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LOWER PART OF THE MARINE CRETACEOUS AT GOLD CREEK, VERMEJO PARK, NEW MEXICO

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INTRODUCTION

An unusually clean exposure of Upper Cretaceous marine rocks, including the Graneros, Greenhorn and Carlile formations, and the Fort Hays and Smoky Hill Members of the Niobrara Formation occurs at Gold Creek on the east flank of the Sangre de Cristo Mountains in extreme northern New Mexico. Throughout most of this area, the ridge-forming Dakota Sandstone is commonly vertical or overturned, and the marine shale part of the sedimentary section is usually covered by debris from the Dakota. In areas to the north, where the Dakota dips eastward into the Raton Basin, the nonresistant marine shales, marls and limestones form slopes that are generally covered by soil and colluvium.

The excellent exposure of Upper Cretaceous rocks at Gold Creek is the apparent result of a combination of landsliding and erosion that occurred on the north side of the creek, immediately east of the point where the creek cuts through The Wall—a steep, rugged hogback formed by resistant rocks of the Dakota Sandstone. We measured a stratigraphic section at this location on July 20, 1966, and collected samples for microfossils. We were assisted by P. J. Varney, U.S. Geological Survey, and C. Porter, University of Colorado. In the laboratory, Michael Evetts analyzed the foraminifera from the upper black shale unit of the Carlile Formation.

Location

The Gold Creek exposure (Fig. 1) is near the road from Vermejo Park to Costilla Lodge in sec. 8, T. 31 N., R. 17 E., Colfax County, New Mexico (Fig. 2). This location is about 3.2 mi (5.2 km) south of the New Mexico-Colorado state line, on privately owned land of the Vermejo Ranch. Vermejo Park is accessible by private roads from Raton, New Mexico, to the east; from Cimarron, New Mexico, to the south; and from Stonewall, Colorado, to the north. The area can also be reached from Torres, Colorado, about 8 mi (13 km) north of the state line; however, locked gates and general unavailability of keys discourage entry from this direction.

Previous Work

This section was examined by C. H. Dane and W. G. Pierce, of the U.S. Geological Survey, in the early 1930's. Their intent was to relate these rocks to Cretaceous rocks to the east (Dane and others, 1937), and the section was not described in detail. A. A. Wanek, of the U.S. Geological Survey, mapped in this area in the 1950's.

GEOLOGIC SETTING

The New Mexico portion of the Raton Basin is a broad asymmetric syncline; the gentle dips of its east flank contrast sharply with vertical to overturned beds along its west flank. The marine Cretaceous rocks form only a part of the total sedimentary section, which ranges in age from the Penn sylvanian and Permian Sangre de Cristo Formation to the

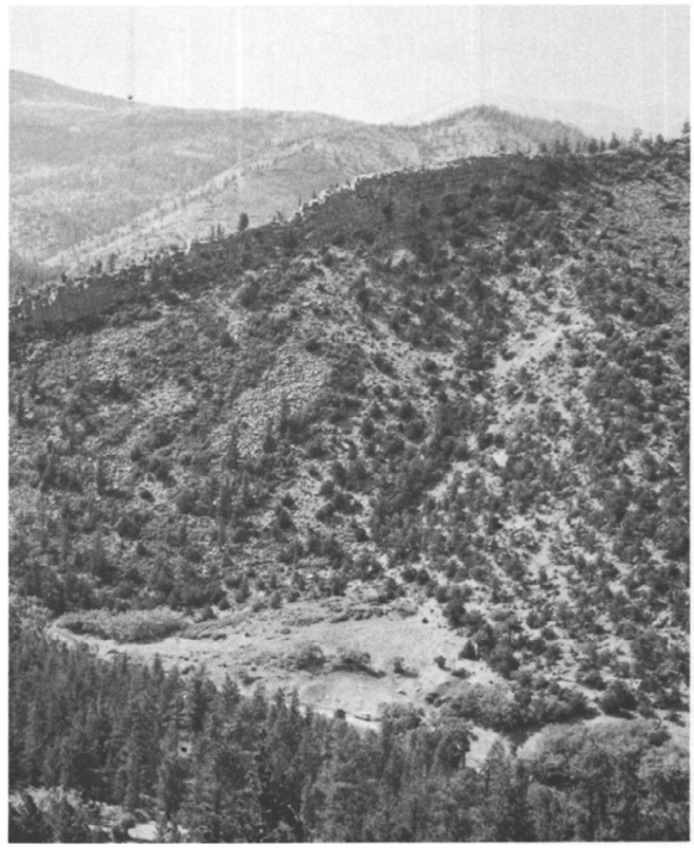

Figure 1. View of Gold Creek section from across the valley, looking northeast. The overturned Dakota Sandstone forms the rugged crest of the ridge; the Fort Hays Member of the Niobrara crops out at the bottom of the slope.

Cretaceous and Paleocene Poison Canyon Formation. About 1.1 mi (1.8 km) west of the Gold Creek section, the oldest sedimentary rocks in the section are sharply overturned beneath Precambrian crystalline rocks that have been thrust faulted from the west. Nearly the entire lower part of the sedimentary section, including the lower half of the Pierre Shale, is overturned. The inverted character of the beds is apparent for more than 10 mi (16 km) to the southwest, to a point where the Dakota Sandstone is cut out beneath the thrust fault. At the Gold Creek exposure, the rocks dip about 55° to the west. Just 1.7 mi (2.7 km) east of the exposure, the rocks of the Trinidad Sandstone and of the Vermejo and Raton Formations dip about 25° to the east. An intervening broad valley, formed of thick Pierre Shale and characterized by limited exposures, reveals little about structural changes necessary to effect this major change of attitude. Even though the rocks at the Gold Creek exposure have been intensely

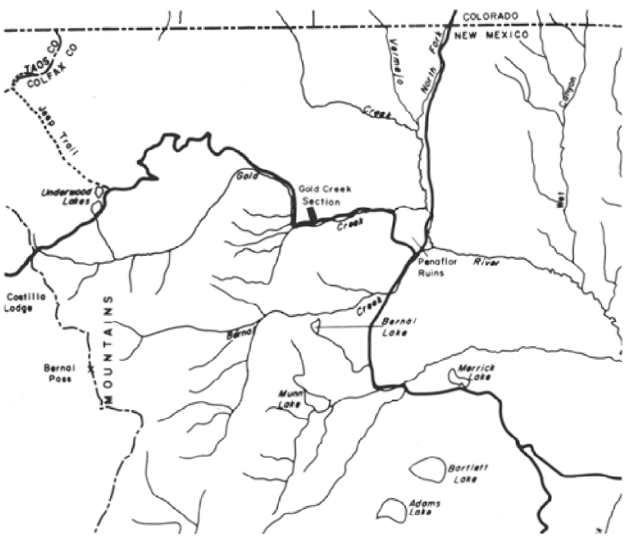

Figure 2. Map of Gold Creek section area, Colfax County, New Mexico. Bar on Gold Creek shows location of section. Inset from Fig. 6 (Pillmore and Scott, this Guidebook).

deformed, the section from Dakota through Niobrara appears to be nearly complete.

STRATIGRAPHY

Because the strata are overturned, the meaning of terms such as "below" or "above" can be ambiguous and must be carefully chosen. For instance, "the lower part of the section" could be used to describe the lower part of the exposure, which is actually the upper part of the section stratigraphically. In the following description, we use these terms only in the stratigraphic sense. The units are described as they are encountered in the outcrop, from youngest to oldest, beginning with the Niobrara.

Niobrara Formation

The Niobrara Formation consists of two members along the eastern flank of the Sangre de Cristo Mountains: the Smoky Hill Shale Member and the Fort Hays Limestone Member. Detailed measurement began at the Fort Hays Limestone Member, but much of the Smoky Hill, which consists of fissile, medium- to dark-gray, hard calcareous shale that weathers silver gray, can be seen in scattered outcrops along the north valley wall of Gold Creek, beneath boulder debris from the overlying pediment. These beds strike N. 35° E. and are overturned from about 45° near the base to about 60°-70° near the top. An interval of calcareous sandstone occurs in the upper half of the member.

At the Gold Creek section, the Fort Hays Limestone Member crops out as distinct blocky beds of yellowish-gray weathering limestone separated by beds of gray calcareous shale. The member is about 8 ft (2 m) thick. The section described by Dane and others (1937) differs from ours in the lower part in that a zone 13 ft (4 m) thick, containing several bentonite beds, is included in the Fort Hays part of the Niobrara Formation. We include only the bentonites that occur in the limestone unit and assign the remainder of the zone to the Carlile Formation.

Carlile Formation

The Carlile Formation at Gold Creek includes (in descending order) an upper black shale unit, the Juana Lopez Member, the Blue Hill Shale Member and the Fairport Member. The total thickness of the formation is 252 ft (76.8 m) compared to about 165 ft (50 m) at Tercio, Colorado, a few miles to the northeast (Cobban, 1956). Cobban's Carlile consists of only the Codell, Blue Hill and Fairport Members, thus accounting for the difference in thickness.

Upper Black Shale Unit

The upper part of the upper black shale unit consists of light-gray calcareous shale that includes several bentonite beds and grades into the overlying Fort Hays. The middle part contains darker, soft, less calcareous shale and a zone of grayish-brown septarian concretions. The lower part consists of dark, soft, noncalcareous flaky shale that contains zones of petroliferous septarian limestone concretions and thin beds of fine-grained burrowed calcarenite. The lowest beds grade downward into the Juana Lopez Member. The 58 ft (18 m) thickness of this unit here is nearly twice that observed by Kauffman and others (1969) 50 mi (80 km) to the north in Huerfano Park.

Juana Lopez Member

The distinctive yellowish-brown fossiliferous, fetid Juana Lopez Member consists of an upper part, 20 ft (6 m) thick, of black calcareous shale that contains several thin beds of fine-grained calcarenite, and a lower part, 5 ft (1.5 m) thick, of fossiliferous calcarenite. The lower 5 ft unit contains limestone fragments, a few thin shale interbeds, and a zone of flattened limy concretions. *Lopha lugubris,* a distinctive fluted oyster (Fig. 3), occurs throughout and also forms a coquina layer at the base of the concretion zone.

Blue Hill Shale Member

The Blue Hill Shale Member can be divided into three parts: an upper unit, 18 ft (5.5 m) thick, of soft, fissile shale; a middle unit, 56 feet (17 m) thick, consisting of two thick concretionary zones separated by an interval of silty shale; and a lower unit, 63 ft (19 m) thick, made up of two shale intervals separated by a 7 ft (21 m) siltstone bed that contains thick limestone concretions. The thickness of the Blue Hill Shale Member at Gold Creek (135 ft or 42 m) is 21/2 times as great as that (55 ft or 17 m) described by Kauffman and others (1969) in western Huerfano Park. Kauffman and others noted that thinning of the Codell Sandstone Member commonly corresponds to thickening of the Blue Hill Shale Member. If the 70 ft (21 m) thick Codell Sandstone Member in Huerfano Park passes laterally into the Blue Hill Member at Gold Creek, this would help account for the extraordinarily thick Blue Hill Member at Gold Creek. At Gold Creek, the Codell Member is not designated separately, because it is represented by only about 3 ft (0.9 m) of siltstone, which is included in the top of the Blue Hill. There appears to have been little if any erosion beneath the disconformity reported at the base of the Juana Lopez Member.

Fairport Member

The Fairport Member at Gold Creek is 32 ft (10 m) of mostly very calcareous gray shale. The top of the member is placed at a thin, petroliferous, bioclastic limestone that

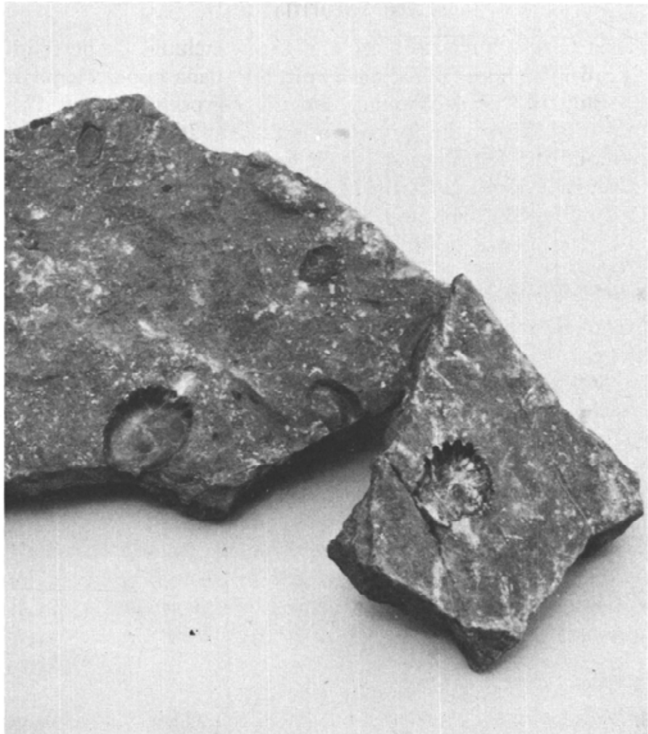

Figure 3. Lopha lugubris. *Note distinctive fluting around edge of shell. Fossils are approximately 1 in. (2.5 cm) in diameter.*

weathers dusky yellow to yellowish-orange and consists almost entirely of *Inoceramus* prisms and planktonic foraminifera. A dark yellowish-orange weathering bentonite bed about 1 ft (0.3 m) thick occurs approximately in the middle of the member. The lower few feet contain *Mytiloides labiatus* and grade down into shaly limestone that becomes thicker bedded in the lower 1 ft (0.3 m).

The 97 ft (30 m) thickness of the Fairport reported by Kauffman and others (1969) in western Huerfano Park probably includes rocks here described as the lower part of the Blue Hill Shale Member. The numerous bentonite beds and thin inoceramite beds in the lower part of the Fairport Member in Huerfano Park were not noted in the Gold Creek section, perhaps indicating north-south facies changes. Foraminifera indicate that the lower part of the Blue Hill Member at Gold Creek is equivalent to the upper part of the Fairport Member to the north.

Greenhorn Formation

The Greenhorn Formation is made up of three members in this area: the Bridge Creek Limestone Member (top), the Hartland Member and the Lincoln Member (bottom). The formation includes 130 ft (40 m) of strata, about the same as it does to the north in Huerfano Park (Kauffman and others, 1969).

Bridge Creek Limestone Member

The Bridge Creek Limestone Member consists of 16 ft (5 m) of gray, yellow weathering limestone in beds about 1 ft (0.3 m) thick or less and interbeds of shaly limestone, gray calcareous shale and bentonite as thick as 8 in. (20 cm). The limestones are hard, granular and petroliferous and contain abundant *Mytiloides labiatus.* In Huerfano Park, Kauffman and others (1969) reported abundant *Sciponoceras gracile,* but none was found at Gold Creek. In 1964 Cobban collected a large specimen of *Mammites nodosoides* at Gold Creek that is nearly identical to one found near Pueblo, Colorado (Fig. 4). Dane and others (1937) included 25 ft (8 m) of "hard gray limy shale" with 25 ft (8 m) of alternating limestone and shale in their Greenhorn Formation. This description would place the entire Fairport Member of the Carlile, as described here, in the Greenhorn.

Hartland Member

The Hartland Member, 52 ft (16 m) thick, consists predominantly of dark-gray brittle calcareous shale that weathers light-bluish-gray and forms a slope covered with flaky shale. Thin bentonite beds occur in the upper and lower parts. The Hartland is in sharp contact with the limestones of the overlying Bridge Creek Member but is gradational with the underlying Lincoln Member.

Lincoln Member

The Lincoln Member consists of flaky, calcareous and noncalcareous shale. The top is defined as a 6-12 in. (0.15-0.3 m) zone of limestone (calcarenites of Kauffman and others, 1969) in beds 2 to 3 in. (5 to 7 cm) thick. The limestones are unfossiliferous but quite pungent when freshly broken.

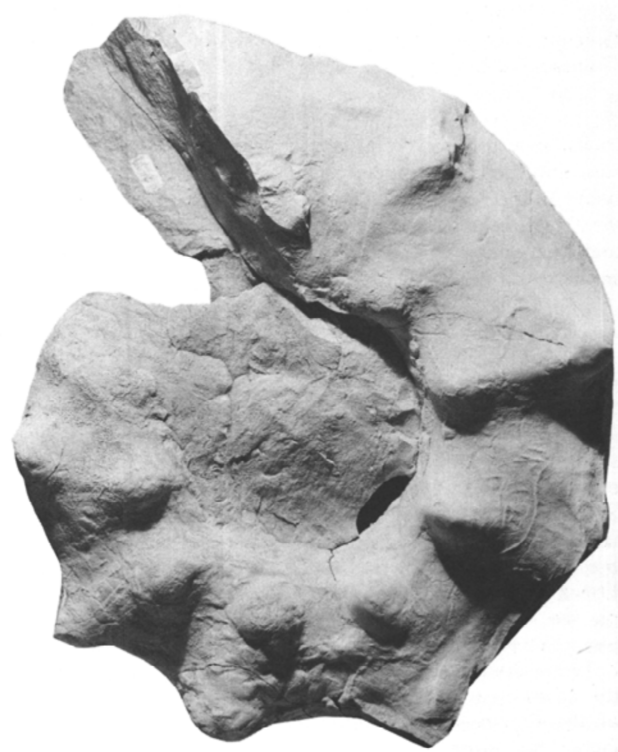

Figure 4. Mammites nodosoides *(Schlotheim) subsp.* wingi *Morrow. Side view of a large specimen, 50 cm maximum diameter, found 25.5 ft (7.7 m) above the base of the Bridge Creek Limestone Member at USGS locality D6149, Boggs Creek, west of Pueblo, Colorado, NW¼ sec. 1, T. 21 S., R. 66 W. (From Cobban and Scott, 1972.)*

The calcarenite beds that define the base of the member elsewhere are evidently obscured beneath debris and soil, but a 1 ft (0.3 m) thick bentonite bed 62 ft (19 m) below the top is assumed to be the "X" bentonite marker bed of Kauffman and others (1969) and is taken to mark the base. Further excavation would probably uncover the calcarenite beds.

Graneros Shale

At Gold Creek, the 112 ft (34 m) thick Graneros Shale is mostly covered. However, scattered exposures allow at least partial examination of nearly the entire formation, and the three-part division described by Kauffman and others (1969) can be used here. The upper unnamed shale unit is roughly 80 ft (24 m) thick and consists mostly of soft, black, flaky, noncalcareous shale that contains a few thin silty zones and is calcareous in the lower part. Below the shale unit is a hard, noncalcareous, mottled gray and brown siltstone 6-12 in. (0.15-0.3 m) thick. The position of this siltstone bed corresponds to that of the calcareous concretion zone described by Dane, Pierce and Reeside (1937) 30-40 ft (9-12 m) above the base of the Graneros. This zone probably represents the Thatcher Limestone Member of the Graneros Shale. The 30 ft (9 m) lower shale unit is almost completely covered by debris from the cliffs at the ridge crest; however, roadcut exposures along the valley floor show this part of the formation to be mostly black silty shale with some thin beds of limestone and bentonite. Dane, Pierce and Reeside (1937) included the Lincoln Member and nearly all of the Hartland Member of the Greenhorn in their Graneros Shale, which explains why their Graneros was about 200 ft (60 m) thick.

Dakota Sandstone

The overturned Dakota Sandstone forms cliffs at the top of the Gold Creek exposure. The Dakota consists of light-gray to white quartzitic sandstone that is fine grained to silty and weathers to various shades of red, yellow and brown. Veinlets and seams of hard secondary silica occur along shear fractures in the sandstone.

MICROPALEONTOLOGY

Forty samples were collected for foraminifera from the stratigraphic interval between the base of the Greenhorn Formation and the lowermost part of the Niobrara Formation. This interval includes parts of two marine cycles of transgression and regression. The lower of these, the Greenhorn cycle, comprises the strata between the upper part of the Dakota Sandstone and the Codell Sandstone equivalent, here contained in the uppermost part of the Blue Hill Shale Member of the Carlile Formation. The upper cycle begins with the Juana Lopez Member of the Carlile Formation, and the transgressive portion of the cycle is recorded in succeeding strata throughout the lower part of the Niobrara Formation. The strata between the upper part of the Dakota and the lower part of the Niobrara represent the Cenomanian and Turonian Stages of the Cretaceous. The vertical changes in the foraminiferal faunas that occur throughout these strata record changes in depositional environments throughout the cycles as well as key evolutionary events in the foraminiferal succession.

The Graneros Shale was not sampled at Gold Creek. In areas to the north, the Graneros contains a foraminiferal fauna of dominantly arenaceous species that have been interpreted as products of a somewhat brackish sea which had limited circulation but was connected with normal open-marine environments to the south (Eicher, 1965, 1966). The ensuing change from arenaceous benthic to planktonic foraminiferal faunas approximately at the base of the Greenhorn Formation signifies the opening of the Western Interior seaway to major open ocean currents.

The solely planktonic foraminiferal fauna in the 114 ft (35 m) of the lower part of the Greenhorn (Lincoln and Hartland Members) includes abundant specimens of *Hedbergella delrioensis, H. planispira, H. amabilis, H. portsdownensis, Heterohelix globu/osa* and occasional specimens of *Rotalipora greenhornensis, Praeglobotruncana stephani, P. delrioensis, Globigerinelloides bentonensis* and *Clavihedbergella simplex*.

The basal 5 ft (1.5 m) of the overlying Bridge Creek Limestone Member contains, in addition to the planktonic species that occur in the Hartland, *Rotalipora cushmani* and numerous benthic species including *Lingulogavelinella sterigerinoides, Dentalina basiplanata, Neobulimina albertensis* and *Gavelinella dakotensis.*

The change upward from a solely planktonic foraminiferal assemblage in the Hartland Member to a fauna consisting of numerous benthic as well as planktonic species in the Bridge Creek may be observed in strata of this age throughout a large area in the Western Interior (Eicher and Worstell, 1970). This change is interpreted to signify the passage from anaerobic to aerobic conditions on the sea floor in the Western Interior at approximately the end of the Cenomanian Stage.

Samples from the overlying 32 ft (10 m) thick Fairport Member of the Carlile Shale contain *Praeglobotruncana stephani* and the species of *Hedbergella* and *Heterohelix* that occur in the strata below. In addition, this interval contains the planktonic species *Globigerinelloides caseyi, Clavihedbergella subdigitata, Lunatriella spinifera, Marginotruncana roddai* and *Whiteinella aprica.* The most common co-occurring ben thic species are *Neobulimina albertensis, Gavelinella dakotensis* and *Lenticulina gaultina.* Throughout much of Kansas and eastern Colorado, these strata, like those of the Hartland Member below, lack benthic foraminifera, signifying a temporary return to anaerobic bottom conditions (Eicher and Worstell, 1970). At Gold Creek, however, the sea floor was sufficiently oxygenated to support a benthic fauna all during deposition of the Fairport Member.

Throughout the lower 47 ft (14 m) of the overlying Blue Hill Shale Member, planktonic and calcareous benthic foraminifera are sparse and tiny. Upward they become increasingly rare and at the top of this interval disappear altogether. Samples from the succeeding 35 ft (11 m) of Blue Hill Member are barren; the overlying 56 ft (17 m) of the member contains an exclusively arenaceous fauna. The presence of planktonic and calcareous benthic species in the lower 47 ft (14 m) of the member at this locality strongly suggests that this interval is equivalent to the upper part of the Fairport Member in the Arkansas Valley, where the contact between calcareous faunas below and arenaceous faunas above occurs at the Fairport-Blue Hill contact.

The decrease upward in number and size of calcareous foraminifera in the lower part of the Blue Hill Member records regression of the sea and accompanying limiting environmental conditions. The barren interval probably represents a time when the sea floor was too anaerobic to support a benthic fauna and the surface waters were too brackish to support a planktonic fauna. The numerous arenaceous species in the upper part of the Blue Hill Member indicate a pronounced change in environmental conditions from those below. This may have included a substantial lowering of salinity or an increase of turbidity of the water or both. The siltstone beds at the top of the member indicate shallow water and the culmination of the Greenhorn cycle.

The Niobrara cycle begins with the calcarenites of the Juana Lopez Member. Foraminifera are absent from the lowermost sample and appear increasingly in numbers and in variety upward. The upper part of the Juana Lopez and lower 30 ft (9 m) of the upper black shale unit of the Carlile Formation contain planktonic specimens and a few common benthic species, chiefly *Gavelinella kansasensis* and *Neobulimina albertensis.* Throughout the remainder of the upper black shale unit, planktonic foraminifera become strikingly abundant and they increase in diversity upward into the lower part of the Niobrara Formation. Benthic species, likewise, increase in diversity upward. The uppermost sample of the upper black shale and the lowermost part of the Niobrara contain abundant species of *Hedbergella, Heterohelix, Archeoglobigerina, Marginotruncana* and *Globotruncana,* indicating the arrival of open-ocean conditions. These planktonic species require additional study. Initial interpretation suggests a Coniacian Age for these strata. Accompanying benthic species are those typical of the Niobrara elsewhere in the Western Interior.

SECTION OF UPPER CRETACEOUS ROCKS MEASURED IN CANYON OF GOLD CREEK NEAR PENAFLOR BENEATH OVERTURNED DAKOTA SANDSTONE CLIFF

[Sec. 4, T. 31 N., R. 17 E. (estimated, area unsurveyed); measured by C. L. Pillmore, D. L. Eicher, P. J. Varney, and C. Porter, July 20, 1966]

	Thickness in Ft	in.	m
Niobrara Formation (part)			
Fort Hays Limestone Member			
16. Occurs as four distinct beds of blocky yellow weathering limestone with interbeds of calcareous, light-gray, platy shale.			
Limestone, medium-gray; weathers yellowish-gray to grayish-orange; fine grained; single bed, blocky; irregularly shaped masses of marcasite altering to limonite; some scattered fossil imprints and fragments		6	0.15
Shale, light-gray; weathers light-gray; flaky, very calcareous, soft		6	.15
Limestone, as above, very fossiliferous; contains poorly preserved, thin shell fragments of oysters and clams		10	.25
Shale, as above		18	.46
Limestone, as above—contains *Inoceramus;* blocky		18	.46
Shale, as above		5	.13
Limestone, as above		11	.28
Bentonite, soft; weathers pale grayish-orange to dark yellowish-orange. Grades into calcareous shale in upper 3 in. (7 cm)		10	.25
Limestone, shaly, soft, light-gray; breaks into irregularly shaped pieces		6	.15
Total thickness, Fort Hays Limestone Member	7	6	2.28
Carlile Formation			
Upper black shale unit			
15. Shale, medium-gray; weathers light-gray; very calcareous to limy in upper 5 ft (1.5 m). Below top 5 ft (1.5 m) shale is darker, less calcareous, and soft; contains prints of *Inoceramus perplexus.* Eighteen ft (5.5 m) below top is zone of light grayish-brown septarian concretions, 3-12 in. (8-30 cm) thick and about 4 ft (1.2 m) in diameter that contain *Inoceramus* fragments; thin bentonitic shale 12 ft (3.7 m) below top and bentonite beds 4 in. (10 cm) and 3 in. (8 cm) thick occur at 5.5 (1.7 m) and 6.5 ft (2 m) below top	28		8.53
14. Shale, as above, but contains zones of septarian limestone concretions and numerous silty beds. Concretions are lenticular, about 6-8 in. (15-20 cm) thick and 2-3 ft (0.6-0.9 m) long, and petroliferous; contain fossil fragments. Calcarenites show traces of burrowing animals. Shale is soft, flaky, and locally noncalcareous	30		9.14
Total thickness, upper black shale unit	58		17.68
Juana Lopez Member			
13. Shale, black, calcareous, with layers of very fine-grained to fine-grained calcarenite. Top of unit has fossiliferous calcareous siltstone concretions as thick as 12 in. (30 cm); 17 ft (5 m) below top is 2 in. (5 cm) bentonite bed	20		6.09
12. Calcarenite, fine-grained; composed mostly of shell and limestone fragments; hard, limy petroliferous concretion zones; shale interbeds; base of concretion zone is coquina of pelecypod fragments (*Lopha lugubris*). Irregularly bedded; cone-in-cone structure; distinct yellowish-orange to yellowish-brown. Lower 1-1.5 ft (0.3-0.45 m) is mostly shale with 3-4 in. (8-10 cm) silty concretions at base	5		1.52
Total thickness, Juana Lopez Member ..	25		7.62
Blue Hill Shale Member			
11. Upper unit: Shale, fissile, noncalcareous, soft, slightly silty, medium-dark-gray; weathers yellowish-brown on bedding surfaces; top 3 ft (0.9 m) is siltstone (probable Codell equivalent); grades down to dark shale	18		5.48
10. Middle unit: Shale and concretionary zones, divisible into three zones:			
Upper concretionary zone. Brownish-gray to dark yellowish-orange weathering, medium gray septarian limestone concretions with veinlets of brown calcite; cone-in-cone structures common; lenticular; 3-5 ft (0.9-1.5 m) in diameter; form resistant ledges in shale slope .. 14 ft (4.27 m)			
Silty zone. Silty shale with brown-weathering beds as thick as 7 in. (18 cm) that have distinct burrow markings as much as 1 in. (2.5 cm) in diameter .... 20 ft (6.09 m)			
Lower concretion zone. Large lenticular concretions of brown-weathering limestone as much as 5 ft (1.5 m) in diameter with interbeds of silty to slightly silty shale .... 22 ft (6.70 m)			
Thickness of middle unit	56		17.07

	Thickness in Ft	in.	m
9. Lower unit: Shale and siltstone; divisible into three parts:			
Upper shale part, medium dark-gray; weathers medium yellowish-brown to grayish-brown; soft, fissile, silty in upper 3 ft (0.9 m), only slightly silty below . . . 25 ft (7.62 m)			
Siltstone, dark-reddish-brown; mostly in beds less than 0.5 in. (1 cm) thick; cone-in-cone structures near top, noncalcareous; contains large, irregular to lenticular limestone concretions as much as 5 ft (1.5 m) thick .... 7 ft (2.13 m)			
Lower shale part, black, soft, fissile; weathers to gray, flaky slope; transition zone to Fairport Member below; lower 18 ft (5.5 m) is calcareous, becoming limy in lower 6 ft (1.8 m) .... 31 ft (9.45 m)			
Thickness of lower unit	63		19.2
Total thickness, Blue Hill Shale Member	137		41.76
Fairport Member			
8. Shale, very calcareous to limy, medium-gray; weathers light-gray; contains thin, very calcareous laminae that weather yellowish-brown. At top of unit is petroliferous bioclastic limestone 2-4 in. (5-10 cm) thick, composed mainly of *Inoceramus* prisms and *Globogerina* forams that weathers dusty-yellow to grayish-brown and dark yellowish-orange; shale becomes progressively more calcareous downward to shaly limestone in bottom few feet; 17 ft (5 m) below top is 1 ft (0.3 m) thick, dark yellowish-orange-weathering bentonite; bottom 4 ft (1.2 m) of member is shaly limestone becoming thicker bedded in lower 1 ft (0.3 m), contains *Mytiloides labiatus*	32		9.75
Total thickness, Fairport Member	32		9.75
Total thickness of Carlile Formation	252		76.80
Greenhorn Formation			
Bridge Creek Limestone Member			
7. Limestone, granular, petroliferous, fossiliferous; weathers light gray to grayish-yellow and orange; in beds about 1 ft (0.3 m) thick with interbeds of limy shale and bentonite as follows:			
Interbedded limestone and shaly limestone	3		0.91
Bentonite, irregular; may be thinned ...		2	.05
Interbedded limestone and shaly limestone	7		2.13
Bentonite		8	.20
Calcareous shale, hard, platy, light-gray		6	.15
Limestone, dense, dark-gray; weathers gray		6	.15
Calcareous shale, as above		6	.15
Bentonite		8	.20
Calcareous shale, as above		2	.05
Limestone, as above		6	.15
Calcareous shale, as above	1	10	.55
Limestone, as above	1		.30
Fossils include *Mammites* and *Mytiloides labiatus*			
Total thickness, Bridge Creek Limestone Member	16	6	5.02
Hartland Member			
6. Shale, calcareous to very calcareous, hard, brittle, dark-gray, weathers light-bluish-gray to light-gray and forms flaky slope; a few inoceramid prisms and shell fragments in upper few inches and thin bentonite beds; scattered exposures below upper 20 ft (6 m); 45 ft (14 m) below top, thin zone of bentonite shale 2-3 in. (5-8 cm) thick	52		15.85
Total thickness, Hartland Member	52		15.85
Lincoln Member			
5. At top, 6-12 in. (15-30 cm) zone of bedded limestone 2-3 in. (5-8 cm) thick; pungent, petroliferous, no fossils. About 10 ft (3 m) above base is zone of black, flaky, noncalcareous shale about 4 ft (1.2 m) thick; base of unit is dark-gray calcareous shale as in Hartland Member above	61		18.59
Total thickness, Lincoln Member	61		18.59
Total thickness, Greenhorn Formation	129	6	39.47
Graneros Shale			
4. Partly covered—scattered exposures; 12 in. (30 cm) thick "X" bentonite at top of unit; mostly black, silty to slightly silty shale, flaky, noncalcareous, soft; a few thin silty zones	13		3.96
3. Mostly covered—scattered exposures indicate dark-gray to black, calcareous to noncalcareous, silty to slightly silty shale; thin shaly limestone beds; noncalcareous, hard, mottled gray and brown silty bed at 68 ft (21 m) below top	100		30.48
Total thickness, Graneros Shale	113		34.44
Dakota Sandstone			
2. Sandstone, light-gray; weathers shades of red, yellow and brown; fine-grained to very fine grained with ridges and veinlets of hard silica, crossbedded, 3 ft (0.9 m) below top is zone of granules and pebbles of chert and quartzite	20		6.09
1. Siltstone, dark-gray to medium-gray; some carbonaceous beds cross-laminated with beds of quartzose sandstones; some sandstone beds carbonaceous in top few feet; sandstone beds as thick as 2 ft (0.6 m) in slope-forming siltstones	41		12.50
Partial thickness, Dakota Sandstone	61		18.59

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