of as much as 0.1 mm, whereas the late or large end may be flush with the surface of the mold (pl. 8, figs. 1, 7). This difference in depth reflects the amount of dissolution of the interior of the baculite shell during the time of growth of the worm.

The amount of dissolution of the interior of living chambers of cephalopods is quite apparent on many internal molds if the oldest part of the living chamber can be examined. This part is commonly a little thicker on one or more sides than the adjacent internal mold of the phragmocone (pl. 8, fig. 5), and the difference in thickness represents the amount of dissolution.

Dissolution of some of the septa is also a common feature. Inasmuch as the last septum was exposed to the sea water, that chamber wall is commonly corroded. On some specimens the last two or three septa, and rarely, as many as five or six, are dissolved away, usually in their middle part or on one side (pl. 9, figs. 1, 4–6). This condition is to be expected because the septa of ammonites are thinner than the outer shell wall (Reyment, 1958, p. 145–147). This thinness of septa is shown very well by a septate fragment of an aragonitic specimen of *Baculites eliasi* from the Kara Bentonitic Member at USGS Mesozoic locality D408. (For stratigraphic section and locality, see Robinson and others, 1959, p. 123.) This specimen, 31 mm in diameter, has an unfilled chamber whose septum (which bounds one side and can be measured) ranges in thickness from 0.06 to 0.072 mm whereas the outer shell wall is as much as 1.5 mm thick. The original thickness of the outer shell wall was probably even greater, as evident from the exterior surface, which has been etched somewhat by the sea water. The thickness of the shell of the living chamber of *Baculites gilberti* shown on plate 9, figures 2, 3, is 1.98 mm at the middle of one side and 1.33 mm at the middle of the opposite side at a width of 30.8 mm. The shell is a little thinner on the dorsum and venter. Although the thickness of the shell at present seems great, it is still less than it was originally, as indicated by the differential dissolution in the attachment areas of bryozoans on the interior. As might be expected, the greatest thickness is on the flank opposite the one that has the attached bryozoans. Presumably, the thicker side lay on the sea floor and was covered by mud, whereas the opposite side was exposed to circulating sea water.

Dissolution of part of each of the last few septa of baculites is also revealed by the remnants of these septa preserved by sediment cover on the side of the ammonite adjacent to the sea floor. Deposition of mud in these air chambers when they were opened to the living chamber was so slow that bryozoans and serpulids were able to become attached to the ceilings of the air chambers (pl. 9, figs. 4, 5), and unidentified sediment eaters inhabited the floor of these spaces (pl. 7, fig. 9). A series of events that occurred from the time that the soft body of the baculite disappeared from its shell to the time of burial of the shell can be determined for a few specimens. As an example, the internal mold of a specimen of *Baculites eliasi* from unit 80 suggests the following events: The empty shell either floated for awhile or lay at an angle on the sea floor with the aperture above the mud level. During this period the last three septa were dissolved except for traces along the venter. At a later time the larva of a serpulid worm attached itself on one side of the venter in the space that had formerly been the second air chamber. Growth of the worm tube was at first away from the aperture of the baculite, then directed laterally, and lastly toward the aperture. During most of this growth period, the interior surface of the baculite shell continued to undergo dissolution. Before the worm tube attained its maximum size, the larva of a pyriporoid bryozoan entered the baculite tube and affixed itself to the side of the venter near the original attachment area of the serpulid larva. A very small zoarium developed by budding before sediment snuffed out the life of both the colony and the serpulid worm. Another example is an adult *Baculites grandis* from unit 96, in which the last six septa are dissolved along the venter and adjacent ventrolateral part. At some time following this dissolution, currents swept small pelecypods and ammonites into the living chamber and into the last air chamber. Still later, after the living chamber and the damaged air chambers were filled with mud on the sea floor, sediment eaters crawled through the mud, as shown by the traces of their burrows and by the fecal pellets in the last few air chambers.

RATE OF DEPOSITION

Deposition of much of the Pierre Shale at Red Bird was moderately rapid, as suggested by the presence of fossils throughout almost all the section, by the manner in which some of the fossils are preserved, and by the fact that the rocks are much thicker than the time-equivalent part of the Pierre Shale farther east in central South Dakota where sedimentation was much slower.

The mere presence of fossils in almost all of the Pierre Shale is interpreted as an indication of moderately rapid sedimentation. If deposition is slow, dissolution by sea water tends to prevent the preservation of shells. Very rapid sedimentation normally results in coarse grain, uneven bedding, and lateral variations.

Most of the larger fossils at Red Bird are ammonites and inoceramids. The inoceramid shells have an inner layer of aragonite (X-ray determination by H. A. Tourtelot), and almost all the ammonite shells are aragonitic. Jefferies (1962, p. 613–615, text fig. 3) pointed out that aragonitic fossils tend to be abundant in the thick Upper Cretaceous sections in the Anglo-Paris Basin where sedimentation was moderately rapid, whereas they are rare or absent in the thinner sections where deposition was slow. As might be expected, the thicker units of rock at Red Bird representing an ammonite range zone tend to be more fossiliferous than the thinner strata representing a range zone. Ten or more stratigraphic levels of fossils were collected from range zones 240 feet or more in thickness, whereas less than 10 were collected from range zones of smaller thickness. Data regarding these collections are shown in table 3.

The state of preservation of some of the fossils suggests that deposition was fairly rapid at times. The echinoids and the starfish (D1954) from unit 75 must have been buried rapidly, inasmuch as their delicate spines are still attached. In the inoceramids of unit 80, both valves are intact, which also suggests rapid burial. However, the valves of most inoceramids in the Pierre are detached, a condition which indicates that they had time to drift awhile with the currents on the sea floor before being buried.

TABLE 3.—*Thicknesses of ammonite range zones, and number of levels of fossil collections*

Range zone	*Thickness of zone (feet)*	*Number of (levels of) fossil collections*
Baculites perplexus (early form)	525	10
gregoryensis	310	18
gilberti	250	14
eliasi	240	12
grandis	225	7
baculus	215	9
scotti	190	8
clinolobatus	175	2
asperiformis	155	3
reesidei	135	7
perplexus (late form)	125	7
Exiteloceras jenneyi	115	6
Didymoceras nebrascense	100	4
Baculites sp. (smooth)	100	1
obtusus	90	1
jenseni	65	2
mclearni	55	2
Didymoceras stevensoni	30	1

Sedimentation was rapid enough much of the time to bury molluscan shells before they could dissolve. Uncrushed living chambers of ammonites in the shale must have been buried rather rapidly, and the mud filling them must have been turned to rock very shortly after their burial. Presumably the surrounding sediment was still plastic enough to flow around these hardened objects (Weller, 1960, p. 303). Some living chambers in the shale that are crushed on the upper side were probably covered by sediment before being completely filled with mud (pl. 12, fig. 5). Other living chambers only partly filled with sediment were saved from crushing by the rapid formation of concretions around them (pl. 12, figs. 1, 6). Also present in the concretions are chambered baculites partly filled with sediment and partly crushed. These represent specimens that were being crushed by the enclosing sediments when the crushing was arrested by the formation of a concretion (pl. 12, fig. 3). Cross sections of the baculites reveal the following order of events: (1) Deposition of mud on the floor of the air chambers, (2) cessation of deposition, probably because the siphuncle became plugged, (3) formation of a thin layer of finely crystalline calcite on top of the muddy floor (plane of composition of Cullison, 1938, p. 983) and on the walls of the overlying cavity, (4) fracture of this layer as the shell underwent partial crushing as the enclosing sediments began to consolidate, (5) discontinuance of crushing because of the formation of a concretion, and (6) formation of large calcite crystals on top of the broken layer of finely crystalline calcite lining the cavity floor and walls. Thus the sediment deposition is followed by a layering of finely crystalline calcite and then of coarsely crystalline calcite, and is accompanied by the formation on the wall of finely crystalline calcite, followed by coarse crystal growth. This progression is much like the drusy calcite growth illustrated by Bathurst (1958, text figs. 1, 2) from examples out of Carboniferous limestone.

Some rough figures on the rate of sedimentation can be obtained from the thickness of the rocks, the number of ammonite zones, and the probable length of the period of accumulation. The Gammon Ferruginous Member, which is only 30 feet thick at Red Bird and lacks megafossils, is excluded from these calculations because this abnormally thin unit cannot be evaluated at present in relation to its much thicker equivalent on the north flank of the Black Hills, where at least three ammonite zones are known in strata that are as much as 1,000 feet thick in the subsurface. Also excluded is the 6 feet of unit 68 which cannot be assigned with certainty to any zone.

A total thickness of about 3,100 feet of Pierre Shale (3,137 ft minus the 30 ft of Gammon and the 6 ft of unit 68) is assignable to 18 ammonite zones—an average of 172 feet per zone. If the half-a-million-year figure (p. 36) is used for the duration of each ammonite zone, an estimated average of 0.000344 feet (0.10485 mm) of rock formed each year is obtained. This is about half of the only other recorded determination of annual sedimentation thickness for Upper Cretaceous rocks of the Black Hills region—that of Rubey (1930, p. 47). Rubey observed that laminations in the Upper Cretaceous rocks occurred in pairs, which he interpreted as seasonal, and that the pairs averaged 0.2 mm in thickness.

Rubey's figure and the one calculated in this study can be evaluated by determining whether the rate of deposition of the original mud was sufficient to cover an ammonite before it could be dissolved by the sea water. Inasmuch as baculites are by far the most abundant ammonite, an example of *B. eliasi* from unit 81 is considered here. This specimen, a living chamber, has a nacreous aragonitic shell that does not appear to be much dissolved. Its cross section is 34 mm high and 25 mm wide and the shell thickness is 1.8 mm on the flank. This living chamber is solidly filled with dark argillaceous limestone containing fecal pellets. All traces of bedding have been destroyed through the ingesting of the original mud filling by organisms. Presumably the specimen lay on its side on the sea floor, the typical attitude of most of the baculites at Red Bird, as shown by partly filled shells and by the common occurrence of bryozoans on the ceiling of the interior of living chambers. The specimen undoubtedly settled in the soft mud, although probably only slightly, as suggested by the experiments of Reyment (1958, p. 116–159) with the buoyancy of waterlogged cephalopod shells. As an allowance for settling, a fifth (5 mm) of the height of the living chamber is arbitrarily eliminated from further consideration, and the height of the baculite above the mud floor is considered as 20 mm. If we assume that the original mud was at least twice as thick as the present rock (Weller, J. M., 1960, p. 333), 95 years would pass before the baculite was buried, according to the rate of deposition calculated at Red Bird. According to Rubey's rate, the figure is 50 years. These are, however, maximum figures; the original mud may have been more than 2.5 times as thick as the present rock (Hamilton, 1961, p. 77). Nevertheless, the baculite would surely be dissolved long before any of these intervals of time had passed. The amount of dissolution that occurred during the growth of bryozoans, sedentary polychaetes, and the unidentified organism with the elliptical attachment base is about 0.1 mm. The life cycle of these organisms cannot be determined at present, but it was probably much less than a year. Living bryozoans show more growth within a year on such seasonal things as seaweeds (MacGinitie and MacGinitie, 1949, fig. 53 on p. 175) than that revealed by the fossil bryozoans on the interior of living chambers. Osburn (1954, p. 361) noted that bryozoans grow so rapidly in the Gulf of Mexico that "oyster shells used as cultch on oyster beds may be completely covered in a few weeks to the exclusion of oyster larvae." At a pier of the Scripps Institution of Oceanography at La Jolla, Calif., Coe (1932, p. 53–54) observed that the larvae of bryozoans settle on objects during the warm months of the year (between April and November, although most commonly during the summer months) and that colonies grow rapidly within a few months. Erect calcareous forms grew as much as 40 mm within 3 months, and one colony had 72 branches and almost 500 zooids when only 4 weeks old. Cory (1964, p. D196) noted that in a 3-month period a single colony of bryozoans covered an area of 961 sq mm in the Patuxent River estuary in Maryland.

If the figure of 0.1 mm is taken as a minimum for the dissolution per half year on both the interior and exterior of baculite shells, the baculite having a shell 1.8 mm thick would have disappeared within 4.5 years if it were not buried. Actually this baculite was probably buried in much less than a year, judging from its very well preserved thick aragonitic shell. Reyment (1958, p. 134) observed that holes appeared in modern *Nautilus* shells that had been in water for only 32 days. Very likely most of the baculites in the Mitten and higher parts of the Pierre Shale were buried rather rapidly inasmuch as nearly all have thick shells which show dissolution effects of only a fraction of a millimeter. This rate of burial is much faster than that calculated from rock thickness or from paired laminations. Possibly the fossiliferous beds (chiefly zones of concretions) were deposited rather rapidly, whereas the barren beds separating them formed much more slowly. Another possibility is that the rock column at Red Bird is much thinner than it is elsewhere, as a result of bypassing of sediments.

CORRELATION OF SECTION

Correlations of the Pierre Shale of the Red Bird section with equivalent rocks elsewhere in Wyoming, Montana, and North and South Dakota, are shown on plate 3. These correlations are shown for seven measured surface sections, one core hole, and three electric and gamma-ray logs of oil and gas test wells. Many additional subsurface and faunal data were examined and used in formulating the final correlation, but these are not shown on the diagram. The portrayal of lithologic units is highly generalized, and only the following broad groups of rock types are shown: (1) Calcareous rocks, including shale, marlstone, and impure chalk; (2) marine siliceous shale; (3) normal marine shale, including bentonitic shale and silty shale; (4) organic-rich marine shale; (5) marine sandstone, including both offshore and nearshore sandstone and siltstone; (6) nonmarine beds, including all rock types deposited in the nonmarine environment and in brackish water; (7) bentonite, including only persistent bentonite beds or groups of bentonite beds deposited in the marine environment; (8) welded tuffs, including ashflows breccias and silicified ash beds; and (9) sedimentary rocks rich in volcanic material.

The correlation of the section depends partly on the tracing of distinctive lithologic units, of which some, such as the Ardmore Bentonite Bed, appear to be time-stratigraphic markers. Extensive collections of ammonites and other groups of fossils permit zonation of Upper Cretaceous rocks of the region (p. A28–A34 and pls. 1, 4 and fig. 16). At many places the range span of an individual index ammonite can be accurately determined, and this aids materially in correlation of strata and in interpretion of the depositional history. The base of the range zone of eight selected index ammonites is shown on plate 3, and the position of the strandline for each of these zones in Wyoming is shown in figure 16.

Stratigraphic nomenclature shown on plate 3 for the various lithologic units at a distance from the reference section at Red Bird reflects local usage that originated in widely separated areas many years ago. The recent paleontologic zonation of the Pierre and equivalent rocks and the recognition of such time-stratigraphic markers as the Ardmore Bentonite Bed will eventually facilitate a meaningful revision of the nomenclature. The authors recognize the need for revision on a regional basis, but until the units in this region can be redescribed and defined, no attempt will be made to alter the currently accepted stratigraphic nomenclature.

The correlation of the Red Bird section of the Pierre Shale with equivalent rocks in the Western Interior of the United States, southern Alberta, and east-central Texas is shown on plate 4. Also shown is the known or inferred position of the Western Interior index ammonite zones in each of the stratigraphic units listed.

REGIONAL GEOLOGIC HISTORY

During much of Late Cretaceous time the Western Interior region of North America was the site of an epicontinental sea that extended from Mexico to the Arctic region and was in places as much as 1,000 miles wide (fig. 15). It was bounded on the west along its entire length by a narrow unstable and constantly rising north-south-trending cordilleran highland. This mountainous region separated the interior Cretaceous sea from Pacific oceanic waters. The eastern margin of the interior sea was formed by the low-lying stable platform of the eastern part of the conterminous United States and Canada. The exact position of this eastern shore is uncertain, but there is scant evidence to justify placing it any farther west in the northern interior than the longitude of eastern Minnesota and Iowa. The Arctic connection of this seaway with west Greenland is also hypothetical.

Ammonites from Nugssuaq Peninsula and Svartenhuk Peninsula, West Greenland, studied by Tove Birkelund of the Mineralogical Museum of the University of Copenhagen, are very closely related to species from the northern part of the Western Interior, particularly certain scaphites of late Turonian, Coniacian, Santonian, Campanian, and Maestrichtian ages. Some connection through the Arctic region had to be present between West Greenland and the Western Interior seaway. Teichert (1939, p. 155, text fig. 12) noted the resemblance between the West Greenland and Montana faunas and postulated a Cretaceous shelf sea that covered the northern part of the Canadian Arctic Archipelago and transgressed across Ellesmere Island to Baffin Bay, thus connecting the West Greenland and Western Interior seaways. Tozer (1960, p. 13), although admitting the possibility of this transgression across Ellesmere Island, believed that more probably a land area lay in the eastern and southern parts of present Ellesmere Island; he considered this area one of the sources of the sediments composing the Cretaceous strata of the Sverdrup basin, which extends from western Ellesmere Island west to Prince Patrick Island (fig. 15). Recently, Tozer and Thorsteinsson (1964, p. 216–218) postulated a more distant source for the Cretaceous rocks of the Sverdrup basin. They suggested that the sediments were carried northwestward by means of a large river

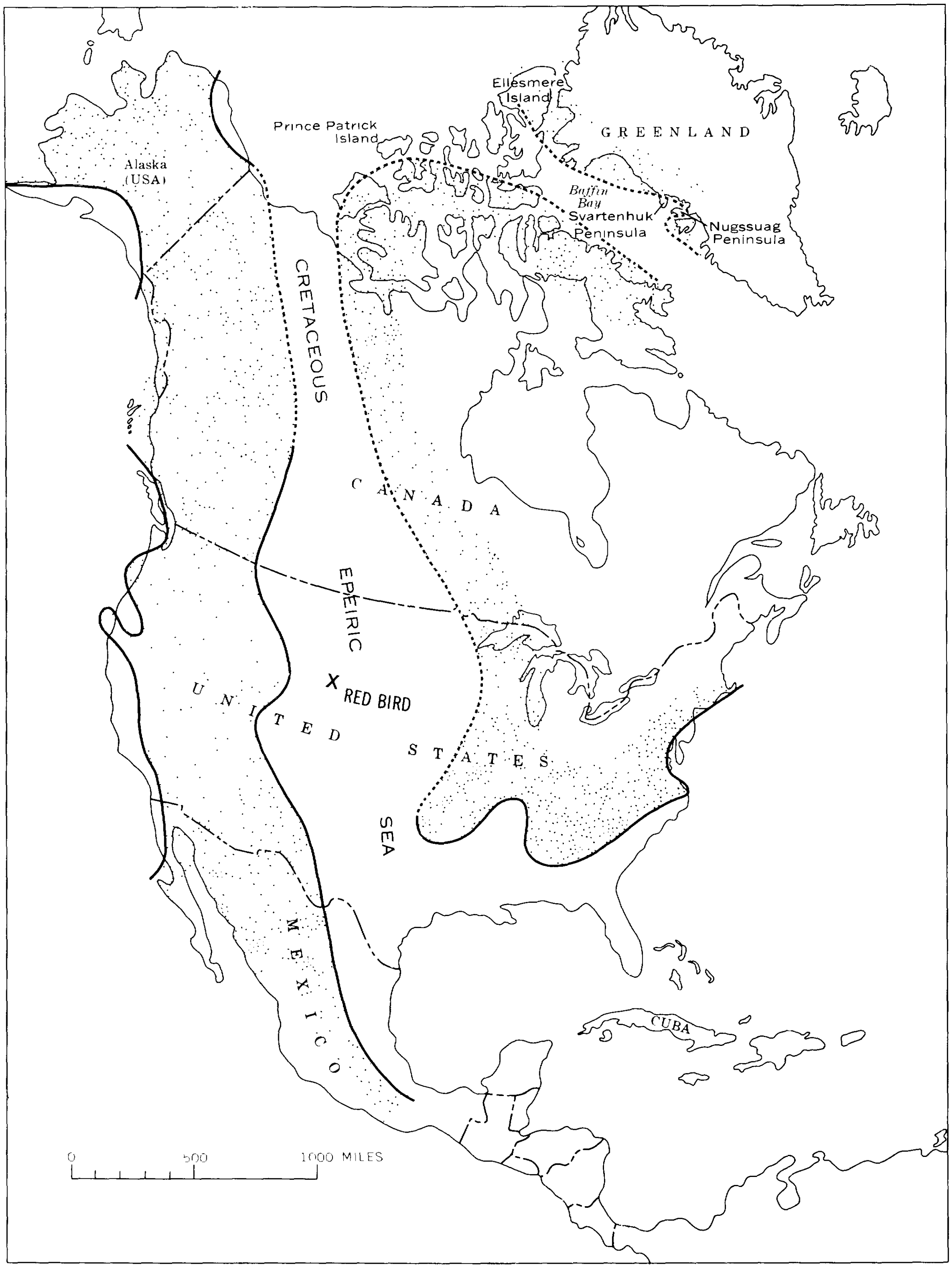


FIGURE 15.—Probable distribution of land and sea in North America during late Campanian time, showing the geographic position of the Red Bird section in relation to the seaway that divided the continent into eastern and western parts. Data for the Pacific Coast and Alaska were supplied by D. L. Jones of the U.S. Geological Survey (written commun. 1964), and for West Greenland by Dr. Tove Birkelund of the Mineralogical Museum of the University of Copenhagen (written commun., 1964).

system draining a highland area in the Appalachian part of eastern United States and the Maritime Provinces of Canada. They also suggested that eastern Greenland was a highland from which westward-flowing streams brought sediment to the Sverdrup basin. The youngest known Cretaceous rocks in the Sverdrup basin have been dated as Santonian or early Campanian by J. A. Jeletzky. The overlying rocks are Paleocene or Eocene, and therefore, time-equivalent strata of most of the Pierre Shale are not known in this Arctic area. The record of a seaway during Pierre time between the Sverdrup basin and the Baffin Bay may be lost in the hiatus between the rocks of Santonian or early Campanian age and those of Tertiary age. The present authors concur with Teichert that some sort of a seaway existed across this region, and it seems reasonable to postulate most of the route of this seaway over areas known to contain Cretaceous rocks, rather than over the areas of Paleozoic and Precambrian rocks farther south.

The bulk of the sediments deposited in Montana and Wyoming part of the Cretaceous sea was apparently derived from several distinct petrographic provinces located along the western cordillera. The Montana part of the sea received a great flood of clastic and pyroclastic volcanic material from the Upper Cretaceous Elkhorn Mountains Volcanics, which was adjacent to the western shoreline in western Montana. In much of Wyoming the sediments delivered to the sea originated in areas of ancient crystalline and metamorphic rocks as well as in the Paleozoic sedimentary beds that formed the western cordillera. Intermittent local tectonic activity and volcanism continually modified the configuration of the western shore, as recorded in a great series of transgressive and regressive deposits.

Throughout much of Late Cretaceous time the epicontinental sea was separated from the western cordillera by a wide coastal plain and piedmont area traversed by streams and rivers which delivered only the finer fraction of their load to the sea—mainly fine sands, silts, and muds. Locally, in western Montana, the coastal plain was very narrow or absent, and marine waters at one time or another inundated hilly volcanic terrane.

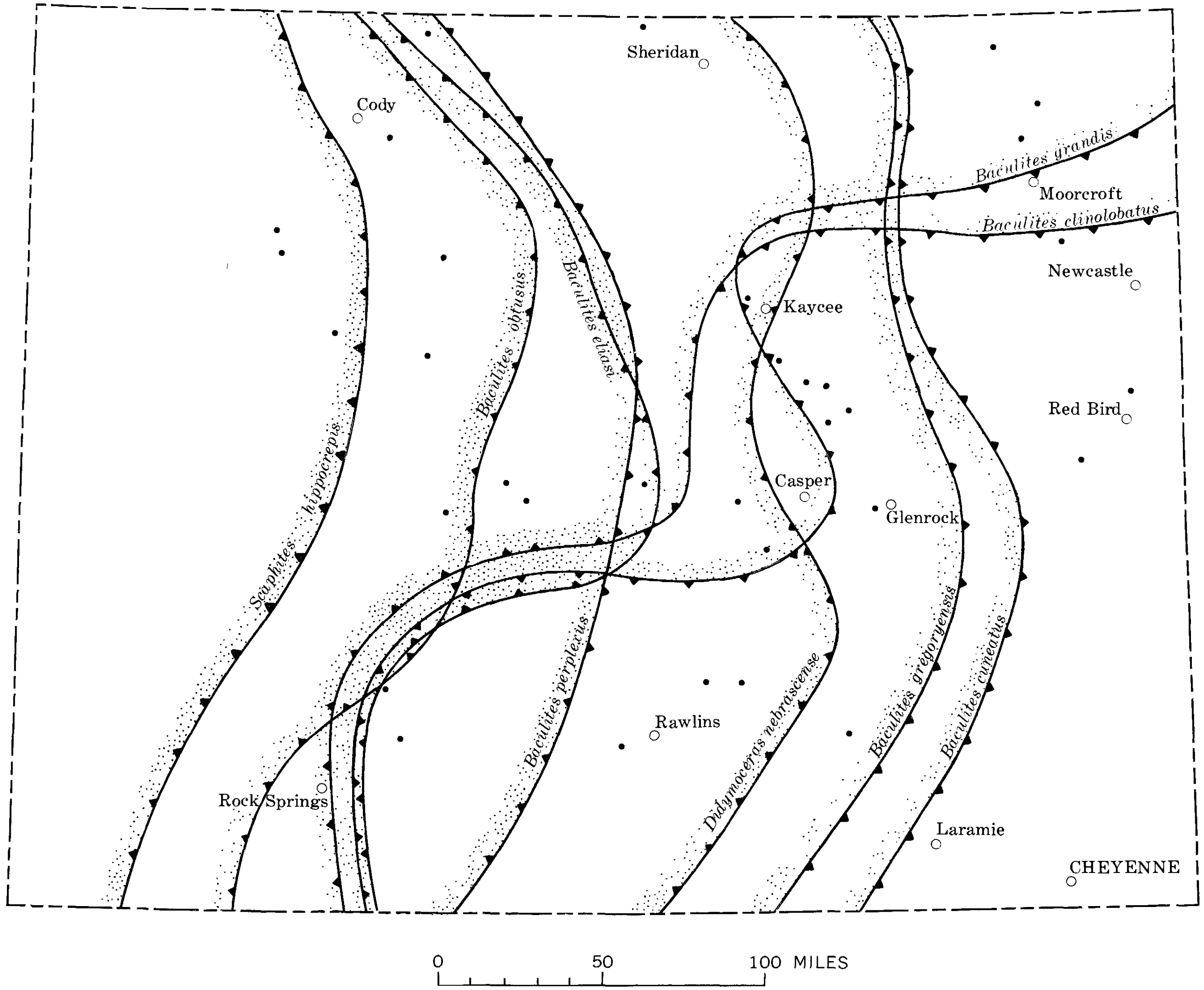
The shoreline fluctuated from time to time and probably never was nearer to Red Bird than about 40 miles west until the close of Pierre deposition in the area. During most of Late Cretaceous time, the Red Bird area was far removed from the shore, and the bulk of the 3,000 feet or more of rocks preserved in the section represents deposition in the claystone and shale facies belt. The Red Bird Silty Member represents deposition in the offshore sandstone and siltstone belt and the Niobrara Formation represents deposition in the chalk and marlstone facies belt.

The geologic history of the Pierre Shale in the northern part of the Western Interior cannot be interpreted solely on the basis of a single set of good exposures, such as are present at Red Bird, but must be inferred from many widely spaced observations. For the following discussions, the authors have drawn upon the published record and on their own unpublished studies of the Pierre Shale and equivalent rocks in a 300,000-square-mile area that includes much of the Dakotas, Wyoming, Montana, and parts of southern Canada. The preliminary results of this effort appear on the fence diagram (pl. 3) and on the strandline map for selected ammonite range zones in Wyoming (fig. 16).

The widely accepted view is that Upper Cretaceous deposits are oscillatory and represent a series of widespread transgressions and regressions. The character and distribution of these rocks have seemed to support the hypothesis that periods of continental uplift and subsidence controlled the configuration of the margins of the Late Cretaceous basin of deposition. Nevertheless, examination of faunal data and study of the distribution of marine and nonmarine rocks and their complex facies relation in the region suggest strongly that local uplift, variations in rate of sediment delivery, and local subsidence within the basin and along the basin margins were the causes of transgression and regression rather than broad regional basin uplift and subsidence. The present authors have not yet recognized a clear-cut example of transgression or regression that can be unquestionably related to anything other than local subsidence and uplift.

From the data shown on the fence diagram (pl. 3), the strandline map (fig. 16), and the stratigraphic section preserved at Red Bird (pl. 2), a few simplified generalizations may be made. The depositional history of the Red Bird part of the Cretaceous basin may be broadly described, and its relation to the more detailed and complex geologic history of the northern part of the Western Interior may be outlined. The examination of any single sequence of fine-grained marine rocks, even when the sequence is complete, seldom provides any logical basis for subdivision of the section into parts representing deposition during a period of regression or transgression. Nevertheless regional studies of these rocks have revealed subtle changes in lithology that are clues to ancient depositional environments.

An example of regressive deposits exists in the thick sequence represented by the Eagle Sandstone and time-equivalent rocks in an east-west transect across its basin of deposition from west-central Montana to the eastern Dakotas. In west-central Montana near the mouth of the Judith River (pl. 3, section 2), the Eagle



Western Interior ammonite zones		Red Bird section
Sphenodiscus (Coahuilites)		Fox Hills Sandstone (part)
Baculites clinolobatus ★	Pierre Shale	Upper unnamed shale member
Baculites grandis ★		
Baculites baculus		
Baculites eliasi ★		Kara Bentonitic Member
Baculites jenseni		Lower unnamed shale member
Baculites reesidei		
Baculites cuneatus ★		
Baculites compressus		
Didymoceras cheyennense		
Exiteloceras jenneyi		
Didymoceras stevensoni		
Didymoceras nebrascense ★		
Baculites scotti		Red Bird Silty Member
Baculites gregoryensis ★		
Baculites perplexus (late form)		
Baculites gilberti		
Baculites perplexus (early form) ★		Mitten Black Shale Member
Baculites sp. (smooth)		
Baculites asperiformis		Sharon Springs Member
Baculites mclearni		
Baculites obtusus ★		
Baculites sp. (weakly ribbed)		Gammon Ferruginous Member
Baculites sp. (smooth)		
Haresiceras natronense		
Haresiceras placentiforme		Niobrara Formation (part)
Haresiceras montanaense and *Scaphites hippocrepis* ★		

FIGURE 16.—Probable positions of strandlines in Wyoming during Pierre time as indicated by selected ammonite zones represented in the Red Bird section. The position of the ammonite zone is shown by the dashed line in the table. The approximate position of the strandline is shown by a line on the map. The triangles point in the direction of strandline movement; the stipple pattern indicates the landward side; a dot on the map is the location of a fossil collection and (or) a measured section. A star in the table indicates an ammonite zone used in determining the position of strandlines.

is represented at its base by massive nearshore and beach sandstones of the Virgelle Sandstone Member, which are in turn overlain by brackish-water and continental deposits. These are locally overlain by a thin marine transgressive sandstone, which in turn is overlain by nonsandy marine shales of the Claggett Formation (pl. 3). Eastward in central Montana the nonmarine beds grade into nearshore marine sandstone and then into less continuous beds of offshore sandstone. The change continues progressively eastward as the rocks become finer grained. Interbedded and laterally gradational with the offshore sandstones are thick units of light-colored siltstone and bentonitic mudstone that contain abundant ironstone concretions of siderite. These rocks change almost imperceptibly eastward by a gradual decrease of the silt and sand components, the disappearance of siderite or ironstone concretions, and the gradual increase of limestone concretions. Progressively eastward, lenses of impure marlstone appear, and at the point farthest east, rocks concurrent with the Eagle Sandstone seem to be represented by chalk and marlstone of the Niobrara Formation. Another example of a large regressive deposit, the Judith River Formation of central Montana, undergoes a similar eastward change in lithology and is represented in the eastern Dakotas by the calcareous Gregory and Crow Creek Members of the Pierre Shale. The Eagle Sandstone is represented at Red Bird by the Gammon Ferruginous Member of the Pierre and by the calcareous beds of the Niobrara Formation. The Judith River regressive complex is represented by the Red Bird Silty Member of the Pierre Shale. On the strandline map (fig. 16) which is based on ammonite zones, the western shore is shown about 230 miles west of Red Bird during Gammon time (Range Zone of *Scaphites hippocrepis*) and about 50–60 miles to the west during the deposition of the Red Bird Silty Member (Range Zone of *Baculites gregoryensis*).

Rocks deposited during periods of transgression seem to have some identifying physical characteristics. The Sharon Springs Member of the Pierre, which was deposited during the widespread Claggett transgression of Montana, is a unique unit of dark fissile shale rich in organic material and containing many widespread and persistent beds of bentonite. This unit and other units known to have been deposited during periods of extensive transgression appear to contain only limestone concretions. It may be possible, in time, to examine a sequence of rocks deposited in the far offshore environment and to estimate rather closely their distance from the shoreline at the time of deposition.

The strandline map (fig. 16) is greatly generalized for simplicity, but it shows that the western margin of the sea, except for minor westward advances, was migrating dominantly eastward throughout the deposition of the Pierre Shale in the Red Bird area. The first major retreat of the sea started sometime after the Range Span of *Scaphites hippocrepis*, during which time the upper part of the Niobrara Formation and the Gammon Ferruginous Member were deposited at Red Bird. The easternmost position of the strandline is not shown on the map (fig. 16), but the line lay east of the shore during the deposition of the overlying Sharon Springs Member (Range Zone of *Baculites obtusus*). After the deposition of the Sharon Springs, an extended period of regression followed, indicated by the strandlines for the Range Zones of *Baculites perplexus* and *B. gregoryensis;* this period culminated in the deposition of silty and sandy beds of the Red Bird Member. The eastward movement of the strandline was terminated by a westward transgression represented by beds in the lower unnamed shale member (Range Zone of *Didymoceras nebrascense*). The alternating sequence of transgressions and regressions was interrupted at this time by uplift and erosion in central and western Wyoming. Shortly after deposition of beds representing the Range Zones of *Didymoceras nebrascense* and *Exiteloceras jenneyi*, uplift followed by erosion took place in the central part of the State. Former areas of sea bottom were exposed to subaerial erosion, and submarine erosion appears to have been active nearby. From evidence in other areas it appears that an undetermined thickness of rocks was probably deposited at Red Bird during the time span of *Baculites compressus*, *Didymoceras cheyennense*, and possibly *Baculites cuneatus*, and that these rocks were subsequently removed by erosion. (See p. A32.)

This period of erosion was followed by another regression (late in the Range Zone of *Baculites cuneatus* or early in the Range Zone of *B. reesidei*) which cannot be recognized by any lithologic criteria at Red Bird. In the western part of the Powder River Basin, however, the regression resulted in the deposition of the Teapot Sandstone Member of the Mesaverde Formation (Gill and Cobban, 1966). During this time the shore moved some 60 miles east of its previous position. The position of the line marking the base of the Range Zone of *Baculites cuneatus* on the fence diagram (pl. 3) shows that during the time of the Teapot regression in Wyoming an extensive transgression was taking place in Montana. Following the deposition of the Teapot, another widespread transgression began in Wyoming, and it was at this time that the Kara Bentonitic Member of the Pierre was deposited and the strandline moved westward about 100 miles. In Wyoming, the range spans of *Baculites grandis* and *B. clinolobatus* were largely times of stationary strandline except for some limited regression. The Red Bird area was the site of continued marine deposition until final withdrawal of marine waters, as shown by the shallow nearshore marine sandstones of the Fox Hills and the continental beds of the Lance Formation.

LOCALITIES AT WHICH FOSSILS WERE COLLECTED

In the list below, fossil collection data are given in the following order: U.S. Geological Survey Mesozoic locality number, collector, year of collection, and locality. The list includes localities of fossil collections both within the lines of the measured sections and as much as 2 miles from the measured sections. All localities are in Niobrara County, Wyo., and all are within secs. 1, 17, and 20, T. 38 N., R. 61 W., and secs. 13, 14, 23, and 24, T. 38 N., R. 62 W.

D1636. J. R. Gill and H. A. Tourtelot, 1957; W. A. Cobban, 1958. SE¼NE¼NE¼NW¼ sec. 23.
D1637. W. A. Cobban, J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. SW¼NW¼NW¼NE¼ sec. 23.
D1639. J. R. Gill and H. A. Tourtelot, 1957. NW¼SW¼NE¼NE¼ sec. 23.
D1855. W. A. Cobban, 1958. SW¼ sec. 1.
D1856. W. A. Cobban, 1958. SW¼ sec. 17 and NW¼ sec. 20.
D1857. W. A. Cobban, 1958. SW¼ sec. 17.
D1858. W. A. Cobban, 1962. SW¼ sec. 17 and NW¼ sec. 20.
D1859. W. J. Mapel and W. A. Cobban, 1958; J. R. Gill, 1962. NW¼SW¼NW¼ sec. 24.
D1860. J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. NE¼SE¼NE¼ sec. 23.
D1861. W. J. Mapel and W. A. Cobban, 1958; J. R. Gill and W. A. Cobban, 1959. NE¼SE¼NE¼ sec. 23.
D1862. J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. SW¼SW¼NE¼ sec. 13.
D1863. W. A. Cobban, 1958. NW¼NW¼SE¼ sec. 13.
D1864. W. A. Cobban, 1958. Divide in the NE¼NE¼NE¼ sec. 23.
D1865. W. J. Mapel and W. A. Cobban, 1958. SW¼NE¼NE¼ sec. 23.
D1866. J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. NE¼SW¼NE¼NE¼ sec. 23.
D1867. J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. W½NE¼NW¼SW¼ sec. 13.
D1868. H. A. Tourtelot, 1958. SE¼SW¼SW¼SE¼ sec. 14.
D1869. W. A. Cobban, 1958. N½NE¼NW¼SW¼ sec. 13.
D1870, D1871. W. A. Cobban, 1958. N½NE¼NW¼SW¼ sec. 13.
D1872. W. A. Cobban, J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. SW¼NE¼NW¼SW¼ sec. 13.
D1873, D1874. W. A. Cobban, 1958. N½NE¼NW¼SW¼ sec. 13.
D1875, D1876. J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. NE¼NW¼NW¼SW¼ sec. 13.
D1877, D1878. W. A. Cobban, 1958. NE¼NW¼NW¼SW¼ sec. 13.
D1879–81. J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A Tourtelot, 1958. NW¼SW¼NE¼NE¼ sec. 23.
D1882. W. A. Cobban, 1958. NE¼SE¼NW¼NE¼ sec. 23 to the center of the W½NW¼NE¼NE¼ sec. 23.
D1883. W. A. Cobban, 1958. NE¼NW¼NW¼SW¼ sec. 13.
D1884. W. A. Cobban, 1958. NE¼SE¼NW¼NE¼ sec. 23 to the center of the W½NW¼NE¼NE¼ sec. 23.
D1885. J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. NE¼NW¼NW¼SW¼ sec. 13.
D1886. W. A. Cobban, 1958. NE¼SE¼NW¼NE¼ sec. 23 to the center of the W½NW¼NE¼NE¼ sec. 23.
D1887. W. J. Mapel and W. A. Cobban, 1958. NE¼SE¼NW¼NE¼ sec. 23 to the center of the W½NW¼NE¼NE¼ sec. 23.
D1888. W. A. Cobban, J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. NE¼SE¼NW¼NE¼ sec. 23 to the center of the W½NW¼NE¼NE¼ sec. 23.
D1889. W. A. Cobban, 1958. Center of the N½NW¼NW¼SW¼ sec. 13.
D1890. J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. Center of the N½NW¼NW¼SW¼ sec. 13.
D1891. W. J. Mapel and W. A. Cobban, 1958. W½NW¼NE¼NE¼ sec. 23.
D1892. W. J. Mapel, 1958. W½NW¼NE¼NE¼ sec. 23.
D1893–97. W. A. Cobban, 1958. NW¼NW¼NW¼SW¼ sec. 13.
D1898. W. A. Cobban, J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. W½SW¼NW¼ sec. 13.
D1899. W. A. Cobban, J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. SE¼NE¼NW¼NE¼ to SW¼SE¼NW¼NE¼ sec. 23.
D1900. W. A. Cobban, J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. W½SW¼NW¼ sec. 13.
D1901. W. A. Cobban, 1958. SE¼NE¼NW¼NE¼ to SW¼SE¼NW¼NE¼ sec. 23.
D1902. J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. NW¼NW¼NW¼SW¼ sec. 13.
D1903. W. A. Cobban, 1958. SW¼SW¼SW¼NW¼ sec. 13.
D1904. G. R. Scott and W. A. Cobban, 1958. NE¼NW¼SW¼NW¼ sec. 13.
D1905. W. A. Cobban, 1958. NE¼NW¼NE¼ sec. 23.
D1906. W. A. Cobban, 1958. W½SW¼NW¼ sec. 13.
D1907. W. A. Cobban, 1958. W½SE¼SE¼ sec. 14.
D1908. W. A. Cobban, J. R. Gill, W. J. Mapel, C. S. Robinson, G. R. Scott, and H. A. Tourtelot, 1958. W½NW¼ sec. 13, E½SE¼ sec. 14, and SE¼SE¼NE¼ sec. 14.
D1909. W. A. Cobban, 1958. E½SE¼ sec. 14.
D1910. W. A. Cobban, 1958. Near the center of the S½NE¼NW¼NE¼ sec. 23.
D1911. J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. NE¼NE¼NE¼SE¼ sec. 14.
D1912. W. A. Cobban, 1958. E½SE¼ sec. 14.
D1913. W. A. Cobban, J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. SW¼NE¼NW¼NE¼ sec. 23.
D1914. J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. SW¼NE¼NW¼NE¼ sec. 23.
D1915. J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. NE¼NE¼NE¼SE¼ sec. 14.
D1916–21. W. A. Cobban, 1958. E½SE¼ sec. 14.
D1922. W. A. Cobban, J. R. Gill, W. J. Mapel, C. S. Robinson, G. R. Scott, and H. A. Tourtelot, 1958. W½NE¼NW¼NE¼, E½SW¼NW¼NE¼, and NW¼NW¼SW¼NE¼ sec. 23.
D1923. W. A. Cobban, J. R. Gill, W. J. Mapel, C. S. Robinson, G. R. Scott, and H. A. Tourtelot, 1958. W½W½NW¼ sec. 13 and E½E½ sec. 14.
D1924. W. A. Cobban, J. R. Gill, W. J. Mapel, C. S. Robinson, G. R. Scott, and H. A. Tourtelot, 1958. W½NE¼NW¼NE¼, E½SW¼NW¼NE¼, and NW¼NW¼SW¼NE¼ sec. 23.
D1925. W. A. Cobban, J. R. Gill, W. J. Mapel. C. S. Robinson, G. R. Scott, and H. A. Tourtelot, 1958. W½W½NW¼ sec. 13 and E½E½ sec. 14.

D1926. W. J. Mapel, J. R. Gill, and W. A. Cobban, 1959. SW¼ SE¼SE¼NE¼ sec. 14.
D1927. W. J. Mapel and W. A. Cobban, 1958. W½NW¼NE¼ sec. 23.
D1928. W. A. Cobban, J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. SW¼SE¼SE¼NE¼ sec. 14.
D1929. W. A. Cobban, 1958. SW¼NW¼NW¼NW¼ sec. 13.
D1930. W. A. Cobban and G. R. Scott, 1958. SW¼NW¼NW¼ NW¼ sec. 13.
D1931. W. A. Cobban, 1958. SW¼NW¼NW¼NW¼ sec. 13.
D1932, D1933. W. A. Cobban, 1958. SW¼SE¼SE¼NE¼ sec. 14.
D1934. W. A. Cobban, 1958. SE¼SE¼NW¼ sec. 23.
D1935–37. W. A. Cobban, 1958. SW¼SE¼SE¼NE¼ sec. 14.
D1938. W. A. Cobban, 1958. SW¼SE¼SE¼NE¼ sec. 14.
D1939. W. A. Cobban, 1958. E½SW¼SE¼NE¼ sec. 14.
D1940. W. J. Mapel and W. A. Cobban, 1958. W½NW¼NE¼ sec. 23.
D1941. W. A. Cobban, 1958. NE¼SW¼SE¼NE¼ sec. 14.
D1942. W. A. Cobban, 1958. NW¼NE¼SE¼NE¼ sec. 14.
D1943. W. A. Cobban, J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. NE¼NW¼NW¼NE¼ sec. 23.
D1944, D1945. W. A. Cobban, 1958. NE¼SW¼SE¼NE¼ sec. 14.
D1946. W. J. Mapel, 1958. SW¼NW¼NW¼NE¼ sec. 23.
D1947. W. A. Cobban, J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. E½NE¼ sec. 14.
D1948–53. W. A. Cobban, 1958. W½NE¼SW¼SE¼ sec. 14.
D1954. W. A. Cobban, 1958. NW¼NE¼SW¼SE¼ sec. 14.
D1955. W. A. Cobban, 1958. W¼NE¼SW¼SE¼ sec. 14.
D1956. W. A. Cobban, 1958. SE¼NE¼NE¼NW¼ sec. 23.
D1957. W. A. Cobban, 1958. SW¼SW¼SE¼NE¼ sec. 14.
D1958. W. A. Cobban, 1958. SE¼NE¼NE¼NW¼ sec. 23.
D1959. J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. NE¼NE¼NW¼SE¼ sec. 14.
D1960. W. A. Cobban, 1958. SE¼NE¼NE¼NW¼ sec. 23.
D1961. J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. NE¼NE¼NW¼SE¼ Sec. 14.
D1962. W. A. Cobban, 1958. Near the center of the NE¼NE¼ NW¼ sec. 23.
D1963, D1964. J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. Near the center of the NE¼NW¼SE¼ sec. 14.
D1965. W. A. Cobban, 1958. Near the center of the NE¼NE¼-NW¼ sec. 23.
D1966. W. A. Cobban, 1958. SW¼NE¼NE¼NW¼ sec. 23.
D1967. J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. Near the center of the NE¼NW¼SE¼ sec. 14.
D1968. J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. SE¼SE¼SE¼SW¼ sec. 14.
D1969. W. A. Cobban, 1958. Near the center of the NE¼ NW¼SE¼ sec. 14.
D1970. W. A. Cobban, 1958. SW¼NE¼NW¼SE¼ sec. 14.
D1971–74. W. A. Cobban, 1958. SW¼NE¼NE¼NW¼ sec. 23.
D1975. W. A. Cobban, J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. NW¼NE¼NW¼SE¼ sec. 14.
D1976. W. A. Cobban, 1958. E½NW¼NE¼NW¼ sec. 23.
D1977. W. A. Cobban, 1958. NW¼NE¼NW¼SE¼ sec. 14.
D1978. J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. Near the center of the S½SE¼SE¼SW¼ sec. 14.
D1979. J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. SW¼SE¼SE¼SW¼ sec. 14.
D1980. W. A. Cobban, 1958. E½NW¼NE¼NW¼ sec. 23.
D1981. J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. SW¼SE¼SE¼SW¼ sec. 14.
D1982. J. R. Gill, 1958. Near the center of the SW¼NW¼SE¼ sec. 14.
D1983. W. A. Cobban, J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. NE¼NW¼NW¼SE¼ sec. 14.
D1984. J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. SW¼SE¼SE¼SW¼ sec. 14.
D1985. J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958; W. A. Cobban, 1959. NE¼NW¼NW¼SE¼ sec. 14.
D1986. W. A. Cobban, J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. Near the center of the N½NW¼ NW¼SE¼ sec. 14.
D1987. W. A. Cobban, J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. NW¼NW¼NW¼SE¼ sec. 14.
D2101. W. A. Cobban, 1959. SW¼ sec. 1.
D2102. J. R. Gill and W. A. Cobban, 1959. SE¼SW¼ sec. 13.
D2113, D2114. W. A. Cobban, 1959. N½NE¼NW¼SW¼ sec. 13.
D2115. W. A. Cobban, 1959. Gully in the SW¼NE¼SW¼NW¼ sec. 13.
D2116. W. A. Cobban, 1959. Stream bank in the SW¼SE¼-SW¼NE¼ sec. 14.
D2117–19. W. A. Cobban, 1959. NE¼NW¼NW¼SE¼ sec. 14.
D2120. W. A. Cobban, 1959. Near the center of the N½NW¼-NW¼SE¼ sec. 14.
D2121. W. A. Cobban, 1959. SW¼SW¼SW¼NE¼ sec. 14.
D2122. W. A. Cobban, 1959. NE¼SE¼NE¼ sec. 23.
D2903. W. A. Cobban, 1960. SE¼SE¼SW¼NE¼ sec. 14.
D2904. W. A. Cobban, 1960. NW¼NE¼ sec. 26.
D2905. L. G. Schultz, J. R. Gill, and W. A. Cobban, 1960. SW¼SE¼, NW¼SE¼, and the center of the SE¼ sec. 23 and NW¼NE¼ sec. 26.
D2906, D2907. J. R. Gill, 1960. NE¼SW¼SE¼ sec. 23.
D2908. G. R. Scott and W. A. Cobban, 1960. NW¼ sec 20.
D2909. J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. S½NE¼NW¼SW¼ sec. 13.
D2910. W. A. Cobban, 1960. NE¼NW¼NW¼SW¼ sec. 13.
D2911. W. A. Cobban, 1958. NE¼SE¼NW¼NE¼ sec. 23 to the center of the W½NW¼NE¼NE¼ sec. 23.
D2912. W. A. Cobban, 1959. SE¼NE¼NW¼NE¼ sec. 23.
D2913. J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. Near center of the N line of the NW¼NW¼NE¼ sec. 23.
D2914. J. R. Gill, W. J. Mapel, C. S. Robinson, and H. A. Tourtelot, 1958. NE¼NW¼NE¼NW¼ sec. 23.
D4008. W. A. Cobban, 1962. SE¼NW¼SE¼NE¼ sec. 14.
D4009. R. E. Burkholder and J. R. Gill, 1962. SE¼SW¼NE¼ sec. 13.
D4349. J. R. Gill, 1962. Center of sec. 14.

DETAILED MEASURED SECTION

The reference section of the Pierre Shale is about 1½ miles north of Red Bird (figs. 1, 2). Two planetable traverses were made across the outcrop in 1958, and supplemental detail was obtained later by Jacob's staff (p. A2). The A traverse is in the N½ sec. 23 and the B traverse is in about the middle of the E½ sec. 14 and the W½ sec. 13, T. 38 N., R. 62 W., Niobrara County, Wyo. All gastropod indentifications by N. F. Sohl.

Fox Hills Sandstone (part) : *Feet*

118. Sandstone, yellowish-gray, fine-grained, irregularly bedded in layers 1–2 ft thick; contains thin lenses of gray sandy shale in lower part. Unit weathers grayish orange, and is capped by a 2-ft-thick bed of medium-brown-weathering hard calcareous flaggy sandstone containing elongate sandstone concretions — 30
117. Sandstone, yellowish-gray, soft, glauconitic; weathers light olive brown; contains a 1-ft-thick layer of brown-weathering hard sandstone in middle of unit, and medium-brown-weathering fossiliferous calcareous sandstone concretions at base of unit — 35
116. Sandstone, light-olive-gray (lighter near top), soft, silty, clayey; weathers to smooth slope; in lower part contains calcareous sandstone concretions that have laminae locally distorted by boringlike structures — 55
115. Siltstone, light-olive-gray; weathers flaky; very sandy in upper part and gradational into overlying sandstone; contains abundant glauconite in middle, and irregularly shaped limy nodules in lower 18 ft — 50
114. Sandstone, yellowish-gray, fine-grained, glauconitic, calcareous; weathers light olive gray; contains ripple laminae 1–2 mm thick, and scattered hollow limonite nodules. Uppermost 3 ft and lowest 2 ft are hard layers — 6.5
113. Siltstone, medium-gray, slightly sandy and very clayey; weathers yellowish gray; blocky fracture — 60
112. Sandstone, medium-greenish-gray, clayey; weathers yellowish olive green; contains 50 percent or more glauconite, a few phosphatic nodules, and numerous scattered limy nodules that weather to hard limonitic masses. A 1.2-ft-thick bed of bentonite occurs locally at base — 13
    USGS D4349:
        Inoceramus subcircularis Meek

Total Fox Hill Sandstone measured — 249.5

Pierre Shale:

Upper unnamed shale member:

111. Shale, gray, sandy — 35.5
110. Shale, gray, sandy; lower 6 ft slightly glauconitic; contains beds of gray- and brown-weathering, closely spaced sandy limestone concretions at top and base and 6 ft above base — 22.5
109. Shale, gray; contains a few limestone concretions weathering gray and brown — 19

Pierre Shale—Continued

Upper unnamed shale member—Continued *Feet*

108. Shale, silty; weathers light gray; contains numerous gray- and brown-weathering limestone concretions, some having fossils — 9
    USGS D2121, from concretions:
        pyriporoid bryozoan
        Inoceramus? fibrosus (Meek and Hayden)
        I. balchii Meek and Hayden
        Baculites clinolobatus Elias
        Discoscaphites n. sp.
        Sphenodiscus cf. *S. lenticularis* (Owen)
        bored wood
107. Shale, silty; weathers light gray — 32
106. Shale, silty; weathers light gray; contains many gray- and brown-weathering limestone concretions, some having fossils — 22
    Iron stake No. 6 in B planetable traverse.
    USGS D1987, from concretions:
        pyriporoid bryozoan
        Inoceramus? fibrosus (Meek and Hayden)
        I. subcircularis Meek
        I. cf. ***I. incurvus*** Meek and Hayden
        Baculites clinolobatus Elias
        Discoscaphites n. sp.
105. Shale, silty; weathers light gray; contains a bed of gray silty shaly limestone concretions 20 ft above base — 35
104. Shale; weathers medium gray; contains numerous limestone concretions weathering light gray to buff. Few fossils — 21
    USGS D1986, from concretions:
        pyriporoid bryozoan
        Inoceramus subcircularis Meek
        I. incurvus Meek and Hayden
        Baculites grandis Hall and Meek
103. Shale; weathers medium gray — 29
102. Shale; weathers medium gray; contains gray- and brown-weathering limestone concretions, some fossiliferous — 8
    USGS D2120, from concretions:
        Baculites grandis Hall and Meek
101. Shale; weathers medium gray; contains a few thin layers of fibrous calcite — 51
    USGS D2914, 15 ft below top:
        Baculites grandis Hall and Meek
100. Shale; weathers gray; contains closely spaced brown-weathering limestone concretions at top — 5
99. Bentonite, olive-gray, impure; forms dark bare gumbo; contains widely spaced limestone concretions commonly 4 ft or more in diameter, which weather light brown — 2

Pierre Shale—Continued

Upper unnamed shale member—Continued *Feet*

98. Shale; dark gray where fresh, and light medium gray where weathered; contains laminae of lighter gray soft siltstone and fine-grained sandstone. A few small brown-weathering limestone concretions, commonly very fossiliferous, are scattered throughout the unit ------ 54

USGS D2119, from concretions throughout unit:

membraniporoid bryozoan
Nuculana bisulcata (Meek and Hayden)
Baculites grandis Hall and Meek
Hoploscaphites sp.

97. Bentonite and bentonitic shale, yellowish-gray, calcareous; weathers to medium-gray bare gumbo surface; contains a few brown-weathering clayey limestone concretions ---------------------------- 8

96. Shale, dark-gray; basal 2–3 ft very bentonitic, forming a gray bare gumbo surface; rest of unit silty, containing a few small very fossiliferous brown-weathering limestone concretions------------- 21

USGS D2118:

Trochocyathus? sp.
Diploconcha? sp.
Nucula (*Pectinucula*) *cancellata* Meek and Hayden
Nuculana evansi (Meek and Hayden)
Idonearca shumardi (Meek and Hayden)
Gervillia sp.
Inoceramus? cf. *I.*? *fibrosus* (Meek and Hayden)
I. sp.
Pteria sp.
Pecten (*Chlamys*) *nebrascensis* Meek and Hayden
Anomia sp.
Cuspidaria sp.
Eutrephoceras montanaense (Meek)
Baculites grandis Hall and Meek
Discoscaphites n. sp.

95. Shale, dark-gray; weathers light medium gray; contains some brown-weathering limestone concretions commonly 6 in. thick and 9 in. in diameter, which in upper few feet and at base are very fossiliferous------------------------------ 31

USGS D1958, from upper few feet:

Diploconcha? sp.
Nuculana evansi (Meek and Hayden)
Nucula planimarginata Meek and Hayden
Idonearca shumardi (Meek and Hayden)
Inoceramus cf. *I. incurvus* Meek and Hayden
I.? cf. *I.*? *fibrosus* (Meek and Hayden)

Pierre Shale—Continued

Upper unnamed shale member—Continued

95—Continued *Feet*

Oxytoma nebrascana (Evans and Shumard)
Anomia sp.
Serrifusus dakotensis (Meek and Hayden)?
Drepanochilus evansi Cossmann
Euspira obliquata (Hall and Meek)
Graphidula culbertsoni (Meek and Hayden)
Bullopsis aff. *B. cretacea* Conrad
Ellipsoscapha occidentalis (Meek and Hayden)
Baculites grandis Hall and Meek
Discoscaphites n. sp.

USGS D2117, from concretions at base:

Diploconcha? sp.
Idonearca shumardi (Meek and Hayden)
Ostrea sp.
Baculites grandis Hall and Meek
Discoscaphites n. sp.

94. Shale; weathers light medium gray; uppermost part bentonitic---------------- 37

93. Shale, silty; weathers light medium gray; contains brown-weathering very fossiliferous limestone concretions as much as 1.5 ft thick and 4 ft in diameter------- 17.5

USGS D1982, D1983, D1984:

pyriporoid bryozoan
Diploconcha? sp.
Nuculana evansi (Meek and Hayden)
Nucula planimarginata Meek and Hayden
Idonearca shumardi (Meek and Hayden)
Inoceramus subcircularis Meek
I.? cf. *I.*? *fibrosus* (Meek and Hayden
Pteria linguaeformis (Evans and Shumard)
Oxytoma nebrascana (Evans and Shumard)
Ostrea sp.
Pecten (*Chlamys*) *nebrascensis* Meek and Hayden
Syncyclonema sp.
Anomia sp.
Modiolus meekii (Evans and Shumard)
Crenella n. sp.
Pholadomya sp.
Protocardia sp.
Dosiniopsis deweyi (Meek and Hayden)
Corbula crassimarginata Meek and Hayden
Serrifusus dakotensis (Meek and Hayden)?
Astandes densatus Wade
Euspira obliquata (Hall and Meek)
Vanikoropsis nebrascensis (Meek and Hayden)

Pierre Shale—Continued
Upper unnamed shale member—Continued
93—Continued *Feet*

Oligoptycha concinna (Hall and Meek)
Ellipsoscapha occidentalis (Meek and Hayden)
Drepanochilus evansi Cossmann
Dentalium gracile Meek and Hayden
Baculites baculus Meek and Hayden
Hoploscaphites quadrangularis (Meek and Hayden)
Discosaphites n. sp.
Eutrephoceras montanaense (Meek)

92. Shale; weathers light medium gray; contains a few brown-weathering limestone concretions---------------------- 36.5

91. Shale, dark-gray, silty; weathers light medium gray; contains many brown-weathering limestone concretions 1–2 ft thick and 1.3–8 ft in diameter crowded with *Inoceramus typicus* (Whitfield). A thin layer of light-gray fibrous calcite lies at top of unit--------------------- 56.5

USGS D2116, in upper 28 ft:
Inoceramus typicus (Whitfield)
Dosiniopsis deweyi (Meek and Hayden)
Anisomyon patelliformis (Meek and Hayden)?

USGS D1981, 51 ft above base:
Nuculana evansi (Meek and Hayden)
Crenella sp.
Astarte gregaria (Meek and Hayden)
Protocardia rara (Evans and Shumard)
Aporrhais biangulata Meek and Hayden
Astandes densatus Wade
Hoploscaphites quadrangularis (Meek and Hayden)
H. plenus (Meek and Hayden)

USGS D1980, 38 ft above base:
Inoceramus incurvus Meek and Hayden
Dosiniopsis deweyi (Meek and Hayden)

USGS D1979, 30 ft above base:
Inoceramus typicus (Whitfield)
Dosiniopsis deweyi (Meek and Hayden)
Euspira sp.

USGS D1977, 22 ft above base:
Inoceramus typicus (Whitfield)
Protocardia rara (Evans and Shumard)
Dosiniopsis deweyi (Meek and Hayden)
Dentalium gracile Meek and Hayden

Pierre Shale—Continued
Upper unnamed shale member—Continued
91—Continued *Feet*

USGS D1976, 10 ft above base:
Inoceramus incurvus Meek and Hayden

USGS D1975, 4 ft above base:
Inoceramus typicus (Whitfield)
I. incurvus Meek and Hayden
Dosiniopsis deweyi (Meek and Hayden)
Protocardia rara (Evans and Shumard)
Dentalium gracile Meek and Hayden
Hoploscaphites plenus (Meek and Hayden)
H. quadrangularis (Meek and Hayden)

USGS D1974, D1978, at base:
Nuculana evansi (Meek and Hayden)
Inoceramus typicus (Whitfield)
Cuspidaria variabilis Warren
Protocardia rara (Evans and Shumard)
Euspira obliquata (Hall and Meek)
Oligoptycha concinna (Hall and Meek)
Hoploscaphites plenus (Meek and Hayden)
H. quadrangularis (Meek and Hayden)

90. Shale; weathers light medium gray; contains gray fibrous calcite near base---- 25

89. Shale; contains brown-weathering limestone concretions, some having numerous scaphites------------------------ 1

USGS D1973:
Nuculana evansi (Meek and Hayden)
Inoceramus cf. *I. subcircularis* Meek
Pecten (*Chlamys*) *nebrascensis* Meek and Hayden
Crenella sp.
Atira? *nebrascensis* (Meek and Hayden)
Hoploscaphites quadrangularis (Meek and Hayden)
H. plenus (Meek and Hayden)

88. Shale; weathers light gray; contains a few limestone concretions------------- 39

USGS D1972, from a concretion near base:
Inoceramus typicus (Whitfield)
Hoploscaphites plenus (Meek and Hayden)

87. Shale; contains closely spaced brown-weathering silty limestone concretions and widely spaced small gray limestone concretions that are crowded with *Inoceramus typicus* (Whitfield); in places contains gray-weathering irregular masses of tepee-butte limestone---- 1.5

Pierre Shale—Continued
Upper unnamed shale member—Continued

	Feet
87—Continued	
USGS D1970, D1971:	
Inoceramus typicus (Whitfield)	
Oxytoma nebrascana (Evans and Shumard)	
Euspira obliquata (Hall and Meek)	
Hoploscaphites quadrangularis (Meek and Hayden)	
86. Shale; silty; weathers light gray; contains brown-weathering limestone concretions, many having numerous baculites	61
USGS D1969, concretion 46 ft above base:	
Nuculana cf. *N. evansi* (Meek and Hayden)	
Baculites eliasi Cobban	
USGS D1966, concretions 32 ft above base:	
Baculites eliasi Cobban	
USGS D1968, concretions 22 ft above base:	
pyriporoid bryozoan	
Inoceramus balchii Meek and Hayden	
Baculites eliasi Cobban	
Hoploscaphites sp.	
Total upper unnamed shale member	680

Kara Bentonitic Member:

	Feet
85. Limestone, concretionary; weathers moderate brown; forms persistent ridge	1.3
USGS D1967:	
Nucula sp.	
Oxytoma nebrascana (Evans and Shumard)	
Pteria sp.	
Euspira obliquata (Hall and Meek)	
Baculites eliasi Cobban	
Hoploscaphites sp.	
84. Bentonite and bentonitic shale; forms light-olive-gray gumbo bare of vegetation	12.5
83. Shale; silty to sandy; weathers light olive gray; contains gray- and brown-weathering limestone concretions	16
82. Bentonite; forms light-olive-gray gumbo surface bare of vegetation	6
Total Kara Bentonitic Member	35.8

Lower unnamed shale member:

	Feet
81. Shale; weathers light gray; contains gray- and brown-weathering limestone concretions in upper 22 ft, a bed of gray- to yellowish-brown-weathering limestone concretions 29 ft above the base, and rarely, a gray limestone concretion in the lower 28 ft	51
USGS D1965, from concretions 30–50 ft above base:	
Baculites eliasi Cobban	

Pierre Shale—Continued
Lower unnamed shale member—Continued

	Feet
81—Continued	
USGS D1964, from concretions 38 ft above base:	
Baculites eliasi Cobban	
USGS D1963, from a concretion 25 ft above base:	
pyriporoid bryozoan	
Baculites eliasi Cobban	
USGS D1962, D2903, from concretions 20 ft above base:	
membraniporoid bryozoan	
pyriporoid bryozoan	
Baculites eliasi Cobban	
B. cf. *B. grandis* Hall and Meek	
Hoploscaphites plenus (Meek and Hayden)	
80. Shale; weathers light gray; contains a few brown-weathering ferruginous limestone concretions, a thin layer of bentonite at top of unit, and a thin layer at base	40
USGS D1961, from a concretion at top of unit:	
pyriporoid bryozoan	
Inoceramus n. sp. (inflated)	
Lucina occidentalis (Morton)	
Baculites eliasi Cobban	
Hoploscaphites sp.	
USGS D1960, from concretions throughout unit:	
pyriporoid bryozoan	
Diploconcha sp.	
Inoceramus cf. *I. typicus* (Whitfield)	
Lucina occidentalis (Morton)	
Baculites eliasi Cobban	
USGS D1959, from a concretion 2 ft above base:	
Hoploscaphites n. sp.	
79. Shale; weathers light gray; contains a few shaly ferruginous concretions. Fossils scarce	47
USGS D1958:	
Baculites eliasi Cobban	
78. Shale; weathers gray; contains brown-weathering iron-stained limestone concretions and shaly dusky-red-weathering ironstone concretions; limestone concretions commonly septarian with thin veins of yellow calcite and red hematite	24
Iron stake No. 3 on bed of large limestone concretions 14 ft above base on A planetable traverse.	
USGS D1636, D1957, from concretions in upper 11 ft:	
Inoceramus sp.	
Baculites eliasi Cobban	
B. cf. *B. baculus* Meek and Hayden	
Hoploscaphites n. sp.	

Pierre Shale—Continued

Lower unnamed shale member—Continued *Feet*

77. Shale; weathers gray; contains a few soft ferruginous concretions in upper 25 ft. A 1-ft-thick gray bed of bentonite with pale-gray fibrous calcite at top of unit and a thinner layer of bentonite 22 ft above base ---------- 41

USGS D1956, from 6 ft above base:

Baculites cf. *B. jenseni* Cobban

76. Shale, dark-gray, flaky; forms very dark outcrop; contains dark-purplish-weathering ironstone concretions with phosphatic centers; very thin layer of bentonite near base ---------- 9

USGS D1955:

Inoceramus sp.

Baculites sp. (*jenseni-eliasi* type)

Hoploscaphites sp.

75. Shale; weathers medium gray; contains a few small gray limestone concretions; persistent layer of larger gray- and brown-weathering septarian limestone concretions at base. Bentonite is present as a thin layer 7 ft above base and as bentonitic shale at base ---------- 39

USGS D1954, from a concretion 10.5 ft below top:

Eurysalenia minima Kier

ophiuran

Lucina sp.

Baculites reesidei Elias

USGS D1953, from a concretion 30 ft below top:

Lingula sp.

Inoceramus sp.

Lucina sp.

Cymbophora sp.

Baculites sp.

fish bones and scales

USGS D1952, from concretions at base:

Inoceramus sagensis Owen

Lucina subundata Hall and Meek

Cryptorhytis cheyennensis (Meek and Hayden)

Drepanochilus cf. *D. scotti* Sohl

Anisomyon centrale Meek

A. sp.

Baculites reesidei Elias

Hoploscaphites nodosus (Owen)

74. Shale, flaky; weathers dark gray; contains a few small gray limestone concretions and at least one thin layer of bentonite ---------- 26

73. Shale, olive-gray, bentonitic; contains gray fibrous calcite ---------- 1

72. Shale; weathers light gray; contains a few inconspicuous dusky-red-weathering soft shaly ironstone concretions, and a few thin layers of bentonite with white fibrous calcite; upper 5 ft contains phosphatic casts of baculites and, rarely, other fossils ---------- 28

USGS D1951, from upper 5 ft:

pyriporoid bryozoan

Pierre Shale—Continued

Lower unnamed shale member—Continued

72—Continued *Feet*

Pteria linguaeformis (Evans and Shumard)

Baculites reesidei Elias

Hoploscaphites sp.

71. Shale; contains conspicous limestone concretions 2–3 ft in diameter, which weather bright orange brown and have thin veins of pale-yellow calcite and white barite ---------- 1.3

USGS D1950:

Inoceramus sp.

70. Shale; weathers light gray; contains a few rusty-brown soft shaly ironstone concretions ---------- 31

USGS D4008, from shale near base:

Baculites cf. *B. reesidei* Elias

69. Shale; weathers light gray; contains a few small limestone concretions; at top and base, has persistent beds of larger limestone concretions 0.5–3 ft thick to 1.3–5 ft in diameter that weather gray, buff, and brown and contain viens of brown calcite, and in places, white to pale-brown barite ---------- 10

USGS D1949, from concretions:

Inoceramus subcircularis Meek

Baculites reesidei Elias

Hoploscaphites nodosus (Owen)

68. Shale; weathers brownish gray ---------- 6

67. Shale; weathers light gray; bentonitic; contains a little fibrous calcite, and, rarely, a limestone concretion ---------- 3

USGS D1948, from a limestone concretion:

Inoceramus cf. *I. balchii* Meek and Hayden

Anomalofusus? sp.

Anisomyon borealis (Morton)

Solenoceras sp.

Placenticeras meeki Boehm

66. Shale; weathers brownish gray ---------- 6

65. Shale; weathers darker gray than overlying unit; contains numerous brown-weathering limestone concretions crowded with fossils ---------- 6.2

USGS D1637, D1947:

pyriporoid bryozoan

Nuculana sp.

Inoceramus n. sp.

Pteria linguaeformis (Evans and Shumard)

Ostrea sp.

Atira? *nebrascensis* (Meek and Hayden)

Anisomyon borealis (Morton)

Baculites rugosus Cobban

Exiteloceras jenneyi (Whitfield)

Solenoceras sp.

Hoploscaphites n. sp.

Placenticeras intercalare Meek

P. meeki Boehm

Pierre Shale—Continued
Lower unnamed shale member—Continued *Feet*

64. Shale, dark-gray; contains brown-weathering fossiliferous limestone concretions at base — 19
    USGS D1945, D1946:
    membraniporoid bryozoan
    pyriporoid bryozoan
    Nuculana sp.
    Inoceramus n. sp.
    Cryptorhytis cheyennensis (Meek and Hayden)
    Baculites rugosus Cobban
    Exiteloceras jenneyi (Whitfield)
    Hoploscaphites n. sp.
    Placenticeras intercalare Meek
    P. meeki Boehm
63. Shale, dark-gray; contains a 0.2-ft-thick layer of gray bentonite 5 ft above base — 20
62. Shale, dark-gray; contains few small fossiliferous limestone concretions and, at top, larger brown-weathering septarian limestone concretions as much as 1 ft thick and 5 ft in diameter. Base is marked by brown-weathering limestone concretions that have an outer cone-in-cone structure — 16.2
    USGS D1944, from small concretions:
    Baculites rugosus Cobban
    Placenticeras intercalare Meek
61. Shale, dark-gray; contains small reddish-brown-weathering ironstone concretions and larger tan-weathering limestone concretions that have cone-in-cone structure — 26
    USGS D1868, D2913, throughout unit:
    pyriporoid bryozoan
    Nuculana sp.
    Inoceramus n. sp.
    Pteria linguaeformis (Evans and Shumard)
    Ostrea inornata Meek and Hayden
    Syncyclonema sp.
    Cuspidaria variabilis Warren
    Lucina cf. *L. mattiformis* Stephenson
    Tenea circularis (Meek and Hayden)
    Dentalium pauperculum Meek and Hayden
    Baculites sp.
    Exiteloceras jenneyi (Whitfield)
    Hoploscaphites n. sp.
    USGS D1942, D1943, from lower half:
    membraniporoid bryozoan
    pyriporoid bryozoan
    Nuculana sp.
    Inoceramus n. sp.
    Ostrea sp.
    Pecten (*Chlamys*) *nebrascensis* Meek and Hayden
    Lucina sp.
    Euspira obliquata (Hall and Meek)

Pierre Shale—Continued
Lower unnamed shale member—Continued
61—Continued *Feet*
    Atira? *nebrascensis* (Meek and Hayden)
    Drepanochilus nebrascensis (Evans and Shumard)
    Dentalium gracile Meek & Hayden
    Eutrephoceras sp.
    Baculites rugosus Cobban
    Exiteloceras sp.
    Hoploscaphites n. sp.
    Placenticeras sp.
    USGS D1941, from base:
    Baculites rugosus Cobban
60. Shale, dark-gray; contains a 0.5-ft-thick gray bed of bentonite 7 ft above base — 17.3
59. Shale, dark-gray; forms a dark outcrop; contains a few grayish-red-weathering ironstone concretions and tan-weathering limestone concretions; at base, has a bed of closely spaced brown-weathering limestone concretions — 16
    USGS D1939, D1940:
    Nuculana cf. *N. evansi* (Meek and Hayden)
    Nucula nacatochana Stephenson
    Inoceramus n. sp.
    Pteria linguaeformis (Evans and Shumard)
    Ostrea inornata Meek and Hayden
    Pecten (*Chlamys*) *nebrascensis* Meek and Hayden
    Crassatella evansi Hall and Meek
    Lucina subundata Hall and Meek
    Dentalium gracile Hall and Meek
    Euspira obliquata (Hall and Meek)
    Atira? *nebrascensis* (Meek and Hayden)
    Graphidula cf. *G. alleni* (White)
    Drepanochilus cf. *D. nebrascensis* (Evans and Shumard)
    Nonacteonina attenuata (Meek and Hayden)
    Baculites crickmayi Williams
    Didymoceras stevensoni (Whitfield)
58. Shale; weathers medium gray; contains a few scattered yellowish-gray-weathering limestone concretions, with more persistent beds of concretions at base and 56 and 76 ft above base; basal concretions have cone-in-cone structure — 101
    USGS D1938, from 88 ft above base:
    Inoceramus aff. *I. turgidus* Anderson
    Trachytriton vinculum (Hall and Meek)
    Atira? *nebrascensis* (Meek and Hayden)
    Drepanochilus sp.
    Didymoceras nebrascense (Meek and Hayden)
    Hoploscaphites sp.

Pierre Shale—Continued
Lower unnamed shale member—Continued
58—Continued *Feet*
USGS D1937, from concretions 76 ft above base:
Inoceramus aff. *I. turgidus* Anderson
Crassatella evansi Hall and Meek
Dentalium sp.
Baculites crickmayi Williams
Hoploscaphites sp.
USGS D1936, from concretions 56 ft above base:
Crassatella evansi Hall and Meek
Cymbophora holmesi Meek
Baculites crickmayi Williams
Hoploscaphites n. sp.
USGS D1935, from a concretion 24 ft above base:
Inoceramus aff. *I. turgidus* Anderson
Tenea circularis (Meek and Hayden)
Didymoceras nebrascense (Meek and Hayden)
USGS D1934, from a concretion 15 ft above base:
Didymoceras nebrascense (Meek and Hayden)

57. Shale; weathers medium gray; contains at 27 ft above base a 0.5-ft-thick bed of fossiliferous clayey limestone concretions that weather yellowish gray and readily break into small pieces — 71
USGS D1933, from 45 ft above base:
Baculites sp.
USGS D1932, from concretions 27 ft above base:
Pteria linguaeformis (Evans and Shumard)
Tenea circularis (Meek and Hayden)
Cymbophora cf. *C. canonensis* (Meek)
Baculites scotti Cobban

56. Shale; contains conspicuous brown-weathering limestone concretions veined by white calcite — 1
USGS D1931:
Baculites scotti Cobban
Anapachydiscus complexus (Hall and Meek)

55. Shale; weathers medium gray; lower 17 ft silty; contains brown-weathering limestone concretions at 50 and 58 ft above the base, and, rarely, a limestone concretion nearer the base — 63
USGS D1928, D1930, from concretions 58 ft above base:
pyriporoid bryozoan
Nucula sp.
Baculites scotti Cobban
Didymoceras n. sp.

Pierre Shale—Continued
Lower unnamed shale member—Continued
55—Continued *Feet*
Anapachydiscus complexus (Hall and Meek)
Menuites n. sp.
Placenticeras sp.
USGS D1927, D1929, from concretions 50 ft above base:
pyriporoid bryozoan
Baculites scotti Cobban
Anapachydiscus complexus (Hall and Meek)
USGS D1926, from a concretion 28 ft above base:
pyriporoid bryozoan
Inoceramus sublaevis Hall and Meek
Tenea circularis (Meek and Hayden)
Trachytriton vinculum Hall and Meek
Baculites scotti Cobban

Total lower unnamed shale member — 720

Red Bird Silty Member:

54. Shale, silty; weathers light gray; contains at top irregularly shaped gray- and brown-weathering fossiliferous limestone concretions; at base, has a ridge-forming bed of larger closely spaced silty fossiliferous limestone concretions that are light olive gray where fresh, and tan to dark yellowish orange where weathered — 4.1
Iron stake No. 7 on B planetable traverse.
USGS D1924, D1925, from both beds of concretions:
pyriporoid bryozoan
Inoceramus tenuilineatus Hall and Meek
Cymbophora sp.
Cryptorhytis? sp.
Baculites scotti Cobban
Didymoceras n. sp.
Exiteloceras n. sp.
Anaklinoceras mortoni (Hall and Meek)
Anapachydiscus complexus (Hall and Meek)

53. Shale, silty; weathers light gray — 43.5

52. Shale, silty; weathers gray; contains at base and top limestone concretions that are light olive gray where fresh; concretions in upper bed are fossiliferous and range from darker weathering, irregularly shaped forms to larger and lighter weathering thick lenses of limestone; lower bed has very long and closely spaced concretions weathering moderate yellowish brown — 8

Pierre Shale—Continued
Red Bird Silty Member—Continued

	Feet
52—Continued	
USGS D1922, D1923, from upper bed:	
pyriporoid bryozoan	
Inoceramus tenuilineatus Hall and Meek	
Camptonectes sp.	
Drepanochilus sp.	
Baculites scotti Cobban	
Anapachydiscus complexus (Hall and Meek)	
51. Shale, silty; weathers medium gray in lower part and light gray in upper part; contains a few buff-weathering limestone concretions and, locally, in the lower part, a mass of tepee-butte limestone	43.7
USGS D1921, from tepee-butte limestone:	
pyriporoid bryozoan	
Inoceramus tenuilineatus Hall and Meek	
Lucina subundata Hall and Meek	
Tenea circularis (Meek and Hayden)	
Baculites gregoryensis Cobban	
50. Shale, silty; weathers light gray; contains light- to moderate-brown-weathering limestone concretions at base, and 20, 41, 52, and 54 ft above base	55.2
USGS D1920, from concretions 52 ft above base:	
pyriporoid bryozoan	
Inoceramus tenuilineatus Hall and Meek	
Baculites gregoryensis Cobban	
USGS D1919, from concretions 41 ft above base:	
pyriporoid bryozoan	
Diploconcha sp.	
Inoceramus aff. *I. proximus* Tuomey	
Baculites gregoryensis Cobban	
bored wood	
USGS D1918, from a concretion 35 ft above base:	
pyriporoid bryozoan	
Baculites gregoryensis Cobban	
USGS D1917, from concretions 20 ft above base:	
Diploconcha sp.	
Inoceramus aff. *I. proximus* Tuomey	
Euspira obliquata (Hall and Meek)	
Drepanochilus obesus Sohl	
Baculites gregoryensis Cobban	
USGS D1916, from concretions at base:	
Inoceramus aff. *I. proximus* Tuomey	
Baculites gregoryensis Cobban	

Pierre Shale—Continued
Red Bird Silty Member—Continued

	Feet
49. Shale, silty; weathers gray	26.3
USGS D1914:	
pyriporoid bryozoan	
Inoceramus aff. *I. proximus* Tuomey	
Oxytoma nebrascana (Evans and Shumard)	
Baculites gregoryensis Cobban	
48. Shale, silty; weathers gray; contains grayish-orange-weathering limestone concretions at base and top, and small brown-weathering limestone concretions 6 ft above base	23
USGS D1915, from concretions at top:	
pyriporoid bryozoan	
Inoceramus aff. *I. proximus* Tuomey	
Baculites gregoryensis Cobban	
USGS D1912, D1913, from concretions 6 ft above base:	
Inoceramus aff. *I. proximus* Tuomey	
Baculites gregoryensis Cobban	
USGS D1911, from concretions at base:	
pyriporoid bryozoan	
Diploconcha sp.	
Inoceramus aff. *I. proximus* Tuomey	
Baculites gregoryensis Cobban	
Placenticeras meeki Boehm	
47. Shale, silty; weathers medium gray; contains a few small tan-weathering fossiliferous concretions	30.3
USGS D1909, D1910, from concretions 15 ft above base:	
pyriporoid bryozoan	
Inoceramus aff. *I. proximus* Tuomey	
Anisomyon borealis (Morton)	
Baculites gregoryensis Cobban	
46. Shale, silty; contains closely spaced limestone concretions commonly 3–5 ft in diameter which weather grayish orange, moderate brown, and orange brown, and locally have thin veins of yellow calcite. In places the concretions are replaced by small masses of tepee-butte limestone	1
USGS D1907, D1908:	
pyriporoid bryozoan	
Nuculana corsicana Stephenson	
Nucula sp.	
Inoceramus tenuilineatus Hall and Meek	
Inoceramus aff. *I. proximus* Tuomey	
Pteria linguaeformis (Evans and Shumard)	
Lucina occidentalis (Morton)	
Tenea circularis (Meek and Hayden)	
Baculites gregoryensis Cobban	
Didymoceras n. sp.	
Placenticeras sp.	

Pierre Shale—Continued

Red Bird Silty Member—Continued — *Feet*

45. Shale, silty; weathers medium gray; contains septarian limestone concretions weathering bright moderate yellowish brown 11 ft above base; small gray fossiliferous limestone concretions appear in upper third of unit — 49
    - USGS D1906, from upper 10 ft:
        - pyriporoid bryozoan
        - *Inoceramus subcompressus* Meek and Hayden
        - *Baculites gregoryensis* Cobban
    - USGS D1905, from concretions 42 ft above base:
        - *Inoceramus* aff. *I. proximus* Tuomey
        - *Baculites gregoryensis* Cobban
        - *Didymoceras* sp.
    - USGS D1904, from concretions 36 ft above base:
        - pyriporoid bryozoan
        - *Inoceramus* aff. *I. proximus* Tuomey
        - *Trachytriton vinculum* (Hall and Meek)
        - *Baculites gregoryensis* Cobban

44. Shale; contains long and closely spaced ridge-forming limestone concretions that weather grayish orange and yellowish gray — 1.3

43. Shale, silty; upper 16 ft weathers light gray, and rest of unit weathers medium gray; contains gray-weathering septarian limestone concretions at base of unit and 11 ft above base, small gray limestone concretions 35 ft above base, and a few small brown-weathering fossiliferous limestone concretions in the upper 16 ft — 51.6
    - USGS D1903, from concretions in upper 16 ft:
        - pyriporoid bryozoan
        - *Inoceramus* aff. *I. proximus* Tuomey
        - *I. subcompressus* Meek and Hayden
        - *Baculites gregoryensis* Cobban
    - USGS D1902, from concretions at base:
        - pyriporoid bryozoan
        - *Inoceramus subcompressus* Meek and Hayden
        - *Ostrea* sp.
        - *Baculites gregoryensis* Cobban

42. Shale, silty; weathers medium gray — 29

41. Shale, silty; weathers light gray; contains at base a bed of closely spaced very fossiliferous limestone concretions that weather moderate yellowish brown and have veins of pale-yellow calcite and white barite; rest of unit contains scattered gray fossiliferous limetone concretions — 9.5
    - USGS D1900, D1901, from concretions throughout unit:
        - pyriporoid bryozoan

Pierre Shale—Continued

Red Bird Silty Member—Continued

41—Continued — *Feet*

- *Nucula* cf. *N. planimarginata* Meek and Hayden
- *Inoceramus subcompressus* Meek and Hayden
- *Anomia* sp.
- *Tenea* sp.
- *Lucina subundata* Hall and Meek
- *Trachytriton vinculum* (Hall and Meek)
- *Anisomyon* sp.
- *Baculites gregoryensis* Cobban
- *Trachyscaphites redbirdensis* Cobban and Scott
- *Hoploscaphites gilli* Cobban and Jeletzky
- *H.* n. sp.
- *Placenticeras meeki* Boehm

40. Shale, silty; weathers light gray — 13

39. Shale, silty; weathers light gray; contains closely spaced yellowish-gray-weathering to moderate-yellowish-brown-weathering limestone concretions at base, smaller light-gray-weathering limestone concretions 10 ft above base, and closely spaced, very fossiliferous limestone concretions at top that weather light olive gray to moderate yellowish brown and contain veins of yellow calcite — 15
    - USGS D1898, D1899, from concretions at top of unit:
        - pyriporoid bryozoan
        - *Omasaria* sp.
        - *Inoceramus subcompressus* Meek and Hayden
        - *Pteria* n. sp.
        - *Ostrea plumosa* Morton
        - *Lucina occidentalis* (Morton)
        - *Baculites perplexus* Cobban (late form)
        - *Hoploscaphites* n. sp.
        - *Placenticeras* sp.
    - USGS D1897, from concretions at base:
        - pyriporoid bryozoan
        - *Inoceramus subcompressus* Meek and Hayden
        - *Baculites perplexus* Cobban (late form)

38. Shale, silty; weathers light gray; contains persistent beds of limestone concretions at base, 11, 26, and 51 ft above base; concretions weather yellowish gray, grayish orange, pale brown, moderate brown, or orange brown, and a few at 11 and 26 ft above base have veins of white to pale-yellow calcite — 79
    - USGS D1896, from concretions 74 ft above base:
        - pyriporoid bryozoan
        - *Baculites perplexus* Cobban (late form)

Pierre Shale—Continued
Red Bird Silty Member—Continued

	Feet
38—Continued	
USGS D2115, from concretions 27–50 ft above base:	
pyriporoid bryozoan	
Inoceramus subcompressus Meek and Hayden	
Ostrea sp.	
Baculites perplexus Cobban (late form)	
Hoploscaphites gilli Cobban and Jeletzky	
USGS D1895, from concretions 26 ft above base:	
pyriporoid bryozoan	
Inoceramus subcompressus Meek and Hayden	
Baculites perplexus Cobban (late form)	
USGS D1894, D2912, from concretions 1–10 ft above base:	
pyriporoid bryozoan	
Inoceramus subcompressus Meek and Hayden	
Cymbophora sp.	
Baculites perplexus Cobban (late form)	
Hoploscaphites gilli Cobban and Jeletzky	
USGS D1892, D1893, from concretions at base:	
pyriporoid bryozoan	
Inoceramus subcompressus Meek and Hayden	
Cymbophora sp.	
Baculites perplexus Cobban (late form)	
37. Shale, silty; weathers light gray; contains a few small light-brown-weathering limestone concretions in lower 15 ft. Locally, a mass of tepee-butte limestone is present 32 ft above base	48
USGS D1891, from 32 ft above base:	
Inoceramus subcompressus Meek and Hayden	
Lucina sp.	
Baculites gilberti Cobban	
36. Shale, silty; weathers light gray; contains a few small scattered brown-weathering limestone concretions. At top and 30 ft above base are ridges of buff-weathering to moderate-brown-weathering closely spaced limestone concretions	47.5
USGS D1888, D1890, from concretions at top:	
pyriporoid bryozoan	
Inoceramus subcompressus Meek and Hayden	
Ostrea sp.	
Baculites gilberti Cobban	
Hoploscaphites sp.	

Pierre Shale—Continued
Red Bird Silty Member—Continued

	Feet
36—Continued	
USGS D2911, from 31–47 ft above base:	
Inoceramus subcompressus Meek and Hayden	
Baculites gilberti Cobban	
USGS D1889, from concretions 30 ft above base:	
Baculites gilberti Cobban	
USGS D1887, from concretions 15 ft above base:	
pyriporoid bryozoan	
Inoceramus subcompressus Meek and Hayden	
Ostrea sp.	
Anisomyon sp.	
Baculites gilberti Cobban	
USGS D1885, D1886, from concretions 3 ft above base:	
Baculites gilberti Cobban	
35. Shale, silty; weathers brown	10
34. Shale, slightly silty; weathers medium gray; contains a few small limestone concretions that weather moderate brown, and 2 ft below top, a bed of closely spaced limestone concretions that weather yellowish gray to moderate brown	19
USGS D1882, D1883, D1884:	
pyriporoid bryozoan	
Baculites gilberti Cobban	
Total Red Bird Silty Member	607

Mitten Black Shale Member:

33. Shale, dark-gray; contains numerous pale-yellowish-brown-weathering fossiliferous limestone concretions and conspicuous beds of darker brown weathering limestone concretions at base (where they form ridges) and top	23.5
Iron stake No. 2 on base of unit in A planetable traverse.	
USGS D1639, D1878, from concretions at top:	
pyriporoid bryozoan	
Inoceramus subcompressus Meek and Hayden	
Baculites gilberti Cobban	
Hoploscaphites gilli Cobban and Jeletzky	
H. n. sp.	
USGS D1887, D1881, from 1–22 ft above base:	
pyriporoid bryozoan	
Inoceramus subcompressus Meek and Hayden	
Aporrhais n. sp.	
Baculites gilberti Cobban	
Hoploscaphites gilli Cobban and Jeletzky	
H. n. sp.	

Pierre Shale—Continued

Mitten Black Shale Member—Continued

33—Continued *Feet*

USGS D1876, D1880, from concretions at base:

pyriporoid bryozoan

Baculites gilberti Cobban

32. Shale, dark-gray; lower half contains a few brown-weathering limestone concretions; in middle are local masses of gray tepee-butte limestone ____________ 71

USGS D1875, D1879, from limestone concretions in lower half:

gall-like object

pyriporoid bryozoan

Inoceramus subcompressus Meek and Hayden

Cymbophora sp.

Baculites gilberti Cobban

Hoploscaphites gilli Cobban and Jeletzky

USGS D2910, from tepee-butte limestone:

Inoceramus subcompressus Meek and Hayden

Thyasira n. spp.

Baculites gilberti Cobban

31. Shale, gray, bentonitic; contains yellowish-weathering limestone concretions: some soft and clayey, others hard and septarian (veined with pale-yellow calcite), some with cone-in-cone structure_ 2

30. Shale, dark-gray; contains a few brownish-weathering limestone concretions and, in the shale, many baculites______ 42

USGS D2114:

pyriporoid bryozoan

Baculites gilberti Cobban

Placenticeras intercalare Meek

29. Shale, dark-gray; contains limestone concretions that weather yellowish gray, light brown, moderate brown, yellowish brown, and dark yellowish orange. Persistent beds of concretions are present at base and top and at 19, 50, and 74 ft above base; concretions in upper 4 ft may be septarian with yellow calcite__ 104.5

USGS D1874, from upper 4 ft:

pyriporoid bryozoan

Baculites gilberti Cobban

USGS D1873, from 86–88 ft above base:

Baculites perplexus Cobban (early form)

Hoploscaphites gilli Cobban and Jeletzky

USGS D1872, from concretions 75 ft above base:

pyriporoid bryozoan

Inoceramus subcompressus Meek and Hayden

Baculites perplexus Cobban (early form)

Hoploscaphites n. sp.

Pierre Shale—Continued

Mitten Black Shale Member—Continued

29—Continued *Feet*

USGS D1871, from 55–74 ft above base:

pyriporoid bryozoan

Baculites perplexus Cobban (early form)

Hoploscaphites gilli Cobban and Jeletzky

USGS D1867, D1870, from 20–50 ft above base:

pyriporoid bryozoan

Nemodon? sp.

Inoceramus subcompressus Meek and Hayden

Baculites perplexus Cobban (early form)

Hoploscaphites sp.

USGS D1866, from 1–19 ft above base:

Thyasira n. spp.

Baculites perplexus Cobban (early form)

Hoploscaphites n. sp.

USGS D1869, D2909, from concretions at base:

pyriporoid bryozoan

Inoceramus subcompressus Meek and Hayden

Thyasira n. sp.

Baculites perplexus Cobban (early form)

Hoploscaphites gilli Cobban and and Jeletzky

28. Shale, dark-gray; contains a few ironstone concretions that weather grayish red to dark reddish brown and limestone concretions that weather yellowish gray to moderate yellowish brown: in upper half, masses of tepee-butte limestone occur very sparsely, and a few limestone concretions have cone-in-cone structure __________________________ 103

USGS D2113, from 44–103 ft above base:

Inoceramus subcompressus Meek and Hayden

Baculites perplexus Cobban (early form)

USGS D1865, from 69–89 ft above base:

pyriporoid bryozoan

Thyasira n. spp.

Baculites perplexus Cobban (early form)

Hoploscaphites n. sp.

Raninella n. sp.

USGS D1864, from 44–59 ft above base:

Inoceramus subcompressus Meek and Hayden

Thyasira n. spp.

Baculites perplexus Cobban (early form)

Hoploscaphites n. sp.

Pierre Shale—Continued

Mitten Black Shale Member—Continued

	Feet
27. Bentonite, dark-gray, soft; weathers to medium-gray loose granular powder beneath a hard crusted bare surface; contains at base a 0.1-ft-thick layer of gray fibrous calcite	2
26. Shale, dark-brownish-gray to gray, bentonitic; weathers grayish brown and forms gumbo-surfaced outcrop with patches of alkali; contains numerous dusky-red-weathering platy ironstone concretions 0.1-ft thick, and a few thicker tan-weathering limestone concretions, some of which have a rind of cone-in-cone structure. Lower part of unit has some silty layers that have cone-in-cone structure	182
25. Shale, dark-gray, nonbentonitic; weathers flaky; contains very thin discontinuous beds of dusky-red- to dark-reddish-brown-weathering ironstone at base and at 2, 6, 8, 12, 15, 18, 24, 29, 31, 35, 36, and 41 ft above base. A 0.1-ft-thick layer of grayish-orange bentonite overlying a persistent grayish-orange-weathering bed of siltstone that has cone-in-cone structure lies 21 ft above base	65
24. Shale, dark-gray, bentonitic, soft; weathers to frothy bare gumbo surface with patches of alkali; contains discontinuous thin beds and concretions of dusky-red-weathering silty ironstone and gray limestone with cone-in-cone structure at 6, 12, 17, 20, and 23 ft above base and at top. A thin lenticular layer of olive-gray hard siltstone lies 5 ft above base	25
23. Shale, dark-gray to black-gray, nonbentonitic, soft; weathers flaky; contains dusky-red- to light-brown-weathering ironstone concretions at 5, 12, and 18 ft above base, and dark-yellowish-orange-weathering small limestone concretions in upper 4 ft	25

USGS D1861, D1862, D2907, from limestone concretions in upper 4 ft:
- *Inoceramus subcompressus* Meek and Hayden
- *Ostrea* sp.
- *Lucina occidentalis* (Morton)
- *Baculites perplexus* Cobban (early form)
- *Hoploscaphites* n. sp.

	Feet
22. Shale, dark-gray to black-gray, soft, flaky; contains tan-weathering shaly lenses of limestone at base and 7 ft above base; a 1-ft-thick bed of grayish-orange-weathering limestone that has cone-in-cone structure, overlain by a 0.4-ft-thick gray bentonite, lies 12 ft above base	22

Pierre Shale—Continued

Mitten Black Shale Member—Continued

22—Continued

Iron stake No. 1 on limestone 12 ft above base on A planetable traverse.

USGS D2122, D2906, from lower 12 ft:
- *Inoceramus subcompressus* Meek and Hayden
- *Baculites perplexus* Cobban (early form)

	Feet
21. Shale, black-gray; weathers soft and flaky; contains small gray- to grayish-orange-weathering limestone concretions at 22, 26, 27, 33, 37, and 38 ft above base, and persistent beds of grayish-orange- to light-brown-weathering shaly limestone (cone-in-cone structure) at base and 18 ft above base; grayish-orange-weathering phosphatic nodules and fossiliferous limestone concretions present 5–18 ft above base	60

USGS D2102, D2904, D2905, from limestone concretions 5–18 ft above base:
- *Inoceramus subcompressus* Meek and Hayden
- *Baculites* sp. (smooth)
- *Hoploscaphites* n. sp.

	Feet
20. Shale, dark-gray, hard, hackly; forms bare outcrop; limonite stains on fracture surfaces give unit a dark-rusty-brown appearance. Unit contains dusky-red- and rusty-weathering ironstone concretions at 10, 12, 19, 48, 131, 139, 145, and 153 ft above base, and grayish-orange-weathering septarian limestone concretions at 10, 33, 60, 88, and 179 ft above base. Ironstone concretions 48 ft above base have grayish-orange-weathering rinds of limestone that show cone-in-cone structure. Grayish-orange-weathering phosphatic nodules occur sparsely 40 ft above base	211

USGS D1855, D1859, from concretions 60 ft above base:
- *Opertochasma* sp. (in bored wood)
- *Baculites asperiformis* Meek

USGS D1857, from a concretion 33 ft above base:
- *Baculites* sp.

USGS D1856, from concretions 19 ft above base:
- *Baculites asperiformis* Meek
- *Hoploscaphites* sp.
- *Placenticeras* sp.

USGS D4009, from a gray shaly limestone concretion 6 ft above base:
- *Baculites mclearni* Landes

	Feet
Total Mitten Black Shale Member	938

Pierre Shale—Continued	Feet
Sharon Springs Member:	
19. Shale, dark-gray to grayish-black, hard; weathers silvery gray and papery; contains grayish-orange nonswelling bentonite in a 0.4-ft-thick bed at base and a 0.2-ft-thick bed at top; small gray limestone concretions are present at base	35
USGS D1858, D2101, from shale in upper 10 ft:	
Baculites mclearni Landes	
18. Shale, as in unit 19; contains a 0.1-ft-thick greenish-gray nonswelling micaceous layer of bentonite 1.8 ft above base	29.9
17. Bentonite, grayish-orange, limonite-stained, nonswelling	.8
16. Shale, like unit 19; contains sparse grayish-orange-weathering phosphatic nodules and numerous vertebrate fossils and gypsiferous limonitic baculites	21.1
USGS D2908 from shale throughout unit:	
Inoceramus cf. *I. agdjakendensis* Aliev	
Baculites obtusus Meek	
15. Bentonite, pinkish-gray to grayish-orange, nonswelling, weathers flaky; upper 0.3 ft is impure and upper contact is gradational; lower contact sharp	1.4
14. Shale, like unit 19; upper 0.3 ft is dark brown to black gray, hard, and cemented with iron and gypsum; a 0.1-ft-thick layer of bentonite 4 ft above base	5.4
13. Shale, dark-gray, organic-rich; weathers silvery gray and papery with much limonite, jarosite, and gypsum along bedding and fracture planes; buttress forming; contains numerous fish scales and bones. A 0.2-ft-thick bed of bentonite lies 2.3 ft above base, and a 0.1-ft-thick bed lies 6.5 ft above base	24.1
12. Bentonite, light-gray to grayish-yellow, soft, nonswelling; weathers granular	.5
11. Shale, brownish-black; weathers moderate brown; cemented with iron and gypsum	.9
10. Bentonite and shale, interbedded; bentonite is similar to unit 12; shale is similar to unit 13, and occurs as a 0.3-ft-thick bed at base, a 0.2-ft-thick bed 0.9 ft above base, and a 0.5-ft-thick bed 1.8 ft above base	3.6
9. Bentonite; grades from light greenish gray up into grayish orange and is dark yellowish orange in uppermost 0.5 ft; nonswelling, mealy texture; lower contact sharp, upper contact gradational; contains thin black shale partings at 0.4 and 2.9 ft above base. Ardmore Bentonite Bed	3.3
Total Sharon Springs Member	126.6

Pierre Shale—Continued	Feet
Gammon Ferruginous Member:	
8. Shale, dark-gray to black-gray; weathers flaky to hackly; buttress forming; contains dusky-red- to light-brown-weathering shaly ironstone concretions 0.2 ft thick and 1 ft in diameter at 6.4 and 11.4 ft above base	24.4
7. Bentonite; weathers pale yellowish orange; soft, nonswelling; contains abundant jarosite, limonite, and gypsum	.5
6. Shale and bentonite, interbedded; shale similar to unit 8; bentonite similar to unit 7, and occurs as a 0.3-ft-thick bed at base, and as 0.1-ft-thick beds at 2.2, 2.9, and 3.5 ft above base	4.9
Total Gammon Ferruginous Member	29.8
Total Pierre Shale (rounded)	3,140.0
Niobrara Formation (part):	
5. Shale, dark-gray; weathers medium bluish gray; slightly to very calcareous with abundant white calcareous specks; blocky fracture; contains a 0.1-ft-thick layer of pinkish-gray to grayish-yellow nonswelling bentonite at base	14.1
4. Chalk, medium-bluish-gray; shaly fracture; contains a 0.2-ft-thick bed of nonswelling bentonite 1.5 ft above base	4.1
3. Bentonite, pinkish-gray to grayish-yellow, nonswelling; contains pyrite nodules 0.1 ft in diameter	.5
2. Chalk, similar to unit 4; basal 0.15 ft and uppermost 0.05 ft are bentonite	12.9
1. Chalk, similar to unit 4; bentonite in 0.02-ft-thick beds occurs at 23.4 and 29 ft above base	34
Total Niobrara Formation measured	65.6

A NEW ECHINOID FROM THE CRETACEOUS PIERRE SHALE OF EASTERN WYOMING[2]

By Porter M. Kier

Echinoids are uncommon in the Mesozoic of the Western Interior of the United States. Only a few species have been reported, and the reports are based on a small number of specimens. This fact makes very remarkable the discovery by W. A. Cobban, in the Upper Cretaceous Pierre Shale, of hundreds of specimens of a single species in a limestone concretion only 2.5 feet in diameter and 1 foot thick. According to Cobban (written commun., 1959), the echinoids occur in the top 3 or 4 inches of this concretion. The specimens are crowded together (fig. 17*A*), almost in contact, and from 10 to 20 are visible in each square inch of surface area. The spines are still attached to most of the specimens or are very near them. Because the spines are usually detached immediately on the death of an echi-

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noid, the presence of the spines indicates that these echinoids were little disturbed after death, and that their concentration here was not due to the action of currents but probably to live burial. Even though echinoids are normally gregarious, so great a concentration is unusual. It may have been caused by the aggregation of the echinoids to spawn; Tennent (1910, p. 659) found in his studies of *Lytechinus variegatus* (Leske) that when these echinoids were ready to spawn they gathered together in abundance, "almost in masses." Or, this concentration may have occurred when the echinoids gathered to feed upon a large dead animal or a large plant, as is customary for many regular echinoids, according to Hyman (1955, p. 554).

Although all the echinoids are small—none exceed 10 mm in horizontal diameter—it is evident that the individuals were mature adults and of normal size. The genital pores, an adult feature, are present in all the specimens, including the smallest, in which the apical system is present. Furthermore, members of this family are commonly small; most of them are 10–15 mm in horizontal diameter. In some of the living species, adults are only 2–3 mm in horizontal diameter.

Unfortunately, the specimens are covered with a thin layer of matrix which, because of the small size of the specimens, is difficult to remove. It was therefore not feasible to make a biometric study of this species, even though so many specimens were available. No single specimen was well enough preserved to show most of the morphological details, and many specimens were studied before the structures of this species were apparent. Most of the plate sutures were visible only when the specimens were immersed in glycerine after being slightly etched with hydrochloric acid. The surface detail was apparent only when the specimens were whitened with ammonium chloride. Because of this poor preservation, satisfactory photographs to illustrate this species could not be taken. Drawings were made of a specimen immersed under glycerine, and then of the same specimen whitened; later these two drawings were combined.

SYSTEMATIC DESCRIPTION

Family ACROSALENIIDAE Gregory, 1900

Genus EURYSALENIA Kier, n. gen.

Type species.—Eurysalenia minima Kier, n. sp.

Generic description.—Small, circular, low; apical system with hexagonal suranal plate, periproct adjacent to genital 5; ambulacra wide, straight; adapically, plates small, primaries; adorally, plates much larger, with two plates covered by one large primary tubercle alternating with a single primary plate; primary tubercles small adapically, large adorally, crenulate, perforate; adoral ambulacral tubercles as large as interambulacral; gill slits not deeply indented.

Comparison with other genera.—This genus, because of the angular suranal plate in its apical system, and crenulate, perforate tubercles, belongs in the family Acrosaleniidae. Of all the genera in this family, *Pseudosalenia* Cotteau, 1859, is closest to *Eurysalenia.* Both genera have adoral compound ambulacral plates, but adapically simple plates. *Eurysalenia* differs from *Pseudosalenia* in having much broader ambulacra. In *Eurysalenia* the ambulacra are 85 percent as wide as the interambulacra, whereas in *Pseudosalenia* they are only 20–25 percent as wide. Furthermore, in *Eurysalenia* the ambulacra are straight, but in *Pseudosalenia* they are sinuous. The primary tubercles on the adoral ambulacral plates are large in *Eurysalenia* and equal in size to those on the interambulacral plates, but in *Pseudosalenia* these tubercles are small—much smaller than the interambulacral tubercles. Finally, the gill slits in *Eurysalenia* are much less indented than they are in *Pseudosalenia.*

Eurysalenia minima Kier, n. sp.

Figure 17

Size.—Small, ranging in horizontal diameter from 5 to 10 mm, with an average of 7 mm.

Shape.—Test circular in marginal outline, low (fig. 17*B*), height slightly less than one-half horizontal diameter; depressed around peristome.

Apical system.—Large—greatest length nearly equal to one-half horizontal diameter of test; genital plate 2, largest plate (fig. 17*C*), pierced with less than 10 madreporic pores, heptagonal; genital plates 4, 1 hexagonal; plate 3, heptagonal; plate 5, pentagonal, smallest of all genital plates; ocular plates II, III, and IV exsert, V and I insert; suranal plate large, hexagonal, adjacent to genital plates 1, 2, 3, and 4, present in 5 of 24 specimens in which apical system is visible, presumably originally present in all of them; periproct half-moon shaped, adjacent to genital 5.

Ambulacra.—Straight, broad, at ambitus approximately 85 percent as broad as interambulacra; adapically, plates small primaries with primary tubercles on approximately every other plate; at ambitus and adorally, plates much larger (figs. 17*D–E*) with two plates covered by one large primary tubercle alternating with a single primary plate; pore pairs in each series.

Interambulacra.—Adapically, plates small, increasing greatly in size at ambitus; approximately two ambulacral plates to each interambulacral; 11–12 interambulacral plates in each series.

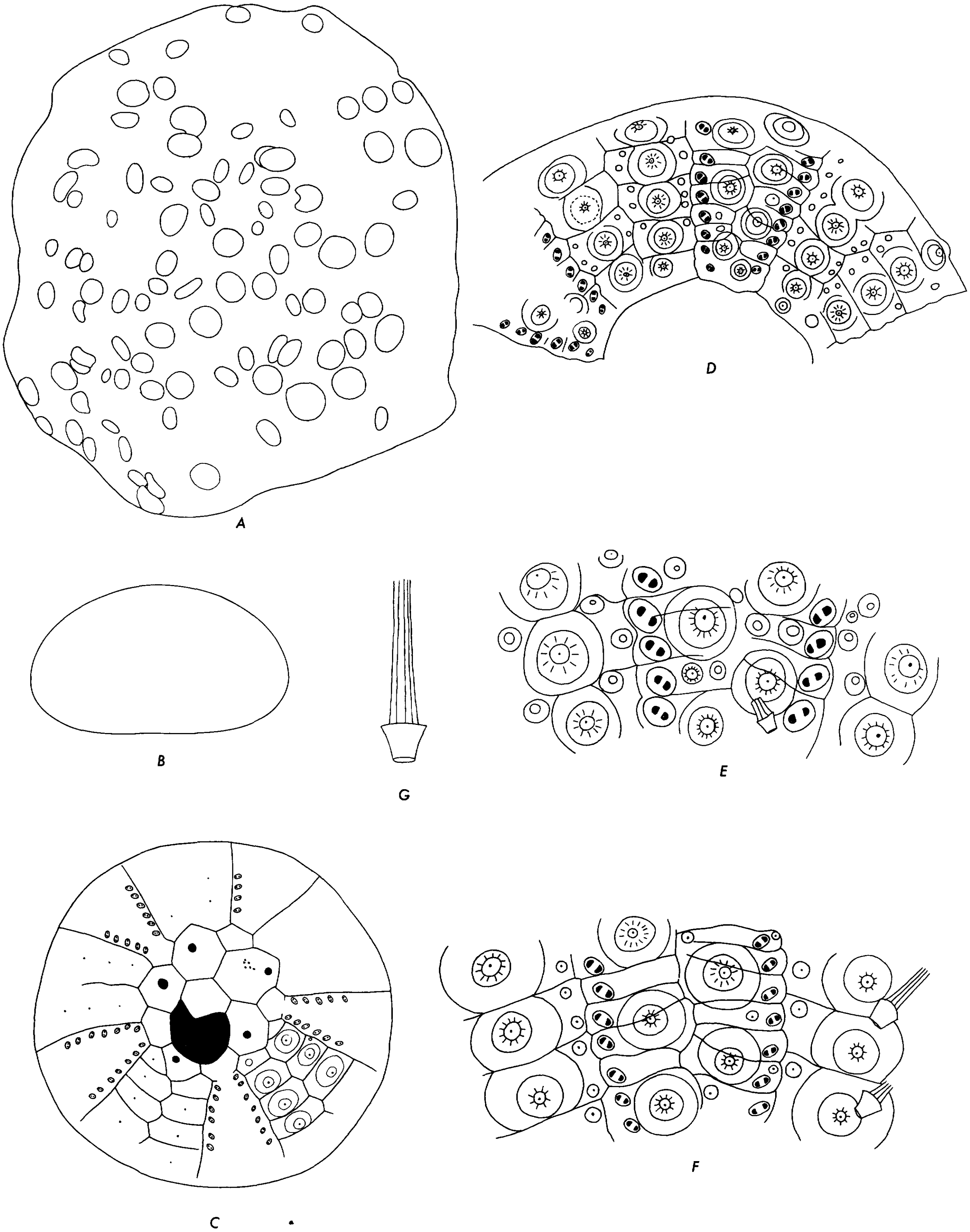


FIGURE 17.—*Eurysalenia minima* Kier, n. sp. *A*, Part of concretion showing concentration of echinoids, USNM 132609, × 1. *B*, Side view of USNM 132607, × 6.6. *C*, Apical view of USNM 132607 showing apical system, × 11. *D*, Adoral view of holotype, USNM 132616, × 14. *E*, View of area slightly adoral to ambitus of USNM 132604, × 19. *F*, View of ambitus and area slightly adoral to ambitus of USNM 132605 with most of the secondary tubercles not visible, × 19. *G*, Spine of USNM 132604, × 33.

Tuberculation.—Primary tubercles perforate, with high mamelon and deep crenulations—approximately 10 on ambital tubercle—broad boss, broad scrobicule (figs. 17*D–F*); one primary tubercle on each interambulacral plate; adapically small, scrobicules not confluent, greatly increasing in size at ambitus (fig. 17*F*), scrobicules confluent from ambitus adorally, primary tubercle on ambulacral plates as large as on interambulacral plate; adorally one on approximately every other plate, distribution irregular, at ambitus (fig. 17*F*) and adorally (fig. 17*D*) primary tubercle on two out of three plates; scrobicules not confluent; secondary tubercles perforate, perhaps crenulate (poor preservation prevents certainty on this point), four to six on each ambital and adoral interambulacral plate (fig. 17*D*), two on each simple primary ambital and adoral ambulacral plate.

Peristome.—Large, slightly more than one-third horizontal diameter of test; gill slits slightly developed.

Lantern.—No lanterns visible; teeth keeled.

Spines.—Long, one-quarter to one-third as long as horizontal diameter of test; longest spine 3 mm long; shaft slender (fig. 17*G*), slightly tapering, striations deep, 8–10 on each spine, extending to milled ring; collar slightly developed.

Occurrence.—Gray limestone concretion 222 feet below the top of the lower unnamed shale member of the Pierre Shale, 1.6 miles northeast of the Red Bird store in the SW¼SE¼ sec. 14, T. 38 N., R. 62 W., Niobrara County, Wyo. Late Campanian or early Maestrichtian.

Types.—Holotype, USNM 132606; illustrated paratypes USNM 132604, 132605, 132607, 132608, 132609.

REFERENCES CITED

Abel, Othenio, 1924, Lehrbuch der Paläozoologie: 2d ed., Jena, Gustav Fischer, 523 p.

Allan, J. A., and Sanderson, J. O. G., 1945, Geology of Red Deer and Rosebud Sheets, Alberta: Alberta Research Council Rept. 13, 116 p., 7 pls.

Ankel, W. E., 1938, Fretz-Spuren von Schnecken: Natur u. Volk, v. 68, no. 7, p. 333–337.

Arkell, W. J., Kummel, Bernhard, and Wright, C. W., 1957, Mesozoic Ammonoidea, pt. L, Mollusca 4, Cephalopoda Ammonoidea, *in* Moore, R. C., ed., Treatise on invertebrate paleontology: Lawrence, Kans., Univ. Kansas Press and Geol. Soc. America, p. L80–L437.

Barbour, E. H., 1898, The barites of Nebraska and the Badlands: Nebraska Acad. Sci. Pub. 6, p. 265–268, pls. 2–4.

Barrell, Joseph, 1917, Rhythms and the measurements of geologic time: Geol. Soc. America Bull., v. 28, p. 745–904, pls. 43–46.

Bassler, R. S., 1953, Bryozoa, pt. G *of* Moore, R. C., ed., Treatise on invertebrate paleontology: Lawrence, Kans., Univ. Kansas Press and Geol. Soc. America, 253 p.

Bathurst, R. G. C., 1958, Diagenetic fabrics in some British Dinantian limestones: Liverpool and Manchester Geol. Jour., v. 2, pt. 1, p. 11–36, pl. 1.

Bøggild, O. B., 1930, The shell structure of the molluscs: Kgl. Danske Vidensk. Selsk., Shrifter, Naturvidensk. math. Afdel., v. 9, no. 2, p. 231–326.

Branson, E. B., 1947, Correction of the horizon of *Pentagonaster browni* Weller: Jour. Paleontology, v. 21, no. 6, p. 590–591.

Brown, W. H., Fyfe, W. S., and Turner, F. J., 1962, Aragonite in California glaucophane schists, and the kinetics of the aragonite-calcite transformation: Jour. Petrology, v. 3, pt. 3, p. 566–582.

Butler, E. A., and Cheetham, Alan, 1958, Cretaceous cheilostome Bryozoa in the Gulf Coast: [abs.] Gulf Coast Assoc. Geol. Socs. Trans., v. 8, p. 127.

Casey, Raymond, 1961, The stratigraphical palaeontology of the Lower Greensand: Palaeontology, v. 3, pt. 4, p. 487–621, pls. 77–84.

——— 1964, the Ammonoidea of the Lower Greensand, pt. V: Palaeontographical Soc. Mon., p. 289–398, pls. 43–66.

Cayeux, M. L., 1916, Introduction à l'étude pétrographique des roches sédimentaires: Paris, Imprimerie Nationale, Service carte géol. de la France Mem., 524 p., and Atlas, 56 pl.

Clark, D. L., 1959, Texas Cretaceous ophiuroids: Jour. Paleontology, v. 33, no. 6, p. 1126–1127.

Cloud, P. E., Jr., 1962, Environment of calcium carbonate deposition west of Andros Island, Bahamas: U.S. Geol. Survey Prof. Paper 350, 138 p., 10 pls.

Cobban, W. A., 1951a, New species of *Baculites* from the Upper Cretaceous of Montana and South Dakota: Jour. Paleontology, v. 25, no. 6, p. 817–821, pl. 118.

——— 1951b, Colorado shale of central and northwestern Montana and equivalent rocks of Black Hills: Am. Assoc. Petroleum Geologists Bull., v. 35, no. 10, p. 2170–2198.

——— 1958, Two new species of *Baculites* from the western interior region: Jour. Paleontology, v. 32, no. 4, p. 660–665, pls. 90–91.

——— 1962a, Baculites from the lower part of the Pierre Shale and equivalent rocks in the Western Interior: Jour. Paleontology, v. 36, no. 4, p. 704–718, pls. 105–108.

——— 1962b, New baculites from the Bearpaw Shale and equivalent rocks of the Western Interior: Jour. Paleontology, v. 36, no. 1, p. 126–135, pls. 25–28.

——— 1964, The Late Cretaceous cephalopod *Haresiceras* Reeside and its possible origin: U.S. Geol. Survey Prof. Paper 454–I, p. I1–I21, pls. 1–4.

Coe, W. R., 1932, Season of attachment and rate of growth of sedentary marine organisms at the pier of the Scripps Institution of Oceanography, La Jolla, California: Scripps Inst. Oceanography Bull., Tech. ser., v. 3, no. 3, p. 37–86, pls. 1–6.

Coleman, R. G., and Lee, D. E., 1962, Metamorphic aragonite in the glaucophane schists of Cazadero, California: Am. Jour. Sci., v. 260, p. 577–595.

Connor, J. J., 1963, Geology of the Angostura Reservoir quadrangle, Fall River County, South Dakota: U.S. Geol. Survey Bull. 1063–D, p. 85–126, pl. 11.

Cornish, Vaughn, and Kendall, P. F., 1888, On the mineralogical constitution of calcareous organisms: Geol. Mag., v. 5, no. 2, p. 66–73.

Cory, R. L., 1964, Environmental factors affecting attached macroorganisms, Patuxent River estuary, Maryland, *in* Short papers in geology and hydrology: U.S. Geol. Survey Prof. Paper 475–D, p. D194–D197.

Cotteau, G. A., 1859, Échinides nouveaux ou peu connus: Rev. Mag. Zool., ser. 2, v. 11, no. 5, p. 212–220, pl. 8.

Craig, G. Y., 1952, A comparative study of the ecology and palaeoecology of *Lingula:* Edinburgh Geol. Soc. Trans., v. 15, p. 110–120, pl. 4.

Cullison, J. S., 1938, Origin of composite and incomplete internal moulds and their possible use as criteria of structure: Geol. Soc. America Bull., v. 49, no. 6, p. 981–988, pl. 1.

Darton, N. H., 1901, Preliminary description of the geology and water resources of the southern half of the Black Hills and adjoining regions in South Dakota and Wyoming: U.S. Geol. Survey 21st Ann. Rept., pt. 4, p. 489–599, pls. 58–112.

——— 1902, Description of the Oelrichs quadrangle [South Dakota-Nebraska]: U.S. Geol. Survey Geol. Atlas, Folio 85, 6 p.

——— 1918, The structure of parts of the central Great Plains: U.S. Geol. Survey Bull. 691–A, p. 1–26, pls. 1–4.

Dobbin, C. E., Kramer, W. B., and Horn, G. H., 1957, Geologic and structure contour map of the southeastern part of the Powder River Basin, Wyoming: U.S. Geol. Survey Oil and Gas Inv. Map OM–185.

Dobbin, C. E., and Reeside, J. B., Jr., 1929, The contact of the Fox Hills and Lance formations: U.S. Geol. Survey Prof. Paper 158–B, p. 9–25, pls. 4, 5.

Dorf, Erling, 1942, Flora of the Lance formation at its type locality, Niobrara County, Wyoming, pt. 2 *of* Upper Cretaceous floras of the Rocky Mountain region: Carnegie Inst. Washington Pub. 508, p. 70–159, pls. 1–17.

Dunbar, C. O., 1928, On an ammonite shell investing commensal Bryozoa: Am. Jour. Sci., 5th ser., v. 16, no. 92, p. 165–166.

Elias, M. K., 1931, The geology of Wallace County, Kansas: Kansas Geol. Survey Bull. 18, 254 p., 42 pls.

——— 1933, Cephalopods of the Pierre formation of Wallace County, Kansas, and adjacent area: Kansas Univ. Sci. Bull., v. 21, no. 9, p. 289–363, pls. 28–42.

Evernden, J. F., Curtis, G. H., Obradovich, J., and Kistler, R., 1961, On the evaluation of glauconite and illite for dating sedimentary rocks by the potassium-argon method: Geochim. et Cosmochim. Acta, v. 23, p. 78–99.

Fisher, S. P., 1952, The geology of Emmons County, North Dakota: North Dakota Geol. Survey Bull. 26, 47 p., 6 pls.

Folinsbee, R. E., Baadsgaard, Halfdan, and Cumming, G. L., 1963, Dating of volcanic ash beds (bentonites) by the K-Ar method: *in* Natl. Acad. Sci.-Natl. Research Council Pub. 1075, p. 70–82.

Folinsbee, R. E., Baadsgaard, Halfdan, and Lipson, J., 1961, Potassium-argon dates of Upper Cretaceous ash falls, Alberta, Canada, *in* Kulp, J. L., ed., Geochronology of rock systems: New York Acad. Sci. Annals, v. 91, art. 2, p. 352–363.

Gilbert, G. K., 1897, Description of the Pueblo Folio: U.S. Geol. Survey Geol. Atlas, Folio 36, 7 p., maps.

Gill, J. R., and Cobban, W. A., 1961, Stratigraphy of lower and middle parts of the Pierre shale, northern Great Plains, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–D, p. D185–D191.

——— 1962, Red Bird Silty Member of the Pierre Shale, a new stratigraphic unit, *in* Short papers in geology, hydrology, and topography: U.S. Geol. Survey Prof. Paper 450–B, p. B21–B24.

——— 1966, Regional unconformity in Late Cretaceous, Wyoming, *in* Geological Survey research 1966: U.S. Geol. Survey Prof. Paper 550–B, p. B20–B27.

Gregory, J. W., 1900, Echinoidea, *in* The Echinoderma, pt. 3 *of* Lankester, E. Ray, ed., A treatise on zoology: London, A. and C. Black.

Griffitts, M. O., 1949, Zones of Pierre formation of Colorado: Am. Assoc. Petroleum Geologists Bull., v. 33, no. 12, p. 2011–2028.

Haas, Otto, 1943, The Vernay collection of Cretaceous (Albian) ammonites from Angola: Am. Mus. Nat. History Bull., v. 81, p. 1–224, pls. 1–47.

——— 1960, Lower Cretaceous ammonites from Colombia, South America: Am. Mus. Novitates 2005, 62 p.

Hall, James, and Meek, F. B., 1855, Descriptions of the new species of fossils, from the Cretaceous formations of Nebraska, with observations upon *Baculites ovatus* and *B. compressus,* and the progressive development of the septa in Baculites, Ammonites, and Scaphites: Am. Acad. Arts and Sci. Mem., n. ser., v. 5, pt. 2, p. 379–411, pls. 1–8 [1856].

Hamada, Takashi, 1964, Notes on the drifted *Nautilus* in Thailand, *in* Contributions to the geology and palaeontology of Southeast Asia, XXI: Tokyo Univ. Sci. Papers Coll. Gen. Education, v. 14, no. 2, p. 255–278, pls. 1–5.

Hamilton, E. L., 1961, Stratigraphy of the deep sea floor, *in* Sears, Mary, ed., Oceanography: Am. Assoc. Advancement Sci. Pub. 67, p. 51–84.

Hancock, E. T., 1920, The Lance Creek oil and gas field, Niobrara County, Wyoming: U.S. Geol. Survey Bull. 716–E, p. 91–122, pls. 10–13.

Horton, M. D., 1953, Stratigraphy and structure of the Old Woman anticline, Niobrara County, Wyo.: Univ. of Nebraska, M.S. thesis.

Howell, B. F., 1943, *Hamulus*, *"Falcula"*, and other Cretaceous Tubicola of New Jersey: Philadelphia Acad. Nat. Sci. Proc., v. 95, p. 139–166, pls. 19, 20.

Hyman, L. H., 1955, The invertebrates, v. 4, Echinodermata, the coelomate Bilateria: New York, McGraw-Hill Book Co., 763 p., 280 figs.

Jefferies, R. P. S., 1962, The palaeoecology of the *Actinocamax plenus* Subzone (lowest Turonian) in the Anglo-Paris Basin: Paleontology, v. 4, pt. 4, p. 609–647, pls. 77–79.

Jeletzky, J. A., 1962, The allegedly Danian dinosaur-bearing rocks of the globe and the problem of the Mesozoic-Cenozoic boundary: Jour. Paleontology, v. 36, no. 5, p. 1005–1018, pl. 141.

Kepferle, R. C., 1959, Uranium in Sharon Springs member of Pierre shale, South Dakota and northeastern Nebraska: U.S. Geol. Survey Bull. 1046–R, p. 577–604, pls. 50–53.

Kobayashi, Teiichi, and Kamada, Yasuhiko, 1959, Bio-, thanato- and fossil-history of *Eutrephoceras japonicum:* Japanese Jour. Geology and Geography, v. 30, p. 115–125, pl. 10.

Kramer, W. B., Dobbin, C. E., and McMillan, Robert, 1943, Geologic map and sections of Lance Creek oil and gas field and vicinity, Niobrara County, Wyoming: U.S. Geol. Survey General Mineral Resource Map.

Krumbein, W. C., and Garrels, R. M., 1952, Origin and classification of chemical sediments in terms of pH and oxidation-reduction potentials: Jour. Geology, v. 60, no. 1, p. 1–33.

Kulp, J. L., 1961, Geologic time scale: Science, v. 133, no. 3459, p. 1105–1114.

Laird, W. M., and Mitchell, R. H., 1942, The geology of the southern part of Morton County, North Dakota: North Dakota Geol. Survey Bull. 14, 42 p., 3 pls.

Landes, R. W., 1940, Palaeontology of the marine formations of the Montana group, pt. 2 *of* Geology of the southern Alberta plains: Canada Geol. Survey Mem. 221, p. 129–223, pls. 1–8.

Landis, E. R., 1959, Radioactivity and uranium content, Sharon Springs member of the Pierre shale, Kansas and Colorado: U.S. Geol. Survey Bull. 1046–L, p. 299–319, pls. 35–38.

Lee, D. E., Thomas, H. H., Marvin, R. F., and Coleman, R. G., 1964, Isotopic ages of glaucophane schists from the area of Cazadero, California, *in* Short papers in geology and hydrology: U.S. Geol. Survey Prof. Paper 475–D, p. D105–D107.

Link, T. A., and Childerhose, A. J., 1931, Bearpaw shale and contiguous formations in Lethbridge area, Alberta: Am. Assoc. Petroleum Geologists Bull., v. 15, no. 10, p. 1227–1242.

Loomis, F. B., 1915, A new mosasaur from the Ft. Pierre: Am. Jour. Sci., 4th ser., v. 39, no. 233, p. 555–566.

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

Manz, O. E., 1962, Investigation of pozzolanic properties of the Cretaceous volcanic ash deposit near Linton, North Dakota: North Dakota Geol. Survey Rept. Inv. 38, 42 p.

Mayer, F. K., 1932, Uber die Modifikation des Kalziumkarbonates in Schalem und Skeletten rezenter und fossiler Organismen: Chemie der Erde, v. 7, p. 346–350.

Meek, F. B., 1876, Invertebrate Cretaceous and Tertiary fossils of the upper Missouri country: U.S. Geol. Survey Terr. Rept., v. 9, 629 p., 45 pls.

Meek, F. B., and Hayden, F. V., 1856, Descriptions of new species of Gastropoda and Cephalopoda from the Cretaceous formations of Nebraska Territory: Philadelphia Acad. Nat. Sci. Proc., v. 8, p. 70–72.

——— 1857, Descriptions of new species and genera of fossils, collected by Dr. F. V. Hayden in Nebraska Territory, * * * with some remarks on the Tertiary and Cretaceous formations of the North-west, and the parallelism of the latter with those of other portions of the United States and Territories: Philadelphia Acad. Nat. Sci. Proc., v. 9, p. 117–148.

——— 1861, Descriptions of new Lower Silurian (Primordial), Jurassic, Cretaceous, and Tertiary fossils, collected in Nebraska, Territory * * * with some remarks on the rocks from which they were obtained: Philadelphia Acad. Nat. Sci. Proc., v. 13, p. 415–447.

Meigen, Wilhelm, 1903, Beiträge zur Kenntnis des kohlensauren Kalkes: Naturf. Gesell. Freiburg Ber., v. 13, p. 40–94.

Mickelson, J. C., 1963, Possible fossil gall from the Pierre Formation: South Dakota Acad. Sci. Proc., v. 42, p. 73–75.

Miller, A. K., and Youngquist, W. L., 1949, The Maquoketa coquina of cephalopods [Iowa]: Jour. Paleontology, v. 23, no. 2, p. 199–204, pls. 40–42.

Moore, H. B., 1939, Faecal pellets in relation to marine deposits, *in* Recent marine sediments—a symposium: Am. Assoc. Petroleum Geologists, p. 516–524.

Moxon, A. L., Olson, O. E., and Searight, W. V., 1939, Selenium in rocks, soils, and plants: South Dakota Agr. Expt. Sta. Tech. Bull. 2, 94 p.

Nascimbene, G. G., 1963, Bentonites and the geochronology of the Bearpaw sea: Univ. of Alberta M. S. thesis, 78 p., 3 pls.

Newton, Henry, 1880, Observations on the routes to and from the Black Hills, chap. 2 *of* Newton, Henry, and Jenney, W. P., Report on the geology and resources of the Black Hills of South Dakota: U.S. Geog. and Geol. Survey Rocky Mtn. Region (Powell), p. 22–38.

Osburn, R. C., 1954, The Bryozoa of the Gulf of Mexico, *in* Gulf of Mexico, its origin, water, and marine life: Fish and Wildlife Service Fishery Bull. 89, p. 361–362.

Osburn, R. C., 1957, Marine Bryozoa, *in* Hedgpeth, J. W., ed., Ecology, v. 1 *of* Treatise on marine ecology and paleoecology: Geol. Soc. America Mem. 67, p. 1109–1112.

Ower, J. R., 1958, The Edmonton Formation: Edmonton Geol. Soc. Quart., v. 2, no. 1, p. 3–11.

Rasmussen, H. W., 1950, Cretaceous Asteroidea and Ophiuroidea with special reference to the species found in Denmark: Danmarks Geol. Undersøgelse, ser. 2, no. 77, 134 p., 18 pls.

Rathbun, M. J., 1917, New species of South Dakota Cretaceous crabs: U.S. Natl. Mus. Proc., v. 52, no. 2182, p. 385–391, pls. 32, 33.

Reeside, J. B., Jr., 1927, The cephalopods of the Eagle sandstone and related formations in the Western Interior of the United States: U.S. Geol. Survey Prof. Paper 151, 87 p., 45 pls.

——— 1957, Paleoecology of the Cretaceous seas of the Western Interior of the United States, chap. 18 *in* Ladd, H. S., ed., Paleoecology, v. 2 *of* Treatise on marine ecology and paleoecology: Geol. Soc. America Mem. 67, p. 505–542.

Regenhardt, Horst, 1961, Serpulidae (Polychaeta sedentaria) aus der Kreide Mitteleuropas, ihre ökologische, taxionomische und stratigraphische Bewertung: Hamburg geol. Staatsinst. Mitt., no 30, p. 5–115, pls. 1–9.

Revelle, Roger, and Fairbridge, Rhodes, 1957, Carbonates and carbon dioxide, chap. 10 *in* Hedgpeth, J. W., ed., Ecology, v. 1 *of* Treatise on marine ecology and paleoecology: Geol. Soc. America Mem. 67, p. 239–295.

Reyment, R. A., 1956, Über den Bau von *Speetoniceras versicolor* (Trautschold) aus dem Neokom Russlands: Neues Jahrb. Geologie u. Paläontologie Monatsh., no. 2, p. 101–105.

——— 1957, Über Farbspuren bei einigen Ammoniten: Neues Jahrb. Geologie u. Paläontologie Monatsh., nos. 7/8, p. 343–351.

——— 1958, Some factors in the distribution of fossil cephalopods: Stockholm Contr. Geology, v. 1, p. 97–184, 7 pls.

Reyment, R. A., and Eckstrand, O. R., 1957, X-ray determinations of some cephalopod shells: Stockholm Contr. Geology, v. 1, p. 91–96.

Reynolds, M. W., 1966, Stratigraphic relations of Upper Cretaceous rocks in the Lamont-Bairoil area, south-central Wyoming, *in* Geological Survey research 1966: U.S. Geol. Survey Prof. Paper 550–B, p. B69–B76.

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

Richter, Rudolf, 1941, Fährten als Zeugnisse des Lebens auf dem Meeres-Grunde: Senckenbergiana, v. 23, p. 218–260.

Ritchie, W. D., 1958, Age dating of Kneehills tuff [Alberta] [abs.]: Edmonton Geol. Soc. Quart., v. 2, no. 3, p. 1.

——— 1960, The Kneehills tuff: Alberta Soc. Petroleum Geologists Jour., v. 8, no. 11, p. 339–341.

Robinson, C. S., Mapel, W. J., and Bergendahl, M. H., 1964, Stratigraphy and structure of the northern and western flanks of the Black Hills uplift, Wyoming, Montana, and South Dakota: U.S. Geol. Survey Prof. Paper 404, 134 p.

Robinson, C. S., Mapel, W. J., and Cobban, W. A., 1959, Pierre shale along western and northern flanks of Black Hills, Wyoming and Montana: Am. Assoc. Petroleum Geologists Bull., v. 43, no. 1, p. 101–123.

Rothrock, E. P., 1947, Geology of the Missouri Valley and vicinity near Mobridge [South Dakota]: South Dakota Geol. Survey Rept. Inv. 58, 29 p.

Rubey, W. W., 1930, Lithologic studies of fine-grained Upper Cretaceous sedimentary rocks of the Black Hills region: U.S. Geol. Survey Prof. Paper 165–A, p. 1–54, pls. 1–5.

Russell, L. S., 1932, Stratigraphy and structure of the eastern portion of the Blood Indian Reserve, Alberta: Canada Geol. Survey Summ. Rept., 1931, pt. B, p. 26B–38B.

Sanderson, J. O. G., 1931, Upper Cretaceous volcanic ash beds in Alberta: Royal Soc. Canada Trans., ser. 3, v. 25, sec. 4, p. 61–70, pl. 1.

Schlüter, Clemens, 1876, Cephalopoden der oberen deutschen Kreide: Palaeontographica, v. 24, p. 121–264, pls. 36–55.

Schuchert, Charles, 1910, Paleogeography of North America: Geol. Soc. America Bull., v. 20, no. 2, p. 427–606, pls. 46–101.

Schwarz, Albert, 1932, Der tierische Einfluss auf die Meeressedimente: Senckenbergischen naturf. Gesell. Senckenberg-Buch, v. 14, no. 3, p. 118–172.

Scott, G. R., and Cobban, W. A., 1959, So-called Hygiene Group of northeastern Colorado, *in* Rocky Mtn. Assoc. Geologists Guidebook 11th Ann. Field Conf., Washakie, Sand Wash, and Piceance Basins, 1959: p. 124–131.

——— 1963, Apache Creek Sandstone Member of the Pierre Shale of southeastern Colorado, *in* Short papers in geology and hydrology: U.S. Geol. Survey Prof. Paper 475–B, p. B99–B101.

——— 1964, Stratigraphy of the Niobrara Formation at Pueblo, Colorado: U.S. Geol. Survey Prof. Paper 454–L, p. L1–L30, pls. 1–10.

Searight, M. V., 1937, Lithologic stratigraphy of the Pierre formation of the Missouri Valley in South Dakota: South Dakota Geol. Survey Rept. Inv. 27, 63 p., 8 pls.

——— 1938, The microfauna of the Sully member of the Pierre: Iowa Acad. Sci. Proc., v. 45, p. 135–137.

Seitz, Otto, 1953, Die Oberkreide-Gliederung in Deutschland nach ihrer Anpassung an das internationale Schema: Deutsche geol. Gesell. Zeitschr., v. 104, p. 148–151.

——— 1956, Über Ontogenie, Variabilität, und Biostratigraphie einiger Inoceramen: Paläont. Zeitschr., v. 30, p. 3–6.

——— 1959, Vergleichende Stratigraphie der Oberkreide in Deutschland und in Nordamerika mit Hilfe der Inoceramen: Internat. Geol. Cong., 20th, Mexico City 1956, El Sistema Cretacio symposium, v. 1, p. 113–129.

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

Sloss, L. L., 1958, Paleontologic and lithologic associations: Jour. Paleontology, v. 32, no. 4, p. 715–729.

Sorby, H. C., 1879, The anniversary address of the President: Geol. Soc. London Quart. Jour., v. 35, p. 39–95.

Spivey, R. C., 1940, Bentonite in southwestern South Dakota: South Dakota Geol. Survey Rept. Inv. 36, 56 p., 7 pls.

Stanton, T. W., 1910, Fox Hills sandstone and Lance formation ("Ceratops beds") in South Dakota, North Dakota, and eastern Wyoming: Am. Jour. Sci., 4th ser., v. 30, no. 177, p. 172–188.

——— 1917, A Cretaceous volcanic ash bed on the Great Plains in North Dakota: Washington Acad. Sci. Jour., v. 7, no. 3, p. 80–81.

——— 1925, The fossil content [of well log in northern Ziebach County]: South Dakota Geol. and Nat. History Survey Circ. 18, p. 8–14.

Stehli, F. G., 1956, Shell mineralogy in Paleozoic invertebrates: Science, v. 123, p. 1031–1032.

Stephenson, L. W., 1916, North American Upper Cretaceous corals of the genus *Micrabacia:* U.S. Geol. Survey Prof. Paper 98–J, p. 115–131, pls. 20–23.

——— 1936, Geology and paleontology of the Georges Bank canyons; pt. 2, Upper Cretaceous fossils from Georges Bank (including species from Banquereau, Nova Scotia): Geol. Soc. America Bull., v. 47, no. 3, p. 367–410, 5 pls.

Stephenson, L. W., 1941, The larger invertebrate fossils of the Navarro group of Texas: Texas Univ. Bull. 4101, 641 p., 95 pls.

——— 1952, Larger invertebrate fossils of the Woodbine Formation (Cenomanian) of Texas: U.S. Geol. Survey Prof. Paper 242, p. 1–211, pls. 1–58 [1953].

——— 1954, Additions to the fauna of the Raritan formation (Cenomanian) of New Jersey: U.S. Geol. Survey Prof. Paper 264–B, p. 25–43, pls. 6–8.

Switzer, George, and Boucot, A. J., 1955, The mineral composition of some microfossils: Jour. Paleontology, v. 29, no. 3, p. 525–533.

Teichert, Curt, 1939, Geology of Greenland, *in* Ruedemann, Rudolf, and Balk, Robert, eds., Geology of North America, v. 1 *of* Krenkel, Erich, ed., Geologie der Erde: Berlin, Gebrüder Borntraeger, p. 100–175, 1 pl.

Tennent, D. H., 1910, Variation in echinoid plutei: Jour. Exp. Zoology, v. 9, p. 657–714, 24 figs.

Thomas, H. D., and Larwood, G. P., 1960, The Cretaceous species of *Pyripora* d'Orbigny and *Rhammatopora* Lang: Palaeontology, v. 3, pt. 3, p. 370–386, pls. 60–62.

Toots, Heinrich, and Cutler, J. F., 1962, Bryozoa from the "Mesaverde" Formation (Upper Cretaceous) of southeastern Wyoming: Jour. Paleontology, v. 36, no. 1, p. 81–86, pl. 18.

Tourtelot, H. A., 1956, Radioactivity and uranium of Cretaceous shales, Central Great Plains: Am. Assoc. Petroleum Geologists Bull., v. 40, no. 1, p. 62–83.

——— 1962, Preliminary investigation of the geologic setting and chemical composition of the Pierre shale, Great Plains region: U.S. Geol. Survey Prof. Paper 390, 74 p., 4 pls.

Tourtelot, H. A., and Schultz, L. G., 1961, Core from the Irish Creek well, Ziebach County, South Dakota: U.S. Geol. Survey open-file report, 20 p., 2 figs.

Tozer, E. T., 1960, Summary account of Mesozoic and Tertiary stratigraphy, Canadian Archipelago: Canada Geol. Survey Paper 60–5, 24 p.

Tozer, E. T., and Thorsteinsson, R., 1964, Western Queen Elizabeth Islands, Arctic Archipelago: Canada Geol. Survey Mem. 332, 242 p., 55 pls.

Turekian, K. K., and Armstrong, R. L., 1961, Chemical and mineralogical composition of fossil molluscan shells from the Fox Hills formation, South Dakota: Geol. Soc. America Bull., v. 72, p. 1817–1828.

Ulrich, E. O., 1904, Fossils and age of the Yakutat formation [Alaska]: Harriman Alaska Exped., v. 4, p. 125–146, pls. 11–21.

Wade, Bruce, 1926, The fauna of the Ripley formation on Coon Creek, Tennessee: U.S. Geol. Survey Prof. Paper 137, 272 p., 72 pls.

Weaver, C. E., 1931, Paleontology of the Jurassic and Cretaceous of west central Argentina: Washington Univ. Mem., v. 1, 594 p., 62 pls.

Weller, J. M., 1960, Stratigraphic principles and practice: New York, Harper & Bros., 725 p.

Weller, Stuart, 1905, A fossil starfish from the Cretaceous of Wyoming: Jour. Geology, v. 13, no. 3, p. 257–258.

Wetzel, W., 1930, Die Quiriquina-Schichten als Sediment und paläontologisches Archiv: Palaeontographica, v. 73, p. 49–106, pls. 9–14.

Wherry, E. T., 1917, Clay derived from volcanic dust in the Pierre in South Dakota: Washington Acad. Sci. Jour., v. 7, no. 19, p. 576–583.

Whitfield, R. P., 1877, Preliminary report on the paleontology of the Black Hills, containing descriptions of new species of fossils from the Potsdam, Jurassic, and Cretaceous formations of the Black Hills of Dakota: U.S. Geog. and Geol. Survey Rocky Mtn. Region (Powell), 49 p.

——— 1880, Paleontology of the Black Hills of Dakota, chap. 6 *of* Newton, Henry, and Jenney, W. P., Report on the geology and resources of the Black Hills of Dakota: U.S. Geog. and Geol. Survey Rocky Mtn. Region (Powell) p. 325–468, pls. 1–16.

——— 1901, Note on a very fine example of *Helicoceras stevensoni* preserving the outer chamber: Am. Mus. Nat. History Bull., v. 14, art. 16, p. 219, pls. 29, 30.

Whitfield, R. P., 1902, Observations on and emended description of *Heteroceras simplicostatum* Whitfield: Am. Mus. Nat. History Bull., v. 16, art. 5, p. 67–72, pls. 23–27.

Wray, J. L., and Daniels, Farrington, 1957, Precipitation of calcite and aragonite: Am. Chem. Soc. Jour., v. 79, no. 9, p. 2031–2034.

Wright, C. W., 1935, The Chalk Rock fauna in East Yorkshire: Geol. Mag. [Great Britain], v. 72, no. 10, p. 441–442.

Zapp, A. D., and Cobban, W. A., 1962, Some Late Cretaceous strand lines in southern Wyoming, *in* Short papers in geology, hydrology, and topography: U.S. Geol. Survey Prof. Paper 450–D, p. D52–D55.

Ziegler, Victor, 1914, The minerals of the Black Hills: South Dakota School Mines Bull. 10, 250 p., 31 pls.

INDEX

[Italic page numbers indicate major references]

PLATES 5–12

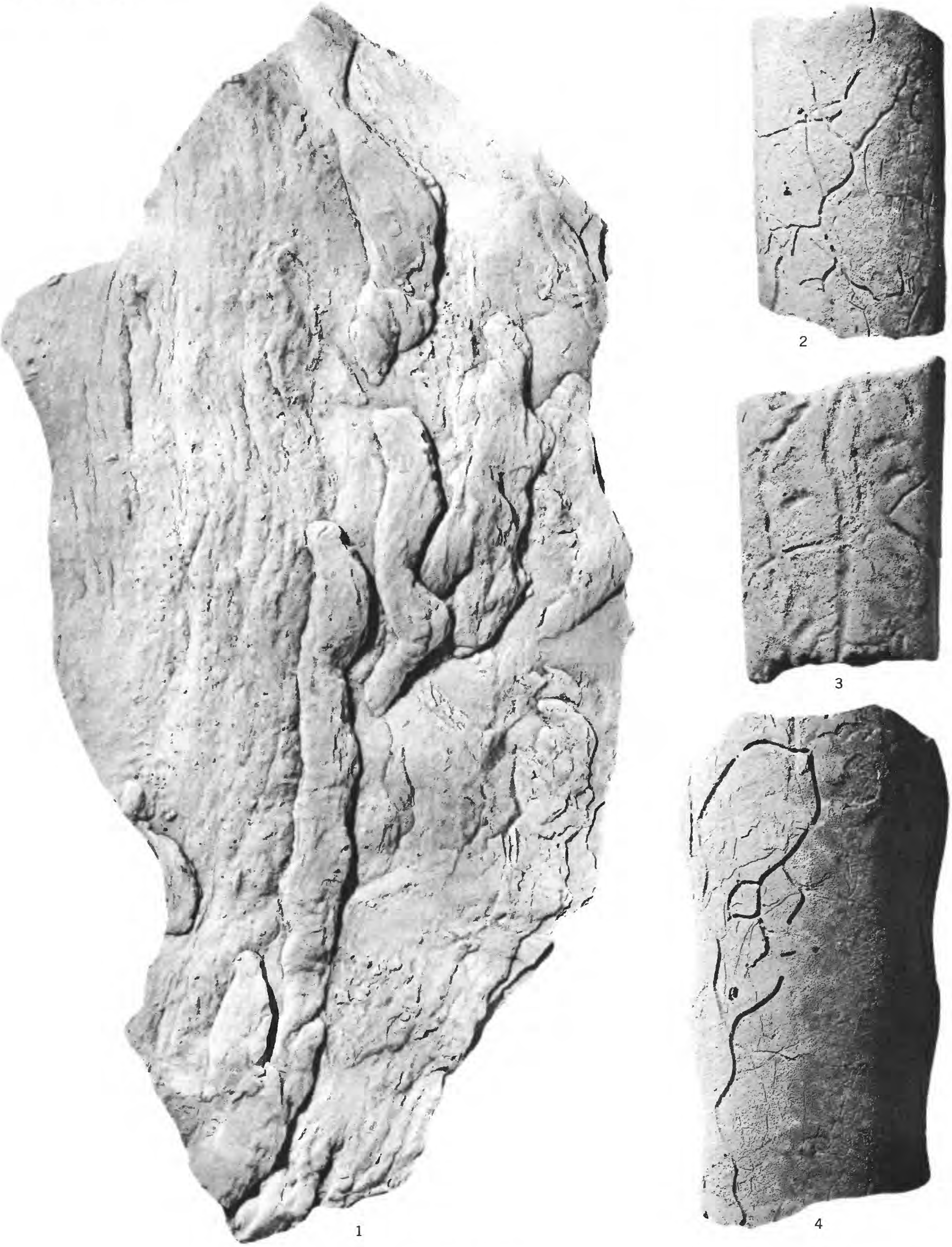
PLATE 5

[All figures natural size except as otherwise indicated]

FIGURE 1. Castings(?), × ¾, of some unidentified organism on a thin slab of siltstone from unit 24 (p. A26). For a view of the opposite side, see plate 6. USNM 145061.

2–4. Various burrows in the sediment filling the living chambers of baculites (p. A26).

2. Lateral view of an internal mold of *Baculites perplexus* from unit 29 (D1866). USNM 145062.
3. Lateral view of an internal mold of *Baculites reesidei* from unit 72 (D1951). USNM 145063.
4. Dorsal view of an internal mold of *Baculites grandis* from unit 102 (D2120). USNM 145064.



TRACE FOSSILS

PLATE 6

[All figures natural size except as otherwise indicated]

FIGURE 1. Trails, × ¾, probably of a worm, on a thin layer of siltstone from unit 24 (p. A26). For a view of the reverse side of this slab, see plate 5. USNM 145061.

2. Burrows of unidentified organisms. Inasmuch as the burrows are more resistant than the matrix of the internal mold of the living chamber of *Baculites perplexus*, they weather out in relief (p. A26). From unit 28 (D1864). USNM 145065.

3. Burrows of unidentified organisms on the flank of an internal mold (uncoated) of a living chamber of *Baculites perplexus* from unit 29 (D1872). The burrows are flush with the surface of the mold and stand out by difference in color (p. A26). USNM 145066.

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TRACE FOSSILS

PLATE 7

[All figures natural size except as otherwise indicated]

FIGURE 1. Burrows of unidentified organisms on the flank of an internal mold (uncoated) of the living chamber of *Baculites gilberti* from unit 33 (D1639) (p. A27). USNM 145067.

2. Very small rod-shaped fecal pellets, × 2, in the older part of an internal mold (uncoated) of the living chamber of *Baculites gilberti* from unit 29 (D1874) (p. A27). USNM 145068.

3. Very small irregularly shaped fecal pellets, × 2, at the base of an internal mold (uncoated) of the living chamber of *Baculites reesidei* from unit 75 (D1952) (p. A27). USNM 145069.

4–6. Lateral, dorsal, and end views of an internal mold of part of the living chamber of *Baculites perplexus* from unit 28 (D1865). The mold is half filled with large ovoid fecal pellets (p. A27). USNM 145070.

7. Lateral view, × 2, of the last two air chambers and the basal part of the living chamber of a scaphite from unit 61 (D2913) (p. A39). The roughened surface of the interior of the living chamber is due to dissolution; in contrast, the unaffected surface of the air chambers is smooth. USNM 145071.

8. Ovoid fecal pellets in a living chamber of a small *Baculites grandis* from unit 96 (D2118) (p. A27). USNM 145072.

9. Lateral view, × 2, of a small part of an internal mold of *Baculites reesidei* from unit 72 (D1951), showing almost total destruction of a septum by dissolution, and subsequent filling of the air chambers with small ovoid fecal pellets (p. A40). USNM 145073.

TRACE FOSSILS

PLATE 8

[All figures natural size except as otherwise indicated]

FIGURES 1, 7. Dissolution of the interior of internal molds of living chambers of baculites as revealed by calcareous worm tubes and traces of other organisms (p. A23, 40). The depth of these fossil traces below the surface of the internal molds represents the amount of dissolution during the life span of the organisms.

1. Worm tube and attachment bases (represented by small pits) on the surface of the flank of an internal mold of *Baculites gregoryensis* from unit 48 (D1911). USNM 145074.

7. Two worm tubes and pyriporoid bryozoans, × 2, on part of the flank of an internal mold of the living chamber of *Baculites cuneatus*, from the Bearpaw Shale at USGS Mesozoic locality D933 in sec. 12, T. 5 N., R. 22 E., Golden Valley County, Mont. The flat attachment area of the left tube is 0.115 mm below the surface of the baculite mold at the bottom of the photograph, 0.070 mm in the middle of the photograph, and 0.025 mm at the top. The attachment areas of the bryozoans, although deeply shadowed, are shallower (and hence younger) than the worm tube on the right. USNM 145079.

2, 3. Pyriporoid bryozoans on the internal mold of an inoceramid from unit 48 (D1911) (p. A24). USNM 145075.

2. Left valve, showing bryozoans over the entire surface.

3. Part of the surface, × 2.

4. Pyriporoid bryozoans on the flank of an internal mold of the living chamber of a small adult of *Baculites perplexus* from unit 36 (D2912) (p. A24). USNM 145076.

5. Dissolution features shown on the flank of an internal mold of *Baculites reesidei* from unit 75 (D1952), × 2 (p. A40). USNM 145077.

6. Relief caused by scratches and small pits made by unidentified organisms on the interior surface of the living chamber of *Baculites reesidei* from unit 72 (D1951), × 2 (p. A27). These features now stand out on the internal mold. USNM 145078.

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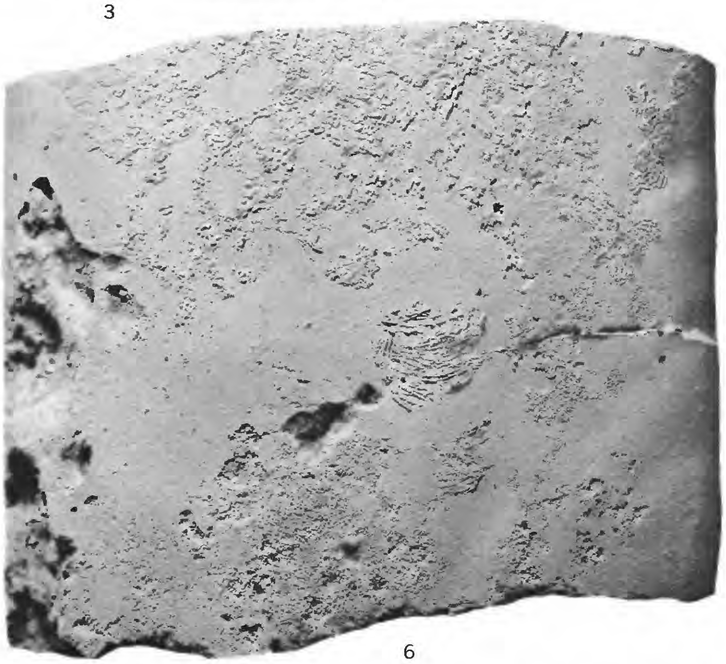

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DISSOLUTION FEATURES AND TRACE FOSSILS

PLATE 9

[All figures natural size except as otherwise indicated]

FIGURES 1–7. Dissolution of the interior surface of baculites revealed chiefly by pyriporoid bryozoans (p. A24, 39, 40). The attachment areas of the bryozoans now appear as teardrop-shaped pits on the internal molds of the baculites. The depth of the pits represents the amount of dissolution of the surrounding baculite shell during the life span of the bryozoan colony. Note how the depth of the pits of the central older part of the colonies tends to be greater than that of the younger extremities.

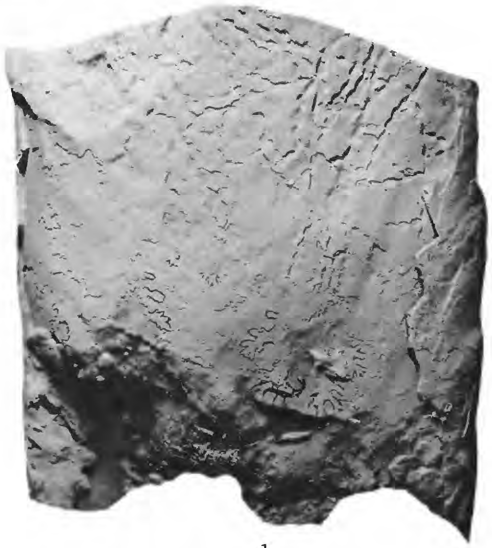
1. Lateral view, × 2, of *Baculites gilberti* from unit 29 (D1874) showing dissolution of much of the last septum, and later(?) growth of a bryozoan. The newest formed zooecia of the bryozoan extend almost into the last air chamber. USNM 145080.

2, 3. Dorsal and lateral views of a living chamber of *Baculites gilberti* from unit 33 (D1877) showing the thickness of the shell, and the manner by which bryozoans on the internal mold reveal dissolution on the interior surface. USNM 145081.

4, 5. Two lateral views of a fragment of an internal mold of *Baculites gilberti* from unit 32 (D1879). Figure 4 shows complete destruction of several septa by dissolution on one side and subsequent growth of bryozoans into the former air chambers. The opposite side (fig. 5), which shows very little dissolution, apparently was nearest the sea floor and was covered with sediment. USNM 145082.

6. Lateral view, × 2, of an internal mold of a living chamber of *Baculites gregoryensis* from unit 46 (D1908), showing partial dissolution of the last septum. Various dissolution effects of the interior of the living chamber are revealed by bryozoans and the attachment bases of an unidentified organism. USNM 145083.

7. Colonies of pyriporoid bryozoans, × 2, on part of the lateral surface of the internal mold of a living chamber of *Baculites perplexus* from unit 29 (D1871). A small patch of shell hides some of the bryozoans. USNM 145084.



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DISSOLUTION FEATURES

PLATE 10

[All figures natural size]

FIGURES 1–4, 6–9. Small pits on internal molds of living chambers of *Baculites gregoryensis* marking the attachment bases of an unidentified organism (p. A27, 40).

1–4. Lateral and ventral views of two baculites from unit 46 (D1908), showing dominance of pits on one side. USNM 145085, 145086.

6–9. Lateral, ventral, lateral, and dorsal views of a baculite from unit 48 (D1911) showing pits on all surfaces except a small strip along the middle of one of the flanks. USNM 145087.

5, 11, 12. Relief at the base of the living chambers of internal molds of two specimens of *Baculites eliasi* from unit 80 (D1961). The relief is evidence ot the rasping action of an unidentified organism (p. A27).

5. Lateral view of a baculite retaining some of its aragonitic shell on the upper part and showing, farther down, strong relief which outlines the last septum. USNM 145092.

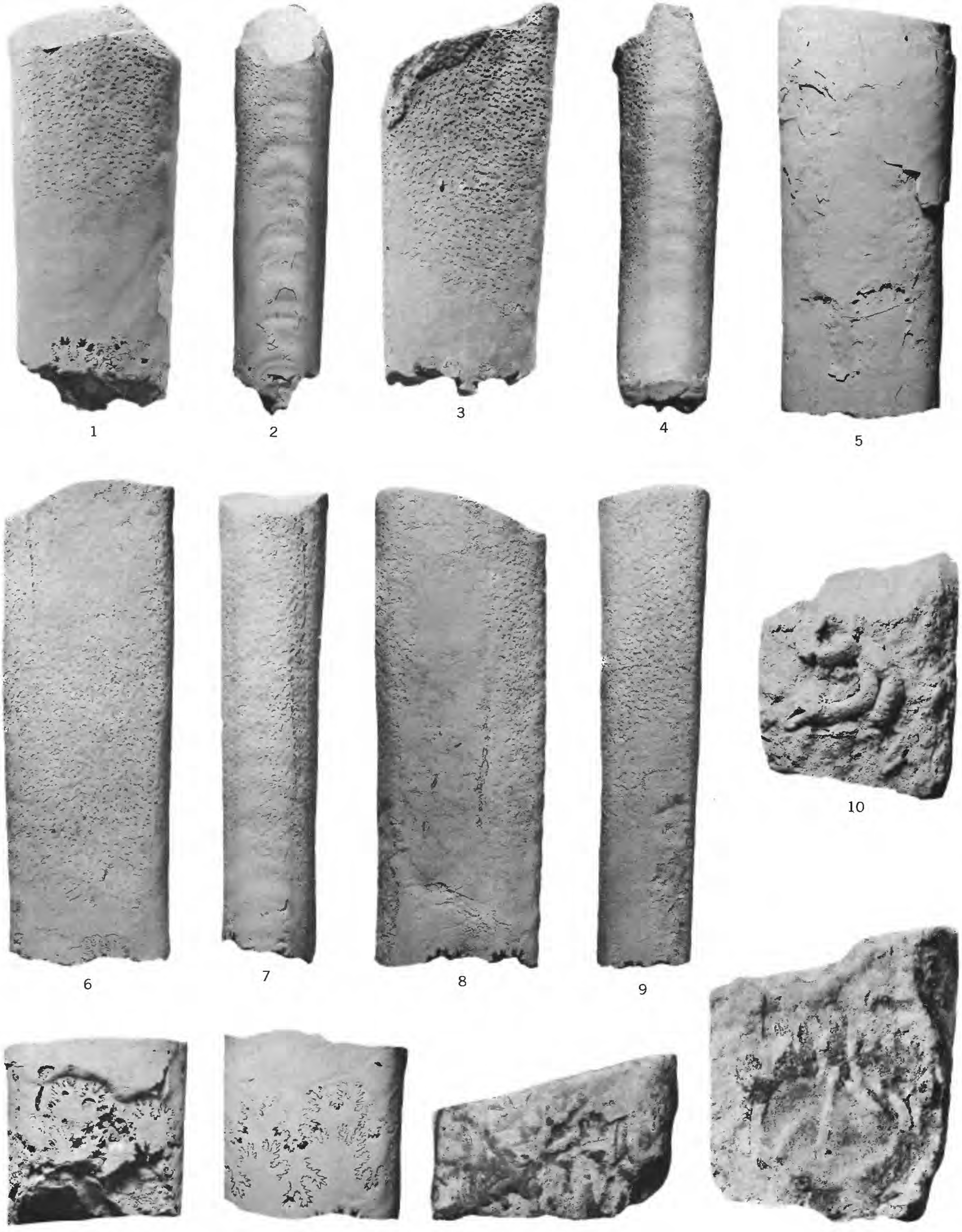
11, 12. Views of both flanks of a baculite; in figure 11, high relief is conspicuous at the contact of the living chamber and the phragmocone, in contrast to the smoothness of the opposite side (fig. 12) which was not rasped. USNM 145089.

10. Siltstone worm(?) tubes on the sediment floor in the living chamber of a baculite from unit 58 (D1936) (p. A27). The baculite was lying on its side on the sea floor and was partly filled with sediment. USNM 145088.

13, 14. Fillings of worm burrows in two living chambers of baculites from unit 72 (D1951) (p. A27).

13. Burrows filled with a dark-brown silty limonitic material contrasting with the lighter matrix of the internal mold of the baculite. USNM 145090.

14. Burrows filled with a lighter colored material than the matrix of the internal mold of the baculite. The dark areas contain fecal pellets. USNM 145091.



DISSOLUTION FEATURES AND TRACE FOSSILS

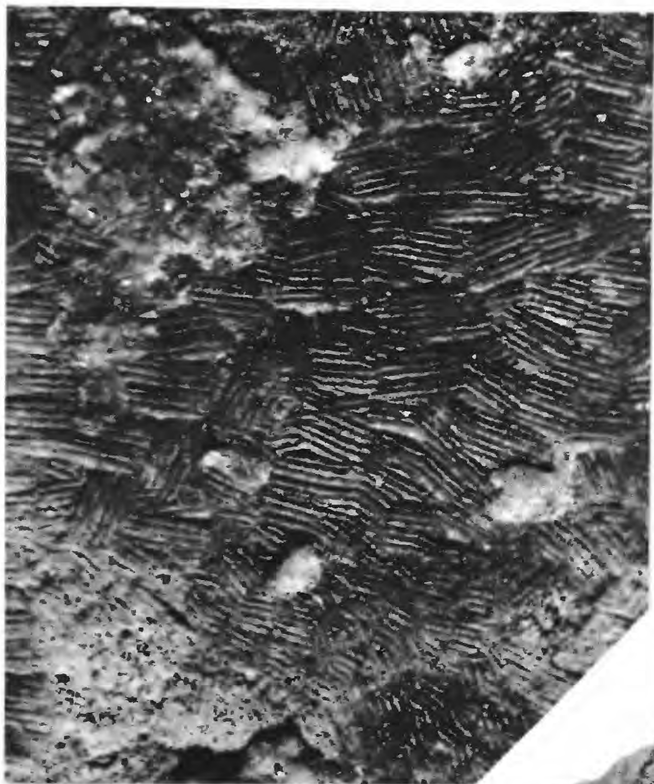
PLATE 11

[All figures natural size except as otherwise indicated]

FIGURES 1, 2. Raspings of some unidentified organism (p. A27).

1. Marks, × 30, at the base of the living chamber of the specimen of *Baculites eliasi* shown on plate 10, figures 11 and 12. Note that the raspings are in groups of six parallel cuts. USNM 145089.
2. Marks, × 23, at the base of the living chamber of the specimen of *Baculites eliasi* shown on plate 10, figure 5. Note the high relief of the rasped area in contrast to the flat, unaltered section of the specimen. USNM 145092.

3. Young specimens of *Baculites perplexus*, accumulated and oriented by the action of currents, in part of a concretion from unit 29 (D1871) (p. A39). USNM 145093.



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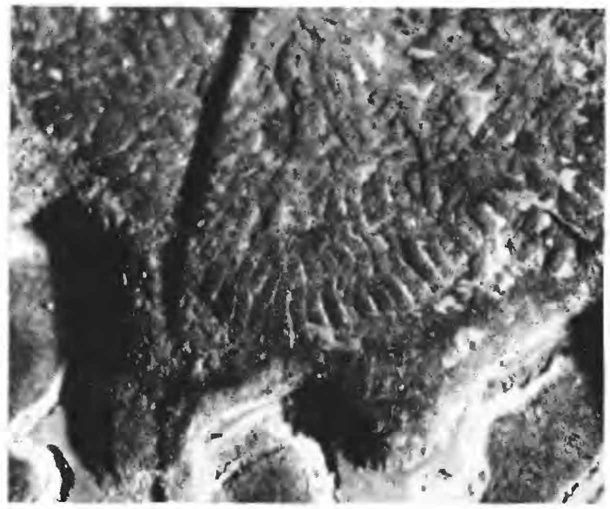

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TRACE FOSSILS AND BACULITE ACCUMULATIONS

PLATE 12

[All figures enlarged as indicated]

FIGURES 1, 3, 5, 6. Sectioned baculites oriented in the position in which they lay on the sea floor (p. A22, 41).

1. Sectior, × 3, across the older part of the living chamber of *Baculites eliasi* from unit 86 (D1968). Muddy seliment containing fecal pellets fills the lower half of the living chamber. The upper half is chiefly a void enclosed by a thin layer of pale-brown finely crystalline calcite lying on a thinner layer of white calcite. Nearly colorless calcite crystals partly fill the right side of this cavity. The formation of a limestone concretion around the baculite prevented crushing of the unfilled part of the shell. USNM 145094.
3. End view, × 3, of a specimen of *Baculites reesidei* from unit 75 (D1952), showing partial filling of sediment containing many fecal pellets, overlain by a layer of debris of white shell fragments, and above this, a layer of colorless calcite crystals. The empty baculite shell originally lay on the sea floor at a slight angle until it was half filled with mud and excrement. After that, the position of the baculite may have shifted. As the shell wall above the unfilled part began to collapse, the debris from the broken chamber walls may then have settled on the mud floor and other low places, or this debris may have been accumulated by the action of currents. The formation of a limestone concretion prevented further crushing of the shell walls. USNM 132866.
5. End view, × 3, of the chambered part of a specimen of *Baculites reesidei* from unit 75 (D1952). The shell lay on the sea floor ventral side down. The ventral part of each chamber was filled with mud (presumably through the siphuncle), and the early consolidation of this sediment preserved the original shape of this part of the shell. The unfilled upper part of the shell was crushed and is now filled with debris of broken chamber walls cemented together by colorless calcite crystals. USNM 132868.
6. Longitudinal section, × 2, of part of a septate specimen of *Baculites reesidei* from unit 75 (D1952). The ventral part of each chamber is filled with muddy sediment, whereas the upper part of the chamber is unfilled except for a thin layer of pale-brown finely crystalline calcite on which are deposited crystals of very pale yellow calcite. The early formation of a concretion around this specimen prevented crushing of the unfilled chambers. USNM 132869.

2. Sectioned specimen, × 3, of *Hoploscaphites* from unit 96 (D2118) (p. A41). The living chamber (right side) is filled with muddy sediment except for a small air pocket at the top. Evidently the scaphite lay on its side on the sea floor. USNM 145095.

4. Dorsal view of a broken specimen, × 2, of *Baculites eliasi* from unit 86 (D1966) (p. A21). The shell apparently lay ventral side down on the sea floor. The chambers are partly filled with sediment, and on top of this sediment bits of the chamber walls lie scattered about. At some time after the partial filling, colorless crystals of analcite formed in some of the chambers. USNM 132867.

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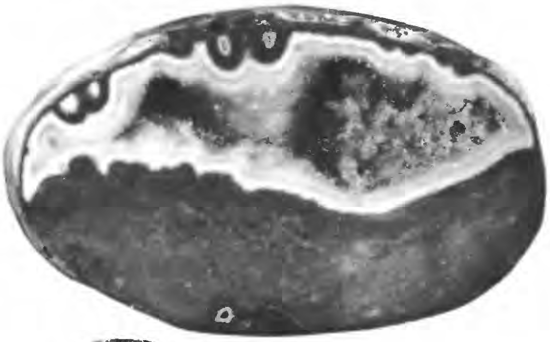

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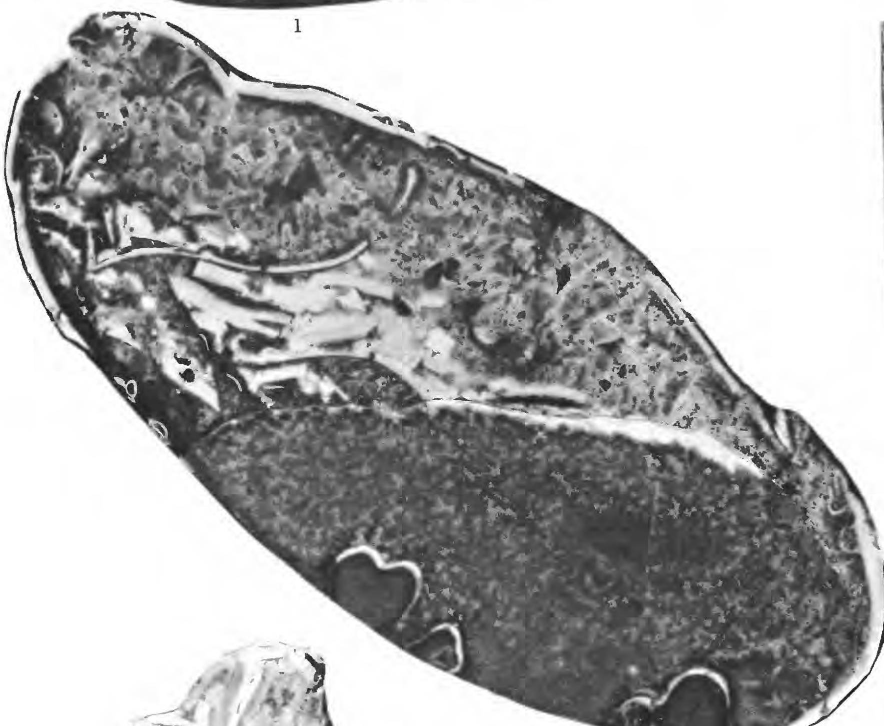

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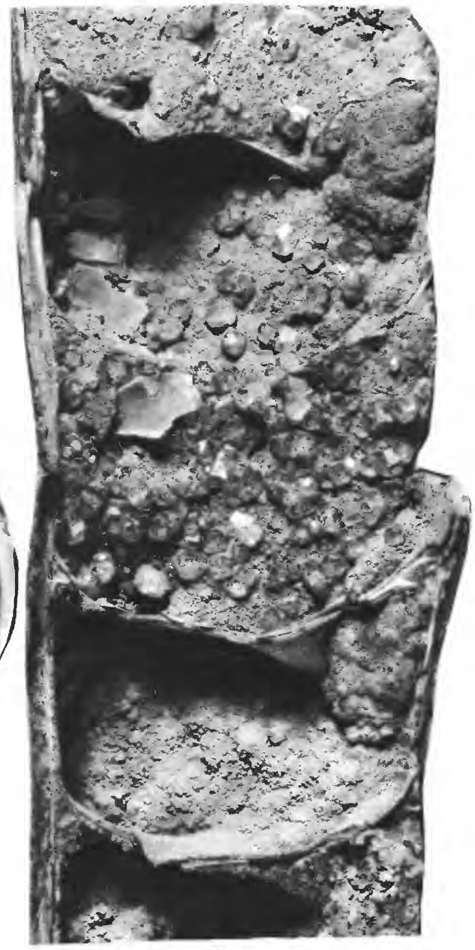

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