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Stratigraphy and Micropaleontology of the Thermopolis Shale

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ABSTRACT

In the Big Horn Basin of Wyoming, the Thermopolis shale (Lower Cretaceous) of U. S. Geological Survey usage consists of three mappable units; a lower sequence of black shale and prominent siltstones, the Muddy sandstone, and an upper sequence of black shale and a few bentonites. This paper restricts the term "Thermopolis shale" to only the lowest of these three units in conformity with local usage, proposes the new name Shell Creek shale for the upper unit, and recognizes all three, the Thermopolis, the Muddy, and the Shell Creek, as formations.

In the Big Horn Basin, the restricted Thermopolis shale consists of four informal members: the rusty beds at the base, a lower black shale, a thin silty shale, and an upper black shale. The uppermost few feet of the underlying Cloverly formation immediately beneath the contact with the rusty beds commonly contain tiny siderite spherulites which weather to iron oxide. Identical spherulites occur regionally at a similar stratigraphic position; they formed in environments accompanying the initial transgression of the Cretaceous sea.

Stratigraphic evidence indicates that the three lower members of the Thermopolis were deposited in an arm of the boreal sea which extended deep into the western interior. The upper shale of the Thermopolis contains twenty-four species of arenaceous foraminifera; five of these are new and the remainder include some of the Gulf Coastal province and others of the boreal province, indicating a joining of the two seas. For the first time, an interior seaway extended the length of the North American continent. The limited number of kinds of foraminifera, as well as molluscs, in the seaway was caused by low salinity. The two distinct biofacies in the seaway may also have resulted from differing salinities. A paucity of individuals in some marginal areas of the seaway resulted from a lack of oxygen on the sea floor.

The Muddy sandstone locally consists predominantly of shale and siltstone. In spite of great lateral variations in thickness, in sequence, and in rock type, the Muddy is a laterally persistent, widespread unit which occupies just one stratigraphic interval and which records a single depositional episode. It was deposited over a large area in a variety of local, very brackish, extremely shallow water environments.

The Shell Creek shale represents renewed transgression of the boreal sea. It contains a new radiolarian species and twelve species of arenaceous foraminifera; four are new and the remainder are known only from the boreal province; three also occur in the Thermopolis. The depositional environment was probably similar to that of the upper shale of the Thermopolis. Its contact with the overlying siliceous Mowry shale is laterally persistent; the two units are not facies of one another. South and east of the Big Horn Basin, the Shell Creek shale thins greatly and has not been mapped, although it can be distinguished in good exposures and on electric logs. In southern Wyoming, it thins out and is overlapped by the siliceous Mowry shale.

INTRODUCTION

It is a pleasure to acknowledge the following persons and organizations whose help in making this study possible is sincerely appreciated:

Dr. K. M. Waagé suggested the problem, directed the research, and generously gave many hours of encouraging guidance and capable advice. Dr. C. O. Dunbar and Dr. J. T. Gregory gave helpful suggestions on various aspects of interpretation and presentation. Audrey Eicher ably assisted both in the field and in the laboratory, and in addition, typed the manuscript. D. S. Barker and A. T. Ovenshine each assisted for a few days in the field. A National Science Foundation Fellowship provided financial support for the study throughout its duration, and the Carter Oil Company lent electric logs.

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AREA

In Wyoming, the rocks that lie above the Cloverly formation and below the Mowry shale of Darton are included in the Thermopolis shale by the U. S. Geological Survey. These rocks are Lower Cretaceous in age, and they represent the earliest marine deposits of the great Cretaceous interior sea in this region. Throughout most of their outcrop area, the gray and black shales of the Thermopolis are poorly exposed, forming valleys or vegetated slopes. In a few exceptional places such as the northeastern flank of the Big Horn Basin, however, they crop out in barren badlands where detailed study and thorough sampling are possible. Here their total thickness is about 600 feet. Most of the field work was concentrated in this area and in the area of the type Thermopolis on the southern flank of the basin. Field work was also extended out of the basin to help establish correlation with other areas. The field studies occupied the summer of 1956 and part of the summer of 1957. All localities visited are shown in figure 1; most represent only partial sections, and most were sampled for microfossils.

THE PROBLEMS

NOMENCLATURE

The first problem encountered in the sequence of beds between the Cloverly formation and the Mowry shale is that of an entangled nomenclature. The multiplicity of meanings for the names has nearly defeated its basic purpose—to replace briefly and clearly a lengthy descripition. As of now, when using the name Thermopolis, for example, one must either specify whose usage he is following, or else leave his reader with a question as to just what rocks he is talking about. Perhaps there is no one best way to apply the names within this sequence, but a standardization—any standardization—of the names would have the obvious advantage of precision in thought and expression. If, in addition, the named units were lithogenetic as well as utilitarian, regional geologic history would be more easily comprehensible.

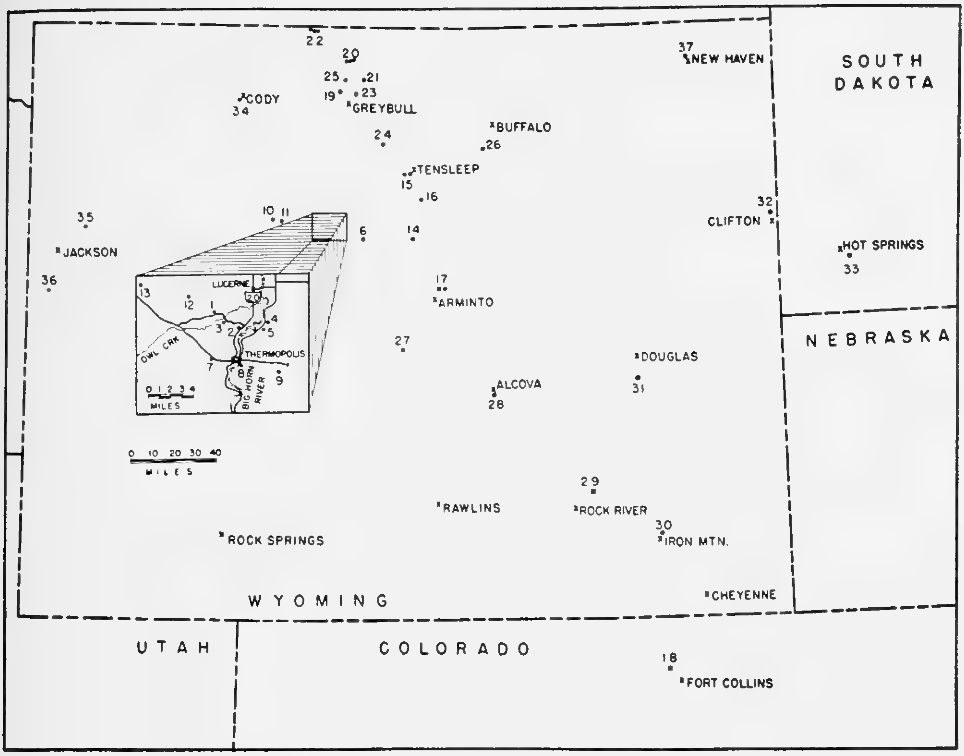

Figure 1. Index map. Localities visited are marked by dots. X's represent towns. For key to localities, see locality register, p.

STRATIGRAPHY

The following are the principal problems which will be discussed in this report:

The Thermopolis shale contains a microfauna which has not been previously described. Inasmuch as macrofossils are generally rare in the Lower Cretaceous marine rocks of the western interior and especially so in most of Wyoming, the microfossils are of particular value in filling certain gaps in the knowledge of the paleogeography. During Early Cretaceous time, the western interior of North America was occupied by the arms of two great seas; one extended south from the boreal regions, and the other extended north from the area of the Gulf of Mexico. The two seas were inhabited by distinctly different contemporaneous faunas, so that their distinctive fossils help to chart their respective movements. Which was the first to reach the western interior? When were the two seas first joined? What was their nature?

The detailed stratigraphic relationships of the Thermopolis shale of the Big Horn Basin with the rocks in other areas have not been previously studied. A disconformity indicating the first transgression of the Early Cretaceous sea was previously recognized in the Colorado Front Range foothills (Waagé, 1955). Above it lie marine and marginal marine rocks deposited under the influence of the transgressing sea; below it lie rocks deposited entirely in nonmarine environments. This two fold arrangement provided a natural framework for mapping the strata of the Front Range Dakota group. Might not a similar arrangement of marine and marginal marine rocks above and nonmarine rocks below continue northward across Wyoming, and even over a large part of the western interior? If so, it would help provide a meaningful classification of the rocks.

The Muddy sandstone, which lies near the middle of the Thermopolis shale of the U. S. Geological Survey, is an important unit recognizable over a large area. Yet, many workers have relegated the Muddy to member, or even lesser status. Perhaps this is due, in part, to the stigma attached to formal recognition of a term which has never been formally proposed and defined, but it may be due also to the suspicion by some geologists that the term Muddy has been indiscriminately applied, not to a single stratigraphic unit, but to any prominent lens or tongue of sandstone in the entire Thermopolis sequence. Thus, the nature of the Muddy and its relationship with the Thermopolis need clarification.

The black shale unit above the Muddy sandstone and below the siliceous Mowry shale of Darton has been previously mapped separately in some areas, but in other areas where it is less easily distinguished, it has been included with the overlying siliceous Mowry shale and their gradational relationship has been stressed. The exact relationship of these units is a problem. Might they be in part contemporaneous facies?

Summary of Previous Work

The nomenclature of the Thermopolis shale of the U. S. Geological Survey usage and its regional correlatives has become unnecessarily complicated. In some places other than the Big Horn Basin this is a result of too many names or of inept application of "foreign" names, many of which, to make matters worse, are surrounded with confusion in their native areas. In and around the Big Horn Basin, however, most nomenclatorial complications are the result of a number of conflicting usages for a few names which have been in use for a long time.

In order to see how these different usages came about, to properly evaluate the nomenclatures currently extant, and to place the stratigraphic problems in historical perspective, it is desirable to review the evolution of the terms, as well as some of the accompanying ideas. This summary pertains chiefly to the Big Horn Basin and immediately adjacent areas. History of usage of terminology is summarized in figure 2.

Eldridge (1894), in a reconnaissance report, was the first to refer specifically to the rocks of the Big Horn Basin now known to be Lower Cretaceous. He recognized a Dakota formation which he described as a commonly iron-stained quartzose sandstone of variable thickness beneath which lay 400 to 600 feet of Jura strata, dominantly shale and (1894, p. 21) "wholly of marine origin." The beds above his Dakota, Eldridge placed in the Colorado formation, separating within it the Benton and succeeding Niobrara formations. His Benton consisted of 300 to 600 feet of gray and black shales with a few thin beds of limestone and numerous small lenticular ironstones, and his Niobrara consisted of 300 to 800 feet of light gray shales with some impure shaly limestones and, locally, well-developed sandstones. He notes (1894, p. 23) that the shales "are of extremely close grain and of fine even texture, indurated in a marked degree, and which, though gray on fresh fracture, weather a characteristic milky white." He described his Niobrara "limestones" in detail: "The limestones are not of a pronounced character but rather are calcareous layers of shales, which are held together with greater tenacity than portions containing less lime. These layers are rarely over a foot of two thick, are very earthy and are usually of fine texture." Most of Eldrige's Niobrara was later to be called the Mowry shale, and his "limestones," bentonites.

Near Five Springs Creek, Eldridge believed that the black shales of his Benton rested directly on the variegated clays of his Jura and that his Dakota was entirely absent as a result of non-deposition.

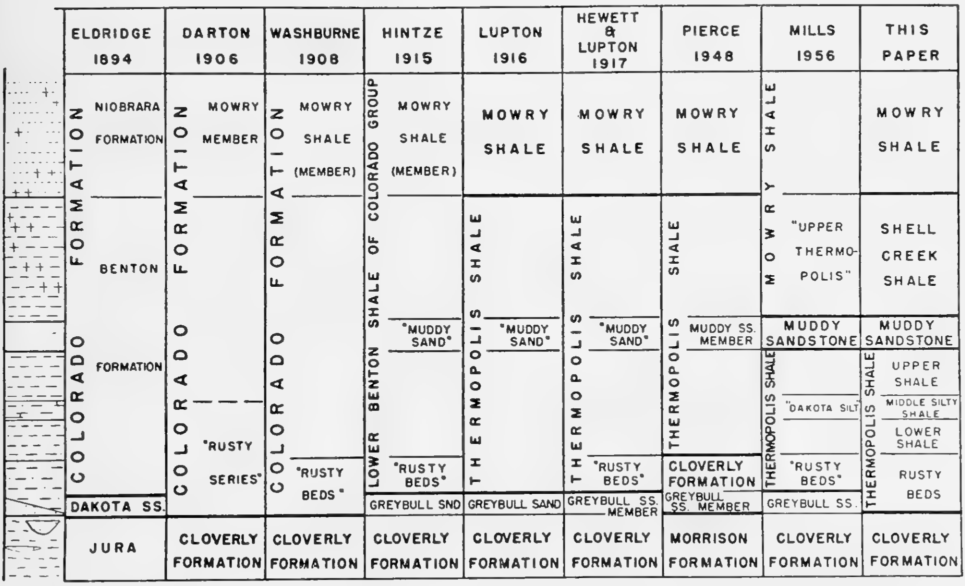

Figure 2. History of terminology of Lower Cretaceous rocks within the Big Horn Basin.

N. H. Darton made the first detailed stratigraphic studies in the Big Horn Mountain area during the years 1901 through 1905. Darton recognized the Morrison formation which shortly before he had correlated into the Black Hills from its type area in Colorado. Above the Morrison, he found a sequence of beds which he believed to be equivalent to his Lakota and Fuson formations of the southern Black Hills. Because overlying lithologic equivalents of his Black Hills Dakota sandstone were absent, however, Darton (1904, p. 398) deemed it best to give this unit a new name, the Cloverly formation, taken from Cloverly Post Office on the east side of the Big Horn Basin where the strata were 113 feet thick.

Above the Cloverly, Darton (1904, p. 399) included about 1300 feet of dominantly shaly strata in the Benton formation. Later he used the term "Colorado formation," stating (1906b, p. 7), "The Colorado formation in the Bighorn region comprizes the Benton and Niobrara formations of the Rocky Mountain and Great Plains region farther south and east. . . . The upper beds of the formation are gray shales, which probably represent the Niobrara formation."

Darton (1904, p. 399) mentioned that, "The basal member of the Benton consists of dark gray shales, in part sandy and of rusty brown color, with occasional thin beds of brown sandstone." He called this interval the "rusty series" (1906a, p. 54) and mentioned that it was about 200 feet thick with a persistent horizon about 100 feet above the base, characterized by round phosphatic concretions up to two inches in diameter. These concretions have since been shown to consist of the mineral dahllite (McConnell, 1935). Darton described the lower contact of the Benton west of Cloverly Post Office as abrupt on top of the Cloverly formation but without sign of unconformity. He suspected that either the rusty series or some of the thin sandstones at the top of the Cloverly possibly represented his Dakota sandstone (the Fall River sandstone of Russell, 1927) of the Black Hills (1904, p. 399). Because the base of the Dakota was, to Darton, synonymous with the base of the Upper Cretaceous, he tentatively placed the Lower-Upper Cretaceous boundary in the upper part of the Cloverly formation.

Above the rusty series, Darton reported 600 feet or more of black fissile shales which contained occasional carbonate and iron concretions and, near the middle, a light-colored sandstone. This unit was overlain in turn by 150 to 300 feet of hard, light gray, fish-scale-bearing shales and thin-bedded sandstones which weathered to light gray barren ridges. Darton (1904, p. 400) designated these "the Mowrie beds . . . from Mowrie creek northwest of Buffalo." Later, he changed the spelling to Mowry beds (1906a, p. 54), and elsewhere (1906b, p. 7) he referred to it as the Mowry member, noting that it could not be Niobrara because it lay below beds containing diagnostic Benton fossils.

Fisher (1906) made a few additions to Darton's stratigraphic descriptions on the east flank of the Big Horn Basin, and carried all of the stratigraphic units over to the west flank. He noted the bentonite beds in the upper part of the soft black shale interval below the Mowry.

Washburne in 1908 published the first report on oil and gas in the Big Horn Basin. From the area of Greybull, he introduced the term "rusty beds" for the thin-bedded sandstone and shale beds at the base of the Colorado formation. Washburne interpreted the rusty beds as a basal transgressive unit of the Cretaceous sea, considering them unconformable on the Cloverly formation and placing the Lower-Upper Cretaceous boundary at their base. He explained the discontinuity of Cloverly sandstones beneath the rusty beds as a result of erosion prior to the marine transgression and suggested that where the Cloverly sandstones were absent, the entire formation had been eroded away leaving the rusty beds in contact with the underlying Morrison formation.

The lower portion of Washburne's (1908, p. 350) generalized section of the Colorado formation follows:

Shales, gray and black, with many fossil fish scales; contain numerous layers of hard flinty shale, and one 3-foot bed of bentonite; the Mowry shale	200
Shales, dark bluish and black, with a few beds of volcanic ash and white clay (bentonite) in the upper part	250
Shales, black, carbonaceous, in many places oily, locally containing one or more lenses of sandstone in the lower 100 feet	300
Sandstone, thin beds 3 to 18 inches thick, weathering brown, which are separated by partings of black shale 1 to 12 inches thick; the 'rusty beds'	20-100

His mention of bentonite and volcanic ash in the dark shale below the Mowry is interesting. Bentonite had been reported from this interval previously by Fisher (1906), but it was nine years before Hewett's (1917) paper advocating the volcanic origin of bentonite appeared. As many bentonite beds contain volcanic shards, perhaps Washburne distinguished his "beds of volcanic ash" on this criterion and restricted his term "white clay (bentonite)" to beds in which shards were not visible. If this is so, however, the origin of bentonite must have been apparent to him because of the similarity of the bentonite beds, with or without obvious shards.

In his detailed section of Mesozoic and Tertiary rocks on the west side of the basin near Cody, Wyoming, Hewett (1914) recognized a lower member of the Colorado formation 1026 feet thick resting on the Cloverly formation. Hewett distinguished no members, but he mentioned an impressive number of bentonite beds in a 392-foot soft black shale unit that lay between a 20-foot buff sandstone containing vertebrate fossils below and a sequence of sandstone and fish-scale-bearing shales above. He included 60 feet of thin-bedded sandstone in the top of his Cloverly formation, most or all of which was equivalent to the lower portion of the rusty beds on the east side of the basin. This practice has since been customary on the west flank of the basin where the rusty beds contain much more sandstone in their lower part.

In the Basin-Greybull area, Hintze (1915) divided the Colorado group into upper and lower formations which he correlated with the Benton and Niobrara formations of the plains. He subdivided the Benton into four members, the lowest of which included the 900 feet of strata between the base of the "Rusty beds" and the top of the Mowry shale. He noticed, as had Washburne, that the rusty beds had a much more uniform character and distribution than the underlying Cloverly. Hintze believed that the contact between the rusty beds and the underlying Cloverly formation was either a disconformity or a slight angular unconformity, but he granted that the intermittent occurrence of sandstone in the upper part of the Cloverly could have resulted from local deposition instead of erosion prior to rusty beds deposition. Hintze concluded that the subsurface "Greybull sand" of drillers in the area was one of these local sandstone beds in the upper part of the Cloverly formation, and he noted the intermittent occurrence of such beds in the subsurface as well as in outcrop. Near the middle part of his Lower Benton shale member, Hintze described a white sandstone 25 to 40 feet thick and mentioned that in the subsurface this unit was locally called the "Muddy Sand." He mentioned its importance in the subsurface as an economic unit and as an excellent marker bed; although he found and examined its outcrops east of Greybull, he did not give it a formal name.

Hintze thought it noteworthy that the Dakota, which is so prominent in Colorado, is not recognizable in its typical form in the Big Horn Basin. He stated (1915, p. 31), "The Cloverly was thought by some to represent the Dakota but it has more recently been proved to be of Lower Cretaceous age," inferring that because of its age it was ineligible for consideration as a Dakota equivalent. This belief, that the term "Dakota" should be restricted to rocks of Upper Cretaceous age, had previously induced others to revise the nomenclature in the Black Hills and southeastern Colorado. The consequences of this misleading concept of the Dakota as a rock unit restricted to a particular time span has plagued the terminology ever since (Waagé, 1955, p. 18). Hintze's statement is the first indication that it had reached the Big Horn Basin.

In order to explain the greater thickness of black shale between the Cloverly and the Mowry in northern Wyoming compared to this interval in southern Wyoming, Hintze entertained the interesting possibility that the original transgression of the Benton Sea came from the north and extended nearly to Colorado where it was later met by the Dakota transgression from the south.

Lupton, in 1916, introduced the stratigraphic classification of the Colorado group that has been used ever since by the U. S. Geological Survey. He raised the

Mowry to the rank of formation, and he applied the name Thermopolis shale to the 700-foot sequence corresponding to that part of Hintze's Lower Benton shale member which lay below the Mowry. He stated (1916, p. 168) that the Thermopolis was conformable with the upper sandstone bed of the Cloverly below and with the Mowry shale above. Lupton noticed the variable thickness of the medial Muddy sand and stated that near Basin, Wyoming, it ranged from 15 to 55 feet. The name Thermopolis was taken from a town in the southern part of the basin "near which it is well exposed," but Lupton gave no section of the Thermopolis from the type area. His generalized section (1916, p. 167) from the Basin oil field follows:

	feet
Mowry shale: (in part)	
Sandstone, Octh Louie sand of drillers; yields a little oil	25
	160
Thermopolis shale:	
Shale, hard; contains lenses of sandstone	230
Shale, soft, dark	170
Sandstone, Muddy sand of drillers; contains a little gas	35
Shale, soft, dark	275
	710
Cloverly formation: (in part)	
Light-buff or tan-colored sandstone (Greybull sand of drillers)	20

Lupton took his Cloverly section from Darton's (1906a, p. 52) description of the type Cloverly. In applying the term Greybull sand to the upper 20 feet of the type section, Lupton was unhesitatingly following Washburne (1908) in correlating the discontinuous Greybull sand of the subsurface with the discontinuous sandstone beds at the top of the Cloverly on outcrop.

The following year, Hewett and Lupton (1917, p. 19) formally designated "the Greybull sandstone member of the Cloverly formation, from the town of Greybull, near which it is typically exposed." They stated that it consisted of 10 to 20 feet of yellowish-gray sandstone at the top of the Cloverly formation. Hewett and Lupton mentioned no specific type locality, and because the unit is totally absent over much of the Greybull area, as Washburne (1908) and Hintze (1915) had previously ascertained, the merit of its formal designation was questionable.

Though Hewett and Lupton made the astute observation that the sandstone near the middle of the Thermopolis shale is unusually persistent, they made no effort to give it the formal status it warranted, but continued to refer to it (1917, p. 19) as "termed by the drillers the 'Muddy sand.'" This is paradoxical in view of the formal designation, on the same page, of the Greybull—a unit long known to be notoriously discontinuous.

Ziegler (1917a, 1917b) traced the Thermopolis shale northward to the Byron oil field on the Shoshone River and westward across the Big Horn Basin to the Oregon Basin field. He noted the uniform occurrence of the rusty beds in the lower part of the Thermopolis, and because of variation in the Cloverly beneath, he considered the contact to be disconformable. In both the Byron and Oregon Basin areas, Ziegler found a sandstone unit near the middle of the Thermopolis shale but was not aware that it represented the Muddy sand. He interpreted the rusty beds as deposits of a transgressing sea and the overlying Thermopolis and Mowry shales as deposits of quiet, but relatively shallow water.

From a study of the floras, Stanton (1922, p. 264-267) correctly postulated that the Muddy sand of central Wyoming and the Newcastle sandstone of the Black Hills were equivalent to the uppermost sandstone of the Dakota formation of the Colorado Front Range. He suggested that the portion of the Thermopolis shale underlying the Muddy, and the Skull Creek of Collier (1922) underlying the Newcastle, were equivalent to the middle shale of the Dakota formation in the Front Range. He also pointed out that marine pelecypods from this shale could be compared as convincingly to Early Cretaceous species as to Late Cretaceous species, but concluded tentatively that they were probably Late Cretaceous and that the sea did not extend north of southern Colorado and central Kansas during Early Cretaceous time.

The following year, Reeside (1923) described, from the dark middle shale of the Dakota formation of northern Colorado and southern Wyoming, the small molluscan fauna previously mentioned by Stanton but regarded it of Early Cretaceous age, the same as faunas from the Purgatoire and equivalent Lower Cretaceous rocks of southern Colorado and adjacent areas. He proposed that the Lower Cretaceous sea invaded at least as far north as southern Wyoming.

Because the Dakota of northern Colorado contained only three species and lacked eight others occurring in the Purgatoire and its equivalents farther south, Reeside concluded that the three species common to both areas were possibly hardier and could endure the more unfavorable environmental conditions that presumably existed to the north. He pointed out that Stanton (1922, pl. 5) had previously shown a progressive change in fauna, marked by the disappearance of one species after another, northwestward from New Mexico and Oklahoma. A continuation of this trend, he believed, might account for the paucity of Purgatoire species in northern Colorado.

The Late Cretaceous age of the flora of the Muddy, Newcastle, and uppermost sandstone of the Front Range Dakota formation, which Stanton (1922) had previously correlated, was still accepted, and hence the Lower-Upper Cretaceous boundary was placed at the base of these sandstone units, where it remained for over a quarter century.

Lee (1923) called the Dakota formation of northern Colorado the Dakota group and divided it into five informal subunits, which he traced northward across Wyoming into the Big Horn Basin. Later, Lee (1927, p. 57) compared the Cloverly-Thermopolis-Muddy sequence at Thermopolis with the five subunits of his Dakota group. He correlated the Cloverly, which consisted of a lower conglomeratic sandstone, overlying red sandy shale, and upper interbedded sandstone and variegated shale with his lower sandstone, lower shale and middle sandstone of northern Colorado, respectively. The dark shale containing rusty beds at the base, and the overlying Muddy sand, he correlated with his upper shale and upper sandstone, respectively. These correlations were essentially correct, but Lee's terminology has not since been used, presumably because his lower subdivisions lack lateral continuity. Lee paid little attention to some stratigraphic details, and his inconsistencies have understandably confused later workers. For example, he (1927, p. 58) said that at a locality two miles northwest of Thermopolis, Wyoming, "the Thermopolis shale includes near the base brown sandy material that constitutes the so-called 'rusty beds.' " Several lines further, we read that above colored sandy shales lie "the ripple-marked, rusty-brown sandstone and thin layers of dark shale which some have called the 'rusty beds.' Above these 'rusty beds' is a thick mass of dark shale—the Thermopolis shale." Still further on, he states (1927, p. 64) that north of Greybull, "The Greybull sandstone consists of many layers of rusty-brown sandstone and shale, which grade upward into the Thermopolis shale without sharp demarkation," confusing the rusty beds with the Greybull sandstone, perhaps intentionally because here, "The beds below the rusty sandstone consist of highly colored material characteristic of middle Cloverly." Thus, in those areas where he found no local upper Cloverly sandstone beds, Lee apparently invoked as convenient correlatives to his middle sandstone subunit the rusty beds, effectively confusing the terms "rusty beds" and "Greybull sandstone." Additional carelessness is illustrated by the statement (1927, p. 18) that certain correlations are made with "the Muddy sand, a name derived from Muddy Creek, in northern Wyoming." Later Wilmarth (1938, p. 1448) stated, "There are at least 8 Muddy Creeks in Wyo., but, although the sand outcrops, it is not known to be exposed on any Muddy Creek." Lee knew better, for further on (1927, p. 23) he used the phrase, "the Muddy sand of the oil men of Wyoming."

The Cloverly-Thermopolis contact has been difficult to pick consistently in mapping. Ever since the name Greybull sandstone was given to a local bed at the top of the Cloverly, the tendency has been to draw the Cloverly-Thermopolis contact arbitrarily above the most prominent sandstone beds below the dark shales of the Thermopolis. This practice included a considerable portion of the rusty beds in the Cloverly on the west side of the basin, where they contain more sand than they do on the east side. Pierce and Andrews (1941, p. 117), who arbitrarily utilized the lowest conspicuous dark gray shale of the Thermopolis in the area south of Cody, emphasized that though it was expedient, it was inconsistent, and that Cloverly thickness variations "are not due to true thickening or thinning of the formation but to the inclusion in the Cloverly of greater or smaller thicknesses of the overlying or underlying strata, depending upon the lithology at the particular place examined."

Similarly, in the area immediately north of the Big Horn Basin, Knappen and Moulton (1930) included with the Cloverly formation thinly bedded shaly sandstones of the lower part of the rusty beds, in the belief that this was the Greybull sandstone and that it had simply become much thicker to the north. They noted, however, that this unit was sharply distinct from the underlying light-colored, more massive strata, and that its upper part indicated marine conditions which continued uninterruptedly upward into the overlying black shales. They mapped this "Greybull" separately.

Love and others (1945), on a correlation chart covering a large area of central Wyoming, included the rusty beds in the Cloverly formation intentionally, because "nonmarine Lower Cretaceous fossils, identical with those found in the underlying variegated claystone zone, are present in the 'Rusty beds'," and because "In some places sandstones in the 'Rusty beds' intertongue with the underlying variegated claystones." Dahllite and ironstone concretions occur in some of their sections in the lower part of their Thermopolis shale and in other sections in the upper part of their Cloverly formation. They considered the Thermopolis shale minus the rusty beds unsatisfactory for mapping, because the upper contact with the Mowry shale was gradational, and because they thought the Thermopolis included at the base of the Muddy sandstone an important time horizon, the Lower-Upper Cretaceous boundary.

On the east side of the Big Horn Basin, Pierce (1948) and Rogers and others (1948) distinguished the rusty beds but intentionally mapped them in the

Cloverly formation for convenience. In Pierce's area, the base of the Cloverly was difficult to map, because the conglomeratic sandstone on which it was defined was absent. Pierce therefore mapped the base of the "Greybull sandstone" as this contact. Rogers and others followed Pierce and used the same contacts on their adjoining map, but in much of their area the discontinuous conglomeratic sandstone which marks the base of the Cloverly was apparently present, for they mapped it separately in the middle of their Morrison formation. Inasmuch as sandstones at the top of the Cloverly are commonly totally absent in these areas, the rusty beds must, in places, make up the entire unit mapped as Cloverly. It follows that, in places, the entire sequence equivalent to the type Cloverly was mapped in the Morrison.

Reeside (1944), in a summary of the western interior Cretaceous, showed on his correlation chart a Muddy sandstone member of the Thermopolis shale. Designation of the Muddy sandstone as a member has since been followed by the U. S. Geological Survey.

For over twenty years, the Muddy sandstone had been accepted as a widespread unit seemingly worthy of formational status. Because of the structure of the pre-existing terminology, however, formational designation of the Muddy would have necessitated other nomenclatorial changes at the same time, perhaps the most logical of which would have raised Thermopolis to a group name and separately named the black shale units below and above the Muddy. This revision must have appeared drastic, for it was never made, but it would have prevented much subsequent confusion.

In the Wind River Basin, Love (1948, p. 106) proposed, for the purposes of a guidebook, that the term Thermopolis shale be limited to the interval of black shale between the Cloverly formation and the Muddy sandstone, that the Muddy be considered a formation, and that the interval of soft black shale between the Muddy and the Mowry shale be included with the Mowry. This was not immediately adopted in other areas. The following year Downs (1949, p. 48), in the Powder River Basin, still referred to the Muddy as a member of the Thermopolis shale and considered the Thermopolis to include the soft black shale above the Muddy. By 1952, however, the Muddy was widely enough accepted as a formation to influence Cobban and Reeside (1952, p. 1030) to say of the Thermopolis, "Many geologists now prefer to restrict the name to the lower part of the dark shales, to designate the sandstone the 'Muddy sandstone' and view it as a formation, and to include the upper part of the dark shale in the Mowry formation. The compilers think this restricted application of Thermopolis much more useful at many places than the older usage." Today this seems by far the most popular classification, although the U. S. Geological Survey uses the term Thermopolis in its original sense and considers the Muddy sandstone a member near the middle.

Crowley (1951) elevated the Lower-Upper Cretaceous boundary from the base to the top of the Newcastle sandstone in the Black Hills on the basis of foraminiferal faunas. He found that the faunas of the Newcastle and the underlying Skull Creek shale were similar. Because he did not find the fauna in the overlying Mowry shale, he concluded that the Newcastle was more closely related to the Skull Creek and thus probably the same age.

Cobban and Reeside (1951) reported Lower Cretaceous ammonites of the boreal genera *Gastroplites* and *Neogastroplites* from the Mowry shale in Wyoming, Colorado and Montana, but they later considered that all properly belonged only to *Neogastroplites* (Imlay and Reeside, 1954, p. 225). These forms enable correlation with rocks of northern Canada which are considered upper Albian or uppermost Lower Cretaceous in age. Thus, Cobban and Reeside concluded that the Lower-Upper Cretaceous boundary correctly belonged at the top of the Mowry shale. Their conclusions were not accepted by Yen (1952, 1954) who dated pre-Mowry equivalents in western Wyoming as lowermost Upper Cretaceous by means of non-marine molluscs which he compared to similar faunas from Europe.

Both Eldridge (1894) and Darton (1906b) had used the term Colorado group in the Big Horn Basin, and had followed White (1878) in placing its boundary at the top of the Cloverly formation. Knechtel and Patterson (1956, p. 17) recently mentioned a change of this lower boundary of the Colorado group as a result of the latest faunal evidence bearing on the position of the Lower-Upper Cretaceous boundary. Knechtel and Patterson stated that the Colorado "is still generally understood to include only Upper Cretaceous rocks. Therefore, the Geological Survey's classification has recently been modified to exclude the Thermopolis and Mowry beds from the Colorado group." This classification also appears in Cobban and Reeside's (1952, pl. I) correlation chart, where the strata between the base of the Fall River sandstone and the top of the Mowry shale are the only Cretaceous beds not included in any group. But why should our latest age determinations, which changed previous notions of the *age* of parts of the Colorado group, be allowed to alter the *physical boundaries* of the Colorado group? The term "Colorado shale" was first applied by White (1878, p. 21, 22, 30) to a sequence of rocks which included the lowest black shales in the Cretaceous sequence on the upper Missouri River. The term "Coloradoan" has since come to be used as a stage name and applied to rocks deposited during the Colorado shale time. Exactly what strata of the European type section were laid down during the same time was unknown, but they were long believed to be entirely Upper Cretaceous. Now that this is no longer thought to be true, the impulse is to change our stratigraphic boundaries to conform to the previous incorrect notion of age and thus to keep the Colorado group entirely within the Upper Cretaceous European stages. But to what extent is the age of a rock unit a part of its definition? Can we ever be certain that our knowledge of the Lower-Upper Cretaceous boundary is subject to no additional modification, or do we intend to periodically readjust the stratigraphic boundaries of the Colorado group to conform to our newest evidence on where in our rock sequence the time boundaries between the European stages lie?

Recently, there has been a trend toward using Black Hills nomenclature for the Lower Cretaceous rocks of central Wyoming. Above the Cloverly, on the east flank of the Big Horn Mountains, Hose (1955) mapped the Skull Creek and Newcastle formations, possibly to avoid the ambiguity that the use of the term Thermopolis might convey and to denote unequivocal formational status for the Muddy sandstone in an area where only member status had been previously implied.

Hose (1955, pl. 9) demonstrated that the Skull Creek and Newcastle strata of the Black Hills were indeed equivalent to the intervals to which he applied these names on the east flank of the Big Horn Range. The unit underlying the Skull Creek, however, changes facies markedly between the Black Hills and the Big Horn Mountains. Whereas the soft, shaly rusty beds are included in the Thermopolis shale to the west in the Big Horn Basin, their correlative in the

Black Hills, the harder, more resistant Fall River sandstone, was always mapped separately and was never included in the Skull Creek shale. Correct extension westward of the term "Skull Creek" therefore excludes the underlying equivalents of the Fall River. These equivalents are the rusty beds and a few feet of overlying strata, including the dahllite concretion-bearing beds. These must now either be considered as a separate unit or included with the underlying Cloverly formation. Hose included them with the Cloverly, thereby expanding Darton's Cloverly to embrace 150 feet of strata that overlie it in the type area just across the Big Horn Range. The base of the Cloverly he drew at the base of a sandstone, 15 to 45 feet thick, underlying the rusty beds. The boundaries of his Cloverly thus were essentially the same as those used for expedience by Pierce (1948) and Rogers and others (1948) on the west side of the Big Horn Range.

Mills (1956, p. 19), in a symposium of the Wyoming Geological Association, considered the Thermopolis shale in the subsurface of the Big Horn Basin to consist only of the dominantly black shale unit below the Muddy sandstone. He included the rusty beds in its lower part and he recognized a silty unit near its middle. He considered the Muddy sandstone a separate formation and assigned the soft black shale unit above the Muddy to the Mowry but discussed it by the informal term "Upper Thermopolis."

In much of central and eastern Wyoming, Burk (1956, p. 30), Faulkner (1956, p. 40), and Peterson (1956, p. 46) proposed that the Black Hills term "Inyan Kara group" be used for the strata previously included in the Cloverly formation and the rusty beds, because the term "Cloverly" has often been misused in the subsurface. In the western part of the Wind River Basin, Burk (1956, p. 31) included the rusty beds in the lower portion of the Thermopolis shale, and in the eastern part, he included them in the upper portion of the Inyan Kara group with the Thermopolis lying above. In the western Powder River Basin, Faulkner (1956, p. 40) considered the term "Thermopolis" synonymous with the term "Skull Creek," consequently excluding the rusty beds from the Thermopolis shale.

Everywhere in central and eastern Wyoming, the authors of the 1956 Wyoming Geological Association symposium included the soft black shale interval between the Muddy sandstone and the siliceous Mowry shale of Darton with the Mowry shale. However, they recognized it separately on all electric log correlations and in all text discussions, where they informally referred to it either as the "Upper Thermopolis shale" or as the Nefsy shale.

NOMENCLATURE

The term "Thermopolis shale" is currently used in three principal ways. The U. S. Geological Survey applies it to all the strata between the Cloverly formation and Mowry shale of Darton and considers the Muddy sandstone a medial member. The Wyoming Geological Association and most petroleum geologists use the term Thermopolis only for the shale and siltstone unit below the Muddy, recognize the Muddy sandstone as a separate formation, refer the shale unit above the Muddy and below the Mowry of Darton to the Mowry in theory, and call it by an informal name in practice. Finally, a few have excluded the rusty beds from the basal part of the Thermopolis and have included them with the nonmarine Cloverly formation. How the names should be applied has thus been a matter of divided opinion, and many convictions have been partially governed by the particular area in which they were formulated.

The status of the Muddy sandstone appears to be the key to much of this nomenclatorial muddle, for if it is not worthy of formational status, the old usage of the Thermopolis of Lupton would seem to be adequate. If, on the other hand, the Muddy is significant and important enough to be considered a formation, then the usage of Lupton is obsolete and should not be allowed for a moment to obstruct a more meaningful classification.

Two different stratigraphic concepts of the Muddy sandstone are prevalent. In the first, the Muddy is viewed as consisting of separate and discontinuous sandstone lenses or tongues of dubious correlation which lie isolated within and surrounded by a thick body of black shale. This view implies that the sandstone deposits are of minimal importance in the geologic history, and it would not encourage recognition of the Muddy as a formation. It seems to be exemplified by Sielaff's (1952, p. 133) statement that, "In general the name is applied to any sandstone in the Thermopolis section."

In the second concept, the Muddy is viewed as a single, persistent unit of highly variable lithology which occupies a single stratigraphic interval and records an important historical episode of basin-wide deposition. Subsurface stratigraphic data presented by Burk and others (1956) strongly support this concept, as does all stratigraphic and paleontologic evidence gathered in the present study. These studies indicate that the Muddy is, indeed, a significant and widely occurring, though variable unit that warrants formational designation.

Another excellent indication that the Muddy can be justifiably considered a formation is that it has been successfully mapped in, and adjacent to the Big Horn Basin at scales ranging from 1:48,000 to 1:125,000 (Knappan and Moulton, 1930; Pierce and Andrews, 1941; Pierce, 1948; Rogers and others, 1948; Richards and Rogers, 1951; Hose, 1955).

A third and equally significant reason for recognizing the Muddy as a formation is that many geologists now follow this usage, and it has received popular acceptance as well.

Paradoxically, there appears to be a surprising amount of popular resistance toward formally recognizing the Muddy and establishing a type section for it. Such resistance does not seem to result from any suspicions or convictions that the Muddy is not worthy of formational status, but rather it seems to stem from feelings that the Muddy has been informally recognized for so long that it has attained sufficient eminence to preclude any need for formal recognition. This is suggested, at least, by informal statements from two petroleum geologists who, when asked for comments, issued the following: "As far as establishing a 'type' locality for the Muddy sandstone, I certainly feel this is unnecessary and would add nothing towards its formal recognition as a widespread correlative unit, as the term is widely accepted and well established in the literature," and "I am not impressed personally with the necessity or convenience of setting up a type locality for *Muddy sand.* On the other hand, the Wyoming Geological Association has a volume, 1956, on Wyoming Stratigraphy in which the Muddy sand is carefully defined and correlated by means of stratigraphic and electrical logs, and at the bottom of page 19, Norman K. Mills states, 'Nomenclature of the Muddy sandstone is considered adequate.' "

There is no legal necessity for formally designating a formation. Indeed the Stratigraphic Commission (1956, p. 2007) says only that, "Groups and formations are customarily given formal names." By popular preference, the Muddy will perhaps always retain its current informal formational status. For future workers who may be disturbed by the lack of a type locality for the Muddy, one might suggest that they call the Muddy the Newcastle formation. The Newcastle has a type locality (at Newcastle, Wyoming), and the name has already been applied as far west as the east flank of the Big Horn Mountains (Hose, 1955). However, such a procedure would probably be little recompense. One might alternatively suggest that the future workers visit outcrops nearest the Greybull oil field where the name Muddy was first used. This is the course followed here, and a good exposure of the Muddy near Greybull in N½ Sec. 36, T. 53 N., R. 93 W. (figure 4) is recommended as the reference locality.

Recognition of the Muddy as a formation divides the old Thermopolis shale of Lupton into three parts: the Muddy itself, an underlying unit of black shale containing prominent siltstone beds, and an overlying unit of shale containing a few prominent bentonite beds. Conventional evolution of terminology suggests the elevation of the term Thermopolis shale to a Thermopolis group embracing three formations, but actual usage has already established a different precedent. Workers who have previously considered the Muddy to be of formational rank (Love, 1948; Thompson and others, 1949; Burk and others, 1956) have always restricted the term Thermopolis to the unit of dominantly black shale beneath the Muddy. It seems desirable to follow this precedent here. Thus the term Thermopolis shale is applied only to that part of Lupton's Thermopolis shale which lies below the Muddy sandstone.

The rusty beds are marine or marginal marine sediments which overlie a regional disconformity formed by the initial transgression of the Lower Cretaceous sea into the western interior. They are, therefore, much more closely related to the overlying black shales than to the underlying light-colored massive nonmarine rocks of the Cloverly formation, and they are here considered the lower part of the Thermopolis shale.

Sandstone beds in the basal part of the rusty beds probably represent deposition in estuarine, deltaic, and other local marginal environments produced during the marine transgression. Sandstones in the uppermost part of the underlying Cloverly were deposited mainly in stream channels. The term Greybull sandstone member (Hewett and Lupton, 1917, p. 19) was once given to some sandstone beds in this general part of the section, and inasmuch as the type locality was not designated accurately, it is not now possible to ascertain whether the term referred only to channel sandstones in the upper part of the Cloverly, or to sandstone beds at the base of the rusty beds, or to some of each. Neither the Cloverly nor the rusty beds' sandstones, however, would constitute a unit that would be practical to map, and the inclusion of all the sandstones in this general interval in one unit would involve ignoring the significance of the regional boundary between nonmarine sediments and marine and marginal marine sediments which is marked by a zone of spherulitic siderite. Hence, the term Greybull should not be used beyond the confines of the Greybull oil field where originally it was informally applied to an oil sand.

Recognition of the Muddy sandstone as a formation and concomitant redefinition of the term Thermopolis to apply only to the shale unit below the Muddy leaves the soft black shale unit, which was originally included by Lupton (1916, p. 168) in the upper part of his Thermopolis shale, without a name. What should it now be called? Two courses are open: one would give the unit a new name; the other would include it in the Mowry shale, thus extending the term Mowry down to the top of the Muddy sandstone. As a guide to the most desirable course, we might examine what has been done in the past with the soft black shale unit whenever the Muddy was considered to be of formation rank.

Most workers who have considered the Muddy a formation have followed Love's (1948, p. 113) suggestion that the term Mowry be extended downward to include the soft black shale sequence. Love first applied this classification in the

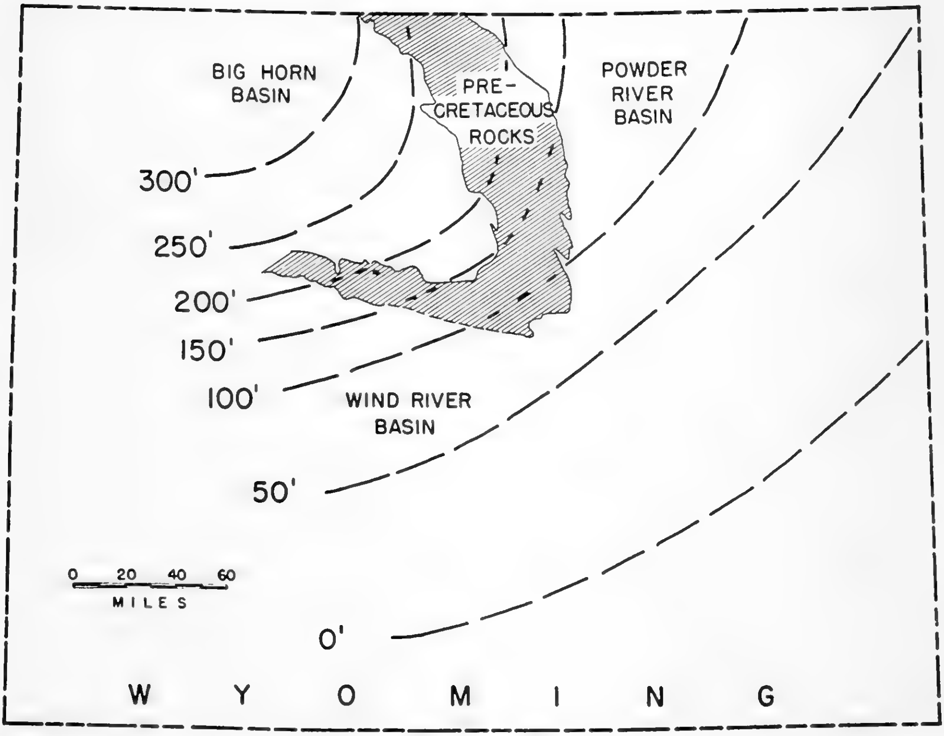

Figure 3. Isopach map of Shell Creek shale in eastern Wyoming, showing decrease in thickness over the mountains which border the Big Horn Basin on the east and south.

Wind River Basin, and it has been extensively used here and in the Powder River Basin. Exactly where this suggestion originated is important, because in the Wind River Basin, and in the Powder River Basin as well, the soft dark shale unit is much thinner than in the Big Horn Basin. Figure 3 illustrates its rapid decrease in thickness southeastward over the mountain uplifts which separate the Big Horn Basin from the Wind River and Powder River Basins. Even in the Big Horn Basin, many workers now follow this classification, but others still find it preferable to continue to recognize the Muddy as a member of the old Thermopolis shale of Lupton rather than to recognize it as a formation and, as a consequence, to so drastically redefine the Mowry shale of Darton. This course fails to recognize the significance of the Muddy sandstone, but the former course expands the Mowry of Darton to a thickness more than twice as great as the beds to which Darton originally applied the term, thus rendering it completely different from the Mowry in parts of Montana where it is still recognized as a siliceous shale.

The issue becomes clearer when one examines more closely what has happened in actual practice whenever the soft black shale sequence has, at least in theory, been included with the Mowry. Even in the Powder River and Wind River Basins where the soft black shale is nearly everywhere considered too thin to map separately on the surface, several informal names have sprung up to distinguish it, in discussions, measured sections, electric logs, and correlation charts, from the siliceous Mowry shale of Darton. This response to necessity is the most convincing evidence possible that separate recognition of this unit is practical in descriptive work. The name most commonly applied to it is "Upper Thermopolis shale," and less commonly, "Lower Mowry" or "Black Mowry." Even the long-abandoned Black Hills term, "Nefsy shale," appeared on a recently published stratigraphic cross-section (Faulkner, 1956, chart). If the term Thermopolis shale is to be firmly restricted to strata below the Muddy, certainly the use, even in an informal sense, of the term "Upper Thermopolis shale" for the soft black shale above the Muddy should be discontinued.

In the Big Horn Basin, the soft black shale is a distinct, mappable unit because of its greater thickness. It has been mapped by many of the same workers who have mapped the Muddy—(Pierce and Andrews, 1941; Pierce, 1948; Rogers and others, 1948). In addition, it is easily distinguishable on electric logs (Mills, 1956, p. 20) where the regional persistence of its contact with the siliceous Mowry shale is especially apparent, verifying that the southeastward thinning results from overlap or convergence within the soft black shale itself and not from facies changes with the overlying siliceous Mowry shale. If the Mowry shale of the Big Horn Basin were redefined to include the soft black shale as well as the siliceous shale to which the name was originally applied, this would not only result in two different regional usages for the term Mowry, but if the units are ever to be distinguished, it would necessitate the ultimate proposal of two new member names.

The alternative course, and the one proposed here, is to accept the Mowry shale as it was originally defined by Darton and to consider as a separate formation the underlying soft black shale sequence which was originally included in the upper part of the Thermopolis shale of Lupton.

Shell Creek shale is the new name proposed for this unit. Its type locality is on the southwest flank of Sheep Mountain anticline about six miles northwest of Greybull, Wyoming (figure 4). The locality is selected for its good exposures, which include well exposed upper and lower contacts, and for the comparative lack of slumping (plate 1a). Although Shell Creek itself flows only within six miles of the type locality, it is one of the nearest geographic features with an unoccupied name. In addition, Shell Creek borders extensive outcrops of the shale, which are prominently visible north across its valley from U. S. Highway 14 between Shell and Greybull, Wyoming, southwest of the type locality.

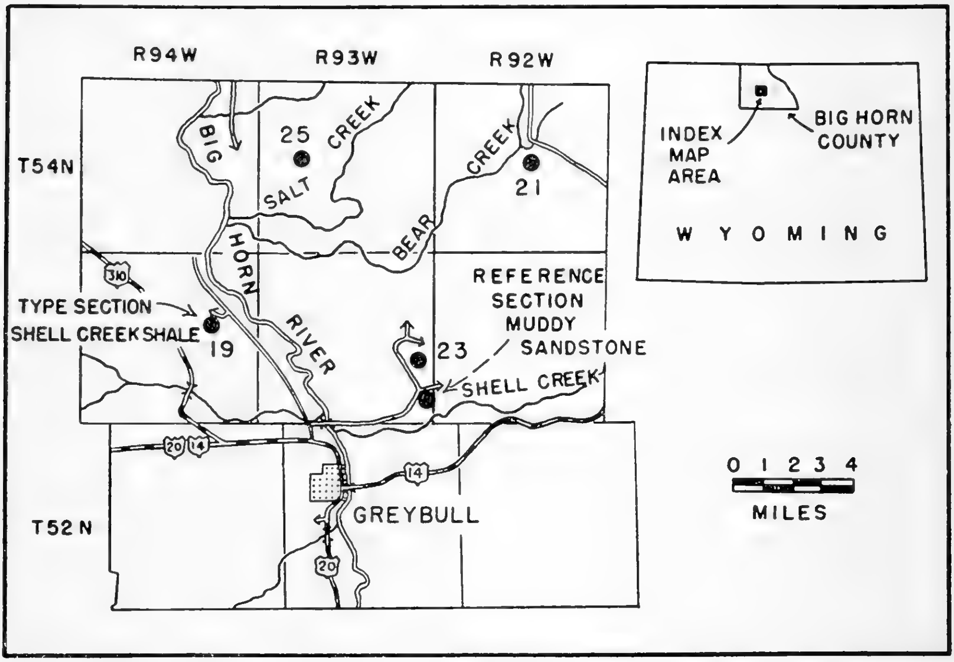

Figure 4. Index map showing type locality of Shell Creek shale and reference locality of Muddy sandstone.

The Shell Creek shale is a mappable unit in the Big Horn Basin. It is also mappable in areas outside the basin to the north and northeast where its thickness is no less than inside the basin (Knappen and Moulton, 1930; Richards and Rogers, 1951). South and east from the basin, however, the Shell Creek equivalent thins out toward the margin of the sea in which it was deposited and is overlapped by the siliceous shale of the Mowry. In these areas, it is thin, and although it is distinguishable in good exposures and on electric logs, it is not generally considered mappable at the scale on which most field mapping has been done. Therefore, although the Shell Creek equivalent is recognized south and east of the Big Horn Basin for purposes of discussing the historical geology, sufficient work has not been done to extend the name formally into these areas at the present time. It remains for future work to determine whether refined scales of mapping will require its formal recognition outside the basin to the south and east. Meanwhile, in these areas where the thin Shell Creek equivalent occurs, all the shale above the Muddy preferably should not be lumped under the term Mowry shale with no explanation, for this is misleading. The Shell Creek equivalent should be differentiated, at least informally, wherever it is found.

STRATIGRAPHIC DESCRIPTIONS

Thermopolis Shale

The Thermopolis shale, as defined here, includes only that part of Lupton's (1916, p. 168) Thermopolis shale which lies below the Muddy sandstone and is about 300 feet thick in the Big Horn Basin. It consists of black shale, the basal member of which contains tan and rusty-weathering interbedded siltstones and sandstones about 120 feet thick, commonly called the rusty beds. The shale sequence above the rusty beds is divided near the middle into lower and upper parts by a tan-weathering silty shale about 30 feet thick. The lower shale, below the middle silty shale, contains a few thin ironstones, siltstones, and silty limestones throughout, and dahllite concretions in its lower part. The upper shale, above the middle silty shale, is generally darker and contains nearly no siltstone or limestone. These four informal members—the rusty beds, lower shale, middle silty shale and upper shale—are easily recognizable, even from a distance, by their weathering characteristics. The rusty beds and middle silty shale weather to tan and brown slopes with small ridges or benches caused by thin siltstone or limestone beds. The lower shale locally contains a few resistant beds, but, like the upper shale, it weathers to dark gray slopes.

RUSTY BEDS AND THE BASAL CONTACT

The rusty beds are composed mainly of interlaminated and very thinly interbedded dark shales and gray siltstones, which range from lenticular beds showing delicate lamination and cross-lamination to laminae, broken and contorted on a very small scale. They contain much carbonaceous material and the castings and trails of burrowing organisms. The rusty beds also generally contain some brown shale and a few thin beds of ironstone, commonly associated with cone-in-cone structures, and flaggy or cross-bedded sandstone and sandy limestone. Typically, these thin beds are very extensive and some can be traced several miles. Thicknesses of individual lithologic units, distinguishable in measuring, and of intervals between key beds, are remarkably consistent over wide areas. In their basal part, the rusty beds commonly contain thicker, brown-weathering sandstone beds which are more local in extent.

Two excellent exposures of the rusty beds near Thermopolis, Wyoming exemplify the lateral uniformity of the entire sequence and the persistence of even the very thin ironstone beds within it. One of these is the type section, locality 2 (figure 1) on highway 20, about three miles north of the town. The other is locality 8 on the east side of the Big Horn River, immediately southeast of the town. The exposures are about three miles apart. At both places, the sequences are nearly identical even with respect to the sandstone beds in the basal portion. The most impressive similarity, however, is the occurrence of four, half-foot ironstone beds in the shale and siltstone sequence above the basal sandstone beds. In both localities, the ironstones occur at intervals of 9, 15, 28, and 42 feet above the base of the interlaminated shale and siltstone unit. Thus, these thin beds are remarkably persistent and extensive.

The upper contact of the rusty beds is chosen at the top of a flaggy siltstone unit below a 30-foot shale containing a bed of dahllite concretions. Above this shale is another 5-foot brown-weathering siltstone unit. All of these beds can be traced widely in the Big Horn Basin. The siltstone and sandstone beds in the upper part of the rusty beds do not interfinger with the overlying lower shale.

Many criteria differentiate the rusty beds from the underlying Cloverly formation. The rusty beds consist of dark-colored, laterally persistent, generally thinly bedded strata, whereas the Cloverly consists mostly of light-colored, highly variable, massive claystones, siltstones, and sandstones. The contact at the type locality is illustrated in plate 1b. In spite of their gross differences, however, the precise contact between the rusty beds and the Cloverly is difficult to select consistently in the Big Horn Basin. Typically, the rusty beds grade downward near their base into an interval containing sandstone beds several feet thick. Unlike most beds in the main part of the rusty beds above, the beds in this interval are variable locally and show lateral changes in thickness and sequence. In some places sandstone beds overlie or are interbedded with rusty beds similar to those above them. In other places, sandstones, or beds of black carbonaceous shale, or slabby siltstone like those in the rusty beds may actually underlie beds of light-colored reddish or tan claystones and siltstones, which appear more like the underlying Cloverly. The variable sequence comprises an interval which may be as much as 35 feet thick below the more typical rusty beds strata.

Elsewhere in the western interior where Lower Cretaceous transgressive sediments overlie Lower Cretaceous nonmarine sediments, tiny iron oxide pellets occur in the rocks, particularly the claystones, immediately below the contact. In outcrop, the pellets appear as profuse tiny orange dots in a light matrix. Analysis of unoxidized pellets from drill cores in the Black Hills has shown them to be spherulites composed of siderite. Here the spherulites occur in the nonmarine rocks immediately below the base of the transgressive Fall River sandstone, and in the Colorado Front Range foothills, they occur in the uppermost part of the Lytle formation immediately below its disconformable contact with the transgressive South Platte formation (Waagé, 1958, p. 75). Along the southeastern flank of the Big Horn Mountains, spherulites occur in the strata immediately below the rusty beds-Cloverly contact (MacClintock, 1957, p. 45). They also occur immediately below the contact on the east flank of the Big Horn Mountains at locality 26 and in the northern part of the Wind River Basin at locality 17. The spherulites in all these areas presumably were formed in like environments, proximal to the transgressing Lower Cretaceous sea. Thus they are believed to mark a contact of regional extent, upon which lie rocks deposited during or after the marine transgression.

In the Big Horn Basin, spherulites occur below the thin variable sequence at the base of the rusty beds, and they are the most useful criterion in selecting a reasonably consistent contact between the Cloverly formation and the Thermopolis shale. They generally occur throughout an interval three to five feet thick, and they are best preserved and most common in claystones, although they also commonly occur in siltstones and sandstones. Claystones containing them commonly weather reddish-orange. The strata immediately above the spherulite-bearing rocks are not everywhere marine; most were probably deposited in transitional environments marginal to the transgressing sea. However, the change at the contact is most significant. The rocks above it were deposited under entirely different conditions from the rocks below it. This is one of the principal reasons that the rusty beds should not be placed in the Cloverly formation.

Although siderite spherulites are distributed widely in the interior region, their occurrence in many local areas is spotty. When absent, they can usually be found in a short distance laterally along the outcrop. The contact can usually be chosen with moderate accuracy, even where the spherulites cannot be found, by comparing rock types which consistently occur above the contact elsewhere. Comparatively thick sandstone units in the variable interval below more uniform thinly bedded rusty beds generally belong with the rusty beds, but local channel sandstones in the uppermost part of the Cloverly are important exceptions. Sandstones above the contact are generally hard, fine-grained, and weather rusty-brown, whereas those beneath the contact are commonly friable, light gray, silty, and fine- to coarse-grained. Very thinly bedded shaly siltstones which weather to light gray slabs belong in the basal part of the rusty beds; they have never been found below the contact. Peat beds and other dark-colored strata with much carbonaceous material generally belong in the rusty beds, but some Cloverly sediments, especially those adjacent to channel deposits, contain profuse carbonaceous material. Additional boundary criteria can generally be recognized locally, but regionally, the spherulites provide the most consistent criterion.

In the Colorado Front Range foothills, spherulites occur below a sharp disconformity, but in the Big Horn Basin, the change they depict seems gradual in most places, apparently because deposition here was more continuous. The transitional change from nonmarine to marginal conditions in the basin and the apparent lack of a clear-cut break in many places makes the spherulites particularly valuable.

In some places on the northeastern flank of the basin, not just one, but two beds contain spherulites. These have been found as much as 25 feet apart. They obviously represent a repetition of environmental conditions at the sea's margin, and they are another indication that deposition was probably more continuous here than in most other areas. Where two spherulite-bearing beds occur, the contact is drawn on the lower one, inasmuch as this is the first indication of environmental change. That this lower zone, where two occur, might be locally absent, however, illustrates that the spherulites are not altogether infallible as a precise boundary criterion in a single outcrop. They are an environmental indicator and have no time value within the limits of time required for the transgression.

Siderite spherulites occur locally in other Cretaceous rocks in the interior. K. M. Waagé (personal communication) reports finding them 40 feet below the top of the Cloverly formation at one locality in the Big Horn Basin and in the Newcastle formation at a few localities in the Black Hills. Merriam (1957, p. 12) reported siderite pellets from the Cruise sandstone and Huntsman shale in Kansas. However, the unusually wide persistence and concentration of the spherulites at the base of transgressive Lower Cretaceous sediments gives them considerable value for consistent lithogenetic correlation.

LOWER SHALE

The member above the rusty beds is about 90 feet thick in the Big Horn Basin. It consists predominantly of fissile, commonly silty shale that generally contains a few very thin sandstone, ironstone, or sandy limestone beds. The shale weathers to a medium-gray, commonly crusty surface which differentiates it from the rusty-weathering strata below. A five-foot siltstone unit about 30 feet above the base of the unit weathers tan. Round dahllite concretions, commonly the size of golf balls, occur in the shale below this siltstone. In the northern part of the basin, dahllite concretions also commonly occur in one or two other horizons higher in the lower shale. These higher concretions, however, are commonly botryoidal rather than round. Bentonite beds are rare, but a single greenish half-foot bed in the upper part can be traced from Tensleep (locality 15) about 60 miles northwest to Five Springs Creek (locality 20).

MIDDLE SILTY SHALE

About 30 feet of tan- and brown-weathering strata similar to the rusty beds separate the gray slopes of the lower shale from those of the upper shale. This unit contains gray and tan silty shale, and thin siltstone and silty limestone beds. It is somewhat more resistant to erosion than the shales above and below, and it commonly forms a slight ridge or bench. Beds within it, like those of the rusty beds and lower shale, are persistent over wide areas. The contact with the upper shale is abrupt (plate 1c).

At Muddy Creek on the eastern flank of the Big Horn Mountains (locality 26), the middle silty shale is exceptionally thick, 45 feet, and consists of three striking cyclic repetitions of beds. Each cycle consists of silty shale in its lower part which grades into thinly bedded siltstone in its upper part. Two of the cycles are capped by beds of silty limestone.

UPPER SHALE

The uppermost member of the Thermopolis shale is about 110 feet thick in the northern part of the basin and about 75 feet thick in the southern part. It consists of fissile black shale which contains an extraordinarily small amount of silt. It generally contains some iron-stone beds but very few siltstone beds. Commonly, one or two very thin bentonite beds occur in the upper 20 feet. It is overlain by the Muddy sandstone.

In some places in the Big Horn Basin, the contact with the overlying Muddy sandstone is sharp, and in other places, it is somewhat gradational. The shale at the extreme top of the upper shale commonly becomes very silty. Several feet of interbedded black shale and light gray siltstone may lie below more prominent siltstone or sandstone beds of the Muddy. Where the interbedded siltstone and shale beds occur, the Muddy contact is chosen at their base, because this horizon depicts the first change that heralds Muddy conditions, and because it is the most consistent one available. Certainly the base of the lowest sandstone is not satisfactory as a contact, because in some places the Muddy contains almost no sandstone beds at all. Where the basal unit of the Muddy comprises non-resistant siltstone and shale beds, the weathered contact is generally obscure and must be exposed with a shovel. In most of these places, there seems to be no break in sedimentation between the Thermopolis and the Muddy. Nowhere, however, are these units known to intertongue with each other.

TYPE SECTION

When Lupton (1916, p. 168) named the Thermopolis shale for exposures in the area of the town of Thermopolis, Wyoming, he designated no specific type section but presented a supplementary lithologic description generalized from subsurface samples from near Basin, 50 miles north. A detailed description of the Thermopolis in its type area has never been published, and actually, the entire sequence is not well exposed in any one place near the town of Thermopolis. The lower part of the redefined Thermopolis shale is best exposed in outcrops about three miles north of the town on U. S. Highway 20 and the upper part, northeast across the Big Horn River on both flanks of Lucerne anticline.

FOSSILS

Macrofossils are uncommon in the Thermopolis shale of the Big Horn Basin. Fossil leaves occur in the extreme lower, variable portion of the rusty beds just above the contact at some localities, and a few poorly preserved casts of what may be nonmarine pelecypods and gastropods occur in a basal sandstone at locality 20. Love and others (1945) mentioned nonmarine fossils from the rusty beds of the Wind River Basin and these, too, undoubtedly came from the extreme lower variable portion.

Fragments of vertebrae, ischium and armor plate of a crocodile from the lower shale at localities 15, 24, and 20 were identified by J. T. Gregory, Yale University, as closely resembling *Coelosuchus reedi* Williston. *Inoceramus comancheanus* Cragin was collected from the upper shale about 25 feet below the Muddy sandstone at locality 21 by K. M. Waagé (personal communication), and prismatic *Inoceramus* shell material occurs in the upper shale at other localities on the northeastern flank of the basin. Trails and castings of burrowing organisms are abundant throughout the rusty beds and are common in the middle silty shale, but actual remains have never been found.

No foraminifera were found in samples from the rusty beds, lower shale, and middle silty shale. However, one microfossil, a tintinnid about 0.10 mm. long, nearly always flattened in preservation, is common throughout these three members. This tiny marine protozoan also occurs in the lower portion of the upper shale. Arthur S. Campbell, St. Mary's College, examined specimens of this tintinnid from the rusty beds and concluded that it is similar to *Calpionella,* but probably represents an undescribed genus.

Teeth and bone fragments of fish also occur in the rusty beds, lower shale, and middle silty shale and less commonly in the upper shale. The uppermost portion of the upper shale in some places contains a few sponge spicules. No ostracods were found in the Thermopolis shale.

Arenaceous foraminifera occur throughout the upper shale. The following 24 species have been found:

Alveolophragmium linki (Nauss)
Ammobaculites euides Loeblich and Tappan
Ammobaculites fragmentarius Cushman
Ammobaculites obliquus Loeblich and Tappan
Ammobaculites petilus n. sp.
Ammobaculites subcretaceus Cushman and Alexander
Ammobaculites tyrrelli Nauss
Ammobaculoides phaulus Loeblich and Tappan
Ammobaculoides whitneyi (Cushman and Alexander)
Ammomarginulina cragini Loeblich and Tappan
Bimonilina variana n. sp.
Glomospira reata n. sp.
Glomospira tortuosa n. sp.
Haplophragmoides gigas Cushman
Involutina kiowensis (Loeblich and Tappan)
Lituotuba sp.

Miliammina ischnia Tappan
Miliammina inflata n. sp.
Miliammina cf. *M. sproulei* Nauss
Saccammina alexanderi (Loeblich and Tappan)
Spirolocammina subcircularis (Tappan)
Trochammina depressa Lozo
Verneuilinoides kansasensis Loeblich and Tappan
Verneuilinoides hectori (Nauss)

All but one of these species occur in the upper part of the upper shale, but only the following six species occur in the lower part. The first of these has been found only in the lower part, the next three are much more common in the lower part than in the upper part, and the last two are common throughout:

Miliammina ischnia
Miliammina inflata
Miliammina cf. *M. sproulei*
Spirolocammina subcircularis
Trochammina depressa
Verneuilinoides kansasensis

Of the 18 species that have been described previously, the following nine are known only from the Kiowa shale of Kansas or Lower Cretaceous rocks of Texas:

Ammobaculites euides
Ammobaculites obliquus
Ammobaculites subcretaceus
Ammobaculoides phaulus
Ammobaculoides whitneyi
Ammomarginulina cragini
Saccammina alexanderi
Trochammina depressa
Verneuilinoides kansasensis

The following eight previously described species are known only from the Joli Fou shale and its correlatives in western Canada or Lower Cretaceous rocks of northern Alaska. In Canada, the Joli Fou and equivalent strata which contain most of these species are referred to as the *Haplophragmoides gigas* zone (Wickenden, 1941, p. 153):

Alveolophragmium linki
Ammobaculites fragmentarius
Ammobaculites tyrrelli
Haplophragmoides gigas
Miliammina sproulei
Miliammina ischnia
Spirolocammina subcircularis
Verneuilinoides hectori

One species, *Involutina kiowensis,* has been reported both from Kansas and from northern Alberta.

The intimate mixture of Gulf Coastal and boreal faunas in the upper shale indicates that the Gulf Coast and boreal seas were connected and that the upper shale is coextensive with the Kiowa shale of Kansas and the Joli Fou shale of

Alberta. All 24 species which occur in the upper shale, including those of boreal provenance, those of Gulf Coastal provenance, and those described as new or undetermined, are considered to constitute the fauna of the *Haplophragmoides gigas* zone in Wyoming. Strata in the lower part of the upper shale, which contain only six of the species, are a biofacies of the strata which contain all but one of the species and will be referred to as the *Verneuilinoides kansasensis* biofacies of the *Haplophragmoides gigas* zone after their most common species. The strata in the upper part, which contain the nearly complete *H. gigas* fauna, including the most common species of the Kiowa and Joli Fou shales, will be referred to as the *Ammobaculites euides* biofacies of the *H. gigas* zone after their most common species. The *H. gigas* zone thus embraces the upper shale member of the Thermopolis shale, although the species *H. gigas* itself does not occur throughout the entire interval in Wyoming. Southward across the Big Horn Basin, the *Verneuilinoides kansasensis* biofacies comprises an increasingly greater proportion of the upper shale.

Muddy Sandstone

Above the black shales of the Thermopolis and below the black shales of the Shell Creek lies a highly variable unit consisting of siltstone, sandstone, shale, and bentonite beds, and locally containing beds of lignite and chert pebble conglomerate. In many places, the term Muddy sandstone is actually a misnomer inasmuch as the unit does not consist predominantly of sandstone. In some places, sandstone beds are almost altogether absent. The Muddy is generally 30 to 50 feet thick in the Big Horn Basin, but its extreme range is from a few feet to more than 100 feet. Thus, it is a distinctive but laterally variable unit which contrasts with the dominantly shale units below and above, whose beds are notably persistent and uniform. However, the Muddy as a heterogeneous unit is equally widespread. The mistaken belief that it must everywhere be a sandstone has led some workers to the erroneous concept that it occurs sporadically.

In the southern part of the Big Horn Basin, the Muddy is more variable, both in thickness and lithology, than in the northern part. Great variations of thickness commonly take place within only a few hundred feet along the outcrop. Local thick lenses of blocky-weathering sandstone account for the more spectacular variations. Localities 14 and 17 (figure 1), for example, are easily accessible areas where prominent sandstone lenses about 50 feet thick and a few hundred feet wide are well exposed. In spite of variations in thickness and lithology, the Muddy is everywhere present, although in places it lacks sandstone beds which give it topographic expression.

The Muddy in the northern part of the basin is basically different. Its striking white or very light gray color is caused by a greater content of bentonite. Bentonite occurs in distinct though rarely pure beds and as matrix for sandstones and siltstones. Scattered rounded and polished chert and quartzite pebbles up to two inches in diameter commonly weather out of the white bentonitic sandstones. Thick, lenticular, hard, blocky-weathering brown sandstone beds appear to be absent. Thicknesses and rock types are somewhat more consistent laterally here than in the southern part of the basin, and facies changes are more gradual.

The contact of the Muddy with the overlying Shell Creek shale is commonly gradational through a thin interval, but nearly everywhere it is easily selected at a horizon above which soft black shale predominates.

FOSSILS

Several kinds of fossils occur sparsely in the Muddy. Richard A. Paull (personal communication) has collected specimens of vertebrates, marine invertebrates, and plants. The plant remains, identified by Erling Dorf, Princeton University, are:

Cinnamomum scheuchzeri Heer
Eugenia primaeva Lesquereux (?)
Salix sp.

The vertebrate remains, identified by D. H. Dunkle, United States National Museum, are:

shark teeth and spines;	*Asteracanthus* sp. cf. *Hybodus* sp. cf. *Synechodus* sp.
chimaeroid fish spines;	cf. *Edaphodon* sp.
holosteans scales;	cf. *Lepidosteus* sp. *Amia* sp.
teleostei fragments	
turtle fragments;	cf. *Glyptops* sp.
crocodile teeth;	*Crocodylus* sp.

Invertebrate fossils found in the Muddy include *Inoceramus* sp. and other clams which were not determinable. Also, one species of foraminifera, *Miliammina ischnia,* occurs in a shale within the Muddy at locality 7. Silty and sandy shale beds transitional with the underlying Thermopolis shale at localities 19 and 22 contain foraminifera of the *Ammobaculites euides* biofacies. A silty shale transitional with the Shell Creek at locality 16 contains *Spirolocammina* sp. Silty shale beds in the uppermost part of the Muddy at locality 29 contain *Miliammina ischnia* and what appears to be *Spirolocammina subcircularis,* a Thermopolis shale species.

Shell Creek Shale

Above the Muddy sandstone and below the siliceous Mowry shale of Darton lies the Shell Creek shale, a unit of dark gray and black shale containing a few ironstone beds and concretions and a few prominent white bentonite beds. Commonly, some of the shale beds are silty, and a cross-bedded sandstone bed was found at one locality (Gypsum Creek, locality 22) in the Big Horn Basin. Bentonite beds are generally less than three feet thick, but beds as thick as nine feet occur. The thicker bentonite beds are widely extensive and are of value in correlation.

In most well exposed outcrops in the Big Horn Basin, the contact of the Shell Creek with the overlying siliceous Mowry shale is easily chosen at the base of a silver-weathering ledge of the basal Mowry. Everywhere, it is persistent laterally, and in most places it marks a sharp vegetation change. Locally at the contact, large calcareous concretions with cone-in-cone structure occur. Difficulties in mapping this contact are understandably encountered in some places where it is poorly exposed, but the Mowry shale of Darton is an unusually resistant, distinctively weathering unit, and its peculiarities of hardness, color, and topographic expression easily distinguish it nearly everywhere from the underlying soft dark Shell Creek shale. In general, these units can be distinguished as easily as any two formations of comparable thickness in the Big Horn Basin.

The regional persistence of the contact is more apparent on electric log cross-sections (Mills, 1956, chart) than on surface cross-sections. On electric logs, the bed with high resistivity on which the contact is chosen can be traced confidently for great distances. This verifies the conclusion drawn independently from outcrop studies that thickness changes in the Shell Creek shale result from overlap or convergence within the unit itself and not from facies changes with the overlying Mowry shale. The base of the Mowry shale appears to be a remarkably uniform horizon.

In the Big Horn Basin, the Shell Creek shale is about the same thickness as the Mowry shale of Darton, ranging from 200 to more than 300 feet. Southeastward, however, it thins rapidly. Much of the decrease in thickness appears to take place across areas of the Big Horn and Owl Creek Mountains where only pre-Cretaceous rocks now occur (figure 3).

FOSSILS

No macrofossils were found at the type section of the Shell Creek shale, but a few fossils of vertebrates and invertebrates were collected in an area north of Shell Creek at localities 21 and 23 (figure 4). The fauna occurs principally in two beds of ironstone concretions whose stratigraphic positions are 160 and 187 feet above the base of the Shell Creek shale. J. T. Gregory identified the vertebrate fragments as scales of a garpike-like fish (which is either *Lepidotes* sp. or *Lepidosteus* sp.) and as pieces of a turtle shell, *Glyptops* sp. J. B. Reeside Jr., U. S. Geological Survey, identified ammonites as *Neogastroplites haasi* Reeside and Cobban, and stated (personal communication) that they represent the lowest of five zones of *Neogastroplites* which he recognizes in the Lower Cretaceous of the western interior. H. B. Roberts, U. S. National Museum, identified two kinds of crabs, *Homolopsis* sp. and *Dakotacancer* sp. In addition, this fauna includes at least one unidentified species of *Inoceramus.*

The following 12 species of foraminifera have been found in the Shell Creek shale:

Bimonilina variana n. sp.
Eggerella sp.
Glomospira glomerosa n. sp.
Haplophragmoides multiplum Stelck and Wall
Haplophragmoides uniorbis n. sp.
Miliammina ischnia Tappan
Miliammina manitobensis Wickenden
Spirolocammina planula n. sp.
Trochammina gatesensis Stelck and Wall
Trochammina umiatensis Tappan
Verneuilina canadensis Cushman
Verneuilinoides hectori (Nauss)

Of these, the following five have been found only in the uppermost portion of the Shell Creek shale in the northern part of the Big Horn Basin:

Eggerella sp.
Glomospira glomerosa
Haplophragmoides multiplum
Haplophragmoides uniorbis
Trochammina umiatensis

The remainder occur commonly throughout the sequence. The fauna is similar to the fauna of the Thermopolis shale in that it includes many of the same genera, and that all species are arenaceous. Only three species, *Bimonilina variana, Miliammina ischnia,* and *Verneuilinoides hectori,* are common to both formations. All previously described species are known only from western Canada or northern Alaska. Thus the fauna of the Shell Creek shale is entirely of boreal province, whereas the fauna of the upper shale member of the Thermopolis below represents both the boreal and Gulf Coastal provinces.

Radiolaria occur in the upper third of the Shell Creek shale in the Big Horn Basin and range upward into the Mowry shale. The bell-shaped *Clathrocyclas irrasa* n. sp. is the most distinctive. The remainder are white, opaque spheres of two kinds, 0.05 mm. to 0.19 mm. in diameter. Some are comparatively smooth and finely perforate, and others have a somewhat spiny surface and are more coarsely perforate throughout. In addition, several kinds of siliceous sponge spicules occur commonly throughout the Shell Creek. No ostracods were found in the Shell Creek shale.

BENTONITE BEDS

Most bentonite beds represent individual falls of volcanic ash which accumulated very rapidly. Their basal contacts are sharp. Shards are coarsest in their lower parts and decrease in size upward. Upper contacts are gradational with overlying shale, indicating that the last of the ash settled out slowly, accompanied by increasing proportions of other clastic material. Some beds extend over thousands of square miles and thus represent large volumes of ash indicating enormous volcanic eruptions.

Because individual bentonite beds were deposited everywhere simultaneously, their sharp basal contacts are excellent time horizons and they enable precise correlation. Many Shell Creek shale bentonite beds are regionally extensive, but others, particularly thin ones, are comparatively local. Inasmuch as even the thinnest beds probably fell universally in large areas, portions must have been eroded by currents after deposition and mixed with, and masked by, other clastic material. Some bentonite beds are only partly reworked and contain intermixed dark shale.

Bentonite beds with peculiar characteristics are especially valuable, for they can be correlated confidently without physical tracing. One such bed in the Thermopolis, Wyoming area is exceptionally thick and has a dark brown-weathering lower portion. It can be traced over much of the southern part of the Big Horn Basin, and, by virtue of its brown-weathering portion, it can be recognized tentatively in the northern part of the Wind River Basin (figure 5). A similar though much thinner bentonite bed whose upper part weathers dark brown, occurs in the upper part of the Shell Creek in the northern part of the Big Horn Basin.

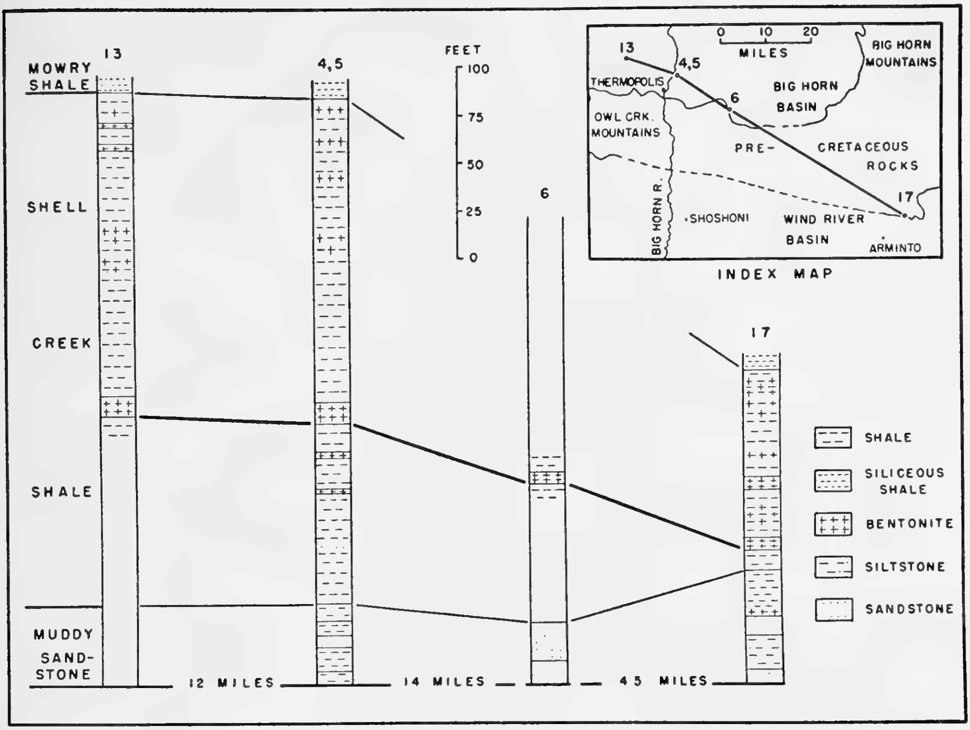

Figure 5. Tentative correlation of a distinctive Shell Creek shale bentonite bed between the Big Horn and Wind River Basins.

Half-foot shale samples were taken immediately below and above five bentonite beds in the Shell Creek and Thermopolis shales in different localities, in order to survey the effect of ash falls on the benthonic foraminiferal faunas. Foraminifera were absent above only one of the bentonites and here some sponge spicules occurred. Immediately above three of the bentonites, a few specimens of some of the species which occurred below them were found. This shows that after ash falls had buried the bottom foraminiferal populations, the new bottom surfaces were repopulated rapidly by some of the same species. The results of the samples taken above and below the fifth bentonite, a bed in the upper part of the Thermopolis shale, were entirely unexpected. No foraminifera occurred immediately below this bentonite, but immediately above it they were profuse. Here the change in bottom conditions must have been distinctly favorable for the benthonic fauna. Table 1 summarizes the results of the five sets of samples.

Locality	Bentonite position	Thickness	Species below		Species above	
13:	Shell Creek, 137′ above Muddy:	0.5′:	*S. planula*	(12)	(4)	
			V. canadensis	(3)	(1)	
			M. manitobensis	(3)	—	
			T. gatesensis	(1)	—	
17:	Shell Creek, 50′ above Muddy:	0.5′:	*V. canadensis*	(15)	(8)	
			M. manitobensis	(1)	(6)	
			S. planula	(2)	—	
			sponge spicules		sponge spicules	
7:	Thermopolis, 18′ below Muddy:	1.2′:	*A. euides*	(9)	—	
			A. subcretaceus	(2)	—	
			A. tyrrelli	(1)	—	
			A. phaulus	(1)	—	
			A. whitneyi	(2)	—	
			B. variana	(7)	—	
			I. kiowensis	(25)	—	
			S. subcircularis	(2)	—	
			V. kansasensis	(13)	—	
					sponge spicules	
19:	Thermopolis, 10′ below Muddy:	0.2′:	*A. linki*	(34)	(4)	
			A. phaulus	(2)	—	
			B. variana	(14)	—	
			I. kiowensis	(1)	—	
			T. depressa	(14)	—	
			V. hectori	(4)	—	
			V. kansasensis	(2)	—	
			sponge spicules		—	
					A. euides (1)	
27:	Thermopolis, 18′ below Muddy:	0.7′:		—	*M.* cf. *sproulei*	
				—	*S. subcircularis*	(all abundant)
				—	*T. depressa*	
				—	*V. kansasensis*	

Table 1. Content of samples from half-foot intervals below and above five bentonites. Number of specimens picked is indicated, approximating the relative abundance of each species.

REGIONAL RELATIONSHIPS

RELATIONS TO THE COLORADO FRONT RANGE

THERMOPOLIS SHALE

The Thermopolis shale thins southeastward (figure 6). On the north flank of the Wind River Basin (locality 17) all four members can still be recognized, but farther south the middle silty shale and lower shale rapidly become thin and obscure. The middle silty shale persists possibly as far as Alcova (locality 28), where it may be represented by a resistant 12-foot sandstone and limestone unit, but in outcrops farther southeast, it cannot be discerned, and all the sandy lower part of the Thermopolis is referred to the rusty beds.

The upper shale is much more consistent in thickness than the underlying members, although it, too, thins somewhat southeastward. Concomitantly, the *Verneuilinoides kansasensis* biofacies occupies an increasing proportion of it, and south of the Big Horn Basin the *Ammobaculites euides* biofacies is absent (figure 7). On the south flank of the Wind River Basin (locality 27), foraminifera are common only in the upper part of the upper shale; in the lower part the shale is sandy, a few sponge spicules occur, and foraminifera are rare. Farther southeast at Alcova (locality 28), the entire upper shale is unusually thin, silty, and exceptionally carbonaceous, and foraminifera are absent altogether. Here only a few tiny tintinnids occur. This locality is unusual in that thinly interbedded black shales and gray siltstones of the rusty beds overlie thick, massive, light gray conglomeratic sandstone of the Cloverly with a sharp contact. Cloverly claystones and siltstones which occur farther north are absent.

Southeast at Rock River (locality 29), the *Verneuilinoides kansasensis* biofacies is again present in the upper part of the upper shale. At Iron Mountain (locality 30), the upper few feet again contain the *Ammobaculites euides* biofacies. The sequence at Bellvue, Colorado (locality 18) is similar, containing *A. euides* in the upper few feet. The upper shale member is equivalent to the shaly middle portion of the South Platte formation in the Front Range foothills. South from Bellvue these strata become increasingly sandy (Waagé, 1955, figure 17).

The upper portion of the upper shale equivalents at Bellvue and at Iron Mountain contains thin sandy limestone beds and abundant fossils. Reeside (1923) described this fauna and reported the following species:

Inoceramus comancheanus Cragin
Inoceramus bellvuensis Reeside
Pteria salinensis White
Ostrea larimerensis Reeside
Ostrea noctuensis Reeside
Anchura kiowana Cragin?

Reeside (1923, p. 200) interpreted this to be a northern extension of the Comanchean fauna which Stanton (1922) had shown to become progressively depleted northward from New Mexico and Oklahoma. Farther north in Wyoming and in the Black Hills, the upper shale and its equivalents appear to be almost entirely barren of macrofossils with the local exception of *Inoceramus*

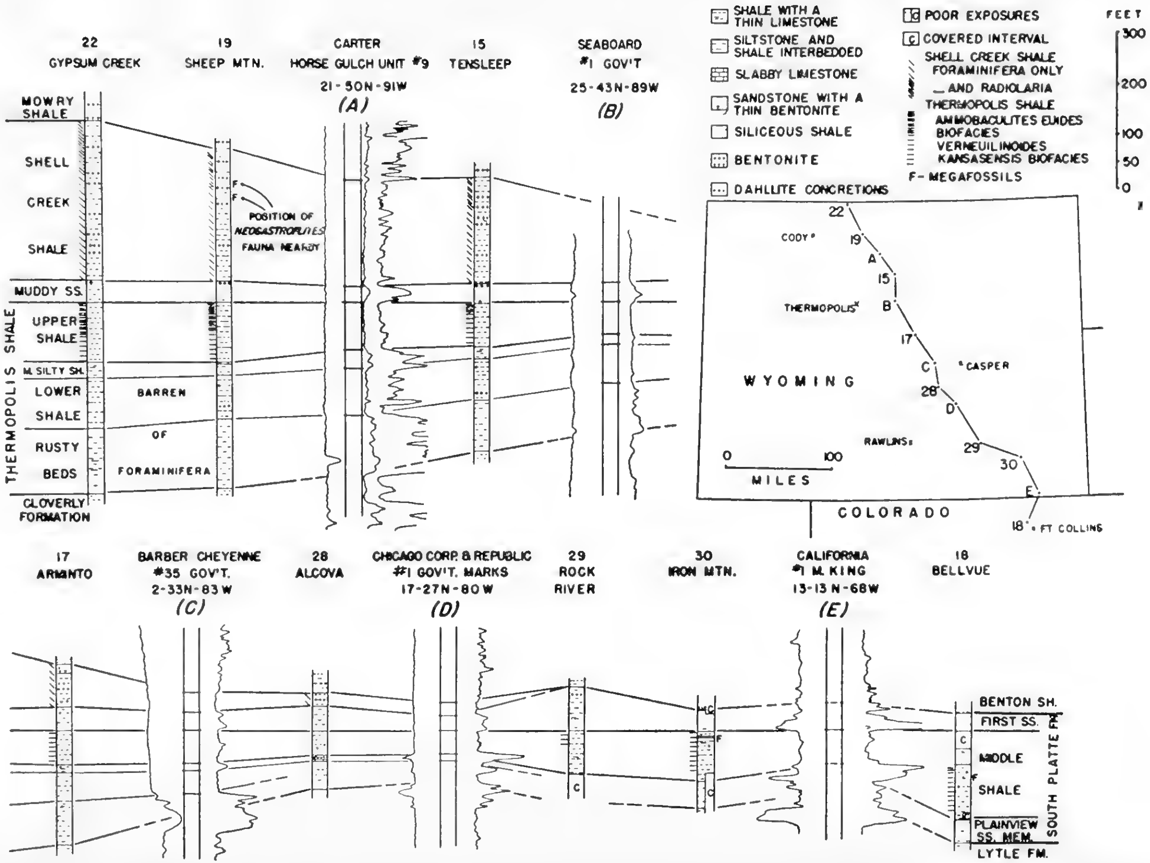

Figure 6. Correlation of the Thermopolis shale, Muddy sandstone and Shell Creek shale between the northern Big Horn Basin and the Colorado Front Range.

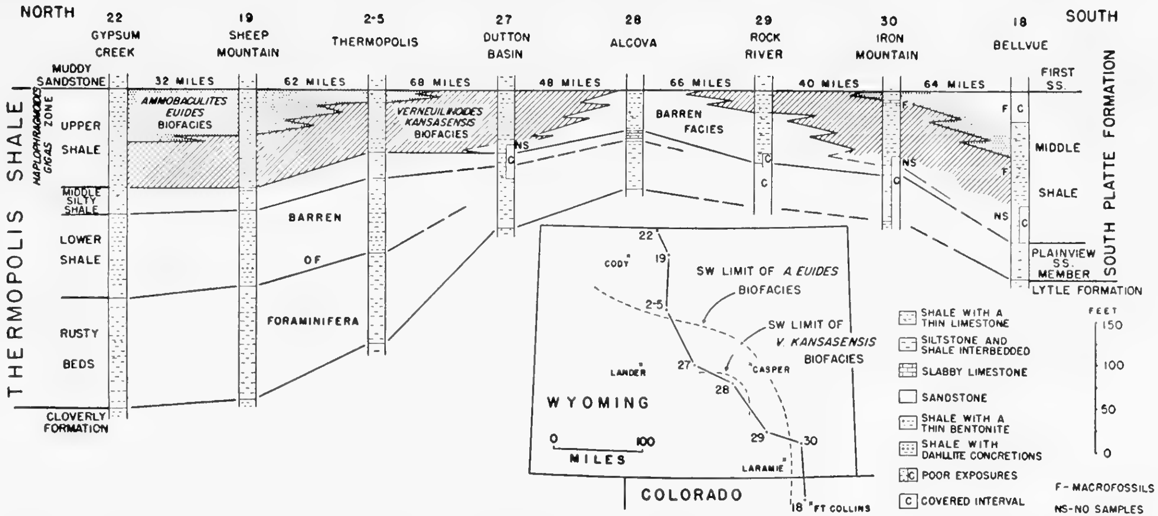

Figure 7. Stratigraphic cross-section of the Thermopolis shale showing faunal changes in the upper shale between the northern Big Horn Basin and the Colorado Front Range.

comancheanus. Still farther north in central Montana, however, Cobban (1951, p. 2176) has reported most of the species described from Colorado by Reeside.

Good outcrops of the lower part of the Thermopolis are scarce between the Wind River Basin and the Colorado Front Range foothills. At Rock River the upper shale is well exposed but the thin rusty beds equivalents are totally covered. Near Douglas (locality 31, not shown on figures 6 and 7), however, more than 40 feet of fucoidal and carbonaceous thin- and medium-bedded sandstone and silty shale of the upper part of the rusty beds is well exposed; below it are less well-exposed, thicker, more resistant beds which help support a prominent hogback. South at Iron Mountain on the east flank of the Laramie Range (locality 30), rusty beds equivalents consist of about 50 feet of resistant brown-weathering interbedded sandstones, siltstones and some shale which form the prominent lower ridge of the Dakota double hogback of the area. In northern Colorado, the Plainview sandstone member of the South Platte formation occupies the same stratigraphic position. It is about 30 feet thick, contains fucoidal markings and carbonaceous material, and it weathers rusty brown. Its lithology is very similar to the rusty beds in northern Wyoming, but it contains more sand and, like the rusty beds in extreme southern Wyoming, it forms a ridge. Light-colored nonmarine strata immediately below it commonly contain iron oxide spherulites. South of the northern Front Range foothills it is absent (Waagé, 1955, p. 42).

MUDDY SANDSTONE

South of the Big Horn Basin, the Muddy remains characteristically variable. At some places, it consists mainly of sandstone beds, but at other places, it consists mainly of siltstone and shale beds. Yet the formation is an easily traceable, persistent stratigraphic unit, occurring always immediately above the *Haplophragmoides gigas* zone of the Thermopolis shale. Its consistent occurrence above these strata and below beds containing the distinctive Shell Creek fauna illustrates that the Muddy everywhere occupies the same position in the stratigraphic sequence, and that as a whole, it is continuous, even though individual beds within it are not. The Muddy can be traced southward into the Front Range foothills where it correlates with the uppermost sandstone of the South Platte formation.

SHELL CREEK SHALE

The Shell Creek shale becomes thinner southward and pinches out altogether in southern Wyoming (figure 6). At Arminto (locality 17) on the north flank of the Wind River Basin, it is only 80 feet thick, and at Alcova (locality 28), where it is only 25 feet thick, the southernmost Shell Creek foraminifera occur. At Rock River (locality 29), the Shell Creek appears to be absent, the siliceous shales of the Mowry resting on thin sandstones and silty shales of the Muddy.

The contact between the Muddy and Shell Creek seems to become increasingly gradational southward. At Alcova, it is particularly difficult to pick but is chosen, as elsewhere, at a horizon below which siltstone and sandstone is dominant and above which black shale is dominant. Possibly the Shell Creek includes some siltstone beds in its lower part near its southern limit. If so, these would probably be included with the Muddy. At Rock River, for example, some of the thin siltstone and shale beds in the uppermost part of the rather thick Muddy sequence possibly correlate with part of the Shell Creek to the north. However, these strata contain only non-diagnostic foraminifera and a few sponge spicules; sponge spicules are known elsewhere from the Muddy as well as from the Shell Creek.

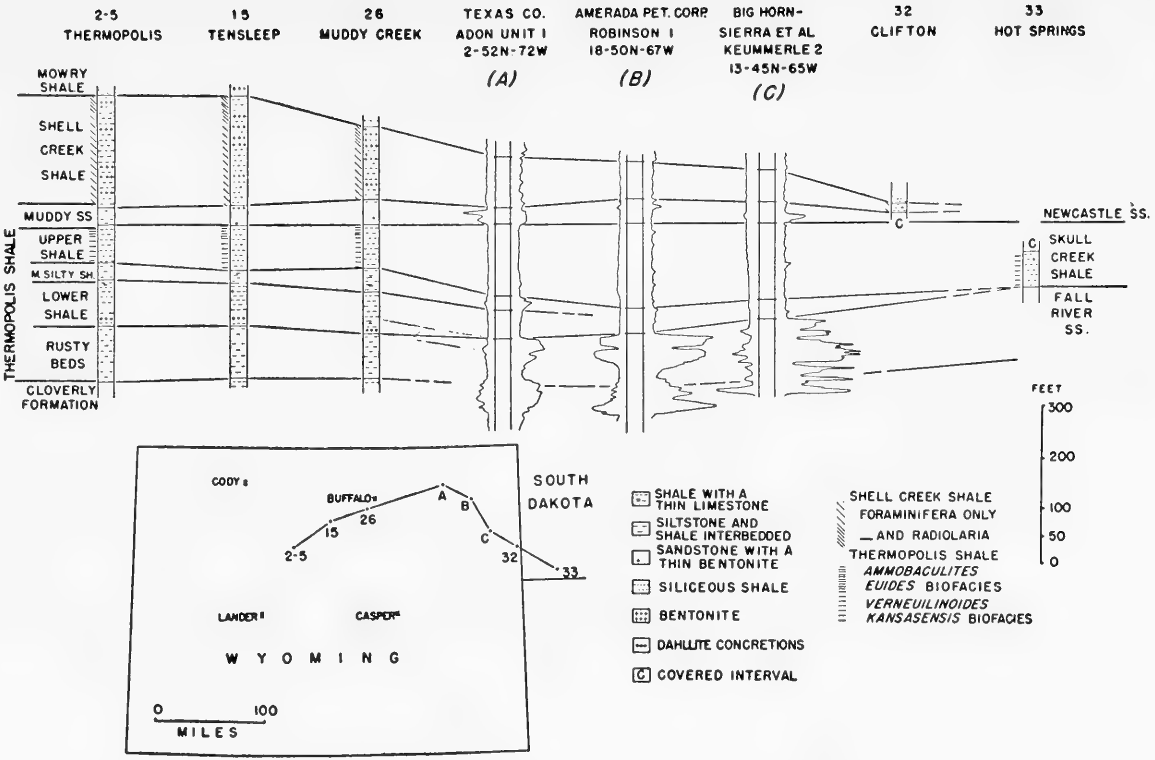

Figure 8. Correlation of the Thermopolis shale, Muddy sandstone and Shell Creek shale between the Big Horn Basin and the Black Hills. Subsurface correlation modified after Hose (1955, pl. 9).

Farther south, no Shell Creek correlatives appear to exist, and it is probably represented by a hiatus at the top of the South Platte formation in the Colorado Front Range foothills.

At Iron Mountain (locality 30) where Shell Creek correlatives are almost certainly absent, the siliceous Mowry shale appears to directly overlie a thick resistant quartzite bed in the upper part of the Muddy. Quartzite rarely occurs in the Muddy to the north where it is overlain by the Shell Creek shale, but south of the Shell Creek pinchout, quartzite is common just below Mowry equivalents. In the Colorado Front Range foothills, quartzite beds usually comprise the uppermost portion of the South Platte formation (Waagé, 1955, p. 40) and help support the first great ridge of the Dakota double hogback.

Relations to the Black Hills

THERMOPOLIS SHALE

On the east flank of the Big Horn Mountains at Muddy Creek (locality 26), four members of the Thermopolis are as easy to recognize as in the Big Horn Basin (figure 8). The rusty beds are slightly thinner, but the middle silty shale is a few feet thicker and has a threefold cyclic character, each cycle grading upward from shale through siltstone to a limestone bed. Eastward across the Powder River Basin, the rusty beds maintain fairly consistent thickness but become progressively more sandy, and in the Black Hills they consist largely of sandstone with some interbeds of shale. The overlying dahllite concretion-bearing shale capped by a six-foot sandstone bed also becomes sandy eastward and gives way similarly to sandstone beds. Together, the equivalents of the rusty beds and overlying 25 feet of the lower shale at Muddy Creek appear to comprise the cliff-forming Fall River sandstone of the Black Hills.

Typically, the Fall River contains some thickly bedded and some thinly bedded flaggy sandstone with abundant fucoidal markings and a little interbedded shale. Its appearance resembles that of the Plainview sandstone of northern Colorado, and like the Plainview, it overlies nonmarine strata which in most places contain iron oxide spherulites immediately below the contact.

Toward the southern Black Hills, the middle silty shale and the upper part of the lower shale become thin and obscure and finally appear to pinch out entirely (figure 8). Toward the northern Black Hills, however, these units maintain their thickness and character, at least in the subsurface (Peterson, 1956, chart), and comprise a significant portion of the Skull Creek shale there.

The upper shale thickens somewhat toward the Black Hills. Northeastward the *Ammobaculites euides* biofacies becomes thicker (figure 9). A complete section of upper shale was not sampled in the Black Hills, and it is not known exactly what proportion belongs in the respective biofacies of the *Haplophragmoides gigas* zone. The upper 60 feet of the Skull Creek shale at locality 37 (figure 9) contains only the *A. euides* fauna, and the lower 60 feet at Hot Springs (locality 33) contains only the *Verneuilinoides kansasensis* fauna (figure 8). At Hot Springs, foraminifera occur down into lowermost Skull Creek strata immediately above the Fall River sandstone. This substantiates electric log correlations that the entire Skull Creek in the southern Black Hills correlates with the upper shale of the Thermopolis. Northward in the Hills, the Skull Creek becomes thicker, not as a result of significant thickening in the upper shale, but as a

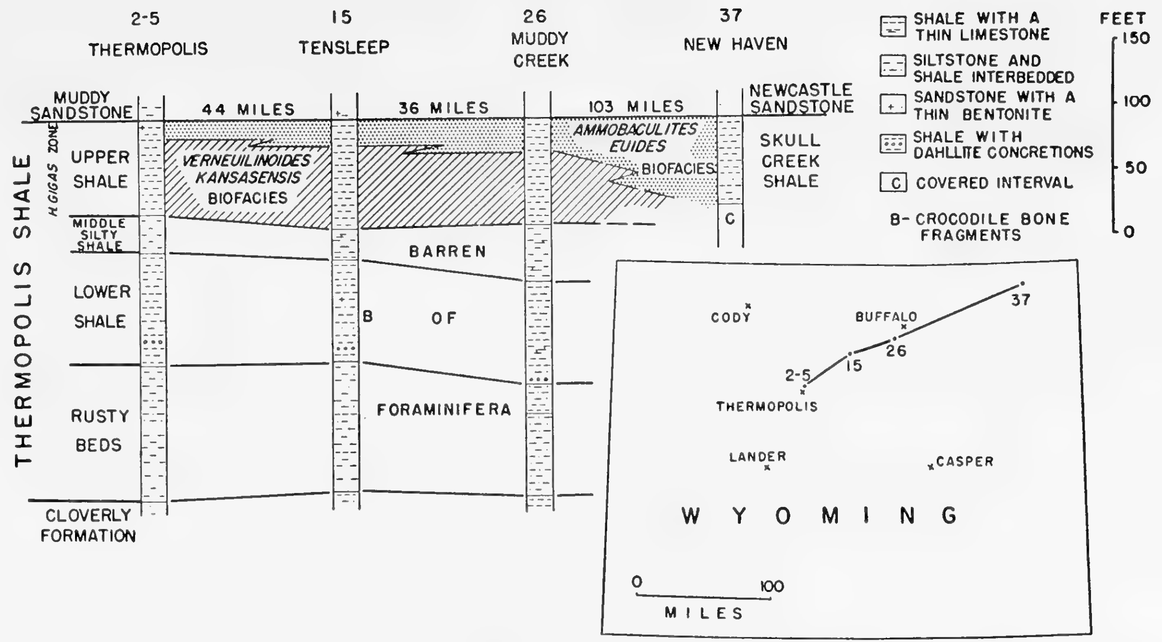

Figure 9. Stratigraphic cross-section of the Thermopolis shale showing faunal changes in the upper shale between the southern Big Horn Basin and the northern Black Hills.

result of the appearance and thickening northward of equivalents of the middle silty shale and the upper part of the lower shale.

MUDDY SANDSTONE

The Muddy sandstone at Muddy Creek (locality 26) consists of soft white sandstone which is similar to the Muddy at Tensleep (locality 15) and No Wood Creek (locality 24). The Muddy extends east across the Powder River Basin into the Black Hills, where it is called the Newcastle formation. Its character remains variable. Grace (1952, p. 14) emphasized that in some places the Newcastle consists predominantly of sandstone and in other places predominantly of siltstone and shale.

SHELL CREEK SHALE

The Shell Creek shale is 135 feet thick at Muddy Creek. Radiolaria occur in the uppermost portion here but were not found elsewhere outside the Big Horn Basin. Eastward, the Shell Creek becomes thinner, and in the Black Hills near Clifton (locality 32), it is only 15 feet thick, but it still contains abundant Shell Creek foraminifera. Apparently, it pinches out a short distance south of Clifton. Near Osage, north of Clifton, this unit was once distinguished separately as the Nefsy shale (Collier, 1922), but the name was soon after abandoned (Rubey, 1931), because it was too thin to map.

Relations to Western Wyoming

THERMOPOLIS SHALE

Westward from the Big Horn Basin, the rusty beds become more sandy and less shaly. On the western flank of the basin, they contain more sand than on the eastern flank, and much farther southwest in extreme western Wyoming at Lower Slide Lake (locality 35), they comprise a resistant cliff-forming unit of brown-weathering thinly bedded siltstone and sandstone about 110 feet thick. Here their lithology and topographic expression is similar to that of the Fall River sandstone of the Black Hills (plate 2). The similar changes of facies both east and west from the eastern Big Horn Basin suggest that the eastern Big Horn Basin was near the center of the rusty beds depositional basin, farthest from the sources of supply, and that both eastward and westward lay sedimentary source areas of the basin's margins.

The thickness of the Thermopolis above the rusty beds changes very little, but exposures do not permit recognition at Lower Slide Lake of the respective members, although they are recognizable on electric logs of nearby wells.

Farther southwest on Little Greys anticline (locality 36), the rusty beds equivalents consist of interbedded gray and tan carbonaceous siltstones, shales, claystones, some light gray limestone beds, and at least two maroon silty claystone beds three or four feet thick. About 100 feet is exposed, but the base is covered. In this area, a few poorly preserved pelecypods and gastropods have been found in this unit (Wanless and others, 1955, p. 57, 64). Ninety feet of black hard shale with a few siltstone beds near the top lie above the rusty beds equivalents and below a thick cliff-forming sandstone equivalent to the Muddy. The upper three members of the Thermopolis are not discernible. The entire shale unit may be a correlative of the upper shale, but it is almost barren of microfossils. Samples from it contained only a few tiny tintinnids, a few sponge spicules and fish teeth, and a fragment of *Verneuilinoides kansasensis.* Wanless and others (1955, p. 65) refer the rusty beds equivalents, the black shale, and the overlying thick sandstone to the lower Bear River formation. They remark that the base of the Bear River is difficult to pick consistently, and that rock types transitional with the underlying Gannett group occur through a 100-foot interval. Siderite spherulites have not yet been found in this area, but if they occur they might provide a helpful boundary criterion.

MUDDY SANDSTONE AND SHELL CREEK SHALE

In extreme western Wyoming, the Muddy is equivalent to the upper part of the lower Bear River formation of Wanless and others (1955, p. 64), and the Shell Creek shale is equivalent to the entire upper Bear River. On Little Greys anticline (locality 36), the Muddy consists of about 150 feet of cliff-forming sandstone, and the Shell Creek equivalents consist of 565 feet of dark shale with interbedded sandstone and sandy limestone beds and a little coal (Wanless and others, 1955, p. 66). In contrast to the lower Bear River, the upper Bear River is commonly rich in fossils and contains the Bear River fauna of the literature. A sample for microfossils from one fossiliferous shale bed in the middle of the upper Bear River yielded only sponge spicules.

PALEOGEOGRAPHY

THERMOPOLIS SHALE

RUSTY BEDS

The rusty beds are an extremely persistent transgressive sequence at the base of the marine Cretaceous. The uniformity and extent of individual beds and groups of beds above the thin basal variable portion indicate that they were deposited in the uniform and widespread environment of a transgressing epicontinental sea. Currents, which may have been caused by tides, continually reworked and sorted much of the sediment into thin lenticular laminae of shale, silt and sand. These were subsequently reworked and contorted by burrowing organisms.

Modern transgressive tidal flat sediments of the Dutch Wadden sea (van Straaten, 1954) resemble the rusty beds. They too consist of alternating lenticular mud and sand laminae, and they contain burrowing organisms and abundant carbonaceous material. However, they also contain many features formed subaerially, such as gullies and channels, washouts (areas scoured by currents and commonly filled with mud pebbles), mud cracks, and other structures. The rusty beds appear to contain none of these, and instead have characteristics which suggest that they were rarely subject to exposure during their deposition. The most striking of these is the remarkable persistence of individual beds, many of which are thin. Thin widespread beds might be temporarily deposited on a tidal flat, but they would not ordinarily be long preserved over very large areas. Thus, although the rusty beds appear similar to modern tidal flat sediments, and although tidal flats undoubtedly occurred at the margins of the transgressing rusty beds sea, the bulk of the sequence in the Big Horn Basin was probably finally deposited under a permanent cover of water in the shallow sublittoral zone.

The burrows and castings are evidence of an abundant bottom fauna, but benthonic fossils are almost entirely absent. The tiny pelagic tintinnids are of interest, however, in that they strongly support the inferred connection with the open sea. Arthur S. Campbell kindly examined specimens from the rusty beds and indicated that they are almost positively marine. He noted (personal communication) that forms related to those living in modern seas are distinctively open-oceanic in distribution.

The water in which the rusty beds were deposited, however, must have been brackish. The sea, extending far into the center of the continent, was undoubtedly strongly diluted by drainage from the land. Inasmuch as the adjacent land areas were large, the runoff must have been great. In addition, the sea was at first very shallow and the small volume of water it contained was probably easily diluted. This may help account for the absence of foraminifera in the rusty beds. Even so, the lack of other fossils, such as molluscs, is difficult to explain, for Cretaceous brackish water forms are common elsewhere. Perhaps they lived in the shallow rusty beds sea, but simply were not preserved. Acidic solutions, which commonly result from organic material under strongly reducing conditions, might have removed any calcareous shells after they were buried.

BASAL PORTION OF THE RUSTY BEDS

The siderite spherulites immediately beneath the basal contact are the first sign of change from Cloverly nonmarine environments to rusty beds marginal and marine environments. The spherulites apparently formed in previously deposited sediment, for they occur in leached claystones below the Lytle-South Platte contact in Colorado. Had they been deposited with the sediment, subsequent leaching probably would have removed them. Under exactly what conditions spherulitic siderite forms is not known, but it probably requires a strongly reducing environment. Clarke (1924, p. 535) mentioned that swamp waters commonly precipitate siderite in the presence of much carbonic acid or decaying organic matter. According to Deans (1934, p. 62), spherulitic siderite from claystones and siltstones of the English Coal Measures have been reprecipitated by descending ground water in a reducing "zone of stagnation" during subaerial leaching after the iron was taken into solution "probably as a ferric oxide hydrosol."

Local peat beds in the lower variable portion of the rusty beds indicate that swamps formed at the sea's margin and perhaps beyond as the water table rose. Inasmuch as spherulites appear to have formed immediately preceding the transgressive deposits everywhere, they probably resulted from certain chemical conditions generated in stagnant paludal or lagoonal environments in front of the advancing sea. The local occurrence of two spherulite zones in the marginal deposits of the northern part of the Big Horn Basin indicates a brief repetition of the particular chemical conditions. Marginal environments similar to those which accompanied the transgressing sea probably continued to exist near the edges of the depositional basin as long as the sea occupied the basin. Thus, in some marginal areas, spherulites might occur throughout a comparatively thick stratigraphic interval if the sediments were preserved.

In their variability, the strata in the lowermost part of the rusty beds are somewhat similar to the strata of the Cloverly. In gross lithology, however, they are different, inasmuch as they are generally darker and thinly bedded. The variability of this interval is undoubtedly a result of a complex of shifting local environments at and near the sea's margin as it transgressed the region.

As the sea encroached, stream gradients decreased and the water table rose far inland. Fluvial sediments were perhaps deposited in the valleys. Nearer the advancing shore, ponding progressively occurred and coastal swamps appeared. Estuaries formed where the sea reached up the valleys. Deltas were perhaps locally built and subsequently destroyed by the transgressing sea. Progressive erosion of coastal marshes probably provided a rich supply of carbonaceous material for the sediments farther seaward.

The higher marsh sediments had a much poorer chance of being ultimately preserved than those of the lagoons or even the tidal flats. Previously deposited fluvial sediments, too, were undoubtedly eroded locally and redeposited in the transgressive sequence. Spherulitic siderite-bearing sediments were locally removed. In general, the thin basal variable portion of the rusty beds consists of the sediments deposited near the strand line before uniform marine conditions were firmly established and transgressive planation and sublevation had eliminated local topographic irregularities.

LOWER SHALE

The lower shale probably indicates deposition farther from shore and in somewhat deeper water than the rusty beds. Comparatively rare siltstone laminae and beds indicate the action of gentle currents on the sea bottom. The single thin widespread bentonite bed in the northern part of the Big Horn Basin is a peculiar green color, different from most other Lower Cretaceous bentonites in the area. What would cause this is not known. If the initial composition of the ash was the same, then bottom conditions must have been different. Possibly the bottom was exceptionally foul and the water there had a low pH value. The unusual dahllite concretions which occur consistently near the base and locally in higher beds of this unit probably grew in the soft bottom mud prior to lithification, but what conditions were responsible for them is unknown.

Tintinnids are the only invertebrate fossils found in the lower shale. Perhaps the bottom was too foul for benthonic life. Pelagic foraminifera could not have occurred even if the water had been favorable, for there were none in the Lower Cretaceous sea in Canada (Stelck and Wall, 1955, p. 20), and at this time the boreal provenance was the only source of life to the interior sea. Crocodiles and fish apparently thrived, but they tell little of the environment.

MIDDLE SILTY SHALE

The middle silty shale possibly represents shallower water. It contains a proportionately larger amount of silt and thin limestone beds than the strata below and above. Bottom conditions apparently remained unfavorable for invertebrate life, however, for it contains only tintinnids and fish remains. The cyclic repetitions in the western portion of the Powder River Basin may indicate fluctuations in the sea level.

SUMMARY OF PRE-UPPER SHALE DEPOSITION

The lower three members of the Thermopolis—the rusty beds, lower shale, and middle silty shale—seem altogether to comprise a closely related sequence representing a transgression and deepening followed possibly by a slight regression or shallowing of the initial Cretaceous interior sea. This sea was a southern extension of the boreal sea which transgressed from the north and had no connection with the Gulf Coastal sea to the south. This is indicated by:

1. The pronounced thinning of the lower shale and middle silty shale toward the south and east from the Big Horn Basin. Apparently the basin's margin lay not far in these directions. If correlatives exist in the southern Black Hills and northern Colorado Front Range, they are thin and sandy and are included with the more widespread rusty beds equivalents.

2. Thickness changes in the rusty beds themselves. They thin southward and are apparently absent south of the northern Front Range in Colorado. Waagé (1955, p. 42) noted that, "Apparently the Plainview member is a northern element in the sequence."

3. Facies changes in the rusty beds. Toward the eastern and western margins of the seaway, away from what is now the eastern Big Horn Basin, the rusty beds become sandier and less shaly. They also become sandier and less shaly southward, suggesting proximity to the sea's margin in that direction as well.

4. The persistence of the lower three Thermopolis members northward. Although they were not studied in detail north of Wyoming, their thickness appears to be consistent northward, and they are probably continuous with part of the Mannville formation of Alberta.

5. The direction of drainage in the interior prior to the transgression. This direction was almost surely to the north (figure 10).

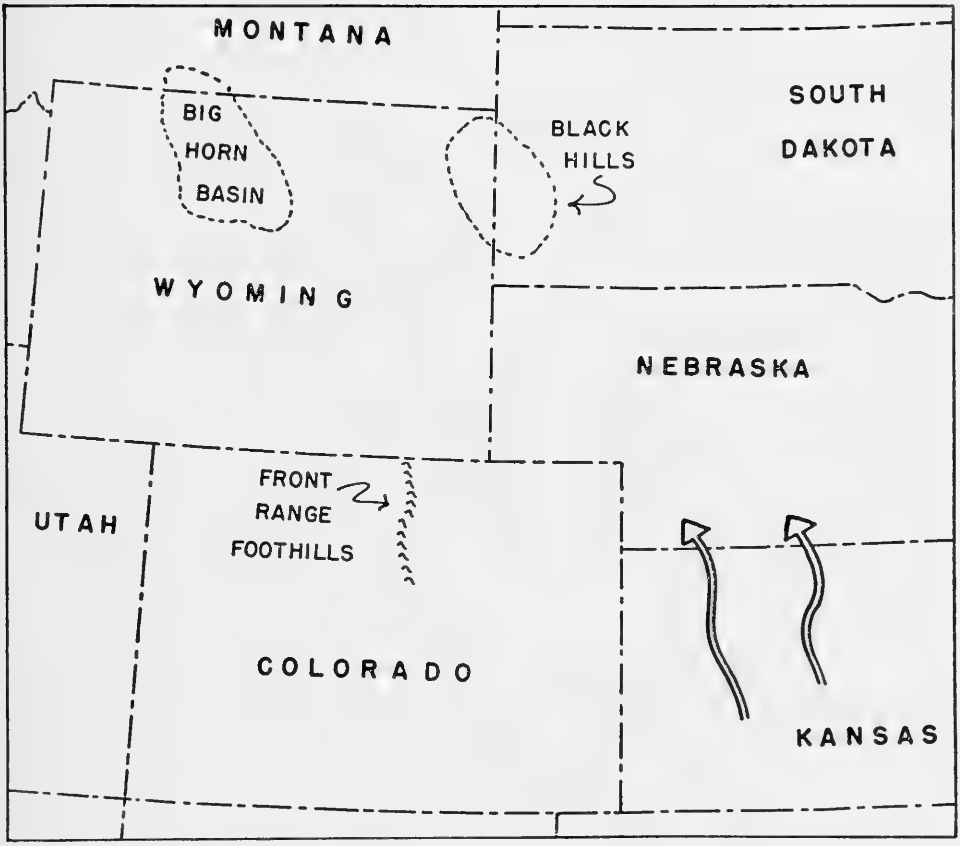

Figure 10. Direction of pre-Cheyenne sandstone drainage in western Kansas prior to the initial transgression of the Lower Cretaceous (rusty beds) sea (based on data from Merriam, 1955).

During the time the three lower members were being deposited, there must have been a drainage divide between the boreal sea in Wyoming and the Gulf Coast sea far to the south. Early Cretaceous physiography in western Kansas helps to locate this divide. In western Kansas, the Jurassic Morrison formation lies on Permian and Triassic rocks north of a line extending northeastward from the southwest corner of the state (Merriam, 1955, fig. 3). Over these Jurassic, Triassic and Permian rocks lies the Lower Cretaceous Cheyenne sandstone. The Cheyenne is in turn overlain by the Kiowa shale, followed by the Cruise sandstone, the Huntsman shale, and succeeding units. The Cheyenne varies greatly in thickness because it fills topographic irregularities on a post-Morrison erosion surface. By effectively contouring this surface, Merriam (1955, fig. 5) discovered two valleys directed slightly west of north and a prominent divide between them with local relief of more than 400 feet. Merriam (1955, p. 44) had initially suspected that these valleys indicated drainage to the south, but recently (personal communication), he stated that he was now quite sure that they indicate drainage to the north.

Earlier, during Morrison time, the drainage was from southeast to northwest in western Kansas (Merriam, 1955, p. 41). Although the original depositional limits of the Morrison were probably not far south of its present limits, the subsequent erosion undoubtedly removed some of the Morrison and determined its present zero isopach. The northeast trend of this erosional limit and the absence of Morrison rocks to the south indicate that the Morrison surface, if it was tilted after deposition, was probably tilted more to the northwest, and that drainage thus continued in this direction. Southerly drainage would have necessitated tilting of the regional surface from the northwest, as it was during Morrison time, to the southeast as the area was uplifted, shortly after Morrison time. Later, the surface would have to have been tilted back to the northwest to attain the present structural configuration. With southeast tilting, the Morrison surface would have been elevated increasingly northwestward, and subsequently, erosion would have removed the Morrison in this direction. However, the Morrison was not removed.

The principal objection to the postulated Early Cretaceous northwest drainage in Kansas is the fact that the Kiowa sea advancing from the south had to cross a former drainage divide. Yet, this sea surely had to cross a former divide somewhere, for it stretched northward the length of the continent and connected with the boreal sea. Evidence from the lower three members of the Thermopolis shale in Wyoming and equivalent rocks in the Black Hills indicates that the pre-Kiowa divide was somewhere south of these areas. The question, then, is only where it was in relation to western Kansas, and the evidence from this area strongly indicates that it was still farther south, and that the pre-Cheyenne streams in western Kansas flowed northward. Prior to the Kiowa advance in Kansas, the area began to subside, probably concomitantly with the submergence which brought the boreal sea southward into Wyoming and adjacent areas. The Cheyenne sandstone filled the valleys, covered the divides between them, and probably reduced the former continental divide to part of a nearly featureless surface just prior to Kiowa time.

UPPER SHALE

In Wyoming, although the sea possibly became shallower during middle silty shale time, it probably did not retreat entirely. The contact with the overlying upper shale, however, is abrupt, indicating a rapid change in conditions. This was probably brought about by submergence of the entire western part of the continent. The Gulf Coast sea advanced northward over the former continental divide south of Kansas and, for the first time, connected with the boreal sea. The upper shale contains the first Cretaceous foraminifera in the western interior, and its fauna is a mixture of species from both the Gulf Coastal and boreal provinces.

Much of the upper shale was deposited in comparatively deep water. It was deep enough, at least, to cover the divide between the western interior and the Gulf Coast. The sea spread widely as it deepened. The clay-sized purity of the shale throughout much of the upper shale interval in the Big Horn Basin suggests deposition in deep water, far from shore, beyond reach of most currents. In some localities south of the Big Horn Basin and in northern Colorado, the shale contains much silt, sand, thin limestone beds, and other features indicating shallower water.

FORAMINIFERAL ECOLOGY

The *Haplophragmoides gigas* fauna consists only of arenaceous foraminifera. Recent and fossil assemblages consisting entirely of arenaceous species are uncommon, and one so large as the *H. gigas* fauna is most unusual. In the upper portion of the Kiowa shale of Kansas, calcareous species occur with arenaceous species of the southern element of the *H. gigas* fauna (Loeblich and Tappan, 1950). The northward change from this partly calcareous assemblage to an entirely arenaceous assemblage in Wyoming and northern Colorado parallels, in general, the depletion of the molluscan fauna northward from Oklahoma and New Mexico. The environmental factor responsible for the changes might have been a northward increase in depth, reducing conditions, or turbidity, or a northward decrease in salinity. Temperature is not believed to have been an important factor.

The Kiowa shale in Kansas is similar lithologically to the upper shale of the Thermopolis shale in Wyoming and must have been deposited in water equally turbid. There are no lithologic indications that turbidity may have increased northward. Therefore, had calcareous species been unable to survive in Wyoming because of high turbidity, they probably would not have been able to survive in Kansas either.

The depth of the sea possibly increased gradually northward from the area of the old submerged continental divide. This corresponds to the direction in which the fauna changes, suggesting a relationship. Farther north, however, in undoubtedly shallow water deposits of the Front Range foothills, the molluscan fauna remains depleted, and no calcareous foraminifera occur. Near nonmarine equivalents, presumably in still shallower water along the foothills, the molluscan fauna becomes more depleted instead of becoming replenished, as would be expected if depth were the factor responsible for the northward depletion. However, the same thing happens toward deeper water environments in Wyoming. This indicates that factors other than depth were responsible for the northward depletion from Oklahoma and New Mexico. It also indicates that the molluscan fauna which remained in the interior preferred shallower water, possibly because of the hard bottom afforded by the sandstone and limestone beds which were deposited in comparatively shallow water and in which it most commonly occurs.

Increased circulation, resulting from the sea's being open at both ends, probably alleviated reducing conditions from what they had been previously, for there was enough oxygen nearly everywhere to sustain a bottom foraminiferal fauna. However, reducing conditions probably persisted in some marginal areas. This is indicated by the paucity or absence of foraminifera in parts of the upper shale at some localities south of the Big Horn Basin.

One indication that neither depth nor reducing conditions caused the northward depletion of the molluscs and disappearance of the calcareous foraminifera is the simultaneous disappearance of the planktonic foraminifer, *Globigerina*. Some globigerinid specimens have been found as far north as the Canon City embayment area in Colorado (K. M. Waagé, personal communication), but they are rare. None have been found in northern Colorado, Wyoming, or the Black

Hills. Globigerinid ecology is not generally affiliated with depth or bottom conditions. The limiting factors were probably in the water itself. Decreased salinity is the most probable one. Northward from the Gulf Coast, the sea was perhaps increasingly diluted by runoff from land on the east and west and this would have created unfavorable conditions for globigerinids.

That reducing conditions could not have controlled the distribution of globigerinids does not prove that they did not partly control the distribution of benthonic species. However, the distribution of globigerinids suggests the effectiveness of decreased salinity as a limiting ecological factor. That this factor simultaneously affected benthonic faunal distribution as well as planktonic faunal distribution is a reasonable inference.

It is also reasonable to infer that whatever factor limited the sparse *Verneuilinoides kansasensis* biofacies relative to the richer *Ammobaculites euides* biofacies also limited the *A. euides* biofacies in relation to the partly calcareous

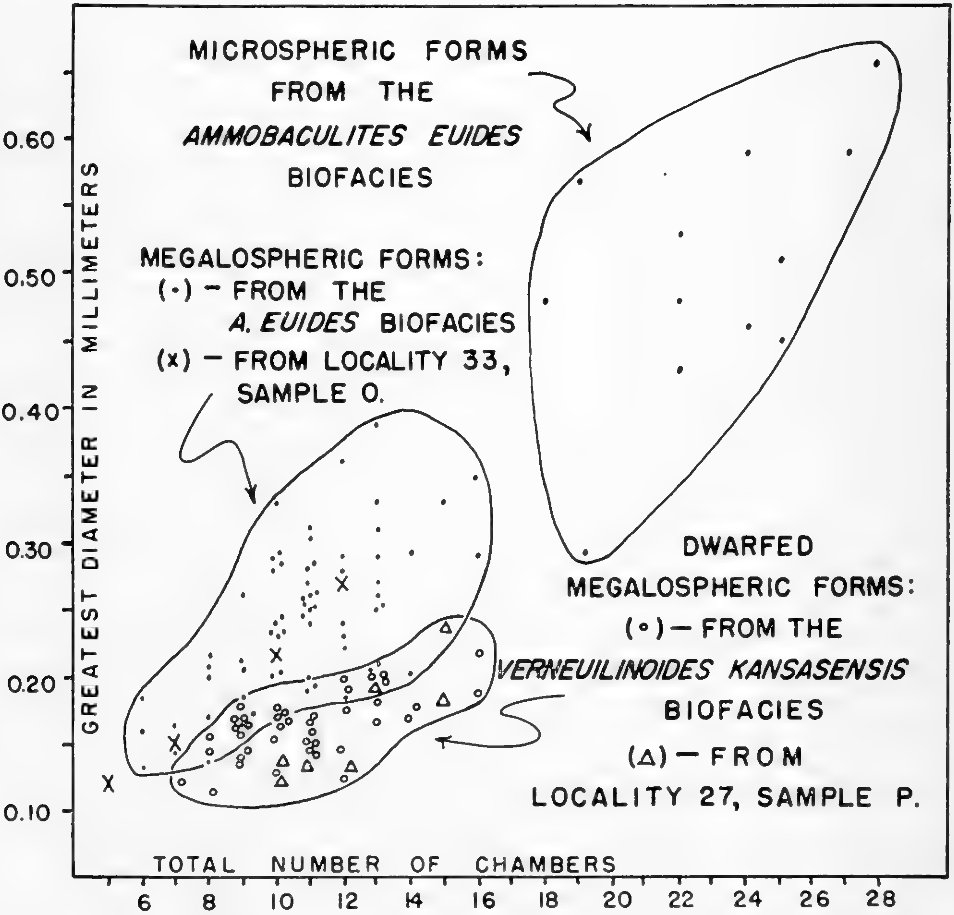

Figure 11. Size distribution of 129 specimens of *Trochammina depressa* from the *Haplophragmoides gigas* zone of the Thermopolis and Skull Creek shales illustrating dwarfing in the *Verneuilinoides kansasensis* biofacies and dimorphism in the *Ammobaculites euides* biofacies.

Kiowa fauna, and simultaneously, the Front Range molluscan fauna in relation to richer faunas to the south. Thus, the fauna of the *V. kansasensis* biofacies is considered the most depleted of a series of increasingly depleted benthonic faunas. The *V. kansasensis* fauna is limited only in number of species; specimens are generally as abundant as in the *A. euides* biofacies.

One species, *Trochammina depressa,* which is common in both the *V. kansasensis* and *A. euides* biofacies, is dwarfed in the *V. kansasensis* biofacies. The less favorable environmental conditions of the *V. kansasensis* biotope restricted its growth. Specimens from the *V. kansasensis* biofacies are smaller, both in diameter and in size of individual chambers (figure 11). This indicates they are not merely immature individuals.

Samples were taken from half-foot shale intervals below and above a 0.7-foot bentonite bed 18 feet below the Muddy sandstone at Dutton Basin (locality 27), where the entire upper shale contains only the *V. kansasensis* fauna. This was one of five similar sets of samples from various horizons of the Lower Cretaceous sequence taken to determine what effect, if any, the sudden accumulation of ash beds had on the benthonic foraminiferal fauna. It was expected that there might be no fauna immediately above the bentonite beds, and that possibly the bottom was very slowly repopulated. This was not borne out by the samples. Most samples from immediately above bentonite beds were not barren but contained a few specimens including some of the species that occurred just below. At Dutton Basin, however, the results were exceptional. Samples from the lower part of the upper shale contained comparatively few specimens, and the half-foot sample from just below the bentonite was completely barren, but sample p (Table 2) from just above the bentonite bed contained a large number of foraminifera, more than in any other sample examined.

Only one explanation seems possible. The ash blanketed black organic mud which was causing reducing conditions and probably low pH in the water at the sea floor, and suddenly provided a new bottom on which there was, at first, virtually no organic material to deplete the oxygen and to generate toxic materials. The shale below the bentonite is black; the shale just above is medium gray and probably contains a small mixture of bentonitic clay. Prior to the replenishing of organic material at the bottom, a large oxygen supply was available to the foraminifera, and they thrived. The portion of the upper shale, above sample p, was deposited under nearly the same conditions as the portion below the bentonite, although foraminifera are slightly more common above.

The foraminifera from sample p, above the bentonite, are like any others from the *Verneuilinoides kansasensis* biofacies in every respect. Four species occur, one of which is *Trochammina depressa*. It is still dwarfed, even in this population, which certainly received an unusually abundant supply of oxygen. Measurements of several specimens of *T. depressa* from sample p are separately indicated in figure 11. They all fall within the size range of those from many other samles from the *V. kansasensis* biofacies. This indicates conclusively that reducing bottom conditions were not responsible for the dwarfing of *T. depressa*. Thus, they were not the cause of the depleted fauna of the *V. kansasensis* biofacies relative to the *Ammobaculites euides* biofacies, and, by analogy, they were not responsible for the depletion in the molluscan fauna and the disappearance of calcareous foraminifera northward from Kansas, Oklahoma, and New Mexico.

This example does indicate, however, that reducing bottom conditions rigidly controlled population density, and suggests that reducing conditions, possibly in addition to further decreased salinity, were responsible for the absence of foraminifera in the Thermopolis samples at Alcova (locality 28). Thus the sea bottom at Alcova, and perhaps in many other marginal areas of the seaway, was probably oxygen-poor. This conclusion is compatible with the exceptionally high content of organic material in the upper shale correlative at Alcova.

Salinity, then, appears to have been the principal environmental factor responsible for the faunal facies in the seaway. In modern coastal waters, the brackish water environments, the lagoons, bays, marshes, and river mouths contain the highest proportion of arenaceous species. Commonly these faunas endure not only low salinity, but also great fluctuations in salinity. Modern, purely arenaceous faunas as large as that of *Haplophragmoides gigas* zone, however, are unknown, probably in part because certain highly tolerant calcareous genera have arisen since the Cretaceous.

Evidence for slight interfingering between the contemporaneous biotopes early in the sea's history comes from locality 33 at Hot Springs, South Dakota. Two small specimens of *Ammobaculites obliquus,* a species of the southern element of the *Ammobaculites euides* biofacies, were found in sample o (Table 2) 24 to 36 feet above the base of the Skull Creek shale in a sequence otherwise consisting of species from the *Verneuilinoides kansasensis* biofacies. This suggests that here the salinity was temporarily increased for a time, perhaps just to the threshold of the *A. euides* biotope. Specimens of *Trochammina depressa* from sample o support this splendidly. They are not dwarfed, and are the only specimens found in the *V. kansasensis* biofacies which distinctly fall within the size range of specimens from the *A. eudies* biofacies. They, too, are separately indicated in figure 11.

SUMMARY OF UPPER SHALE DEPOSITION

Early in the history of the sea in which the upper shale was deposited, before the sea had attained its maximum depth and extent, salinity was very low in its interior, and only the *V. kansasensis* biotope occurred. Meanwhile, the northern and southern elements of the *A. euides* biotope occupied their respective ends of the seaway in Alberta and in Kansas. In Kansas, calcareous species were not yet present. Later, as the sea deepened, increasing salinity enabled both the northern and southern *A. euides* elements to migrate into the interior and to mix. Several calcareous species migrated north as far as Kansas. Simultaneously, the *V. kansasensis* biotope was displaced to areas nearer the edges of the interior seaway where salinity remained somewhat lower. Other marginal areas which were exceptionally brackish or oxygen-poor constituted still another biotope. Here no foraminifera lived, and only tintinnids occur.

The sea probably attained its maximum extent when the upper portion of the upper shale was being deposited in the Big Horn Basin. The maximum abundance and variety of foraminifera occur about 20 to 50 feet below the Muddy sandstone in the northern part of the basin. It is noteworthy that the shale in this interval contains an unusually low proportion of silt. At the time of the sea's maximum extent, the fossil-bearing strata which extend far south into the deltaic facies of the South Platte formation along the Colorado Front Range foothills (Waagé, 1955, p. 31) were probably deposited.

MUDDY SANDSTONE

At the close of the deposition of the upper shale, an extremely uniform, perhaps nearly level sediment surface had been formed over a large part of the interior. Subsequently, much of this area was brought nearly to sea level, and the seaway's connection to the south was closed off. The sediments of the Muddy sandstone and its correlatives were deposited upon the upper shale and its correlatives, and spread rapidly over a wide area from Idaho to South Dakota and from Colorado into Canada. Sudden lateral facies changes, fossils, and distinctive rock types indicate that Muddy sediments were deposited in a variety of local shallow water environments.

The foraminifera, clams, fish, turtles and crocodiles probably lived in extremely brackish, shallow water. Peat beds and plant fossils indicate paludal environments. In the Big Horn Basin, many thick sandstone lenses possibly were deposited as sand bars, inasmuch as a single lens may be much thicker than the entire formation nearby and yet will not appear to cut significantly into the underlying strata. Channeling must have occurred in some localities nearer the margins of the depositional basin, however, and local erosion must have been common. The relative persistence of facies in the northern part of the Big Horn Basin suggests that the water here may have been deeper, in general, than in most other areas. Here, also, there is generally no sharp lithologic break at the base of the Muddy, which suggests that this area was still part of the central portion of the depositional basin, as it was earlier during rusty beds time. Yet the scattered pebbles which weather out of the sandstones at some localities indicate that, at some stage at least, the water must have been very shallow and the current swift.

In contrast to the underlying Thermopolis shale, bentonite is common in the Muddy sandstone and also in overlying strata. An important outburst of volcanic activity apparently coincided with the uplift of the depositional basin at Muddy time and the influx of coarser sediments. This probably reflects significant orogeny. Thin bentonite beds in the uppermost portion of the underlying Thermopolis probably record the volcanic beginnings of the orogeny before coarser Muddy sediments arrived in the depositional basin. Probably the volcanoes themselves were somewhere to the west. Much of this region is now covered by younger rocks, many of them volcanic, and possibly some of the areas of Tertiary volcanic activity were also areas of Cretaceous volcanic activity.

SHELL CREEK SHALE

The gradational contact of the Muddy sandstone and Shell Creek shale indicates rather continuous deposition in deepening water. The Shell Creek represents renewed subsidence of the western interior region and renewed transgression of the sea from the north. Volcanic activity continued.

The environment of the Shell Creek shale was probably similar to that of the upper shale of the Thermopolis, for the faunas and rocks are similar. Most of Shell Creek shale, however, was deposited in a shallower sea. Cross-bedded sandstone lenses in the middle part of the Shell Creek in the northern part of the Big Horn Basin (locality 22) indicate comparatively shallow water. Probably the depth gradually increased during deposition of the Shell Creek, for it is believed to have been shallowest just above the Muddy and deepest at the Mowry contact. At its maximum, however, the sea was confined to a much smaller area than the upper shale sea had been and connection with the Gulf Coast sea was never made. Unless the basin had been significantly warped or tilted, the sea certainly had to be much more shallow. Northward tilting had possibly occurred during the Muddy orogeny, however, with renewed uplifting in the area of the old continental divide south of Kansas.

Salinity was low at first, but it probably increased gradually as the depth increased. Throughout most of the Shell Creek sequence, only seven foraminiferal species occur; five more appear in the extreme upper part in the northern part of the Big Horn Basin. The macrofauna, which includes the ammonite *Neogastroplites,* also occurs in the upper part of the Shell Creek in this area and indicates that salinity must have been comparatively high. Radiolarians which occur in the upper portion of the Big Horn Basin also suggest nearly normal marine salinity and open sea conditions.

In far western Wyoming, Wanless and others (1955, p. 66) reported a total of seven feet of coal in the 565-foot sequence of shale and sandstones in the upper Bear River formation on Little Grays anticline (locality 36). Apparently, the coal is distributed throughout the sequence. It indicates paludal environments and suggests that the entire sequence was deposited in comparatively shallow water. The water was, in general, probably less saline than in the Big Horn Basin. Fossiliferous beds in the lower portion contain only nonmarine mulluscs, whereas those in the upper portion contain molluscs which indicate marine brackish water (Wanless and others, 1955, p. 66–68).

THE MOWRY CONTACT

The overlying Mowry shale is an unusual deposit. Like the Shell Creek, it consists mainly of dark shale with occasional interbeds of bentonite, but unlike the Shell Creek, its shales are extremely hard and weather to silvery-gray ridges, because they are composed of a very high proportion of uncombined silica. Rubey (1929, p. 157) showed that the siliceous Mowry shales have the chemical composition of a "silicified bentonite," as though altered volcanic ash had somehow been enriched with an excess amount of silica. This high silica content Rubey (p. 166–7) attributed to volcanic activity, but the Mowry bentonite interbeds alone, he concluded, are incapable of providing nearly enough silica for the enrichment of the great volume of siliceous shales. Besides, many other shale units, such as the Shell Creek, contain bentonites but are not silicified to any important degree. Rubey (p. 168) concluded that altered volcanic ash other than bentonite was responsible for the siliceous shales. He formulated the theory that siliceous muds formed on the sea floor as a result of the more or less complete chemical decomposition of slowly accumulating, very fine-grained, highly siliceous volcanic ash. The precipitation of amorphous silica from the water at the sea floor was accomplished by decaying organic matter. The bentonite beds, on the other hand, resulted from single, sudden ash falls and accumulated so rapidly that they were only briefly in contact with sea water. In this way Rubey accounted for two entirely different sedimentary rock types resulting from essentially the same source material. In addition to amorphous silica and organic matter, the Mowry shales contain some sand, silt and clay. The angularity and freshness of many of the grains, however, indicate that they, too, may be volcanic shards instead of ordinary clastic material.

Both the shales and bentonites of the Mowry thus had their principal source in volcanic ejectamenta, much of which was fine enough to be transported the width of the interior depositional basin—several hundred miles. The shales of the Shell Creek, although lacking silicification, also seem to contain much material derived from volcanic ash. Beds of bentonite and bentonitic shale are common, and montmorillonite seems to be an important constituent throughout. Other Cretaceous shales of the region similarly are made up of significant amounts of volcanic material. Why then is the Mowry so peculiar? What changes occurred in the environment of deposition of relatively non-siliceous Shell Creek mud to permit deposition of siliceous Mowry mud?

Possibly different chemical media were necessary to the formation of the unique Mowry sediments, but changes in the physical environment were probably also important. If Rubey is correct in supposing that the Mowry shales accumulated very slowly, the influx of ordinary mechanical sediments, for example, probably had to decrease. Deposition had to be very slow, for time was evidently an important factor in the decomposition of the ash and the coagulation of silica precipitant. Thus, although Mowry volcanic ash may have been exceptionally siliceous to begin with and chemical conditions may have been particularly favorable for the concentration of silica, equally important, perhaps, was the fact that the ash was deposited very slowly and was diluted by very little non-volcanic material. The Shell Creek and other Cretaceous shales might contain much material derived from volcanic ash, but their ash was possibly either mixed with a lot of mechanical sediment, or it accumulated much more rapidly than that of the Mowry. In any case, decomposition of volcanic ash material on the sea floor and ensuing concentrations of silica gel precipitated by organic matter were effectively prevented before and after Mowry time.

The change then from Shell Creek to Mowry conditions probably consisted not so much of an increase in rate of supply of volcanic material as of a decrease in supply of non-volcanic clastics. To accomplish this, the water possibly deepened, became less turbid, and thus less effective in transporting terriginous clastics.

A decrease in drainage gradient in surrounding land areas would also have aided the decrease in sedimentation rate. This could have occurred simultaneously with the postulated deepening of the sea as a result of gradual subsidence of the entire interior area. This continued subsidence is also suggested by the Mowry's overlapping of the Shell Creek and its extending over a much wider area of the western interior. Apparently, the subsidence was not great enough, however, to cause a connection with the southern sea, for the Mowry fauna is still entirely of boreal provenance (Cobban and Reeside, 1951). Possibly other essential factors contributed significantly to the change from Shell Creek to Mowry sedimentation, but whatever the causes, the resulting change was significant, and it seems to have occurred essentially simultaneously over all parts of the basin of deposition.

PALEONTOLOGY

Previous Work

Most of the foraminifera from the Lower Cretaceous rocks of the western interior have been previously described from either the northern or southern extremities of the interior seaway. Work by Loeblich and Tappan (1950) in Kansas provides the nearest information to the south, but many of the species had been described earlier by a number of workers in Texas.

Cushman (1927), Wickenden (1932), and Nauss (1947) described the nearest Lower Cretaceous foraminifera to the north from the subsurface of Alberta and Saskatchewan. More recently, Stelck and others (1956) and Tappan (1957) have added more information from the Peace River area of western Alberta and from northern Alaska, respectively.

Summary of Microfaunas

The microfaunas of the Thermopolis shale, Muddy sandstone, and Shell Creek shale described here consist of 33 species of foraminifera and one radiolarian. In the Thermopolis, foraminifera occur exclusively in the upper shale, above the middle silty shale and below the Muddy sandstone. The upper shale of the Thermopolis contains 24 species of arenaceous foraminifera: five are new; eight were previously known only from western Canada or Alaska; nine were previously known only from Kansas or Texas; one had been reported from both Kansas and western Canada; and one is undetermined.

The Muddy sandstone contains foraminifera mainly in its lower portion where silty strata gradational with the underlying Thermopolis shale are included in the Muddy. Of the two rare species which were identified from beds within the Muddy, one occurs in both the Thermopolis and Shell Creek shales, and the other occurs only in the Thermopolis.

In addition to one new species of radiolarian, the Shell Creek shale contains 12 species of arenaceous foraminifera: four are new; seven were previously known only from western Canada or Alaska; and one is undetermined. Three species, including one new one, also occur in the Thermopolis shale.

Field and Laboratory Methods

Samples for microfossils were collected from 24 of the 37 localities visited in the field. Most sections could not be sampled entirely, and several are represented by only a few samples each.

Samples were taken from individual lithologic units distinguished in measuring. In thick homogeneous units, samples were collected from regular intervals generally 10 to 15 feet thick. Because deep digging was usually necessary to acquire fresh material, it was generally impractical to collect true channel samples. Instead, material was taken from several holes within the interval to provide a representative sample from nearly every foot of strata. A few spot samples were taken just below and above bentonite beds to determine the effect of ash falls on the bottom faunas.

Though shales from the Thermopolis and Shell Creek are not generally hard, many have a peculiar toughness which makes them difficult to break down by ordinary boiling and washing. The method finally adopted, though somewhat involved, generally gives cleanest residues and thus results in maximum efficiency.

About a pound of each sample is crushed, dried in an electric oven for several hours, and then covered with Stoddard Solution while still hot. After standing a few more hours the excess solution is poured off, and water is immediately added. Next the sample is washed on a 200-mesh sieve and the remaining residue then boiled in a weak solution of washing soda until defloculation is complete. Then the sample is again washed on the 200-mesh seive, then dried, and later sorted through 40- or 60- and 100-mesh sieves for convenient microscopic examination.

SAMPLE DATA

The samples from each lithologic unit and interval thereof are designated in the measured sections. Table 2 is intended as a summary of this data and as a supplement to the occurrence information given for each species in the systematic descriptions. It tabulates the locality and interval within the major stratigraphic unit for each sample. In occurrences listed under each of the following descriptions the numbers refer to localities and the letters to individual samples.

The collections are deposited in the Peabody Museum of Natural History at Yale University.

LOC.	2	3	4	5	7	9	13	15	16	17	18	19	21	22	26	27	28	29	30	32	33	34	36	37
SMPL.	SHELL CREEK SHALE AND EQUIVALENTS																							
zz														293-305										
yy														281-293										
xx														268-281										
ww														255-268										
vv														237-253										
uu														223-237										
tt														211-223										
ss														198-210										
rr												242-252		186-198										
qq												228-242		177-185										
pp												212-228		164-177										
oo												199-212		151-164										
nn												192-197		138-151										
mm												178-192		(129-138)										
ll				(187-205)				188-203				164-178		(108-127)										
kk				(166-187)				170-188				150-164		97-108	123-135									
jj				(146-166)				150-169				135-150		87-97	(110-123)									
ii				126-146				131-150				120-135		81-85	98-108									
hh				114-126				115-131				(105-120)		66-80	85-97									
gg				104-114				100-115		51-69		90-105		56-65	77-84									
ff				84-104				87-100		51		76-90		54-56	62-74									
ee				63-75				72-87		50		60-75		48-53	50-62	47-57				11-15				
dd			(167-177)	48-61		114-129		(60-72)		41-50		45-60		37-48	(36-50)	38-44				6-10				
cc			157-167	33-47		99-114	201-211	32-48		30-36		30-45	187-188	27-37	(28-36)	26-35	22-23			4				
bb			147-157	25-32		84-99	139	16-32		13-21		15-30	(160-165)	14-27	13-27	13-25	10-22			3.5				
aa			0-25	(13-25)		69-84	138	0-16		0-8		0-15	155-160	0-14	0-13	(0-12)	(1-8)			0-6				
	MUDDY SANDSTONE																							
z			(31-33)									(31-41)					(39-48)	(71-76)						
y			(24-27)						37-42			(16-31)					(23-29)	(58-67)						
x			(21-23)		(21-23)				(34-37)	(5-7)		(10-16)		(34-43)			(17-19)	(52-58)						
w			(16-21)		11-15			10-30	(8-13)	(0-5)		0-10		12-24	(0-10)		(11-12)	(2-28)				(1-2)		
	THERMOPOLIS SHALE; UPPER SHALE AND EQUIVALENTS																							
v												99-112	99-108											+12-17
u												102.5	88-99											+17-20
t												102	77-88	102-113										+20-23
s												86-99	66-77	89-102	69-81									+23-29
r											96-106	72-86	55-66	76-89	56-69				89-97					+29-34
q		60-72									(86-96)	68-78	44-55	64-76	43-56	55-72		70-82	64-74		48-60		(83-88)	+34-41
p		48-60						63-84			76-86	52-62	33-44	51-64	30-43	55	(35-46)	57-70	53-64		36-48		(68-73)	+44-48
o		36-48	16-28					42-63		51-71	66-76	42-52	22-33	27-40	18-30	(54)	(28-35)	(44-56)	42-53		24-36		(45-60)	+44-51
n		24-36	4-12		+17			21-42		31-51	56-66	(27-40)	11-22	14-27	5-18	32-54	(12-28)	(31-44)	32-42		12-24	+0-7	30-45	+51-58
m		12-24	0-4		+18			0-21		8-31	44-56	0-11	0-11	(0-14)	(0-5)	15-24	(0-12)	(10-31)	22-32		0-12	+8-11	(10-30)	+(53-61)
	THERMOPOLIS SHALE: RUSTY BEDS, LOWER SHALE, AND MIDDLE SILTY SHALE																							
l	(118-123)											(234-240)		(241-253)										
k	(108-118)											(219-233)		(227-241)	(193-208)									
j	(98-103)							(179-200)				(199-218)		(206-222)	(172-192)									
i	(77-88)							(162-178)				(186-198)		(190-206)	(164-172)									
h	(63-77)							(130-145)				(165-186)		(174-190)	(152-164)									
g	(50-63)							(116-129)				(130-161)		(143-173)	(139-152)									
f	(50-63)							(99-104)				(98-107)		(125-140)	(125-139)									
e	(44-50)		(206-222)					(79-99)				(56-75)		(110-124)	(112-125)									
d	(35-44)		(194-206)					(43-78)		(151-156)		(37-56)		(80-106)	(90-112)									
c	(16-18)		(180-195)					(29-43)		(40-60)		(31-37)		(77-80)	(68-90)		(46-54)							
b	(10-16)		(165-180)	(128-138)				(22-28)		(20-40)		(18-24)		(56-77)	(35-44)	(49-57)	(23-46)							
a	(0-10)		(150-165)	(108-118)				(19-22)		(0-20)		(8-11)	(224-235)	(0-7)	(21-34)	(12-27)	(0-23)							

Table 2. Tabulation of stratigraphic interval of samples studied for microfossils. Plain numbers represent distance in feet above base of stratigraphic unit; numbers preceded by (+) represent distance below Muddy or Newcastle sandstone; numbers in parentheses represent samples barren of foraminifera and radiolaria; single numbers represent horizons of half-foot samples immediately below and above bentonite beds.

SYSTEMATIC DESCRIPTIONS

ORDER FORAMINIFERA

FAMILY SACCAMMINIDAE EIMER AND FRICKERT, 1899

Genus *Saccammina* M. Sars, 1869

Saccammina alexanderi (Loeblich and Tappan)

Plate 3, figures 1, 2

Proteonina alexanderi Loeblich and Tappan, 1950, Univ. of Kansas Paleontological Contr., Protozoa, art. 3, p. 5, pl. 1, figs. 1, 2.

Test free, consisting of one bulbous, slightly elongate chamber with the apertural end drawn out into a neck; well preserved specimens circular in cross-section; wall arenaceous with medium to coarse grains; aperture terminal, round.

Length of specimen in figure 1, 0.66 mm.; in figure 2, 0.25 mm. These represent the size extremes found.

REMARKS. *Proteonina* Williamson, 1858, has recently been discovered to be a junior synonym of *Reophax* Montfort, 1808 (Loeblich and Tappan, 1955, p. 8), hence this species is removed from that genus and referred to *Saccammina*.

OCCURRENCE. *S. alexanderi* occurs only in the *Ammobaculites euides* biofacies of the *Haplophragmoides gigas* zone of the Thermopolis and Skull Creek shales. It is also known from the Kiowa shale of Kansas.

MATERIAL. Most of the 45 specimens found are flattened in preservation but a few are well preserved.

LOCALITIES AND SAMPLES. 3; p. 19; q, r. 21; r, s. 22; s. 26; s. 37; n.

TYPES. Plesiotypes, YPM 20447 and 20448.

FAMILY TOLYPAMMINIDAE CUSHMAN, 1929

Genus *Involutina* Terquem, 1862

Involutina kiowensis (Loeblich and Tappan)

Plate 3, figure 3

Ammodiscus kiowensis Loeblich and Tappan, 1950, Univ. of Kansas Paleontological Contr., Protozoa, art. 3, p. 5, pl. 1, fig. 3. —Stelck and others, 1956, Research Council of Alberta Rept. no. 75, p. 25, pl. 5, figs. 16, 17.

Test very small, consisting of a proloculus followed by a coiling undivided tubular chamber; tubular second chamber increasing very gradually in diameter, making as many as six whorls in fully developed specimens, varying slightly from a true planar spiral in many specimens so that in places it overlaps previous whorls on one side of the test or the other; spiral suture distinct, depressed; wall finely agglutinated, smoothly finished; aperture at the open end of the tube.

Greatest diameter of figured specimen, 0.17 mm. Other specimens are from 0.13 mm. to 0.21 mm. in greatest diameter.

REMARKS. The genus *Ammodiscus* Reuss was recently discovered to be a junior synonym of *Spirillina* Ehrenberg (Loeblich and Tappan, 1954), and the type species of *Involutina* was discovered to represent the species previously referred to *Ammodiscus*. Under the rules of nomenclature the name *Ammodiscus* must be discarded unless a special ruling of the International Commission would retain it and assign it a proper type species.

Stelck and others (1956, p. 26) referred specimens from the Joli Fou shale of Alberta to this species and reported that some of them have erratically coiled nuclei. This character was also observed in four of the specimens in hand. If found alone these specimens would probably be referred to the genus *Glomospira,* but they are clearly parts of *Involutina kiowensis* populations. This suggests that this species is related to *Glomospira.*

OCCURRENCE. In the Thermopolis and Skull Creek shales this species is limited to the *Ammobaculites euides* biofacies of the *Haplophragmoides gigas* zone. It has been previously reported from the Kiowa shale of Kansas in addition to the Joli Fou shale of Alberta.

MATERIAL. Sixty-five specimens were found in the Thermopolis and Skull Creek shales.

LOCALITIES AND SAMPLES. 3; p. 7; m. 19; q, r, t, v. 21; u. 22; r, s. 26; r, s. 30; r. 33; o. 37; s, u, v.

TYPES. Plesiotype, YPM 20437.

Genus *Glomospira* Rzehak, 1885

Glomospira glomerosa Eicher, n. sp.

Plate 3, figure 6

Test small, nearly equidimensional, some specimens becoming almost spherical; the broad and flat tubular second chamber coiled in varying planes throughout, each whorl causing only slight relief on the surface of the test and promoting the tendency to over-all sphericity; the size of the tube increasing very gradually; suture distinct, slightly depressed; wall finely arenaceous, fairly smooth; aperture a slit at open end of the tube, obscure in most specimens.

Greatest diameter of holotype, 0.15 mm.; greatest breadth of tubular second chamber, 0.055 mm. Other specimens are from 0.12 mm. to 0.26 mm. in greatest diameter.

REMARKS. *G. glomerosa* differs from *G. tortuosa* n. sp. in its lower and much broader tubular chamber. As a result the test is more compact and the surface tends to have fewer indentations and less relief. Also this species has a greater size range and includes specimens that are larger than any of *G. tortuosa.* It differs from *G. watersi* Loeblich in having low, broad chambers and in being more equidimensional whereas the latter is generally planispiral and compressed. Moreover, the end of the tubular chamber of *G. glomerosa* does not tend to grow away from the uncoiled portion.

OCCURRENCE. It occurs in the uppermost strata of the Shell Creek shale in the Big Horn Basin and in the thin Shell Creek equivalents in the Black Hills.

MATERIAL. Only 21 specimens have been found.

LOCALITIES AND SAMPLES. 19; rr. 22; yy, zz. 32; ee.

TYPES. Holotype, YPM 20428, from SW Sec. 18, T. 43 N., R. 60 W., Weston Co., Wyoming, from Shell Creek shale equivalents in the lower part of the Mowry shale, 11 to 15 feet above the Newcastle sandstone.

Glomospira reata Eicher, n. sp.

Plate 3, figures 4, 5

Test free, circular, flat, early portion of tubular second chamber coiled in varying planes, but tending to lie within the plane of the later coils, the early portion of mature specimens comprising about one-fourth of total diameter of test, later portion consisting of about two irregularly planispiral whorls, more of a given portion visible from one side of the test than from the other; diameter of the tube increasing gradually; spiral suture variable, depressed; wall arenaceous with fine- and medium-sized grains; aperture at the open end of the tube.

Maximum diameter of holotype, 0.52 mm.; minimum diameter, 0.41 mm.; maximum width, 0.13 mm.; maximum thickness of last whorl, 0.13 mm. Maximum diameter of figured paratype, 0.63 mm. Other specimens are from 0.31 mm. to 0.74 mm. in greatest diameter.

REMARKS. *G. reata* is similar to some specimens that have been referred to *G. gordialis*

(Jones and Parker) by Cushman from the Upper Cretaceous and Recent, but differs from *G. gordialis* in its more rapid expansion and larger diameter of the later coils, and in that the earlier portion tends to lie within the disc formed by the later coils. *G. reata* differs from *Ammodiscus gaultinus* Berthelin in being larger and in having a larger, more rapidly expanding tubular second chamber which makes fewer whorls. Some specimens which have been referred to *A. gaultinus* (Tappan, 1943, pl. 77, fig. 6) have a visible proloculus and no early glomospirine stage.

OCCURRENCE. It occurs in the *Ammobaculites euides* biofacies of the Thermopolis and Skull Creek shales.

MATERIAL. About 35 specimens were recovered.

LOCALITIES AND SAMPLES. 19; q, r. 21; r, s, u. 22; p, q, r. 37; p, q.

TYPES. Holotype, YPM 20429. From the Thermopolis shale 9 to 20 feet below the Muddy sandstone in SW Sec. 15, T. 54 N., R. 92 W., Big Horn Co., Wyoming. Figured paratype, YPM 20430.

Glomospira tortuosa Eicher, n. sp.

Plate 3, figure 8

Test very small, some specimens nearly equidimensional, others somewhat compressed, the tubular second chamber coiled in varying planes throughout; tubular chamber round or oval in section, the diameter increasing very gradually; suture depressed, distinct; wall finely arenaceous, smoothly finished; aperture at the open end of the tube.

Greatest diameter of holotype, 0.14 mm.; greatest breadth of tubular second chamber 0.025 mm. Other specimens are from 0.11 mm. to 0.20 mm. in greatest diameter.

REMARKS. Like *Glomospira glomerosa* this tiny species has no fixed growth plan, the second chamber coiling in random planes throughout. This is characteristic of the genus. Unlike *G. glomerosa* this species has a rounded tubular chamber, greater surface relief, and less over-all tendency to appear spherical.

G. tortuosa is similar in size to *G. watersi* Loeblich though generally different in shape, *G. watersi* being generally planispiral and rather thin. Also, the tubular second chamber of *G. tortuosa* is not as broad, and it lacks the tendency to grow away from the coiled portion; furthermore the wall is not generally as smoothly finished.

G. tortuosa differs from *G. gordialis* (Jones and Parker) principally in that it is much smaller.

OCCURRENCE. This species was found only in the *Ammobaculites euides* biofacies of the *Haplophragmoides gigas* zone of the Thermopolis shale. None was found in samples from the Skull Creek shale of the Black Hills.

MATERIAL. Only about 20 specimens were recovered.

LOCALITIES AND SAMPLES. 15; p. 19; v. 21; u. 22; r, s. 30; r. 33; p.

TYPES. Holotype, YPM 20431, from NE Sec. 35, T. 19 N., R. 70 W., Albany Co., Wyoming, from the Thermopolis shale 0 to 8 feet below the Muddy sandstone.

Genus *Lituotuba* Rhumbler, 1895

Lituotuba sp.

Plate 3, figure 7

Test free, consisting of a proloculus and a tubular undivided second chamber, second chamber increasing rapidly in diameter, coiling in a plane for about one and one-half whorls, then uncoiling; wall arenaceous, of medium to coarse grains; aperture the open end of the tube.

Length of figured specimen, 0.27 mm. Other specimens range from 0.27 mm. to 0.73 mm. in length.

REMARKS. Specimens are too few and too poorly preserved to provide the basis for a new species.

OCCURRENCE. Specimens of *Lituotuba* have been found in the *Ammobaculites euides* biofacies of the *Haplophragmoides gigas* zone of the Thermopolis shale.

MATERIAL. Six individuals have been found.

LOCALITIES AND SAMPLES. 3; p. 19; q. 22; s. 26; s.

FIGURED SPECIMEN. YPM 20438.

FAMILY LITUOLIDAE REUSS, 1861

Genus *Haplophragmoides* Cushman, 1910

Haplophragmoides gigas Cushman

Plate 3, figure 16

Haplophragmoides gigas Cushman, 1927, Royal Soc. Canada Trans., v. 21, sec. 4, p. 129, pl. 1, fig. 5; 1946, U. S. Geol. Survey Prof. Paper 206, p. 21, pl. 3, fig. 2. —Nauss, 1947, Jour. Paleontology, v. 21, p. 338, pl. 49, fig. 8. —Stelck and others, 1956, Research Council of Alberta Rept. no. 75, p. 36, pl. 5, fig. 1.

Trochammina phaseolus Skolnick, 1958, Jour. Paleontology, v. 32, p. 284, pl. 38, fig. 6.

Test planispiral, compressed, not entirely involute, periphery narrowly rounded; nine or ten chambers in last whorl, inner portion of chambers tending to be lobate; sutures sigmoid, distinct, depressed; wall arenaceous, with considerable cement, smooth; aperture a low slit at base of apertural face, with a slight lip.

Greatest diameter of figured specimen, 0.90 mm. Other specimens are from 0.43 mm. to 0.90 mm. in greatest diameter.

REMARKS. Specimens previously reported from various parts of western Canada are from 0.55 mm. to 2.25 mm. in greatest diameter. Hence, those from the Thermopolis and Skull Creek shales are rather small. Most specimens are smashed either from the side or obliquely, making dimensions difficult to ascertain. Distortion has also been noted in the Canadian specimens.

OCCURRENCE. This rather rare species occurs in the *Ammobaculites euides* biofacies in the Thermopolis and Skull Creek shales. It is considered an index for the Joli Fou shale and equivalent strata in western Canada where the *Haplophragmoides gigas* zone was originally named. This zone is considered coextensive with the Joli Fou shale at its type locality (Stelck and others, 1956, p. 17) but here *H. gigas* itself occurs only in the basal part of the zone, and thus only in the lower part of the Joli Fou.

MATERIAL. Only 24 specimens were found in the Thermopolis and Skull Creek shales.

LOCALITIES AND SAMPLES. 19; v. 21; s, u, v. 22; p, s. 37; n, p, u, v.

TYPES. Plesiotype, YPM 20432.

Haplophragmoides multiplum Stelck and Wall

Plate 3, figure 12

Haplophragmoides sp. E. Wickenden, 1951, Geol. Survey Canada Paper 51-16, p. 43, pl. 1B, fig. 2.

Haplophragmoides multiplum Stelck and Wall, 1956, Research Council of Alberta Rept. no. 75, p. 37, pl. 4, figs. 14-16.

Test small, planispiral, evolute, two or three complete whorls following the proloculus; ten or eleven chambers in last whorl, six to eight in preceding whorl, increasing very gradually in size; sutures distinct, later one generally with small forward-pointing lobes; wall finely arenaceous with much cement, smoothly finished; aperture indistinct, at base of apertural face.

Greatest diameter of figured specimen, 0.20 mm. Other specimens are from 0.18 mm. to 0.30 mm. in greatest diameter.

REMARKS. This small species is distinguished by its size, evolute coiling, numerous chambers, and commonly lobed sutures. Only seven specimens were found.

OCCURRENCE. Specimens were found only in the upper portion of the Shell Creek shale. *H. multiplum* has been previously reported from a 370-foot shale interval above the Gates sandstone of the St. John group in the Peace River area of British Columbia and from the middle shale member of the Peace River formation where a microfaunal zone was named after it by Stelck and others (1956, p. 15). This zone lies between the ammonite zone of *Lemuroceras* below and that of *Gastroplites* above. The occurrence in the uppermost part of the Shell Creek shale with the ammonite *Neogastroplites* is thus somewhat later than the occurrences in northern Alberta and British Columbia.

MATERIAL. Seven specimens were found.

LOCALITIES AND SAMPLES. 15; ll. 19; qq, rr. 22; zz.

TYPES. Plesiotype, YPM 20433.

Haplophragmoides uniorbis Eicher, n. sp.

Plate 3, figures 13, 14, 15

Test small, somewhat evolute throughout, umbilicus shallow, periphery broadly rounded, generally with a large proloculus followed by only one complete whorl, rarely composed of a minute proloculus and up to two complete whorls; six or seven chambers in last whorl; sutures distinct, slightly depressed, gently curved; wall arenaceous, with mostly fine grains, smoothly finished; aperture obscure, apparently a low slit at base of apertural face.

Greatest diameter of holotype, 0.28 mm.; least diameter, 0.23 mm.; thickness, 0.10 mm. Greatest diameter of figured paratype in figure 13, 0.19 mm.; in figure 14, 0.29 mm. Other specimens are from 0.14 mm. to 0.36 mm. in greatest diameter.

REMARKS. *H. uniorbis* shows dimorphism. Most specimens have a large prominent proloculus followed by just one whorl and are probably megalospheric forms.

This species resembles *Alveolophragmium linki,* but it differs in several respects. In general it is somewhat smaller; it is much more evolute; its umbilicus is not so deep; its chambers are not generally so inflated; and its sutures are much more straight. Finally, it is notably dimorphic; most specimens have a large proloculus and appear to be megalospheric forms.

It is similar also to *Haplophragmoides* sp. B. described by Stelck and others (1956, pl. 4, figs. 19-22) from the middle portion of the Commotion formation of northern British Columbia, except that it is much more broadly rounded.

OCCURRENCE. It has been found only in the uppermost portion of the Shell Creek shale and in the lower portion of the Mowry shale.

MATERIAL. A total of about 60 specimens was found.

LOCALITIES AND SAMPLES. 15; ll. 19; qq, rr. 22; xx, yy, zz, and a sample from the Mowry shale 61 to 78 feet above the base.

TYPES. Holotype, YPM 20434, from Sec. 14, T. 53 N., R. 94 W., Big Horn Co., Wyoming, from the Shell Creek shale 0 to 10 feet below the Mowry shale; figured paratypes, YPM 20435 and 20436.

Genus *Alveolophragmium* Stschedrina, 1936

Alveolophragmium linki (Nauss)

Plate 3, figures 9, 10, 11

Haplophragmoides rugosa Cushman and Waters. Cushman, 1927, Royal Soc. Canada Trans., v. 21, sec. 4, p. 128, pl. 1, fig. 2.

Haplophragmoides linki Nauss, 1947, Jour. Paleontology, v. 21, p. 339, pl. 49, fig. 7. —Stelck and others, 1956, Research Council of Alberta Rept. no. 75, p. 36, pl. 4, figs. 17, 18, pl. 5, figs. 5, 6.

Haplophragmoides paralius Skolnick, 1958, Jour. Paleontology, v. 32, p. 283, pl. 38, fig. 2.

Haplophragmoides regularis Skolnick, 1958, Jour. Paleontology, v. 32, p. 284, pl. 38, fig. 1.

Test planispiral, biumbilicate, nearly involute, becoming somewhat evolute in later stages, periphery broadly rounded; chambers slightly inflated, six to eight in last whorl; sutures distinct, depressed, with a slight sigmoidal curve in most specimens; wall finely arenaceous, smoothly finished; aperture interio-areal in position, a horizontal elongate opening just above base of apertural face with a slight lower and upper lip, visible in exceptionally well-preserved specimens, indistinct in most specimens.

Greatest diameter of specimen in figure 9, 0.28 mm.; in figure 10, 0.40 mm.; in figure 11, 0.36 mm. Other specimens range from 0.16 mm. to 0.47 mm. in greatest diameter.

Remarks. Nauss's (1947, p. 339) original description stated that the test was entirely involute, but Cushman's (1927, pl. 1, fig. 2) illustrated specimen which Nauss included in synonomy is somewhat evolute in its later stages as are most of the Thermopolis and Skull Creek specimens.

Many specimens resemble *Haplophragmoides collyra* which Nauss (1947, pl. 49, fig. 2) originally described from Lloydminster strata only above the interval of the Viking sand, but which Stelck and others (1956) have since tentatively identified from the Joli Fou which underlies the Viking sand.

In only four specimens is the aperture clearly visible, and in these its position is slightly above the base of the apertural face. In one specimen in which the last chamber has been partly broken away (pl. 3, fig. 10), the aperture of the penultimate chamber with its slight lower and upper lips is particularly clear. In all other specimens the aperture is peculiarly indistinct, even though many of these specimens are otherwise well preserved.

Students of foraminifera agree that the interio-areal aperture, surrounded by the apertural face, is a character of generic significance. They do not agree, however, as to what genus these should be assigned. Frizzell and Schwartz (1950, p. 1, 4) assign such forms to *Cribrostomoides* Cushman in the belief that the aperture with tooth-like interruptions described by Cushman in the type species of this genus is an atypical character and a mere variation of the basic interio-areal slit-like aperture. *Labrospira* Hoglund is considered by them a synonym of *Cribrostomoides* as they broadly interpret it. Loeblich and Tappan (1953, p. 28), on the other hand, feel that the particular apertural characters upon which Cushman erected *Cribrostomoides* are valid, and are distinct from forms referred to *Labrospira* by Hoglund. They consider *Labrospira* to be a synonym of *Alveolophragmium* Stschedrina inasmuch as they do not agree with Stschedrina that the wall of the latter has alveolar structure. The species described here is referred to *Alveolophragmium* because this seems the more conservative course at present. If the apertural characters of *Cribrostomoides,* as a natural group, prove to be as encompassing as Frizzell and Schwartz indicated, *Alveolophragmium* will become a junior synonym of that genus.

Occurrence. *A. linki* is one of the most common species in the *Ammobaculites euides* biofacies of the *Haplophragmoides gigas* zone of the Thermopolis and Skull Creek shales. Nauss (1947) reported this species from both below and above the interval of the Viking sand in the Lloydminster shale. Stelck and others (1956) reported it from the Joli Fou shale and from the Commotion formation of the Fort St. John group.

Material. About 500 specimens were recovered.

Localities and Samples. 3; p. 15; p. 19; p, q, r, s, t, u, v, w. 21; r, s, t, u, v. 22; p, q, r, s. 26; s. 30; r. 34; m, n. 37; n, p, q, r, s, t.

Types. Plesiotypes, YPM 20401, 20402, and 20403.

Genus *Ammomarginulina* Wiesner, 1931

Ammomarginulina cragini Loeblich and Tappan

Plate 3, figure 20

Ammomarginulina cragini Loeblich and Tappan, 1950, Univ. of Kansas Paleontological Contr., Protozoa, art. 3, p. 6, pl. 1, figs. 4-6.

Test fairly large, flattened, with a faintly polygonal outline in side view; early portion consisting of a large proloculus followed by seven to nine chambers forming an evolute coil of little more than one whorl, followed in turn by one or two uniserial chambers; sutures straight or curved, slightly thickened, obscure; wall arenaceous with fine to medium grains and considerable cement; aperture at the base of the apertural face in coiled portion, terminal and elongate in uniserial portion.

Length of figured specimen, 0.88 mm.; width, 0.56 mm. Length of other specimens varies from 0.58 mm. to 0.88 mm., and greatest width varies from 0.28 mm. to 0.58 mm.

Occurrence. This species is rare in the *Ammobaculites euides* biofacies of the *Haplophragmoides gigas* zone of the Thermopolis shale. It was originally described from the Kiowa shale of Kansas.

Material. Only four specimens were positively identified.

Localities and Samples. 3; p. 19; q, r. 30; r.

Types. Plesiotype, YPM 20421.

Genus *Ammobaculites* Cushman, 1910

Ammobaculites euides Loeblich and Tappan

Plate 3, figures 17, 18, 19

Ammobaculites euides Loeblich and Tappan, 1949, Jour. Washington Acad. Sci., v. 39, p. 90; 1949, Jour. Paleontology, v. 23, p. 250, pl. 46, fig. 8; 1950, Univ. of Kansas Paleontological Contr., Protozoa, art. 3, p. 6, pl. 1, figs. 7-11. —Frizzell, 1954, Texas Bureau of Econ. Geol. Rept. of Investigations no. 22, p. 61, pl. 2, fig. 25. —Skolnick, 1958, Jour. Paleontology, v. 32, p. 280, pl. 37, fig. 5.

Ammobaculites altilis Skolnick, 1958, Jour. Paleontology, v. 32, p. 280, pl. 36, fig. 1.

Ammobaculites imbriciatus Skolnick, 1958, Jour. Paleontology, v. 32, p. 281, pl. 36, fig. 4.

Ammobaculites impolitus Skolnick, 1958, Jour. Paleontology, v. 32, p. 281, pl. 36, fig. 2.

Ammobaculites torosus Loeblich and Tappan. Skolnick, 1958, Jour. Paleontology, v. 32, p. 282, pl. 37, fig. 1.

Test large, early portion involutely coiled, bulbous, broadly rounded, sometimes with a very faint narrow peripheral bulge, later portion uniserial, rounded in section; three or four chambers visible in the coil followed by as many as seven uniserial chambers; sutures straight, broken at the periphery in the coil, depressed in the uniserial portion; wall finely arenaceous, surface smoothly finished; aperture round, at the peripheral angle in coiled chambers, terminal on uniserial chambers.

Maximum diameter of specimen in figure 17, 0.25 mm. Length of specimens in figures 18 and 19, 0.94 mm. and 0.48 mm. Other specimens range up to 1.25 mm. in length. Width of fully developed coiled portions varies from about 0.25 mm. to 0.35 mm.

Occurrence. *A. euides* is one of the most common species in the *Haplophragmoides gigas* zone of the Thermopolis and Skull Creek shales, occurring only in that biofacies which was named for it. It has previously been reported from the Skull Creek shale, from the Kiowa shale of Kansas and the Kiamichi formation and the Walnut clay of southern Oklahoma and northern Texas.

Material. Over 600 specimens have been found, but they are rarely well preserved. Differences in preservation appear to have given rise to unwarranted splitting of this species in the past.

Localities and Samples. 3; p. 7; n. 15; p. 18; r. 19; p, q, r, s, u, v, w. 21; r, s, t, u, v. 22; p, q, r, s. 26; r. s. 30; r. 34; m, n. 37; n, o, p, q, r, s, t, u, v.

Types. Plesiotypes, YPM 20404, 20405 and 20406.

Ammobaculites fragmentarius Cushman

Plate 4, figure 11

Ammobaculites fragmentaria Cushman, 1927, Royal Soc. Canada Trans., v. 21, sec. 4, p. 130, pl. 1, fig. 8.

(?) *Ammobaculites fragmentarius* Cushman, 1946, U. S. Geol. Survey Prof. Paper 206, p. 23, pl. 3, figs. 10-16.

(?) *Ammobaculites fragmentarius* Cushman. Frizzell, 1954, Texas Bureau of Econ. Geol. Rept. of Investigations no. 22, p. 62, figs. 16-18.

Ammobaculites fragmentarius Cushman. Stelck and others, 1956, Research Council of Alberta Rept. no. 75, p. 21, pl. 5, figs. 18, 19.

Test elongate, early portion a small coil, later uniserial, apparently with a round cross-section in undeformed specimens; three or four chambers in coil gradually increasing in size, followed by four to six chambers in uniserial portion generally increasing relatively rapidly in height and diameter; sutures distinct, depressed; wall arenaceous, with some medium to rather coarse grains; aperture terminal, round.

Length of crushed figured specimen, 0.93 mm.; width of coil, 0.19 mm. Other Skull Creek specimens range from 0.62 mm. to 1.56 mm. in length.

Occurrence. *A. fragmentarius* was found only in the *Ammobaculites euides* biofacies of the *Haplophragmoides gigas* zone of the Skull Creek shale.

It was originally described from the Lower Cretaceous of Canada where it is considered a characteristic species in the Joli Fou shale. It has also been reported from the Cummings member of the Mannville formation and from the Lloydminster shale below and above beds correlative with the Viking sand. In addition it has been reported from several Upper Cretaceous formations of the Gulf Coast, but some of these identifications are in doubt.

Material. Only 18 specimens have been recovered from the Skull Creek samples. All have been flattened to some extent in preservation.

Localities and Samples. 37; n, o, p, q, r.

Types. Plesiotype, YPM 20407.

Ammobaculites obliquus Loeblich and Tappan

Plate 4, figures 4, 5

Ammobaculites obliquus Loeblich and Tappan, 1949, Jour. Washington Acad. Sci., v. 39, p. 90-91; 1949, Jour. Paleontology, v. 23, p. 250, pl. 46, figs. 4, 5; 1950, Univ. of Kansas Paleontological Contr., Protozoa, art. 3, p. 7, pl. 1, figs. 14-17. —Frizzell, 1954, Texas Bureau of Econ. Geol. Rept. of Investigations no. 22, p. 62, pl. 2, fig. 29. —Stelck and Wall, 1955 Research Council of Alberta Rept. no. 70, p. 32, pl. 1, figs. 7, 8, pl. 3, figs. 18, 19. —Skolnick, 1958, Jour. Paleontology, v. 32, p. 281, pl. 36, fig. 3.

Test compressed in early coiled portion, later uniserial chambers becoming progressively more rounded in section; four to seven chambers visible in the coil followed by as many as five uniserial chambers; sutures straight, broken at the periphery in the coil and in early uniserial chambers, oblique in the uniserial portion, becoming perpendicular to long axis of test in later uniserial chambers of some specimens, depressed in the uniserial portion; wall finely arenaceous, surface smoothly finished; aperture rounded, at the peripheral angle in the coil and early uniserial chambers, terminal on later chambers.

Length of the exceptionally large specimen in figure 4, 0.93 mm. Length of the specimen in figure 5, 0.54 mm. Length of other specimens varies from 0.39 mm. for an unusually small one with two uniserial chambers to 0.93 mm.

Occurrence. *A. obliquus* is fairly common in the *Ammobaculites euides* biofacies of the *Haplophragmoides gigas* zone of the Thermopolis and Skull Creek shales. It has previously been reported from the Skull Creek shale, from the Kiowa shale of Kansas, from the Walnut clay and Kiamichi shale of southern Oklahoma and northern Texas, and from the Kaskapau formation of northern Alberta.

Material. About 65 specimens were found.

Localities and Samples. 3; p. 19; q, s, t. 21; s, u. 22; p, q. 26; s. 30; r. 33; n, o. 37; n, p, q.

Types. Plesiotypes, YPM 20408 and 20409.

Ammobaculites petilus Eicher, n. sp.

Plate 4, figures 2, 6

Test slender, elongate, early coiled portion somewhat compressed, periphery rounded, later portion uniserial, becoming cylindrical; five to seven chambers in last whorl of coil, followed by three to seven uniserial chambers which increase gradually in height and very slightly in diameter as added, the later ones about as high as broad; sutures straight, very slightly depressed in uniserial portion; wall finely arenaceous, aperture terminal, on a short neck, broken or obscure in most specimens.

Length of holotype, 0.47 mm.; greatest width of coil, 0.10 mm.; greatest width of uniserial portion, 0.10 mm.; greatest thickness of uniserial portion, 0.09 mm. Length of paratype in figure 6, 0.28 mm.; greatest width of coil, 0.10 mm. Other specimens are from 0.36 mm. to 0.78 mm. in length and 0.08 mm. to 0.16 mm. in width of coil.

REMARKS. The holotype, although it is rather small, was selected because it is relatively undeformed. The species shows less variation than most other species from the Thermopolis and Skull Creek shales.

A. petilus resembles *A. fisheri* Crespin from the Lower Cretaceous of Australia. *A. fisheri* is just slightly larger and the only significant difference appears to be that its chambers are much more inflated.

A. petilus differs from *A. tyrelli* Nauss principally in being much more slender with less inflated chambers, and in having a smaller coil often with more chambers.

OCCURRENCE. *A. petilus* occurs only in the *Ammobaculites euides* biofacies of the *Haplophragmoides gigas* zone of the Thermopolis and Skull Creek shale.

MATERIAL. About 135 specimens were found; many of the specimens are crushed or broken.

LOCALITIES AND SAMPLES. 3; p. 19; r, v. 21; r, s, t, u, v. 22; p, q, r. 37; n, o, p, q, r, s, t, v.

TYPES. Holotype, YPM 20410, from SW Sec. 15, T. 54 N., R. 92 W., Big Horn Co., Wyoming, from the Thermopolis shale 9 to 20 feet below the Muddy sandstone; figured paratype, YPM 20411.

Ammobaculites subcretaceus Cushman and Alexander
Plate 4, figure 3

Ammobaculites subcretacea Cushman and Alexander, 1930, Contr. Cushman Lab. Foram. Research, v. 6, p. 6, pl. 2, figs. 9, 10.

Ammobaculites subcretaceus Cushman and Alexander. Albritton, 1937, Jour. Paleontology, v. 11, p. 20, pl. 4, figs. 3, 4. —Lozo, 1944, Amer. Midland Naturalist, v. 31, p. 538, pl. 4, figs. 2, 3. —(in part) Cushman, 1946, U. S. Geol. Survey Prof. Paper 206, p. 23, pl. 3, figs. 18, 19 (not fig. 20). —Loeblich and Tappan, 1949, Jour. Paleontology, v. 23, p. 251, pl. 46, figs. 9-13; 1950, Univ. of Kansas Paleontological Contr., Protozoa, art. 3, p. 7, pl. 1, figs. 21, 22. —Stead, 1951, Texas Jour. Sci., v. 3, p. 589, pl. 1, figs. 7-9. —Frizzell, 1954, Texas Bureau of Econ. Geol. Rept. of Investigations no. 22, p. 62, pl. 2, figs. 27, 28.

Early portion of test close coiled, concave in umbilical area, slightly evolute, later portion uniserial, nearly cylindrical in some specimens, flattened in others; seven to nine chambers in last whorl of coil increasing gradually in size, followed by as many as four uniserial chambers increasing very little in height or diameter; sutures straight, slightly depressed particularly in uniserial portion; wall arenaceous, of fine and medium grains; aperture terminal, rounded.

Length of figured specimen, 0.71 mm.; width of coil, 0.37 mm. Length of other specimens ranges from 0.42 mm. to 0.93 mm.; width of coil ranges from 0.24 mm. to 0.39 mm.

REMARKS. The flattened uniserial portion of many specimens may be in part due to compaction after burial. The uniserial chambers of some obviously deformed specimens are flattened in front view rather than in side view, and many presumably undeformed specimens have nearly cylindrical uniserial portions.

OCCURRENCE. *A. subcretaceus* occurs in the *Ammobaculites euides* biofacies of the *Haplophragmoides gigas* zone. It is much more common in the Skull Creek shale of the Black Hills area than in the Thermopolis shale in central Wyoming. It has previously been reported from the Kiowa shale of Kansas, the Kiamichi formation and Walnut clay of southern Oklahoma and northern Texas, and the Maness shale, Goodland limestone, Glen Rose limestone, Torcer formation, and Eagle Ford group of Texas.

MATERIAL. A total of about 70 specimens was found.

LOCALITIES AND SAMPLES. 3; p. 7; n. 19; r, v. 21; t, u. 22; p, q, r. 30; r. 37; n, p, q, u.

TYPES. Plesiotype, YPM 20412.

Ammobaculites tyrrelli Nauss

Plate 4, figure 1

Ammobaculites coprolithiforme (Schwager). Cushman, 1927, Royal Soc. Canada Trans., v. 21, sec. 4, p. 130, pl. 1, figs. 6, 7.

Ammobaculites coprolithiformis (Schwager). Wickenden, 1932, Jour. Paleontology, v. 6, p. 204, pl. 29, fig. 2.

Ammobaculites tyrrelli Nauss, 1947, Jour. Paleontology, v. 21, p. 333, pl. 48, fig. 2. —Tappan, 1951, Cushman Foundation Foram. Research Contr., v. 2, pt. 1, p. 3, pl. 1, figs. 12-14.

Ammobaculites tyrrelli Nauss var. *jolifouensis* Stelck and Wall. Stelck and others, 1956, Research Council of Alberta Rept. no. 75, p. 23, pl. 5, fig. 20.

Ammobaculites culmula Skolnick, 1958, Jour. Paleontology, v. 32, p. 280, pl. 37, fig. 2.

Test cylindrical, early coiled portion generally with a visible central chamber followed by four or five chambers in the last whorl which gradually increase in size, later portion consisting of two to four inflated uniserial chambers which increase very slowly in height and diameter; sutures distinct, depressed; wall finely arenaceous; aperture terminal, rounded, on a short neck which is commonly broken off.

Length of figured specimen, 0.72 mm.; width of coil, 0.22 mm. Length of other specimens ranges from 0.44 mm. to 0.72 mm.; width of coil ranges from 0.16 mm. to 0.22 mm.

REMARKS. The height of given uniserial chambers is somewhat variable. Many specimens examined, including some from southern Alberta, show the central chamber of the coil clearly only when moistened and viewed in transmitted light. What is here considered the last chamber of the coil has apparently been considered by others to be the first chamber of the uniserial portion.

Figures of *A. minimus* Crespin from the Lower Cretaceous of Australia appear strikingly similar in all respects to *A. tyrrelli.* If the flattened test of *A. minimus* is a primary character, however, this would distinguish it.

OCCURRENCE. *A. tyrrelli* is rare in the *Ammobaculites euides* biofacies of the *Haplophragmoides gigas* zone in the Thermopolis and Skull Creek shales. It has previously been reported from the Skull Creek shale and the Greenhorn formation of the Black Hills, from the basal Cody shale of the Big Horn Basin, from the upper Topagoruk member of the Umiat formation in northern Alaska, and from the Joli Fou shale and equivalent rocks in Alberta where it is considered a characteristic species in the *H. gigas* zone.

MATERIAL. Only 12 specimens were found.

LOCALITIES AND SAMPLES. 3; p. 7; n. 19; r, s, v. 21; s, t. 37; n, o, q.

TYPES. Plesiotype, YPM 20413.

Genus *Ammobaculoides* Plummer, 1932

Ammobaculoides phaulus Loeblich and Tappan

Plate 4, figures 7, 8, 9, 10

Ammobaculoides phaulus Loeblich and Tappan, 1950, Univ. of Kansas Paleontological Contr., Protozoa, art. 3, p. 8, pl. 1, figs. 18-20.

Test small, flattened, early coiled portion consisting of little more than one complete whorl, later biserial, and finally uniserial; five or six chambers in last whorl of coil followed by two to eight biserial chambers, the last chamber becoming terminal or, less commonly, the biserial portion followed by as many as five uniserial chambers which are less compressed than the earlier portions of the test; sutures distinct, straight to very slightly curved back in coil, becoming slightly curved and depressed in later portions of test; wall finely arenaceous, surface smoothly finished; aperture terminal.

Length of specimen in figure 7, 0.39 mm.; in figure 8, 0.65 mm.; in figure 9, 0.26 mm.; in figure 10, 0.38 mm. The length ranges from 0.21 mm. for specimens with only three or four biserial chambers to 0.71 mm. for an unusually large specimen with a substantial uniserial series; width of coil varies from 0.09 mm. to 0.16 mm.

Remarks. Specimens are particularly variable in the relative development of biserial and uniserial portions. Size and shape of the coiled portion are fairly consistent.

Occurrence. *A. phaulus* is very common in the *Ammobaculites euides* biofacies of the *Haplophragmoides gigas* zone of the Thermopolis and Skull Creek shales. It has also been reported from the Kiowa shale of southern Kansas and the Kiamichi formation of northern Texas and southern Oklahoma.

Material. About 350 specimens were found.

Localities and Samples. 3; p. 7; n. 15; p. 19; q, r, s, t, v. 21; r, s, t, u, v. 22; p, q, r. 26; r, s. 30; r. 37; n, o, p, q, s, t, u.

Types. Plesiotypes, YPM 20414, 20415, 20416 and 20417.

Ammobaculoides whitneyi (Cushman and Alexander)

Plate 4, figures 12, 13, 14

Spiroplectammina whitneyi Cushman and Alexander, 1930, Cushman Lab. Foram. Research Contr., v. 6, no. 1, p. 8, pl. 2, fig. 12.

Spiroplectammina cf. *whitneyi* Cushman and Alexander. Lozo, 1944, Amer. Midland Naturalist, v. 31, p. 551.

Ammobaculoides whitneyi (Cushman and Alexander). Loeblich and Tappan, 1949, Jour. Paleontology, v. 23, p. 252, pl. 47, figs. 2-4. —Frizzell, 1954, Texas Bureau of Econ. Geol. Rept. of Investigations no. 22, p. 68, pl. 4, fig. 21. —Skolnick, 1958, Jour. Paleontology, v. 32, p. 283, pl. 38, fig. 4.

Ammobaculoides minuens Skolnick, 1958, Jour. Paleontology, v. 32, p. 283, pl. 38, fig. 5.

Early coiled portion and biserial portion somewhat compressed, uniserial portion only slightly compressed, periphery broadly rounded; coil centrally umbilicate, somewhat evolute in many specimens, with six to nine chambers in last whorl, followed by two to twelve biserial chambers and finally one to six uniserial chambers; sutures distinct, slightly depressed in coil becoming more depressed in biserial and uniserial portions; wall finely arenaceous, smooth to finely granular appearance; aperture terminal, elliptical.

Length of specimen in figure 12, 0.64 mm.; in figure 13, 0.94 mm.; in figure 14, 0.65 mm. Length of other specimens is from 0.31 mm. to 1.03 mm.; greatest width of coil from 0.12 mm. to 0.31 mm.

Remarks. *A. whitneyi* is highly variable in size and general proportions. An apparently related species which has been identified from the Kiowa shale of Kansas as *A. plummerae* (Loeblich and Tappan, 1950) seems to be generally smaller and has a somewhat more evolute coiled portion.

Occurrence. It is very common in the *Ammobaculites euides* biofacies of the *Haplophragmoides gigas* zone of the Thermopolis and Skull Creek shales. It has previously been reported from the Skull Creek shale, and from the Walnut clay, the Goodland formation and the Kiamichi formation of southern Oklahoma and northern Texas.

Material. Over 400 specimens were found.

Localities and Samples. 3; p. 7; n. 15; p. 19; p, q, r, s, v. 21; r, s, t, u, v. 22; p, q, r, s. 26; s. 30; r. 37; n, o, p, q, v.

Types. Plesiotypes, YPM 20418, 20419, 20420.

FAMILY TEXTULARIIDAE D'ORBIGNY, 1846

Bimonilina Eicher, new genus

Type species. *Bimonilina variana,* new species.

Name. From Latin; *bi,* two + *monile,* string of beads + *ina,* diminutive suffix. Gender, feminine.

Diagnosis. Test free, biserial throughout, final chamber at any stage of growth commonly with a false appearance of becoming uniserial, but a uniserial arrangement is not attained; test may appear twisted about an elongate axis; wall agglutinated, insoluble in acid; aperture terminal in all chambers, elongate.

Remarks. *Bimonilina,* new genus, differs from *Siphotextularia* Finlay in lacking a quadrate outline and in having a terminal aperture rather than a tube-like opening at the inside face of the last chamber. It differs from *Planctostoma* Loeblich and Tappan chiefly in having the aperture terminal throughout rather than textularian in the early stages and then variable in position and character later.

Occurrence. *Bimonilina* is at present known only from the Lower Cretaceous. In addition to the type species from the Thermopolis and Shell Creek shales and equivalent strata, the genus almost certainly includes *Tritaxia athabaskensis* Mellon and Wall from the Clearwater formation of northern Alberta inasmuch as this appears to be completely biserial rather than triserial in its early stages. In addition it probably includes *Ammobaculoides coonensis* Crespin from the Lower Cretaceous of Australia. *A. coonensis* does not appear to have its first four chambers arranged in a coil as described, but instead it appears to be biserial beginning with a large megalospheric proloculus. The distinctive way in which the chambers are added, each appearing to be the initial one of a uniserial

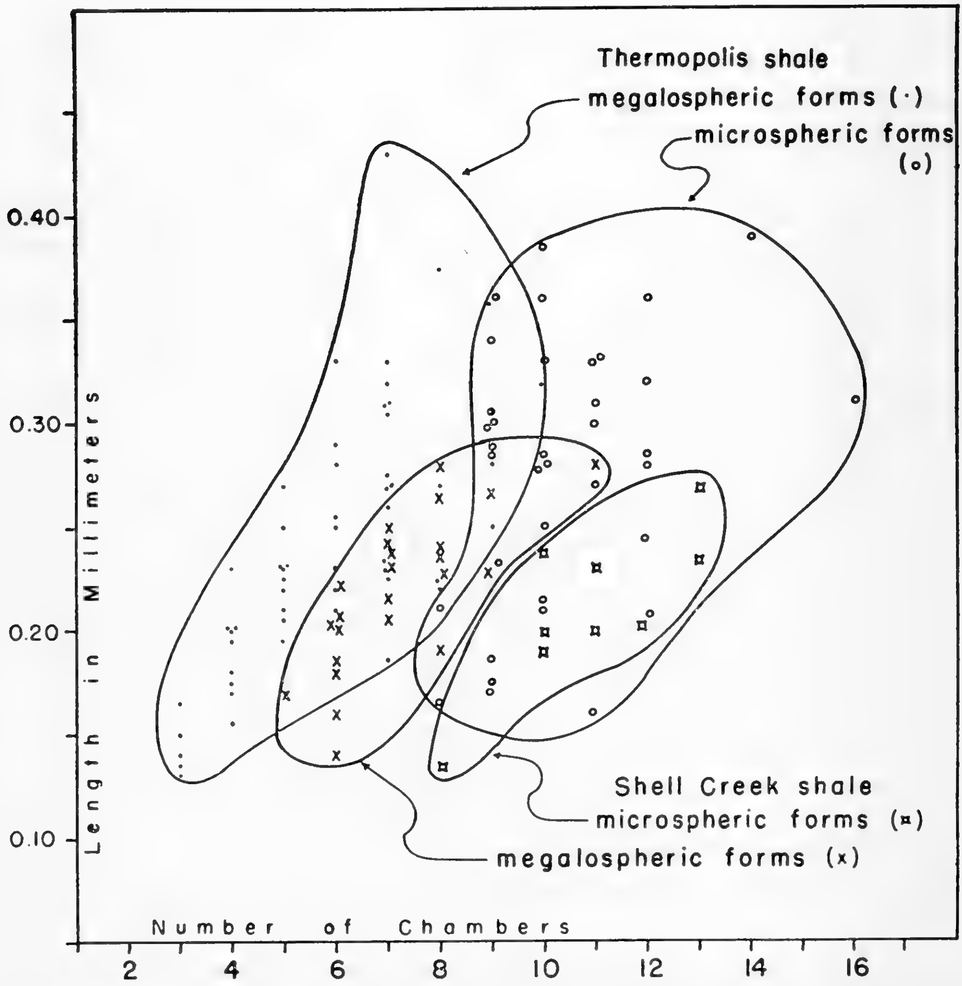

Figure 12. Size distribution of 123 specimens of *Bimonilina variana* illustrating dimorphism and greater size range of Thermopolis shale specimens compared to Shell Creek shale specimens.

series, is particularly suggestive of *Bimonilina*. Also *Siphotextularia? rayi* Tappan from the Topagoruk and Grandstand formations of Alaska belongs to this genus.

Bimonilina variana Eicher, n. sp.

Plate 4, figures 15, 16, 17, 18, 19

Test small, elongate, biserial throughout, proloculus large in megalospheric forms, minute in microspheric forms, each biserial chamber typically overlapping the preceding two chambers somewhat so that at every stage of growth the last chamber commonly appears to be terminal becoming uniserial, some specimens with a slight twist to the biserial rows; chambers inflated, increasing gradually in size; sutures distinct, depressed; wall finely arenaceous, smoothly finished; aperture a terminal slit, with a prominent lip best developed on only one side appearing as a sort of flap.

The holotype, an exceptionally large microspheric individual, is 0.39 mm. in length; 0.16 mm. in width; and 0.14 mm. in thickness. Length of paratype in figure 15, 0.32 mm.; in figure 16, 0.19 mm.; in figure 18, 0.18 mm.; in figure 19, 0.36 mm. Size distribution of the species is shown in figure 12.

Remarks. Megalospheric individuals are somewhat more common than microspheric individuals. In general both are about the same size, but microspheric individuals have more chambers.

Specimens from the Shell Creek shale, allowing that they are less common, are less variable in both size and shape than specimens from the Thermopolis and Skull Creek shales.

This species differs from *Tritaxia athabaskensis* Mellon and Wall from the Clearwater formation of Alberta, and from *Siphotextularia? rayi* Tappan from the Topagoruk and Grandstand formations of Alaska in being about half as large. Illustrations of *T. athabaskensis* specimens, all of which have been somewhat distorted in preservation, also show a wider aperture.

Occurrence. *B. variana* occurs in both the Shell Creek shale and in the *Ammobaculites euides* biofacies of the *Haplophragmoides gigas* zone of the Thermopolis and Skull Creek shales.

Material. A total of about 260 specimens was found.

Localities and Samples. 4; bb, cc. 5; cc, ii. 7; n. 9; cc. 15; p, bb, cc. 17; aa. 19; q, r, t, v, bb, ee, ii, oo, rr. 21; q, r, s, t, u. 22; p, q, r, bb, dd, ee, ii, kk. 26; r, s. 30; r. 32; aa, cc, dd, ee. 33; o. 37; n, o, p, q, t, v.

Types. Holotype, YPM 20422, from Sec. 14, T. 53 N., R. 94 W., Big Horn Co., Wyoming, from the Thermopolis shale 26 to 40 feet below the Muddy sandstone; figured paratypes, YPM 20423, 20424, 20425, and 20426.

FAMILY VERNEUILINIDAE CUSHMAN, 1911

Genus *Verneuilina* d'Orbigny, 1848

Verneuilina canadensis Cushman

Plate 5, figures 1, 2

Verneuilina canadensis Cushman, 1927, Royal Soc. Canada Trans., v. 21, sec. 4, p. 131, pl. 1, fig. 11; 1937, Cushman Lab. Foram. Research Special Pub. 7, p. 13, pl. 1, figs. 16, 17; 1946, U. S. Geol. Survey Prof. Paper 206, p. 31, pl. 7, figs. 2, 3.

Test triserial throughout, sides relatively flat, edges narrowly rounded, size and degree of elongation variable; chambers inflated, gradually increasing in size, sutures distinct, depressed, sloping downward toward the edges of the test; wall arenaceous, with fine to medium grains, some coarse grains in large specimens, with much cement; aperture an arch at the inner side of the last chamber.

Length of the specimens in figures 1 and 2 are 0.42 mm. and 0.41 mm., respectively. Other specimens are from 0.18 mm. to 0.72 mm. in length.

Remarks. This species is variable in size and degree of elongation, some forms being stubby and others narrow. Chamber shape, arrangement, and rate of growth, however, is moderately consistent. Small specimens generally have as many chambers as large ones. Size differences do not seem to be results of environmental differences inasmuch as large and small specimens commonly occur together. Some small, exceptionally elongate specimens tend to develop a somewhat loose triserial arrangement in their later chambers.

Cushman's (1927, pl. 1, fig. 11) type specimen is badly crushed.

OCCURRENCE. This species occurs throughout the Shell Creek shale and is one of the most common. It was described originally from what is now the Lloydminster shale of east-central Alberta.

MATERIAL. About 650 specimens have been found.

LOCALITIES AND SAMPLES. 4; bb, cc. 5; bb, cc, dd, ee, ff, hh, ii. 9; aa, bb, dd. 13; aa, bb. 15; aa, cc, ee, ff, gg, hh. 17; aa, bb, cc, dd, ee, ff, gg. 19; aa, bb, cc, dd, ee, ff, gg, kk, ll, mm, oo, pp. 21; aa. 22; aa, bb, cc, dd, ee, ff, gg, hh, ii, jj, kk, nn, oo, qq, rr, ss, tt, uu, ww, xx, zz. 26; bb, hh. 27; bb, cc, ee. 32; aa, bb, dd, ee.

TYPES. Plesiotypes, YPM 20458 and 20459.

Genus *Verneuilinoides* Loeblich and Tappan, 1949

An apparent twisted biserial arrangement of later chambers is a common feature in this ordinarily triserial genus. This variable characteristic was not discussed in the original description of the genus (Loeblich and Tappan, 1949, p. 91), but Lozo's (1944, pl. 3, fig. 6) illustration of the type species, *Verneuilina schizea* Cushman and Alexander, shows it quite well. It is also well shown in the two species that occur in the Thermopolis and Shell Creek shales and equivalent rocks in the western interior.

The apparent twisted biseriality results from the chambers being added in an extremely high triserial spiral in which not all chambers in a given whorl are in contact with chambers of the preceding whorl. Thus, the arrangement is not biserial, but actually loosely triserial. It develops from an expansion of the earlier closely triserial chambers both in height and diameter without corresponding expansion in the diameter of the test itself. This modifies the preceding closely triserial portion, effectively stretching the chamber arrangement upward along the axis of coiling, and separating succeeding chambers in each vertical row. That the chambers are still added by trochoid coiling is apparent in the asymmetry of the apertural face, the differing nature of the suture on opposite sides of a given chamber, and in the structural development of the test. The chambers themselves remain integral, asymmetrical parts of a true coil that maintains its triserial arrangement. Simultaneous with the stretching, a slight departure from exact triseriality commonly occurs as the preceding 120-degree rotation between chambers increases somewhat so that even the separated chambers belonging to the same row will no longer be precisely above one another. Even some specimens which are closely triserial throughout also appear slightly twisted about their coiling axes, and this, too, results from a rotation of slightly more than 120 degrees between each chamber.

Verneuilinoides hectori (Nauss)

Plate 5, figures 3, 4

Gaudryina hectori Nauss, 1947, Jour. Paleontology, v. 21, p. 335, pl. 48, fig. 6. —Stelck and others, 1956, Research Council of Alberta Rept. no. 75, p. 32, pl. 5, figs. 14, 15.

Early portion closely triserial, rounded later twisted biserial appearance resulting from expansion of the earlier triserial pattern along the axis of coiling with simultaneous slight increase in arc of rotation between chambers; chambers very slightly to moderately inflated, increasing gradually in size; sutures distinct, depressed; wall arenaceous, with fine to moderately coarse grains and considerable cement; aperture a high arch in the apertural face.

Length of figured specimens is 0.48 mm. and 0.68 mm., respectively. Other specimens are from 0.33 mm. to 1.00 mm. in length.

REMARKS. This species has been included in the genus *Gaudryina* previously because of the apparent twisted biseriality of its later chambers. However, the mechanism by which this pattern comes about, developing gradually as a modification of the earlier triserial portion, differs from that of typical species of *Gaudryina,* and has counterparts in other species of *Verneuilinoides.*

The specimens from the Shell Creek have, as a group, subtle differences from the specimens from the *Haplophragmoides gigas* zone below. They are, in general, somewhat more slender, and have slightly less inflated chambers and often a less twisted biserial portion. Also they are not so coarsely arenaceous as specimens from the *H. gigas* zone. They are similar in being highly variable in many features such as size, shape, and inflation of chambers. Both groups, in fact, are so variable as to include variants which compare closely with average forms from the other group, and it is only the extremes of both groups that can be distinguished with confidence. Because of this overlap of characteristics, the two groups, one from the Shell Creek shale and the other from the *H. gigas* zone below, are considered the same species.

The distinction between *V. hectori* and *V. kansasensis* is generally easily made. *V. hectori* is much larger with correspondingly larger chambers, and the walls are more coarsely arenaceous. Immature specimens of *V. hectori,* however, may be about the size of *V. kansasensis.* When poorly preserved these may be confused with stout specimens of *V. kansasensis.*

Gaudryina canadensis Cushman appears similar to this species, but the specimens figured (Cushman, 1943, pl. 6, figs. 7, 8) have biserial portions with no apparent twist. This does not totally rule out the possibility of its belonging to this species however, particularly since occasional individuals from the Shell Creek shale become nearly untwisted. It is not certain that Nauss ever compared this species with *G. canadensis* inasmuch as he seems to have been unaware of its designation. He refers to *"Bigenerina" angulata* (1947, p. 331, 332), a name which Cushman initially gave to some very poorly preserved specimens and later replaced with *G. canadensis.*

Occurrence. *V. hectori* has been found in the *Ammobaculites euides* biofacies of the *Haplophragmoides gigas* zone in the Thermopolis and Skull Creek shales, throughout the Shell Creek shale, and in the lowermost portion of the Mowry shale at locality 22. Previously it has been reported from the Joli Fou shale and equivalent rocks of western Canada.

Material. About 530 specimens have been found.

Localities and Samples. 3; p. 15; kk. 19; o, p, q, r, s, t, v, w, ll, mm, nn, oo, pp, qq, rr. 21; q, r, s, t, u, v, cc. 22; p, r, s, w, oo, uu, ww, yy. 26; s, ee, hh, kk. 27; bb. 32; dd. 34; m. 37; n, o, p, q, r, s, t, u, v.

Types. Plesiotypes, YPM 20460 and 20461.

Verneuilinoides kansasensis Loeblich and Tappan

Plate 5, figures 6, 7, 8, 9, 10

Verneuilinoides kansasensis Loeblich and Tappan, 1950, Univ. of Kansas Paleontological Contr., Protozoa, art. 3, p. 10, pl. 2, figs. 1, 2.

Test small, triserial, rounded, many specimens becoming loosely triserial in later portion so that succeeding chambers in each vertical row are not in contact, this generally accompanied by a slight increase in the arc of rotation between chambers resulting in a biserial appearance to the later portion of the test; chambers generally moderately inflated, about as high as broad; sutures distinct, depressed; wall finely arenaceous, surface smoothly finished; aperture a high arch in the apertural face.

Length of specimen in figure 6, 0.25 mm.; in figure 7, 0.46 mm.; in figure 8, 0.28 mm.; in figure 9, 0.44 mm.; in figure 10, 0.34 mm. Other specimens are from 0.16 mm. to 0.48 mm. in length; those exceeding 0.40 mm. are rare.

Remarks. All gradations are found between specimens uniformly closely triserial throughout and those in which all but the tiny initial chambers form an apparent twisted biserial arrangement. This species also varies considerably in size, in the degree of inflation of the chambers, and in shape, some specimens being slender and others comparatively short and stout.

OCCURRENCE. It occurs abundantly throughout both the *Ammobaculites euides* and *Verneuilinoides kansasensis* biofacies of the *Haplophragmoides gigas* zone in the Thermopolis and Skull Creek shales. It was described previously from the Kiowa shale of Kansas.

MATERIAL. Over 1000 specimens were found.

LOCALITIES AND SAMPLES. 3; m, n, o, p. 4; m, n, o. 7; n. 15; n, o, p. 17; m, n, o. 18; m, n, o, r. 19; m, o, p, q, r, s, t. 21; m, n, p, q, r, s, t, u, v. 22; m, n, o, p, q, r. 26; n, o, q, r, s. 27; n, p, q. 29; p, q. 30; m, n, o, p, q, r. 33; m, n, o, p, q. 36; n. 37; n.

TYPES. Plesiotypes, YPM 20462, 20463, 20464, 20465, and 20466.

Genus *Eggerella* Cushman, 1933

Eggerella sp.

Plate 5, figure 5

Test small, coiled in a high spiral, first three or four whorls of four to five chambers, last whorl becoming triserial, early chambers indistinct, later chambers inflated, increasing gradually in size; sutures distinct, depressed; wall arenaceous with medium-sized grains; aperture an arch at the inner side of the last chamber.

Length of figured specimen, 0.31 mm. Other specimens are from 0.21 mm. to 0.33 mm. in length.

REMARKS. The specimens from the Shell Creek shale closely resemble a species described as *Eggerella* sp. B by Stelck and others (1956, pl. 4, fig. 7) from the middle part of the Commotion formation of northern British Columbia.

OCCURRENCE. Specimens were recovered from two samples from the uppermost portion of the Shell Creek shale at locality 19.

MATERIAL. This small species is represented by only four fairly well preserved specimens.

LOCALITIES AND SAMPLES. 19; qq, rr.

FIGURED SPECIMEN. YPM 20427.

FAMILY RZEHAKINIDAE CUSHMAN, 1933

Genus *Miliammina* Heron-Allen and Earland, 1930

Miliammina inflata Eicher, n. sp.

Plate 5, figures 13, 14

Test small, oval or rounded in side view, arrangement of chambers quinqueloculine; chambers inflated, three visible from one side of test and generally four, rarely three, from the other side; sutures distinct, depressed; wall finely arenaceous, surface fairly smooth; aperture at the end of the last chamber, without a neck, inconspicuous in most specimens.

Length of holotype, 0.21 mm.; width, 0.15 mm.; thickness, 0.12 mm. Length of figured paratype, 0.24 mm.; width, 0.14 mm. Other specimens range from 0.14 mm. to 0.30 mm. in length and from 0.08 mm. to 0.19 mm. in width.

REMARKS. The shape of the test ranges from nearly round to fairly elongate and is the most variable feature of this species. Extreme length: width ratios of the paratypes are 0.56 and 1.00.

M. inflata is not likely to be confused with the previously described species of *Miliammina*. Its small size, short inflated chambers, and often nearly equidimensional outline are distinctive.

OCCURRENCE. *M. inflata* occurs in both biofacies of the *Haplophragmoides gigas* zone in the Thermopolis shale, but it is comparatively rare. It was not found in samples from the Skull Creek shale.

MATERIAL. About 70 specimens were found.

LOCALITIES AND SAMPLES. 15; o. 17; o. 19; m, r, s. 21; m, p, t, u. 22; m, q. 26; q. 30; o, q.

TYPES. Holotype, YPM 20441, from SW Sec. 15, T. 54 N., R. 92 W., Big Horn Co., Wyoming, from the Thermopolis shale 64 to 75 feet below the Muddy sandstone; figured paratype, YPM 20442.

Miliammina ischnia Tappan

Plate 5, figures 11, 12

Miliammina ischnia Tappan, 1957, U. S. National Museum Bull. 215, p. 211, pl. 67, figs. 25, 26.

Test small, somewhat compressed, chamber arrangement quinqueloculine; chambers elongate, four visible from one side of test, the visible portion of the central two chambers about the same length, three visible from the other side; sutures distinct, slightly depressed; wall very finely arenaceous, smoothly finished; aperture indistinct, at the end of final chamber, without a neck.

Length of specimen in figure 11, 0.26 mm.; width, 0.11 mm.; thickness, 0.06 mm. Length of specimen in figure 12, 0.21 mm.; width, 0.13 mm. Other specimens are from 0.14 mm. to 0.35 mm. in length and from 0.07 mm. to 0.22 mm. in width.

REMARKS. Because the aperture is obscure and the last two chambers nearly the same size, many specimens are difficult to orient.

Miliammina ischnia differs from *M. sproulei* chiefly in that it is smaller, and has less depressed sutures and no apertural neck. *M. manitobensis* is generally larger and proportionally wider, has a substantial neck, and has different proportions of the central chambers visible in side view.

OCCURRENCE. *M. ischnia* was found in the Shell Creek shale, the Muddy sandstone, and the Thermopolis and Skull Creek shales where it occurs only in the *Verneuilinoides kansasensis* biofacies. It was first described from the Grandstand formation of northern Alaska.

MATERIAL. A total of about 135 specimens was found.

LOCALITIES AND SAMPLES. 3; n. 4; n, aa. 5; bb, cc. 7; w. 9; cc. 15; m, o, bb, jj. 17; aa, cc. 18; m. 19; aa, bb, ii, oo, qq. 22; aa, bb, uu, zz. 26; m, n, aa. 27; cc. 29; p, y. 30; m, p. 32; aa, dd. 33; n, o.

TYPES. Plesiotypes, YPM 20439 and 20440.

Miliammina manitobensis Wickenden

Plate 5, figures 15, 16

Miliammina manitobensis Wickenden, 1932, Royal Soc. Canada Trans., v. 26, sec. 4, p. 90, pl. 1, fig. 11. —Cushman, 1946, U. S. Geol. Survey Prof. Paper 206, p. 48, pl. 14, figs. 4-6.

Test of medium size, nearly always flattened in preservation, chamber arrangement quinqueloculine; four chambers visible on one side of test, three on the other side, the central chambers generally indistinct in flattened specimens; sutures slightly depressed in best preserved specimens; wall arenaceous, of fine to medium grains with considerable cement; aperture terminal, on a pronounced neck.

Lengths of figured specimens are 0.57 mm. and 0.59 mm., respectively. Other specimens are from 0.23 mm. to 0.68 mm. in length.

REMARKS. *M. manitobensis* is the largest of four species of *Miliammina* which occur in the Lower Cretaceous of Wyoming and adjacent areas. It is generally distorted in preservation but even poorly preserved specimens are quite distinctive.

OCCURRENCE. *M. manitobensis* is very common throughout the Shell Creek shale; it has not been observed in underlying rocks. It has previously been reported from the Ashville beds of Manitoba, and from the portion of Lloydminster shale just above the interval of the Viking sand in Alberta.

MATERIAL. A total of about 300 specimens was found.

LOCALITIES AND SAMPLES. 4; bb. 5; cc, dd, ee, ff, gg, ii. 9; aa, cc, dd. 13; aa, cc. 15; cc, ee, ff, gg, hh. 17; aa, cc, dd, ee, ff. 19; aa, bb, cc, ee, kk, ll, mm, nn, oo, pp, qq, rr. 21; cc.

22; bb, cc, dd, ee, jj, nn, oo, pp, qq, tt, uu, ww, xx. 26; ff, gg, hh, ii. 27; ee. 32; aa, bb, dd.

TYPES. Plesiotypes, YPM 20443 and 20444.

Miliammina sp. cf. *M. sproulei* Nauss

Plate 5, figures 17, 18

Miliammina sproulei Nauss, 1947, Jour. Paleontology, v. 21, p. 339, pl. 48, fig. 13. —Stelck and others, 1956, Research Council of Alberta Rept. no. 75, p. 45, pl. 5, figs. 7-12.

Test elongate, chamber arrangement quinqueloculine; chambers slender, slightly larger at base, tapering toward apertural end, four chambers visible from one side of test and three from the other side; sutures distinct, depressed; wall finely arenaceous, smooth; aperture at the end of the last chamber, on a short distinct neck.

Length of specimen in figure 17, 0.24 mm.; width, 0.07 mm.; length of specimen in figure 18, 0.30 mm.; width, 0.11 mm. Other specimens are from 0.14 mm. to 0.35 mm. in length and from 0.07 mm. to 0.22 mm. in width. Some badly deformed specimens are larger.

REMARKS. *M. sproulei* was originally described as being generally larger but considerably variable in size, the Canadian specimens ranging from 0.27 to 0.90 mm. in length. Thus, the forms described here are small for this species. However, most species of the genus *Miliammina* encompass much variation and require wide latitude in interpretation.

OCCURRENCE. This species occurs in both biofacies of the *Haplophragmoides gigas* zone of the Thermopolis shale; only one specimen was identified from the Skull Creek shale.

MATERIAL. About 100 specimens were found. Many were flattened in preservation.

LOCALITIES AND SAMPLES. 3; m, o. 15; o. 17; n, o. 19; o, w. 21; n, p, r, s. 22; n, r. 26; q, s. 27; p, q. 29; q. 30; q. 37; n.

TYPES. Plesiotypes, YPM 20445 and 20446.

Spirolocammina Earland, 1934

Until recently *S. tenuis* Earland from the Antarctic region was the only species of *Spirolocammina* known. Then Tappan (1957, p. 211-213) found two additional species in samples from the Cretaceous rocks of Alaska. These were described as a new genus, distinguished from Earland's species in lacking the slightly sigmoid chamber arrangement noticeable in some of Earland's specimens. The slight sigmoid shape of some of these specimens appears to be due mainly to their pronounced apertural necks. Thus, in effect the primary distinction between *Spirolocammina tenuis* and the suggested new genus is the presence or absence of an apertural neck. This characteristic is not considered of generic value in related genera, and it is not considered of generic value here.

The two species from Alaska are both planispiral throughout, but supposed microspheric specimens of *Spirolocammina planula*, n. sp. from the Shell Creek shale have a tiny bundle of early coiled chambers, apparently quinqueloculine, in the center of the test. *S. planula* is closely related to *Spirolocammina subcircularis* (Tappan). This indicates that the genus *Spirolocammina* includes some species which may begin with early quinqueloculine or similar coiling just as some species of the structurally parallel calcareous genus, *Spiroloculina*.

Spirolocammina planula Eicher, n. sp.

Plate 6, figures 1, 2

Test small, oval or elliptical in outline, thin, sides nearly flat in most specimens, microspheric specimens with a slight bulge in central portion of one side where very earliest chambers are coiled in apparently a quinqueloculine arrangement, later arrangement spiroloculine with as many as six pairs of chambers, megalospheric specimens with a visible proloculus followed by only spiroloculine coiling; chambers numerous, slender and delicate in microspheric specimens, slightly enlarged at basal end, narrowing toward aperture; sutures distinct, very slightly depressed; wall very finely arenaceous; aperture small and inconspicuous at end of last chamber; without a neck.

Length of holotype, 0.24 mm.; width, 0.12 mm.; thickness, 0.04 mm. Length of figured paratype, 0.24 mm.; width, 0.15 mm. Other specimens are generally from 0.15 mm. to 0.34 mm. in length, and rarely larger.

REMARKS. The presumed megalospheric form, with a visible proloculus and immediate spiroloculine coiling, has larger, more inflated, rapidly expanding chambers, and is comparatively rare.

S. planula is similar to *S. subcircularis* from the Thermopolis shale, and it is occasionally possible to confuse individual specimens, for both species show considerable variation. *S. planula,* however, is generally flat whereas *S. subcircularis* has concave sides; hence *S. planula* specimens rarely have a hole in the middle whereas *S. subcircularis* specimens commonly do. *S. planula* has narrower, more slowly expanding chambers, and thus more chambers for a given width. In general the axis of the test does not tend to rotate as much with growth. Finally, *S. planula* specimens are commonly more elongate than *S. subcircularis* specimens, particularly in the early stages of growth.

OCCURRENCE. This species occurs commonly throughout the Shell Creek shale.

MATERIAL. About 320 specimens were found.

LOCALITIES AND SAMPLES. 4; aa, bb, cc. 5; bb, cc, dd, ee, gg, hh, ii. 9; bb, cc, dd. 13; aa, bb. 15; bb, cc, ee, ff, gg, hh, ii, kk. 17; aa, cc, dd, ee, gg. 19; aa, cc, dd, ee, ff, ii, jj, ll, mm, oo, qq, rr. 21; aa, cc. 22; bb, dd, ee, ff, ii, kk, ll, nn, oo, pp, qq, rr, tt, uu, vv, ww, yy. 26; aa, bb, ee, ff, hh. 27; bb, cc, dd, ee. 28; bb, cc. 32; aa, bb, cc, dd.

TYPES. Holotype, YPM 20451, from Sec. 16, T. 43 N., R. 94 W., Hot Springs Co., Wyoming, from the Shell Creek shale about 25 to 32 feet above the Muddy sandstone; figured paratype, YPM 20452.

Spirolocammina subcircularis (Tappan)

Plate 5, figures 19, 20

Psamminopelta subcircularis Tappan, 1957, U. S. National Museum Bull. 215, p. 213, pl. 67, figs. 8-10.

Test small, compressed, longer than broad, sides concave, periphery rounded, central portion thin and fragile, generally with indistinct early chambers, arrangement spiroloculine with as many as six pairs of chambers; chambers tubular, tapering, slightly enlarged at base so that in many specimens the long axis of the test rotates perceptibly with growth; sutures distinct, depressed; wall finely arenaceous; aperture a small obscure opening at end of last chamber; without a neck.

Length of specimen in figure 19, 0.175 mm.; width, 0.135 mm.; thickness, 0.03 mm. Length of specimen in figure 20, 0.26 mm.; width 0.19 mm. Other specimens are from 0.13 mm. to 0.31 mm. in length.

REMARKS. In many specimens the apertural end of the final chamber partly abuts against the protruding base of the penultimate chamber; in others the end of the final chamber overlaps the base of the penultimate chamber, but still clings to the test and does not protrude as a neck. Some small specimens are nearly round in outline and superficially resemble *Involutina*. Others have chambers which become straight near the apertural end. Many specimens have a small hole in the center where the fragile early chambers have been broken away; this, in fact, is characteristic of the species.

OCCURRENCE. *S. subcircularis* occurs in both the *Ammobaculites euides* biofacies and the *Verneuilinoides kansasensis* biofacies of the Thermopolis and Skull Creek shales, but is most common in the *V. kansasensis* biofacies. It was described initially from the Grandstand and Topagoruk formations of northern Alaska.

MATERIAL. About 325 specimens were found.

LOCALITIES AND SAMPLES. 3; m, n, o. 4; o. 7; n. 15; n, o. 17; m, n, o. 18; n, o. 19; m, o.

21; m, n, p, s. 22; m, n, o. 26; n, o, p, q. 27; m, n, p, q. 29; p, q, z. 30; m, n, o, p, q, r. 33; n, o, p, q.

Types. Plesiotypes, YPM 20449 and 20450.

FAMILY TROCHAMMINIDAE SCHWAGER, 1877

Genus *Trochammina* Parker and Jones, 1859

Trochammina depressa Lozo

Plate 6, figures 3, 4

Trochammina depressa Lozo, 1944, Amer. Midland Naturalist, v. 31, p. 552, pl. 2, figs. 4, 5. —Loeblich and Tappan, 1949, Jour. Paleontology, v. 23, p. 256, pl. 49, figs. 1, 2. —Frizzell, 1954, Texas Bureau of Econ. Geol. Rept. of Investigations no. 22, p. 79, pl. 7, fig. 13. —Skolnick, 1958, Jour. Paleontology, v. 32, p. 284, pl. 38, fig. 3.

Trochammina callima Loeblich and Tappan, 1950, Univ. of Kansas Paleontological Contr., Protozoa, art. 3, p. 10, pl. 1, fig. 23, pl. 2, figs. 4, 5.

Test trochoid, ventrally umbilicate, megalospheric forms generally consisting of two whorls, microspheric forms consisting of up to four complete whorls; chambers somewhat inflated, increasing fairly rapidly in size, five to seven in the last whorl; sutures depressed, distinct, curved backward on the dorsal side, relatively straight on the ventral side; wall finely arenaceous, smoothly finished; aperture a low slit at the inner margin of the ventral side of the last chamber.

Greatest diameter of megalospheric specimen in figure 3, 0.28 mm.; greatest diameter of microspheric specimen in figure 4, 0.48 mm. Megalospheric forms are from 0.11 mm. to 0.38 mm. in greatest diameter; undeformed microspheric forms range up to 0.50 mm. in greatest diameter, and flattened ones to 0.66 mm.

Remarks. This species is commonly flattened in preservation, and this has been the apparent cause of misleading variation. The holotype from the Kiamichi shale is only 0.02 mm. thick and was described as collapsed; specimens from the Walnut clay are up to 0.09 mm. thick; specimens of *T. callima* from the Kiowa shale are up to 0.12 mm. thick. These differences are believed to be largely the result of different degrees of flattening in preservation. In addition this species encompasses a great deal of genuine variation in characters such as size of test and chambers.

Specimens from the *Ammobaculites euides* biofacies are, as a group, larger than those from the *Verneuilinoides kansasensis* biofacies which are considered to be dwarfed. Microspheric forms have been recognized only in the *A. euides* biofacies. Figure 11, summarizes the size distribution of these forms.

Many specimens of this species resemble *Trochammina lattai* Loeblich and Tappan from the Kiowa shale in size, shape and number of chambers in the final whorl. *T. lattai,* however, has very obscure chambers in the early portion of the test prior to the final whorl. This character may not be of specific value.

Occurrence. *T. depressa* occurs in both biofacies of the *Haplophragmoides gigas* zone in the Thermopolis and Skull Creek shales. It also occurs in the Kiowa shale of Kansas and the Kiamichi formation and Walnut clay of Texas.

Material. A total of about 330 specimens has been found.

Localities and Samples. 3; o. 4; n, o. 15; n, p. 17; m, n. 18; o, p, r. 19; q, r, s, t, v. 21; n, r, s, t, u. 22; o, p, q, r, s. 26; m, n, r, s. 27; p, q. 29; p. 30; n, o, r. 33; n, o, p, q. 37; n, r.

Types. Plesiotypes, YPM 20454 and 20455.

Trochammina gatesensis Stelck and Wall

Plate 6, figures 6, 7

Trochammina gatesensis Stelck and Wall, 1956, Research Council of Alberta Rept. no. 75, p. 53, pl. 4, figs. 9-11.

Test small, dorsal surface convex and smoothly rounded, ventral surface concave, periphery narrowly rounded; chambers thin, not inflated, their planes at a relatively high angle to the axis of coiling, six or seven chambers in last whorl; sutures distinct, very slightly depressed, dorsally gently curved, ventrally faintly sigmoid in some specimens; wall arenaceous, of fine- and some medium-sized grains, with considerable cement; aperture a small notch at the inner margin of the ventral side of the last chamber.

Maximum diameter of specimen in figure 6, 0.26 mm.; in figure 7, 0.24 mm. Other specimens range from 0.14 mm. to 0.30 mm. in diameter.

Remarks. Many specimens are flattened in preservation and some of these may be difficult to distinguish from flattened specimens of *Trochammina depressa* although they do not occur together. In undeformed specimens the test itself is generally rather thick as a result of comparatively thin individual chambers being added at an angle to the coiling axis.

In several of the specimens the chambers are added so that the gently curved dorsal sutures between them join the corresponding sutures of the preceding whorl, resulting in a reticulate pattern in dorsal view.

Occurrence. This species occurs in the Shell Creek shale. It was previously reported from the Ft. St. John group of British Columbia and the Harmon shale of the Peace River area of Alberta.

Material. About 50 specimens have been found.

Localities and Samples. 4; cc. 5; ee. 9; dd. 13; aa. 15; ff. 19; ee, ll, pp, rr. 32; bb, dd.

Types. Plesiotypes, YPM 20456 and 20457.

Trochammina umiatensis Tappan
Plate 6, figure 5

Trochammina umiatensis Tappan, 1957, U. S. National Museum Bull. 215, p. 214, pl. 67, figs. 27-29.

Test trochoid, dorsally gently convex, periphery broadly rounded, ventral side with a shallow umbilicus; chambers comparatively few, somewhat inflated, three or four in last whorl, increasing rapidly in size; sutures nearly straight, distinct, depressed ventrally and peripherally, very slightly depressed dorsally; wall arenaceous with fine and medium grains; aperture indistinct, at the inner margin of the ventral side of the last chamber.

Greatest diameter of figured specimen, 0.28 mm.; least diameter, 0.24 mm.; thickness, 0.15 mm. Undeformed specimens are from 0.23 mm. to 0.33 mm. in greatest diameter, and flattened ones range up to 0.50 mm.

Remarks. The small number of inflated, rapidly expanding chambers is distinctive. Most specimens are colored with iron oxide, but this is secondary.

Occurrence. This species occurs in the uppermost part of the Shell Creek shale. It was initially described from the Grandstand formation of northern Alaska.

Material. About 20 specimens were found. Most have been flattened in preservation to varying degrees although a few are well preserved.

Localities and Samples. 15; ll. 19; rr. 22; yy, zz.

Types. Plesiotype, YPM 20453.

Order Radiolaria

FAMILY THEOPHORMIDIDAE HAECKEL, 1877
Genus Clathrocyclas Haeckel, 1822
Clathrocyclas (Clathrocyclas) irrasa Eicher, n. sp.
Plate 6, figures 8, 9, 10

Shell fairly large, variably bell-shaped, most specimens with a hyaline apical horn which may be short and stout or elongate, ranging up to 0.05 mm. in length; cephalis caplike, sides convex, rarely conical, generally with a sharp change in contour of shell at base; thorax large, inflated, in some specimens making up as much as 0.50 of total length of shell, greatest diameter near the base, limited basally by a broad internal septal ring; abdomen variable, rimlike in many specimens, in others a short flared cone; apertural margin generally with about twenty surrounding pronglike teeth, in many specimens with a rough appearance as though broken or unfinished; outside wall surface rough causing pores to be obscure; pores small, numerous, well separated, set in depressions, somewhat smaller on cephalis than on rest of shell; cephalis with perhaps 16 pores or so, thorax with 150 or so, in seven or more circular rows, pores of abdomen about the same density as those of thorax.

Over-all length of specimens varies from 0.115 mm. for a small specimen with no horn and a virtually undeveloped abdomen, to 0.20 mm. for large, well developed specimens. The holotype is 0.17 mm. in length, of which 0.031 mm. is the horn, 0.039 mm. the cephalis, 0.057 mm. the thorax, and 0.043 mm. the abdomen. The figured paratypes in figures 9 and 10 are 0.19 mm. and 0.20 mm., respectively, in over-all length.

REMARKS. Variation in size of the shell is limited, but variation in shape and relative development of constituent parts is high. The apical horn of the holotype is clearly composed of two blades which are slightly parted at the tip.

This form is referred to *Clathrocyclas* inasmuch as the majority of specimens with appreciably developed abdomens show them to be flared and not cylindrical as they are in most species of *Calocyclas*. Most specimens, however, have only a rudimentary abdomen consisting of a ring of lattice. These represent early ontogenetic stages, but many of these, if found alone, would seem to fit the diagnosis of the genus *Anthocyrtium*.

This species is similar to *Clathrocyclas universa* Clark and Campbell in size and in the amount of variability. *C. irrasa* differs chiefly in having the rough outer surface and smaller, much less distinct pores.

OCCURRENCE. This species is fairly common in the upper part of the Shell Creek shale. It also occurs in samples from the lower part of the Mowry shale, and is probably the same form as was noted by Rubey (1929) to occur in the Mowry of the Black Hills area.

MATERIAL. About 235 specimens were found.

LOCALITIES AND SAMPLES. 13; cc. 15; hh, jj, kk, ll. 19; ll, nn, oo, pp, qq. 22; tt, vv, xx, zz. 26; ii, kk. 32; ee.

TYPES. Holotype, YPM 20467, from E½ Sec. 26, T. 58 N., R. 96 W., Big Horn Co. Wyoming, from the Mowry shale 4 to 7 feet above the Shell Creek shale; figured paratypes, YPM 20468 and 20469.

LOCALITY REGISTER

1. North of Owl Creek, SW¼ Sec. 10, T. 43 N., R. 95 W., Hot Springs Co., Wyoming.
2. Highway 20, NW¼ Sec. 19, T. 43 N., R. 94 W., Hot Springs Co., Wyoming.
3. South of Owl Creek, NW¼ Sec. 14, T. 43 N., R. 95 W., Hot Springs Co., Wyoming.
4. Northeast flank Lucerne anticline, NW¼ Sec. 16, T. 43 N., R. 94 W., Hot Springs Co., Wyoming.
5. Southwest flank Lucerne anticline, SW¼ Sec. 16, T. 43 N., R. 94 W., Hot Springs Co., Wyoming.
6. Alkali Creek, N½ Sec. 29, T. 42 N., R. 92 W., Hot Springs Co., Wyoming.
7. Thermopolis Hill, NW¼ Sec. 34, T. 43 N., R. 95 W., Hot Springs Co., Wyoming.
8. Southwest of Thermopolis, NE¼ Sec. 1, T. 42 N., R. 95 W., Hot Springs Co., Wyoming.
9. Warm Springs Creek, NW¼ Sec. 10, T. 42 N., R. 94 W., Hot Springs Co., Wyoming.
10. North Fork Owl Creek, NE¼ Sec. 8, T. 43 N., R. 99 W., Hot Springs Co., Wyoming.
11. South Fork Owl Creek, NW¼ Sec. 6, T. 8 N., R. 2 E., Hot Springs Co., Wyoming.
12. North of Owl Creek, NW¼ Sec. 5, T. 43 N., R. 95 W., Hot Springs Co., Wyoming.
13. Nose of Thermopolis anticline, S½ Sec. 28, T. 44 N., R. 96 W., Hot Springs Co., Wyoming.
14. No Wood, SW¼ Sec. 19, T. 42 N., R. 88 W., Washakie Co., Wyoming.
15. Tensleep, SE¼ Sec. 21, and SE¼ Sec. 24, T. 47 N., R. 89 W., Washakie Co., Wyoming.
16. About twelve miles south of Tensleep, Sec. 1, T. 45 N., R. 88 W., Washakie Co., Wyoming.
17. Arminto, NE¼ Sec. 24, T. 38 N., R. 87 W., and NW¼ Sec. 22, and NW¼ Sec. 22 and Sec. 19, T. 38 N., R. 86 W., Natrona Co., Wyoming.
18. Bellvue, SE¼ Sec. 13, T. 8 N., R. 70 W., Larimer Co., Colorado. Measured by K. M. Waagé.
19. West flank of Sheep Mountain anticline, Sec. 14, T. 53 N., R. 94 W., Big Horn Co., Wyoming.
20. Five Springs Creek, NW¼ Sec. 5, T. 55 N., R. 93 W., and NE¼ Sec. 35 and Sec. 34, T. 56 N., R. 93 W., Big Horn Co., Wyoming.
21. Bear Creek, SW¼ Sec. 15, T. 54 N., R. 92 W., Big Horn Co., Wyoming.
22. Gypsum Creek, E½ Sec. 26, SE¼ Sec. 25, and Sec. 22, T. 58 N., R. 96 W., and E½ Sec. 29, T. 58 N., R. 95 W., Big Horn Co., Wyoming.
23. Bentonite Road, Sections 24 and 25, T. 53 N., R. 93 W., Big Horn Co., Wyoming.
24. No Wood Creek, Sec. 13, T. 49 N., R. 91 W., Big Horn Co., Wyoming.
25. Salt Creek, SE¼ Sec. 17, T. 54 N., R. 93 W., Big Horn Co., Wyoming.
26. Muddy Creek, SW¼ Sec. 25, T. 49 N., R. 83 W., Johnson Co., Wyoming.
27. Dutton Basin, NE¼ Sec. 18, T. 33 N., R. 89 W., Fremont Co., Wyoming.
28. Alcova, SE¼ Sec. 30, T. 30 N., R. 82 W., Natrona Co., Wyoming.
29. Rock River, NW¼ Sec. 28, T. 22 N., R. 75 W., Albany Co., Wyoming.
30. Iron Mountain, SE¼ Sec. 3, T. 18 N., R. 70 W., Laramie Co., Wyoming.
31. LaBonie Creek, NW¼ Sec. 29, T. 31 N., R. 71 W., Converse Co., Wyoming.
32. Clifton, SW¼ Sec. 18, T. 43 N., R. 60 W., Weston Co., Wyoming.
33. Hot Springs, NE¼ Sec. 33, T. 7 N., R. 6 E., Fall River Co., South Dakota.
34. Cody, on U. S. Highway 20 at Sulphur Creek, one-fourth mile southeast of Cody, T. 52 N., R. 102 W., Park Co., Wyoming.
35. Lower Slide Lake, Sec. 34, T. 43 N., R. 114 W., Teton Co., Wyoming.
36. Little Greys anticline, in Snake River Canyon, Sec. 2, T. 37 N., R. 117 W., Lincoln Co., Wyoming.
37. New Haven, NW¼ Sec. 11, T. 55 N., R. 67 W., Crook Co., Wyoming.

MEASURED SECTIONS

The following includes type sections, all sections from which samples for microfossils were collected, and a few other sections which were measured in detail.

Type section of the Thermopolis shale; upper part measured at locality 4 on northeast flank of Lucerne anticline, east of the Big Horn River; NW Sec. 16, T. 43 N., R. 94 W., Hot Springs Co., Wyoming.

Thickness in feet

Muddy sandstone (in part)

23. Sandstone, light gray, fine- to medium-grained, hard, beds to one foot thick are cross-bedded, ripple-marked, weathers dark brown, thickens southeastward and forms ridge.
    Sample w 3.0
22. Shale, gray, very silty, iron-stained near top, weathers to light gray slope. 10.0
21. Siltstone, light gray, some sandy, and shale, black, fissile, interbedded in 0.1- to 0.3-foot beds. 6.0

Thermopolis shale

(upper shale)

20. Shale, black, fissile, cone-in-cone concretion bed at 47 feet above base.
    Sample o, 16-28 feet above base
    n, 4-12
    m, 0-4 72.0

(middle silty shale)

19. Shale, black and tan, fissile, finely silty, and some thinly interbedded siltstone, tan, fucoidal, in lower 4 feet, a 0.5-foot iron-impregnated siltstone at top; 1.5 feet above base is a 0.8-foot siltstone, dark grayish-brown, calcareous, hard, forms small ledge; unit weathers tan.
    Sample e 16.0
18. Shale, black and tan, fissile, finely silty; basal 0.5 foot is iron-impregnated; weathers tan.
    Sample d 12.0

(lower shale)

17. Shale, black and dark gray and some tan, fissile, some silty, a 0.5-foot gray, hard, cross-bedded, brown-weathering sandy limestone lens 7 feet below top; unit weathers to gray crusty surface.
    Sample c, 37-51 feet above base
    b, 22-37
    a, 7-22 51.0

Section offset to locality 5, southwest flank of Lucerne anticline, SW Sec. 16, T. 43 N., R. 94 W.

16. Siltstone, tan, and sandstone, tan, very fine-grained, thinly interbedded and interlaminated, fucoidal, minor amount of gray shale, carbonaceous material, weathers tan. 5.0
15. Shale, gray and black, silty, some iron-stained, dahllite concretions in lower part.
    Sample a, 0-10 feet above base
    b, 20-30 30.0

Section offset to locality 2 west of the Big Horn River on U. S. Highway 20, NW

Sec. 19, T. 43 N., R. 94 W. (rusty beds)	
14. Siltstone, gray, cross-laminated, fucoidal, and shale, gray, carbonaceous, interlaminated, some iron stains, weathers tan.	5.0
13. Shale, black and gray, and siltstone, gray, in lenticular laminae; a 0.5-foot blocky, hard, gray mudstone bed is 4 feet above base. Sample j	5.0
12. Siltstone, gray, cross-laminated, fucoidal, and shale, gray, carbonaceous, interlaminated, some iron stains, weathers tan.	10.0
11. Shale, black and gray, and siltstone, gray, and some sandstone, gray, non-calcareous, in lenticular laminae, fucoidal, abundant carbonaceous material; thin ironstone beds about 0.5 foot thick are at 9, 15, 28, and 42 feet above the base. Sample i, 42-53 feet above base h, 28-42 g, 15-28 f, 9-15 e, 0.9	53.0
10. Sandstone, gray, very fine-grained, and siltstone, gray, non-calcareous, in thin interbeds and wavy laminae, black carbonaceous material, slightly shaly upward; alternating hard and soft beds weather differentially. Sample d	17.0
9. Sandstone, light gray, very fine-grained, hard, calcareous, cross-bedded	0.5
8. Siltstone, gray, fairly hard, some iron-impregnated, some interlaminated carbonaceous shale. Sample c	1.0
7. Siltstone, gray and light gray, clayey, hard, irregularly laminated in part. Sample c	0.5
6. Siltstone, gray, maroon in upper part, very clayey, soft, lower part iron-stained. Sample b	1.5
5. Siltstone, green, hard, blocky, weathers distinctive yellow-brown. Sample b	5.0
4. Siltstone, gray, hard, and shale, gray, silty, in contorted laminae and thin lenses, some iron stains. Sample a	6.0
3. Siltstone, light gray, hard, and shale, gray, silty, hard, interlaminated, carbonaceous material, some iron stains. Sample a	3.5
Total Thermopolis shale	294
Cloverly formation (in part)	
2. Claystone, red, variegated green and gray, silty, spherulites not present at this locality.	2.0
1. Sandstone, tan, fine-grained, sparkly, thickly bedded, cross-bedded, blocky.	6.5

Reference section of Muddy sandstone, near locality 23; measured southeast of road junction in N½ Sec. 36, T. 53 N., R. 93 W., Big Horn Co., Wyoming by Richard A. Paull.

	Thickness in feet
Shell Creek shale (in part)	
12. Shale, black, fissile, soft.	not measured

11. Bentonite, light gray.	0.3
10. Shale, black, fissile, siliceous.	0.8
Muddy sandstone	
9. Sandstone, lignitic, silty.	2.0
8. Sandstone, medium-grained quartz, reddish-weathering, contains microscopic clam fragments and leaves.	0.5
7. Lignite, brown-black, shaly, fibrous vegetable material.	1.5
6. Sandstone, salt and pepper, massive, irregularly bedded, poorly indurated, interbedded with thin irregular stringers of black shale; fair sorting, fine-grained, subangular quartz with lesser amounts of angular plagioclase, biotite, and dark chert in a bentonitic matrix. Local lenses of more resistant, calcareous, slightly conglomeratic, cross-bedded, iron-stained sandstone common at top. Lenses contain rare *Synechodus?* sp. and *Crocodylus* sp. teeth.	39.0
Total Muddy sandstone	43
Thermopolis shale (in part)	
5. Shale, black, fissile, silty.	1.8
4. Siltstone, nodular.	0.3
3. Shale, black, fissile, soft.	0.3
2. Bentonite, light gray.	0.2
1. Shale, black, fissile, soft.	not measured

Type section of the Shell Creek shale; measured at locality 19, six miles northwest of Greybull, Wyoming, in N½ Sec. 14, T. 53 N., R. 94 W., Big Horn Co., Wyoming.

	Thickness in feet
Mowry shale (in part)	
17. Shale, black, hard, siliceous, weathers to light gray chips, contains fish scales.	not measured
16. Bentonite, light gray.	3.0
15. Shale, black, hard, siliceous, weathers to light gray chips, contains fish scales; lower foot is iron-stained and possibly bentonitic.	6.0
Shell Creek shale	
14. Shale, black and gray, fissile, slightly silty. Sample rr, 14-24 feet above base qq, 0-14	24.0
13. Bentonite, gray, weathers yellowish.	0.5
12. Shale, black, fissile; hard and splintery immediately below overlying bentonite. Sample pp, 13-29 feet above base oo, 0-13	29.0
11. Bentonite, greenish-gray, with a 0.2-foot, brown, shaly, iron-impregnated bed 0.5 feet below top, upper part weathers dark brown.	2.0
10. Shale, black, fissile, some silty. Sample nn	4.0
9. Bentonite, greenish-gray.	0.5
8. Shale, black, fissile. Sample mm	12.0
7. Bentonite, greenish-gray.	0.3
6. Shale, black, fissile, some silty. Sample ll, 14-29 feet above base kk, 0-14	29.0
5. Bentonite, light gray, greenish-gray at top; lower half weathers brownish.	1.2

4. Shale, black and gray, fissile, some very silty at 35 and 60 feet above base and near the top of the unit.
    Sample jj, 67-82 feet above base
    ii, 52-67
    hh, 37-52
    gg, 22-37
    ff, 7-22
    ee, 0-7 — 82.0
3. Bentonite, very light gray. — 1.5
2. Shale, black, fissile, two or three very thin ironstone beds in upper half of unit.
    Sample ee, 60-66 feet above base
    dd, 45-60
    cc, 30-45
    bb, 15-30
    aa, 0-15 — 66.0

Total Shell Creek shale 252

Muddy sandstone (in part)

1. Claystone, dark gray and light gray, slightly silty, hard, thinly bedded and laminated, some laminae contorted; light gray claystone is very bentonitic; unit has a 0.2-foot black ironstone at base; contains some carbonaceous material; weathers to very light gray popcorn-textured surface. — 10.0

Locality 3: South of Owl Creek, 300 yards southeast of road corner; SW Sec. 14, T. 43 N., R. 95 W., Hot Springs, Co., Wyoming.

Thickness in feet

Muddy sandstone (in part)

4. Sandstone, light gray, fine-grained, thin-bedded, cross-bedded, ripple-marked, vertical worm tubes, and a few thin dark red ironstone beds. — 15.0
3. Bentonite, white, iron-stained. — 1.0
2. Shale, black, fissile, and siltstone, light gray, thinly interlaminated. — 4.0

Thermopolis shale
(upper shale, in part)

1. Shale, black, fissile.
    Sample p, 1-15 feet below Muddy
    o, 15-30
    n, 30-44
    m, 44-56 — (exposed) 56.0

Locality 4: Northeast flank of Lucerne anticline, east of Big Horn River; NW Sec. 16, T. 43 N., R. 94 W., Hot Springs Co., Wyoming.

Thickness in feet

Shell Creek shale

23. Covered interval, upper part of Shell Creek including Mowry contact. — (about) 30.0
22. Shale, black, poorly exposed, two one-foot bentonites noted about 70 feet above base.
    Sample dd, 80-90 feet above base
    cc, 70-80
    bb, 60-70 — 90.0
21. Bentonite, light gray and white, with dark brown-weathering beds

one foot thick one foot above base and 0.2-foot thick 3.5 feet above base.	9.0
20. Shale, black, hard in upper part immediately below overlying bentonite.	12.0
19. Bentonite, light gray.	2.0
18. Shale, black, and a few very thin interbedded light brown bentonite beds.	13.0
17. Bentonite, greenish-gray.	1.5
16. Shale, black, and a few thin interbedded light brown bentonite beds.	14.0
15. Bentonite, white and light brown.	1.0
14. Shale, black, some iron stains on s-surfaces, some bentonitic material.	7.0
13. Sandstone, gray, fine-grained, hard, cross-laminated, ripple-marked, weathers dark brown.	0.5
12. Shale, black, some iron stains on s-surfaces, some bentonitic material, and a few very fine-grained light gray sandstone laminae. Sample aa	25.0
Total Shell Creek shale	205
Muddy sandstone	
11. Siltstone, gray, shaly, thinly laminated.	1.0
10. Shale, gray, slightly silty, weathers light gray to tan. Sample z	2.0
9. Siltstone, light gray, shaly carbonaceous, cross-laminated, some fucoidal.	4.0
8. Shale, gray, silty, some iron-stained, contains some carbonaceous material. Sample y	3.0
7. Siltstone, gray, soft, shaly, topmost 0.2-foot bed is hard, some carbonaceous material.	1.0
6. Shale, black, silty, soft, non-fissile. Sample x	2.0
5. Sandstone, light gray, fine- to medium-grained, hard, thin-bedded, beds to 0.5 foot thick, vertical worm tubes. Sample w	1.0
4. Siltstone and sandstone, gray, fine-grained, ripple-marked, lenticular laminae, carbonaceous material, weathers slabby. Sample w	1.0
3. Sandstone, light gray, fine- to medium-grained, hard, thin-bedded, some beds to 0.1 foot thick. Individual beds are cross-bedded, other bedding contacts are ripple-marked; basal contact is sharp on soft silty shale; weathers dark brown, thickens southeast and forms ridge. Sample w	3.0
2. Shale, gray, very silty, iron-stained near top, weathers to soft, light gray slope.	10.0
1. Siltstone, light gray, some sandy, and shale, black, fissile, interbedded in 0.1- to 0.3-foot beds.	6.0
Total Muddy sandstone	34

Locality 5: Southwest flank of Lucerne anticline, east of Big Horn River; SW Sec. 16, T. 43 N., R. 94 W., Hot Springs Co., Wyoming.

	Thickness in feet
Mowry shale (in part)	
16. Shale, gray, hard, siliceous, weathers to light gray chips, contains fish scales.	not measured

Shell Creek shale

15. Shale, dark gray and black, two thin bentonites about 22 feet above base and several others in upper 45 feet; unit is just fairly exposed; appears to become harder upward.
    Sample ll, 61-85 feet above base
    kk, 40-61
    jj, 20-40
    ii, 0-20 85.0
14. Shale, black, containing two or three very thin ironstone beds.
    Sample hh 12.0
13. Shale, black, some iron-stained, weathers brownish.
    Sample gg, 20-30 feet above base
    ff, 0-20 30.0
12. Bentonite, white and light gray, with dark brown-weathering beds one foot thick one foot above base and 0.2-foot thick 3.5 feet above base. 9.0
11. Shale, black, hard in upper foot immediately below overlying bentonite.
    Sample ee 12.0
10. Bentonite, very light gray, with a very thin shale parting near base. 2.0
9. Shale black, with a few very thin yellow-brown bentonite beds.
    Sample dd 13.0
8. Bentonite, greenish-gray. 1.0
7. Shale, black, with a few very thin yellow-brown bentonite beds.
    Sample cc 14.0
6. Bentonite, white and very dark brown. 0.5
5. Shale, black, fissile, with some iron stains.
    Sample bb 7.0
4. Sandstone, gray, fine-grained, very hard, ripple-marked, weathers dark brown. 0.5
3. Shale, black, fissile, with some iron stains.
    Sample aa 12.0
2. Covered interval, includes Muddy contact. 30.0

Muddy sandstone (in part)

1. Sandstone, light gray, fine-grained, thin-bedded, beds to one foot thick, some interbedded gray siltstone and shale in upper part, forms ridge. 10.0

Locality 7: Thermopolis Hill west of Thermopolis, Wyoming; NW Sec. 34, T. 43 N., R. 95 W., Hot Springs Co., Wyoming.

Thickness in feet

Shell Creek shale (in part)

12. Shale, black, some rusty stains, large ironstone concretions, sandstone dikes. not measured

Muddy sandstone

11. Shale, gray, silty and siltstone, light gray, ripple-marked, interlaminated, much carbonaceous material, shale weathers papery, siltstone weathers flaggy to light brown. 9.0
10. Shale, black, 0.5-foot bentonite in middle.
    Sample x 2.0
9. Sandstone, light gray, fine-grained, fairly hard. 1.0
8. Shale, gray and tan, silty, and sandstone, fine-grained, interlaminated, carbonaceous material. 4.0
7. Sandstone, light gray, fine-grained, fairly hard. 0.5

6. Shale, black, soft, and siltstone, tan. Sample w	4.0
5. Sandstone, gray, fine-grained, calcareous, ripple-marked, cross-bedded, beds to one foot thick, hard, weathers dark brown.	4.0
4. Sandstone, light tan and white, fine-grained, some salt and pepper, non-calcareous, thin-bedded, ripple-marked.	5.0
3. Sandstone, gray and tan, salt and pepper, soft, friable, silty, fine-grained.	2.0
Total Muddy sandstone	31.5
Thermopolis shale (upper shale, in part)	
2. Shale, black, fissile, a 1.2-foot gray bentonite at base and two thinner ones with associated ironstone beds, one near middle, and one 3 feet below top of unit. Sample n, 0.5-foot above basal bentonite m, 0.5-foot below basal bentonite	18.0
1. Shale, black, fissile.	not measured

Locality 9: East of Thermopolis, Wyoming, about 0.4 miles south of oil field road; NW Sec. 10, T. 42 N., R. 94 W., Hot Springs Co., Wyoming.

	Thickness in feet
Mowry shale (in part)	
30. Shale, black, hard, siliceous, weathers to light gray chips, contains fish scales.	65.0
29. Bentonite, white and light gray.	2.0
28. Shale, black, hard, becoming harder upward, some iron stains, and a few very thin bentonites, weathers brownish-gray, contains fish scales.	30.0
27. Bentonite, light gray.	1.0
Shell Creek shale	
26. Shale, dark gray, hard, contains fish scales.	30.0
25. Bentonite, light gray.	1.0
24. Shale, dark gray, hard.	3.0
23. Shale, black, some hard, 0.2-foot ironstone 39 feet above base; one-foot bentonite laterally replaced by ironstone at 51 feet; one-foot bentonite with a thin ironstone bed at its base at 57 feet; 0.5-foot tan bentonite at 66 feet; 1.5-foot gray bentonite at 70 feet; 2-foot gray bentonite at top of unit. Sample dd, 45-60 feet above base cc, 30-45 bb, 15-30 aa, 0-15	100.0
22. Bentonite, white, two thin dark brown-weathering beds in lower 2 feet, and dark brown-weathering beds near top.	8.0
21. Shale, black, fissile, some iron stains, somewhat hard at extreme top just below the overlying bentonite.	7.0
20. Bentonite, light gray and greenish gray, with a 0.2-foot ironstone in middle part.	2.0
19. Shale, black, fissile.	7.0
18. Bentonite, gray and light gray.	0.5
17. Shale, black, fissile, some iron stains.	4.0
16. Bentonite, gray.	1.5
15. Shale, black, fissile, some iron stains.	11.0
14. Bentonite, orange and gray.	0.5

13. Shale, black, fissile, some iron stains. 4.0

12. Sandstone, gray, fine-grained, hard, calcareous, cross-bedded, basal surface very irregular, contains shale inclusions. 0.5

Section offset to about one mile east of Thermopolis state park on oil field road; NW Sec. 5, T. 42 N., R. 94 W.

11. Covered interval, black shale in upper part. 27.0

Total Shell Creek shale 207

Muddy sandstone

10. Sandstone, dark gray, fine-grained, hard, calcareous, thin-bedded, weathers brown, lenticular along strike. 0.5

9. Siltstone, gray, and shale, gray, silty, interlaminated, some carbonaceous material, upper 2 feet well-sorted fine-grained sandstone cross-bedded on very small scale. 6.0

8. Sandstone, light gray, fine-grained, silty, hard, massive. 1.0

7. Shale, dark gray, silty, some carbonaceous material. 6.0

6. Bentonite, gray and brown. 2.0

5. Sandstone, gray, fine-grained, some medium-grained, salt and pepper, some irregular gray shale inclusions, possibly worm tubes. 0.5

4. Sandstone, gray and brown, fine-grained, silty, friable, very thinly bedded. 4.0

3. Shale, black, fissile. 0.5

2. Bentonite, gray and brown. 2.5

Total Muddy sandstone 23

Thermopolis shale
(upper shale, in part)

1. Shale, black, fissile. not measured

Locality 13: On northwest-plunging nose of Thermopolis anticline, 11 miles northwest of Thermopolis; S½ Sec. 28, T. 44 N., R. 96 W., Hot Springs Co., Wyoming.

Thickness in feet

Mowry shale (in part)

5. Shale, black, hard, siliceous, weathers to gray chips, forms small ridge. not measured

Shell Creek shale (in part)

4. Shale, black, and some brownish-gray, hard, interbedded gray bentonites as follows:
    0.5-foot at 4 feet above base;
    0.5-foot at 5 feet;
    2-foot at 7 feet;
    0.5-foot at 13 feet;
  unit weathers brownish-gray.
    Sample cc, 11-21 feet above base 21.0

3. Shale, black, fissile, upper part fairly hard, prominent ironstone concretionary beds at 38, 40, 44, and 85 feet above base, interbedded bentonites as follows:
    0.5-foot at 53 feet above base;
    0.2-foot at 56 feet;
    0.1-foot at 65 feet;
    0.2-foot at 66 feet;
    0.5-foot at 67 feet;
    1.5-foot at 69 feet;
    2.5-foot at 103 feet.

Sample bb, 0.5 foot above bentonite at 53 feet aa, 0.5 foot below bentonite at 53 feet	105.0
2. Bentonite, very light gray, with a very dark brown-weathering bed near base.	8.0
1. Shale, black, poorly exposed.	not measured

Locality 15: North of U. S. Highway 16, west of Tensleep, Wyoming; SE Sec. 21, T. 47 N., R. 89 W., Washakie Co., Wyoming.

	Thickness in feet
Mowry shale (in part)	
30. Shale, black, hard, siliceous.	not measured
29. Bentonite, gray.	3.0
28. Shale, dark gray, fissile, very hard, siliceous, weathers to light gray chips, forms ridge.	12.0
Shell Creek shale	
27. Shale, black, fissile, interbedded bentonites as follow: one-foot white bentonite at 26 feet above base; one-foot bentonite at 29 feet; 1.5-foot light gray bentonite at top of unit; large cone-in-cone concretions occur at the Mowry contact, unit weathers gray and brownish-gray, gradational with unit below. Sample ll, 18-33 feet above base kk, 0-18	33.0
26. Shale, black, fissile, lower 3 feet weathers to especially black surface, above 100 feet becomes harder, iron stains on s-surfaces, contains some thin ironstone beds, interval 48-56 feet above base is covered, interbedded bentonites as follow: 2-foot white and light gray at 58 feet above base; 2-foot white bentonite at 116; 0.7-foot white underlain by 0.5-foot ironstone at 121; 1.5-foot light gray bentonite at 125 feet; 1.5-foot greenish-gray with some interbedded shale at 144 feet; 0.5-foot greenish-gray at 154 feet; 1.5-foot greenish-gray at 161 feet. Sample jj, 150-169 feet above base ii, 131-150 hh, 115-131 gg, 100-115 ff, 87-100 ee, 72-87 dd, 60-72 cc, 32-48 bb, 16-32 aa, 0-16	170.0
Total Shell Creek shale	203

Section offset eastward to steeply-dipping beds on Tensleep fault in SE Sec. 24, T. 47 N., R. 89 W.

Muddy sandstone	
25. Bentonite, light gray, and thin silty gray shale laminae, interlaminated and cross-laminated; some bedding planes contain polygonal markings which may be mud cracks one to three inches in diameter.	4.0
24. Bentonite, light gray, carbonaceous material.	1.0
23. Bentonite, white.	1.0
22. Shale, gray, fissile, carbanaceous fragments.	1.0

21. Sandstone, light gray and tan, fine-grained, salt and pepper, soft and friable, cemented with bentonitic clay; long, sweeping cross-beds; resistant six-foot concretionary masses in lower part apparently secondarily developed from ground water activity. Sample w	20.0
20. Sandstone, gray and brown, fine-grained, silty, soft, bentonitic clay cement, grades into unit above.	3.0
19. Bentonite, gray.	2.0
18. Siltstone, brown, shaly, very soft.	5.0
Total Muddy sandstone	37
Thermopolis shale	
(upper shale)	
17. Shale, black, fissile, iron concretions at 28 and 56 feet above base. Sample p, 63-84 feet above base o, 42-63 n, 21-42 m, 0-21	84.0
(middle silty shale)	
16. Shale, black and brown, fissile, rare laminae of light gray siltstone, a few very thin beds of soft, fine-grained, tan sandstone and fucoidal, hard, gray limestone in upper part, some carbonaceous material, weathers light tan, supports vegetation. Sample j	22.0
15. Siltstone, dark brown, iron-impregnated, carbonaceous material, vertical worm tubes.	1.0
(lower shale)	
14. Shale, black, fissile, some brown near base, rare lenticular laminae of light gray siltstone, dahllite concretions in lower 10 feet, a 4-foot sandy bed 26 feet above base, a thin bentonite bed 50 feet above base, ironstone beds at 17, 30, and 63 feet above base, weathers to gray slope with hard crust, crocodile bone fragments 34 feet above base. Sample i, 63-79 feet above base h, 31-46 g, 17-30 f, 0-15	79.0
(rusty beds)	
13. Shale, black and brown, fissile, and siltstone, gray and brown, interlaminated, a few beds iron-impregnated, carbonaceous material, weathers to rusty color. Sample e	20.0
12. Sandstone, gray, fine-grained, hard, calcareous, thinly bedded, weathers brown.	1.0
11. Shale, black and brown, fissile, and siltstone, gray and brown, interlaminated, fucoidal, some beds iron-impregnated, carbonaceous material, weathers to rusty color. Sample d	35.0
10. Shale, black and brown, fissile, carbornaceous, 0.3-foot ironstone beds 9 feet above base and at top of unit, upper 5 feet is silty. Sample c	14.0
9. Ironstone, dark brown, cone-in-cone structure.	1.0
8. Shale, black and brown, fissile, carbonaceous, silty and yellow-stained at base. Sample b	6.0

7. Claystone, dark gray, silty, some interbedded siltstone beds, carbonaceous material. Sample a	3.0
6. Sandstone, light gray, fine-grained, friable, thinly bedded in uneven beds, some interbedded siltstone, vertical worm tubes, lenticular along strike.	3.0
5. Claystone, dark gray, silty, siltstone in upper part, carbonaceous material.	7.0
4. Peat, brown, very soft, abundant plant remains, very local.	3.0
3. Sandstone, very light gray, fine-grained, silty, massive to thickly bedded, weathers dark brown.	6.0
Total Thermopolis shale	285
Cloverly formation (in part)	
2. Claystone, gray and light gray, very silty.	8.0
1. Claystone, very dark gray, silty.	3.0

Locality 16: About 12 miles south of Tensleep, Wyoming; Sec. 1, T. 45 N., R. 88 W., Washakie Co., Wyoming.

	Thickness in feet
Shell Creek shale (in part)	
11. Shale, black and brown, slightly silty, poorly exposed.	not measured
Muddy sandstone	
10. Sandstone, fine to medium-grained, hard, calcareous, very thin bedded.	0.2
9. Shale, black, fissile, rare thin gray siltstone laminae. Sample y	5.0
8. Shale, light gray, silty, carbonaceous material, gradational with shale above. Sample x	3.0
7. Sandstone, gray, fine-grained, some medium-grained, salt and pepper, calcareous, cross-bedded and unevenly bedded.	1.0
6. Bentonite, gray and light yellow, silty, cross-bedded.	12.0
5. Sandstone, light gray, fine-grained, calcareous, cross-bedded in long, sweeping, very thin beds, unit is lenticular, weathers light brown.	1.0
4. Bentonite, light gray, silty, some brown-weathering beds.	6.0
3. Bentonite, light gray, becoming very shaly at top, iron oxide stains on weathered surfaces.	1.0
2. Shale, gray, silty, very hard, 0.5-foot bentonite 8 feet above base. Sample w	13.0
Total Muddy sandstone	42.2
Thermopolis shale (upper shale, in part)	
1. Shale, black, fissile.	not measured

Locality 17: A few miles north of Arminto, Wyoming; NE Sec. 24, T. 38 N., R. 87 W., Natrona Co., Wyoming.

	Thickness in feet
Mowry shale (in part)	
36. Shale, gray, very hard, some bentonites and interbedded siltstones, weathers to silver-gray slopes.	not measured
Shell Creek shale	
35. Bentonite, light gray.	1.0
34. Shale, gray, hard.	2.0
33. Bentonite, light greenish-gray.	0.3

32. Shale, gray, hard.	1.5
31. Bentonite, greenish-gray.	1.0
30. Shale, black, hard.	4.0
29. Bentonite, light gray.	1.0
28. Shale, black, fissile, hard.	2.0
27. Bentonite, light gray.	1.0
26. Shale, black, fissile. Sampe gg	18.0
25. Bentonite, gray. Sample ff, 0.5-foot shale interval above ee, 0.5-foot shale interval below	0.5
24. Shale, black, fissile. Sample dd	9.5
23. Bentonite, light gray.	4.5
22. Shale, black, fissile. Sample cc	7.5
21. Bentonite, light gray.	0.5
Section offset about 3.5 miles east to NW Sec. 22, T. 38 N., R. 86 W.	
20. Shale, black, fissile.	1.5
19. Bentonite, gray.	0.5
18. Shale, black, fissile.	1.5
17. Bentonite, gray.	0.5
16. Shale, black, fissile. Sample bb	8.0
15. Bentonite, gray and greenish-gray, weathers dark brown in lower foot.	5.0
14. Shale, black, fissile, lower 3.5 feet is gray. Sample aa	8.0
Total Shell Creek shale	79.3
Muddy sandstone	
13. Siltstone, gray, very clayey, and sandstone, gray, very fine-grained, thinly interbedded and interlaminated.	12.0
12. Claystone, gray, hard, thin-bedded, ripple-marked, rough bedding surfaces, some carbonaceous material. Sample x	2.0
11. Shale, gray, brown carbonaceous material, a 0.3-foot gray bentonite at base, and a 0.2-foot bentonite 3 feet below top. Sample w	5.0
Total Muddy sandstone	19
Thermopolis shale (upper shale)	
10. Shale, black, fissile, some ironstone beds and concretions, and some cone-in-cone concretions; intervals 0-8 and 56-71 feet above base are poorly exposed. Sample o, 51-71 feet above base n, 31-51 m, 8-31	71.0
Section offset about 3 miles west to NW Sec. 19, T. 38 N., R. 86 W. (middle silty shale)	
9. Shale, black and brown, fissile, a few thin beds of gray silty limestone and siltstone which weather to dark brown chips, unit weathers tan, supports vegetation. Sample d, 10-15 feet above base	15.0

(lower shale)	
8. Shale, gray and black, fissile, rare lenticular laminae and very thin beds of light gray siltstone, a few prominent ironstone beds, weathers medium-gray.	56.0
(rusty beds)	
7. Shale, gray and black, fissile, and siltstone, gray, interlaminated, fucoidal, a few ironstone beds; shale predominates lower 35 feet; prominent silty intervals 36-41 and 53-58 feet above base; upper 6 feet contains several thin siltstone beds and a 0.5-foot silty gray limestone; poorly exposed in part. Sample a, 0-20 feet above base b, 20-40 c, 40-60	85.0
Total Thermopolis shale	227
Cloverly formation (in part)	
6. Claystone, gray, hard, silty, contains profuse spherulites of iron oxide, weathers tan.	2.0
5. Siltstone, gray, very hard, clayey, weathers rusty with dark brown surface, lenticular along strike.	2.0
4. Siltstone, gray, very fine-grained, hard.	2.0
3. Siltstone, gray, very hard, very fine-grained, weathers rusty.	1.0
2. Claystone, variegated red and gray, lower part weathers reddish-brown.	7.0
1. Claystone, light gray and lavender, silty, soft.	5.0

Supplemental section of the Muddy sandstone at the original western locality; NE Sec. 24, T. 38 N., R. 87 W.

Shell Creek shale (in part)	
12. Covered interval.	29.0
11. Shale, black, fissile.	1.0
Muddy sandstone	
10. Shale, black and gray, fissile, rare ironstone and hard gray mudstone beds.	6.0
9. Shale, light gray, and siltstone, gray, carbonaceous, thinly interbedded, a hard, gray ripple-marked siltstone at top.	3.0
8. Covered interval, mainly light-colored shale.	5.0
7. Shale, black, fissile.	0.5
6. Shale, black, gray, and brown, a hard 0.2-foot mudstone at top.	1.5
5. Shale, light greenish-gray, fissile, bentonitic, a 0.3-foot black, fissile shale in middle.	1.5
4. Shale, gray and dark gray, fissile, rare thin, light gray siltstone beds.	8.0
3. Shale, gray, silty, and siltstone, gray, ripple-marked, interbedded in 0.1- to 0.5-foot beds.	15.0
2. Sandstone, light gray, fine-grained, medium and thick beds, hard, ripple-marked, basal part covered.	6.0
Total Muddy sandstone	46.5
Thermopolis shale	
(upper shale, in part)	
1. Shale, black, fissile, some brown-weathering iron-impregnated beds.	not measured

Locality 18: On irrigation canal immediately east of U. S. Highway 287 in SE Sec. 13, T. 8 N., R. 70 W., Larimer Co., Colorado; measured by K. M. Waagé.

	Thickness in feet
South Platte formation	
(contact with Benton shale obscured)	
35. Sandstone, brown-weathering, fine-grained, massive to ledgy, cross-laminated, top and base obscured.	(about) 35.0
34. Covered interval, obscured by slope wash; some float of sandy, calcareous siltstone with shell fragments.	35.0 to 40.0
33. Siltstone and sandstone, fine-grained, calcareous, platy; interbedded with thin beds of sandy limestone and gray calcareous silty shale; contains *Inoceramus comancheanus* Cragin and *Ostrea* sp.	30.0
32. Shale, dark gray, silty, calcareous, some siltstone laminae.	2.5
31. Bentonite-like clay.	0.4 to 1.0
30. Shale, as in 32 above. Sample r	2.6
29. Bentonite-like clay.	1.1
28. Shale, gray, silty, calcareous, interbedded with platy calcareous siltstone. Sample r	3.7
27. Shale, gray, finely silty, calcareous, some fine siltstone laminae. Sample r, 2.0-4.7 feet above base q, 0-2.0	4.7
26. Bentonite-like clay.	0.1
25. Shale, gray, finely silty. Sample q	4.0
24. Siltstone, platy, calcareous, sandstone, fine-grained, shale, gray, calcareous, gypsiferous, and limestone, gray, sandy, crystalline, petroliferous, thinly interbedded; limestone and siltstone beds are fossiliferous: *Inoceramus comancheanus* Cragin, *I. bellvuensis* Reeside, *Ostrea noctuensis* Reeside, *Pteria salinensis* White, and fish scales and bones. Sample q, 4.3-8.3 feet above base p, 0-4.3	8.3
23. Shale, dark gray, silty, gypsiferous. Sample p, 1.8-7.5 feet above base o, 0-1.8	7.5
22. Shale, gray, silty, interbedded with thin beds of siltstone and fine-grained sandstone that weather olive-brown. Sample o	2.2
21. Shale, silty, weathers olive-brown, grades downward into dark gray shale below. Sample o	2.5
20. Bentonite-like clay.	0.3
19. Shale, dark gray, scattered thin siltstone beds. Sample o, 1.0-4.5 feet above base n, 0-1.0	4.5
18. Shale, mottled dark and light gray, silty, block fracture, gypsum in cross-fractures. Sample n, 4.5-13.5 feet above base m, 0-4.5	13.5
17. Shale, dark gray to black, very silty, and siltstone, shaly, in thin beds and laminae. Sample m, 3.2-10.7 feet above base	10.7
16. Shale, dark gray to black.	3.2

15. Shale, dark gray, silty in lower foot; bed of white-weathering argillaceous siltstone, 0.1- to 0.3-foot thick at top. 6.8
14. Bentonite-like clay. 0.1
13. Shale, dark gray, silty, with laminae and thin beds of siltstone in lower 11.6 feet. 14.2
12. Obscured, chiefly dark gray shale. 12.5
11. Sandstone, weathers with greenish cast, platy to shaly, fine-grained. 1.5
10. Shale, gray with greenish cast, weathers red, silty. 1.2

Plainview sandstone member

9. Sandstone, brown-weathering, fine-grained, even-bedded, finely laminated, upper 0.5-foot is shaly, forms hogback. 14.2
8. Sandstone, fine-grained, platy, in beds 0.2- to 0.4-feet thick, and shale, dark gray, containing thin beds and laminae of siltstone, interbedded, trails and worm castings on bedding surfaces, some vertical borings. 6.0
7. Shale, dark gray to black mottled yellow with iron stain on weathered surfaces, silty; upper foot is argillaceous siltstone. 3.1
6. Sandstone, brown-weathering, massive, fine-grained, dense. Locally quartzitic where pierced by fine tubular cavities that cut bed at all angles. 5.5
5. Shale, dark gray; fine-grained, brown-weathering sandstone in middle part; sandstone locally thickens to as much as 2 feet and shales above and below thin to mere partings. 1.2
4. Sandstone, weathers brown to reddish-brown, massive, fine-grained, dense; shales out locally. 3.7
3. Shale and claystone, black, silty, carbonaceous, with interbeds gray and dark gray argillaceous siltstone. 3.6
2. Sandstone, varies from 4-foot bed, dense, fine-grained, as in 4 above, to 0.3-foot soft carbonaceous sandstone. Locally absent and unit 3 rests directly on surface of disconformity. 0.3 to 4.0

Total South Platte formation 255±

disconformity

Lytle formation

1. Clay, claystone, and argillaceous siltstone, variegated, upper third gray-white to yellow-gray with orange-brown stain, middle third chiefly light red-purple claystone with lens green siltstone, lower third light greenish-gray to gray-white; colors vary laterally. Chert concretions, light gray, up to one foot in diameter in upper gray-white zone; some scattered pyrite concretions, gypsum in fractures throughout. 16.0

Locality 19: Seven miles northwest of Greybull, Wyoming on west flank of Sheep Mountain anticline, Sec. 14, T. 53 N., R. 94 W., Big Horn Co., Wyoming.

Thickness in feet

Shell Creek shale, type section (in part)

32. Shale, black, fissile, two or three very thin ironstone beds in upper half of unit. 66.0

Muddy sandstone

31. Shale, dark gray and light gray, hard, thinly interbedded and interlaminated, some laminae contorted; light gray shale is very bentonitic; unit has a 0.2-foot ironstone at base, contains some carbonaceous material, weathers to gray, popcorn-textured surface. Sample z 10.0

30. Sandstone, very light gray, fine-grained, salt and pepper, friable, bentonitic cement, very thinly to thickly bedded, contains rare black chert pebbles to two inches in diameter, brown carbonaceous material, weathers to very light gray popcorn-textured surface.
Sample y 15.0

29. Sandstone, gray and tan, fine-grained, salt and pepper, slightly friable, bentonitic cement, some contorted black shale laminae and a few very thin black shale beds near top, brown carbonaceous material.
Sample x 6.0

28. Shale, gray, fissile, rare very light gray siltstone laminae, brown carbonaceous material, sandy near top, grades into overlying sandstone; north along strike this interval contains 0.5-foot lens of sandstone, gray, silty, medium-grained, salt and pepper, cross-bedded, each lens only a few feet wide.
Sample w 10.0

Total Muddy sandstone 41

Thermopolis shale
(upper shale)

27. Shale, black, fissile, some poorly exposed, a 0.2-foot bentonite 10 feet below Muddy sandstone.
Sample v, 99-112 feet above base
u, 0.3 feet above bentonite 10 feet below Muddy
t, 0.3 foot below bentonite 10 feet below Muddy
s, 86-99 feet above base
r, 72-86
q, 68-78
p, 52-62
o, 40-52
n, 27-40
m, 0-11 112.0

(middle silty shale)

26. Limestone, gray, hard, silty, in beds to 0.2-foot thick, weathers tan; and shale, black, fissile, thinly interbedded. 4.0

25. Shale, black and gray, fissile, weathers light gray.
Sample l 6.0

24. Siltstone, tan, hard, laminated, weathers to thin, rusty chips. 0.5

23. Shale, black, some dark brown, fissile, slightly silty, weathers tan.
Sample k 14.5

22. Siltstone, tan, and sandstone, tan, very fine-grained, hard, very thinly interbedded, contains worm markings, weathers to brown chips. 1.0

(lower shale)

21. Shale, black, fissile, slightly silty, soft, deeply weathered, grades into siltstone above; greenish 0.5-foot bentonite is 12 feet above base.
Sample j, 13-32 feet above base
i, 0-12 32.0

20. Shale, black, some brown, fissile, slightly silty, fairly hard, some iron stains, a few thin beds of tan, cross-laminated fine-grained sandstone with worm tubes, weathers light gray.
Sample h 21.0

19. Shale, dark gray, silty, and siltstone, light gray, soft, friable, thinly interbedded, weathers deeply to yellow-brown color, supports vegetation. 4.0

18. Shale, black, fissile, and sandstone, tan, fine-grained, in thin irregular beds marked with worm tubes; sandstone chips litter weathered slope. Sample g	6.0
17. Shale, black and tan, fissile, dahllite concretion bed 24 feet above base, lower 5 feet appears bentonitic in part. Sample g	25.0
(rusty beds)	
16. Siltstone, gray, and sandstone, gray, very fine-grained, cross-laminated beds to 1.5 feet thick, some interbedded shale, dark gray and brown, carbonaceous material; at top of unit is a 2-foot ridge-forming sandstone, tan, fine-grained, cross-laminated, weathers brown.	23.0
15. Shale, gray, some silty, with a few light gray siltstone laminae, carbonaceous material. Sample f	9.0
14. Siltstone, tan, and sandstone, gray and tan, fine-grained, cross-laminated beds to 0.7 foot thick, some interbedded gray fucoidal shale; at top is a resistant 0.7-foot ripple-marked sandstone bed which weathers rusty brown.	7.0
13. Shale, gray and tan, fissile, some silty, some fucoidal, and siltstone, gray, interlaminated, carbonaceous, a few thin ironstone beds, a prominent one 30 feet above base; lower 5 feet poorly exposed but appear to contain some thin, gray, fine-grained sandstone beds; weathers tan. Sample e, 19-38 feet above base d, 0-19	54.0
12. Sandstone, tan and dark brown, fine-grained, massive to thickly cross-bedded, beds to one foot thick, grades laterally and vertically into light-colored fine-grained sandstone which weathers grayish-orange and is medium-bedded to massive and contains vertical worm borings; unit forms high ridge, pinches out about one mile north, poorly exposed base and top. Sample c	6.0
11. Claystone, light gray, very silty, iron oxide veinlets, gradational with siltstone below.	1.4
10. Siltstone, light gray, clayey, massive, slightly blocky, becomes finely sandy downward, grades into siltstone below.	2.6
9. Siltstone, light gray and tan, hard, blocky, weathers tan.	2.8
8. Shale, brown, lignitic, carbonaceous plant material; upper 3 feet is gray and silty.	1.0
7. Claystone, very dark gray, soft, finely silty, gypsiferous, black carbonaceous material, upper foot is light gray and contains iron oxide veinlets, lower 1.5 feet is shaly and silty; laterally contains sandy red and tan claystone with iron oxide spherulites. Sample b	5.8
6. Sandstone, light gray, fine-grained, and shale, gray, very silty, thinly interbedded, some carbonaceous material, iron oxide stains on bedding planes.	2.0
5. Siltstone, gray, very fine-grained, soft in upper two feet; harder with thinly interbedded very fine-grained sandstone in lower part, weathers light brown, blocky.	4.5
4. Siltstone, olive green, clayey, blocky when fresh, weathers splintery; grades down to gray, hard shale with brown plant remains in lower foot. Sample a	3.0

3. Siltstone, gray, clayey, gradational with siltstone above, brown plant material. 1.8
2. Siltstone, tan and gray, hard, some soft beds; beds to one foot thick, weathers light brown, splintery. 6.5

Total Thermopolis shale 356

Cloverly formation

1. Claystone, gray, variegated red, silty, scattered iron oxide spherulites in upper few feet; laterally some thin beds of fine-grained sandstone with chert grains are 3 feet below top. not measured

Locality 20: On Five Springs Creek, south of Wyoming Highway 14; NW Sec. 5, T. 55 N., R. 93 W., Big Horn Co., Wyoming.

Thickness in feet

Mowry shale (in part)

61. Shale, gray, hard, siliceous, weathers light gray and flaggy, contains fish scales. not measured
60. Bentonite, deeply weathered to orange color. 4.0
59. Shale, gray, hard, siliceous, weathers gray and flaggy, contains fish scales. 2.0

Shell Creek shale

58. Shale, dark gray to black, fissile, hard, a 0.3-foot ironstone at base and ironstone concretions 6 feet above base; bentonite beds occur as follows: 0.3-foot gray bentonite 12 feet above base; a 1.5-foot light gray bentonite with a dark brown-weathering top at 15 feet; thin, poorly exposed bentonite at 42 feet. Upper 30 feet is slightly silty and supports vegetation. 68.0
57. Shale, black, fissile, with ironstone concretions and iron stained s-surfaces. 5.0
56. Shale, dark gray and light gray, thin lenticular beds and laminae of light gray siltstone to 0.3-foot thick interbedded; some ironstone concretions containing *Inoceramus* sp. 22.0
55. Shale, light gray, bentonitic, weathers to popcorn surface. 3.0
54. Bentonite, light gray, gradational with shale above it. 2.0
53. Shale, black, fissile, ironstone concretions, vertebrate fragments and *Inoceramus* sp. 1.0
52. Bentonite, gray. 0.4
51. Shale, black, fissile, some light gray siltstone interlaminae, contorted; extreme upper part is dominantly siltstone; unit contains many ironstone concretion beds. 81.0
50. Bentonite, gray and greenish-gray. 1.5
49. Shale, black, fissile, occasional ironstone concretion beds, poorly exposed. 73.0

Total Shell Creek shale 257

Section offset eastward to NE Sec. 35, T. 56 N., R. 93 W.

Muddy sandstone

48. Claystone, gray and very light gray, in contorted interlaminae and very thin beds; light gray clay is mainly bentonite; this comprises most of lower 2 feet. 5.0
47. Sandstone, light tan, very fine-grained to medium-grained, silty, soft and friable, thinly bedded, a 0.4-foot ironstone 5 feet above base; unit weathers tan. 16.0
46. Shale, dark gray, fissile, hard, and siltstone, light gray, interlaminated in lower foot; unit contains fish scales, grades into sandstone above. 10.0

45. Sandstone, gray, fine-grained, shaly, and claystone, gray, very sandy, iron oxide veinlets and brown carbonaceous material, upper 5 feet becomes harder and contains contorted laminae of dark gray shale, unit weathers to tan slope.	10.0
Total Muddy sandstone	41
Thermopolis shale	
(upper shale)	
44. Shale, black, fissile.	110.0
(middle silty shale)	
43. Limestone, gray, silty, hard, weathers to dark brown chips.	0.5
42. Shale, black and brown, fissile.	8.0
41. Siltstone, tan, hard, thinly bedded, weathers dark brown.	0.5
40. Shale, black and brown, fissile.	16.0
39. Limestone, gray, silty, hard, weathers to dark brown chips.	1.0
38. Siltstone, tan, and sandstone, tan very fine-grained, and shale, gray and brown, fissile, thinly interbedded and interlaminated in small lenses; unit weathers deeply to yellow-brown slope, supports vegetation.	5.5
Section offset about a mile west to Sec. 34, T. 56 N., R. 93 W.	
(lower shale)	
37. Shale, black, fissile, hard, some interlaminated light gray siltstone near base; siltstone increases upward and dominates at top of unit, grades into siltstone above, unit weathers grayish-tan.	15.0
36. Shale, brown, fissile, weathers tan; capped by a bench-forming, silty, gray limestone 0.1-foot thick.	1.0
35. Shale, black, fissile, hard, some slightly silty, botryoidal dahllite concretions, weathers light gray, crocodile bones.	14.0
34. Limestone, gray, silty, hard, weathers dark brown, crocodile bones immediately above.	0.1
33. Shale, black, fissile, with rare lenticular light gray siltstone laminae, botryoidal dahllite concretions, weathers light gray.	6.0
32. Bentonite, greenish-gray, black shards, gradational with shale above.	0.5
31. Limestone, gray, silty, hard, weathers dark brown.	0.2
30. Shale, black, fissile, with lenticular laminae of light gray siltstone, crocodile fragments in middle part, weathers medium-gray.	9.0
29. Limestone, gray, silty, hard, in very thin irregular beds, forms bench, weathers light brown.	0.3
28. Shale, black, fissile, rare lenticular laminae of light gray siltstone and light gray fine-grained sandstone; in lower 2 feet are a few continuous thin beds of gray siltstone and some fucoidal ironstones. Unit weathers medium gray.	12.0
27. Shale, black, fissile, rare lenticular laminae of light gray siltstone, one very thin bed of tan fine-grained sandstone 8 feet above base; at base and top are very thin ironstone beds; weathers light gray.	13.0
26. Shale, gray, fissile, and sandstone, tan fine-grained, soft, thinly interbedded and interlaminated in about equal amounts. In middle is a gray silty fucoidal limestone weathering to dark gray chips. Unit weathers to tan slope; supports vegetation.	4.0
25. Shale, black, fissile, with rare lenticular laminae of light gray siltstone; contains a few very thin beds of tan fine-grained noncalcareous sandstone; dahllite concretions occur at base; unit weathers medium gray.	14.0
24. Limestone, gray, silty, cross-bedded, fucoidal, weathers to dark gray chips.	0.3

23. Shale, black, fissile, and siltstone, light gray, in lenticular and contorted laminae, siltstone decreases upward, bone fragments weather out at extreme base, weathers medium gray.	15.0
(rusty beds)	
22. Shale, black, some brown, fissile, with minor amount of interlaminated light gray siltstone laminae which increase upward. In upper 3 feet are a few thin beds of fine-grained sandstone which weather yellow-brown. Unit contains carbonaceous material, weathers light tan.	11.0
21. Limestone, gray, silty, some cone-in-cone structure, weathers brown, forms ledge.	0.2
20. Shale, black, some brown, fissile, rare laminae of light gray siltstone which decreases upward; 3 feet below top is a one-foot bed of soft, brown siltstone which weathers yellow-brown; carbonaceous material; weathers light tan.	16.0
19. Limestone, gray, silty, weathers to dark brown chips.	0.1
18. Shale, gray and brown, fissile, with some lenticular laminae of light gray siltstone, carbonaceous material, a gray silty cross-bedded limestone in lenses to one foot thick is 14 feet above base; unit weathers deeply to light tan color.	22.0
17. Limestone, gray, silty, cross-bedded, weathers to brown chips, forms ledge.	0.3
16. Shale, gray and brown, fissile, and siltstone, gray, interlaminated and interbedded in about equal amounts, ironstone concretions in lower 6 feet, lenticular ironstone bed 21 feet above base, carbonaceous material, some beds fucoidal, weathers light tan.	23.0
15. Sandstone, tan, fine-grained, ironstone concretions, cross-laminated, massive appearing on weathering, forms prominent ledge, contains poorly preserved pelecypods and gastropods.	2.0
14. Siltstone, tan, thinly bedded, irregular bedding planes, a few sandy beds, ironstone at top and at 1.7 and 8 feet below top; weathers to light gray chips with yellow stains.	11.0
13. Claystone, gray, grades downward to light greenish-gray mottled with red, silty at top, black spherulites throughout.	5.0
12. Covered interval.	2.0
11. Shale, dark gray to black, clayey, silty at base.	3.5
10. Siltstone, light gray, sandy, massive, grades abruptly into units above and below.	3.0
9. Siltstone, gray, variegated red, clayey, grades in lower one foot into silty gray claystone with carbonaceous fragments; contains iron oxide veinlets and blebs.	4.5
8. Sandstone, yellow-brown, very fine-grained, consists of quartz with red and black chert grains, friable.	3.0
7. Shale, dark gray, fissile, becoming silty upward, contains carbonaceous material.	1.6
6. Siltstone, light gray, massive.	3.5
5. Siltstone, olive-green, locally stained red, massive.	2.0
4. Siltstone, gray, slightly clayey, massive.	1.1
Total Thermopolis shale	361
Cloverly formation	
3. Claystone, dark gray, silty.	2.0
2. Claystone, dark gray, silty, becomes variegated with red downward.	4.0
1. Claystone, gray, variegated with red, silty, weathers to red and maroon fluted face.	not measured

Locality 21: West of old Cloverly Post Office, 2 miles south of school; in SW Sec. 15, T. 54 N., R. 92 W., Big Horn Co., Wyoming.

	Thickness in feet
Mowry shale (in part)	
18. Bentonite, gray.	not measured
17. Shale, black, hard, siliceous, large cone-in-cone concretions at base, weathers to light gray chips.	5.0
Shell Creek shale	
16. Shale, black, fissile, some fairly hard, ironstone concretion bed 45 feet above base, bentonite thicknesses and horizons follow: gray, 0.5-foot bentonites at 60 and 149 feet above base; 0.2-foot gray bentonite at 189 feet; 2-foot gray bentonite with dark brown-weathering top at 192 feet; thin 0.3-foot bentonites at 212 and 218 feet; 0.5-foot ironstone concretion beds at 70 and 121 feet above base; ironstone concretion bed at 160 feet contains a small species of *Inoceramus;* similar ironstone concretion bed at 187 feet contains *Neogastroplites hassi* Reeside and Cobban, *Inoceramus* sp., *Glyptops* sp., *Homolopsis* sp., *Dakoticancer* sp. and fish bone fragments and scales, either *Lepodotes* sp. or *Lepodosteus* sp. Small cone-in-cone concretions at 195 feet above base, and very large ones up to 4 feet in diameter at Mowry contact. Upper 20 feet supports vegetation. Sample cc, 187 feet above base bb, 160-165 feet above base aa, 155-160	243.0
Muddy sandstone	
15. Shale, black, and bentonite, brown to light gray, interbedded and interlaminated, deeply weathered.	5.0
14. Sandstone, light gray, medium-grained, salt and pepper, soft, very friable, cross-bedded, carbonaceous material, upper 10 feet becomes coarser and contains rare chert pebbles up to one inch in diameter, weathers to light gray slope.	25.0
13. Shale, gray, silty, and siltstone, light gray, in contorted laminae, brown carbonaceous material; laminae become more contorted and unit becomes sandier upward.	18.0
Total Muddy sandstone	48
Thermopolis shale	
(upper shale)	
12. Shale, black, fissile, lower half with the exclusion of the basal 30 feet very deeply weathered soft material. Sample v, 99-108 feet above base u, 88-99 t, 77-88 s, 66-77 r, 55-66 q, 44-55 p, 33-44 o, 22-33 n, 22-33 m, 11-22 0-11	108.0
(middle silty shale)	
11. Shale, black and brown, fissile, interlaminated siltstone in middle 5	

feet and upper 3 feet, weathers tan, supports vegetation, appears gradational with unit above.
Sample a, 13-24 feet above base 24.0

(lower shale)

10. Shale, black, fissile, minor amount of tan siltstone in lenticular laminae, prominent 0.5-foot ironstone 6 feet above base, upper half contains some brown fissile shale, upper 8 feet of unit is silty, unit is capped by a 0.2-foot fucoidal gray hard bench-forming calcareous siltstone. 65.0
9. Shale, black, and siltstone, light gray, interlaminated in contorted, lenticular laminae, very thin sandy dark brown-weathering ironstone forms vegetation-supporting bench at top of unit. 5.0
8. Shale, black, fissile, lower 10 feet very deeply weathered to yellowish and rusty colors, possibly bentonitic, yellow-stained black shale weathering light gray comprises 0.5-foot beds at 23, 24, and 26 feet above base, dahllite concretions in bed at 25 feet above base, unit weathers light gray. 34.0

(rusty beds)

7. Sandstone, gray, silty, calcareous, thinly bedded. 1.0
6. Shale, gray, silty, soft and deeply weathered, and siltstone, tan, interbedded, iron oxide stains, weathers distinctive yellow-brown. 8.0
5. Shale, dark gray and brown, fissile, with interlaminated light gray siltstone, some fucoidal, broken laminae, rare thin fine-grained brown-weathering sandstone beds, 0.5-foot beds of gray hard silty limestone at 23 and 31 feet above base, a few very thin ironstone beds which weather very dark brown, carbonaceous material. 90.0
4. Shale, black and brown, fissile, silty. 2.0
3. Sandstone, tan, fine-grained, silty, lenticular, weathers light brown. 3.0
2. Siltstone, gray, hard, very platy, carbonaceous plant remains. 3.0

Total Thermopolis shale 343

Cloverly formation

1. Claystone, gray variegated red, silty, with prominent iron oxide spherulites in uppermost part. not measured

Locality 22: Just west of Gypsum Creek, about one mile south of Montana line, immediately west of road; E½ Sec. 26, T. 58 N., R. 96 W., Big Horn Co., Wyoming.

Thickness in feet

Mowry shale (in part)

61. Shale, gray, slightly sandy, hard, siliceous, weathers to light gray chips, fish remains. 5.0
60. Shale, gray and black, silty, hard, weathers to brown, thinly bedded appearance, supports vegetation. 43.0
59. Bentonite, gray, some dark shale laminae. 4.5
58. Shale, gray and black, fissile, silty, hard, contains fish scales. 26.0
57. Bentonite, light gray. 4.0

Shell Creek shale

56. Shale, black, fissile, some carbonaceous material.
Sample zz, 38-50 feet above base
yy, 26-38
xx, 13-26
ww, 0-13 50.0
55. Bentonite, gray, thin ironstone at base. 1.6

54. Shale, black, fissile. Sample vv	13.0
53. Bentonite, greenish gray.	0.3
52. Shale, black, fissile, some carbonaceous material. Sample vv, 27-30 feet above base uu, 13-27 tt, 0-13	30.0
51. Bentonite, gray.	0.5
50. Shale, black, fissile. Sample ss, 12-24 feet above base rr, 0-12	24.0
49. Bentonite, gray.	0.6
48. Shale, black, fissile, with a dark gray shaly siltstone 2 feet above base. Sample qq, 39-47 feet above base pp, 26-39 oo, 13-26 nn, 0-13	47.0
47. Sandstone, light gray, fine- to medium-grained, salt and pepper, silty, friable, micaceous, calcareous, cross-bedded, in lenses several tens of feet wide, weathers brown.	3.0
46. Shale, gray and light gray with some bentonitic laminae, ironstone concretions one foot above base. Sample mm	6.0
45. Bentonite, white, with persistent dark brown-weathering ironstones 0.5-foot thick, 0.3-foot above base.	2.0
44. Shale, gray, silty, hard, and siltstone, olive gray interbedded in beds to 0.2 foot thick, and rare 0.3-foot ironstone concretions; at top is a 0.5-foot gray siltstone. Sample ll	19.0
43. Shale, gray, fissile, becoming darker upward, rare light gray siltstone laminae near middle and rare ironstone concretions throughout, at top is persistent 0.5-foot ironstone concretion bed. Sample kk, 10-21 feet above base jj, 0-10	21.0
42. Bentonite, very light gray, greenish-gray near top.	1.4
41. Shale, dark gray, fissile, some with rare very light gray siltstone laminae. Sample ii	4.0
40. Bentonite, light gray, some reworked with shaly material.	1.5
39. Shale, dark gray and black, fissile, hard, slightly silty in upper portion. Sample hh	14.0
38. Bentonite, light gray and greenish-gray, some shaly.	0.5
37. Shale, gray, fissile, some possibly bentonitic, unit becomes darker upward. Sample gg	9.0
36. Bentonite, gray and light gray, grades into shale above.	0.8
35. Shale, black, fissile, some splintery. Sample ff	1.5
34. Bentonite, light gray, greenish-gray near top, includes some reworked shaly material.	1.3
Section offset about a mile southeast to SE Sec. 25, T. 58 N., R. 96 W.	
33. Shale, black, fissile. Sample ee, 48-53 feet above base dd, 37-48 cc, 26-37	

bb, 14-28
aa, 0-14 53.0

Total Shell Creek shale 305

Muddy sandstone

32. Bentonite, white, a 0.2-foot brown-weathering bed one foot above base. 1.5
31. Shale, black, fissile, hard.
    Sample x 1.5
30. Bentonite, white, reworked shale one foot above base and at top, a distinctive 0.2-foot brown-weathering bed 2 feet above base. 3.0
29. Shale, black, fissile, hard.
    Sample x 1.0
28. Sandstone, gray, fine-grained, silty, thinly laminated, some fucoidal.
    Sample x 2.0
27. Shale, bentonitic, weathers deeply to tan, vegetated slope. 5.0

Section offset about 2 miles northwest to Sec. 22, T. 58 N., R. 96 W.

26. Shale, black, fissile, silty, some slightly bentonitic, a few sandy beds in middle portion, weathers to tan hills.
    Sample w, 12-24 feet above base 29.0

Total Muddy sandstone 43

Thermopolis shale

(upper shale)

25. Shale, black, fissile, some fairly hard, a few thin ironstone beds, rare very thin sandy beds about 60 feet above base.
    Sample t, 102-113 feet above base
    s, 89-102
    r, 76-89
    q, 64-76
    p, 51-64
    o, 27-40
    n, 14-27
    m, 0-14 113.0

Section offset about 4 miles east to E½ Sec. 29, T. 58 N., R. 95 W.

(middle silty shale)

24. Shale, black and brown, fissile, some silty, some very thin beds of very fine-grained sandstone and one or two thin hard beds of brown-weathering limestone, unit capped by platy-weathering 0.4-foot tan siltstone, weathers tan.
    Sample l, 14-26 feet above base
    k, 0-14 26.0
23. Siltstone, gray, fucoidal, and shale, black, fissile, thinly interbedded in about equal amounts, capped by thin gray brown-weathering ledge-forming limestone bed, weathers tan. 5.0

(lower shale)

22. Shale, gray and black, fissile, some black carbonaceous material, weathers gray.
    Sample j, 32-48 feet above base
    i, 16-32
    h, 0-16 48.0
21. Sandstone, gray, very fine-grained, thinly bedded, fucoidal, weathers dark brown. 1.0
20. Shale, black, fissile, some brown, basal 3 feet very deeply weathered.
    Sample g 30.0
19. Siltstone, gray, and shale, black, fissile, thinly interbedded in about

equal amounts, worm markings and carbonaceous material; at top is a 0.5-foot thin-bedded, ridge-forming, very fine-grained sandstone. Sample f, 0-5 feet above base	8.0
18. Shale, black, fissile, greasy appearance, weathers dark gray. Sample f	10.0
(rusty beds)	
17. Sandstone, tan, fine-grained, very thinly bedded and cross-laminated, ripple-marked, fucoidal, weathers yellow-brown.	1.0
16. Shale, black, some brown, fissile, some interlaminated light gray siltstone lenses, top 2 feet deeply weathered. Sample e	14.0
15. Sandstone, tan, fine-grained, silty, calcareous, in beds to 0.3-foot thick, cross-laminated, some gray, thin fucoidal siltstone beds, weathers yellow-brown.	4.0
14. Shale, black and brown, fissile, and siltstone, tan, and sandstone, tan, very fine-grained, thinly interbedded; shale dominates lower part; sandstone becomes dominant upward, gradational with sandstone above. Sample d	26.0
13. Limestone, dark gray, sandy, hard, thinly cross-bedded in long, sweeping cross-beds, some interbedded gray calcareous fine-grained sandstone beds, weathers dark brown, forms ridge. Sample c	3.0
12. Shale, gray and tan, fissile, some thin beds of tan, cross-laminated, fine-grained sandstone and siltstone, some worm markings. Sample b	21.0
11. Limestone, dark gray, sandy, hard, thinly cross-bedded, ripple-marked, weathers brown, forms ridge.	1.0
10. Siltstone, tan, shale, gray and brown, and sandstone, tan, fine-grained, thinly interbedded, sandstone beds to one foot thick are thinly cross-bedded, 0.5-foot ironstone is 6 feet above base, worm markings, carbonaceous material.	31.0
9. Sandstone, tan, very fine-grained, silty, non-calcareous, thinly bedded and cross-bedded, fucoidal.	5.0
8. Shale, gray, fissile, and siltstone, tan, fucoidal, interlaminated in about equal amounts.	6.0
7. Sandstone, tan, very fine-grained, silty, and siltstone, tan, in thin irregular interbeds, weathers light brown, gradational above and below.	1.1
6. Siltstone, gray, and shale, gray, fissile, thinly interbedded, weathers orange to light brown, vertical worm borings.	1.1
5. Claystone, gray and dark gray, rare yellow iron oxide veinlets, silty near base.	3.0
4. Siltstone, gray, mottled orange, sandy, soft, friable, contains iron oxide spherulites.	0.8
3. Sandstone, gray and tan, fine- to medium-grained, non-calcareous, beds to 1.2 feet thick are thinly cross-bedded and ripple-marked, vertical worm borings, weathers light brown, blocky, forms cliff. Sample a	6.0
2. Sandstone, light gray, very fine-grained, micaceous, non-calcareous, fucoidal, ripple-marked beds to 0.2-foot thick, rare partings of gray carbonaceous shale. Sample a	1.0
Total Thermopolis shale	366

Cloverly formation	
1. Claystone, gray and tan, occasional iron oxide veinlets.	not measured

Locality 24: North of highway, east of Nowood Creek; NE Sec. 13, T. 49 N., R. 91 W., Big Horn Co., Wyoming.

	Thickness in feet
Mowry shale (in part)	
33. Bentonite, gray.	4.0
32. Shale, black, hard, siliceous, weathers to silver-gray chips, forms prominent ledge, contains fish scales.	7.0
Shell Creek shale	
31. Shale, black, fissile, hard, weathers to brownish slope which supports some vegetation, fish scales.	6.0
30. Shale, black, fissile, not well-exposed, some bentonites noted as follows: one-foot gray bentonite at 16 feet above base; one-foot greenish-gray with a dark brown-weathering bed at top at 124 feet; 0.5-foot gray bentonite at 155 feet; bentonitic shale bed 100 feet above base.	156.0
29. Bentonite, gray, ironstone at base.	1.0
28. Shale, black, fissile, fairly hard.	15.0
27. Sandstone, gray, very fine-grained, calcareous, thinly bedded, weathers to dark brown slabs, forms ridge.	1.0
26. Shale, black, fissile, rare thin lenticular beds of light gray siltstone and very fine-grained sandstone, silt content diminishes upward from gradational contact below, weathers to popcorn-textured surface.	30.0
Total Shell Creek shale	209
Muddy sandstone	
25. Sandstone, light gray, fine-grained, silty, and shale, gray, interbedded, shale content increases upward, worm tubes, black carbonaceous material, weathers to low rounded light gray hills, grades into unit above.	12.0
24. Sandstone, light gray, fine-grained, silty, calcareous, thinly cross-bedded in high-angle sweeping cross-beds, weather slight gray, basal contact sharp.	24.0
Total Muddy sandstone	36
Thermopolis shale	
(upper shale)	
23. Shale, black, fissile, thin brown-weathering siltstone beds at 24 and 34 feet above base, ironstone concretions about 65 feet above base.	98.0
(middle silty shale)	
22. Shale, black and brown, fissile, some interlaminated and very thinly interbedded very fine-grained sandstones and siltstones and one or two very thin beds of platy, brown-weathering silty limestone; unit weathers to light tan slope which supports vegetation.	28.0
(lower shale)	
21. Shale, black, fissile, with some siltstone and sandstone, tan, very fine-grained, in lenticular very thin beds and laminae, a 0.5-foot greenish-gray bentonite is 20 feet above base, bone fragments occur 42 feet above base, gradational with unit above.	50.0
20. Sandstone, tan, fine-grained, and shale, sandy, thinly interbedded, weathers yellow-brown, supports vegetation.	4.0
19. Shale, black, some brown, fissile, some slightly silty; a gray, fine-grained, calcareous, cross-bedded, brown-weathering sandstone in	

a lenticular 0.5-foot bed 20 feet wide, 17 feet above the base; unit weathers gray, dahllite concretion bed 20 feet above base. 29.0

(rusty beds)

18. Sandstone, brown, fine-grained, silty, thin- to medium-bedded, weathers yellowish-orange. 1.0
17. Shale, gray and tan, fissile, some interlaminated gray, fucoidal siltstone. 4.0
16. Shale, gray and tan, fissile, becomes silty upward, some tan fucoidal siltstone lenses, at top is a 0.5-foot lenticular unevenly bedded, gray, very fine-grained sandstone. 13.0
15. Shale, gray, and siltstone, tan soft, inter-bedded, ironstone beds and concretions, weathers yellowish-brown, forms a hilly dip slope. 6.0
14. Shale, dark gray, fissile, and siltstone, gray, interlaminated and thinly interbedded, prominent thin ironstone beds are 7 and 30 feet above base, weathers tan, thin brown-weathering sandstone bed at top of unit forms ridge. 48.0
13. Claystone, dark gray to black, blocky and waxy at top, becoming shaly locally, silty at base. 2.5
12. Claystone, silty, gray, local red to yellow iron-stained areas from weathering of scattered accumulations of iron oxide spherulites. 2.2
11. Claystone, dark gray, some hard, tough, slickensided, finely silty at base, appears to be lenticular. 1.6
10. Claystone, gray, silty, locally clayey siltstone, considerable red, yellow and orange stain from spherulites and other iron oxide accumulations. 2.2
9. Sandstone, tan, fine-grained, cross-bedded, weathers brown and gray and red, odd hollow concretions, bedding surfaces irregular and ripple-marked, lenticular, much relief on upper surface. 2.0
8. Siltstone, gray, sandy, platy, hard, thinly cross-bedded, weathers light gray with yellow and brown stain, grades into sandstone above. 4.0
7. Siltstone, gray, thinly interbedded and interlaminated with silty shale. 4.0
6. Shale, dark gray, blocky, finely silty, scattered carbonaceous fragments. 3.2
5. Sandstone, gray, very fine-grained, friable, thin interbeds and partings silty shale, stained orange, brown and red. 1.2
4. Shale, gray to black, finely silty, some carbonaceous flecks, few silt laminae. 3.3
3. Siltstone, massive, finely sandy, light gray weathering powdery yellow gray. 3.2
2. Siltstone, gray, hard, ledgy, some with black shale partings. 6.0

Total Thermopolis shale 316

Cloverly formation

1. Claystone, gray mottled red, finely silty. not measured

Locality 26: Muddy Creek, about 12 miles southwest of Buffalo; SW Sec. 25, T. 49 N., R. 83 W., Johnson Co., Wyoming.

Thickness in feet

Mowry shale (in part)

43. Shale, gray, siliceous, hard, weathers silvery-yellow, fish scales. not measured

Shell Creek shale

42. Shale, black and brown, fissile, some fairly hard, some silty, four 0.5-foot bentonites, one at extreme top, and several thinner ones, some lenticular, some associated with cone-in-cone layers, unit supports vegetation.

Sample kk, 13-25 feet above base
jj, 0-13 25.0

41. Bentonite, light greenish-gray, some cone-in-cone beds associated. 2.0
40. Shale, black, fissile, weathers grayish-brown, contains fish scales.
Sample ii 6.0
39. Bentonite, light greenish-gray, cone-in-cone beds associated. 0.5
38. Shale, black, fissile, weathers grayish-brown.
Sample ii 3.5
37. Bentonite, light gray, weathers orange, cone-in-cone concretions at top. 0.5
36. Shale, black, fissile, iron stains on s-surfaces, a prominent ironstone concretion bed 5 feet above base, scattered concretions throughout.
Sample hh 12.0
35. Bentonite, light gray, 0.5-foot lenticular ironstone at extreme top. 1.5
34. Shale, black, fissile, iron-stained s-surfaces.
Sample gg 7.0
33. Bentonite, gray and greenish-gray, lower foot and a 0.2-foot bed in middle weathers dark brown, remainder weathers gray, iron concretions at extreme top. 2.5
32. Shale, black, fissile, upper 3 feet silty, 0.5-foot ironstone beds at 22 and 41 feet above base, ironstone concretions throughout lower 22 feet, weathers gray, upper 3 feet weathers slightly lighter; ironstone bed 22 feet above base contains *Inoceramus* sp.
Sample ff, 34-46 feet above base
ee, 22-34
dd, 8-22
cc, 0-8 46.0
31. Bentonite, greenish-gray. 1.0
30. Shale, dark gray and black, silty, slightly sandy, bentonic, some ironstone concretions in upper part, weathers crusty.
Sample bb, 13-27 feet above base
aa, 0-13 27.0

Total Shell Creek shale 135

Muddy sandstone

29. Shale, dark gray, very silty and sandy, upper foot is shaly siltstone which grades into unit above, weathers deeply to gray color. 8.0
28. Sandstone, light gray and tan, fine- to medium-grained, salt and pepper, silty, soft and friable, some thinly interbedded dark gray silty shale. 22.0
27. Sandstone, tan, fine-grained, salt and pepper, sparkly, friable, thin-bedded, lenticular, weathers light brown, forms ledge. 2.0
26. Sandstone, light gray and tan, fine-grained, salt and pepper, silty and shaly, soft, very friable, some interbedded gray sandy shale; sandstone beds are up to one foot thick. 5.0
25. Sandstone, as unit 27 above.
Sample w 1.0
24. Sandstone, light gray, fine- to medium-grained, salt and pepper, silty, soft and friable, and shale, gray, brown and black, silty, thinly interbedded in beds to 0.2-foot thick, a sandstone bed at top is 2 feet thick, unit weathers light brown, supports vegetation.
Sample w 9.5

Total Muddy sandstone 47.5

Thermopolis shale
(upper shale)

23. Shale, black, fissile, some brown carbonaceous fragments near base,

ironstone 0.4-foot thick at 13 feet above base, some light gray siltstone laminae at about 21 feet above base.
Sample s, 39-51 feet above base
r, 26-39
q, 13-26
p, 0-13 51.0

22. Shale, black, fissile, some iron-stained, lower 5 feet contains lenticular laminae of light gray siltstone, ironstones occur at 12,18, 20, 24, 26, and 30 feet above the base.
Sample o, 18-30 feet above base
n, 5-18
m, 0-5 30.0

(middle silty shale)

21. Shale, black, fissile, some light gray siltstone laminae, siltstone increases upward and beds become thicker, in upper foot beds of clayey siltstone to 0.2-foot thick occur and weather light yellow-brown, remainder weathers grayish-tan. 5.0

20. Siltstone, light gray, fairly hard, and shale, black, interlaminated, some thinly interbedded in contorted lenses. Siltstone beds to 0.3-foot thick, forms ledge, weathers tan, apparently the top unit of the uppermost cycle of a cyclic sequence.
Sample k 4.0

19. Shale, black, some tan, fissile, some lenticular interlaminations of light gray siltstone increasing upward in thickness and amount, grades into unit above.
Sample k 6.0

18. Limestone, gray, silty, and siltstone, light gray, interbedded, weathers yellowish-tan, forms ledge, top second cycle. 1.5

17. Siltstone, light gray, fairly hard, beds to 0.3-foot thick, some shale, black, thinly interbedded, gradational with unit above and unit below, supports vegetation.
Sample j 6.0

16. Shale, black, some tan, fissile, some lenticular interlaminations of light gray siltstone near base increasing upward in thickness and amount, grades into unit above.
Sample j 14.0

15. Siltstone, gray, fairly hard, and limestone, gray, silty, interbedded, weathers light tan, forms ledge, top lowermost cycle.
Sample i 1.3

14. Siltstone, light gray, and shale, black, fissile, interlaminated and thinly interbedded in beds to 0.2-foot thick, some beds fucoidal, weathers tan, supports vegetation.
Sample i 7.0

(lower shale)

13. Shale, black, some tan, fissile, some lenticular light gray siltstone laminae near base increase upward in thickness and amount, gradational above, weathers light gray.
Sample h, 13-25 feet above base
g, 0-13 25.0

12. Shale, black and tan, fissile, some lenticular interlaminations of light gray siltstone which decrease upward, 0.5-foot ironstone is 6 feet above base, one-foot tan silty shale weathering yellow-brown locally containing ironstone lenses is 18 feet above base, weathers light gray to light tan, not well exposed.
Sample f, 13.5-27 feet above base
e, 0-13.5 27.0

11. Shale, black, fissile, and siltstone, light gray in contorted laminae and thin fucoidal beds to 0.1-foot thick, thin bentonitic ironstone is 8 feet above base, thin ironstone is 14 feet above base, siltstone is dominant in upper 6 feet where it is thinly interbedded with fine-grained tan calcareous sandstone and silty gray limestone, carbonaceous material, weathers tan, baseball-sized dahllite concretions near base. Sample d	25.0
(rusty beds)	
10. Shale, black, fissile, some siltstone, light gray, in lenticular laminae, two or three tan siltstone beds to 0.5-foot thick in upper part, thin ironstone bed 8 feet above base, scattered iron concretions throughout lower part, carbonaceous material, weathers medium gray. Sample c, 5-24 feet above base	24.0
9. Siltstone, light gray and tan, fairly hard, fucoidal, thinly bedded, beds to 0.6-foot thick, some iron-impregnated, and shale, gray and tan, interlaminated and thinly interbedded, capped by dark brown-weathering iron-impregnated siltstone, weathers light tan.	19.0
8. Shale, black, and siltstone, light gray, fucoidal, thinly interbedded and interlaminated in lenticular and contorted laminae, some beds of tan, very fine-grained sandstone, carbonaceous material, weathers grayish-tan. Sample b	9.0
7. Siltstone, gray and tan, very thin, wavy beds, iron-impregnated.	0.5
6. Shale, black, some brown, fissile, carbonaceous, and siltstone, light gray, thinly interbedded and interlaminated, contains rare large ironstone concretions, 0.5-foot siltstone lenses in lower 3 feet, 0.1-foot concretionary ironstone at 9 feet above base, weathers light gray. Sample a	13.0
5. Ironstone, dark brown, worm-markings, tiny clams; unit is lenticular, interfingering locally with light gray very fine-grained sandstone and siltstone containing what appear to be spherulites. Sample a	0.5
4. Claystone, light gray, orange to light brown blebs and beds, silty, contains spherulites mainly in orangish clays.	9.0
3. Shale, brown and black, silty, fissile, some bright yellow stain on s-surfaces, much black and brown organic material, one-foot brown lignite bed 2 feet below top forms weak ledge.	6.0
Total Thermopolis shale	284
Cloverly formation	
2. Claystone, light gray with orange blebs and beds, very silty, contains profuse spherulites.	5.5
1. Claystone, dark gray to black, silty, grades downward into a gray, very clayey siltstone.	3.0

Locality 27: Dutton Basin, about one mile east of main Uranium mine road; NE Sec. 18, T. 33 N., R. 89 W., Fremont Co., Wyoming.

Shell Creek shale (in part)	Thickness in feet
13. Shale, black, fissile, bentonites occur as follows: one-foot bentonite at 12 feet above base; 3-foot bentonite with top part mixed with black shale at 22 feet; 3-foot gray and brownish bentonite with brown-weathering bed in middle at 31 feet; the shale around 40 feet above base is silty; shale around lower two bentonites is locally	

gypsiferous; top of unit is covered, but Mowry contact is probably not far above. Sample ee, 34-44 feet above base dd, 24-31 cc, 13-22 bb, 0-12	44.0
12. Limestone, gray, silty, ripple-marked, hard, irregularly bedded, some light gray, fine-grained calcareous sandstone thinly interbedded, weathers dark-brown, forms ridge.	0.6
11. Shale, black, fissile, some silty, about six 0.4- to 0.5-foot orange-weathering bentonites interbedded. Sample aa	12.0
10. Bentonite, light gray.	0.4
Exposed Shell Creek shale	57
Muddy sandstone	
9. Siltstone, light gray, fine grained, fairly hard, thinly bedded, 0.4-foot bentonite one foot below top.	10.0
8. Siltstone, gray, very fine-grained, hard, fucoidal, thinly bedded in beds to 0.4-foot thick, weathers light gray, forms tree-covered ledge.	10.0
Total Muddy sandstone	20
Thermopolis shale	
7. Shale, black, fissile, some ironstone beds and associated iron-impregnated shales and rare ironstone concretions in lower part; lower half badly covered; 0.7-foot gray orange-weathering bentonite is 18 feet below top. Sample q, 55-72 feet above base p, 0.5 foot above bentonite o, 0.5 foot below bentonite n, 32-54 feet above base m, 15-24	72.0
6. Covered interval; siltstone and limestone slabs in float may represent the middle silty shale; a small outcrop of dark fissile shale at 23 feet above base.	29.0
5. Shale, black, fissile, rare ironstone concretions, weathers medium gray. Sample b	8.0
4. Shale, black, fissile, some brown, and siltstone, light gray, in lenticular laminae, 0.1-foot ironstone at 9 feet above base, thinly interbedded gray siltstone and limestone 17 to 19 feet above base, same interbedded with very fine-grained ripple-marked sandstone 27 to 37 feet above base, silty portions weather tan and support vegetation, shaly portions weather medium gray. Sample a, 0-15 feet above base	37.0
3. Sandstone, light gray, fine-grained, hard, fucoidal, ripple-marked in upper part, some iron-impregnated, weathers brown, supports ridge.	10.0
2. Siltstone, gray and reddish-brown, some clayey.	2.0
Total Thermopolis shale	158
Cloverly formation	
1. Siltstone, dark gray, clayey, no spherulites found.	not measured

Locality 28: About 2 miles south of Alcova, Wyoming, on Beer Spring Creek; SE Sec. 30, T. 30 N., R. 82 W., Natrona Co., Wyoming.

	Thickness in feet
Mowry shale (in part)	
42. Shale, dark gray, very hard, a few thin iron-impregnated siltstones, silty concretions at base, a few bentonite and ironstone beds, weathers platy, contains fish scales.	not measured
41. Bentonite, light gray.	0.4
40. Shale, dark gray, very hard, a few thinly interbedded iron-impregnated siltstones, cone-in-cone bed 5 feet above base, iron-stained s-surfaces, weathers platy, contains fish scales.	11.0
39. Bentonite, light gray and tan.	0.4
38. Shale, dark gray, silty, very hard.	0.7
37. Bentonite, light gray.	0.5
36. Shale, black, fissile, very hard, some silty, iron-stained s-surfaces, 2 or 3 0.1-foot bentonite beds, weathers to silver-gray chips.	11.0
Shell Creek shale	
35. Bentonite, light gray. Sample cc	0.6
34. Shale, black, fissile, fairly soft. Sample cc	0.3
33. Bentonite, light gray.	0.2
32. Shale, black, fissile, some bentonitic and iron-stained, rare interlaminated bentonite and light gray siltstone, one-foot interval beneath top contains 0.1-foot light gray cross-laminated siltstone bed. Sample bb	11.5
31. Bentonite, light gray, two thinly interbedded black shale beds, gradational with shale above.	2.2
30. Shale, black, fissile, some bentonitic, some iron-stained. Sample aa	4.3
29. Ironstone, dark brown, thin lenticular cone-in-cone beds immediately above and below.	0.3
28. Shale, black, fissile. Sample aa	2.5
27. Shale, black, slightly fissile, slightly blocky, iron-stained, bentonitic.	1.0
Total Shell Creek shale	23
Muddy sandstone	
26. Siltstone, gray, hard, laminated and thinly bedded, some interlaminated black shale, bedding planes are very fucoidal.	0.8
25. Shale, black, fissile, and siltstone, light gray, evenly interlaminated near base and in lenticular laminae throughout, fucoidal, a 0.2-foot bentonite 0.6 foot above base, unit is gradational below. Sample z	3.5
24. Siltstone, gray, shaly, fucoidal, laminated and thinly interbedded with black shale.	3.0
23. Shale, black, fissile, silty, and some siltstone, gray, fucoidal, interlaminated and thinly interbedded, siltstone decreases upward, gradational below and above. Sample z	3.0
22. Siltstone, gray, very sandy, shaly, much carbonaceous material, thin- to medium-bedded, weathers blocky.	10.0
21. Shale, black, fissile, very silty, fairly hard, some slightly blocky, fucoidal, iron-stained s-surfaces, gradational with siltstone above. Sample y	2.5
20. Bentonite, brown.	0.2

19. Shale, as unit 21 above. Sample y	3.0
18. Siltstone, gray, very fine-grained, shaly, hard, fucoidal, weathers blocky, gradational below and above.	4.0
17. Siltstone, light gray, shaly, soft, grades upward to shale, black, fissile, silty, contains a 0.1-foot bentonite in middle, gradational below and above. Sample x	1.8
16. Sandstone, light gray, very fine-grained, silty, slightly shaly, massive to thickly bedded, a black shale parting in the lower one foot, black carbonaceous plant fragments, vertical worm tubes, weathers tan.	5.0
15. Siltstone, dark gray, very shaly, fucoidal, grades upward to shale, black, fissile. Sample w	1.0
14. Sandstone, light gray, very fine-grained, slightly silty, hard, lignitic near top, very thinly cross-bedded, weathers to light gray and tan color.	11.0
Total Muddy sandstone	49
Thermopolis shale	
(upper shale)	
13. Shale, dark gray to black, fissile, silty, carbonaceous material. Sample p	10.5
12. Shale, dark gray to black, much carbonaceous plant material. Sample o	7.0
11. Shale, black, fissile, ironstone concretions in lower half, poorly exposed. Sample n	16.0
10. Bentonite, light gray, weathers orange.	0.3
9. Shale, black, fissile, some sandstone, tan, very fine-grained, thinly interbedded in lower part, and a one-foot gray silty limestone 3 feet below top, poorly exposed. Sample m	12.0
(middle silty shale?)	
8. Sandstone, tan, very fine-grained, siltstone, tan, and some limestone, gray, silty, interbedded in cross-laminated beds to 0.4-foot thick, rare interlaminations of gray shale, ripple-marked, fucoidal, sandstone and siltstone weathers tan, limestone brown; some sandstone beds contain specks of iron oxide; unit forms ridge.	12.0
(lower shale and rusty beds?)	
7. Shale, black and brown, fissile, and siltstone, light gray, interlaminated and thinly interbedded in about equal amounts; fucoidal, carbonaceous material, gradational with shale below. Sample c	8.0
6. Shale, black and gray, fissile, and siltstone, tan and gray, fucoidal, in lenticular laminae and thin interbeds; lower portion is less silty, contains rare thin beds of gray limestone; poorly exposed. Sample b	23.0
5. Shale, black and tan, fissile, silty, some lenticular laminae of light gray siltstone, some thin beds of tan very fine-grained sandstone and gray silty limestone, ironstone concretions in lower part of unit, poorly exposed. Sample a	23.0
Total Thermopolis shale	112

Cloverly formation	
4. Sandstone, light gray, fine-grained, some medium-grained, silty, massive, non-calcareous, upper foot is soft and friable, forms ridge, weathers gray to dark brown.	4.0
3. Sandstone, light gray and tan, fine- to coarse-grained, silty and conglomeratic, pebbles mostly about one-fourth inch diameter concentrated in thin to thick beds and crossbeds, conglomeratic beds become thicker downward, maximum pebble size increases from a half inch near top to about 2 inches near base of unit, most is medium-bedded, most weathers gray, base is covered.	(exposed) 60.0
Section offset about 200 yards north across road	
2. Conglomerate, brown, consisting mainly of black chert pebbles up to 2 inches in diameter in matrix of fine- to coarse-grained poorly sorted sandstone; unit is separated locally from unit 3 above by up to 5 feet of gray silty claystone.	12.0
Morrison formation	
1. Claystone, gray and greenish-gray, silty, iron oxide veinlets.	not measured

Locality 29: About 10 miles northeast of Rock River; NW Sec. 28, T. 22 N., R. 75 W., Albany Co., Wyoming.

	Thickness in feet
Mowry shale (in part)	
37. Shale, black, fissile, hard, weathers to silver-gray chips, contains fish scales, forms ridge.	not measured
Muddy sandstone	
36. Bentonite, light gray.	0.7
35. Sandstone, light gray, fine-grained, silty, shaly and carbonaceous material in blebs and contorted thin lenses, and shale, dark gray, very sandy, interbedded in beds 0.3- to 0.8-feet thick, 0.1-foot bentonite at 0.5-foot above base.	3.2
34. Sandstone, light gray, fine-grained, silty, shaly and carbonaceous material in blebs and contorted thin lenses, forms ledge.	1.2
33. Shale, black, fissile, very silty.	0.7
32. Sandstone as in unit 34 above.	1.2
31. Shale, dark gray to tan, fissile, lower 1.5 feet is very bentonitic, upper part has some light gray siltstone laminae, much carbonaceous material, gradational below. Sample z	5.0
30. Bentonite, light gray.	4.0
29. Shale, gray to dark gray, silty and sandy, bentonitic, lenses of siltstone and fine-grained sandstone laminae throughout, fucoidal, very hard immediately below overlying bentonite. Sample y	9.0
28. Lignite, black and brown, shaly, much yellow stain on s-surfaces. Sample x	2.0
27. Shale, dark gray, silty, soft, much brown carbonaceous plant material, gradational with unit above. Sample x	4.0
26. Bentonite, gray, poorly exposed.	2.0
25. Shale, black, fissile, and siltstone, light gray, interlaminated in lenticular and contorted layers.	3.0
24. Shale, black, fissile, and siltstone, gray, clayey, thinly interbedded and interlaminated in about equal amounts at base, shale decreases upward, much carbonaceous material, bedding planes fucoidal.	7.5

23. Siltstone, gray, very soft, carbonaceous material. 0.3

22. Shale, black and dark brown, lignitic, much carbonaceous plant material. 0.3

21. Siltstone, greenish-gray to tan, very clayey, very soft, laminated, becoming shaly upward, much carbonaceous plant material, weathers tan. 4.5

20. Sandstone, gray, fine-grained, fairly hard, very calcareous, ripple-marked, contains worm tubes, weathers medium gray. 0.2

19. Sandstone, gray, very fine-grained, silty, very soft, and shale, black, thinly interlaminated, carbonaceous material. 1.0

18. Shale, black and dark brown, very lignitic, silty, much carbonaceous material. 1.0

17. Siltstone as unit 21 above. 4.5

16. Limestone, gray, sandy, hard, weathers to brown slabs. 0.2

15. Siltstone, light gray, shaly, fucoidal, very thinly bedded, and shale black, fissile, silty, interbedded; shale increases upward and dominates upper part.
    Sample w 9.0

14. Limestone, gray, silty, hard, weathers to brown slabs. 0.2

13. Shale, black, fissile, becoming very silty upward, light gray siltstone laminae dominate upper part of unit.
    Sample w 5.0

12. Sandstone, light gray, very fine-grained, silty, and minor amount of shale, black, fissile, in strongly contorted interlaminations and thin interbeds; sandstone beds are to one foot thick, contain vertical worm tubes, all beds fucoidal, ripple-marked, forms ledge.
    Sample w 6.0

11. Siltstone, gray, shaly, carbonaceous, shale, gray, very silty, carbonaceous, lignite, dark grayish-brown, and some sandstone, light gray, very fine-grained, carbonaceous plant remains.
    Sample w 6.0

10. Sandstone, gray, very fine-grained, calcareous massive, friable, plant fragments, weathers tan, forms ridge. 1.5

Total Muddy sandstone 83

Thermopolis shale

9. Shale, black and gray, fissile, minor amount of light gray siltstone laminae throughout and some interbeds near base, 0.5-foot gray, orange-weathering bentonite 5 feet above base and a very thin bentonite near top, local cone-in-cone concretions.
    Sample q, 13-25 feet above base
    p, 0-13 25.0

8. Limestone, gray, concretionary, in concretions to 3 feet in diameter, weathers dark brown, distinctive large radiating cone-in-cone structure. 1.0

7. Shale, black, some gray, fissile, some silty near base, two thin interbeds of gray limestone weathering light brown, unit weathers medium gray.
    Sample o 12.0

6. Shale, black, fissile, rare beds with minor amount of interlaminated light gray siltstone, orange-weathering shaly ironstone 11 feet above base above which the shale weathers to very hard crust, ironstone beds also at 8 and 13 feet above base; in upper 2 feet are one or two very thin brown-weathering fine-grained sandstone beds, unit weathers medium gray.
    Sample n 13.0

5. Limestone, gray, silty, cone-in-cone structure, weathers brown, forms ridge.	1.0
4. Shale, black, fissile, some lenticular laminae of light gray siltstone, some interbedded very fine-grained light gray sandstone near base, and one or two interbedded gray limestones in upper portion, weathers medium gray. Sample m	21.0
3. Limestone, gray, silty, hard, granule-sized pyrite concretions, fucoidal, weathers to dark brown slabs.	0.5
2. Covered interval, probably carbonaceous siltstone and shale.	10.0
1. Sandstone, light gray, fine-grained, silty, fairly hard, thin to medium, irregular beds, some iron-impregnated, poorly exposed in gully bottoms.	not measured

Locality 30: About one mile north of Iron Mountain, Wyoming, about 400 yards south of road crossing on railroad track; SE Sec. 3, T. 18 N., R. 70 W., Laramie Co., Wyoming.

	Thickness in feet
Muddy sandstone (in part)	
10. Sandstone, white, fine-grained, hard, quartzitic, medium to thickly bedded, ripple-marked on large scale, large ridge.	(exposed) 20.0
9. Sandstone, light gray and tan, fine-grained, silty, thinly bedded, some iron oxide cement, friable, weathers yellow-brown.	1.6
8. Sandstone, light gray, fine-grained, silty, some shaly and carbonaceous material in extremely contorted and lenticular thin beds and laminae, weathers gray.	2.5
7. Siltstone, light gray to olive gray, non-calcareous, thinly bedded, beds to 0.3-foot thick, minor amount of shale, dark gray, thinly interbedded, sharp contact below, weathers tan.	4.5
Thermopolis shale	
6. Shale, black, fissile, some thinly interbedded and interlaminated tan and light gray siltstone, some bentonitic shale. Sample r	8.2
5. Limestone, gray, silty, hard, wavy beds, beds to 0.3-foot thick, some thinly interbedded black and brown fissile shale increasing upward, light gray bentonite bed 0.2-foot thick, 2.5-feet below top, *Inoceramus comancheanus* Cragin, *Ostrea* sp. and other pelecypods.	7.5
4. Siltstone, tan and light gray, and shale, black, fissile, and some sandstone, tan, very fine-grained, thinly interbedded and interlaminated, some beds iron-impregnated, weathers light brown.	7.5
3. Shale, black, fissile, rare lenticular laminae of soft light gray siltstone, most common in upper 45 feet, joints filled with secondary ironstone, some beds iron-impregnated, one or two 0.1-foot bentonites occur near base of exposure and in upper 4 feet, one at extreme top, possible fish remains. Sample q, 42-52 feet above base p, 31-42 o, 20-31 n, 10-20 m, 0-10	52.0
2. Covered interval, apparently mainly black shale.	20.0
1. Sandstone, tan and light gray, fine-grained, thinly and medium-bedded, some interbedded dark gray shale and gray siltstone, some beds iron-stained, weathers dark brown, poorly exposed, forms high ridge.	not measured

Locality 32: Near Clifton, Wyoming, east of old U. S. Highway 85; SW Sec. 18, T. 43 N., R. 60 W., Weston Co., Wyoming.

	Thickness in feet
Mowry shale (in part)	
7. Shale, dark gray, fissile, hard, weathers silver-gray, some light gray siltstone and sandstone thinly interbedded, unit contains fish scales.	not measured
6. Siltstone, light gray, hard, minor amount of interlaminated shale, black, silty, hard, forms ledge.	1.0
Shell Creek shale	
5. Siltstone, tan, soft, shaly, and shale, black, fissile, thinly interbedded in about equal amounts, four or five 0.2-foot bentonite beds, weathers brown. Sample ee	4.0
4. Bentonite, light gray.	1.2
3. Shale, black, fissile, 0.2- to 0.3-foot bentonite beds at 3 and 3.5 feet above base. Sample dd, 6-10 feet above base cc, 0.5 foot above bentonite 3.5 feet above base bb, 0.5 foot below bentonite 3.5 feet above base aa, 0-6 feet above base	10.0
2. Bentonite, light gray.	0.2
Total Shell Creek shale	15.4
Newcastle formation	
1. Sandstone, light gray, fine-grained, medium-bedded, fairly hard, poorly exposed.	not measured

Locality 33: On Fall River, five miles southeast of Hot Springs, South Dakota; NE Sec. 33, T. 7 N., R. 6 E., Fall River Co., South Dakota.

	Thickness in feet
Skull Creek shale (in part)	
3. Shale, black, fissile, some light gray soft shaly siltstone laminae in lower 20 feet, much iron stain on s-surfaces, 0.5- to 0.6-foot gray hard ripple-marked limestone beds at 29 and 39 feet above base, shale is lighter gray between 45 and 65 feet above base, and contains some bentonitic shale, ironstone concretions at 60 feet above base with some associated gypsum and limonite, above this the formation is covered. Sample q, 48-60 feet above base p, 36-48 o, 24-36 n, 12-24 m, 0-12	(exposed) 65.0
2. Sandstone, light gray, reddish-brown stain, very fine-grained, hard, silty, and shale, black, fissile, thinly interbedded.	2.0
Fall River sandstone	
1. Sandstone, light brown, fine-grained, hard, massive and thickly bedded.	not measured

Locality 34: On U. S. Highway 20 at Sulphur Creek, one-fourth mile southwest of Cody, Park Co., Wyoming.

	Thickness in feet
Muddy sandstone (in part)	
6. Sandstone, tan, fine-grained, fairly hard, some clayey cement, thin to thickly bedded, cross-bedded, ripple-marked, exposed below alluvium.	(about) 20.0
5. Shale, gray, silty, slightly bentonitic. Sample w, lower 0.5 foot	8.0
4. Bentonite, gray.	1.5
Thermopolis shale	
(upper shale, in part)	
3. Shale, gray, slightly silty. Sample n	7.0
2. Bentonite, gray.	0.5
1. Shale, gray, silty, yellow stains. Sample m	(exposed) 3.0

Locality 35: On Lower Slide Lake; Sec. 34, T. 43 N., R. 114 W., Teton Co., Wyoming.

	Thickness in feet
Thermopolis shale (in part)	
(lower shale, in part)	
5. Shale, black, fissile, silty.	(exposed) 15.0
4. Siltstone, tan, and shale, black, fissile, thinly interbedded.	15.0
(rusty beds)	
3. Siltstone, tan, thinly to thickly bedded, cross-bedding and lenticularity on very small scale; beds greatly persistent laterally but individual laminae of which they are composed are very lenticular; some ironstone beds, nearly no shale with exception of lower few feet, fucoidal and ripple-marked beds common, weathers rusty brown, forms high cliff.	(about) 110.0
2. Covered interval, appears to be black silty claystone with some gray iron-stained claystone beds at contact.	15.0
Cloverly formation	
1. Claystone, gray, variegated red, silty, some iron-stained, no spherulites found.	not measured

Locality 36: West flank of Little Greys anticline, on U. S. Highway 89 and 26, in Snake River Canyon; Sec. 2, T. 37 N., R. 117 W., Lincoln Co., Wyoming.

	Thickness in feet
Muddy sandstone (in part)	
9. Sandstone, light gray and tan, fine- to medium-grained, salt and pepper, most thickly bedded, ripple-marked, cross-bedded, forms cliff.	(estimated) 125.0
8. Siltstone, tan, some thinly interbedded shale.	20.0
Thermopolis shale	
7. Shale, black, fissile, hard. Sample q	5.0
6. Siltstone, gray, and shale, black, in very lenticular interbeds.	10.0
5. Shale, as in unit 7 above. Sample p	5.0
4. Siltstone, as in unit 6 above.	8.0
3. Shale, as in unit 7 above, base poorly exposed. Sample o, 45-60 feet above base n, 30-45 m, 10-30	(about) 60.0

(rusty beds equivalent?)

2. Covered interval. (about) 10.0
1. Claystone and siltstone, tan and gray, interbedded, some carbonaceous material, at least 2 maroon beds 3 or 4 feet thick, base not exposed. (exposed about) 100.0

Locality 37: Road cut northwest of New Haven; NW Sec. 11, T. 55 N., R. 67 W., Crook Co., Wyoming. Measured and sampled by K. M. Waagé.

Thickness in feet

Newcastle formation (in part)

18. Sandstone, fine-grained to medium-grained, thinly cross-bedded to irregularly bedded, weathers brown, platy; overlying units obscured by forest cover. 3.0
17. Covered interval, obscured by slope wash. 4.3
16. Sandstone, fine- to medium-grained, thinly bedded, forms brown-weathering platy ledge in upper part, friable below. 4.5
15. Sandstone, fine-grained, forms massive ledge; lower half has beds 0.6-1.0-foot thick with "worm-marked" surfaces; weathers yellowish-gray, locally pitted. 10.0
14. Sandstone, fine-grained, thin-bedded to thinly cross-bedded, "worm-tracked," with some shaly partings and carbonaceous fragments; locally hard, calcareous, weathers yellowish-gray; locally iron-stained in basal 1.5 feet. 3.6
13. Sandstone, clayey, fine-grained, and shale, sandy, laminated, soft; weathers gray; basal 0.8-foot forms crumbly orange-brown ledge. 9.5
12. Sandstone, clayey, as in unit 13 above, with thin interbeds of massive fine-grained sandstone and partings of gray shale. 7.0
11. Sandstone, as unit 12 above, conglomeratic, pebbles smooth, blue-black, possibly phosphatic. 0.1

Skull Creek shale

10. Shale, partially obscured by slump; upper 2.0 and basal 3.0 feet, black, slightly silty, weathers to blue-gray chips; some rusty stain on joint surfaces. 12.0
9. Shale, clay, black, fissile; at top is zone of orange-brown-weathering limy concretions 0.6- to 0.8-foot in diameter, 0.2-foot thick.
   Sample v 5.3
8. Shale, clay, black, fissile; at top is clay-pellet zone cemented by gypsum and ferruginous crust; contains scattered ironstone concretions; pellet zone sparingly fossiliferous; ammonite fragment; shark tooth.
   Sample u 2.4
7. Shale, clay, black, fissile; at top are small flat, ironstone concretions weathering iron-brown to purple; other beds scattered ironstone concretions 2.7 feet from top and 4 feet from base.
   Sample t, 6-9.5 feet above base
   s, 0-6 9.5
6. Shale, locally silty, dark gray to black; upper 2 feet and basal 0.5-foot interlaminated with siltstone and fine-grained sandstone; upper 0.3-foot weathers rusty brown.
   Sample r 4.3
5. Shale, finely silty, dark gray to black, fissile, bed of interlaminated siltstone one foot below top.
   Sample q 7.3
4. Sandstone, fine-grained, and siltstone, clayey, irregularly interbedded

and interlaminated with silty black clay; contains scattered large rusty-weathering limy concretions; weathers to crumbly yellow-gray outcrop. 3.3

3. Shale, clay, black, fissile, with thin layers and laminae fine-grained sandstone at top and base; thin sandstone bed locally with concretionary ironstone at 2.7 feet above base.
    Sample p, 3-7 feet above base
    o, 0-7 7.0

2. Shale, clay, dark gray to black, fissile, with thin interbeds siltstone and fine-grained sandstone in lower 5 feet; sandstone bed 1.2 to 1.8 feet below top.
    Sample n 6.7

1. Shale, clay, black, fissile, base exposure.
    Sample m (exposed) 3.5

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INDEX

Numbers in bold face type indicate page on which the reference is illustrated. Numbers preceded by an asterisk indicate pages of complete description of reference.

PLATES

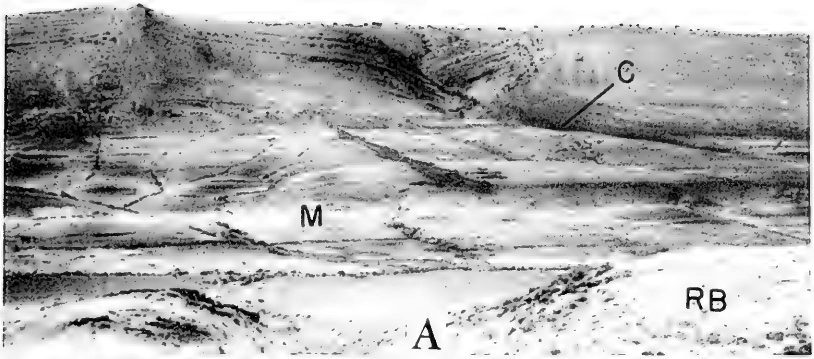
PLATE 1

EXPOSURES OF THE CLOVERLY, THERMOPOLIS AND SHELL CREEK FORMATIONS

A.—Type locality of Shell Creek shale looking west. Here the Mowry shale supports sagebrush vegetation, the Shell Creek practically no vegetation. Section was measured in right half of picture. C, well exposed Mowry contact in gulch. M, Muddy sandstone. RB, rusty beds.

B.—Cloverly-Thermopolis contact (C) at the type locality of the Thermopolis formation (locality 2). Dark thinly bedded siltstones and sandstones of the Thermopolis (rusty beds) overlie massive light-colored sandstones and claystones of the Cloverly.

C.—Upper portion of the Thermopolis shale at the type locality (locality 4). Person marks contact of middle silty shale and upper shale. M, Muddy sandstone. Mowry shale and Frontier sandstone form ridge in background.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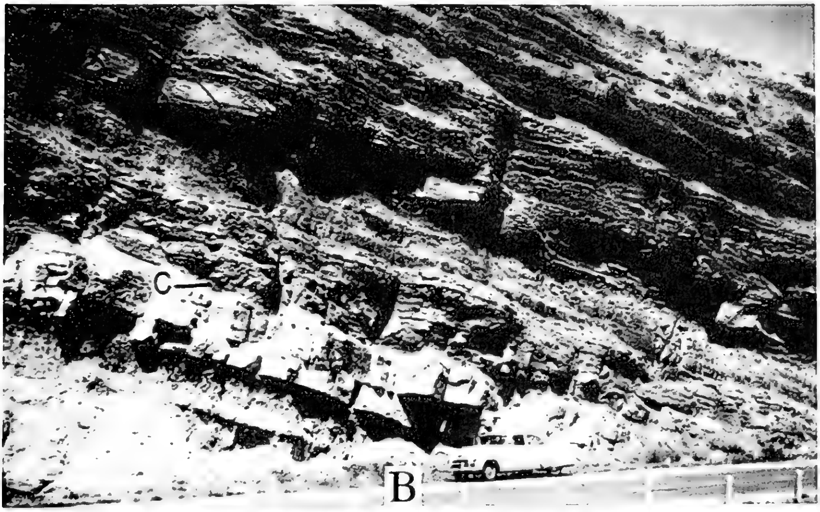
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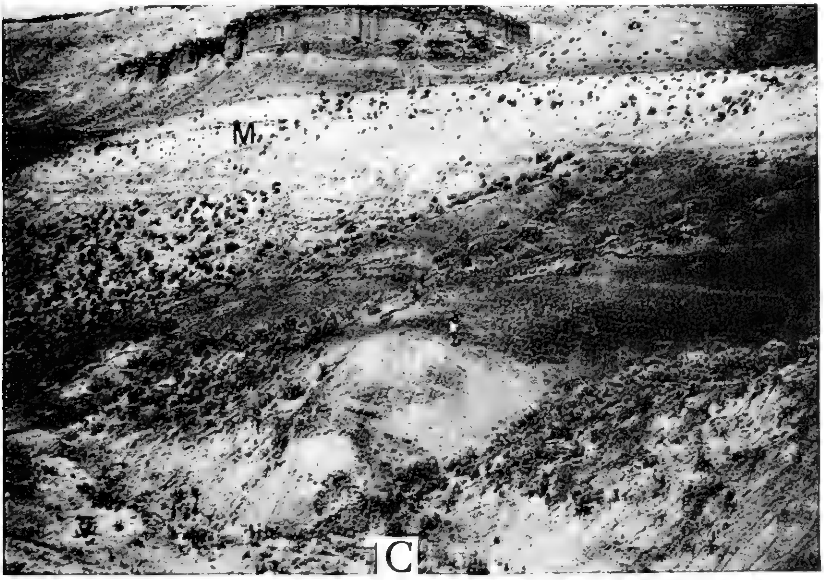
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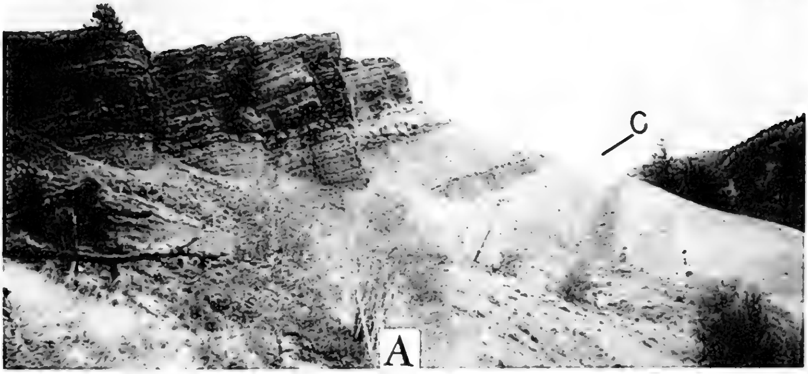
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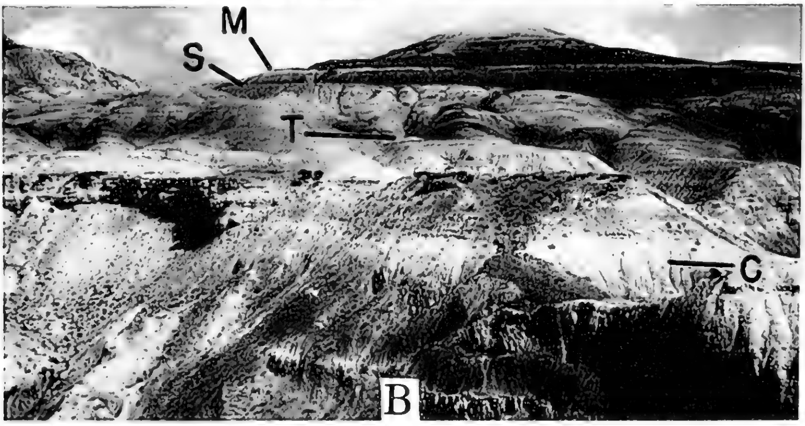
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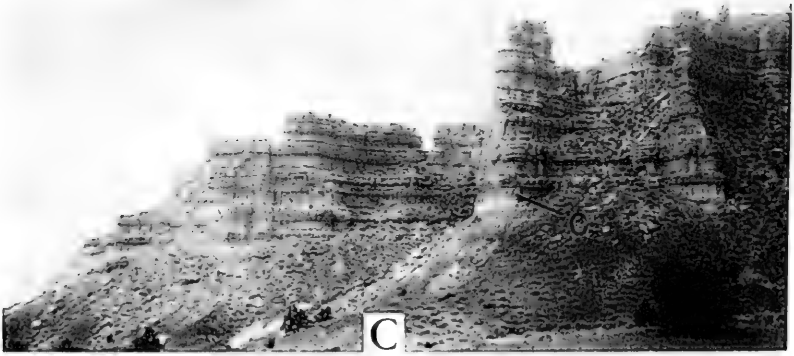
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C

PLATE 2

Lithologic variations in the rusty beds and their correlatives to the east and west. C, contact of the rusty beds and equivalents and underlying Cloverly and equivalents. In B, T, S, and M point to the top of the rusty beds, the middle silty shale, and the Muddy sandstone, respectively.

A.—Locality 35, extreme western Wyoming.
B.—Locality 20, northern Big Horn Basin.
C.—Sec. 20, T. 57 N., R. 64 W., northern Black Hills.

PLATE 3

SACCAMMINIDAE, TOLYPAMMINIDAE AND LITUOLIDAE

FIGURE

1, 2. *Saccammina alexanderi* (Loeblich and Tappan). 1a, b, side and top views of a large specimen, YPM 20447; 2a, b, side and top views of a small specimen, YPM 20448; X50.

3. *Involutina kiowensis* (Loeblich and Tappan). 3a, b, side and edge views of a specimen with erratic coiling particularly in early portion, YPM 20437; X125.

4, 5. *Glomospira reata* Eicher, n. sp. 4a, b, side view and edge view of holotype, YPM 20429; 5, side view of specimen with a slightly crushed final portion, YPM 20430; X50.

6. *Glomospira glomerosa* Eicher, n. sp. 6a, b, opposite sides of holotype, YPM 20428; X125.

7. *Lituotuba* sp. Side view of a small specimen with a broken apertural end, YPM 20438; X50.

8. *Glomospira tortuosa* Eicher, n. sp. 8a, b, opposite sides of holotype, YPM 20431; X125.

9-11. *Alveolophragmium linki* (Nauss). 9, side view of a specimen, YPM 20402; 10; edge view of a specimen with the final chamber partially broken away showing interioareal aperture in penultimate chamber, YPM 20401; 11, side view of another specimen, YPM 20403; X83.

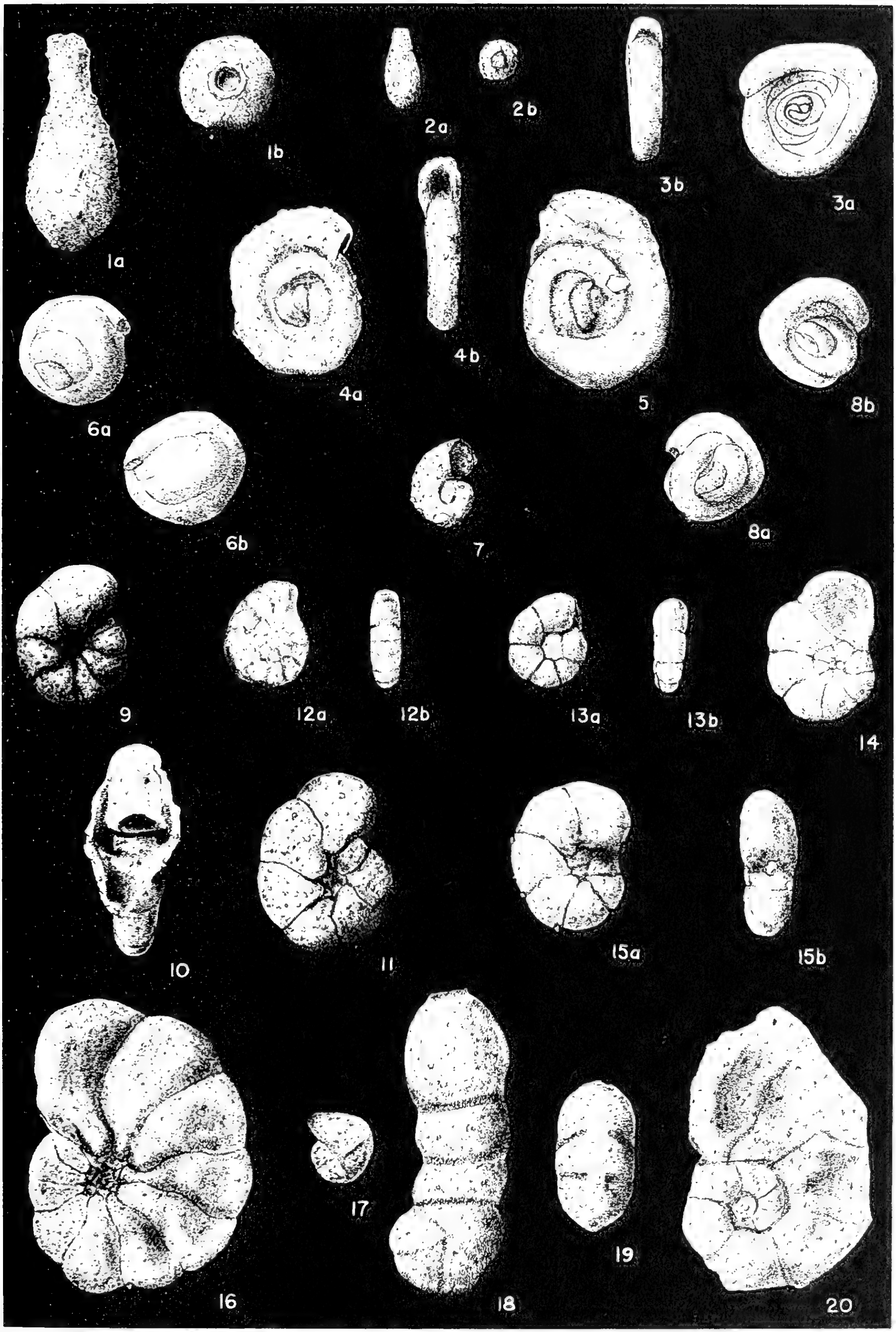
12. *Haplophragmoides multiplum* Stelck and Wall. 12a, side view of a specimen viewed in water, 12b, edge view, YPM 20433; X83.

13-15. *Haplophragmoides uniorbis* Eicher, n. sp. 13a, b, side and edge views of megalospheric specimen, YPM 20435; 14, side view of microspheric specimen with flattened ultimate chamber, YPM 20436; 15a, b, side and edge views of holotype, a megalospheric specimen, YPM 20434; X83.

16. *Haplophragmoides gigas* Cushman. Side view of a flattened specimen, YPM 20432; X50.

17-19. *Ammobaculites euides* Loeblich and Tappan. 17, side view of an immature specimen with the aperture at the peripheral angle, YPM 20404; 18, side view of a large, well-preserved specimen, YPM 20405; 19, peripheral view of a smaller specimen showing the broken sutures typical of the early growth stages, YPM 20406; X50.

20. *Ammomarginulina cragini* Loeblich and Tappan. Side view of a flattened specimen. YPM 20421; X50.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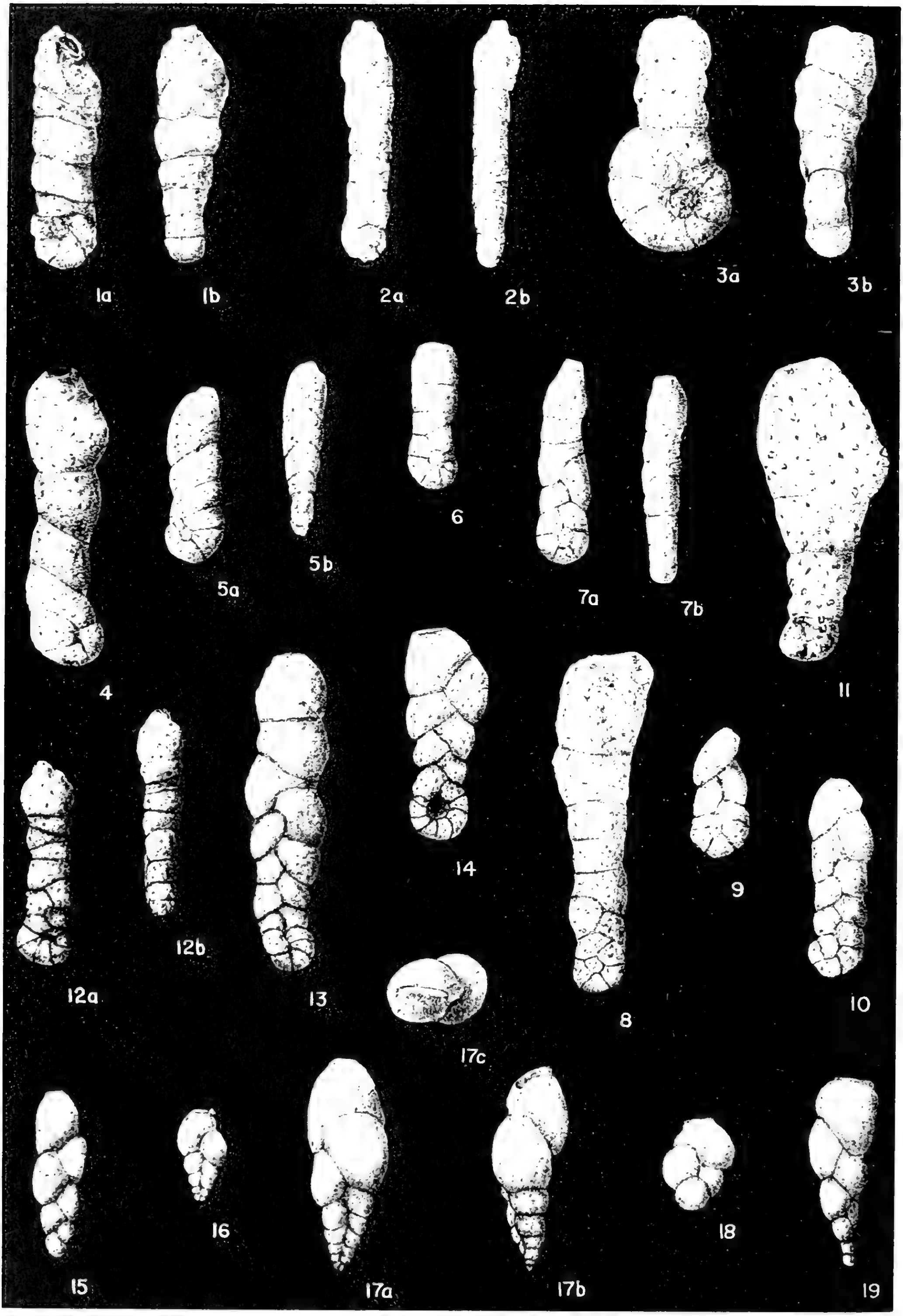
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PLATE 4

LITUOLIDAE AND TEXTULARIIDAE

FIGURE

1.	*Ammobaculites tyrelli* Nauss, 1a, b, side and edge views of a specimen with a partly crushed final chamber, YPM 20413; X50.
2, 6.	*Ammobaculites petilus* Eicher, n. sp. 2a, b, side and edge views of holotype, YPM 20410; 6, side view of a small specimen, YPM 20411; X83.
3.	*Ammobaculites subcretaceus* Cushman and Alexander. 3a, b, side and edge views of a specimen with a nearly cylindrical uniserial portion, YPM 20412; X50.
4, 5	*Ammobaculites obliquus* Loeblich and Tappan. 4, side view of a large specimen, YPM 20408; 5a, b, side and edge views of a specimen, YPM 20409; X50.
7-10.	*Ammobaculoides phaulus* Loeblich and Tappan. 7a, b, side and edge views of a specimen with notable uniserial portion, YPM 20414; 8, side view of specimen with exceptionally well developed uniserial series and a crushed final chamber, YPM 20415; 9, 10, side views of two additional specimens with no uniserial series, YPM 20416 and 20417; X83.
11.	*Ammobaculites fragmentarius* Cushman. Side view of a crushed specimen, YPM 20407; X50.
12-14.	*Ammobaculoides whitneyi* (Cushman and Alexander). 12a, b, side and edge views of a specimen, YPM 20418; 13, 14, side views of two additional specimens, YPM 20419 and 20420; X50.
15-19.	*Bimonilina variana* Eicher, n. sp. 15, side view of a megalospheric specimen, YPM 20423; 16, side view of a small microspheric specimen, YPM 20424; 17a, b, c, side, edge, and top views of the holotype, a large microspheric specimen, YPM 20422; 18, 19, side views of two additional megalospheric specimens, YPM 20425 and 20426; Note how each chamber appears to be terminal or the initial one of a uniserial series; X83.

PLATE 5

VERNEUILINIDAE AND RZEHAKINIDAE

FIGURE

1, 2. *Verneuilina canadensis* Cushman. 1, edge view of a specimen, YPM 20459; 2, side view of another specimen, YPM 20458; X83.

3, 4. *Verneuilinoides hectori* (Nauss). 3, a small specimen from the Shell Creek shale, YPM 20461; 4, a specimen from the Thermopolis shale, YPM 20460; X50.

5. *Eggerella* sp. Side view, YPM 20427; X83.

6-10 *Verneuilinoides kansasensis* Loeblich and Tappan. 6. 10, two specimens with closely triserial chambers throughout, YPM 20462 and 20466; 7, 8, two specimens whose chambers become loosely triserial in the later portions, YPM 20463 and 20464; 9, an extremely uncoiled specimen in which early loosely triserial chambers give rise to later only slightly twisted biserial chambers by means of an increase in the arc of rotation, YPM 20465; X83.

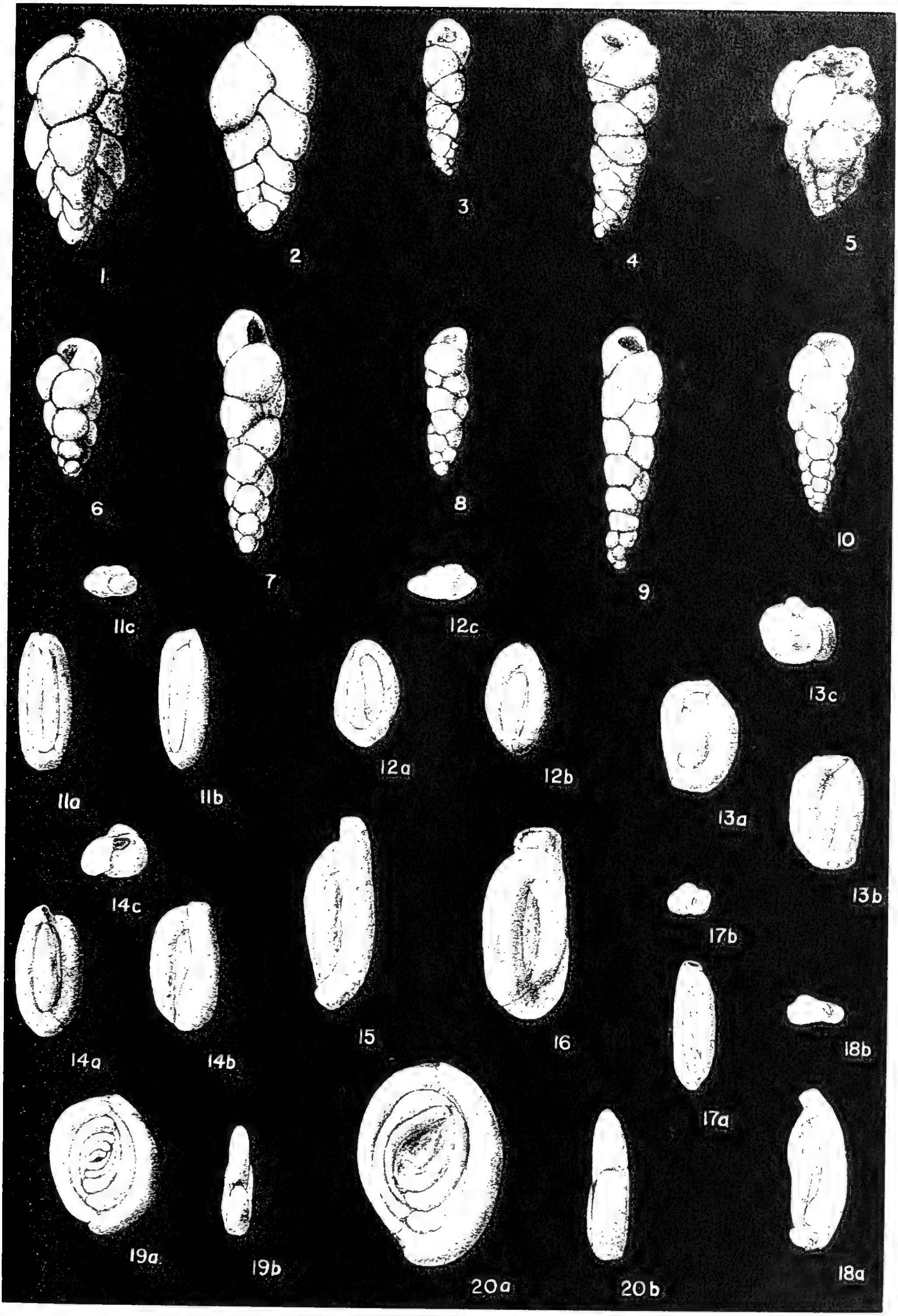
11, 12. *Miliammina ischnia* Tappan. 11a, b, c, opposite sides and top view of a specimen, YPM, 20440; 12a, b, c, opposite sides and top view of a broad specimen, YPM 20439; X83.

13, 14. *Miliammina inflata* Eicher, n. sp. 13a, b, c, opposite sides and top view of holotype, YPM 20441; 14a, b, c, opposite sides and top view of another specimen, YPM 20442; X83.

15, 16. *Miliammina manitobensis* Wickenden. Side views of two partly flattened specimens, YPM 20443 and 20444; X50.

17, 18. *Miliammina* cf. *M. sproulei* Nauss. 17a, b, side and top views of a specimen, YPM 20446; 18a, b, side and top views of another specimen, YPM 20445; X83.

19, 20. *Spirolocammina subcircularis* (Tappan). 19a, b, side and top views of a specimen, YPM 20450; 20a, b, side and top views of a large specimen, YPM 20449; X125.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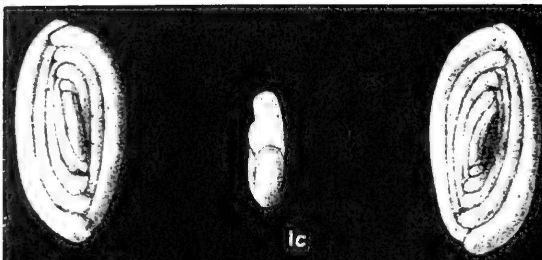

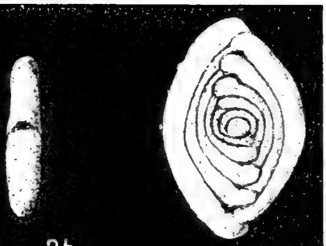

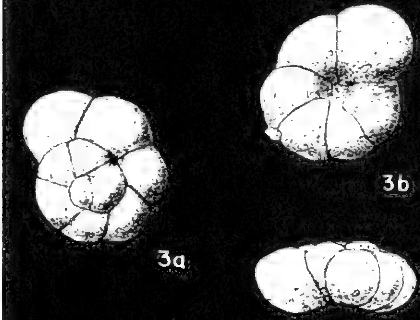

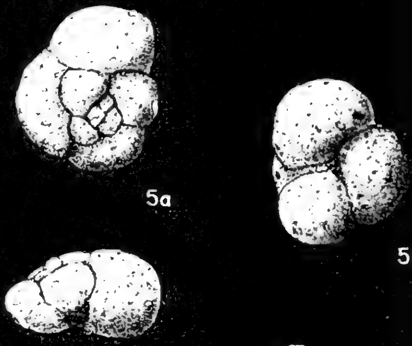

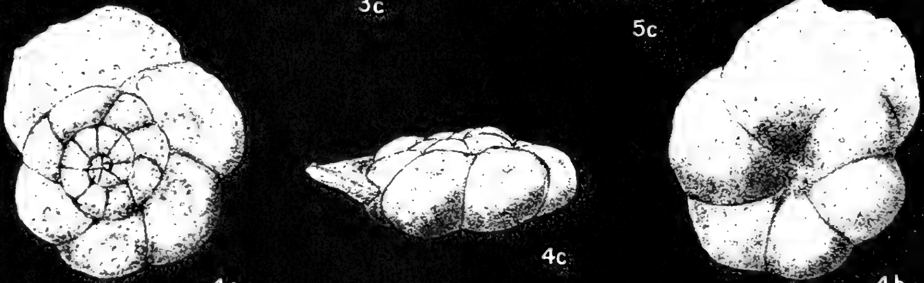

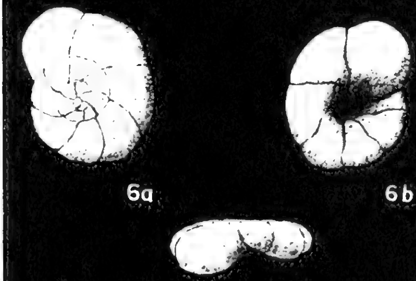

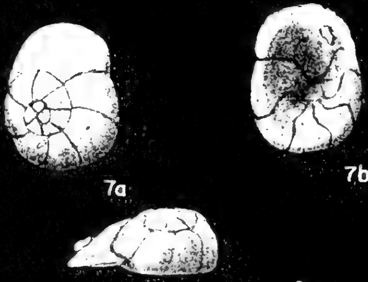


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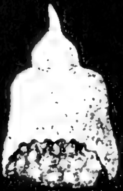
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PLATE 6

RZEHAKINIDAE, TROCHAMMINIDAE AND THEOPHORMIDIDAE

FIGURE

1, 2. *Spirolocammina planula* Eicher n. sp. 1a, b, c, opposite sides and top view of holotype, believed to be a microspheric specimen, YPM 20451; 2a, b, side and top view of a specimen believed to be a megalospheric form, YPM 20452; X125.

3, 4. *Trochammina depressa* Lozo. 3a, b, c, opposite sides and edge view of a large megalospheric specimen, YPM 20454; 4a, b, c, opposite sides and edge view of a microspheric specimen with a crushed final chamber, YPM 20455; X83.

5. *Trochammina umiatensis* Tappan. 5a, b, c, opposite sides and edge view of specimen, YPM 20453; X83.

6, 7. *Trochammina gatesensis* Stelck and Wall. 6a, b, c, opposite sides and edge view of a rather flat specimen, YPM 20457; 7a, b, c, opposite sides and edge view of an exceptionally high-spired specimen, YPM 20456; X83.

8-10. *Clathrocyclas (Clathrocyclas) irrasa* Eicher, n. sp. 8, holotype, YPM 20467; 9, 10, two other specimens showing variations in shape, YPM 20468 and 20469; X125.