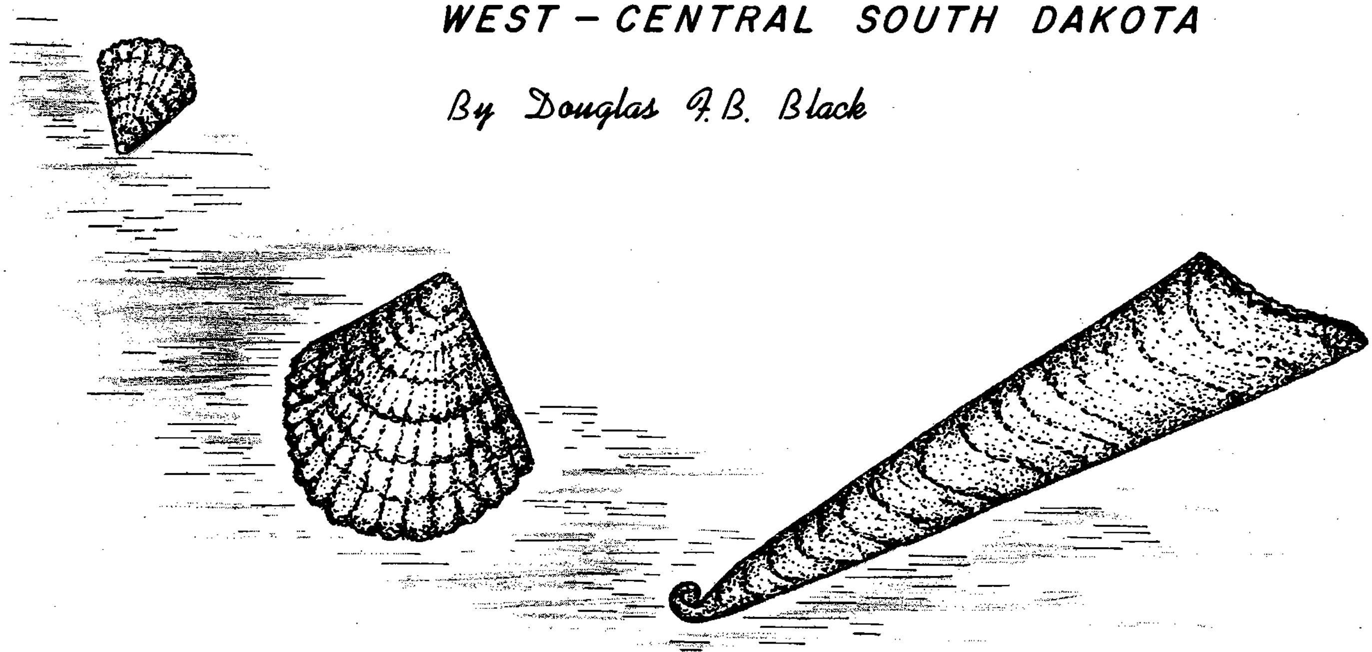
STATE OF SOUTH DAKOTA ARCHIE GUBBRUD, GOVERNOR

Report of Investigations No. 92

GEOLOGY OF THE BRIDGER AREA

WEST-CENTRAL SOUTH DAKOTA

By Douglas F.B. Black



South Dakota State Geological Survey

Duncan J. McGregor, State Geologist

Science Center, University
Vermillion, South Dakota
1964

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GEOLOGY OF THE BRIDGER AREA
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ABSTRACT

This study was made to ascertain the usefulness of surface geologic mapping in regions of Pierre Shale and Fox Hills Formation outcrop in west-central South Dakota. The field work for this report was accomplished during the summers of 1960 and 1961.

Preliminary reconnaissance indicated that the Pierre Shale could be divided into two mappable units. The upper boundary of the Pierre Shale-Lower, which was later shown to be the top of the Virgin Creek Member when related to the type section of the Pierre Shale, was established at the top of a zone of swelling bentonite beds. The upper boundary of the Pierre Shale-Upper1/ was established at the highest occurrence of glauconite associated with a zone of rusty-brown weathering concretions that marks the top of the Pierre Shale in the area mapped.

Although certain rock sequences in the area mapped are lithologically dissimilar to the members of the Pierre Shale in the type section along the Missouri River, the Pierre Shale-Lower is stratigraphically equivalent to the Verendrye and Virgin Creek Members; the Pierre Shale-Upper is stratigraphically equivalent to the Mobridge and the Elk Butte Members. Fox Hills rocks include equivalents of the Trail City, Timber Lake, Bullhead, and Colgate Members.

In the western part of the area, the rock sequence between the Virgin Creek Member and the Fox Hills Formation above is designated here as the Pierre Shale-Upper. The Pierre Shale-Upper is stratigraphically equivalent but lithologically dissimilar to the Mobridge and Elk Butte Members of the Pierre Shale along the Missouri River. An intertonguing relationship exists between the chalky Mobridge in the eastern part of the area and the middle part of the non-calcareous Pierre Shale-Upper unit in the western part of the area.

A change of lithologies across the Bridger area that involves the eastward introduction of a series of bentonite beds with a total thickness in excess of 90 feet is present at the eastern edge of the area. These bentonites were studied and included as part of an upward extension of the Virgin Creek lithology, occurring at the expense of the overlying Pierre Shale-Upper unit.

1/ Plate 2 uses the term "Unnamed Member" as synonymous with Pierre Shale-Upper. In editing the manuscript, the term "Unnamed Member" has been deleted from the text. The term "Pierre Shale-Upper" is used instead, in order to agree with the terminology as shown on Plate 1.

INTRODUCTION

General Statement

The present study is an investigation of the stratigraphy of the Pierre and Fox Hills Formations in the vicinity of the Cheyenne River in west-central South Dakota (fig. 1).

The field work for this report was done during the summer field seasons of 1960 and 1961, under the supervision of Earl J. Cox and Dr. Allen F. Agnew of the South Dakota State Geological Survey, and Dr. Edward L. Tullis of the South Dakota School of Mines and Technology.

This report is modified from a Master of Science thesis submitted to the Department of Geology and Geological Engineering of the South Dakota School of Mines and Technology, in Rapid City (Black, 1962).

Location and Accessibility

The area mapped includes parts of eastern Meade, southern Ziebach, and the northern fringe of Haakon Counties, South Dakota (fig. 1). State Routes 73 and 34 traverse the western part of the area. Gravel roads and trails are present throughout much of the area. Parts of the area are relatively inaccessible except by jeep.

Physiography

The area is in the Missouri Plateau division of the Great Plains physiographic province (Rothrock, 1943).

The terrain in the area of study is characterized by flat to gently rolling prairie. Outcrops are usually confined to the deeply incised drainages.

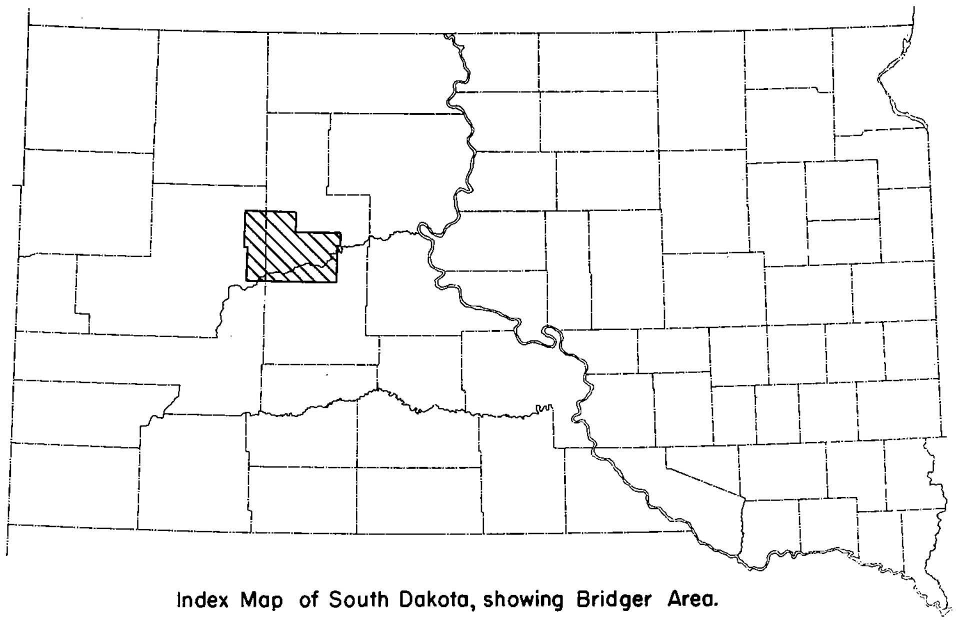
The Cheyenne River, a mature tributary of the Missouri River, flows east-northeast through the mapped area. Terraces developed by the ancestor of the present Cheyenne River cover large upland areas bordering the present river valley. These terrace deposits attain thicknesses of as much as 40 feet. They are poorly sorted sands and gravels which contain numerous rounded cobble and boulder-size particles.

The land south of the Cheyenne River is utilized mainly for farming, whereas ranching predominates north of the river. Tributary canyon bottoms are locally brushy, and clusters of juniper and cedar trees grow on north-facing slopes. Valley trees include cottonwood, box elder, ash, and elm. Outcrops in cutbanks are common.

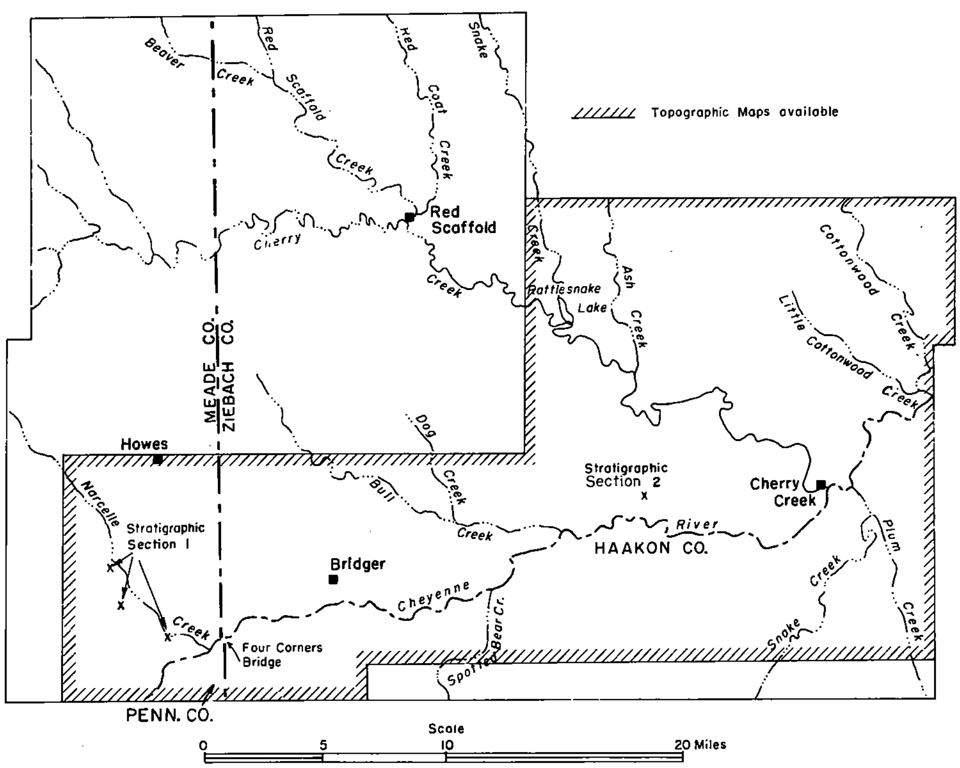
Method of Present Investigation

An approach to understanding the stratigraphy in this region was made by detailed descriptions of 40 stratigraphic sections in widely spaced exposures, in an attempt to find key horizons suitable for mapping. Large-scale slumping in the Pierre Shale is common, and may be mistaken for structural features. Lithologies of the rocks are locally variable and the rocks are commonly poorly exposed. Concretionary beds, bentonite

Figure I



Index Map of South Dakota, showing Bridger Area.



Index Map of Bridger Area.

layers, and fossiliferous zones vary in thickness or pinch out entirely within very short distances.

Before columnar sections were measured, a reconnaissance both on the ground and with air photos was made of a wide area surrounding the outcrop selected, to determine the absence of slumping and to be certain that the section would be representative of that area. As a result of this work, two composite stratigraphic sections were selected, one representative of the western and one representative of the eastern parts of the area. The fossils collected during the summer of 1961 were deposited with the Department of Geological Engineering of the South Dakota School of Mines and Technology in Rapid City.

Previous Investigations

For an early history of geologic investigations in the Pierre Shale, the reader is referred to Searight (1937). Of special note is the work of Russell (1927) in the area under consideration here. Recent investigators of the Pierre and Fox Hills Formations in the Cheyenne River region include Gries (1942), Waage (1961), Tourtelot (1962) and Tourtelot, Schultz and Gill (1960).

Acknowledgments

The writer wishes to express his appreciation to J. P. Gries, D. W. Hammerquist, and R. W. Wilson of the South Dakota School of Mines and Technology for their help. Thanks is given to H. A. Tourtelot and W. A. Cobban of the United States Geological Survey, without whose help the correlation of the rocks of the Pierre Shale of the mapped area with the type section would not have been possible. Thanks is also given to K. M. Waage of Yale University for his help in interpreting the stratigraphy of the Fox Hills Formation. Identifications of fossils collected from the Pierre Shale were made by W. A. Cobban, and Fox Hills specimens were identified by K. M. Waage.

Special gratitude is expressed to Elmo Brown and Jack Walker of the Western Cattle Company, and to F. E. Pohle of Philip, South Dakota, for their hospitality during the field seasons. Thanks is especially given to Joseph Kulik for his aid in preparing and categorizing the fossil specimens, and to P. P. Aberle for his valuable field assistance during the summer of 1960.

STRATIGRAPHY

Pierre Shale

Meek and Hayden (1861) first described the dark shale and claystone deposits of the western inland Cretaceous sea and called them the Fort Pierre Group. Searight (1937) subdivided the Pierre into members, the names of which are still in use today along the Missouri River.

The diagrammatic geologic cross-section (fig. 2) of the area described in this report shows the writer's interpretation of the stratigraphic

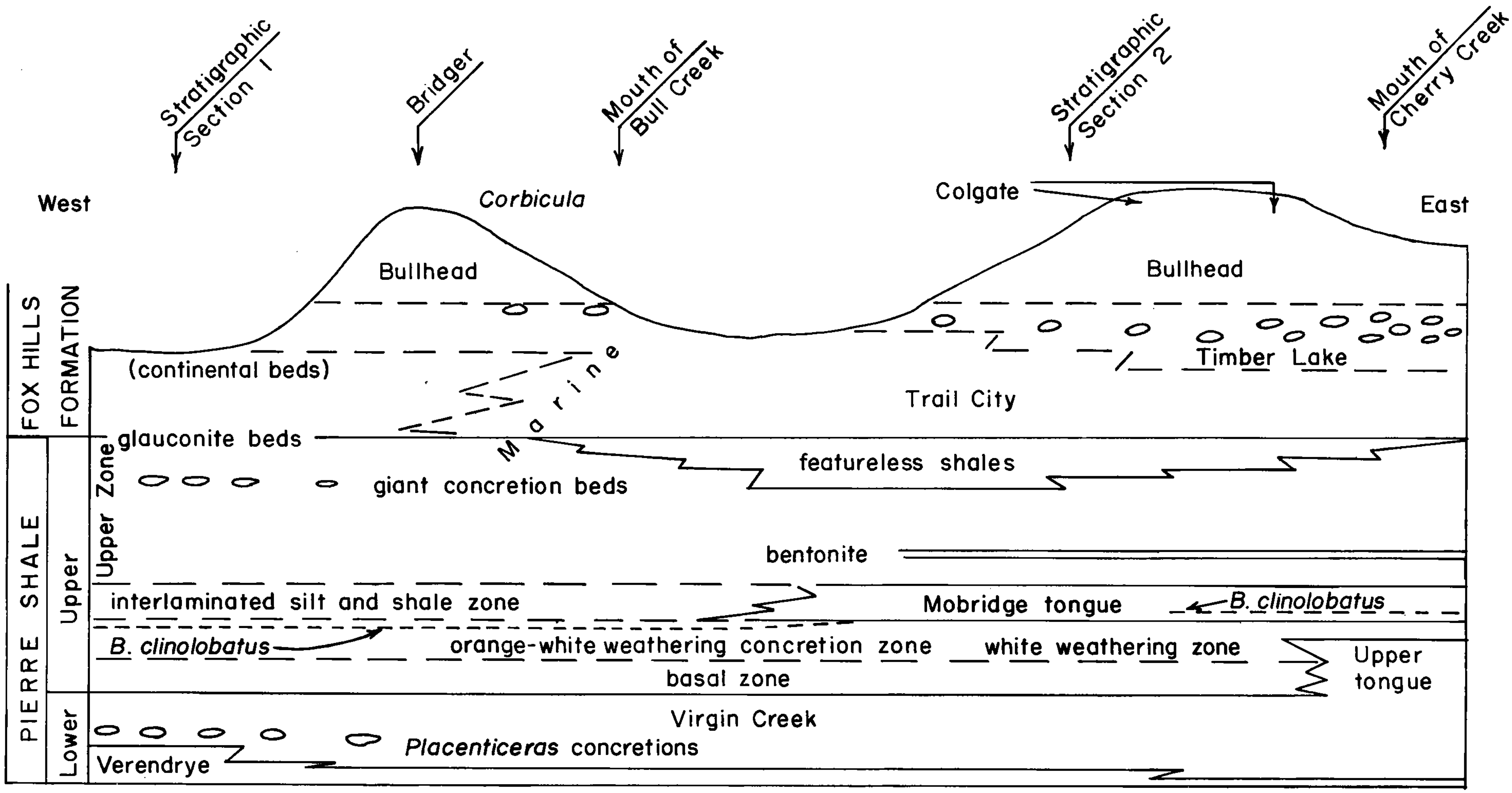


Figure 2. Diagrammatic Cross-Section of the Bridger Area. (Not to scale)

relationship of the Pierre and Fox Hills Formations in west-central South Dakota.

Because much difficulty was encountered in correlating relatively short stratigraphic sections of recurring or non-distinctive lithology, the writer concluded that the Pierre Shale should be divided into a lower unit (Pierre Shale-Lower), and an upper unit (Pierre Shale-Upper), for the purpose of mapping (pl. 1). The Pierre Shale-Lower consists of the Verendrye and the overlying Virgin Creek Members. The Pierre Shale-Upper consists of lithologic units to which formal names have not been assigned. Thus the entire Pierre Shale-Upper is mapped as a unit.

The lithologies of the Verendrye and Virgin Creek Members, as described at the type section are recognizable in the area mapped. Thus, their discussion as related to the type section was believed to be warranted, although the individual members were not mapped separately.

The lithology of the Pierre Shale-Upper, with the exception of the Mobridge tongue, is different from the Mobridge and Elk Butte Members of the Pierre Shale at the type section, and thus cannot be correlated. The Pierre Shale-Upper can be subdivided into four zones which are deemed significant enough to be discussed in detail, but none of which can be correlated with the members at the type section.

Pierre Shale-Lower

(Verendrye Member)

Name and Type Locality.--The type section of the Verendrye Member is at the Verendrye Monument, Fort Pierre, Stanley County, South Dakota, 75 miles east of Bridger (fig. 1). The member was originally described by Searight (1937) as a zone of the Sully Member, and was later raised to full member status by Crandell (1950).

Distribution.--The Verendrye Member is stratigraphically the lowest unit present in the area mapped. On Plate 1 the Verendrye together with the overlying Virgin Creek was mapped as Pierre Shale-Lower. The Verendrye is exposed at the surface in the basal parts of cutbanks along the Cheyenne River south and west of Bridger. To the east near the mouth of Spotted Bear Creek, these beds pass below the surface and were not observed again in the area.

Lithology.--The shales of the Verendrye Member are notable for the flat ovoid sideritic concretions, which weather orange to reddish brown. These concretions are typical of the Verendrye (H. S. Tourtelot, personal communication, 1961), and are the primary criterion on which the correlation was made. They range from 3 inches to slightly more than 1 foot in maximum dimension, have smooth outer surfaces, and normally exhibit a thin rim of weathering. On fresh surfaces these concretions are gray to olive green.

A prolific paleofauna is present in some localities, with the fossils contained both in the concretions and scattered through the enclosing shales.

Verendrye shales are dark gray to black on fresh exposure, and commonly exhibit a blocky appearance. However, on weathered surfaces they may show as very fissile, paper-like shales. Jarosite is abundant in fractures in the Verendrye. The value of jarosite zones as a stratigraphic marker, however, may well be questioned. Its occurrence as fracture fillings shows a post-depositional origin, but its zonal restriction suggests a close tie to original conditions of deposition. Lacking a better marker, the jarosite zones might be used as generalized stratigraphic indicators at least locally.

Thickness and Contacts.--The total thickness of the Verendrye Member was not obtained in the area mapped. Cutbank outcrops in the vicinity of the Four Corners Bridge across the Cheyenne River west of Bridger (fig. 1) expose slightly more than 40 feet of Verendrye. On Plate 2--composite stratigraphic section 1 (NW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 3, T. 6 N , R. 17 E.; center of the N$\frac{1}{2}$N$\frac{1}{2}$ sec. 32, T. 7 N., R. 17 E.; also SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 20, T. 7 N., R. 17 E.) a thickness of 38 feet of Verendrye is described. The contact with the overlying Virgin Creek Member is placed (H. A. Tourtelot, personal communication) at the top of the zone of sideritic concretions. Although a contact based on a lithologic feature as unpredictable as a concretion zone may be subject to question, its validity seems borne out by the Baculite zones established by W. A. Cobban (personal communication by H. A. Tourtelot).

(Virgin Creek Member)

Name and Type Locality.--W. V. Searight (1937) gave the name Virgin Creek Member to a succession of bentonite-bearing shales lying below the chalky Mobridge Member and above the Verendrye Member. The type section is in the valley of Virgin Creek south of Promise in Dewey County, South Dakota, 85 miles northeast of Bridger.

Distribution and General Character.--Virgin Creek shales crop out in a continuous belt along the valley of the Cheyenne River through the area studied, and extend up tributary valleys as far north as the Indian settlement of Red Scaffold (Sec. 6, T. 9 N., R. 19 E.).

Perhaps the most noteworthy lithologic feature of the Virgin Creek Member is the abundance of bentonite beds, which weather to rounded step-like prominences. Bare exposures may show seasonal variations in color, depending on the degree of dryness of the surface. When wet the outcrop belt is dark, but when dry it is light gray. Limestone concretions are locally abundant in the lower part of the Virgin Creek, and commonly these are very fossiliferous. Fossils and concretions are less common within the zone of swelling bentonite beds near the top of the member. Roads in areas underlain by Virgin Creek may become impassable during wet weather.

Lithology, Thickness and Contacts.--The Virgin Creek Member thins appreciably to the west (fig. 2). This thinning is believed to be caused by the Verendrye lithology ascending westward in the stratigraphic column. However, the interval between the upper contact of the Virgin Creek Member and the horizon marking the top of *Baculites clinolobatus* above, remains essentially constant (fig. 2).

Step-like prominences of extruded bentonite which weather to a surface resembling popcorn are common features of the Virgin Creek Member where conditions are amenable to their development. They are best developed on gently sloping, poorly vegetated terrain. During rainy periods, montmorillonite in the bentonitic shales absorbs water, swells and becomes a slippery gel. On drying, the swollen shales contract to nearly their original volume, and in so doing crack to form a diagnostic popcorn-like weathering. The dry weathered material may flow down over the underlying, less bentonitic shales, giving the appearance of a thicker bentonitic shale than actually exists. The bentonitic shales resist weathering to a slightly greater degree than the enclosing nonbentonitic shales and therefore tend to stand out as conspicuous hillside ledges and buttresses, giving the step-like appearance mentioned above. On steep cliff exposures the weathered material is carried away, exposing the bentonite beds as cream-colored bands in contrast to the dark shales.

The Virgin Creek Member in the western part of the area shows a total thickness of 77 feet at Stratigraphic Section 1 (pl. 2), near the western limit of the mapped area. The lower part of the Virgin Creek contains abundant jarosite and limonite as fracture fillings zonally distributed as in the underlying Verendrye. Limestone concretions of various sizes are randomly distributed in the shale exposures. Some of the concretions are septarian, but most are massive and weather to various shades of light gray. Fossils, especially Baculites cuneatus, are locally abundant. The shales are nondescript, generally dark in color, and are less fissile when fresh and moist to very fissile when weathered. Near the middle of the member is a fairly continuous zone of septarian limestone boulder concretions which weather to a pale yellow color. The largest measured about 4 feet across, and the fractures are filled with golden crystalline calcite. Placenticeras and large specimens of Baculites cuneatus are contained within some of these concretions and buried in the surrounding shale. This concretion zone, though outstanding to the west, could not be traced east of Bull Creek (fig. 1).

The upper part of the Virgin Creek in the western area is characterized by a zone of four bedded bentonites. The upper two beds show well-developed popcorn-like weathering. These bentonites are generally light greenish yellow, and commonly become orange near the upper and lower contacts with the shale. Disseminated flakes of biotite are abundant in some of the bentonite beds, but the writer was unable to use biotite content for long-range correlation of individual beds.

The Virgin Creek Member in the west-central part of the area shows an increase in the number of bentonite beds. In the hills above the town of Bridger, five or six bentonites are present, although multiple slumping prevents an accurate count. Popcorn-like weathered steps are strikingly developed in the vicinity of Bridger. The zone of large septarian concretions is likewise present, but it disappears to the east between Bridger and Bull Creek. Discontinuous layers of fibrous calcium carbonate are commonly associated with the bentonite beds, usually forming a caprock. At Stratigraphic Section 2 (SE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 1, T. 7 N., R. 20 E.; N$\frac{1}{2}$NW$\frac{1}{4}$ sec. 6, T. 7 N., R. 21 E.), 11 bentonites are present in the Virgin Creek. Popcorn-like weathered zones are best developed on the upper bentonites. The shales are not perceptibly different from those described above, and concretions are most abundant in the lower part of the Virgin Creek, as to the west. Two specimens of Baculites grandis were collected from the lower part of the Virgin Creek, whereas only Baculites cuneatus was found in comparable position farther west.

The Virgin Creek Member in the east and northeast part of the area shows an additional group of 1-3 typical Virgin Creek bedded bentonites in the vicinity of the town of Cherry Creek, near the eastern boundary of the area studied. These are 50-75 feet above the prominent step-like ledges which mark the top of the Virgin Creek Member to the south and west. These higher bentonites, within the rather nondescript, poorly concretionary shales of the lower part of the overlying Pierre Shale-Upper unit, are represented on figure 2 as a tongue of Virgin Creek. Immediately to the east, and to the northwest along Cherry Creek, more bentonite beds appear above and below the above-described cluster, giving a total of 90 feet of Virgin Creek lithology correlative with the lower part of the Pierre Shale-Upper to the west. Popcorn-like weathering is well developed, especially on the two uppermost bentonites. Baculites are rare in the upper tongue of the Virgin Creek in this area (fig. 2), but Inoceramus incurvatus is locally abundant, especially in the vicinity of Rattlesnake Lake (pl. 1). At Stratigraphic Section 2 the Virgin Creek is 122 feet thick.

Shales of the Virgin Creek in the east and northeast are similar to those described to the west. Limonite and jarosite zones are especially evident near the Cheyenne River. Concretions appear to be less abundant than in the overlying Pierre Shale-Upper unit.

Pierre Shale-Upper

(Distribution)

The Pierre Shale-Upper unit is a succession of heterogeneous shaley rocks in the Bridger area (pl. 1). This unit is well exposed at three localities: (1) near the center of the north line of Sec. 32, T. 7 N., R. 17 E.; (2) in the SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 20, T. 7 N., R. 17 E.; and (3) in the NW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 3, T. 6 N., R. 17 E.

The Pierre Shale-Upper crops out extensively and may be seen as far to the north as the upper reaches of Red Scaffold Creek, north of the village of Red Scaffold. To the south, these rocks form the divide between the Cheyenne River and the Bad River, which is south of the mapped area. In the north and northwest part of the mapped area, the Pierre Shale-Upper passes below the Fox Hills Formation.

(Lithology and Thickness)

The stratigraphy of the Pierre Shale-Upper is complex. Although lateral changes in lithology are common, certain zones are recognizable throughout fairly large areas. To facilitate the understanding of the stratigraphy of this unit, it is here subdivided vertically into four lithologic zones: the basal zone, the orange to white weathering zone, the interlaminated silt and shale zone, and the upper zone (fig. 2). These zones are not formally named, as the knowledge of their boundaries, depositional environments, and regional extent is incomplete.

The basal zone is a rather nondescript shale above the bedded bentonites of the Virgin Creek Member and below the orange to white weathering concretionary zone (fig. 2). At Stratigraphic Section 1 the basal zone is 45 feet thick (pl. 2), whereas farther east (Stratigraphic Section 2), it is 55 feet thick. These shales have poor to medium fissility on fresh exposures, and become more fissile when dry. Their color is variable depending on the moisture content, but generally it is medium-gray tinged with olive-green when fresh. Concretions are scarce near the base of the zone, but become more abundant upward. Several types of concretions were observed, the most important being the locally continuous bedded pavement-limestones that commonly show well developed cone-in-cone structure. This type of concretion appears to be diagnostic of the Pierre Shale-Upper. Two other types of concretion are present in the basal zone--elongate small boulder-size limestone concretions, and flat cobble-size limestone concretions.

The orange to white weathering concretion zone lies above the basal zone of the Pierre Shale-Upper unit; it is an interval of abundant concretions. These concretions weather rusty orange in the western part of the mapped area, whereas to the east they are light gray to white.

In the southwestern part of the area (Stratigraphic Section 1) this zone is slightly less than 60 feet thick. The distinctive orange-weathering flat cobble-size limestone concretions occur as discontinuous beds enclosed in blocky olive-gray slightly silty noncalcareous shale. At Stratigraphic Section 2 the orange to white weathering concretion zone is approximately 70 feet thick. The associated shale is similar to that to the west when fresh, but when weathered it is very light in color and for this reason makes a valuable stratigraphic marker that is easily seen at a great distance.

Throughout the mapped area the orange to white weathering concretion zone is highly fossiliferous with <u>Baculites</u> <u>clinolobatus</u>. In the upper part of the zone <u>Inoceramus</u> <u>fibrosus</u> is common.

The upper limit of Baculites is a significant stratigraphic feature. At Stratigraphic Section 1 no Baculites were collected above a large concretion bed that marks the top of the orange to white weathering concretion zone (pl. 2). At Stratigraphic Section 2 this upper limit occurs 12 feet below the upper contact of this zone. This abrupt upward termination of Baculites was noted throughout the area mapped, and its value as a stratigraphic marker of wide distribution was first made known to the writer by Karl Waage (personal communication, 1961).

The interlaminated silt and shale zone is a 50-foot interval of intercalated silt and black shale beds that occurs immediately above the orange to white weathering concretion zone (fig. 2) in the southwestern part of the mapped area. This zone is strongly banded, with strata of blue-black highly fissile noncalcareous shale interposed with brown colored zones of very silty shale. These alternating bands are somewhat variable in thickness, but normally are 10-15 feet thick. The silt is concentrated in laminae within the brown colored zones. This unit is noncalcareous west of the Bull Creek drainage (fig. 1). The upper contact of the orange to white weathering concretion zone is arbitrarily drawn at the top of the highest band of black shale at Stratigraphic Section 1, although at this locality the entire interval between the top of this zone and the base of the Fox Hills Formation is quite silty. Inoceramus fibrosus is the predominant fossil, although some Scaphites were collected from the interlaminated silt and shale zone. Types of concretions include pavement limestones with cone-in-cone structure, and several kinds of ellipsoidal limestone concretions.

East of the Bull Creek drainage, and lying directly above the orange to white weathering concretion zone, is an interval of highly calcareous silty shale that makes up the Mobridge tongue (because of its similarity to the Mobridge Member of the Pierre Shale near Mobridge, South Dakota). This tongue is lithologically similar to the interlaminated silt and shale zone described above, with alternating intervals of intercalated shale and silt laminae and beds of blue-black very fissile noncalcareous shale, giving a banded appearance to the outcrop. In the Mobridge tongue, however, the silty strata are highly calcareous and weather to a pale-cream color which contrasts with the gray color of overlying and underlying units. The megafossil content of the Mobridge is very similar to that of the interlaminated silt and shale zone to the west, but in addition several foraminiferal beds that do not occur farther west are present at Stratigraphic Section 2. Further study might relate the microfossil occurrence to the calcareous nature of the Mobridge tongue. The cream-colored Mobridge tongue occurs south of the Cheyenne River along the canyon of Spotted Bear Creek (fig. 1), but is not present farther west. Rocks of the Mobridge tongue commonly form conical peaks and crop out extensively in the vicinity of Dog Creek (fig. 1); farther to the north and east, along Cherry Creek, they are present above the white layer of the orange to white weathering concretion zone. Forty-two feet of Mobridge calcareous siltstone were measured at Stratigraphic Section 2 (pl. 2).

The rocks of the upper zone of the Pierre Shale-Upper are laterally variable in lithology, as are those of the underlying zones. The only complete stratigraphic section of this upper zone was in the southwest part of the mapped area where 238 feet were measured (Stratigraphic Section 1). In other areas only partial sections were seen, and as a result no accurate long-range correlation of individual beds within the zone is possible. Their mutual stratigraphic relationships have been extrapolated from their positions with respect to the overlying Fox Hills contact.

In the southwest part of the area the upper zone is silty throughout, the silt occurring as disseminated grains or as fine laminae. Shales and mudstones are dominant. The differences in permeability of the more silty and less silty zones to water-deposited minerals such as limonite and less commonly jarosite, may explain the banded appearance of certain strata. The limonitic zones weather light brownish gray in contrast to the darker grays of the interposed less silty layers. Certain concretion beds are noteworthy and make good local stratigraphic markers. Notable in the southwestern section are several intervals of flat ovoid limestone concretions which weather white; the lowest of these intervals was used to correlate between the different exposures that make up the composite Stratigraphic Section 1. Enclosed within these concretions are several fossils, of which the most prevalent is Inoceramus fibrosus. Scaphites are also present in these concretions.

The giant concretion beds (Stratigraphic Section 1) are of wide lateral extent in the southwestern part of the area. They are readily recognized by their extraordinarily large size, commonly exceeding 6 feet across. Individual concretions are generally rounded, asymmetrical, medium brown, and have a rough surface. Some are convex and lenticular in shape, and have a peripheral development of cone-in-cone structure that is thickest on the upper surface of the concretion. Calcite-filled septaria are locally present. Scaphites are locally abundant and some are well preserved. Specimens of Lingula are present in the upper shales in this area, and there is a marked increase in their abundance to the north. Pavement limestone concretion beds with associated cone-in-cone structure are present but scarce in the southwestern part of the area.

In the southeast part of the area, the upper zone is 70 feet thick at Stratigraphic Section 2. Thirty feet above the top of the Mobridge tongue is the base of a locally important assemblage of four bentonite beds, in a zone 17 feet thick. Two of the four bentonite beds are closely spaced and form prominent popcorn-like ledges. These two bentonite beds may be traced northeastward to the limit of the mapped area. At Stratigraphic Section 2 an interval of light-gray weathering, cobble to boulder size, spheroidal limestone concretions is present above the two bentonite beds. Within some of the concretions are specimens of Inoceramus fibrosus and small chitinous Lingulids. These Lingulids resemble flax seeds, and become increasingly abundant to the north.

The upper strata of the Pierre Shale-Upper in the northern part of the mapped area are so lithologically uniform that they have been termed featureless. The application "featureless shale", coined by the writer to describe the rocks of the upper zone in this area, had also been chosen by Karl Waage to describe this same sequence of rocks farther northeast (personal communication, 1961). This shale body thins to the south and is not seen in the southwestern part of the area. The featureless shale unit was observed in all sections measured in the northern exposures of the upper part of the Pierre Shale-Upper. Cutbanks along Cherry Creek and its tributaries from the north clearly display the featureless shales. The rocks are dark gray strongly fissile noncalcareous shales containing numerous thin-bedded pavement limestone concretions similar to those found in the basal zone. These concretions range in thickness from slightly more than 1 inch to more than 1 foot, and occur as thin tabular sheets of variable lateral extent. Cone-in-cone structure is generally best developed on the upper surface of the pavement limestone concretions. Though these bedded limestones would appear to be excellent markers, they are valueless for even local correlation because of the unpredictable lateral discontinuity of the individual beds. Commonly present within these featureless shales are the Lingulids described for the southeastern part of the area. Although they are seemingly restricted to the shales of the upper zone in this part of the area, they are present through more than 200 feet of section, and are thus of little stratigraphic value.

(Correlation and Contacts)

The Pierre Shale-Upper lies between the Virgin Creek Member of the Pierre Shale and the overlying Fox Hills Formation. As has been described, lateral changes in lithologies are common, and exact correlation with the Mobridge and Elk Butte Members at the type section along the Missouri River is not possible at this time.

With the exception of the Mobridge tongue in the area east of Bull Creek, identifiable by its chalky nature, no readily recognizable widespread lithostratigraphic planes were identified in the Pierre Shale-Upper of the mapped area. For this reason the Pierre Shale-Upper was mapped as a single unit (pl. 1), although local lithologic zones are described.

The lower contact of the Pierre Shale-Upper is drawn at the top of the uppermost bentonite bed of the underlying Virgin Creek Member. Throughout the mapped area the upper contact of the Pierre Shale-Upper was drawn at the highest occurrence of glauconite in a zone of ferruginous limestone concretions that weather reddish brown.

Except for the dark-gray featureless shales immediately underlying the Fox Hills Formation in the northwestern part of the mapped area (fig. 2), the weathered Pierre Shale-Upper is usually lighter in color than the underlying Virgin Creek and Verendrye Members. In the west the silt content of the shales in the Pierre Shale-Upper is generally higher than that of underlying members. The silt content is especially high within the Mobridge tongue and overlying rocks. The absence of cone-in-cone structure on concretions within the Virgin Creek and Verendrye Members, in contrast to the generally well developed cone-in-cone structure in association with concretions of the Pierre Shale-Upper, may also be significant.

Fox Hills Formation

Name and Type Locality

The name Fox Hills was originally proposed for the sandy marine strata of the Upper Cretaceous by Meek and Hayden (1861, p. 415-447), as exposed typically south of the Moreau River, 20 miles east of the town of Dupree (45 miles northeast of Bridger). The formation has subsequently been subdivided into the following four members on the basis of lithology: the Trail City, Timber Lake, Bullhead, and Colgate Members. Within the mapped area, however, these four rock units change laterally and detailed mapping of them was not attempted. They are discussed because they have application locally.

Distribution

The Fox Hills Formation underlies the surface throughout the northern and western part of the area mapped and is present as isolated hilltop exposures farther south (pl. 1).

Trail City Member

The name Trail City was assigned to the lower silty clay of the Fox Hills Formation by Morgan and Petsch (1945), from exposures near the town of Trail City, 90 miles northeast of Bridger. Rocks equivalent to Trail City within the area studied exhibit lithologic variability both vertically and laterally. Throughout most of this area these lower beds are presumably of deltaic to nearshore marine environment. Outcrops are thinly banded in shades of light gray and tan. Beds of friable fine-grained sand and silt are intercalated with light-colored silty clays. Small fragments of carbonaceous plant remains are locally abundant. Several types of concretions are present. Near the base of the Fox Hills there is locally an upward continuation of the rusty- and orange-weathering concretions of the uppermost part of the Pierre. Dark-brown sandstone concretions are common in the upper part of the Trail City Member. These are usually tabular, somewhat rounded, and are locally in beds widely dispersed. Certain concretions are fossiliferous, containing numerous pelecypods. Another type of concretion not seen by the writer below the Fox Hills (although Russell (1927) noted that they were one of the four types of concretions in his worm-eaten zone of Virgin Creek Member of the Pierre) is termed "pipestem" by the writer. These concretions are chalky white and phosphatic, showing elongate hollow cylinders resembling thick pipestems. In past studies these have sometimes been referred to as Serpula (Russell, 1927). The pavement limestone concretionary beds with well-developed cone-in-cone structure, typical of the basal zone of the Pierre Shale-Upper, are seemingly absent from the Fox Hills.

In some areas numerous thick bentonite beds were observed within the Trail City Member. These lower bentonite beds locally swell with the consequent popcorn-like weathering which is light colored. Although some of these bentonites might be considered thick enough for commercial development, included sheets of fibrous calcium carbonate make them valueless for this purpose (Earl Cox, oral communication, 1961).

Flat or gently sloping topographic surfaces underlain by Trail City rocks commonly display white "flats" of alkali. These alkali flats show to advantage on air photos and are useful in locating approximately the Trail City boundaries. However, this feature must be used with caution, as the alkali may be carried far downslope.

The lower part of the Fox Hills near the southwestern extremity of the mapped area is lithologically distinct from the Trail City described before. Here and farther to the west the Fox Hills rocks exhibit sedimentary features indicative of very near-shore or even continental environment. No bentonites are present. There is a noticeable increase in total sand content, as compared with rocks of similar stratigraphic position farther north. Ripple-mark and large-scale festoon cross-bedding are present in the flaggy resistant sandstone bed shown at the top of Stratigraphic Section 1. Several small pelecypods were collected 20 feet above the Fox Hills-Pierre contact. It is unknown presently whether these are of marine or non-marine origin.

Timber Lake Member

The Timber Lake Member was named by Morgan and Petsch (1945) from exposures near the town of Timber Lake, 80 miles northeast of Bridger. Immediately west of the town of Lantry (45 miles northeast of Bridger) Karl Waage and the writer saw a thick section of medium-grained fossiliferous sandstone containing the ammonites Sphenodiscus sp. and Discoscaphites nebraskensis, and the pelecypod Idonearca sp. This member thins considerably and eventually pinches out to the southwest, and its position was recognized at only two localities within the mapped area. At the Freeman Ranch outcrop (NE$\frac{1}{4}$ sec. 20, T. 11 N., R. 19 E.) this member is thin and it is represented by a series of closely spaced dark-brown sandstone concretion beds occurring within a silty claystone of Trail City lithology, which can be correlated with the Timber Lake by fossils. At the Leo Collins Ranch outcrop (center of the N$\frac{1}{2}$ sec. 31, T. 9 N., R. 17 E.) near the western extremity of the area mapped, Waage was able to recognize one Scaphite specimen characteristic of Timber Lake.

Where the Timber Lake Member is absent the Trail City and overlying Bullhead lithologies grade into one another, and no adequate contact criterion between the two members was established by the author.

Bullhead Member

The "banded beds" of the upper Fox Hills was named by Stevenson (1956), from exposures near the town of Bullhead, 120 miles northeast of Bridger. Although rocks of this member were seen at only two locations in the area studied, the Freeman Ranch and Leo Collins Ranch outcrops mentioned above, no evidence of lateral thinning or of change in lithology was observed. Outcrops are restricted to topographic highs. The banding so characteristic of the Bullhead (although not restricted to this member) is caused by compositional and thereby color variations between beds. Notable among the various lithologic types are bentonites and bentonitic shales. Shales and sandy clays are present, commonly with an abundance of minute fragmental carbonaceous material. Friable sandstones, generally less than 5 feet thick, also occur within the Bullhead. These sandstones are generally well sorted, but grain size varies from bed to bed. To the west, beds of fine, medium, and even coarse-grained sand are present. The color of the sandy beds is usually brown, but some beds have a strong yellow cast, owing perhaps to interstitial jarosite. Calcareous sandstone concretions are present although not abundant. Few fossils were collected from the Bullhead, and Waage corroborates that they are rare in this member throughout the total area of its distribution. At one locality (Leo Collins Ranch), several small pelecypods and scattered fish scales were collected.

Colgate Sandstone Lenses

The name Colgate was originally applied by Calvert (1912) to the upper gray-white sandstones of the Fox Hills that crop out in eastern Montana. The name has subsequently been applied in Wyoming, North Dakota, and South Dakota to similar sandstones at or near the Hell Creek-Fox

Hills contact. Typical Colgate sandstones crop out on the Freeman Ranch north of the mapped area, on the divide between Red Coat and Snake Creeks (fig. 1). At this locality the sandstone occurs as lenses and hugh spheroidal bodies embedded in the upper part of the Bullhead Member. These sandstone masses are dark reddish brown and exhibit convolutions and crossbedding, which suggest origin as sand-filled channels cut into the sediments of the Bullhead. No fossils were collected at this outcrop.

Near the western limit of mapping, on the Hlovka Ranch (NE$\frac{1}{4}$ sec. 7, T. 8 N., R. 17 E.) a reef of Corbicula crops out at the crest of a hill composed of the upper part of the Bullhead. This pelecypod is considered to be indicative of Colgate equivalence (Waage, oral communication, 1961).

Correlation and Contacts

Correlation of Fox Hills rocks in the mapped region with those of the type locality was made by Karl Waage (oral communication).

The lower contact of the Fox Hills Formation with the underlying Pierre Shale is gradational. Within the area mapped by the writer, this contact was drawn on the upper zone of glauconite associated with the zone of ferruginous concretions described in the preceding section. This glauconite is not believed to be correlative with the glauconite of the zone of Protocardia found well up in the Trail City Member of the Fox Hills Formation, outside the mapped area to the east. No outcrops of the Hell Creek Formation were identified in the mapped area.

GEOLOGIC HISTORY

During late Cretaceous time an extensive inland sea prevailed throughout the Western Interior Region which includes the State of South Dakota. This relatively shallow seaway is believed to have joined the deep sea both to the north and south and to have been bounded by continental masses on the east and west. These continents are presumed to be the source areas from which the sediments of the Pierre and Fox Hills Formations were derived. The lithology of rocks of these formations is not uniform owing to environmental changes during their deposition. Alternate shoaling and deepening of the Western Interior sea before its final withdrawal is indicated by the recurrent deposition of sediments of coarser grain size within the clays of the upper part of the Pierre and the lower part of the Fox Hills Formations.

In the Bridger area the general coarsening of grain size to the west and southwest seems to imply that the seas withdrew to the east. This is supported by the increasing abundance of marine fauna toward the east.

A study is presently being made by members of the United States Geological Survey to determine the relationship between the bentonites of the upper Cretaceous in South Dakota to the late Cretaceous volcanic activity in south-central Montana (Tourtelot, oral communication).

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