Stratigraphy of the Inyan Kara Group in the Black Hills

By KARL M. WAAGE

CONTRIBUTIONS TO GENERAL GEOLOGY

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By Karl M. Waagé

ABSTRACT

Darton's subdivision of beds, originally called Dakota in the Black Hills, has proved difficult to apply outside of a limited area in the southeastern Black Hills in which the names were first applied. As early as 1930 the principal subdivisions, the Lakota, Fuson, and Fall River (Dakota of Darton) formations were placed in the Inyan Kara group because they could not be distinguished consistently as separate units. Early miscorrelation of the Fall River (Dakota) with the Dakota sandstone of southeastern Colorado has led to confusion in the application of Darton's terminology outside of the Black Hills.

Stratigraphic studies of the Inyan Kara group reveal a basic twofold lithogenetic subdivision which has been recognized in equivalent beds elsewhere in the western interior region. Deposits of the lower part of this twofold division are dominantly sandy sediments of varied continental facies and are allied lithogenetically with the underlying Morrison formation. Deposits of the upper part are dominantly sandy sediments of marginal marine facies allied lithogenetically and gradational with the overlying marine Skull Creek shale. The contact of the two parts is a transgressive disconformity of regional extent marking the initial incursion of the Cretaceous sea.

The subdivision and nomenclature of the Inyan Kara group is adjusted to conform to this twofold lithogenetic division by refining the definition of the Fall River formation so that it corresponds to the upper part, and by extending the term "Lakota" to include the entire lower part. The transgressive disconformity becomes the contact of the Lakota and Fall River formations. The Inyan Kara group is retained to include these two formations. The Minnewaste, called a formation by Darton, is recognized as a local limestone member of the Lakota. Use of the name Fuson as a member of the Lakota is considered permissible only where the Minnewaste limestone member is present. Because of the strictly local nature of much of the Inyan Kara group neither its name nor the names Fall River and Lakota should be used outside of the Black Hills region.

The sequence of Lakota rocks in the southern part of the Black Hills is markedly different from that in the northwestern part. Additional beds are added progressively at the base of the formation as it thickens eastward and southeastward. The relationship of these beds to the underlying Morrison is not completely understood, but they do not interfinger. The base of the Lakota

is an admittedly arbitrary, indefinite, and inconstant boundary generally drawn at the base of the first appreciable sandstone bed above the Sundance formation, the local, distinctive Unkpapa sandstone excepted. The base of the first dark-gray or black claystone above the variegated marlstone beds of the Morrison serves as a convenient contact in the absence of thick sandstone bodies. More precise definition of units in the complex of continental facies making up the Morrison-Lakota interval must await more detailed study of these closely related formations. Included plant remains indicate that the Lakota is Early Cretaceous in age.

The contact of the Lakota and Fall River formations is a surface of disconformity that can be found throughout the Black Hills. Its aspect varies from place to place depending on the rock types that are locally in contact; dark-gray laminated siltstone is the commonest basal Fall River rock and light-colored claystone or clayey siltstone the commonest upper Lakota rock. Scattered small spherulites of siderite characterize the upper several feet of the Lakota beneath the contact.

The major features of Fall River rocks extend throughout the Black Hills area. The chief variations within the formation are the presence of a thin tongue of continental claystone and siltstone in the southern and eastern parts of the Black Hills and the increase in thickness of included massive sandstone subunits in the southern part. Fossils from the Fall River formation are not diagnostic as to age, but the formation is gradational with the overlying Skull Creek shale, which contains an Albian fauna.

INTRODUCTION

Field parties of the U.S. Geological Survey currently working in different parts of the Black Hills found the contacts between the Lakota, Fuson, and Fall River formations too ill-defined to map consistently from place to place and questioned the validity of the Fuson as a formation. During July and August of 1955 and for 5 weeks in August and September of 1956, a special study of this problem was made for the Geological Survey, on behalf of the Division of Raw Materials of the U.S. Atomic Energy Commission, to determine whether any suitable basis existed for subdividing the Inyan Kara group. Results of these studies are the subject of the present paper.

Fieldwork in 1955, done with the able assistance of Copeland MacClintock, was concentrated largely in the Inyan Kara outcrops of Crook County, Wyo., and a reconnaissance examination of these beds was made all around the Black Hills. Without the constant help and guidance of the Geological Survey field parties working in the area and without the information they had already accumulated and generously gave, it would have been impossible to make much progress with the study. I am particularly grateful to Charles S. Robinson, who suggested the study and to his coworkers and assistants, and to Garland Gott and the field parties under his supervision for help in acquainting me with the stratigraphy in the southern Black Hills. I am indebted to Henry Bell, also of the Geological Survey, who furnished information on Lakota fossils; to Bruce MacPherson of the Atomic Energy Commission, who furnished drill core samples of the Lakota-Fall River contact beds; to V. Rama Murthy, graduate student at Yale University, who identified the spherulitic siderite from many samples; and to Daniel Barker, who assisted in the field the summer of 1956. For the opportunity to continue the study in 1956 and 1957 and for his willing help throughout the project I am much indebted to William J. Mapel of the Geological Survey.

The desirability of consistent stratigraphic classification in an area where many detailed studies are underway in the highly variable Inyan Kara beds has prompted presentation at this stage of the work, in spite of the fact that much of the material is general and necessarily preliminary. Nevertheless, the gross features of Inyan Kara stratigraphy are clear, and it is the purpose of this paper to reveal the regional pattern of Inyan Kara sedimentation and to suggest its use as a nomenclatural framework within which local stratigraphic complexities in the Black Hills region can be described without confusion in terminology. Necessary adjuncts to the study are an understanding of the existing nomenclature, of the type localities of its units, and of the principal variations within the Inyan Kara group of the Black Hills as a whole. Of first importance as a background for the interpretation of Inyan Kara stratigraphy is an acquaintance with the simple, persistent pattern of sedimentation evident in basal Cretaceous deposits throughout the Great Plains and adjacent parts of the Rocky Mountain region.

REGIONAL PATTERN OF EARLY CRETACEOUS SEDIMENTATION

A persistent disconformity separating continental deposits of varied facies from overlying marginal marine deposits and marine deposits was recognized within the Dakota group of the northern Colorado Front Range (Waagé, 1955), where this twofold lithogenetic pattern was used as a basis for subdivision of the group. Earlier (Waagé, 1953, p. 11) the same disconformity, whose regional significance was not recognized at the time, was used as the contact between the Lytle and Glencairn members of the Purgatoire formation in south-central Colorado. Reconnaissance studies supplemental to those of the Front Range and additional local studies as yet unpublished reveal the disconformity and the two gross lithogenetic units it separates, in the Purgatoire-Dakota sequence of southeastern Colorado and southwestern Kansas, in the Cloverly-Thermopolis-Muddy sequence of the Bighorn Basin area and eastern Wyoming, in the type area of the original Dakota formation along the Missouri River in Iowa and Nebraska, and in the Inyan Kara-Skull Creek-Newcastle sequence of the Black Hills region. The inferred lithogenetic relationships of most of these differently named Lower Cretaceous units and their positions relative to the regional disconformity are summarized in figure 5.

Within the broad twofold lithogenetic framework the Dakota group and its equivalents varies considerably from place to place. Changes in type of rock, sequence of rocks, and thickness of individual subunits locally obscure the basic pattern. The many environments of deposition represented in the two parts of the sequence account for much of the variation. Sediments of the lower part are chiefly channel and flood-plain deposits, but swamp and lacustrine deposits occur locally. In the sediments of the upper part estuarine, coastal-swamp, tidal-flat, and deltaic deposits, including distributary channel deposits, can be recognized among the marginal marine environments; marine offshore deposits are also abundantly represented, chiefly by gray or black, poorly fossiliferous shale.

More specialized environmental conditions account for local deposits of distinctive sedimentary rocks—such as fresh-water limestone, like the Minnewaste of the southeastern Black Hills, and refractory shale and clayrock,[1] like that in the South Platte formation in the Colorado Front Range. Other distinctive types of rock limited to a part of the area of deposition reflect the source rather than the environment; examples include the predominance of bentonite and bentonitic claystone in the northern part of the western interior region and, possibly, the conglomerate lenses with abundant black chert pebbles, like the Pryor conglomerate member of the Cloverly formation which also are prevalent in the northern interior region.

Another type of variation causing the Dakota and equivalent rocks of one area to appear strikingly different from those in another is the change in the ratio of sandstone to clay rocks as the sequence is traced from the sides of the basin of deposition toward its central part. As an example, the upper part of the Dakota group (South Platte formation) along the northern Colorado Front Range changes from a dominantly sandy sequence in the south to a dominantly shaly sequence in the north as deltaic sands thin out northward into marine shale and siltstone (Waagé, 1955). Moreover, the dumping of sand into the basin of deposition was not uniform; much of it occurred at different times in different places with the result that the conspicuous sandstone units within the sequence in one part of the basin are not necessarily represented in another part. Indeed, of all the dominantly sandy units in the Dakota and

[1] As defined by Ingram, 1953, p. 870.

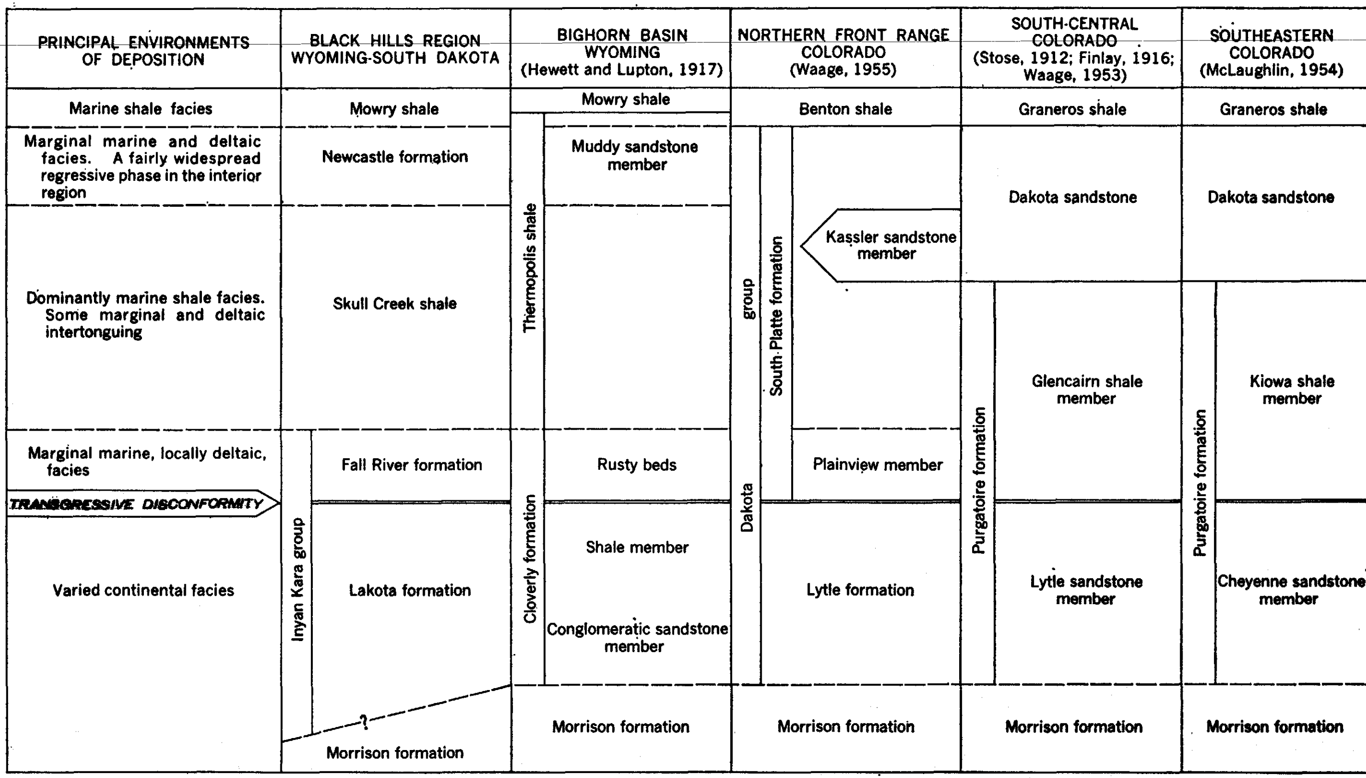


FIGURE 5.—Probable lithogenetic equivalents of the Lakota, Fall River, and adjacent formations.

equivalents, only those in the upper part of the sequence (Muddy, Newcastle, and presumed equivalents) suggest a general basin-wide phase of sand deposition rather than a local one; but even these beds were obviously derived from a number of different source areas and are commonly discontinuous in the central parts of the basin where the sandstone is sparsely distributed and lateral shaly facies common.

The heterogeneity presented by the sequence of the Dakota and equivalents as a whole is impressive, and a great amount of detailed stratigraphic study of individual areas is necessary before any satisfactory account of its complex history can be compiled. Nevertheless most of the local variations in deposition are within the basic pattern of a lower continental part separated by a transgressive disconformity from an upper marginal marine part and marine part. These two gross lithogenetic units differ from one another in a number of ways.

Deposits of the lower part of the sequence are, in general, typified by fine- to coarse-grained, buff to white, lenses of sandstone and conglomeratic sandstone, irregularly interbedded with variegated red, green, yellow, gray, and black claystone. Shale is rare and generally limited to local lacustrine deposits. Most of the coarser fraction in this part of the sequence is chert, quartzite, and quartz, obviously many cycles removed from the parent rock. In some areas, such as in south-central and much of southeastern Colorado, the lower part of the sequence is dominantly sandy, and variegated claystone is rare. In other areas, such as the northern part of the Bighorn Basin, variegated claystone and argillaceous siltstone predominate. In the northern part of the interior region, where the claystone content is generally high, scattered polished pebbles of colored chert and quartzite, once referred to as "gastroliths," are common.

Fossils are not common in the lower part of the sequence but plant remains include coniferous wood, cycadeoids, charophytes and other algae, and the foliage of ferns and cycads; animal remains include dinosaur bones, fresh-water mollusks, ostracodes, and branchiopods. The lower part of the Dakota sequence is more closely related lithogenetically to the underlying Morrison formation, than it is to the upper part of the sequence. No persistent conglomeratic bed or obvious stratigraphic break marks the contact with the Morrison, and at many places it is impossible to separate the two units except on some arbitrarily selected local feature. Nevertheless, the scanty fossil evidence indicates an appreciable hiatus (Reeside, 1952).

The upper part of the Dakota sequence consists chiefly of fine-grained, commonly thin bedded, laminated to tabular, cross-laminated, buff- to brown-weathering, sandstone interbedded with gray to black shale and siltstone. Sandstone and thinly interbedded siltstone and shale containing ripple marks and the trails, castings, and borings of soft-bodied wormlike animals are common. Thin bedding and lamination characterize this part of the sequence and contrast strongly with the generally lenticular, massive, cross-laminated beds of the lower part. Nevertheless thick bodies of massive, brown-weathering sandstone are common in the upper part of the sequence in or near local deltaic areas. In these deltaic areas that bordered the encroaching sea, such as in the northern Colorado Front Range south of Boulder, on the west side of the basin of deposition, and in eastern Nebraska, on the east side, sandstone bodies predominate and alternate with thin shale subunits in a series of transgressive-regressive phases. In areas, such as central Wyoming, that lay within the central part of the basin of deposition, nearly the entire sequence of beds is shale and silty shale (Thermopolis) except for some sandy shale and local sandstone at the top (Muddy) and base (Rusty beds). Fossils in the marginal marine beds include dicotyledonous leaves, wood, false trunks of the genus *Tempskya*, some freshwater clams, linguloid brachiopods and Foraminifera, as well as the abundant burrows, trails, and castings of soft-bodied animals. Marine beds contain pelecypods, gastropods, linguloid brachiopods, Foraminifera, and the bones of fish, crocodiles, and plesiosaurs.

The contact of the two lithogenetically distinct parts of the sequence is, in many places, a relatively plane surface of disconformity marking an abrupt lithic change. In eastern Colorado (Waagé, 1955) and southeastern Wyoming the contact is marked locally by a weathered zone in the underlying beds and by a thin layer of chert and quartzite pebble conglomerate or conglomeratic sandstone on the surfaces of disconformity. Northward into central and northeastern Wyoming and the Black Hills region conglomerate is not common above the disconformity and the existence of a weathered zone beneath it, although suspected at some localities, remains to be demonstrated. In these areas the contact is commonly marked by a lithic change from variegated claystone below to sandstone or gray to black siltstone and shale above. In addition, the claystone a few feet beneath the contact is commonly peppered with spherulites of siderite, which weather to red and yellow spots. Locally carbonaceous siltstone and lignite rest on the plane of contact, and at some of these localities the top of the claystone underlying the contact contains the remains of plant roots. Many other combinations of types of rocks are locally in contact at the disconformity, but the ones noted are the more common. In some areas the contact is locally obscured where it has been breached by channelling prior to the deposition of massive sandstone bodies above; in other areas fluctuation of the strand line produced an additional "contact" above the initial one.

The gross two-fold lithogenetic subdivision is emphasized purposely here because it affords the only consistent means of orientation within the varied local Dakota sequences. The change from continental deposition to marginal marine deposition, or marine deposition, had to take place wherever the Cretaceous sea encroached; thus the break between the two categories of deposition exists, and should be evident, throughout much of the interior region. Whether or not this disconformity transgresses time, it is an excellent datum to use in working out the equivalency of the lithogenetic units within the Dakota sequence, and, if local terminologies can be adjusted to it, many of the Dakota nomenclatural problems will resolve themselves. In central and eastern Wyoming, the Black Hills region, eastern Colorado, and western Kansas, the first marine faunas above the transgressive disconformity are Albian in age; most described species belong to the *Inoceramus comancheanus* zone. Consequently, on the basis of our present knowledge of the stratigraphic paleontology, the sequence of beds in the area does not noticeably transgress time.

HISTORY OF THE BLACK HILLS NOMENCLATURE

Many of the problems of the stratigraphy of Dakota and equivalent rocks have their roots in the nomenclature. Examples of this are apparent in the summary of the Black Hills nomenclature which follows. References to the inadequacy of some of these systems are in no way intended as criticisms of the men, especially Darton, who initiated them. To the degree that the stratigraphy of the Dakota was known to Darton and other investigators and within the confines of the nomenclatural practices of their day, their classifications were generally useful. The fact that they need revision in light of much more complete data and modern standards of nomenclatural procedure is no discredit to the founders.

Geologic explorations in the vicinity of the Black Hills began as early as 1849 when D. D. Owen sent John Evans to collect fossils in the White River badlands. The badlands and the country between them and the Missouri River became popular grounds for collecting parties from this time, but the Black Hills themselves were not examined by a geologist until 1857. In this year F. V. Hayden accompanied Lt. G. K. Warren on the first Government expedition into the heart of the Black Hills. Hayden had begun his work in the interior region in 1853, when he and F. B. Meek were sent by James Hall to collect from the badlands. From their observations on this expedition Meek and Hayden made the first classification of the interior Cretaceous rocks, published initially by Hall and Meek in 1856 (p. 405). The classification recognized five Cretaceous formations exposed along the upper Missouri River valley. Each unit was given a number; Formation No. 1 included basal sandy beds that were later named the Dakota (Meek and Hayden, 1861, p. 418–419).

Hayden recognized Formation No. 1, as well as the other Cretaceous units, when he entered the Black Hills from the southwest with Warren. The accounts of this trip (Meek and Hayden, 1858, p. 41–59; Hayden, 1862, p. 22) indicate that he included in his No. 1, beds now called the Morrison formation and, possibly, the top of the Sundance, although he did recognize that No. 1 rested on marine Jurassic beds in the Black Hills and not on Carboniferous beds as it did in its typical area along the Missouri.

Hayden's only other geologic examination in the Black Hills proper was in 1859 as geologist for Capt. W. F. Raynold's expedition, which crossed the north end of the Black Hills on its way west. Initial descriptions of fossils from this expedition included Meek's and Hayden's (1861, p. 419) first classification of the Cretaceous in which names instead of numbers were given the units. No. 1 became the Dakota group and No. 2 the Fort Benton group; the terms "group" and "formation" were used synonomously at that time. The only noteworthy addition to Hayden's observations on the Black Hills Cretaceous from the Raynolds expedition (Hayden, 1869, p. 45) was the recognition of "beds of transition, or passage—" between the marine Jurassic (Sundance) and the sandstone beds of the Dakota group. He made no attempt to name these beds or to separate them from the Dakota.

Meek's and Hayden's paper of 1861 naming the Cretaceous units also includes reference to these transition beds (p. 417–418) and to the relationships between the Dakota and Fort Benton groups (p. 420–421). The authors suspect that the Dakota "—is probably only a subdivision or member of the Fort Benton Group," and that perhaps the type Fort Benton "blended" with the Dakota "further south at the Black Hills, and along the Rocky Mountains west of them." The works of Meek and Hayden nowhere indicate clearly whether they included in the Dakota as formerly used in the Black Hills only those beds now included in the Inyan Kara group or whether they also included the Skull Creek and Newcastle formations.

Raynold's expedition was the last into the Black Hills until the Custer expedition of 1874, which had N. H. Winchell as geologist. Winchell's (1875) report of this hurried march affords no new information on the Dakota group. He includes in it all beds down to the marine Jurassic (Sundance). Custer's expedition substantiated the rumors of gold in the Black Hills and forced a more thorough study of the geology. This was undertaken in 1875 by Jenney and Newton under authority of the Bureau of Indian Affairs and resulted in the first comprehensive study of Black Hills geology.

Newton and Jenney did not make as detailed a study of the Cretaceous units as they did of the older rocks but from their measured sections and figures (Newton and Jenney, 1880, p. 151–180) it is obvious that they limited their usage of Dakota group to those beds now included in the Inyan Kara group, assigning beds now called Skull Creek and Newcastle to the Fort Benton group. The Morrison formation and the members of the Sundance can be identified in a number of their more complete Jurassic sections, but they made no subdivisions. They also mentioned that variegated clays locally separate the sandstone beds in the Dakota, stating (1880, p. 176) that these "variegated clays are not a constant feature."

After Newton's and Jenney's work little was added to the knowledge of the Dakota and adjacent beds in the Black Hills, until the early 1890's. During this time the Dakota came to be accepted as the basal unit of the Upper Cretaceous in the interior; Meek's and Hayden's earlier suspicion that it was a Lower Cretaceous unit perished with the insistence of paleobotanists that the leaves from the type area proved a Late Cretaceous age. Newton's and Jenney's interpretation of the basal Dakota contact was strengthened both by local discoveries of unconformity at the base of the sandstone (Carpenter, 1888) and by the discovery of dinosaur bones in the upper part of the underlying Jurassic beds (Marsh, 1890, p. 86, and 1899, p. 228).

Discovery of fossil cycads in the Black Hills was made known in 1893 from two different sources. McBride (1893, p. 248) described a cycad from near Minnekahta, and the National Museum announced (Anonymous, 1893, p. 355) that it had received a collection of cycad trunks from near Hot Springs, So. Dak. In the following year Calvin (1894) and Ward (1894) made independent field studies to determine the source of the cycads. Calvin established that they were from the Dakota and went no further. Ward, in a critical study of outcrops along Fall River, south of Hot Springs and at the Minnekahta locality, found that the cycads came from a horizon within the Dakota below that at which the typical "Upper Cretaceous" angiosperm leaves locally occurred. To Ward and his contemporaries, the name Dakota was synonymous with Upper Cretaceous. The discovery of the Early Cretaceous cycads meant to Ward (1894, p. 265) that a considerable portion of the deposits underlying the marine Cretaceous of the Rocky Mountain region which have heretofore been referred to the Dakota Group on purely stratigraphic evidence may really be much older.

This opinion was strengthened by the discovery of fossil plants from the Dakota group, which Jenney collected in the northern part of the Black Hills in 1894. Concerning this flora Ward (1895, p. 138) states that it is "—certainly as old as Lower Cretaceous and—probably of Kootanie age." He emphasizes that "the Dakota group of Newton must be subdivided and that a large portion of it belongs to the Lower Cretaceous."

Jenney described the stratigraphic position of these plant fossils in a letter to Ward, which Ward (1899, p. 566) later published. The letter contained an informal subdivision of the Dakota group in the Hay Creek coal field of the northern Black Hills. Subsequently Jenney submitted to Ward a detailed paper on this coal field, which elaborated on the subdivision (Jenney, 1899). Jenney recognized four divisions within Newton's Dakota group and restricted the name Dakota to the uppermost division; he gave the names Oak Creek beds, Barrett shales, and Hay Creek coal formation to the remaining beds in descending order. To the claystone lying between these beds and the marine Jurassic he gave the name Beulah clays and recognized them as Jurassic and equivalent to the "Atlantosaurus beds" of Colorado and Wyoming.

In the same year that Jenney's work was published by Ward, Darton (1899) wrote on the Jurassic beds of the southern Black Hills, employing Jenney's name Beulah shales. In this paper he applies (p. 387) the name Lakota without formal definition, to "Lower Cretaceous (or Jurassic?)" beds of undesignated thickness overlying the Beulah shales and consisting of "coarse buff sandstone with fireclays and local coal beds." This paper was followed by Darton's preliminary report on the southern Black Hills in which he (1901a, p. 526) follows Ward's suggestion and Jenney's prior usage in restricting the name Dakota to the "upper sandstone, containing the upper Cretaceous flora, . . ." The underlying beds, which he considers "Lower Cretaceous," possibly "Late Jurassic," he subdivides into three formations, ascending, the Lakota formation, the Minnewaste limestone of local extent only, and the Fuson formation. In this publication Darton retained the name Beulah shales for the beds between the Lakota and Sundance, but subsequently he was persuaded (Darton, 1901b) that they were equivalent to the Morrison formation of Colorado and adopted the latter name in place of the Beulah shales. Darton made no attempt to correlate his units with Jenney's subdivisions in the northern Black Hills, and Jenney's units were never used again.

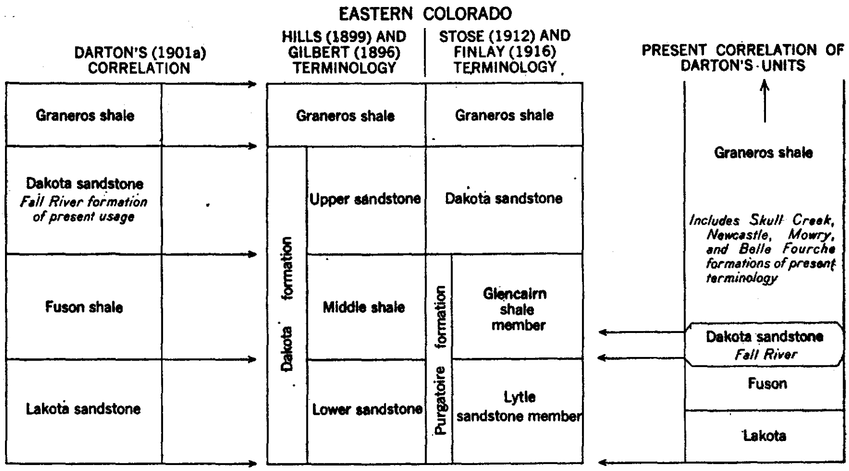
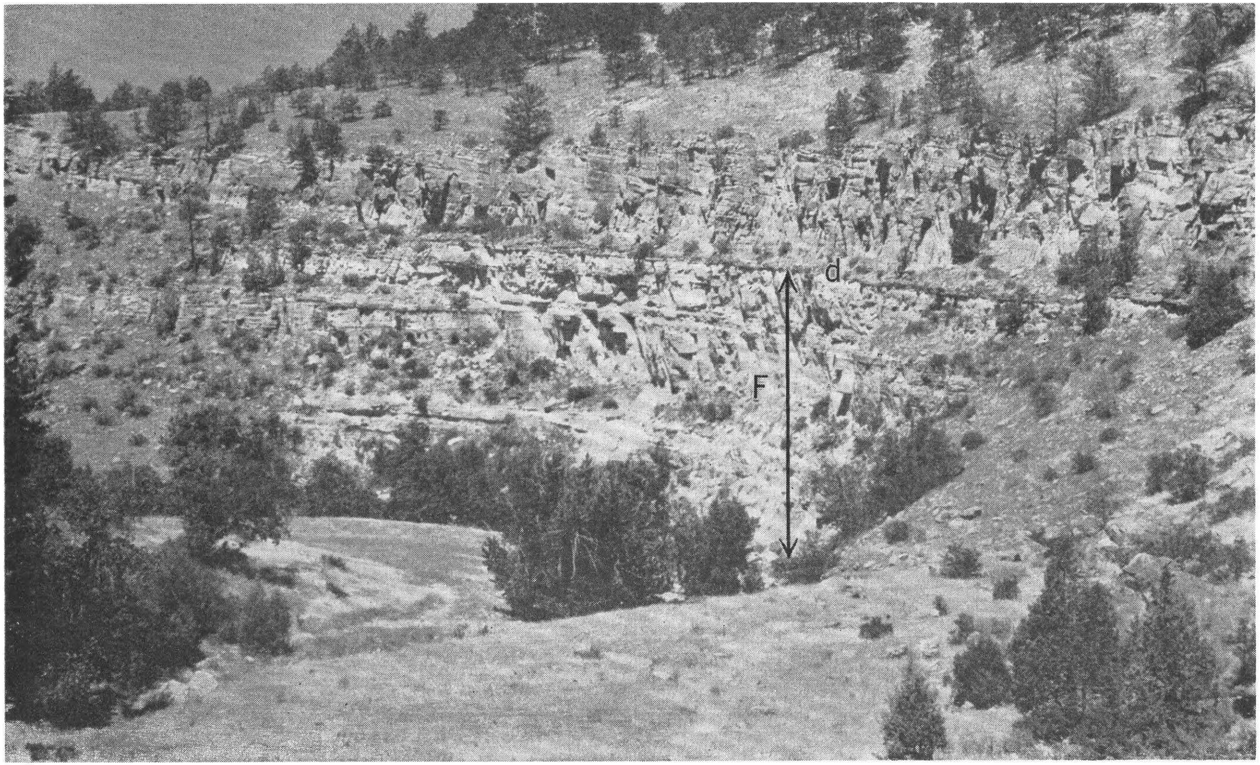


FIGURE 6.—Darton's miscorrelation of his Black Hills units with the Dakota and equivalents of eastern Colorado.

Darton firmly established his terminology in his many publications on the Black Hills. Unfortunately he established, as firmly, a miscorrelation of these beds with the Dakota of eastern Colorado when he (Darton, 1901a, p. 532) became convinced that the Fort Benton formation of the Black Hills was the "precise equivalent" of Gilbert's (1896) Graneros shale in eastern Colorado and introduced the name Graneros into the Black Hills terminology. This miscorrelation, illustrated in figure 6, has had lasting effect. The name Fuson is still misapplied by some geologists to the black shale of the Glencairn member of the Purgatoire formation, the Skull Creek equivalent in the southern part of the Colorado Front Range.

In light of the subsequent difficulty in mapping separately Darton's Lakota, Fuson, and Dakota formations, one can not help but suspect that he was strongly influenced toward this threefold division by the contemporary work of Hills (1899, 1900) in eastern Colorado. Hills recognized a threefold division of the Dakota group consisting of lower conglomeratic sandstone, medial shale, and upper sandstone beds. Thus in southeastern Colorado, where the most intensive work on the Dakota group was being done at that time, the pattern of two sandstone ledges separated by a shale slope became the topographic trademark of the Dakota group. Whether Darton was aware of the threefold nature of Hill's Dakota group in Colorado when he made his subdivisions in the Black Hills is a matter of conjecture, but that he subsequently related the two sections, in large part on the basis of this superficial threefold resemblance, is a matter of fact. Discussing the Dakota group of Colorado in a regional correlation paper Darton (1904a, p. 428) states that "The



DARTON'S TYPE FUSON IN FUSON CANYON

The base of the Fuson (F) is not exposed; *d*, transgressive disconformity at the base of the Fall River formation.

tripartite succession strongly suggests the Dakota sandstone, Fuson clay, and Lakota sandstone of the Black Hills." Elsewhere in the same article he makes this correlation both in his conclusions and in graphic sections.

In correlating the Black Hills sequence with the Bighorn Mountains sequence Darton (1904a, p. 398) introduced the name Cloverly formation for beds in the Bighorn Mountains that he believed were equivalent to the Lakota and Fuson; he hesitated to use the Black Hills names "—especially in consideration of the apparent absence of deposits representing the Dakota sandstone above the (Fuson) clay . . ." He did suspect that the "rusty claystone" layers at the base of the overlying "Benton formation" might be equivalent to the Dakota and in his subsequent work on the Bighorn Mountains (Darton, 1906, p. 53) he makes the correlation of the Lakota, Fuson and Dakota with the Cloverly and basal Benton.

Lee eventually (1923) corrected Darton's miscorrelation of the Dakota group of the Colorado Front Range with the Cloverly and basal Benton of central Wyoming, recognizing that a large part of Darton's Benton shale (Thermopolis, including Muddy sandstone) was equivalent to the Dakota in the Front Range. Lee (1927) elaborated on this correlation but did not carry his correction of Darton's work into the Black Hills. However, geologists working in the Wyoming oil fields had already distinguished the Newcastle sandstone (Hancock, 1920) and Skull Creek shale (Collier, 1922) as members of the Graneros shale of the Black Hills and had correlated them with the Muddy sandstone and that part of the Thermopolis shale beneath it in central Wyoming.

The name "Dakota" disappeared from the Black Hills terminology in 1927 when Russell introduced the name Fall River for it. Here again the reason for the change was the discovery that the plant remains in Darton's Dakota sandstone of the Black Hills were older than those of the type Dakota and were probably Early Cretaceous in age (Russell, 1928, p. 134–137). Russell interpreted (p. 136) the Fall River as the older and thinner seaward portion of "an overlap deposit formed along the shores of a sea which advanced from the west." The thicker Dakota in the type area he regarded as the younger eastern phase of this deposit. This relationship has subsequently been elaborated on and brought up to date with the changes in age designations by Ballard (1942, p. 1572) and Gries (1954) among others. It is now well established that a large part of the sediments in the Lakota-Fall River sequence of the Black Hills was derived from the east and southeast.

The last change in the nomenclature of the Dakota sequence in the Black Hills was the grouping by Rubey (1930, p. 5) of the

Lakota, Fuson, and Fall River formations as the Inyan Kara group. The introduction of this group was a practical necessity, inasmuch as Rubey (written communication, 1956) found that the Lakota, Fuson, and Fall River were unmappable units in the northwestern Black Hills. Other geologists working in the Black Hills experienced similar difficulty in identifying Darton's units. Russell[2] referring to Darton's Lakota, Fuson, and Dakota formations states that ". . . it is often exceedingly difficult and in some places impossible to distinguish between them and certainly no accurate boundaries can be drawn between them." In this paper Russell discussed the three formations as an informal group, describing the variations that made it so difficult to trace them laterally. More recently Gries (1952, p. 75) expressed the opinion that "The Fuson should not be considered a separate formation, but merely a shaly closing facies of Lakota deposition."

Nomenclatural changes since Rubey's work have been limited to the beds above the Fall River. Of these beds the Skull Creek shale and Newcastle sandstone are pertinent to this paper insofar as they are now known to be equivalents of part of the Dakota group of Colorado and of part of the type Dakota of eastern Nebraska and Iowa. Both the Skull Creek and Newcastle were raised to the rank of formation by Reeside (1944). Subsequently Crowley (1951) classed the Skull Creek as a formation and the Newcastle sandstone as a member and defined the Skull Creek group to include these two discrete units of unequal rank. Crowley's reluctance to consider the Newcastle a formation is presumably based on its discontinuous distribution in widely separated sandstone lenses around the Black Hills. Grace (1952) considered the Newcastle a formation and recognized distinct facies of it. Because the Newcastle has a siltstone-shale facies as prevalent as its better known sandstone facies, Grace (1952, p. 14) considered the term Newcastle sandstone misleading and replaced it with Newcastle formation.

Few of these recent nomenclatural changes in the beds above the Fall River have been generally adopted. The name Graneros is still used locally by most geologists in spite of the fact that it is a hangover from a miscorrelation by Darton and is misleading in regional correlation. It is used both as a formation and group to include the beds between the Fall River formation and Greenhorn limestone.

In summary, the Black Hills area is one of several that have followed a similar pattern in the development of the terminology applied to its pre-Benton (Dakota and equivalents) Cretaceous beds. In much of the central and northern Great Plains and Rocky Moun-

[2] Russell, W. L., 1927, Structural and stratigraphic problems in the Cretaceous of South Dakota. Unpublished doctorate thesis, Yale University.

tains these beds vary considerably in stratigraphic detail from place to place, but their sequence is uniform in its major lithogenetic features. This uniformity is obscured by a complex and conflicting terminology that has resulted largely from the unfortunate, and now generally discredited, practice of distinguishing stratigraphic units on the basis of their supposed age. Soon after it was introduced, the name Dakota came to be used synonomously with sandy basal Upper Cretaceous rocks. Subsequent discovery of Early Cretaceous fossils in these rocks resulted in their subdivision, generally with the retention of the name Dakota for that part of the sequence still considered Upper Cretaceous. As Grace (1952, p. 9–10) has pointed out, the division between Lower and Upper Cretaceous rocks in the northern part of the interior region has been placed at progressively higher horizons in the sequence. As the history of the Black Hills terminology attests, each shift of this time boundary has resulted in a change in the nomenclature. A similar procedure was followed in other parts of the interior region, the degree of restriction of the term Dakota depending on the local distribution of Early Cretaceous fossils, or on less accurate inferences as to age.

A second factor complicating the terminology at the time of its origin was the general miscorrelation of the upper part of the Dakota sequence. The Dakota stratigraphy was not well enough understood at that time for geologists to be aware that much of the sandstone in the Dakota of the Missouri River valley passed westward and southwestward into shale similar to the Benton or that much of the sandstone in the Dakota of the Colorado Front Range did likewise to the north and northeast. The details of these changes are still being worked out, but the general relationships are widely known and the changes in facies no longer need be misleading in regional correlation. Moreover the position of the boundary between the Lower Cretaceous and Upper Cretaceous is no longer an obstacle, in part because of a more widespread present adherence to a lithologic definition for rock units, but more specifically because the boundary, in much of the area in question, is now placed above the Dakota and equivalent beds.

Many existing nomenclatures of the Dakota reflect the obsolete beliefs on the ages and continuity of the sandstones in the Dakota, and revisions are necessary in some areas; in general these will lead to simplification rather than to complication of the nomenclature. For the Black Hills, where the name Dakota has passed from the nomenclature, the principal subunits, the Lakota, Fuson, and Fall River formations, have not proved to be satisfactory mappable units. It is with this problem that the present paper is concerned.

TWOFOLD INYAN KARA SUBDIVISION

CHARACTER OF THE SUBDIVISION

The areal distribution of Inyan Kara rocks around the Black Hills is shown in figure 7. Darton's subdivision was made in the southeastern part of the outcrop, where the type localities of the Lakota, Fuson, and Fall River are found; the name Inyan Kara group was applied in the northwestern part of the outcrop. This relationship of nomenclature to geography is pertinent because of the conspicuous differences in Inyan Kara stratigraphy between these two areas. Moreover, lithology and succession differ appreciably within the group in other parts of the Black Hills so that no simple, unqualified statement can be made about the nature of the Inyan Kara sequence that would apply to the entire outcrop area.

In the Black Hills, the transgressive disconformity marking the change from continental to marginal marine deposition in the Dakota sequence falls within the Inyan Kara group, dividing it into two lithogenetically distinct parts. The upper third, or less, above the disconformity is characterized chiefly by well-bedded, fine-grained, brown-weathering sandstone with intercalated gray to black shale and siltstone; thin bedding and lamination, ferruginous staining, ironstone layers, ripple marks, and "worm" castings, tubes, and trails are common in these beds. The lower two-thirds is much more variable, commonly it contains varicolored and variegated claystone and siltstone, and massive, locally poorly sorted sandstone, carbonaceous shale and coal beds, and lacustrine shale and limestone. In the discussion that follows, beds above the transgressive disconformity are called the upper part of the Inyan Kara group and beds below it the lower part.

The upper part of the Inyan Kara group is relatively constant in its thickness, which is generally between 120 and 150 feet. Lithically it varies chiefly in the lateral and vertical distribution of its shale, siltstone, and sandstone beds. In addition to the characteristic even-bedded sandstone, massive sandstone bodies are common; these are thickest in the southern Black Hills where they were once quarried extensively for building stone in the vicinity of Hot Springs. The most unusual variation in the upper part of the Inyan Kara group is a wedge of continental beds, chiefly variegated siltstone and claystone, which thins out northward and northwestward from an area of maximum thickness (about 30 feet) in the southeastern corner of the outcrop.

In contrast to the relative uniformity of the beds in the upper part of the Inyan Kara group, those beneath it in the lower part are not only highly variable locally, but they also show marked

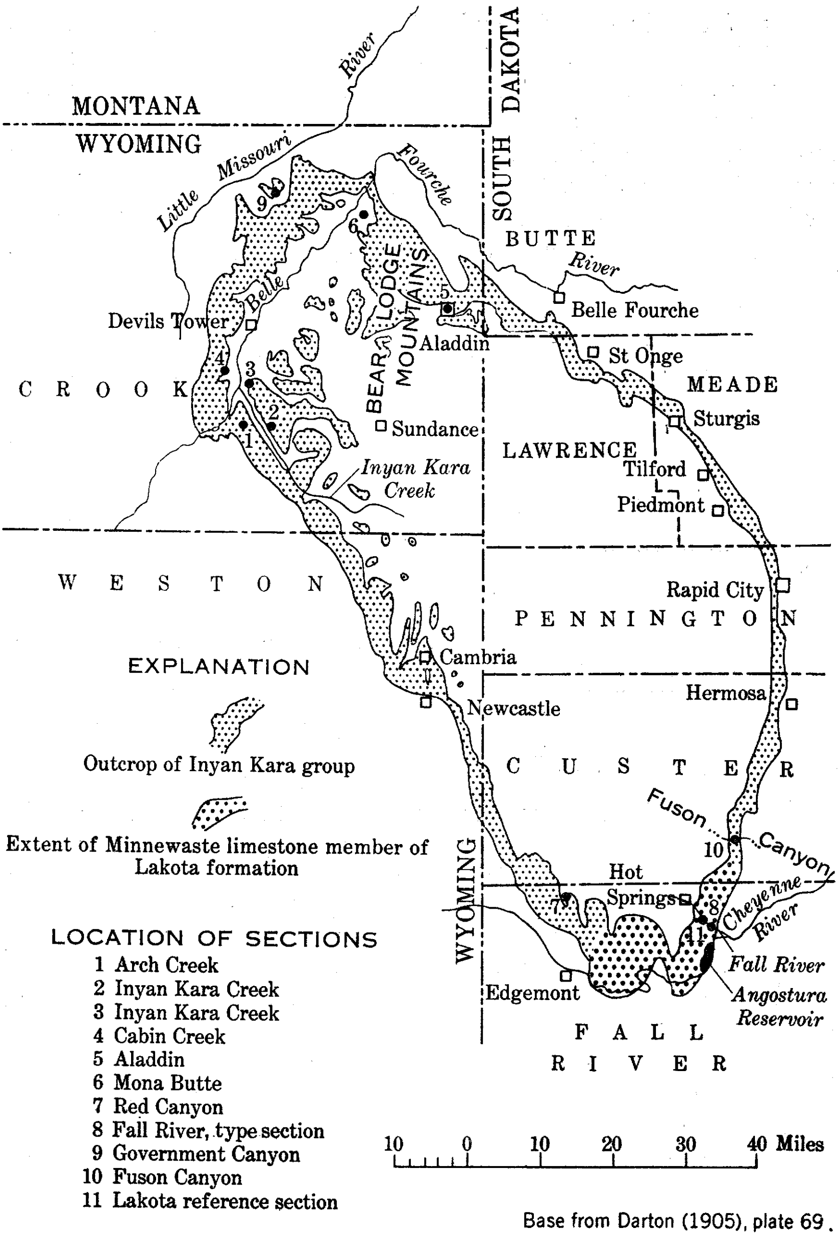


FIGURE 7.—Outcrop of the Inyan Kara group in the Black Hills region.

lateral changes in thickness and sequence. The extremes of difference are found in opposite ends of the outcrop area: at the south end of the outcrop in Fall River County and adjacent parts of Custer County, S. Dak., the lower Inyan Kara is thickest, and at the northwestern end of the outcrop in the vicinity of Devils Tower and Inyan Kara Creek, it is thinnest. Thickening, which apparently takes place toward the south and east by addition of new beds at the base, is accompanied by lithic changes that give the lower Inyan Kara rocks in different parts of the Black Hills distinctive characteristics.

In spite of the pronounced changes from one place to another within the lower part of the Inyan Kara group the disconformity separating it from the upper Inyan Kara group was located with little or no difficulty. It appears to furnish the only suitable basis for subdivision of the Inyan Kara group in all parts of the Black Hills region and permits a logical twofold division into gross lithogenetic units, which fit in with the regional pattern of Early Cretaceous sedimentation.

RELATION TO EXISTING TERMINOLOGY

Usage of the terms Lakota, Fuson, and Fall River in the Black Hills region still follows the subdivision (Lakota, Fuson, Dakota) that Darton made in his many publications. All these subdivisions originated in the southern end of the Black Hills and it was here that Darton formed his ideas of their lithic character and their stratigraphic relationships. In relation to these divisions of the southern Black Hills the upper part of the Inyan Kara group conforms very closely to the Fall River formation. Darton's Dakota sandstone included at its base the local massive sandstone in Evan's quarry on Fall River about 5 miles south of Hot Springs (Darton 1901a, 1902). This conspicuous local sandstone was noted by most early investigators, so it serves as a common unit in comparing their different interpretations of the local stratigraphy. Ward (1894, p. 258) called it the Quarry sandstone—an informal local usage that is followed in this report. Russell's (1927) definition of the Fall River formation, based on exposures around Evan's quarry on Fall River, also includes the Quarry sandstone at its base (Russell, written communication, 1955); thus at its type locality the Fall River formation is completely synonymous with Darton's Dakota. The transgressive disconformity in this locality lies a short distance beneath the Quarry sandstone.

Many examples from his publications could be cited to show that Darton thought of the Dakota (Fall River) sandstone as a unit of thick-bedded, fine- to medium-grained, brown-weathering sandstone with relatively little flaggy sandstone and shale. The wedge of variegated claystone and siltstone similar to the Fuson, noted above as a variation of the upper Inyan Kara group in the southern Black Hills, did not mislead him when he discovered it in the Edgemont quadrangle. Here he noted (Darton and Smith, 1904, p. 5) that his Dakota consists of massive sandstone separated by "25 to 30 feet of maroon and gray clay, with thin buff sandstone intercalations." And further that these "clays somewhat resemble those of the Fuson beds, but are underlain by typical massive sandstone of the lower Dakota."

The Minnewaste limestone is present in the Fall River area and Darton (1901a, p. 530–532) made it plain that what he called the Fuson formation included those beds lying between the locally prominent Quarry sandstone and the Minnewaste limestone. For the type locality of the Fuson, he chose Fuson Canyon, the canyon of Dry Creek, about 3 miles north of Buffalo Gap, on the east side of the south end of the Black Hills. The Minnewaste limestone is not present in Fuson Canyon; according to Darton it pinches out between the canyon and Buffalo Gap. The type Fuson is shown in plate 2; details of its succession are given on page 84, section 10.

Darton's measurement of the type Fuson (Darton, 1901a, p. 530; and a more complete revision, Darton and Paige, 1925, p. 13) corresponds very closely to section 10 and his base of the Dakota (Fall River) is precisely at the disconformity. The lithologic contrast across the contact is very sharp at this exposure inasmuch as the base of the Fall River formation is conglomeratic, an unusual feature in the Black Hills.

Darton's Fuson is the key to the difficulties that have arisen in attempts to map his threefold subdivision in different parts of the Black Hills. In the southeastern corner of the Black Hills where the Minnewaste limestone is present and the lower part of the Fall River is generally a massive sandstone affording a clearcut base, the upper and lower contacts of Darton's Fuson are sharp and unmistakable. But the Minnewaste limestone is limited to a very small fraction of the total outcrop of the Inyan Kara group (see fig. 7) and the basal part of the Fall River formation is commonly shaly outside of the southern Black Hills. Consequently the Fuson contacts, particularly the lower one, become indefinite outside of the limited area in the southern Black Hills where they were first used.

In his subsequent work outside of the southeastern Black Hills Darton's interpretation of the Fuson varied from one exposure to the next. In general his distinction was largely topographic and he included all the soft beds lying between massive ledge-forming sandstone bodies in the upper part of the Inyan Kara group and the uppermost ledge-forming sandstone bodies in the lower part. Consequently both Darton's contact of the Fuson and Dakota (Fall River) formations and his contact of the Lakota and Fuson formations wander up and down in the section with lateral changes in the ratio of sand to clay-rock in the beds above and below the disconformity. Changes in the contact of the Fuson and Dakota (Fall River) formations are particularly evident inasmuch as Darton's contact can be compared with the persistent disconformity. Outside the southeastern Black Hills it is apparent that Darton's Fuson includes much of the shale, siltstone, and flaggy sandstone of the upper part of the Inyan Kara group except in those scattered localities where the upper Inyan Kara beds are dominantly sandy or where a massive sandstone lens is present in their basal part.

A few examples will illustrate the vagrancy of the upper Fuson contact. North along the east side of the Black Hills from Fuson Canyon the massive lower sandstone beds in the upper part of the Inyan Kara group pass into interbedded shale and thin-bedded sandstone. From about the latitude of Hermosa north through Rapid City and in the hogbacks west of Tilford and Piedmont the upper part of the Inyan Kara group consists of three subunits; subunit 1, at the base, is a gray to black shale and flaggy sandstone and siltstone; subunit 2 is a thin series of variegated beds representing the northward-thinning wedge of continental deposits; and subunit 3 an upper series of platy sandstone beds with interbedded gray shale and local bodies of massive sandstone. At some places in this area Darton drew the upper Fuson contact at the base of subunit 3, and at other places included only part of subunit 1, as the following description attests (Darton, 1909, p. 48). "North of Tilford the upper half of the [Fuson] formation is a soft shale, purple, buff, and red below [subunit 2], underlain by black shale [subunit 1]. Southeast of Piedmont the upper beds are dark-gray and black shales with a few layers of soft sandstone [subunit 1 in part]. South of Rapid the upper shale is dark [subunit 1 in part], the middle beds white [just beneath disconformity] and the lower beds yellow and red fire clay and shale."

In describing the Fuson at a locality in the northern Black Hills, Darton (1909, p. 46) revealed the sharp lithologic break that marks the disconformity. "Near Eothen [about 6 miles east of Aladdin], the sandstones constitute nearly half of the formation. Here the upper [Fuson] beds usually show a rapid transition from purple and red clay to yellow, gray and carbonaceous shales with thin ironstone and sandstone layers." The last part of the quotation is an excellent description of the basal beds of the upper part of the Inyan Kara group in this area.

Similar discrepancies are evident in Darton's (1907) stratigraphic description of the Devils Tower quadrangle. For example at the excellent exposures in Government Canyon, a section of which is given on pages 81–83, the beds above the transgressive disconformity are chiefly sandstone, and Darton's Dakota (Fall River) formation corresponds almost exactly to the upper part of the Inyan Kara group. But along Cabin Creek, about 30 miles southwest of Government Canyon, most of the beds in the upper part of the Inyan Kara group are shaly for many feet above the disconformity and Darton (1907, p. 3) included these gray shale beds in his Fuson, placing the base of the Fall River more than 40 feet above the transgressive disconformity.

Darton's location of the contact of the Lakota and Fuson formations is even more evasive than his contact of the Fuson and Dakota (Fall River) formations, but lacking a plane of reference, such as the disconformity, for comparison this is not as simple to demonstrate. In the absence of the Minnewaste limestone Darton, understandably, was not consistent in his definition of the Lakota and Fuson contact. At many places he took the first massive, ledge-forming sandstone beneath the soft beds of his Fuson as the top of the Lakota. But in the Devils Tower region, for example, he (Darton, 1907, p. 3) found that his Fuson contained considerable sandstone and in describing the Lakota noted that "in many places it is difficult to separate it from the overlying Fuson beds." Again, in his description of the Fuson near Eothen (Darton, 1909, p. 46), in the northern part of the Black Hills, he notes that the lower half of the formation is sandstone. However in earlier publications Darton tried to limit the Fuson to soft beds, for in his description of the Newcastle area (Darton, 1904b, p. 4), where the beds are locally mostly sandstone, he notes that "possibly in some localities the formation is absent, but in nearly all clear exposures it appears to be separable from adjoining beds." In these "clear exposures" he found the Fuson very thin at many localities; on Oil Creek, for instance, he described only 15 feet of it. Restricting the Fuson to shaly beds in the Newcastle area was inconsistent with Darton's own definition of the Fuson, for at its type locality the upper 50 feet or more of it are sandstone and the remainder chiefly siltstone.

Other works have tended, or tried, to follow Darton rather closely, using his criteria for subdivision. Expressions of dissatisfaction with Darton's classification, outside of the limited area in the southern Black Hills where it was first used, are numerous; some have been mentioned on page 24. All reflect the inadequacy of Darton's Fuson as a mappable unit outside of the limited area occupied by his Minnewaste limestone. Usage has not distinguished it consist-

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ently except possibly when it was employed simply as a topographic unit. It lacks definite upper and lower contacts and is too variable in rock type and too like beds that have been separated locally from it as Lakota to permit consistent identification on the basis of its own lithic content.

Devices used to get around the inadequacy of the nomenclature include grouping all three formations in a single unit; a procedure which led to the definition of the Inyan Kara group (Rubey, 1930). Gries (1952) was the first to suggest that the Fuson was not a valid formation. He considered it a shaly closing phase of Lakota deposition. This is probably true in part, but it presumes a more precise lithogenetic definition of Fuson than has ever been used in practice for certainly the gray and black shale beds above the transgressive disconformity which formerly have been referred to the Fuson are not related genetically to the Lakota. Most workers, following Darton, have distinguished the Fuson from the surrounding beds purely on the gross relations of argillaceous to arenaceous rocks regardless of whether their Fuson included lithogenetically distinct types of argillaceous beds. This is probably the reason that the sharp, persistent transgressive disconformity has not previously been recognized and used as a contact between formations in the Black Hills region.

REVISION OF NOMENCLATURE

The threefold subdivision of the Inyan Kara group into the Lakota, Fuson, and Fall River formations is useless as a working classification for detailed studies of the group because it cannot be consistently applied throughout the Inyan Kara outcrop in the Black Hills region. Moreover it serves to obscure the basic twofold lithogenetic pattern of the group, which is a regional feature. A change to a twofold subdivision corresponding to the gross twofold lithogenetic pattern of the group provides two major units which could be consistently separated, at the disconformity, all around the Black Hills. This simple division would serve as a framework within which local variations could be expressed by formal subunits where such detail is desirable.

Change to the twofold subdivision involves little nomenclatural adjustment. The Fall River formation is re-defined so that its basal contact conforms to the transgressive disconformity; in other words it becomes the upper part of the twofold division of the Inyan Kara group. In terms of Russell's definition of the Fall River and Darton's interpretation of the Dakota in the Fall River area, the re-definition consists merely of a slight shift downward in the basal contact. In terms of the remainder of the Inyan Kara outcrop the re-defined Fall River would include, locally, a variable thickness of shale and thin-bedded sandstone, which Darton included in the Fuson.

For the lower part of the Inyan Kara group the name "Lakota formation" is retained. The chief reason for retaining this name and discarding Fuson is that the name "Fuson" has been the principal source of confusion whereas the name "Lakota" has played a more passive role in the difficulty. Moreover the name "Fuson" is widely misapplied outside of the Black Hills to beds equivalent to the Skull Creek shale, as a result of Darton's old miscorrelation with the Dakota and equivalents of the Colorado Front Range. Retention of Lakota also can be argued on taxonomic grounds inasmuch as Darton introduced this name (Darton, 1899) before he introduced the name "Fuson" (Darton, 1901a). Use of the name "Fuson" as a member of the Lakota in the limited area of the southern Black Hills where the Minnewaste is present may be helpful, but it should not be used beyond the limits of the Minnewaste. If this procedure is followed the Fuson member should be given a new type section.

The status of the Minnewaste limestone needs revision under the twofold subdivision introduced here. Darton (1901a) defined the Minnewaste as a formation and subsequently treated it as such in most of his publications, although admitting it was of limited extent. It is listed as a formation in Wilmarth (1938, p. 1382) and has so been considered by many geologists. However its limited extent does not qualify it as a formation, but rather as a member. Because it is a distinctive unit in a part of the southern sequence of the Lakota, it is retained as a member of that formation.

Detailed studies of the Inyan Kara group may eventually reveal some sound basis for subdivision of the Lakota formation, as redefined, or may reveal additional stratigraphic or economic subunits that warrant formal recognition. Meanwhile use of the term "Lakota" in the new broad sense affords the flexibility necessary to deal with marked changes that take place between its different sequences. It is a gross lithogenetic unit of the type mentioned under Article 5b of the Classification of Rock units (Ashley and others, 1933, p. 431), a formation "marked by extreme heterogeneity of constitution, but that in itself—[constitutes] a form of unity." Because much of this heterogeneity arises from local conditions of sedimentation within the Black Hills, use of the names "Fall River" and "Lakota" should be restricted to the Black Hills region. The name "Inyan Kara group" is useful in general description and in mapping at small fractional scales, consequently it is retained to include the revised Lakota and Fall River formations.

STRATIGRAPHIC SUMMARY

The following summary describes some of the pertinent features of the re-defined Lakota and Fall River formations and discusses certain problems of their stratigraphy. Detailed local lithologic descriptions are not within the scope of this paper; these will be forthcoming in reports of the Geological Survey. Except for specific examples and measured sections, lithic descriptions are simplified; the general, rather than the local, aspects of the stratigraphy are the primary concern.

LAKOTA FORMATION

Because of its different aspect from one part of the Black Hills to the next the Lakota does not lend itself to regional generalization. Since its definition, it has lacked an adequate type section for reference and comparison. Darton did not originally designate a type locality; the name (Darton, 1901a, p. 527) was "derived from one of the tribal divisions of the Sioux Indians." Later, Darton and O'Harra (1909, p. 4) gave the type locality as "Lakota Peak, a summit on the hogback 4 miles northwest of Hermosa, South Dakota." Lakota Peak is a grass- and tree-covered ridge capped by at least 8 feet of very fine grained quartz sandstone in beds as much as 2 feet thick. The uppermost part of the sandstone is quartzitic and fragments of it litter the crest. No adequate section can be measured on or around Lakota Peak; moreover, much of the formation lies in the dip slope and in subsidiary ridges to the east.

Requisites of a reference section for the revised Lakota are several. It should be located in the southern Black Hills where the name was first applied and where the formation approaches a maximum in thickness and complexity. Preferably, it should include the Minnewaste limestone member. Exposures of the Lakota in Fall River canyon, between 4 and 5 miles by road southeast of Hot Springs, S. Dak., combine these requisites with the obvious advantages of adequate exposure, clarity of contacts, and relative ease of access. Here a 460-foot reference section for the revised Lakota, section 11 on page 85, was measured by W. J. Mapel, Charles Pillmore, and the author from outcrops in canyon walls and road cuts. The intervals of nonresistant rock are mostly covered by vegetation or mantled by talus and slope wash, as is true of most Lakota outcrops in the southern Black Hills. Nevertheless, by shallow trenching, all but about 40 feet of the softer beds in the reference section were completely exposed. These exposures along Fall River adjoin the type exposures of the Fall River formation to the south, the combined exposures affording a new, continuous reference section for the Inyan Kara group.

Sequences of the Lakota in four different parts of the Black Hills are selected to illustrate some of its principal variations, and to highlight some of the stratigraphic problems. For convenience in description these are referred to as the northwestern, coal-bearing, southern, and eastern sequences.

NORTHWESTERN SEQUENCE

The northwestern part of the Black Hills in Crook County, Wyo., where much of the fieldwork was concentrated, includes both the northwestern sequence and the coal-bearing sequence bordering it to the east. In the thinner northwestern sequence, which very rarely exceeds 200 feet in thickness, the Lakota consists chiefly of a variable succession of sandstone lenses and varicolored claystone lenses, both locally conglomeratic. The sandstone lenses occur at any stratigraphic position but usually a few feet, at least, of claystone underlies the Fall River contact. Over local areas the pattern of vertical distribution of sandstone beds may be relatively constant, but the pattern is subject to abrupt local change.

The sandstone beds range from fine-grained and silty to coarse-grained and conglomeratic. Most are not well bedded but tend to be massive, though there are exceptions. They are equally variable in resistance to weathering; some are compact and well cemented, some sugary and friable, and some are made soft by interstitial clay.

The claystone beds range in type from semiplastic clay to hard silty claystone with blocky fracture. Their only common characteristic is the lack of lamellar structures of any kind. Many are bentonitic, swelling to form a hard rough "popcorn" crust on the outcrop. Locally the claystone beds grade into siltstone or contain lenses of siltstone. Claystone beds range in color from dark gray through greenish gray, purple, red, yellow, and gray white; locally they are variegated but solid colors predominate.

Chert, quartz, and quartzite fragments, ranging in size from coarse grains to cobbles, are a characteristic constituent of the Lakota in the northwestern sequence. Conglomeratic material is considered separately here because it occurs in both the sandstone and claystone lenses and because it has more than one mode of occurrence. The sandstone lenses commonly contain concentrations of the conglomeratic material at their base and in pockets, layers, and scattered pieces within them. One very common type is a granule to small-pebble conglomerate containing much black chert. This type of conglomerate marks the base of the Lakota at many localities throughout the northwestern sequence. Similar conglomerate with more varied constituent pebbles also occurs, but not as commonly in the basal sandstone lenses.

A second type of conglomeratic material, consisting of smoothly polished pebbles, is characteristic of the Lakota and serves to relate it unmistakably to the Cloverly formation elsewhere in Wyoming. These polished pebbles, once widely mistaken for gastroliths—the gizzard stones of dinosaurs (see Stokes, 1942, p. 18–19 and 1944, p. 976–980) occur scattered throughout the claystone and siltstone beds but are less common in the sandy beds, except where they have obviously been concentrated at the base of channel sandstone. Although polished pebbles an inch or two in diameter are conspicuous, examination of the conglomeratic claystone generally reveals more plentiful material of granule and coarse grain size. The largest pebble found was over 7 inches in long diameter. Chert of various kinds and pink quartzite are the commonest materials; white quartz is also common.

Special types of rocks occur in small quantity in the Lakota of the northwestern sequence. Brittle, dense, bone-white porcellanite occurs rarely in thin lenticular beds; less pure types may be common but are difficult to distinguish from claystone. Over local areas porcellanite may prove useful in matching sections. Authigenic gray to gray-white chert occurs locally in irregular masses and in at least one place it appears to be associated with porcellanite. Ferruginous concretions are not very common, although they are abundant in the overlying Fall River formation; they are largely found only in sandstone where they are concentrated as cementing material to form subspherical bodies the size of marbles. Selenite occurs as isolated crystals and small crystalline masses and appears to be limited to gray and dark-gray claystone. Spherulitic siderite, in fine to coarse grains, commonly peppers the claystone, siltstone, and, locally, clayey sandstone within a few inches to as much as 12 feet below the disconformity marking the contact of the Lakota and Fall River formations. It has not been found at any other horizon in the Morrison, Lakota, or Fall River formations in the northwestern Black Hills; consequently it has value as a marker. On the outcrops the siderite weathers to specks of orange, red, or yellow iron oxides.

Four measured sections of the Lakota formation in the northwestern sequence are given on pages 68–74 (sections 1 through 4) and are shown graphically in figure 8. These sections were purposely chosen from adjacent localities to demonstrate the variability of the formation within short distances along the strike. Nevertheless they are representative of the general aspect and lithic character of the Lakota in the northwestern sequence as a whole; they also serve to show that it is impossible to recognize a distinct lithologic unit that would correspond to Darton's Fuson formation.

The extremes of Lakota variation—which consist of a nearly continuous sequence of sandstone and conglomeratic sandstone at one extreme, and, at the other extreme, a sequence almost entirely of claystone and siltstone—are not represented by the sections. On the east limb of the Pine Ridge-Oil Butte anticline just north of Keyhole Reservoir in SW¼ sec. 20, T. 51 N., R. 66 W., Crook County, the Lakota is locally about 120 feet thick, all except the upper 15

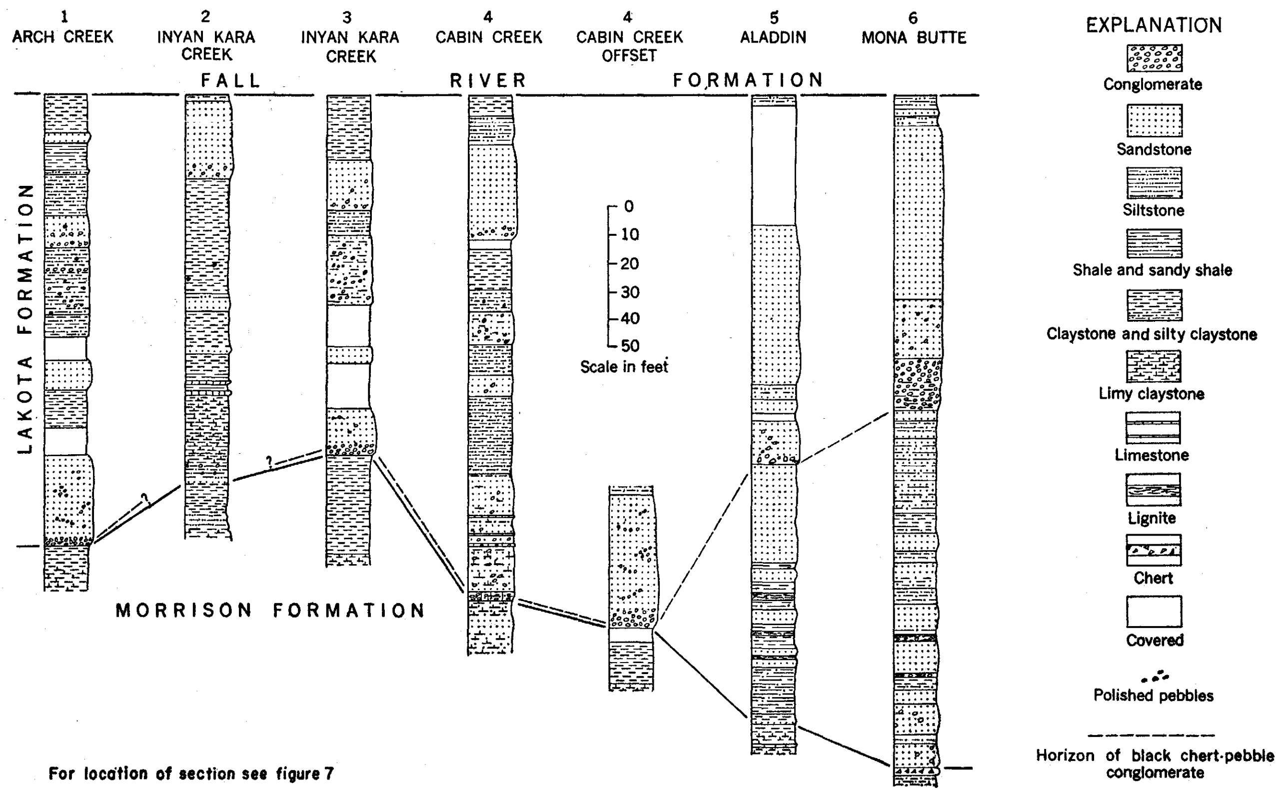

FIGURE 8.—Inferred relationships of columnar sections of the Lakota formation in the northern Black Hills.

feet is sandstone and conglomeratic sandstone in massive, ledge-forming beds. An even sandier section of the Lakota in which only half a foot of the 125-foot section was not sandstone, was measured by Mapel about 6 miles southeast of Devils Tower in sec. 2, T. 52 N., R. 65 W., Crook County. About 13 miles northeast of Devils Tower in Sourdough Canyon, sec. 12, T. 55 N., R. 65 W., Crook County, Robinson found 143 feet of Lakota exposed beneath the Fall River contact; all but 2 feet of this section was claystone and siltstone. Although these extremes are rare, compared with the more typical mixtures of sandstone and claystone lenses, they are common enough to be confusing. Of the two extremes the dominantly sandy Lakota sequence is the more common.

MORRISON CONTACT IN THE NORTHWESTERN SEQUENCE

Throughout the northwestern sequence three principal criteria have been used to distinguished the contact of the Morrison and Lakota formations, namely, the lowest occurrence of conglomerate or conglomeratic sandstone, the lowest occurrence of dark-gray or black claystone, and the highest occurrence of calcareous matter—either limestone beds, marlstone, or claystone with nodules of limestone. The dominantly black chert conglomerate, where it rests on greenish-gray claystone of Morrison aspect—as in the Arch Creek section (fig. 8), marks a contact no one would dispute; especially as typical Morrison marlstone and limestone occur within a relatively short distance beneath the contact and can be demonstrated to continue unbroken to the Sundance in adjacent areas.

At section 2, on Inyan Kara Creek, the only conglomeratic sandstone (weakly conglomeratic at that) lies just beneath the Fall River contact. This lens can be shown by lateral tracing and comparative stratigraphy (fig. 8) to be too high in the section to be basal Lakota. Here the contact is placed at the sharply defined base of a bed of sandy variegated claystone, which underlies gray claystone with intercalated limestone beds. The top of the limy beds (unit 8) lies 47 feet above typical Morrison limy beds, which include dinosaur bones; if the practice of putting all limy beds in the Morrison were strictly adhered to, the arbitrary contact would have to be placed above unit 8. Although age cannot be used as a criterion until more is known about Morrison and Lakota fossils, the flora and fauna of unit 8 compare with that described by Peck (1941) from lower Bear River and Kootenai beds which he considers Early Cretaceous.

At section 3, on Inyan Kara Creek, the contact is placed at the base of the lowest of several conglomeratic sandstone ledges; this is probably the same lens as that marking the contact on Arch Creek, but the black chert granules are less conspicuous. Although this is seemingly the most logical choice of contact in section 3, dark-gray, locally carbonaceous claystone continues for 35 feet beneath this contact before there is an abrupt change, but with apparent gradation, to the gray-green and red marlstone more characteristic of the Morrison.

Obviously the lowest conglomerate and the lowest dark-gray claystone do not coincide to mark a single contact; many measured sections other than those given could be used to show this equally well. Throughout much of the northwestern sequence dark-gray noncalcareous claystone commonly underlies the lowest Lakota conglomerate. At localities, such as that on Arch Creek, where the lowest conglomerate is in contact with greenish-gray calcareous claystone characteristic of undoubted Morrison beds, local deeper incision of the channel in which the conglomerate was deposited probably accounts for the absence of the dark-gray claystone.

The juxtaposition of dark-gray claystone and underlying limy beds in both of the Inyan Kara Creek sections suggests a constant relationship, but other sections prove the contrary. This is adequately demonstrated in the Cabin Creek section (stratigraphic section 4), perhaps the outstanding exposures in the northern Black Hills for confounding would-be placers of a logical Morrison-Lakota contact. In this section the limy beds begin in the conglomeratic part of the sequence at the base of unit 10, and the lowest dark-gray argillaceous beds are the marlstone in the upper part of unit 6, here included in the Morrison. The conglomeratic limestone and calcareous conglomeratic sandstone units are probably a local calcareous phase higher in the sequence than the relatively persistent calcareous phase, which is typical of the Morrison in the northwestern Black Hills, because the typical calcareous beds are abundantly represented in unit 4 low in the Cabin Creek section. Moreover, within half a mile southwest of the Cabin Creek exposure a thick lens of sandstone with the familiar black chert pebble conglomerate becomes a part of the sequence. This conglomeratic lens, shown diagrammatically in figure 8 as the Cabin Creek offset, thins out toward the Cabin Creek exposure at approximately the same position as unit 7, taken as the probable base of the Lakota.

Conglomeratic sandstone lenses, dark-gray to black carbonaceous claystone, and limy beds all occur locally in the vicinity of the Morrison-Lakota contact, but none of them are persistent. Where the dark-colored claystone and conglomeratic lenses appear together the claystone consistently underlies the sandstone. Limy beds in general are a poor criterion of the contact as they are associated locally with both the dark claystone and conglomeratic sandstone. Such limy beds are visibly different, however, from those that occur in the pastel-green and red marlstone of undoubted Morrison beds. Apparently limestone must be added to the list of minor lithic constituents in the Lakota of the northwestern sequence.

In summary, the three criteria that have been used locally to mark the contact of the Morrison and Lakota formations, do not coincide with one another. The base of the lowest lens of conglomeratic sandstone above the pastel-red and green marl with intercalated dense gray limestone beds, which are undoubted Morrison, seems to be the best criterion in the northwestern sequence where conglomerate is common. Obviously, however, such lenses may be at different horizons from place to place. More detailed study may prove that the distinctive black-chert conglomerate has a relatively constant position where it occurs within the northwestern sequence, a suspicion based on its marked similarity to the Pryor conglomerate member of the Cloverly formation of the northern Bighorn Basin. The common occurrence of the dark-gray claystone under the conglomeratic sandstone suggests that it, too, is associated with the change from Morrison to Lakota deposition; claystone of this type does not occur in undoubted Morrison beds below this horizon. In the absence of conglomeratic beds, the base of the dark claystone beds may be a useful, if arbitrary, choice of contact.

Mention should be made of an unusual stratigraphic relationship, as yet not thoroughly studied, involving the Lakota of the northwestern sequence. A few miles north of Devils Tower in the Storm Hill quadrangle, the Lakota is locally in contact with the Redwater shale member of the Sundance formation, and its basal conglomerate contains fragments of Sundance belemnites at some places. In the vicinity of Sawmill Gulch, sec. 25, T. 54 N., R. 66 W., W. J. Mapel reports (written communication) that all the Morrison and an estimated 100 feet of the underlying Redwater shale are missing and the Lakota is about 220 feet thick. Although this is a thick Lakota section for the northwestern sequence, it is only 50 feet thicker than the Cabin Creek section, which had beneath it 114 feet of Morrison and a complete section of the Redwater shale member of the Sundance. The lack of an abnormally thick Lakota and the unusual omission of beds indicate that deep channeling alone, prior to Lakota deposition, is insufficient to account for the relationship. Such channeling could only have taken place across local upwarp in Morrison sediments. This implies that, locally at least, the evasive Morrison-Lakota contact is one of angular unconformity.

COAL-BEARING SEQUENCE

In eastern Crook County, in and east of the northern Bear Lodge Mountains the Lakota is largely in the coal-bearing sequence. Here the succession of its beds is appreciably different from that in the northwestern sequence, being thicker, sandier, and containing coal beds in its lower part. Because of its greater thickness it is difficult to get complete exposures of the entire Lakota at any one locality.

Section 5, pieced from exposures in the vicinity of Aladdin, serves to illustrate the major features of the Lakota in the coal bearing sequence. These include an upper part in which intersecting thick lenses of sandstone (units 32–39) underlie varicolored claystone beds with thin siltstone and sandstone layers (units 40–42) and a lower part in which relatively well-bedded to laminated, locally soft and shaly sandstone bodies (units 30, 31) overlie gray to black claystone and shale containing a few coal beds, beds of siltstone, and some sandstone (units 6–29). The two parts appear to meet consistently along a locally channeled surface of disconformity made conspicuous by the conglomerate that rests on it (base of unit 32).

The claystone at the top of the upper part of the Lakota in the Aladdin area generally underlies a slope below the sandstone ledges of the Fall River and is seldom well exposed. Because the lower part of the Fall River is commonly shaly, the contact of the Lakota and Fall River formations is obscured in the slope as well. However the turf locally tends to slump off the beds immediately beneath the contact, revealing a characteristic color pattern of a few feet of white-weathering claystone overlying bright-red, orange, or yellow claystone. At many places the bright colors obviously result from the weathering of the tiny spherulites of siderite common at this horizon. At other places red appears to have been the original color of the claystone, for the red color extends without change in intensity for many feet below the siderite zone. Thin sandstone lenses, which thicken abruptly over limited areas, also occur within these upper claystone beds, and polished pebbles are locally abundant in their lower part.

The underlying sandstone beds are highly variable, coalescing at some places to form massive cliffs, thinning and spreading at other places as siltstone and claystone lenses become intercalated with them. No clear cut division separates this dominantly sandy part of the upper Lakota from the dominantly clayey part above; rather the entire upper part of the Lakota is a continuous sequence in which the sandstone lenses are generally concentrated in the lower part.

The lower part of the Lakota in the coal-bearing sequence is rarely as well exposed as it is in the section at Nichelson Ranch (section 5). Generally the sandstone beds over the coal-bearing shale are exposed above abandoned mine openings, but the beds below are obscured. The sandstone beds appear to be characterized by their lack of coarse or conglomeratic materials, their locally even bedded to crossbedded structure and their intercalation with finely laminated siltstone, sandstone, and shale. Plant remains are locally abundant in these beds and in the dark-gray shale beneath. Two coal beds in the shale below the sandstone apparently were thick enough to mine locally in the coal-bearing sequence of the Aladdin area.

An extensive literature is available on the Lakota coals; most of the references were published before 1915 and can be found in O'Harra's (1917) bibliography on Black Hills geology. The Hay Creek area around Aladdin, and the Cambria area north of Newcastle were the two centers of mining. In general, minable coal occurs only where the lower part of the Lakota is thick, particularly the basal shaly part that includes the coal beds. Laterally from the local areas of minable coal the shaly portion becomes thinner and more sandy.

Where the coal-bearing Lakota is thick in the Aladdin area, characteristic types of Morrison rocks beneath the dark shale are thin. The Aladdin section has only 31 feet of Morrison, but elsewhere north of Aladdin the Morrison formation is at least 60 feet thick. The change from the dark coaly shale above to the greenish-gray locally calcareous claystone below has commonly been chosen as the contact of the Morrison and Lakota formations. At many places this is an indefinite, seemingly gradational contact. At a few places a thin sandstone or conglomeratic sandstone lies near the contact.

The contact of the upper and lower parts of the Lakota in the Aladdin area is a conspicuous feature of the local sections. It appears to persist northward throughout the Inyan Kara outcrop in the northern Bear Lodge Mountains. Even in the many sections of the coal-bearing sequence in the Bear Lodge area that contain no coal, the upper and lower parts of the Lakota are distinctly separated at a medial disconformity. Sections with no coal generally differ only in having the lower dark shale more silty and sandy, and the carbonaceous matter dispersed rather than concentrated in beds.

An unusually sandy succession of Lakota beds is well exposed in a prominent butte north of Mona near the Belle Fourche River. In this section (section 5) both the upper and lower parts of the Lakota are recognizable although they differ appreciably from their counterparts in the Aladdin section, 12 miles to the southeast. The conglomerate of unit 23, resting on a locally channeled surface of disconformity, marks the contact of the two parts. The upper part is exceptional in being almost all sandstone and conglomerate except for the uppermost few feet of clayey siltstone containing the weathered siderite spherulites. At this same locality, the overlying Fall River formation is also exceptionally sandy and massive.

The lower part of the Lakota in the Mona Butte section lacks the clear-cut division into sandstone above and shale below that characterizes it in areas where there are coal beds. Instead the whole succession of beds is locally sandy and friable. Thinly interbedded to interlaminated sandstone and shale alternate with gray claystone in the upper beds; lower in the section sandstone becomes the dominant type of rock and is coarser and more massive. Two peculiar beds of conglomeratic claystone, lignitic shale, carbonized wood, and chert granules—units 9 and 11—occupy stratigraphic positions almost identical with the two principal coal beds in the Aladdin area and are probably lateral equivalents of them. The Morrison contact is marked locally by a friable conglomeratic sandstone overlying cherty claystone.

A significant feature of the Mona Butte section is the conglomerate at the base of the upper part of the Lakota (unit 23); this bed consists largely of black chert and closely resembles the black-chert conglomerate which occurs in the base of the Lakota at many places in the northwestern sequence. If these similar conglomerates mark the same general horizon, then the lower part of the Lakota in the coal-bearing sequence is a discrete subunit that comes in near the contact of the Morrison and Lakota formations and thickens eastward and southeastward. Unfortunately, exposures between the northwestern and coal-bearing sequences are insufficient to show whether the coal-bearing beds are a lateral eastward expansion of the dark-gray claystone which occurs at or near the Morrison-Lakota contact in the northwestern sequence.

A single section, measured near mines in the Cambria area in the southern part of the coal-bearing sequence, revealed that the major features of the Lakota were similar, at least locally, to those of the Aladdin area. The formation seems to be similarly divisible into an upper and lower part, the contact being marked by an irregular surface of disconformity at the base of a massive sandstone ledge with conglomerate at its base. Both the upper and lower parts of the Lakota are sandier than in the Aladdin section. The coal beds occur in the same relative position, and locally in the same pattern, as those in the Aladdin area. Exposures of the beds beneath the coal were not seen.

EASTERN SEQUENCE

The Lakota outcrop along the eastern side of the Black Hills is poorly exposed. Much of the sequence is of soft beds and these are generally covered. The best exposures are of local massive sandstone lenses scattered throughout the Lakota and of the upper beds of the Lakota that immediately underly the Fall River contact.

In the Sturgis area the Lakota as a whole appears to consist of five fairly distinct subunits listed below in a highly generalized section.

	Approximate thickness (feet)
Fall River formation.	
Disconformity.	
Lakota formation:	
5. Claystone and silty claystone, colorbanded to variegated; some thin sandstone lenses, and at least one local thick lens of massive sandstone occupying most of the interval; siderite spherulites common in upper 5 to 12 ft	40–75
4. Siltstone, massive; clayey at top becoming sandy downward and grading into a silty, commonly structureless, friable sandstone; white with purplish stain common	60–80
3. Sandstone bodies, thick-bedded to massive, brown-weathering; some claystone in upper part; a varied interval	25–35
2. Shale, chiefly ostracodal; some thin beds of limestone in upper half, lower half generally underlies slope wash	70–90
1. Sandstone bodies, brown-weathering; similar to those in unit 3 above; interbedded with siltstone and silty claystone	10–50
Morrison formation.	

At Sturgis a lens of massive, resistant, sandstone as much as 60 feet thick occupies most of the uppermost subunit, the colored claystone. Although a prominent ridge former at Sturgis, this sandstone pinches out north and south of the town. North to St. Onge, subunit 5 is chiefly colored claystone with its lower part mostly gray to dark gray and its upper part banded or variegated greenish gray and red. Polished pebbles are locally common in the claystone. The underlying siltstone of subunit 4 is a very distinctive type of rock. Darton (1910a, p. 530) described it well in writing of the Fuson, in which he doubtless included it, calling it "a mixture of fine sand and clay, usually massive bedded and weathering out in small cylindrical blocks like dried starch." Actually it is predominantly a silt in the upper part, becoming sandy below, and the claystone content is generally slight. The massive siltstone is relatively resistant and tends to crop out on steep slopes. It is quarried extensively as surfacing for local roads. In outcrops near Bear Butte thin lenses of a brownish-black lignitic shale with granules and small pebbles of black chert locally lie at the base of the siltstone.

South of the Sturgis area, only the upper two subunits can be traced without difficulty. Thick lenses of massive sandstone occur locally in the sequence but these are largely in the beds beneath the massive siltstone subunit. Soft beds in the lower subunits are exposed in only a few places, and whether the three lower Lakota subunits can be recognized south of the Sturgis area is not known.

The upper two subunits, particularly the massive siltstone, are common throughout the eastern Black Hills. The upper claystone thins southward progressively, being 64 feet thick north of Sturgis, 54 feet at Rapid City, and 28 feet on Billover Creek northwest of Hermosa. At Fuson Canyon the claystone is absent and the Fall River rests on a sandy lateral phase of the massive siltstone. This latter subunit becomes more sandy southward, even becoming conglomeratic locally, but the upper part is generally a siltstone and its characteristic appearance changes little. It is the lightest colored unit in the Inyan Kara group, varying from light gray to dead white on the outcrop and commonly stained purple and pink. Although Darton's type Fuson is made up entirely of this subunit, the claystone above it comes back into the section an unknown distance south of Fuson Canyon, and occurs intermittently throughout the southern Black Hills.

A general correspondence between the upper part of the Lakota in the coal-bearing sequence and the upper two persistent subunits in the eastern sequence is apparent. Lithologically, the colored claystone of the top half of the upper Lakota in the coal-bearing sequence is identical to the upper claystone (subunit 5) of the eastern sequence. The sandstone of the bottom half of the upper Lakota in the coal-bearing sequence has the same stratigraphic position relative to the colored claystone as the massive siltstone of the eastern sequence. The continuity of these units has yet to be substantiated by lateral tracing, but another piece of evidence also suggests their equivalency. In addition to the peculiar conglomeratic, lignitic shale at the base of massive siltstone around Bear Butte, a lens of conglomerate with abundant black-chert pebbles was found 20 feet beneath the nearest outcrop of the massive siltstone east of Tilford. This conglomerate resembles the black-chert-pebble conglomerate at the base of the northwestern Lakota and at the base of the upper Lakota of the Mona Butte section.

SOUTHERN SEQUENCE

Except for a few brief field trips with members of Geological Survey parties working in the area and several week's work around Fall River and Angostura Reservoir, this sequence was not studied. Consequently only its most general features are outlined here. The Lakota exposures of the southern Black Hills are grouped as the southern sequence because they are thicker, stratigraphically more complex, and obviously different in many respects from the other sequences. Because of its complexity, no one section of the southern sequence can be representative of the whole. The reference section for the revised Lakota (section 11) illustrates its general character where the Minnewaste limestone member is present, and the Red Canyon section (section 8), contributed by Garland Gott, illustrates its character where the Minnewaste is absent.

Gott believes (oral communication) that the approximate horizon of the Minnewaste limestone member in the Red Canyon section is probably at the top of the sandstone of unit 8. The Minnewaste, or its projected horizon, appears to separate an upper fourth of the Lakota that is characterized by varicolored claystone and siltstone, local sugary white sandstone beds, and thick, massive brown-weathering commonly conglomeratic channel sandstone beds, which locally thicken to take up most of the interval between the top of the Lakota and the Minnewaste.

Beds beneath the horizon of the Minnewaste are chiefly thick, broad but elongate bodies of fine-grained sandstone and siltstone and dominantly clayey bodies of interbedded shale, siltstone, sandstone, claystone, and limestone of lacustrine origin. In the Red Canyon section the lacustrine beds are represented by the partly covered interval of unit 5. Bell (oral communication) has found ostracodes, charophytes, and freshwater mollusks in the lacustrine beds. The sandstone bodies contain local coal beds. Both the sandstone bodies and the lacustrine deposits are elongate and trend northwestward (Post, Schnabel, Gott, and Bell, 1955, p. 155, fig. 26). Lacustrine deposits have not been identified in the reference section of the Lakota in Fall River canyon.

A rather conspicuous feature of the southern sequence is the general scarcity of conglomeratic materials. Conglomeratic lenses and scattered polished pebbles occur above the horizon of the Minnewaste, but they are not as prolific as in the northwestern and coal-bearing sequences. Beneath the horizon of the Minnewaste conglomeratic material is uncommon.

In much of the southern Black Hills the contact of Lakota and Morrison formations presents a problem similar to that in the other sequences. At some localities massive brown-weathering sandstone at the base of the Lakota rests on greenish-gray claystone characteristic of the Morrison, but at other localities dark-gray to black locally carbonaceous shale and claystone lie beneath the lowermost sandstone and are in fairly sharp but apparently conformable contact with the greenish-gray Morrison claystone. Elsewhere in the southern sequence the Lakota is in contact with the local distinctive Unkpapa sandstone.

RELATIONSHIP OF THE LAKOTA SEQUENCES

The foregoing stratigraphic summary of the Lakota does not treat the entire Inyan Kara outcrop or go into detail in the highly complex southern sequence. Nevertheless it performs its principal purpose by demonstrating that the Lakota is a complex unit lacking a well-defined basal contact and containing beds in the southern and eastern part of the Black Hills that do not occur in the northwestern part. The next obvious step is to relate the differing Lakota sequences to one another; to do this adequately many more details must be known. Still, with a few additional facts on the source of Lakota sediments, certain inferences are permissible and a general geographic pattern to the distribution of Lakota rock types becomes evident.

A number of lines of evidence point to a southern or southeastern source for most of the Lakota sediment. The formation thickens both eastward and southeastward from the northwestern outcrop and new subunits appear in its lower part as it is traced southward and eastward. In addition it has long been recognized (Russell, 1927) that the cross lamination of Lakota sandstone in the southern Black Hills dips dominantly to the northwest and north. The recent studies in the southern and the northwestern parts of the Black Hills have substantiated this.

Most of the Lakota sandstone occurs in massive lenses; some are broad and almost sheetlike, others are elongate with limited lateral extent. For the Black Hills outcrop as a whole these sandstone bodies are concentrated chiefly in the southern part and in the outcrop extending northward along the west side of the Black Hills to the vicinity of Newcastle. Due north from here, sandstone bodies continue to be common in the coal-bearing sequence, but the Lakota thins appreciably, presumably because the lower subunits found in the southern Black Hills disappear from the sequence northward. It is the complication imposed on the Lakota by the abundance of sandstone bodies that makes it difficult to work out the relationships between the coal-bearing sequence and the southern sequence along the western Lakota outcrop. Around the north end of the Black Hills and down the eastern outcrop a gross uniformity in the Lakota sequence is apparent even though there are appreciable changes. Lenticular sandstone bodies are sparsely scattered in these areas and do not mask the more persistent parts of the Lakota. Consequently the longer outcrop trace across the northern Black Hills and down the east flank is the most promising for establishing the relationships between the northwestern and southern sequences.

Eastward from the northwestern sequence into the coal-bearing sequence, additional beds come into the section beneath the horizon of the conglomeratic lenses so that upper and lower parts of the Lakota may be distinguished. The upper part is similar to the complete Lakota of the northwestern sequence, the lower part generally has sandstone at the top and interbedded siltstone, gray to carbonaceous shale, and coal in its lower part. The bipartite character appears to continue eastward into the eastern sequence where the Lakota is even thicker than in the coal-bearing sequence. The upper part of the Lakota in the coal-bearing sequence, which commonly has sandstone and siltstone below and variegated claystone above, matches well with the massive siltstone and sandstone and the upper variegated claystone of the eastern sequence; an indication of equivalency supported by the local lens of conglomerate with numerous black-chert pebbles, which lies 20 feet or less below the massive siltstone and sandstone subunit at Tilford.

The siltstone and sandstone beds that make up Darton's type Fuson in Fuson Canyon are no doubt a continuation of the massive siltstone-sandstone subunit and lie above the horizon of the Minnewaste limestone member. Similar siltstone and sandstone bodies overlain by colored claystone beds occur a short distance above the Minnewaste at Angostura Reservoir and at other localities in the southeastern Black Hills; although in this area the general uniformity found in the upper Lakota along the eastern Black Hills becomes obscured locally by omission of beds at the contact of the Lakota and Fall River formations and by the interference of massive sandstone bodies throughout the Inyan Kara section.

If the correlations suggested here are correct, beds Darton called Lakota and Fuson (in part) in the northwestern Black Hills are equivalent only to beds he called Fuson in the southeastern Black Hills. To state it another way, using Darton's classification, there is no Lakota in the northwestern Black Hills—it is all Fuson. This is a tentative correlation that needs to be more firmly established by detailed tracing and mapping. The strong possibility that it is the correct interpretation emphasizes the need for the broader, more flexible nomenclature proposed in this paper.

The apparent difference between the Lakota of the southern part of the Black Hills and that of the northwestern part has regional implications. The northwestern sequence is similar to the Cloverly formation of the eastern flank of the Bighorn and Pryor Mountains and to much of it in the Bighorn Basin, although in both these areas sandy shale and sandstone, which would correspond to at least part of the Fall River, are included in the Cloverly (Greybull sandstone and "rusty beds" of some authors). In these areas the Cloverly locally has at its base lenses of conglomerate with numerous black-chert pebbles. In the northern part of the Bighorn Basin where this conglomerate is common and relatively thick it is known as the Pryor conglomerate member. Probably similar conglomerate beds at the base of the Lakota in the northwestern sequence are extensions of the Pryor type of conglomerate; they are only common in the northwestern sequence and have not been reported south of Tilford on the eastern side of the Black Hills; on the western side, they have not yet been reported south of the headwaters of Inyan Kara Creek. The dominant types of rock in beds above the horizon of these conglomeratic lenses include massive white sandstone and siltstone, and variegated to color-banded claystone, with scattered polished pebbles, both in the Cloverly and in the Lakota of the northwestern Black Hills. In both terrains the sandstone-siltstone part tends to be at the base, with the variegated claystone above, but locally no such simplicity of section exists.

In summary, it appears that the Lakota, in all but the northwestern part of the Black Hills, contains older beds that crop out only in the Black Hills area and have no lithogenetic equivalent in the Cloverly formation of the Bighorn Mountains region—a compelling reason for restricting the name Lakota to the Black Hills area. These older beds in the lower part of the Lakota are derived from a southeastern source. Beds in the upper part of the Lakota may also be in part derived from the more local southeastern source, but general resemblance to other continental Lower Cretaceous rocks elsewhere in the interior region bespeaks much less local derivation and certain specific lithic types, like the conglomerate with numerous black chert pebbles and the claystone with polished pebbles, indicate a western source.

A question repeatedly raised in regard to the Black Hills asks whether or not the core of the present Black Hills was a positive area during Lakota deposition. Crowley (1951, p. 89) concludes that "The Black Hills probably was part of a landmass during the deposition of the Inyan Kara group." He cites as evidence (p. 88) for the emergence of the Precambrian core the gold content of Lakota coals and cassiterite and varicolored tourmalines in the Fall River; all these minerals can be found in the Precambrian of the Keystone region. Nevertheless, it seems difficult to account for the lack of first-cycle sediments, such as arkose or pebbles of granite and other core rocks, or of limestone from the Paleozoic rocks on the hypothesis of an exposed core. The three minerals mentioned by Crowley in support of his hypothesis are resistant multicycle minerals in sedimentary rocks; possibly they were passed on to the Lakota and Fall River from preceding sediments rather than directly from the core rock.

Certainly the overall pattern of Lakota deposition as far as it is known in the present outcrop belt around the Black Hills affords no direct evidence whatsoever of an exposed core. Neither the type and distribution of conglomerate nor the directions of flow indicated by the crossbedding suggest drainage out from the central part of the Black Hills. One remote possibility is that the concentration of sandstone lenses in the southern and western Black Hills might have resulted from the presence of a low positive area in the Keystone region that prevented a broader spread of sediment northeastward. This is at best an indirect suggestion, for the distribution of sand can as easily be attributed to direction of drainage.

CONTACT OF THE MORRISON AND LAKOTA FORMATIONS

In each of the Lakota sequences the position of the Morrison contact is a problem, at least locally, because of the lack of a persistent, well-defined lithic change. The nature of the contact is remarkable in that at one place it suggests gradation and at another place it suggests angular discordance. The local absence of the Morrison in the Storm Hill quadrangle of the northwestern sequence may be a special local relationship, but perhaps it is the only conspicuous example of a more widespread, gentle discordance. Moreover, the relationship of the lower Lakota to the Morrison is not clearly understood. Are the additional beds, which come into the Lakota southeastward from the northwestern Black Hills, added wedgelike to the section at the Morrison contact, or do they grade laterally into typical Morrison rocks?

A more thorough study of the Morrison formation in the Black Hills is needed before these problems can be satisfactorily solved. The gross relationships suggest that Lakota deposition was independent of Morrison deposition and that the lower part of the Lakota is not a lateral equivalent of Morrison rocks in the northwestern sequence. This is suggested chiefly by the fact that the Morrison does not thin southeastward as the Lakota thickens. The thickness of the Morrison formation is highly variable and generally independent of thickening of the Lakota. Local thinning, such as that demonstrated for the Morrison in the Aladdin area, may suggest some relation to thickening of the Lakota in a few areas, but for the outcrop belt as a whole this is not so.

Deposition of the Morrison formation was locally influenced by a sediment source to the southeast, as is attested by the gradual disappearance of characteristic Morrison rocks beneath the Lakota as the Unkpapa sandstone thickens. The Unkpapa and beds of similar lithologic character within the Morrison occupy an area roughly the same as that occupied by the thicker and sandier part of the Lakota in the southern and southwestern Black Hills. Lakota and Unkpapa sandstone bodies are distinct and where they are in contact the lithologic break is obvious.

In the absence of a definite, persistent contact the custom of placing the base of the Lakota at the first massive sandstone beds above typical gray-green Morrison claystone and marlstone is a possible solution, which has been in practice since the Lakota was defined. More recently, dark-gray, locally carbonaceous claystone beds, which occur in the neighborhood of the contact, have been included in the Lakota and their base used as the contact. These ubiquitous dark-gray claystone beds are common to all sequences of the Lakota. They even occur, as in section 3 (p. 71), beneath massive, locally conglomeratic, sandstone beds that offer a more sharply defined base for the Lakota, and they commonly appear to grade into the lighter colored Morrison claystone and marl. Nevertheless comparable beds are not found elsewhere in the Morrison sequence whereas they are a rock type common in the Lakota.

Both the dark-gray claystone and massive sandstone beds are useful criteria in distinguishing Morrison from Lakota; although they conflict locally, they as often supplement one another. For the Black Hills area as a whole the contact of the Morrison and Lakota formations remains an indefinite horizon determined by different criteria in different places. Undoubtedly its position in the section varies from place to place, and locally, at least, there is evidence of angular unconformity.

An obvious alternative solution to the problem of the indefinite Morrison contact would be to include the whole complex of continental beds between the base of the Morrison and the transgressive disconformity at the top of the Lakota in a single unit and recognize formal subunits where they are locally mappable. This procedure would be in accord with a gross lithogenetic basis for stratigraphic classification and would afford a nomenclature of desirable flexibility. However, the little precision so gained would hardly be worth the confusion that would result from such a drastic change in established practice. Moreover it would ignore the somewhat scanty, though compelling, paleontologic evidence that indicates a hiatus embracing part of the Portlandian, the Purbeckian, and all of the Neocomian (Reeside, 1952, p. 26) between the dinosaur-bearing beds of the Morrison and the plant-bearing beds of the Lakota and its equivalents, or partial equivalents, elsewhere in the interior region.

An additional uncertainty must be kept in mind when dealing with the contact of the Morrison and Lakota formations in the Black Hills region. This is the possibility that the beds called Morrison in the Black Hills are equivalent to only a part of the sequence of beds embraced by the type Morrison of the Colorado Front Range. At the time Darton (1901b) introduced the term Morrison to the Black Hills to replace Jenny's name Beulah clays, very little was known about the detailed stratigraphy of the beds. Our knowledge is still too incomplete to confirm or deny the supposed equivalency. In the area of the type Morrison, conglomeratic lenses occur chiefly at two horizons, suggesting hiatuses. One of these is at the base of the Lytle formation, the other at the base of the upper third of the Morrison formation (Waage, 1955, p. 23). The top of the Lytle formation is marked by the transgressive disconformity that also marks the top of the Lakota (see fig. 5). Matching the apparent breaks in the Black Hills and Front Range sequences leads to matching the Lytle with the upper Lakota and the upper third of the Morrison with the lower Lakota. Certainly this possibility is as tenable as the possibility that the entire type Morrison is equivalent to the Morrison in the Black Hills region.

AGE OF THE LAKOTA FORMATION

Although the literature on the fossils from the Lakota and adjacent beds is voluminous all that can be said with relative certainty is that the sequence of continental beds (Morrison-Lakota) between the Sundance and Fall River formations is of Jurassic age in its lower part and Early Cretaceous in its upper part. The paleobotanical evidence, once heavily relied on, has proved to be equivocal and will probably remain so until a thorough restudy is made of the old "Dakota flora." Ward's (1894) original study of the stratigraphic distribution of "Dakota" plants in the Black Hills is still pertinent; there has been no improvement on it. Briefly, he recognized that in the southern Black Hills angiosperm leaves were limited to beds (upper Fall River) above the Quarry sandstone; cycads occurred in the beds (formerly Fuson) just beneath the Quarry sandstone; and a flora of fern, cycad, and conifer foliage occurred in dark shale, well below the cycads, in the lower part of the coal-bearing and southern sequences of the Lakota. The Early Cretaceous age of the cycads has never been questioned. The fern, cycad, and conifer foliage, found in profusion in the shale interbedded with coal in the lower Lakota of the northern Black Hills, was studied by Fontaine (1899) who considered it Early Cretaceous. The age of all beds included in the Lakota based on the study of fossil plants, is Early Cretaceous.

Until recently other fossils found in the Lakota have been few and not diagnostic of age. In recent work on the southern Black Hills, Henry Bell (oral communication) and others have collected a variety of fossils from the Lakota including ostracodes, charophytes and freshwater mollusks. Some of these collections, contain fossils that Peck (1941) assigns to the Early Cretaceous. Critical study of the collections and their stratigraphic relationships should afford a valuable check on the age determinations based on plants and shed light on the obscure age relationships of the Morrison-Lakota interval.

CONTACT OF THE LAKOTA AND FALL RIVER FORMATIONS

TRANSGRESSIVE DISCONFORMITY

The transgressive disconformity which marks the contact of the Lakota and Fall River formations separates different rock types from place to place; consequently its aspect varies somewhat. The lithologic change across the contact is more marked where the rocks on either side are clay-rocks or siltstones. Contact zones of this type weather to a conspicuous banded outcrop on bandland slopes consisting of a dark-gray to bluish-gray band on the basal dark siltstone of the Fall River formation; a light-gray to white band, usually between 1 and 4 feet thick, just beneath the disconformity; and a pink to bright-red, yellow, or orange band of variable thickness beneath the white. The latter two color bands are formed on uppermost Lakota claystone and silty claystone, which commonly contains the iron-stained specks of weathered siderite spherulites beginning in or just below the lower part of the white-weathering band.

This red, white, and bluish-gray contact zone is locally conspicuous in the northwestern, coal-bearing, and eastern sequences of the Lakota. The dark siltstone and shale above the contact may be replaced laterally by coal or sandstone, but gray, somewhat carbonaceous, laminated siltstone is the most common basal Fall River rock type. Where coal rests on the contact rootlets commonly extend into the underlying Lakota clay rocks. The beds below the contact also vary in color locally but the uppermost foot or more of claystone is generally light gray and, unless stained by iron oxide or carbonaceous matter from overlying beds, it weathers white.

The color pattern beneath the disconformity suggests that leaching has taken place, but detailed tests on the claystone would be necessary to prove this. In the vicinity of Rapid City, claystone beds (Fuson of old reports) lying beneath the disconformity were once mined as fire clay, and analyses of some of them (Darton, 1909, p. 96) clearly show that they are relatively free of fluxible impurities. Whether this indicates a leaching of the claystone or deposition of a relatively pure clay can only be determined by detailed tests, which would reveal whether the composition of the bed varies from top to bottom or is uniform.

A weathered zone consisting of leached claystone with secondary accumulations of iron oxide in panlike sandy zones is a common feature beneath the transgressive disconformity at the top of the Lytle formation along the Front Range in Colorado (Waagé, 1955, p. 26). If a similar zone exists in the Black Hills it is not as evident; perhaps, as the common occurrence of coaly beds on the contact suggests, intermittent or seasonal swamp conditions prevented the formation of a more conspicuous weathered zone, although leaching does occur today in the tropics where swampy conditions prevail. The Black Hills area was within the central part of the basin of subsequent Early Cretaceous marine deposition where swamps would be likely to precede the marine transgression. However, most of the Colorado Front Range area was a delta plain on the west and southwest side of the basin where better drainage would locally result in more mature weathering.

It is less easy to recognize the disconformity where sandstone beds lie close to the contact, a common occurrence in the southern and southwestern Black Hills. Even in these areas the carbonaceous siltstone characteristic of the basal Fall River is widespread and of considerable aid in locating the contact. Locally, as in Fuson Canyon, a thick lens of massive sandstone forms the lower part of the Fall River and rests directly on the Lakota. Here a thin basal conglomeratic sandstone and a marked change from hard rusty-brown sandstone above to friable, light-gray, silty sandstone below accentuate the contact. However, conglomerate is relatively rare at the Fall River contact.

At a number of places in the Black Hills, but chiefly in the southern part, massive, brown-weathering sandstone bodies locally occur in the upper, dominantly clayey part of the Lakota. These bodies range in breadth from narrow channel fills, a few hundred feet across, to larger elongate bodies more than a mile across; it is difficult to determine width unless the body can be traced across several exposures. Some of these bodies lie far enough below the Fall River contact so that at least a few feet of the usual variegated claystone and silty claystone remain, and the disconformity is obvious. The massive cliff-forming sandstone at Sturgis, for example, is a local lens of this kind, lying 15 to 20 feet beneath the disconformity. Elsewhere, however, these massive sandstone lenses directly underlie the disconformity and it is very difficult to differentiate them locally from massive Fall River sandstone lenses. In places where the basal Fall River is not a massive lens its thin bedding contrasts sufficiently with the massive sandstone of the Lakota to make the contact evident. At other places truncation of the Lakota lens at the contact may also be evident. Where the contact is in doubt, lateral tracing along the strike usually leads to local areas where the top of the Lakota sandstone body is lower in the section and varicolored claystone and siltstone are between it and the Fall River contact.

The massive sandstone bodies in the uppermost Lakota are commonly fine- to medium-grained and some are conglomeratic. At places they are more than 75 feet thick, and the channeled disconformity at their base, locally is incised deeply in the underlying beds. Much remains to be learned about these sandstone units and their relationships. From their position so close to the disconformity and their general lithic resemblance to Fall River sandstone it is conceivable that they are fills of drainage channels through which sand was carried seaward to accumulate in distant marginal marine areas of the advancing sea as deposits lithogenetically equivalent to the Fall River formation.

As a rule the contact of the Fall River and Lakota formations is relatively easy to locate throughout the Inyan Kara outcrop. One possible source of confusion is the presence of a stratigraphic break of similar appearance at the top of the thin tongue of continental beds within the middle of the Fall River formation in the southern and eastern part of the Black Hills. Genetically this break within the Fall River is a transgressive disconformity identical to that at its base; the continental tongue marking a local return to conditions of deposition similar to those of the Lakota and the disconformity at the top marking the readvance of the marginal marine environments. Where the entire Fall River and upper part of the Lakota are exposed the two disconformities could not be confused, but where exposures are few and the typical Fall River rocks beneath the continental tongue are covered, the upper disconformity could be mistaken for the contact.

SIDERITE ZONE

A zone of tiny pellets of siderite has been used for some time by geologists (Gries, 1954, p. 448, among others) to mark the top of the "Fuson" in the subsurface. On the outcrop this siderite zone begins within a foot, or at most a few feet, beneath the transgressive disconformity marking the contact of the Lakota and Fall River formations, and extends downward as much as 12 feet. On the surface as well as in the subsurface it is an extremely useful zone, helpful in identifying the transgressive disconformity. Siderite pellets are also in the local continental tongue of the Fall River, where they bear the same relation to the local disconformity at the top of this tongue that the far more extensive siderite zone below bears to the regional disconformity at the Lakota-Fall River contact. Similar pellets also occur locally in two discontinuous zones within a coaly facies of the Newcastle sandstone in the northern Black Hills. Samples examined from the Newcastle, Fall River, and Lakota appear to be identical in composition and structure, and they occur in identical positions relative to their associated rock types.

On the outcrop the siderite pellets beneath the contact of the Lakota and Fall River formations commonly weather to earthy, red and yellow, ferruginous specks in the claystone. They are generally less than 0.5 mm in diameter but the size varies; the largest found were about 3.0 mm in diameter. Thin sections of several fresh samples obtained from drill cores in Crook County show that the siderite of the Lakota occurs as spherulites with a radial fibrous structure, although most have an opaque core. Silt-size grains of quartz are scattered throughout the spherulites. Murthy (written communication) states that ". . . Each spherulite shows a hazy cross extinction, which is considered characteristic of materials precipitated from a colloid or a gel."

The spherulitic siderite in the Fall River and Newcastle formations is a local feature but the siderite zone beneath the transgressive disconformity has regional extent. I have found it in the Cloverly in the Bighorn and Laramie Basins; in the top of the Lytle formation in northern Colorado, and at Sergeant Bluff, Iowa, across the Missouri River from Meek's and Hayden's type Dakota. Baker (1948, p. 2) also observed the siderite at Sergeant Bluff and states that it ". . . can be traced from outcrop at Sergeant's Bluff . . . underground all the way westward to the Black Hills." Within the Black Hills region the siderite pellets have been found locally in all areas of the Lakota outcrop, although the zone is not completely continuous but has gaps for short distances along the strike.

Authigenic spherulitic siderite is common in the geologic record where it has been noted chiefly in coal-bearing rocks. In the English Coal Measures spherulitic siderite is apparently most common in the lower part of underclays or in silty and sandy beds just beneath the underclay (Deans, 1934). In the Indian Coal Measures, however, it occurs in the coals themselves (Spencer, 1925, p. 678–682). In the Appalachian coal fields of western Pennsylvania and Maryland, I have found it in the lower portion of underclays in the Pottsville and lower part of the Allegheny formations where it is commonly associated with high-alumina flint and diaspore clays. Spencer (1925) reports many other occurrences of the spherulites. Swain (1944, p. 604) lists a few occurrences of spherulitic siderite in the Upper Jurassic and Cretaceous of the Gulf Coast and describes the spherulites of the Dorcheat member of the Schuler formation (Upper Jurassic) in some detail (Swain, 1949, p. 1241–1243).

Deans' (1934) study of the siderite spherulites in a part of the English Coal Measures is the most detailed study to date. His conclusions as to the origin of the spherulites are summarized by Swain (1949, p. 1242) who broadens the interpretation in applying it to the noncyclothemic deposits in the Dorcheat member. Deans (1934, p. 62) invokes a long period of subaerial leaching and oxidizing by ground-water action to form an underclay. During this process iron is taken into solution "probably as ferric oxide hydrosol" and carried down to the zone of stagnation where, in a reducing environment, it is precipitated in colloidal form as ferrous carbonate. Deans speculates that the colloidal ferrous carbonate undergoes segregation into nodules of gel, which then crystallize in the spherulitic habit.

Deans stresses the relation of spherulitic siderite to cyclothemic deposition and in particular to the formation of the underclay by subaerial leaching. In the Black Hills region the spherulitic siderite in the Newcastle formation occurs in light-gray silty claystone directly underlying lignite or lignitic shale in a local cyclothemic deposit consisting of two complete cycles. At many places the succession of beds in the Lakota-Fall River contact zone resembles the underclay-coal part of a cyclothem, with the coal represented by local thin lenses of impure lignite and carbonaceous siltstone at the base of the Fall River. The local continental tongue in the Fall River formation in the southeastern Black Hills repeats this pattern. However it is questionable whether leaching of the underclay, or its equivalent, prior to the deposition of the coal is prerequisite for the formation of spherulitic siderite. Considerable difference of opinion still exists concerning the formation of underclays in general, and it would be previous to postulate that the contact of the Lakota-Fall River formations represents an episode of nondeposition and subaerial leaching on the presence of the spherulitic siderite alone. Nevertheless, other evidence of leaching was found where the same disconformity separates the Lytle and South Platte formations along the northern Front Range in Colorado (Waage, 1955, p. 26).

Present knowledge of the nature and distribution of spherulitic siderite permits few generalizations as to its genetic significance. Although it is found in nonmarine deposits it appears to be found consistently only in terrains in which these nonmarine deposits are closely associated with marine deposits. This suggests that conditions optimum to its formation obtain in areas at or very close to sea level possibly within or on the landward sides of coastal swamps and salt marshes. Among the known occurrences of spherulitic siderite these conditions are met in three types of stratigraphic sequence. The prevalent occurrence is in certain cyclothems of coal-bearing sequences characterized by small-scale intertonguing of marine and continental deposits; why the spherulites are limited to certain cyclothems or to certain areas covered by a particular cyclothem is not known. A second type of occurrence is that described by Swain (1949) for the scattered zones of spherulites in the nonmarine areas of the Dorcheat member of the Schuler formation. Swain points out that whereas the Dorcheat passes laterally into marine deposits the shoreline was relatively stable and there was no close marine intertonguing with the nonmarine, spherulite-bearing Dorcheat deposits. He postulates the formation of the siderite spherulites according to Deans hypothesis during repeated periods of quiescence which permitted the leaching of the Dorcheat clays.

In the third type of stratigraphic occurrence, that illustrated by the Lakota spherulites, the shoreline was neither stable nor periodically fluctuating but was encroaching gradually over a large area to form the initial interior Cretaceous epeiric sea. Consequently, except in local areas along the margins of the sea where minor fluctuations were recorded, a single widespread zone of sideritic spherulite was formed.

FALL RIVER FORMATION

TYPE SECTION

Restriction of the name Fall River formation to the dominantly sandy marginal marine facies above the transgressive disconformity requires only slight redefinition of the type. Russell's (1928, p. 136) original definition includes "the sandstones and interbedded shales of post-Fuson age lying below the base of the Graneros shale." Russell (written communication) included the Quarry sandstone in these beds, consequently he followed Darton's restriction of the latter's Dakota formation in Fall River Canyon inasmuch as the base of the Quarry sandstone marked the Fuson contact in both classifications. Russell states that the type locality is "at Evan's Quarry on Fall River below Hot Springs, Fall River County, S. D." Actually there are two Evan's quarries, both abandoned—an old one on the northeast side of the river and a somewhat more recent one on the southwest side. Ward (1899, pl. 54) shows the northeast quarry as Evan's quarry. Inasmuch as both are in the same bed of sandstone it makes little difference. However, the newer, southwest quarry shows only the face of the massive sandstone and a few feet of beds above, whereas the original Evan's quarry shows the massive sandstone and, in a gully leading from it, all the beds beneath it to the basal contact of the Fall River formation. Adequate exposures of the formation above the Quarry sandstone can be seen a short distance downstream on the northeast side of the river below the falls formed by the Quarry sandstone.

This general area in the vicinity of the falls and the two quarries is here included as part of the type locality which affords, by piecing, complete exposures of the formation, as well as supplementary outcrops showing some of its lateral variations. A detailed composite section of the type Fall River is given on pages 79–81, section 8; figure 9 includes a generalized columnar section.

GENERAL CHARACTER AND THICKNESS

The Fall River formation is a dominantly sandy unit with some interbedded shale and siltstone. In general it is characterized by the fine grain size of its sandstones; the high content of ferruginous matter, which appears interstitially or in masses as oxides, or as concretionary ironstone and pyrite; the lamination of most of its finer sediment and the tabular, laminated to cross-laminated bedding of much of its sandstone; and the abundant ripple marks and trails, burrows, and castings of soft-bodied organisms. The iron content accounts for the characteristic brown, orange-brown, and red-brown colors to which the sandstone commonly weathers. Rounded quartz grains are the chief constituent of the dominantly fine-grained Fall River sandstone, and mica flakes are locally conspicuous. The abundant iron oxides commonly impregnate the upper surfaces of sandstone beds or occur in concretionary masses. Calcium carbonate locally cements thin beds or large concretionary masses in thicker beds. Carbonaceous fragments are abundant locally.

Throughout the Black Hills the Fall River formation maintains a fairly constant thickness, ranging between 110 and 160 feet. Its basal contact is sharply delimited by the transgressive disconformity. Its upper contact is commonly an abrupt change from sandstone to gray sandy shale, which grades within 5 to 15 feet to the black clay shale typical of most of the Skull Creek. Locally, where the upper Fall River is dominantly shaly, its contact with the Skull Creek is an imperceptible gradation through an interval as much as 20 feet thick. Throughout the Black Hills the contact, even where relatively sharp, is conformable.

In the southern and eastern Black Hills the Fall River formation is susceptible to a threefold subdivision because of a tongue of beds similar to the Lakota in its middle part. How far this tongue extends north of the southern Black Hills along the western outcrop is not known. It extends throughout the east side, becoming indistinct in the outcrop south of Belle Fourche. In the Bear Lodge Mountains and the area about Aladdin, a foot or two of purplish-gray shale may mark the edge of the tongue. Throughout the northwestern Black Hills there is no evidence of the tongue.

SOUTHEASTERN AND EASTERN BLACK HILLS

Description of the Fall River formation from its type section northward along much of the east side of the Black Hills will suffice to point out the characteristics of the formation where the continental tongue is present. Here the divisions, none of which warrant formal names, can be called the lower, middle, and upper Fall River for convenience in description. Generalized columnar sections of the formation in this area are given in figure 9.

As the columnar sections indicate, the Fall River thins northward from the southern Black Hills. From the Cascade Springs quadrangle to Billover Creek northwest of Hermosa, the formation is between 130 and 160 feet thick. In the Tilford-Rapid City area it is about 110 to 125 feet thick. Northward from the Tilford quadrangle no complete sections were measured; chiefly because beds above the lower Fall River formation are generally shaly and do not crop out.

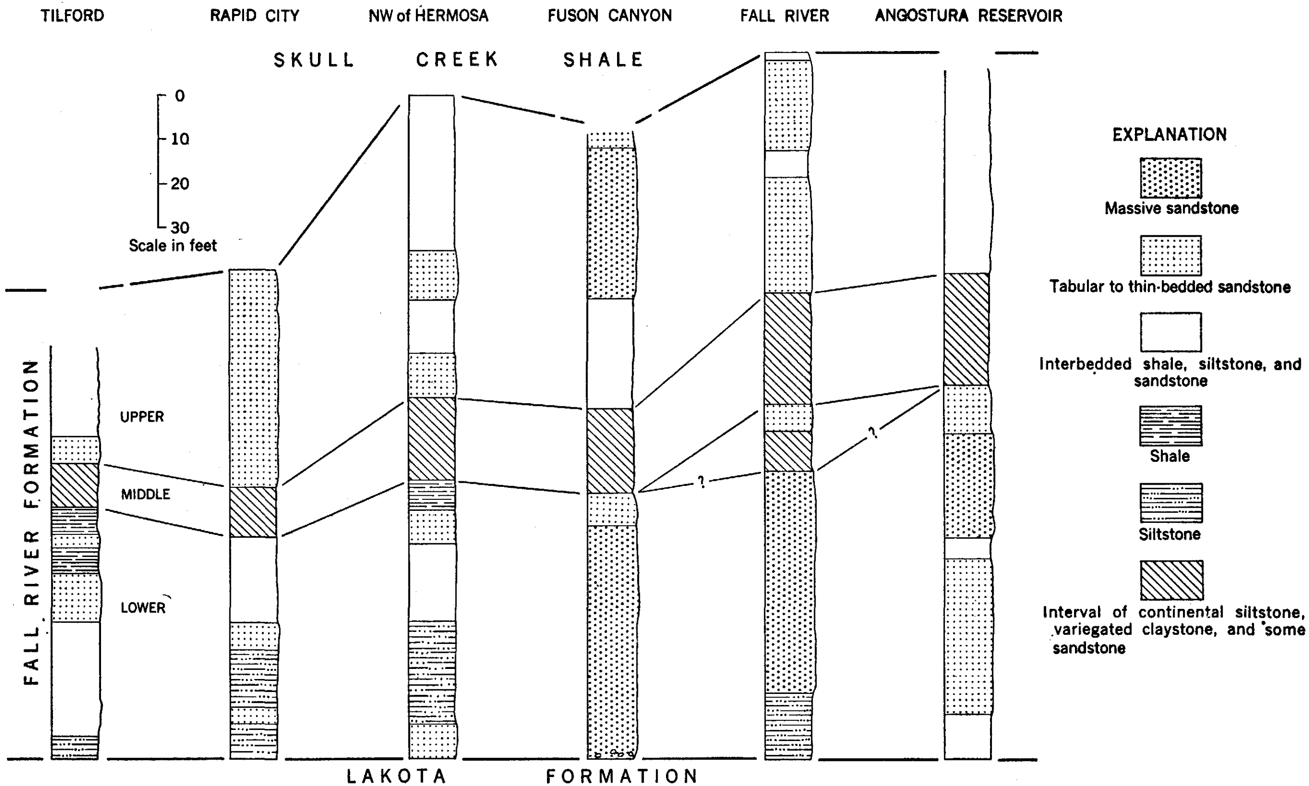

FIGURE 9.—Generalized columnar sections of the Fall River formation in the southeastern Black Hills.

The lower part of the Fall River formation is quite variable in the southern part of the outcrop, but in general its basal beds are commonly tabular, ripple-marked, worm-tracked sandstone with gray somewhat carbonaceous, laminated siltstone at the base. Locally, as at the type section, the basal bed is shale. The thick massive sandstone bodies, such as the local Quarry sandstone succeed the well-bedded subunit. Locally the well-bedded subunit has been eroded prior to the deposition of the massive sandstone bodies, as in the Fuson Canyon section. The massive sandstone bodies are in turn commonly succeeded by a few feet of bedded siltstone and sandstone before the colored claystone of the middle Fall River appears. North of the latitude of Hermosa the lower Fall River tends to have fewer and thinner massive sandstone bodies and is commonly made up only of well-bedded siltstone, sandstone, and shale. This probably accounts in part for the northward thinning of the formation.

Silty claystone, claystone, and massive clayey siltstone are the commonest rock types in the middle Fall River formation. They are generally soft and underlie slopes. Commonly they are light colored and variegated and generally they are stained yellow to rusty red and purple. Lignitic shale and abundant carbonaceous matter in other forms are common locally as are irregular bodies of massive friable white-weathering fine-grained sandstone.

No sharp contact marks the base of the middle Fall River; it becomes silty or sandy at the base and grades into the bedded siltstone and sandstone of the lower Fall River. For example, at the type locality clayey siltstone beds like those of the middle part intertongue with bedded fine-grained sandstone within a zone as much as 18 feet thick overlying the Quarry sandstone. The upper contact of the middle Fall River is sharp, a transgressive disconformity closely resembling the basal contact of the formation with the underlying Lakota, even to having a zone with spherulitic siderite beneath the contact.

Because of the indefinite lower contact, it is difficult to state a precise thickness for the middle Fall River. At the Angostura Reservoir it is about 25 feet thick, in Fuson Canyon about 15 or 20 feet thick, and at Tilford little more than 10 feet thick. At the type section the intertongued zone above the local Quarry sandstone is 18 feet thick and the variegated clayey silts extend for another 17 feet above the zone.

Tabular to thin-bedded sandstone, laminated siltstone, and shale are the predominant rock types in the upper Fall River. All three may be thinly interbedded, but the sandstone, which is fine- to very fine-grained, commonly occurs in separate units with minor amounts of the other rock types. Both siltstone and sandstone beds are commonly ripple marked and show "worm" tracks. Bodies of massive sandstone are less common and much thinner than in the lower part of the formation.

The contact with the Skull Creek shale is obscured in most places because of the lack of resistant beds at the top of the Fall River formation. In general the upper Fall River formation appears sandier from Fuson Canyon south than it does to the north, but the Rapid City area is an exception to this. Too few complete sections of the upper Fall River are available to permit accurate determination of trends of variation in its thickness, but superficially it does not appear to change much northward as far as Rapid City. At the type section it is 64 feet thick and on St. Cloud Street in Rapid City at least 50 feet thick. North of Rapid City the uppermost Fall River and basal Skull Creek are rarely exposed.

NORTHWESTERN BLACK HILLS

The Fall River formation in the northwestern Black Hills is not subject to a threefold division because it lacks the middle continental tongue. It varies chiefly in its sand-shale ratio and in the distribution of bodies of massive sandstone. The average thickness is 135 feet. An example of dominantly sandy Fall River is given in the Government Canyon section, section 9 (p. 81–83). Although this section is somewhat sandier than most exposures of the Fall River in the northwestern Black Hills, considerable lateral variation in its sand-shale ratio is a local characteristic of the formation. An extreme shaly phase occurs along the north side of Cabin Creek in sec. 1, T. 52 N., R. 67 W., Crook County, where the entire formation is shaly except for a few thin sandstone beds. Fall River shale beds are commonly silty and generally gray to black, though locally light-gray clay shale is common. The silt is both disseminated and in laminae and thin beds. Locally some shale is nearly silt free, dark, clay shale with selenite crystals. Carbonaceous matter is a common constituent of the shale, locally so abundant that the shale is carbonaceous, or lignitic.

Relatively thick, generally massive sandstone beds, which may persist over as much as several 7.5 minute quadrangles, are locally common in the upper half of the Fall River. Some are narrow and elongate, others are broader, sheetlike lenses. They are probably of varied origin. Some are channellike and have northwestward trends indicating direction of flow similar to that of the sands in the Lakota; these may be distributary channels. One narrow body of massive sandstone has the form of an inverted channel and is probably a bar. Beach sands may also be represented by some of these sandstone bodies.

AGE AND ENVIRONMENT

The Early Cretaceous age of the Fall River formation is based on the Early Cretaceous plant fossils of the underlying Lakota and the Early Cretaceous marine fossils of the overlying Skull Creek shale. In addition, the freshwater clam *Protelliptio douglassi*, an Early Cretaceous zonal guide, was identified by W. A. Cobban from carbonaceous shale in the basal foot (unit 30) of the Fall River formation in the Cabin Creek section of the northwestern Black Hills. In general fossils other than plant remains and the plentiful traces of soft-bodied organisms are exceedingly rare.

The type of bedding prominent in the Fall River and the abundance of soft-bodied animals, indicated by the numerous burrows and castings, are indicative of marginal marine, probably tidal-flat, environment. Associated carbonaceous beds, dominantly shaly local phases, and massive sandstone, probably were formed in coastal swamp, estuarine and deltaic environments respectively. Ordinarily marine fossils might be expected at least in the tidal flat and estuarine phases. Washings of a few Fall River shale samples revealed worn mollusk shell fragments and some fragments of what may have been arenaceous Foraminifera, but no undoubted marine fossils. Considering the environment in terms of the local Cretaceous conditions rather than in terms of what one might expect to find in a similar environment around modern seas, the absence of fossils is understandable. The Fall River and its equivalents are the initial deposits of the transgressive Cretaceous sea. Drainage into this continental sea was from a vast land area and its connections to open seas were remote. An abundant supply of moisture is indicated by the varied "Dakota flora," which Knowlton (1919, p. 526) interprets as a warm-temperate rain-forest flora. Consequently fresh-water contributed by large rivers draining the peripheral watershed probably diluted the sea water, particularly in the parts of the seaway remote from the Gulf or boreal connections to the ocean, thereby preventing the spread of typical marine faunas.

The local fossil record of the overlying Skull Creek shale shows that about two-thirds of it was deposited before what might be classed as typical marine invertebrates appear. Just above the Fall River, in the basal portion of the Skull Creek, is a widespread horizon at which the remains of crocodiles and short-necked plesiosaurs (pliosaurs) commonly occur. Arenaceous Foraminifera, probably indicative of brackish water, are found throughout the Skull Creek. Linguloid brachiopods were found within 25 feet of the Fall River formation at one locality; and these too are indicative of low salinity. One ammonoid fragment too poor for identification, gastropods, a fragment of an *Inoceramus*, and a few smaller pelcypods were found in the upper 40 feet of the Skull Creek and constitute the only typical marine fossils in the collection.

The meagre fauna of the Early Cretaceous interior seaways has been noted by paleontologists (Reeside, 1923) who point out the gradual impoverishment of the fauna northward from the Gulf region. Decrease in salinity was probably the major factor. Under these conditions it would be unusual to find marine fossils in the initial marginal deposits of the seaway particularly as far north from the Gulf region or south from the boreal region as the Black Hills. More detailed sampling of Fall River shale is desirable inasmuch as correlative strata in the Cloverly and lower Thermopolis formations have yielded arenaceous Foraminifera.[3]

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MEASURED SECTIONS OF INYAN KARA ROCKS

The upper and lower contacts of the Lakota are clear cut in exposures in the bluffs west of Arch Creek in NW¼ SE¼ sec. 14, T. 51 N., R. 55 W., Sunny Divide quadrangle, Crook County. The following composite section, measured in these bluffs, shows especially well the conglomeratic claystone and the basal black chert conglomerate. Spherulitic siderite pellets beneath the Fall River contact, though common in adjacent exposures along the strike, were not found in the trench dug for section measurement. Trenching the outcrop is necessary even in badland areas, because the weathered hard-clay "popcorn" crust on Lakota claystone obscures its true character.

Section 1. Arch Creek

	Thickness (feet)
Fall River formation (in part):	
26. Sandstone, fine-grained, irregularly thin bedded, cross-laminated; some massive beds, partings of shaly siltstone; local iron impregnation, forms buff, shelving ledge	6.3
25. Sandstone; as in 26 above, but more thinly bedded and becoming shaly; grades to interbedded shale and siltstone about 2 ft from top, and into dark-gray silty shale in lower foot	4
24. Siltstone, hard; interbedded with clayey siltstone and dark-gray silty shale; plant fragments common; weathers to crumbly gray-white and yellow-gray ledges	6
23. Siltstone, clayey, and silty claystone, hard, dark-gray to black; with numerous plant fragments	3.5
Disconformity.	
Lakota formation:	
22. Claystone, waxy, gray to light-gray; soft above becoming silty and tougher downward	3.5
21. Claystone, silty, variegated; tough in upperpart becoming softer downward; gradational with units above and below; chiefly red and red-brown, mottled with green in lower foot and with purple and green in upper 1.5 ft	4.9
20. Claystone and shale; upper 3.8 ft chiefly greenish-gray silty claystone; basal 1.5 ft soft waxy shale, probably bentonitic, light grayish green	5.3
19. Sandstone, fine-grained, thin-bedded, cross-laminated, micaceous; thin interbeds of light-gray shale; bedding with ripple marks and "worm" tracks; weathers light gray to yellow gray	3.6
18. Shale, light-gray; weathers yellowish to olive gray	5.3
17. Claystone, silty; upper 2.5 ft black, becoming dark gray and gray below	4.5
16. Siltstone and silty claystone, hard, light-greenish-gray	1.2
15. Claystone, soft, gray to dark-gray	2.6
14. Claystone, silty, hard, dark-gray and black; locally a clayey siltstone; contains scattered coarse grains of chert and quartz	5.3

	Thickness (feet)
Lakota formation—Continued	
13. Siltstone, clayey, massive, hard; contains sand as coarse scattered grains of chert and quartz; weathers light gray	4
12. Claystone, silty, dark-gray, hard	1
11. Claystone, sandy, hard, dark-gray; some irregularly interbedded sand at base	2. 3
10. Sandstone, fine- to medium-grained, conglomeratic: poorly consolidated; some interstitial clay; contains chert and quartz granules and a few polished chert, quartz, and quartzite pebbles, as large as 0.3 ft in diameter, scattered throughout; basal 0.2–0.4 ft is chiefly a granule and small pebble conglomerate. Parts of this unit, commonly the basal conglomerate, are locally chertified in irregular, gray-white tabular masses	8
9. Sandstone, fine- to medium-grained; with scattered coarse grains; soft, clayey at base; weathers gray white; contains polished pebbles	3
8. Claystone, sandy; light gray with greenish cast; contains scattered chert and quartz granules in upper 2 ft; basal 0.5 ft is clayey, conglomeratic sandstone with scattered polished pebbles of chert, quartz, and quartzite	8
7. Claystone, sandy, conglomeratic; local lenses of clayey conglomeratic sandstone; conglomeratic material is chert, quartz granules, and small pebbles; upper 4 ft gray to dark gray, then 3 ft yellowish gray, remainder is light green	16
6. Claystone, vivid-green; contains local lenses of clayey sandstone with chert and quartz granules; partly obscured; upper 3–8 ft sandy; basal 8 ft completely obscured but has fossil wood in float	16
5. Sandstone, fine- to medium-grained massive, cross-laminated, weathers white	10. 6
4. Claystone, partially obscured, variegated; chiefly greenish gray in upper 10 ft, beneath this about 3 ft variegated red and green; basal 10 ft obscured	23. 5
3. Sandstone, medium- to coarse-grained and conglomeratic; conglomerate lenses of black, gray, and white chert, black predominating; basal 3 ft is similar conglomerate	18–32
Total thickness Lakota formation (rounded)	160
Morrison formation:	
2. Claystone, silty, stained tan to brown	1. 5– 2. 5
1. Claystone, gray-green; grading within about 8 ft to marlstone; thin beds of limestone begin about 18 ft from top	27—

The following section, combined from measurements by C. S. Robinson, P. K. Theobald, and the writer, is exposed in the east wall on Inyan Kara Creek in the NE ¼ NW ¼ sec. 21, T. 51 N., R. 65 W., Sunny Divide quadrangle, Crook County. Note that the only sizable sandstone bed in the Lakota is just beneath the Fall River contact, and that in the absence of a sandstone or conglomerate lens lower in the Lakota, the Lakota-Morrison contact is indefinite and appears transitional.

Section 2. Inyan Kara Creek

	Thickness (feet)
Fall River formation (in part):	
16. Sandstone, light-gray, fine-grained carbonaceous; 1-ft. bed of gray shale in middle part separates it into two ledges; ripple-marked at top	18
15. Shale, medium- to dark-gray, silty; contains few 1- to 2-in. beds of yellowish-brown, fine-grained to silty sandstone	21
Disconformity.	
Lakota formation:	
14. Claystone, sandy, variegated, weathers grayish white with pink stain; contains scattered coarse grains of chert and quartz; becomes increasingly sandy downward and grades into unit below	2.5
13. Sandstone, fine- to coarse-grained, massive, grayish-white, friable; contains granules and pebbles of chert and quartzite locally, chiefly in basal 4 ft	27.5
12. Claystone, partially obscured; upper 10 to 15 feet red, grading downward to purplish red in middle part; lower 10 or so feet greenish gray. Few scattered polished pebbles in float may be from this unit or sandstone above	41
11. Sandstone, soft, grayish-white, fine-grained, to sandy siltstone, local secondary calcite cementation	7
10. Claystone; greenish-gray in upper 7 feet, below which is a 1-foot red band; lower 7 feet gray to black with local lens of hard, fine-grained, pyritic sandstone at base	15
9. Claystone, dark-gray to black; shaly at base	6
8. Shale, gray to greenish-gray; with interbeds of dense light-gray limestone; contains charophytes, ostracodes, and poorly preserved gastropods	9
7. Claystone, gray, calcareous; with a few inches of argillaceous limestone at top and base	5
6. Claystone, gray to dark-gray, calcareous; shaly in upper part, blocky below, with scattered small lenses and thin beds of argillaceous, white-weathering limestone up to 0.8 ft thick; contains ostracodes and charophytes	17
5. Claystone, waxy, sandy; greenish-gray at top, becoming mottled with red and, in lower 2 ft, variegated purple, red, and green; grains to small granules of chert	5
4. Claystone, sandy, greenish-gray; weathering to rusty orange; 0.1–0.2 ft bed of sand at base; float of polished pebbles appears to be coming from this unit or unit 5 above, but none seen in place	3
Total thickness beds included in Lakota formation	138
Disconformity (?)	
Morrison formation:	
3. Claystone; chiefly a bright blue-green with minor purple mottling	11
2. Claystone, silty to waxy, variegated; chiefly a reddish gray with some green; upper foot highly silty with thin lenses resistant siltstone locally; dinosaur bones from near top and base	5.5
1. Siltstone, clayey, calcareous, nodular; weathers light gray to white, similar in color to unit 2 on fresh surfaces; contains dinosaur bones	5+

Section 3 is a composite section along a ridge 0.7 mile northeast of the confluence of Inyan Kara Creek and the Belle Fourche River, on the east side of the valley in northeast corner, SE¼ sec. 25, T. 52 N., R. 66 W., Sunny Divide quadrangle. The section lies about at the apex of an equilateral triangle formed by it and the two preceding sections:

Section 3. Inyan Kara Creek

	Thickness (feet)
Fall River formation (in part):	
25. Sandstone, fine- to medium-grained, tabular; bedding surfaces ripplemarked; iron impregnated; weathers dark brown	2
24. Shale, dark-gray silty; obscured, some exposed patches on slope	9
23. Sandstone, fine-grained, massive; chiefly a single, buff-weathering bed, with 1-ft bed at base and upper 2-ft platy to thinbedded	6. 8
22. Sandstone; fine-grained, cross-laminated, brown-weathering; interbedded with siltstone; in beds 1–1.6 ft thick, with some vertical "worm" borings; siltstone vaguely laminated, locally "worm" worked, weathers gray with local yellow to rusty stain	6. 5
21. Sandstone, fine-grained, thin-bedded, cross-laminated, to crossbedded, ripple-marked, "worm"-tracked; some thin beds and partings of shaly sandstone and few thin layers gypsum; some iron-impregnated beds in upper 3 ft; weathers buff	8. 5
20. Shale, silty, dark-gray to black, selenitic; interbedded with laminae and thin layers fine-grained sandstone which are "worm" tracked, locally iron impregnated; becomes sandier upward grading to unit 21	4. 3
19. Siltstone; clayey in lower 2.5 ft, becoming hard, massive, sandy, white-weathering ledge in upper 2 ft	4. 5
18. Siltstone, clayey, and silty claystone; dark-gray to black, hard, with carbonized plant fragments	5
Disconformity.	
Lakota formation:	
17. Claystone, silty, light-gray, weathers white	2
16. Claystone, silty, variegated; covered by wash and crust of clay; upper 10 ft chiefly greenish gray with minor red mottling; lower 11 ft is chiefly red in upper part, green at base, with some scattered ferruginous specks from weathered siderite spherulites as large as 2 mm in diameter	21
15. Sandstone, fine- to coarse-grained and conglomeratic; chert, quartz, and quartzite granules and small pebbles in irregular beds chiefly in lower 4 ft; plant stem molds common; weathers rusty orange-brown to red	18
14. Claystone, silty to sandy, dark-brownish-gray, selenitic	6. 8
13. Claystone, sandy, gray to brownish-gray	2. 5
12. Sandstone, clayey, and sandy claystone, scattered coarse grains and granules of chert, polished chert and quartzite pebbles in float; upper 0.6–1.6 ft is white-weathering, hard, flaky claystone, may be porcellanitic	14
11. Sandstone, clayey, conglomeratic; chert and quartz in coarse grains, granules, and small pebbles; scattered polished pebbles and cobbles as large as 0.7 ft in diameter	10. 5

	Thickness (feet)
Lakota formation—Continued	
10. Probably sandstone or sandy claystone as above, obscured	15
9. Sandstone, fine-grained, massive, cross-laminated	6
8. Obscured by float and slope wash	16
7. Sandstone, medium-grained, hard; with varicolored chert and quartz-pebble conglomerate in basal 2–3 ft; weathers to gray or brown ledge, which also contains some large pebbles and cobbles of gray, unpolished chert, and subangular claystone fragments as large as 0.8 ft in diameter	16
Total thickness of Lakota formation (rounded)	128
Morrison formation:	
6. Claystone, locally silty, noncalcareous; brownish-gray, dark-gray, and red-brown; contains scattered carbonaceous flecks	35
5. Marlstone, locally silty, variegated gray-green and red; contains thin interbeds of fine-grained gray limestone and zones of limestone nodules; dinosaur bone fragments occur up to 43 feet above base; weathers pastel shades of red and green	75
4. Limestone, massive; weathers gray-white	1
Total thickness Morrison formation	111
Sundance formation; Redwater shale member:	
3. Shale, gray, calcareous	1
2. Sandstone, medium- to fine-grained; calcareous; weathers yellow; locally a sandy limestone; has thin interbeds of gray shale and irregular beds of gypsum; locally masses of gypsum 1–2 ft thick in upper part	11
1. Shale, gray, calcareous, fissile	2

Section 4 was measured from exposures in the bluffs north of Cabin Creek in the northeast corner, SE¼, and southwest corner, NE¼ sec. 10, T. 52 N., R. 66 W., Missouri Buttes quadrangle, Crook County. The easily accessible outcrops are only 0.5 mile north of U.S. Highway 14, 3.2 miles west of where it crosses the Belle Fourche River. In relation to preceding sections they are only 3.6 miles north-northwest of Inyan Kara Creek section 2.

Section 4. Cabin Creek

	Thickness (feet)
Fall River formation (in part):	
32. Sandstone, fine-grained, thin-bedded to tabular, cross-laminated; upper half contains shaly partings, iron-impregnated layers, ripple-marked and "worm"-tracked bedding surfaces; lower part becomes silty downward	7. 7
31. Siltstone and fine-grained sandstone interlaminated with black shale; laminae locally disrupted by "worm" workings	1. 9
30. Shale, silty, dark-gray; abundant carbonized plant fragments; local ferruginous stain; fresh-water clams rare (*Protelliptio douglassi*)	1. 9
Disconformity.	

Lakota formation:	Thickness (feet)
29. Claystone, silty, light-gray; massive; minor amounts of clayey siltstone, becoming less silty downward, scattered bright-orange ferruginous specks of weathered siderite spherulites	4. 3
28. Claystone, gray; mottled red with some yellow stain; scattered ferruginous specks of weathered siderite	1
27. Claystone; as above but gray with yellow stain; scattered ferruginous specks of weathered siderite; becoming silty downward	1. 7
26. Siltstone, massive, light-gray to white; clayey at top, ferruginous specks of weathered siderite throughout	5. 8
25. Siltstone, friable, gray-white; contains local clayey lenses and scattered thin hard beds	2. 8
24. Siltstone; with interbeds fine-grained sandstone increasing downward; lower 1 ft chiefly sandstone	2
23. Sandstone, chiefly fine- to medium-grained; with local thin layers of chert and quartz pebble conglomerate in lower 5–10 ft; massive to thinly crossbedded; weathers gray white with yellow stain to red brown	34
22. Obscured by slump. Base of unit 23 above lies in this interval	3
21. Claystone; upper 5 feet a soft-gray weathering to lumpy crust; partly obscured	10. 5
20. Claystone, slightly sandy, gray; weathers light gray; some scattered coarse grains chert and quartz	4. 3
19. Sandstone, clayey and sandy claystone; conglomeratic; coarse grains and granules chert and quartz; some white claystone fragments in upper 0.3 ft may be porcellanitic; polished chert and quartz pebbles in float	1
18. Claystone, sandy; contains light-gray to dark-gray scattered chert granules; polished chert and quartz pebbles in float	2. 5
17. Sandstone, medium- to coarse-grained, conglomeratic; with interstitial gray claystone; local zones of sandy conglomeratic claystone; chert and quartz granules and scattered polished pebbles of chert, quartz and quartzite; weathers gray-white	12
16. Claystone, slightly sandy; light-gray with greenish cast; contains scattered grains and granules chert and quartz, and crystals of selenite	2. 6
15. Claystone, sandy; scattered medium-sized to coarse chert and quartz grains, mottled red, reddish gray, gray and purple	7. 9
14. Sandstone, fine- to medium-grained, conglomeratic clayey, friable; gray; scattered granules chert and quartz; weathers white	7. 9
13. Claystone, sandy, gray-green; scattered chert and quartz grains chiefly in upper part	4
12. Claystone, sandy; scattered chert and quartz grains; upper 3 ft variegated red and green, chiefly red below with some bright green and yellow mottling in lower 5 feet	10. 6
11. Claystone, sandy, scattered chert and quartz grains; red with minor amounts of green mottling	12. 8
10. Sandstone, fine- to medium-grained, locally conglomeratic; some interstitial claystone; upper 2 ft chiefly sandy greenish-gray claystone; below this gray, unconsolidated sand with scattered granules and small pebbles chert and quartz; weathers yellow gray; basal 0.3 ft is hard, limy, conglomeratic bed, which crops locally as ledge	15. 6

	Thickness (feet)
Lakota formation—Continued	
9. Sandstone, fine- to coarse-grained and conglomeratic, clayey; some sandy claystone in upper 2 ft; progressively coarser downward with scattered chert and quartz granules; basal 0.4–0.8 ft hard, limy, coarse, conglomeratic sandstone	6.7
8. Sandstone, gray, fine- to medium-grained and conglomeratic, limy; some sandy marlstone; zone sandy to conglomeratic limestone concretions 1 ft from top and a ledge sandy, conglomeratic limestone 0.8–1 ft thick at the base, conglomeratic material granule to small pebble chert and quartz; weathers white, limy layers brown	3.3
7. Sandstone; as in unit 8 above, limy throughout, with 2 or 3 zones small, hard, sandy to conglomeratic limestone concretions and several conglomeratic zones including indurated basal limy bed as much as 3.5 ft thick, which contains carbonized plant fragments; weathers grayish white, some brown stain	19.9
Total thickness of Lakota formation (rounded)	176
Morrison(?) formation:	
6. Marlstone, sandy, and marly sandstone; contains a few scattered chert and quartz granules; gray and dark gray in upper part becoming light gray near base; thin red marlstone at base thickens laterally to include lenses of orange-brown-weathering limestone as much as 2 ft thick	6.5
5. Sandstone, gray, fine-grained, marly, and sandy marlstone; weathers yellowish gray; chiefly sandstone in upper third becoming marly downward	14.5
4. Marlstone, locally silty, variegated; green-gray with some red bands predominate in lower 26 ft, upper 40 ft chiefly red, with minor amounts of green; numerous lenses and thin beds of gray limestone, zones of scattered limestone nodules, and some limestone septaria	66
3. Sandstone, fine-grained, limy, weathers to platy brown ledge	2.5
2. Marlstone, variegated; slope chiefly obscured	24.5
Sundance formation; Redwater shale member:	
1. Sandstone, medium-grained, calcareous; weathers to yellow	4+
Slope wash.	

For composite section 5, units 1 to 32 were measured on the south face of a local high ridge on the Nichelson Ranch, just south of Wyoming State Route 111, about ¾ mile east of Aladdin, in northwest corner, sec. 34, T. 54 N., R. 61 W., Aladdin quadrangle, Crook County. Units 33 to 49 were measured on the bluffs just north of State Route 111, 0.4 mile due east of Aladdin and about 0.5 mile airline northwest of the Nichelson Ranch exposure.

Section 5. Aladdin

	Thickness (feet)
Fall River formation (in part):	
49. Sandstone, fine- to medium-grained massive, cross-laminated; weathers yellow gray to orange-brown	11.5

	Thickness (feet)
Fall River formation—Continued	
48. Sandstone, fine- to medium-grained, thin-bedded, laminated; weathers light gray with local yellow to orange-brown stain; forms shelving ledge	13. 6
47. Obscured slope, float of platy laminated sandstone	30
46. Sandstone, fine-grained, massive, laminated to cross-laminated; weathers light yellow gray to brown	3. 7
45. Obscured slope	6
44. Sandstone, fine- to medium-grained, tabular, cross-laminated; "worm"-marked and ripple-marked bedding surfaces; some vertical borings; weathers buff to brown	4
43. Shale, silty, gray to dark gray, with carbonaceous fragments	4. 6
Disconformity.	
Lakota formation:	
42. Siltstone and silty claystone, light-gray to white	. 5
41. Claystone, silty; contains some clayey siltstone; massive, white, mottled yellow and orange	2
40. Obscured by slump and slope wash on nonresistant beds	44
39. Sandstone, medium-grained; variable zone with channel-fills of massive, cross-laminated brown-weathering sandstone irregularly interbedded with friable crossbedded sandstone as in unit 38	21. 5
38. Sandstone, medium-grained, thinly crossbedded, locally friable; with silty zones; weathers gray-white with iron-impregnated layers contributing pink to red staining; local lenses of thick-bedded sandstone	20. 4
37. Sandstone, medium-grained, massive, cross-laminated, brown-weathering; some scattered sandy claystone pellets in lower part	15
36. Sandstone, fine-grained, and siltstone, shaly, soft; with some thin iron-impregnated layers; weathers white with pink stain	5. 3
35. Sandstone, medium-grained, massive, cross-laminated, lenticular; weathers buff to brown with pink cast	5
34. Obscured, float of gray-white shaly siltstone	2. 5
33. Sandstone, medium-grained, locally conglomeratic, massive, cross-laminated; thin layers and scattered granules and pebbles of chert and quartzite; few lenses intraformational siltstone and sandstone fragments and pebbles; weathers buff to brown; locally has iron-impregnated upper surface	13
32. Conglomerate, mixture of large blocks and poorly rounded pieces of sandstone and hard, platy siltstone, pellets of claystone, chert, and quartzite granules, and scattered polished pebbles; iron-stained molds of plant fragments; matrix fine- to coarse-grained sandstone	0. 5–2. 5
31. Sandstone, medium-grained, massive, cross-laminated; weathers yellow-gray to yellow	20
30. Sandstone; as above but irregularly bedded in beds 0.5–2 ft thick; interbeds silty to sandy, gray to brown shale, as much as 0.5 foot thick, increase in number and thickness downward	15
29. Shale, silty, dark-brownish-gray; contains plant remains, fern and cycad foliage; weathers gray with yellow stain on fracture surfaces; basal 0.5 is lignitic shale	1. 5
28. Sandstone, fine-grained, clayey; and sandy claystone; contains plant fragments	1

	Thickness (feet)
Lakota formation—Continued	
27. Sandstone, medium-grained, massive, friable; forms jointed, broken ledge; thin layer shaly sand 1 ft above base; weathers yellow to yellow-gray	4
26. Shale, silty, dark-gray to dark-brownish-gray; weathers gray to purplish gray; contains plant fragments locally concentrated to form layers of lignitic shale	4
25. Coal, and shaly lignite; upper 1 ft chiefly soft black coal, lower 1.5 chiefly lignite with shale partings	2. 5
24. Shale, dark-brownish-gray, becoming sandy at base, many plant fragments	1. 5
23. Shale, sandy; grading downward to shaly sandstone with thin shale interbeds; contains gray to brownish gray, plant fragments and fern foliage	1. 8
22. Sandstone, medium-grained; upper 1 ft clean, becoming carbonaceous and shaly downward	5. 5
21. Shale, silty, plastic, dark-gray; weathers with blocky fracture	2. 5
20. Coal, lignitic	1. 1
19. Claystone and blocky shale, hard; lignitic beneath coal, black grading downward to dark gray	3
18. Sandstone, fine-grained, gray, friable	0. 4
17. Shale, silty, blocky, dark-gray	1. 1
16. Sandstone, fine-grained, massive, friable; weathers gray; some siltstone	2. 6
15. Shale; as above, becoming lignitic at base	1
14. Lignite	. 2
13. Sandstone, fine-grained, massive; some siltstone; weathers light gray with yellow and brown stain on joint faces	2. 8
12. Shale, silty, blocky, dark-gray	2. 8
11. Siltstone, locally sandy, lignitic	1
10. Shale, blocky, dark-gray; carbonaceous fragments; locally a claystone	10
9. Shale, silty, with 0.3-ft clayey siltstone at base, weathers gray	1. 6
8. Shale, as above	1. 3
7. Claystone, silty to sandy, tough, lignitic, brown	2. 4
6. Sandstone, fine-grained, massive; weathers yellow-gray; some laminae of lignitic, gypsiferous silty shale and sandstone in basal 0.2 ft	1
Total thickness Lakota formation (rounded)	223
Morrison formation.	
5. Claystone, greenish-gray, gypsiferous at base	2. 8
4. Marlstone, dark-greenish-gray; with zones scattered limestone nodules, and thin irregular beds limestone	13
3. Marlstone, green; small patches exposed but mostly obscured by slope wash; limestone fragments in float	15
Total thickness of Morrison formation	31
Sundance formation: Redwater shale member:	
2. Sandstone, fine- to medium-grained, thin bedded and laminated; contains zones of gray, fissile shale as laminae and thin beds; grades to unit below, weathers yellow	11

	Thickness (feet)
Sundance formation—Continued	
1. Shale, fissile, gray, with laminae of silt. Wash covered gully bottom	5

Section 6. Mona Butte

[Exposures on the south end of the prominent butte north of Mona, just south of the Belle Fourche River in NE¼ SW¼ SE¼ and NW¼ SE¼ SE¼, sec. 22, T. 56 N., R. 63 W., Crook County, Wyo.]

Fall River formation (in part):	
31. Sandstone, medium-grained, crossbedded to cross-laminated, friable; weathers ochrous red to orange	5. 3
30. Sandstone, medium-grained, massive, ledge-forming, crudely tabular, cross-laminated; weathers variably yellow gray or orange-red; considerable ferruginous cement, concretionary layers, and scattered small, hollow concretions; basal 0.1 ft is ironstone	51
Disconformity.	
Lakota formation:	
29. Siltstone, clayey, gray; weathers to white clayey wash; peppered with ferruginous specks from weathering of spherulites of siderite; becomes sandy at base	4. 7
28. Sandstone, fine-grained, massive, light-gray to yellowish-gray; upper 0.5–1 locally quartzitic; locally has vertical tubular ferruginous concretions	2. 7
27. Sandstone, fine-grained, friable, locally clayey; contains scattered yellow ferruginous specks from weathered siderite spherulites	3. 2
26. Sandstone, chiefly medium-grained, massive, cross-laminated; forms sheer cliff; some coarse-grained lenses in lower part	62
25. Sandstone, coarse-grained, locally conglomeratic, friable	18
24. Sandstone, as in 26 above	3
23. Conglomerate, granule to small pebble, chiefly gray to black chert and quartzite, some claystone	13
22. Obscured by slope wash, upper foot appears to be conglomerate as above with claystone matrix	5
Disconformity(?)	
21. Sandstone, fine-grained, clayey, friable; some interbeds sandy gray claystone	3. 5
20. Claystone, sandy, dark-gray; with irregular laminae and thin lenses of fine-grained sandstone	6. 5
19. Sandstone, fine-grained, friable; irregularly interbedded and laminated with dark-gray to carbonaceous sandy shale and claystone	5. 5
18. Sandstone, medium-grained, white-weathering, friable; alternating with dark-gray to black shale alternating beds chiefly 0.4 to 1.0 foot thick	22
17. Claystone, plastic, dark-gray to black; some shaly with leaf fragments at top; sandy at base	7
16. Sandstone, chiefly medium grained, clayey, massive; lower foot contains scattered coarse grains of chert	6. 4
15. Claystone, sandy, light-gray; grades to unit below	4. 2
14. Sandstone, medium-grained, friable, becoming increasingly more clayey downward	9. 2
13. Claystone, sandy, to clayey sandstone; light gray, weathers yellowish gray	6

	Thickness (feet)
Lakota formation—Continued	
12. Sandstone, medium-grained, friable, gray; with partings of shaly lignite in basal 2 ft	10.6
11. Sandstone, medium- to coarse-grained; thinly interbedded with hard, conglomeratic, lignitic, sandy shale; conglomerate of granules and small pebbles of chert, claystone and carbonized wood; some larger wood fragments; color variable, gray, brown and black	2.6
10. Sandstone, medium- to coarse-grained, massive, cross-laminated, friable, light-gray; locally has scattered chert granules in lower 2.0 ft	11.2
9. Claystone, sandy and conglomeratic, lignitic and black to brown; granules and small pebbles of chert, sandstone, claystone, and carbonized wood	.7
8. Claystone, slightly sandy, gray to brownish-gray; with carbonaceous specks	4.6
7. Sandstone, medium-grained, friable; some interbedded sandy claystone	4.9
6. Sandstone, medium- to coarse-grained and conglomeratic; granules and small pebbles of chert scattered throughout upper 9 ft; lower 2 feet becoming clayey; light-gray with some yellow and red stain	11
5. Claystone, sandy, gray; locally a clayey sandstone	3.7
4. Sandstone, fine- to coarse-grained; conglomeratic in lower 6 ft; granules and small pebbles of chert and quartzite; chiefly friable with lower 2 or 3 ft locally a resistant ledge	8
Total thickness of Lakota formation (rounded)	239
Morrison(?) formation:	
3. Chert, irregularly bedded, gray-white to yellow gray	2.2
2. Claystone, locally sandy; with lenses slabby, fine-grained sandstone at top; upper half gray with greenish cast	6
1. Sandstone, fine-grained; with veinlets gray chert	2+
Slope wash.	

Section 7. Red Canyon

[Measured by Garland Gott from exposures in the west wall of Red Canyon in about the center, W½ NE¼ sec. 29, T. 7 S., R. 3 E., Fall River County, S. Dak.]

	Thickness (feet)
Fall River formation.	
Contact covered.	
Lakota formation:	
16. Covered, probably maroon to gray silty claystone	23
15. Claystone, silty to nonsilty, brownish-gray	17
14. Sandstone, very fine grained to silty; massive at base to tabular at top; white to pink with orange-red specks; grades laterally to yellow and light-gray siltstone	12.5
13. Siltstone, maroon; variegated with gray and yellow	25
12. Sandstone, fine-grained, massive, white to pink	23
11. Covered slope; probably on greenish to maroon siltstone and claystone	11
10. Sandstone, light-gray to white; with interbeds of green siltstone; as much as 2 ft thick; weathers pinkish yellowish brown with variegated stain	10.5

	Thickness (feet)
Lakota formation—Continued	
9. Siltstone, green; with interbeds of sandstone as much as 1 ft thick	9
8. Sandstone, fine-grained; massive with indistinct cross-lamination and bedding; weathers yellowish brown with red splotches; cliff-forming; abundant grains of white clay in upper part	23
7. Siltstone, grayish-green	2
6. Sandstone, fine-grained; yellowish brown with splotches of pink	3
5. Siltstone, brownish-gray; carbonaceous in lower part; with interbeds of fine-grained white sandstone; upper 20 ft chiefly greenish-gray to red siltstone; partly covered	76
4. Sandstone and siltstone, interbedded, fine-grained; gray sandstone in beds with a maximum thickness of 1 ft; siltstone platy, brownish-gray, carbonaceous; partly covered	13
3. Sandstone, fine-grained, white, chiefly massive, ledge-forming, faintly crossbedded; lower 5 ft. composed of lenses with intervening seams carbonaceous silt	57
2. Covered slope. One small outcrop of brownish-gray carbonaceous shale about 10 ft above the base	56
1. Sandstone, very fine-grained, tabular; forms massive cliff; weathers light pinkish tan with yellow iron stain and carbonaceous splotches; upper portion contains as much as 5 percent white clay grains	31. 5±
Slope wash.	
Total Lakota formation measured (rounded)	393

Composite section 9, the type section of the Fall River formation, is from exposures in the bluffs of Fall River in the area of the falls and of Evan's quarries which lie on opposite sides of the river just above the falls. All exposures lie in the N½ sec. 33, T. 7 S., R. 6 E., Hot Springs quadrangle, Fall River County, S. Dak. Unit 7, the Quarry sandstone of Ward (1894), was measured on the bluff above the road to Buffalo Gap about 900 feet from its intersection with U.S. Highway 18; units 3 through 6 were measured in a gully, draining the original Evan's quarry, which crosses Buffalo Gap road about 500 feet from the intersection; and additional details of the contact described in the supplement were observed about 200 feet southeast of the gully along Buffalo Gap road. That part of the Fall River formation above the Quarry sandstone, units 8 through 22, was measured from continuous exposures on the northeast side of the river from the foot of the falls southeastward to the bluffs of Skull Creek shale opposite the power plant.

Section 8. Type section of the Fall River formation

	Thickness (feet)
Skull Creek Shale (basal part):	
22. Shale, and silty shale, black; scattered ironstone concretions in upper 0.5; basal 1.5 is tough black argillaceous siltstone with rusty stain	4
21. Shale, black, silty; lower half siltier with pink stain	2

Fall River formation:	*Thickness (feet)*
20. Siltstone and silty shale; minor amounts of fine-grained sandstone; thinly and irregularly interbedded; partings gray fissile shale; uppermost silty beds iron stained	2
19. Sandstone, fine-grained, thin- to thick-bedded; local ripple-marked and "worm"-tracked surfaces; weathers buff to brown; upper 5 ft thinly bedded, locally crossbedded, lower part with more massive beds; whole unit thin-bedded upstream from powerhouse	19. 5
18. Siltstone, light-gray; in thin, laminated beds, with black shale partings; some irregular interbeds of fine-grained sandstone; weathers gray with red and yellow stain; becomes more sandy laterally	6
17. Sandstone, fine-grained- even-bedded to crossbedded, cross-laminated; some silty shale partings; weathers buff to brown; some iron impregnation at top and local red stain on bedding surfaces; base includes coarse sandstone and some clay pellets	26
16. Claystone, light-gray; increasingly silty downward, some pink mottling; coloring varies laterally; locally a black band in center of bed with yellow-stained claystone below containing weathered ferruginous spherulites	10
15. Siltstone, carbonaceous, sandy	1
14. Siltstone, gray, sandy, massive; much carbonaceous matter and pyrite; massive sandstone 2 ft thick locally at top; weathers gray to dark gray with local orange, yellow and pink stain	5. 5
13. Sandstone, fine-grained, even-bedded, massive to laminated; weathers brown with local iron stain	4. 5
12. Siltstone, gray; with 1 ft silty sandstone in middle part; locally argillaceous in upper part which is stained pink and purple; ferruginous specks (weathered spherulites?)	4
11. Sandstone, even-bedded to thin-bedded, micaceous; brown-weathering with some rusty stain on bedding surfaces	6
10. Shale, silty, gray to brownish-gray; thinly interbedded with sandstone; upper half dominantly sandy; lower half shaly	3
9. Lignite; with local lenses hard, carbonaceous siltstone and sandstone as much as 0.4 foot at base	0. 2–1
8. Claystone, silty; grading down to clayey siltstone; upper part gray with long plant rootlets extending to middle of bed, becomes red in middle part gray again in basal silty part	5. 5
7. Sandstone, fine- to medium-grained, massive, brown-weathering; some shaly sandstone interbeds at basal foot (Quarry sandstone of Ward, 1894)	49
6. Siltstone, sandy, hard, locally platy; contains plant fragments and some claystone fragments; weathers with brown and purple stain; locally grades laterally to fine-grained sandstone	2
5. Siltstone, massive, hard, subconchoidal fracture, gray; grades downward and laterally into rock type of unit 4	1. 5
4. Siltstone, irregularly laminated gray; with fine-grained sandstone; massive, fractures in big subconchoidal blocks, contains plant fragments	5. 5

	Thickness (feet)
Fall River formation—Continued	
3. Claystone, silty, black; becoming shaly; some irregular interbeds of clayey siltstone; grades to unit 4 above, becomes sandy at base	5.5
Total thickness of Fall River formation (rounded)	158
Lakota formation (in part):	
2. Sandstone, fine- to coarse-grained, massive, crossbedded; with some conglomeratic beds; weathers reddish brown; upper 1–1.5 ft is capping interval with sandstone at top, a middle layer of light-gray gritty claystone, and a basal 1-ft layer of red ferruginous, locally conglomeratic sandstone	24.4
1. Claystone, slightly silty, gray; subconchoidal fracture	.4+
Obscured by slope wash	

Supplemental section showing details of the Lakota contact about 200 feet southeast of the old quarry gully locality

	Thickness (feet)
Top.	
Fall River formation (in part):	
E. Siltstone, dark-gray, clayey to shaly; equivalent to unit 3 of preceding section	1.5+
Lakota(?) formation—Fall River(?) formation:	
D. Sandstone, silty, ferruginous red; similar to and apparently continuous with ferruginous layer near top unit 2 of preceding section	.4
Lakota formation (in part):	
C. Claystone, light-gray mottled pink and purple; becoming more silty downward, with ferruginous specks from weathered spherulites	1±
B. Siltstone, purple; with weathered ferruginous spherulites; grades to unit below	1.5
A. Sandstone, fine to coarse-grained and conglomeratic; like unit 2 of preceding section	1
Obscured by wash	

Laterally, toward the old quarry gully, the spherulitic claystone and siltstone (units B and C) beneath the ferruginous layer grade into sandstone. The contact of the Fall River and Lakota formations could be placed either above or below unit D. This ferruginous layer, unit D, and its equivalent in the preceding section, the ferruginous layer and beds above in unit 2, may represent a reworked zone at the contact.

Section 9. Government Canyon

[Exposures in the bluffs north of Government Canyon in sec. 20, T. 57 N., R. 64 W., Crook County, Wyo.]

	Thickness (feet)
Grass covered flat.	
Fall River formation (approximately at Skull Creek contact):	
63. Sandstone, fine-grained, thin-bedded; with thin interbeds, gray shale; partly obscured	3

Fall River formation—Continued	*Thickness (feet)*
62. Sandstone, fine-grained, thin-bedded, with numerous red-brown iron-impregnated layers and vermicular iron-concretionary masses	2
61. Sandstone, fine-grained, chiefly massive, friable; some zones platy to shaly sandstone and siltstone in lower part; scattered thin iron-impregnated layers	12
60. Shale, gray, silty; weathers brownish, with thin interbeds siltstone; upper 2 ft chiefly siltstone beds with some silty shale and fine-grained sandstone interbeds	8
59. Sandstone, fine-grained, thin-bedded, white; few thin beds of gray shale	.7
58. Ironstone; concretionary ledge, weathers purplish-brown	.6
57. Shale, gray; thinly interbedded and interlaminated with siltstone	3.4
56. Shale; dark gray to black at base to gray at top; siltstone laminae become more numerous upward	2.9
55. Shale, light-gray, silty; capped by thin layer ferruginous, fine-grained sandstone with "worm" borings and casts	.7
54. Shale, carbonaceous; "paper shale" in upper 1 ft, grading downward to slickensided black, finely silty clay shale	2.6
53. Shale, gray, silty; stained red to pink; carbonaceous fragments	.5
52. Sandstone, fine- to medium-grained, cross-laminated; weathers buff with much local brick red to orange staining; upper 7- to 10-ft massive; lower beds 0.5 to 2 ft thick with some shaly sandstone partings	15
51. Siltstone, clayey, laminated; interbedded with silty clay and thin lenses of cross-laminated sandstone; gray clayey siltstone with pink and lavender stain; some iron-impregnated layers; much "worm" workings evident	2.2
50. Siltstone, clayey, gray; with carbonaceous flecks; locally a silty shale	1
49. Sandstone, fine- to medium-grained; in thin beds with maximum thickness of 1 ft; beds massive to laminated and cross-laminated, some silty layers, many "worm"-worked, friable beds; upper 1.1 ft laminated, white, with ferruginous, brown cap; remainder buff and brown, basal 1.5–2 ft iron-impregnated; ripple marks, "worm" casts, and trails on bedding surfaces	10.6
48. Siltstone, shaly; interlaminated with silty shale; scattered layers siltstone in upper 1.4 ft; weathers to crumbly, gray-white face, commonly with crude vertical columnar structure	5.7
47. Sandstone, fine-grained; irregularly thin bedded, to laminated; some interbedded shale, chiefly in lower part; "worm" casts and trails on bedding planes	2.1
46. Sandstone, fine-grained, massive to vaguely laminated; weathers yellow gray; thins out locally	1.3
45. Sandstone, fine-grained; locally interlaminated with dark-gray, sandy shale containing carbonaceous flecks	.9
44. Sandstone, fine- to medium-grained, laminated to thin-bedded, cross-laminated; minor partings of sandy shale; bedding irregular, some ripple marks and "worm"-tracked surfaces	4.5
43. Sandstone, fine-grained, massive; basal 0.9 ft iron impregnated, brown; remainder weathers yellowish gray	2.5
42. Sandstone, fine-grained, silty, locally clayey, friable, irregularly bedded; weathers light buff; many "worm"-worked iron-impregnated layers; weathers brown	2

	Thickness (feet)
Fall River formation—Continued	
41. Siltstone, gray, sandy, massive to shaly; scattered carbonaceous fragments; weathers gray white to light gray	0.8
40. Shale, sandy; gray at top, reddish purple in lower 0.3 ft	.5
39. Sandstone, fine-grained, cross-laminated, hard	.5
38. Sandstone, fine- to medium-grained, "worm" worked throughout; weathers crumbly, light buff to pinkish gray	1.1
37. Sandstone, medium-grained, chiefly massive, crosslaminated,-buff-weathering; red, iron-impregnated crust on surface is "worm" tracked; many slender, vertical "worm" tubes extend from top to base of bed	2
36. Sandstone, medium-grained, even-bedded, iron-impregnated; weathers banded shades brown and red brown; bedding surfaces "worm" tracked	1.5
35. Siltstone; with pink to yellow brown ferruginous stain; interbedded with silty gray claystone which predominates in basal 0.5 ft; upper 1 foot has interbeds fine-grained sandstone	3.4
34. Shale, gray to dark-gray, silty	2.8
33. Siltstone, sandy; interbedded with shaly siltstone	1.8
32. Shale, gray, silty	1
31. Shale, sandy, pink to reddish-purple	.5
30. Sandstone, fine-grained, thin-bedded, laminated to cross-laminated; weathers buff; some sand and shale interbeds in upper 1.5 ft	7
29. Sandstone, fine-grained, massive, cross-laminated, ripple-marked; weathers buff	1.1
28. Sandstone, fine-grained; interlaminated with siltstone; scattered iron-impregnated ledges 0.1–0.3 ft thick	1.6
27. Siltstone, shaly, laminated to thin-bedded, locally clayey; scattered, thin, iron-impregnated beds with "worm"-tracked surfaces	4.6
26. Ironstone; concretionary bed	.3
25. Shale, gray, finely silty to sandy, hard	1.4
24. Sandstone, fine-grained; carbonaceous fragments throughout; weathers light yellowish-gray; lower 1.5 ft with interbeds gray, clayey siltstone	3.2
23. Shale, lignitic; locally a shaly lignite	.5
22. Siltstone, dark-gray, lenticular; grades upward to dark gray silty claystone; carbonaceous fragments throughout	0–1.3
Total measured thickness Fall River formation (rounded)	121
Disconformity.	
Lakota formation (top only):	
21. Siltstone, clayey, and light-gray hard silty claystone, weathers yellowish white; contains carbonized rootlets and irregular branching ferruginous concretions	4.4
20. Sandstone, fine-grained, argillaceous, gray-white; local purplish streaks; grades into unit below	1
19. Claystone, silty, tough, locally flinty, gray; with local orange to red concretionary masses made up of limonitic ooliths of weathered siderite spherulites	3
18. Claystone, soft, plastic; purple in lower part grading into green gray with purple mottling	2, 4

Section 10. Type section of Darton's Fuson formation

[Exposures in cliff at apex of sharp north bend in Dry Creek, Fuson Canyon SW¼ SE¼ NE¼ SW¼ sec. 36, T. 5 S., R. 6 E., Hermosa 30-degree quadrangle, Custer County, S. Dak.]

	Thickness (feet)
Fall River formation (in part):	
8. Sandstone, fine- to medium-grained, massive, cross-laminated; tabular at top; weathers to brown and rusty-brown cliff	49
7. Sandstone, coarse-grained; locally conglomeratic with granule size chert and quartzite, locally iron impregnated, rusty brown	4
Transgressive disconformity.	
Darton's type Fuson formation:	
6. Sandstone, very fine-grained, and siltstone; massive ledge, irregularly laminated to crudely tabular and crossbedded; middle part chiefly sandstone, silty zones top and base; weathers light gray to brownish gray, locally with ironstone cap	24
5. Sandstone, medium-grained; in beds 0.2 to 1 ft thick and cross-laminated, grossly crossbedded; scattered iron-impregnated layers including one at top and base; basal 2 ft locally concretionary; lower 6 ft has some coarse-grained laminae with fragments light-gray silty claystone	26
4. Claystone, silty, and gray, clayey siltstone; weathers gray white with some yellow stain	15
3. Siltstone and sandy siltstone, hard, massive; white with purple mottling in upper 5 ft, purple in lower 4 ft; local irregular chert stringers and masses at top and irregular bodies of fragmental siltstone	10
2. Siltstone and silty claystone, massive crumbly; with local beds of massive purplish-red siltstone; ferruginous concretions and some of barite at base	10
1. Siltstone, massive; contains a few thin claystone layers; weathers purple gray with some yellow stain; ferruginous concretions and some of barite at top	6
Slump and wash in bed of Dry Creek	
Total Fuson formation	92

Section 11, composite reference section of the re-defined Lakota formation, was pieced by W. P. Mapel, Charles Pillmore, and the author from exposures in the valley of Fall River in center W½, NW¼ sec. 33, and in N½ NE¼ sec. 32, and adjacent parts sec. 29, T. 7 S. R. 6 E., Fall River County, Hot Springs quadrangle, South Dakota.

Exposures are between 4 and 5 miles by road (U.S. 18) south from Hot Springs, S. Dak. Units 1 through 9 were measured in the road cut and bluff on the north side of U.S. Highway 18 about at the apex of the northward bend of the road in NE¼NW¼NE¼, sec. 32, and the adjacent part of sec. 29. Units 10 and 11 were measured about 1,000 feet due east of the preceding locality in about the center N½, NE¼, NE¼, sec. 32. Units 12 through 14 were measured south of Fall River on slopes above the dam at which the old flume begins, in center W½, W½, NW¼ sec. 33. Remaining units were measured in the river bluffs about 800 feet due east of the dam, in center E½, W½, NW½, sec. 33.

Section 11. Reference section of re-defined Lakota formation

	Thickness (feet)
Fall River formation (in part):	
37. Sandstone, massive, cross laminated; chiefly fine grained, medium grained at base, weathers light brown to brown, cliff-forming. [The Quarry sandstone of Ward (1894)]	50
36. Shale, silty, dark-gray; contains plant fragments, thin interbeds of siltstone in upper part, and some concretionary ironstone at top; weathers pink locally	1. 5
35. Siltstone, light-gray, irregularly laminated; contains interbedded fine-grained brown-weathering sandstone; forms hard ledge with upper surface weathering purplish gray	1. 5
34. Shale, silty; gray to dark-gray; grading upward to shaly siltstone in upper 5 ft; contains scattered carbonaceous fragments and irregular laminae of white silt in upper part	8
33. Siltstone, dark-gray to black, hard, blocky	1
Disconformity.	
Lakota formation:	
32. Sandstone; chiefly fine grained with thin clayey lenses; weathers light gray with pink and purple stain; scattered ferruginous specks presumably from weathered siderite spherulites	4. 5
31. Sandstone, conglomeratic; irregularly interbedded with sandy claystone; mixed fine-, medium-, and coarse-grained sandstone with chert and quartzite granules and some small pebbles; stained orange brown; weathers to slope	7. 5
30. Claystone, somewhat silty, gray, blocky; lower 3 ft silty to sandy; stained pink to red	15
29. Sandstone, light-gray, very fine grained; irregularly laminated to cross-laminated; weathers with pink to brown stain	6
28. Sandstone and siltstone, variegated gray, light-gray and purplish-gray; some pink stain; clayey in lower half, grading upward to silty claystone	10
27. Sandstone, very fine grained, soft, with interstitial clay; contains scattered lenses of silty claystone; zones of claystone pellets, including one at base; some calcareous zones; chiefly light-gray to yellowish-gray with pinkish stain	18
26. Claystone, silty; gray to purplish-gray with some yellowish-gray to purple-gray siltstone in lower foot	6
25. Sandstone, very fine grained; becoming silty near top which is marked locally by bright-green clayey sandstone bed; zones with interstintial green to purple claystone throughout	13
24. Obscured by talus and slope wash	18
23. Claystone, gray to black; calcareous in lower 4 ft, becoming waxy above; basal foot contains tan zones of ostracodal claystone	11
22. Limestone, gray, hard, compact	. 5
21. Claystone, calcareous, gray to dark-gray; becoming sandy downward; basal foot is very fine-grained tan calcareous sandstone	5. 5
Thickness of Lakota above Minnewaste limestone member	115
Minnewaste limestone member:	
20. Limestone, light-gray; with granulelike blebs of white limestone or calcite; locally sandy and containing a parting of limy sandstone with few black shale interbeds in middle part; bedding irregular, beds 0.5–3 ft thick	36

	Thickness (feet)
Lakota formation below Minnewaste limestone member:	
19. Shale and claystone, sandy, dark-gray to black, calcareous; thin lenses of limestone	1
18. Sandstone, very fine grained; grading to a sandy claystone in its middle part; weathers yellow-gray	7
17. Sandstone, fine-grained to very fine-grained, crossbedded; weathers to gray ledges with yellow to rusty brown stain	20
16. Claystone, silty, dark-gray; contains interbeds of blocky, light-gray, calcareous siltstone, and silty limestone, as much as 1.5 ft thick; a 1-ft bed of calcareous, brown-weathering sandstone lies 4 ft above the base; nearby, the sandstones above and below this unit coalesce, eliminating, it	25
15. Sandstone, very fine grained, calcareous, crossbedded; weathers yellowish gray; some beds of dark-gray shaly siltstone in lower part	17
14. Siltstone, clayey, and silty claystone, dark-gray; blocky fracture; sharp contact with unit above; upper 1 ft is hard light gray to cream-colored claystone	7
13. Siltstone, slightly calcareous; forms massive, crumbly to blocky, yellow-weathering ledge in slope	1. 5
12. Claystone, calcareous, dark-gray to black; with zones of fissile calcareous shale; locally has silty layers in upper part and a few limestone concretions 10 ft from top; basal 10–15 ft with interbeds of calcareous, yellow-weathering, siltstone; ostracodes present about 18 ft and 30 ft from top	48
11. Sandstone, very fine-grained, calcareous, crossbedded; contains zones of claystone pellets; weathers yellowish gray, forms ledges	22
10. Claystone silty, gray, calcareous, and some black calcareous shale flakes with ostracodes; chiefly covered	13
9. Sandstone, fine-grained, calcareous; with bed clay-pellet conglomerate 1–3 ft above base; weathers gray to orange brown; forms prominent bench	10
8. Siltstone, greenish-gray, calcareous; grading downward to calcareous sandy claystone	18
7. Sandstone, very fine grained, calcareous, crossbedded, ledge-forming; weathers pink to reddish brown; contains clay pellets and molds of wood fragments in base	17
6. Claystone, greenish-gray, noncalcareous; locally silty; partly covered; crops out in patches at top and base; unit thins out to west	18
5. Sandstone, very fine grained, calcareous, crossbedded, cliff-forming; weathers pinkish brown; upper 5 ft contain clay pellets and small lenses of noncalcareous claystone	40
4. Claystone, silty to sandy, gray to dark-gray; locally shaly; grades laterally into sandstone	7. 5
3. Sandstone, very fine grained, calcareous, crossbedded; weathers yellowish gray; forms a cliff	20
2. Shale, silty, calcareous, olive-gray; upper 3–4 ft gray, carbonaceous; apparently grades downward to sandy claystone; ostracodes common in upper half; unit thins to 2 ft about 150 yds to west	15
Thickness of Lakota below Minnewaste limestone member (rounded)	310±
Thickness of Lakota formation (rounded)	460±

	Thickness (Feet)
Unkpapa sandstone (in part):	
1. Sandstone, fine-grained to very fine grained, massive, friable; gray-white mottled with pink and purple; grades laterally and in upper part to clayey sandstone and siltstone	14
Road bed.	

Unit 2 is a lithic type common to the Lakota but not to the Unkpapa or Morrison. However, the base of the overlying prominent sandstone of unit 3 is an acceptable base to use for local mapping of the Lakota inasmuch as the underlying ostracodal shale appears to be a lens of very limited lateral extent.

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