Stratigraphy of the Upper Cretaceous Fox Hills Sandstone and Adjacent Parts of the Lewis Shale and Lance Formation, East Flank of the Rock Springs Uplift, Southwest Wyoming

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1532

Stratigraphy of the Upper Cretaceous Fox Hills Sandstone and Adjacent Parts of the Lewis Shale and Lance Formation, East Flank of the Rock Springs Uplift, Southwest Wyoming

By HENRY W. ROEHLER

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1532

Description of three offlapping barrier shorelines along the western margins of the interior seaway of North America

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1993

U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, ***Secretary***

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, ***Director***

Library of Congress Cataloging-in-Publication Data

Roehler, Henry W.
Stratigraphy of the Upper Cretaceous Fox Hills sandstone and adjacent parts of the Lewis shale and Lance formation, east flank of the Rock Springs Uplift, southwest Wyoming / by Henry W. Roehler.
p. cm.—(U.S. Geological Survey professional paper ; 1532)
Includes bibliographical references.
Supt. of Docs. no.: I19.16:P1532
1. Geology, Stratigraphic—Cretaceous. 2. Geology—Wyoming. 3. Fox Hills Formation. I. Geological Survey (U.S.). II. Title. III. Series.
QE688.R64 1993
551.7'7'09787—dc20 92–36645
CIP

For sale by USGS Map Distribution
Box 25286, Building 810
Denver Federal Center
Denver, CO 80225

CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

METRIC CONVERSION FACTORS

To convert from	To obtain	Multiply by
inches (in.)	centimeters (cm)	2.54
feet (ft)	meters (m)	0.3048
mile (mi)	kilometers (km)	1.6
°F	°C	5/9 (°F–32)

STRATIGRAPHY OF THE UPPER CRETACEOUS FOX HILLS SANDSTONE AND ADJACENT PARTS OF THE LEWIS SHALE AND LANCE FORMATION, EAST FLANK OF THE ROCK SPRINGS UPLIFT, SOUTHWEST WYOMING

By HENRY W. ROEHLER

ABSTRACT

Stratigraphic investigations of the Upper Cretaceous Fox Hills Sandstone and adjacent parts of the overlying and underlying Lance Formation and Lewis Shale on the east flank of the Rock Springs uplift reveal that these formations were deposited during a regression of the interior Cretaceous seaway of North America. This regression produced three eastward offlapping shorelines that form the Fox Hills Sandstone along outcrops in the study area. Cyclic sedimentation that accompanied the regression is believed to have been periodic and climate related.

The shorelines of the Fox Hills Sandstone were deposited as chains of barrier islands. The barrier islands are as much as 7 miles long and consist of mostly lower, middle, and upper shoreface sandstone lithofacies. Separating the barrier islands are tidal inlets and a sound, which have associated flood-tidal deltas, ebb-tidal deltas, and accretionary swash bars. Continental rocks of bay or lagoon origin in the Lance Formation overlie and intertongue with landward parts of the barrier islands. Underlying and seaward of the barrier islands are rocks of nearshore marine origin that make up the Lewis Shale.

Columnar sections, restored cross sections, and paleogeographic maps analyze and illustrate the description of stratigraphy of the Fox Hills Sandstone, Lance Formation, and Lewis Shale. Descriptions of five long measured surface sections and one corehole section support the barrier island analysis and provide basic subsurface data. Coal beds in the Lance Formation are identified and correlated.

INTRODUCTION

This report investigates the origin, composition, mode of deposition, and paleogeography of the Upper Cretaceous Fox Hills Sandstone and adjacent parts of the Lance Formation and Lewis Shale on the east flank of the Rock Springs uplift. Field work began in the area in 1973 and continued intermittently through 1983. During this time, 193 stratigraphic sections were measured by Jacob staff and Abney level, and the outcrops were mapped in reconnaissance fashion on U.S. Geological Survey topographic maps at the scale of 1:24,000. Five of the stratigraphic sections measured are described herein. In 1982, the basal 377 ft of the Lance Formation and the upper 10 ft of the Fox Hills Sandstone were cored by the U.S. Geological Survey in the BC No. 1 corehole located in NW¼NW¼NE¼ sec. 4, T. 19 N., R. 100 W. Lithologies of the core are described and fossils are identified.

DESCRIPTION AND ACCESSIBILITY OF THE STUDY AREA

The Fox Hills Sandstone, Lance Formation, and Lewis Shale were investigated along an arcuate belt of partly faulted outcrops about 3 mi wide and 45 mi long (fig. 1). These formations are well exposed along the east flank of the Rock Springs uplift, but are unconformably overlain and covered by the Tertiary Fort Union Formation along the west flank of the uplift and in parts of adjacent basins.

Interstate Highway 80 crosses the center of the Rock Springs uplift in an east-west direction (fig. 1). Two paved roads branch north and south of Interstate Highway 80 near the middle of the study area and provide the primary access routes to outcrops. The paved road to the north leaves Highway 80 at Point of Rocks, Wyo., in sec. 27, T. 20 N., R. 101 W.; it trends east for 2.5 mi and then north for 5.0 mi to the Jim Bridger coal mine and power plant located in sec. 3,

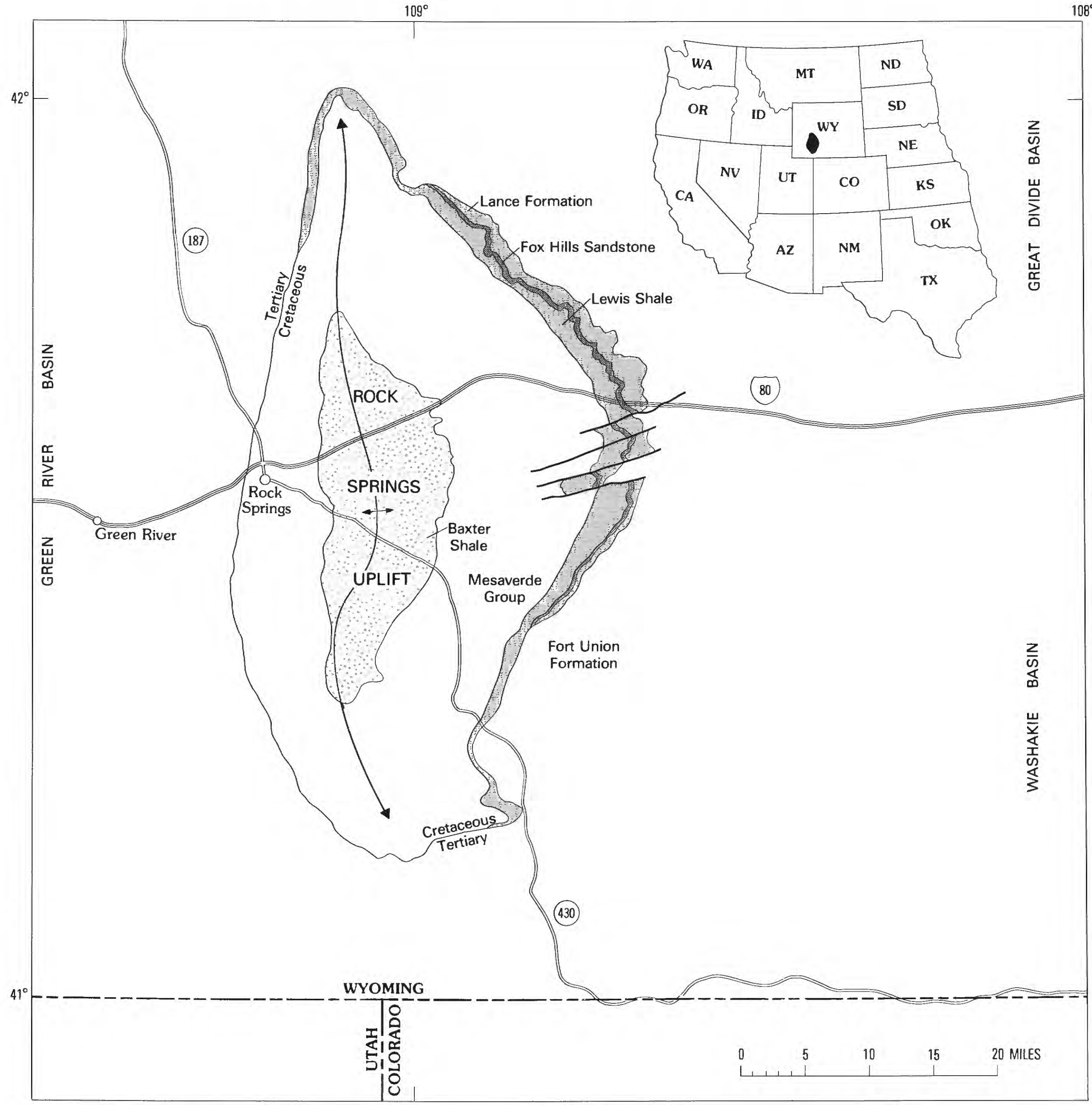


FIGURE 1.—Index map showing location of outcrops (shaded) of the Fox Hills Sandstone, Lance Formation, and Lewis Shale in the study area on east flank of Rock Springs uplift.

T. 20 N., R. 101 W. (pl. 1). The paved road to the south leaves Highway 80 at an underpass located near the southwest corner of sec. 3, T. 19 N., R. 100 W., and continues 6 mi south to the Black Butte coal mine offices located in sec. 33, T. 19 N., R. 100 W. Numerous improved and unimproved roads and trails branch from these paved roads and provide access to remaining parts of the study area.

The study area is also less easily accessible from the south by Wyoming Highway 430, which trends southeast from Rock Springs, Wyo. (pl. 1). Sixteen miles southeast of Rock Springs, an improved gravel road branches east from Highway 430 near the southwest corner of sec. 8, T. 17 N., R. 102 W. This road follows Cutthroat Draw and Black Butte Creek for about 9.5 mi to where it crosses the southernmost exposures of the Fox Hills Sandstone in sec. 28, T. 17 N., R. 101 W. (pl. 1).

GEOGRAPHIC SETTING

The study area is an arid, windy desert, where the annual precipitation ranges from 7 to 14 in. and the temperature ranges from about –30 °F in winter to more than 100 °F in summer (Root and others, 1973). The dominant vegetation is sage, which commonly grows in patches, or thickets. Between the patches of sage and along larger drainages, thin desert grasses, greasewood, rabbit brush, moss, lichens, and a variety of other plants can be found growing. The area is devoid of trees.

The primary drainage is Bitter Creek, which flows from east to west across the Rock Springs uplift and through the study area adjacent to the Union Pacific Railroad (pl. 1). Deadman Wash, a major tributary of Bitter Creek, trends southward along outcrops of the Lewis Shale and joins Bitter Creek near Interstate Highway 80. Numerous smaller, named and unnamed drainages form tributaries of Deadman Wash and Bitter Creek.

The study area is uninhabited, except for itinerants involved in coal mining and electrical power generation, oil and gas exploration and production, and sheep ranching. The Jim Bridger mine in Tps. 20–21 N., Rs. 99–100 W. and the Black Butte mine in Tps. 17–19 N., Rs. 99–100 W. are large strip mines that extract coal from the Deadman seam (as much as 30 ft thick) at the base of the Fort Union Formation. Oil and gas drilling has taken place for several decades along the outcrops studied, but only a few small and widely separated discoveries have been reported. Antelope hunting is permitted in the area each fall, and wild horses and other nongame animals are present in large numbers. Archeological sites are fairly common.

The Lewis Shale, Fox Hills Sandstone, and Lance Formation are locally covered by alluvium across drainages and in small areas of sand dunes. Altitudes generally range between 6,500 ft and 7,000 ft (pl. 1). The terrain consists of a long valley formed by outcrops of the Lewis Shale. East of this valley, outcrops of the Fox Hills Sandstone and Lance Formation rise rapidly along steep slopes (figs. 2 and 3). The strata that make up the three formations dip from 3° to 6° east and are generally homoclinal along the broad arching of the east flank of the Rock Springs uplift.

FIGURE 2.—Outcrops of 1, Lewis Shale, 2, Fox Hills Sandstone, and 3, Lance Formation viewed to the northeast in sec. 32, T. 20 N., R. 100 W. The Fox Hills Sandstone is about 135 ft thick.

FIGURE 3.—Outcrops of 1, Fox Hills Sandstone, and 2, Lance Formation in SW¼SW¼ sec. 33, T. 20 N., R. 100 W. Outcrops shown are about 275 ft thick.

The outcrops along the northeast flank of the Rock Springs uplift are offset by numerous east-west-trending, high-angle, normal and reverse faults. The displacement along these faults ranges from a few feet to several hundred feet. A normal fault in Tps. 18–19 N., Rs. 100–101 W. has caused 3 mi of horizontal displacement of the base of the Fox Hills Sandstone. There is no stratigraphic evidence that the fault movements occurred during or before deposition of the Cretaceous formations studied, and younger overlying rocks of Eocene age in the Wasatch Formation are not faulted. These relationships indicate that the faulting occurred during late stages of the Laramide orogeny during deposition of the Paleocene Fort Union Formation.

PREVIOUS INVESTIGATIONS

The first geographical and geologic explorations of the western United States that included the Rock Springs uplift area are believed to have been undertaken by Bonneville (1837). He was followed a few years later by Fremont (1845), who conducted geographical surveys for the United States Army. Howard Stansbury, guided by Jim Bridger, made the first survey of coal resources of the Rock Springs uplift in 1852 (Rock Springs Rocket-Miner, March 15, 1975). The first significant fossil discovery was a dinosaur skeleton, which was collected by Cope (1872) from the Lance Formation in T. 18 N., R. 100 W. near Black Buttes Station on the Union Pacific Railroad. A number of geologic and paleontological investigations followed these early explorations, but it was not until the work of Schultz (1920) that the stratigraphic relationships and age of the outcropping formations in the Rock Springs uplift area were accurately determined.

Schultz (1920, pl. 1) combined the Fox Hills Sandstone and Lance Formation as the Laramie Formation on a geologic map that included the Rock Springs uplift. Later, Hale (1950) proposed that the term Lance Formation be used in place of the name Laramie Formation used by Schultz (1920). The name Fox Hills Sandstone, applied to the basal sandstone beds of Hale's (1950) Lance Formation, was apparently first introduced into the uplift area by Weimer (1961).

A barrier origin for the Fox Hills Sandstone on the northeast flank of the Rock Springs uplift, and a lateral facies change of the sandstone to lagoonal shale of the Lance Formation to the west and to marine shale of the Lewis Shale to the east, were discussed by Weimer (1961). Weimer's work was reexamined by Harms and others (1965), who questioned the barrier origin of the sandstone but could offer no convincing alternative. Weimer's barrier hypothesis for the sandstone was subsequently supported by Asquith (1970), who believed that the Fox Hills was deposited as a prograding barrier facies. A comprehensive study of the Fox Hills Sandstone and associated formations on the east flank of the Rock Springs uplift by Land (1972) proved conclusively that the sandstone is of barrier origin.

Land's (1972) field investigations of the Fox Hills Sandstone and associated formations included the measurement of 44 sections along the length of the outcrops on the east flank of the Rock Springs uplift. The data acquired from these measured sections were then used to determine depositional environments. Land (1972, pl. 6) also isopached the barrier sandstone and determined "lithologic trends." While undertaking field work, Land (1972) examined North inlet and Jim inlet, which had been studied earlier by Weimer (1961) and Harms and others (1965). Land discovered Black Butte inlet and part of Salley sound, but he did not identify South inlet and other small inlets shown on plate 2 of this report. The data presented by me in this report indicate that Land consistently misidentified parts of the upper shoreface sandstone lithofacies along the marineward margins of barrier islands, which contributed to a number of correlation errors.

ACKNOWLEDGMENTS

Geophysical logs of the U.S. Geological Survey BC No. 1 corehole were prepared by S.B. Roberts. Proximate-ultimate analyses of coal beds in the corehole were prepared by Geochemical Testing, F.E. Walker, Director. Ostracodes and charophytes from the core were identified by R.M. Forester and E.M. Brouwers. Mollusk and ammonite fossils collected along outcrops by J.R. Gill, Paula LaPoint, and the author were identified by W.A. Cobban.

STRATIGRAPHY

REGIONAL STRATIGRAPHIC RELATIONSHIPS

The Fox Hills Sandstone and Lance Formation were deposited along the western shores of the interior Cretaceous seaway of North America (fig. 4). The Lewis Shale was deposited contemporaneously across the floor of the seaway. The interior seaway extended from northern Alaska and Canada southward to the Gulf of Mexico, and was nearly 1,000 mi wide east of the study area. The primary source area for sediments deposited along the western shores of the seaway was the Sevier orogenic belt located in Idaho and Utah, 150–200 mi west of the study area. From mountains in the Sevier orogenic belt, these sediments were carried by streams eastward across an extensive foreland to the interior seaway (fig. 4). During the Late Cretaceous, the western shorelines of the interior seaway repeatedly transgressed westward and regressed eastward in response to tectonism and eustatic changes, until the time that the Fox Hills Sandstone was deposited. At that time, the seaway made a final eastward regression and permanently evacuated the Central Rocky Mountain

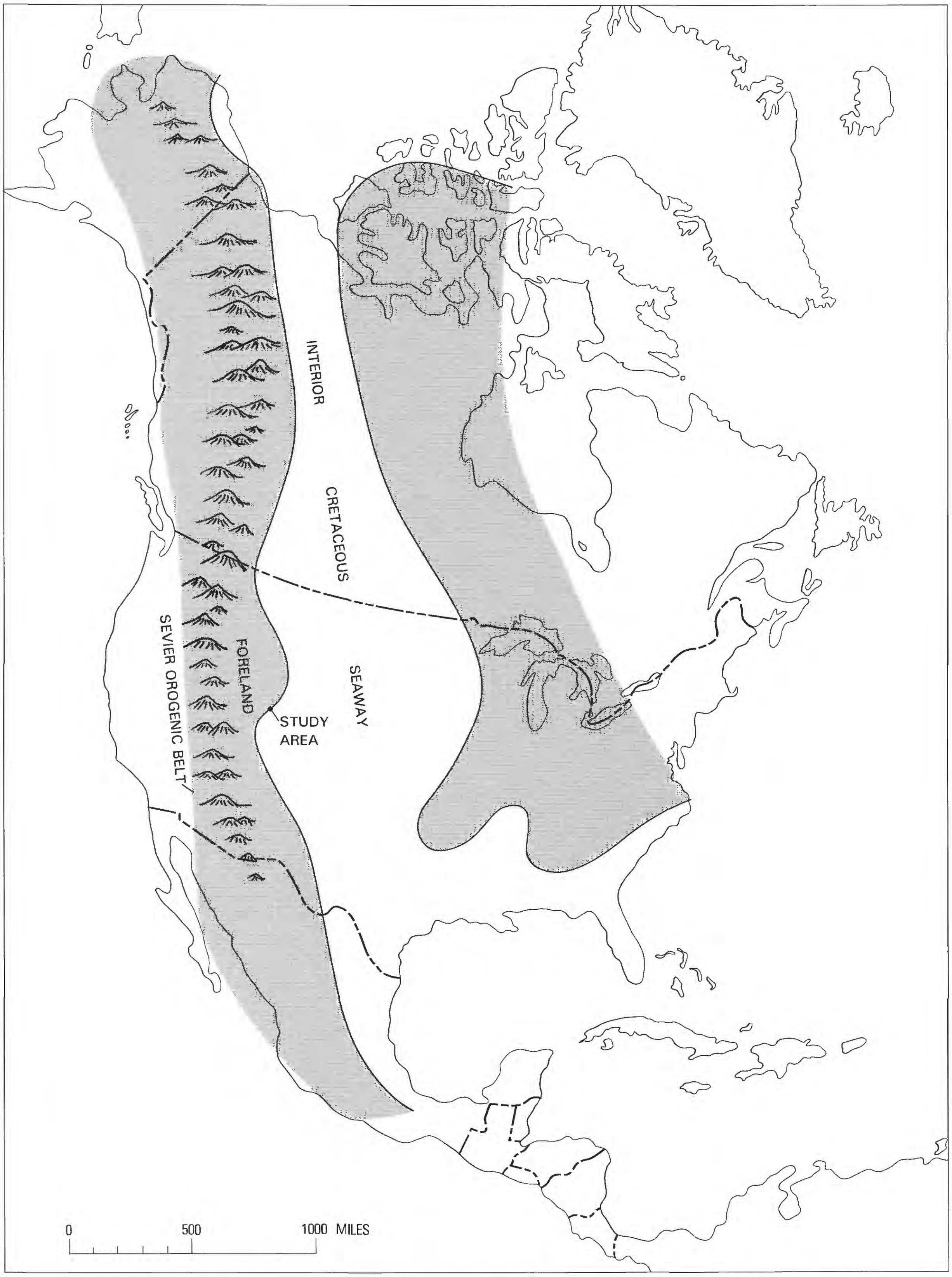


FIGURE 4.—Paleogeographic map of North America during the Maastrichtian Age, showing location of study area along western margins of interior Cretaceous seaway. Land areas are shaded. From Roehler (1990); modified from Gill and Cobban (1966).

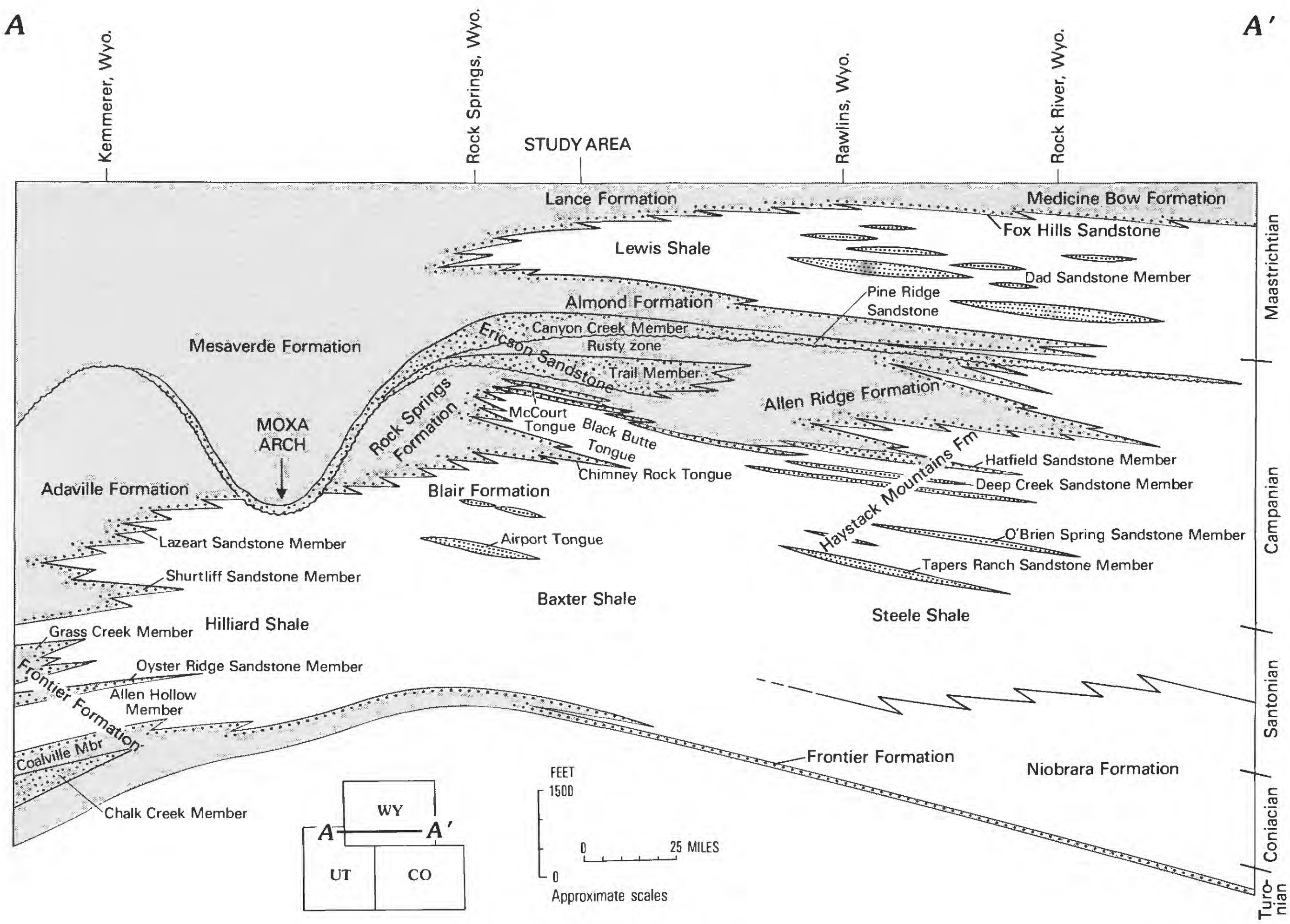


FIGURE 5.—Restored regional cross section showing age and stratigraphic relationships of the Fox Hills Sandstone and other Upper Cretaceous formations across northeast Utah and southern Wyoming. Rocks of continental origin shaded; alluvial-plain and marine shoreline, shelf, slope, and basin sandstone and siltstone units shown by dot pattern; marine shale and limestone unpatterned. From Roehler (1990).

region. The final regression of the seaway occurred in progressive stages, which caused the offlapping of shoreline sandstones that form the Fox Hills Sandstone in the study area. The nomenclature, age, and general stratigraphic relationships of the Fox Hills Sandstone and other Upper Cretaceous formations across northeastern Utah and southern Wyoming are shown in an east-west cross section (fig. 5).

FORMATIONS EXPOSED ON THE EAST FLANK OF THE ROCK SPRINGS UPLIFT

Upper Cretaceous formations exposed from the center of the Rock Springs uplift eastward across the east flank of the uplift begin at the base with the upper part of the Baxter Shale, 4,500 ft thick. The upper part of the Baxter Shale forms the eroded center or soft core of the uplift. Overlying the Baxter Shale are more resistant ridge-forming outcrops of the Mesaverde Group, about 3,500 ft thick, consisting in ascending sequence of the Blair Formation, Rock Springs Formation, Ericson Sandstone, and Almond Formation (figs. 1 and 5). Overlying the Mesaverde Group and cropping out in the study area are the Lewis Shale, Fox Hills Sandstone, and Lance Formation, which have a combined maximum thickness of about 2,500 ft. Unconformably overlying the Upper Cretaceous formations is the Paleocene Fort Union Formation, which, in turn, is conformably overlain by the Eocene Wasatch Formation.

LEWIS SHALE

TYPE OF OUTCROPS

The Lewis Shale weathers to a long, drab-gray shale valley bounded on both sides by tan, east-dipping sandstone escarpments that form parts of overlying and underlying formations. The valley has minor topographic relief and extensive areas of flat terrain. Parts of the valley form low, undulating hills separated by shallow valleys containing networks of dry drainages. Most of the dry drainages are bordered by sage or greasewood; many are narrow, steeply incised, and as much as 20 ft deep. In a few places, small, flat-topped mesas rise a few tens of feet above the valley floor. The mesas are capped with coarse gravels, which are remnants of Pleistocene erosion surfaces.

COMPOSITION AND THICKNESS

The Lewis Shale is mostly composed of dark-gray shale and some thin interbedded ledge-forming tan or brown, very fine to fine-grained sandstone and siltstone. A few knobby outcrops of dolomite concretions are present in the upper 250 ft. The Lewis Shale thickens from west to east across the Rock Springs uplift area (fig. 5). In the study area, it ranges in thickness from 600 ft to 700 ft (Roehler, 1983). The Lewis Shale intertongues with the overlying Fox Hills Sandstone, which makes the contact of these units arbitrary (pl. 2).

PALEONTOLOGY AND AGE

Fossils are rare in the Lewis Shale, except for trace fossils in a few ledge-forming sandstone and siltstone beds in the upper part. The trace fossil *Helminthoidea* is present locally (fig. 6). The saltwater mollusks *Inoceramus fibrosus*, *Pteria* sp., *Modiolus* sp., and *Pholadomys*? sp. were collected by J.R. Gill (unpub. data) from the upper part of the Lewis Shale at locality D6419 in SW¼NW¼SE¼ sec. 7, T. 21 N., R. 101 W. (pl. 2). Gill also collected the ammonite *Baculites clinolobatus* from a dolomite concretion in the upper part of the Lewis Shale at locality D6415 in SE¼NW¼NW¼ sec. 23, T. 21 N., R. 101 W. (pl. 1), near the base of measured section 28 (pl. 2). *Baculites clinolobatus* is an index fossil which indicates that the age of the upper part of the Lewis Shale is lower Maastrichtian.

DEPOSITIONAL ENVIRONMENTS AND LITHOFACIES

The Lewis Shale is mostly composed of rocks of nearshore marine origin. It was deposited in the study area across a shallow marine embayment nearly 100 mi long (north-south) and about 75 mi wide (east-west) that extended from the interior seaway westward to what is now the west flank of the Rock Springs uplift (Roehler, 1990, pl. 2). Separating the northern shores of this embayment from the open waters of the interior seaway was a large lobate delta named the Red Desert delta by Asquith (1970). Rocks comprising the west edge of the delta lap onto the east flank of the Rock Springs uplift, where they consist of sandstone and siltstone that is interbedded with typical Lewis Shale. The delta sediments thicken in the subsurface in basins east of the uplift toward the center of the delta, where the beds of sandstone increase in number and thickness and locally produce commercial quantities of natural gas.

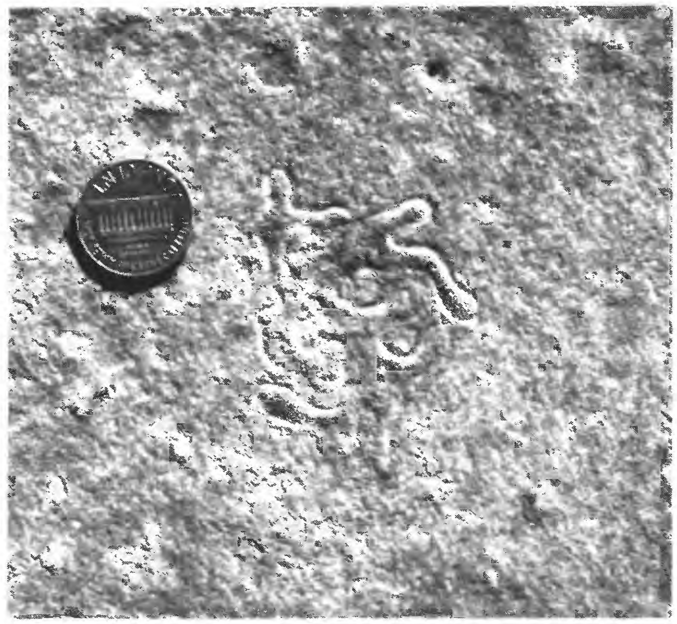


FIGURE 6.—Trace fossil *Helminthoidea* on the upper surface of a ledge-forming sandstone near top of the Lewis Shale in SW¼ sec. 30, T. 18 N., R. 100 W. Coin used for scale is 0.75 in. wide.

FOX HILLS SANDSTONE

TYPE OF OUTCROPS

The lower part of the Fox Hills Sandstone, generally less than 100 ft thick, forms steeply inclined steplike slopes composed of mostly gray shale that is interbedded with thin resistant ledge-forming tan and brown sandstone and siltstone. Rising abruptly 50–150 ft above the lower steplike slopes are thick sandstone beds that weather to tan and brown cliffs and benches. The tan and brown sandstone is generally overlain by light-gray or white sandstone, as much as 45 ft thick, that forms the cap rock along the Fox Hills outcrops. The light-gray or white cap-rock sandstones are overlain by and partly intertongued with less resistant tan sandstone and interbedded gray mudstone, carbonaceous shale, and coal that form the base of the Lance Formation. The beds that make up the Fox Hills Sandstone often appear to be laterally persistant and of uniform thickness along outcrops, but the outcrops rarely parallel the facies strike of the barrier shorelines, and as a result, most of the beds are broadly lenticular (pl. 2).

COMPOSITION AND THICKNESS

The Fox Hills Sandstone is composed of mostly tan, brown, gray, or white sandstone, and some interbedded tan or brown siltstone and gray shale. Thin interbeds of gray dolomite, gray or brown carbonaceous shale, and coal are present locally. The Fox Hills Sandstone ranges in overall thickness from about 75 ft to 225 ft, depending on where the lower and upper intertongued contacts are placed (pl. 2). The sandstone beds that make up the unit are composed of mostly quartz grains that coarsen upwards from very fine and silty at the base to medium to coarse at the top.

PALEONTOLOGY AND AGE

The Fox Hills Sandstone contains numerous beds of oyster shells that range in thickness from less than 1 ft to more than 15 ft. The oysters, genus *Crassostrea*, mostly occur as lenticular coquinas composed of transported shells and shell fragments deposited in tidal channels, flood-tidal deltas, and ebb-tidal deltas (pl. 2). Tidal current influence on the deposition of some of the coquinas is discernible by directionally oriented shell material (fig. 7). Oyster shells are also present in a few places as lenticular coquinas on the upper surface of forebeach sandstones of barrier islands (measured section 10, pl. 2) and as isolated shell fragments and shell layers in middle shoreface sandstones (fig. 8).

Trace fossils are abundant in the Fox Hills Sandstone, particularly in the lower, more marine parts of the formation. *Helminthoidea* (fig. 6) and *Terebellina* (fig. 9) are fairly common in lower shoreface sandstone, and *Ophiomorpha* (fig. 10) and *Cylindrichnus* (figs. 11, 12) are present in middle shoreface sandstone. *Thalassinoides* and *Arenicolites* were identified in accretionary swash bar sandstones.

The age of the Fox Hills Sandstone is lower Maastrichtian based on the occurrence of the ammonite *Baculites clinolobatus* (D6415, pl. 2) in the upper part of the Lewis Shale and on the occurrence of other ammonite fossils in Upper Cretaceous rocks in the eastern part of the greater Green River basin (Roehler, 1990, fig. 5).

FIGURE 7.—Upper surface of coquina composed of current-oriented oyster shell fragments in tidal channel in the Fox Hills Sandstone located in SW¼SW¼ sec. 9, T. 21 N., R. 101 W. Flow direction is left to right. Pencil is 6 in. long.

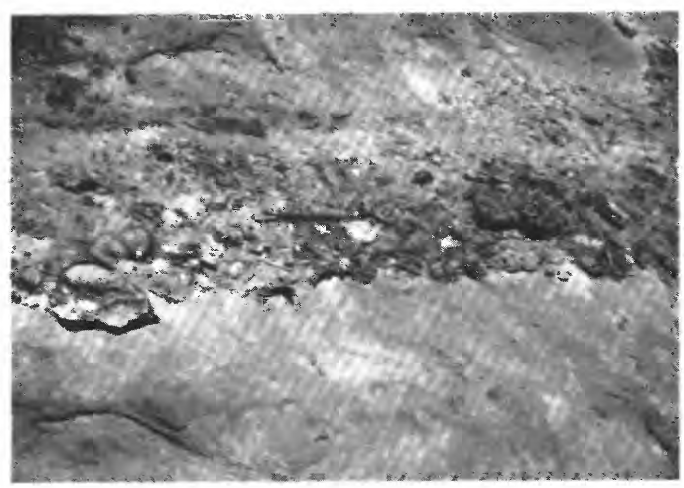


FIGURE 8.—Side view of oyster shell layer in a middle shoreface sandstone in the lower part of measured section 49 (pl. 2) in NW¼NE¼SE¼ sec. 12, T. 20 N., R. 101 W. Pencil is 6 in. long.

DEPOSITIONAL ENVIRONMENTS AND LITHOFACIES

The beds that make up the Fox Hills Sandstone comprise the eroded remnants of three eastward offlapping barrier island chains. Separating the barrier islands along the length of these chains are beds of sandstone and shale that were deposited in association with tidal inlets and a sound (pl. 2). The stratigraphic relationships of the barrier islands and associated marine and lagoon depositional environments and lithofacies are illustrated by a generalized cross section (fig. 13).

The barrier islands in the Fox Hills Sandstone were deposited along wave-dominated shorelines

FIGURE 9.—*Terebellina* on upper surface of lower shoreface sandstone of Fox Hills Sandstone in SW$^1/_4$ sec. 30, T. 18 N., R. 100 W., near measured section 162 (pl. 1). Coin is 0.6 in. in diameter.

FIGURE 10.—*Ophiomorpha* burrows in lower shoreface sandstone of Fox Hills Sandstone in SE$^1/_4$ sec. 36, T. 21 N., R. 100 W. (pl. 1). Pencil for scale.

FIGURE 11.—Top view of *Cylindrichnus* from middle shoreface sandstone of the Fox Hills Sandstone in C SE$^1/_4$ sec. 2, T. 20 N., R. 101 W., in measured section 42 (pl. 1). Coin is 0.6 in. in diameter.

FIGURE 12.—Side view of *Cylindrichnus* shown in figure 11. Pencil for scale.

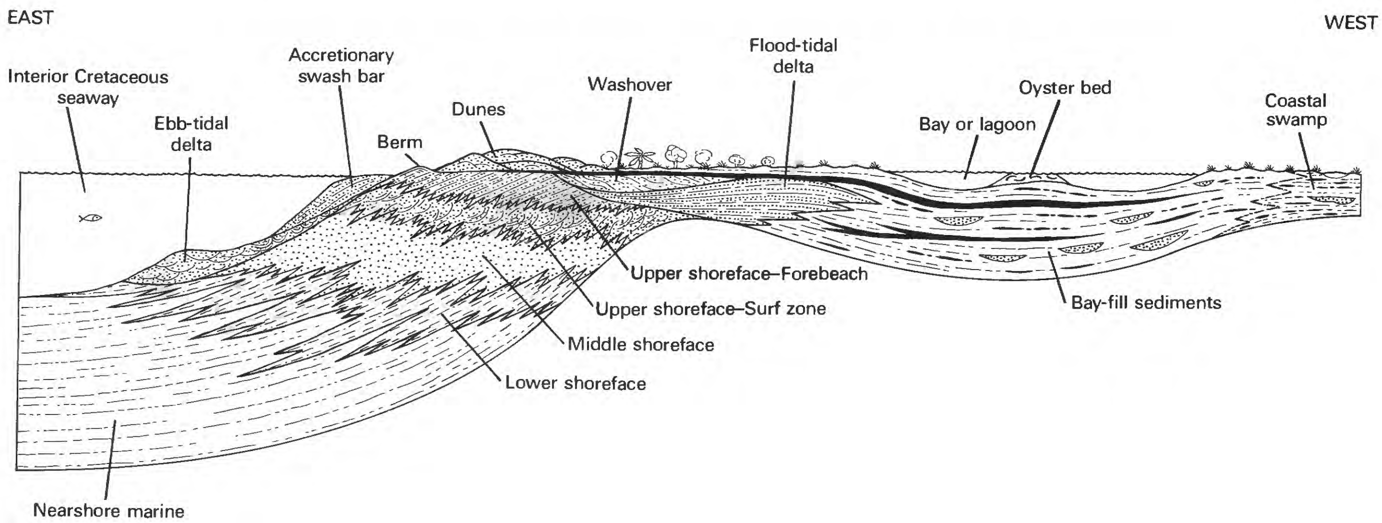


FIGURE 13.—Nomenclature of barrier islands and associated depositional environments and lithofacies. Not to scale. Modified from Roehler (1988, fig. 12).

having moderately high tides. The barrier islands were generally 3 mi to 7 mi long. Tidal inlets were numerous, flood-tidal deltas were large, and ebb-tidal deltas were moderate to large. These criteria correspond to mesotidal barrier islands as classified by Hayes and Kana (1976). The tidal ranges were probably between 4 ft and 10 ft, which was undoubtedly higher than normal for most of the eastern shorelines of the interior Cretaceous seaway. The higher tides can be explained by the focusing effect of tides as they converged toward the head of the coastal embayment along which the barrier islands were located. (See previous discussion of Lewis Shale.) Sedimentary structures in shoreline sandstones and the location and configuration of accretionary swash bars leave little doubt that dominant longshore currents and sediment transport directions were north to south.

BARRIER SHOREFACE

The rocks of barrier island origin consist of mostly vertical successions of lower, middle, and upper shoreface sandstone and shale that comprise distinct lithofacies. The approximate thickness, stratigraphic position, composition, and sedimentary structures that define these lithofacies are illustrated in a generalized columnar section (fig. 14).

The lower shoreface lithofacies forms the basal sandstone and shale slopes along outcrops of the Fox Hills Sandstone (fig. 15). The sandstone in the lithofacies is mostly tan, very fine grained to fine grained, and commonly silty, and was usually deposited in thin, parallel beds (fig. 16).

The middle shoreface lithofacies weathers to tan cliffs and benches composed of thick, parallel beds of very fine grained to medium-grained sandstone (fig. 17). In places, the beds are massive as a result of bioturbation. In other places, they exhibit large-scale, low-angle hummocky, trough crossbeds that reflect the churning of offshore bottom sediments by large storm waves, at water depths normally below wave base. These hummocky trough crossbeds are sometimes referred to as “storm wash” (fig. 14). In sec. 25, T. 21 N., R. 101 W., the middle shoreface sandstone lithofacies contains exceptionally large calcareous concretions. One of these concretions, excavated at the Jim Bridger coal mine, is shown in figure 18.

The upper shoreface lithofacies forms a distinctive “white cap” along the Fox Hills outcrops (fig. 17). The white cap is generally composed of a surf zone sandstone in the lower part and a forebeach sandstone in the upper part (fig. 14). The surf zone consists of small-scale, trough crossbeds that, in places, are interspersed with planar crossbeds (fig. 19). The direction of dip of the foresets in the planar crossbeds often reveals the direction of prevailing longshore currents. The forebeach part of the upper shoreface lithofacies consists of sandstone deposited mostly in the swash zone—the planar, seaward-sloping parts of beaches. The forebeach sandstone was deposited in mostly thin, parallel, tabular beds (fig. 20).

Sandstones deposited subaerially on the barrier islands are rarely preserved along outcrops. As they comprised most of the elevated, soft-sand parts of the barrier islands, they were rapidly eroded after the islands were abandoned, during ensuing marine transgressions and regressions. A few lenticular

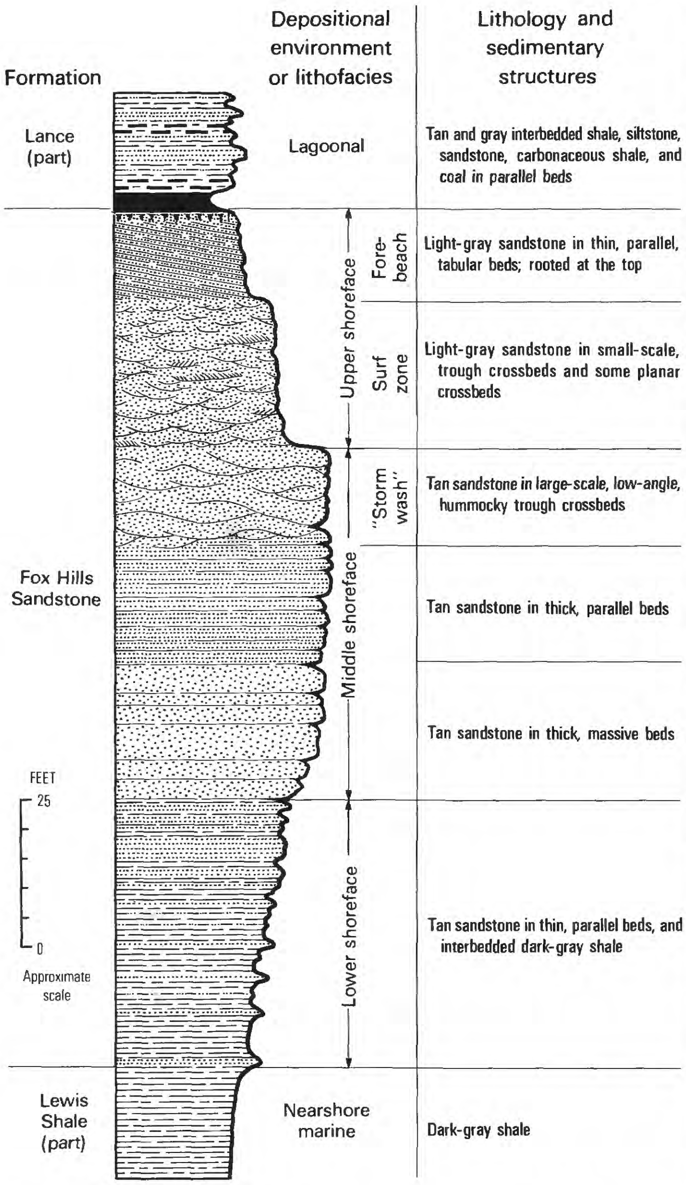


FIGURE 14.—Generalized section showing nomenclature of shoreface and associated depositional environments and lithofacies in the Fox Hills Sandstone and adjacent parts of the Lance Formation and Lewis Shale.

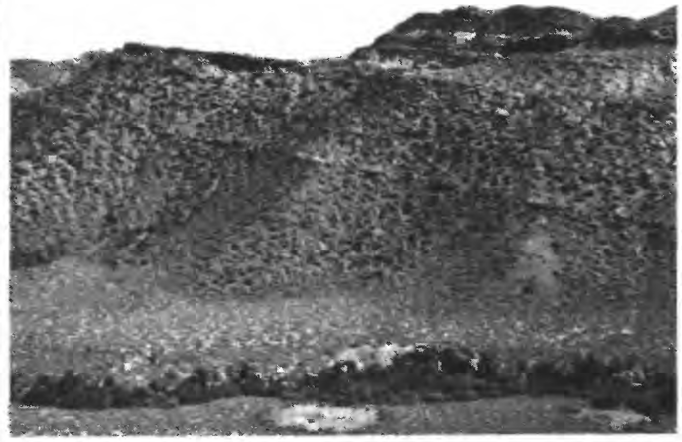


FIGURE 15.—Thin, parallel-bedded, lower shoreface sandstone and shale in the lower part of the Fox Hills Sandstone in NW1/4 sec. 1, T. 17 N., R. 101 W. (pl. 1), near measured section 175 (pl. 2). Outcrops shown are about 200 ft thick.

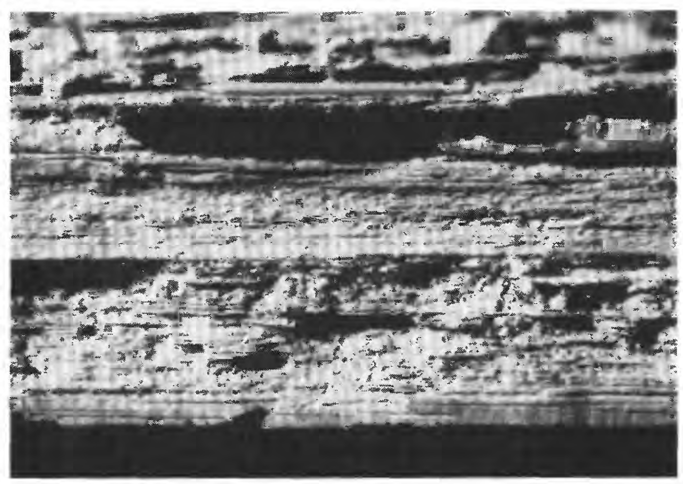


FIGURE 16.—Very thin, parallel beds in lower shoreface sandstone in the Fox Hills Sandstone in SW1/4 sec. 30, T. 18 N., R. 100 W. Pencil for scale.

remnants of washover fans and dunes were nonetheless identified along the upper surfaces of some of the barrier sandstones. Because they are very thin and have small lateral extent, they are included in the forebeach part of the upper shoreface lithofacies in plate 2.

TIDAL INLETS, FLOOD-TIDAL DELTAS, AND EBB-TIDAL DELTAS

Tidal inlets, flood-tidal deltas, and ebb-tidal deltas are well preserved in outcrops of the Fox Hills Sandstone. The interpreted geomorphology and nomenclature of these deposits are shown in figure 21.

The tidal inlets are as much as 3,500 ft wide and 70 ft deep. They are irregularly bowl shaped in profile. Four inlets are named herein: North inlet, Jim inlet, Black Butte inlet, and South inlet (pl. 2). The inlets are filled with mostly gray, soft, sandy shale, and some interbedded tan sandstone and dark-brown to dark-gray carbonaceous shale. Flaser bedding is common; trace fossils are fairly abundant. The presence of flaser bedding and trace fossils suggests that low-tidal ranges (probably less than 3 ft) and low current velocities were controlling factors during

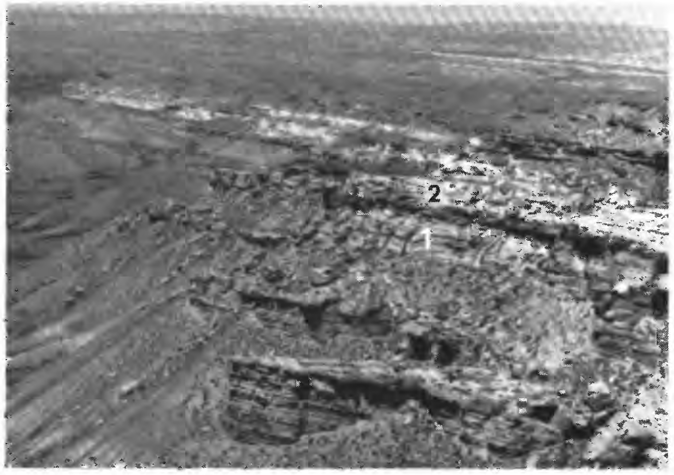


FIGURE 17.—Outcrops of the Fox Hills Sandstone in SE¼ sec. 2, T. 17 N., R. 101 W., near measured section 176 (pl. 2). 1, Tan, parallel-bedded, middle shoreface sandstone overlain by 2, upper shoreface "white cap" sandstone.

FIGURE 18.—Large calcareous concretion in middle shoreface sandstone of the Fox Hills Sandstone in SE¼NE¼ sec. 25, T. 21 N., R. 101 W. Scale is indicated by person standing below left side of concretion.

abandonment and infilling stages of the inlets, and that this deposition took place at a very slow rate. The sandstone-filled parts of the inlets consist of mostly fine grained to medium-grained sandstone that commonly exhibits large-scale, a bimodal (landward- and seaward-dipping), planar crossbeds. The presence of the planar cross beds suggests that these sandstones were deposited by higher tides (probably 6 ft or more) having strong current velocities, and that deposition took place at a rapid rate prior to the

FIGURE 19.—Small-scale, trough- and planar-crossbedded upper shoreface (surf zone) sandstone in the Fox Hills Sandstone in SE¼ sec. 9, T. 22 N., R. 102 W., in measured section 3 (pl. 2). Pick handle is 1.5 ft long.

FIGURE 20.—Thin, parallel, tabular-bedded upper shoreface (fore-beach) sandstone in the Fox Hills Sandstone in SE¼ sec. 9, T. 22 N., R. 102 W., in measured section 3 (pl. 2).

time that the tidal inlets were abandoned. Smaller unnamed inlets at the top of the Fox Hills Sandstone in measured sections 119 and 157 (pl. 2) are filled with mostly sandstone having the same bedding characteristics as the named inlets.

Flood-tidal deltas were identified in outcrops of the Fox Hills Sandstone at North inlet in barrier shoreline No. 2 and at Jim inlet, Salley sound, and South inlet in barrier shoreline No. 3 (pl. 2). The flood-tidal deltas are as much as 50 ft thick and 5 mi wide. They are composed of mostly interbedded light-gray fine- to coarse-grained sandstone and dark-gray carbonaceous shale that often grade laterally into oyster

EXPLANATION

1. Nearshore marine	7. Flood ramp	13. Distributary ebb channel	→ Longshore current
2. Lower shoreface	8. Ebb ramp	14. Ebb channel shell fragments	→ Flood-tidal current
3. Middle shoreface	9. Flood channel	15. Accretionary swash bar	→ Ebb-tidal current
4. Upper shoreface (surf zone)	10. Interchannel spillover	16. Innerbay oyster bed	
5. Upper shoreface (forebeach)	11. Peripheral oyster flat	17. Reed swamp	
6. Dune ridge	12. Main ebb channel	18. Forest swamp	

FIGURE 21.—Geomorphology and nomenclature of shoreline, tidal, and associated deposits in the Fox Hills Sandstone, east flank of the Rock Springs uplift. Not to scale.

flats at the periphery of the deltas. Current ripples and flaser bedding are common throughout the flood-tidal deltas. In the vicinity of flood ramps (fig. 21), the sandstone generally occurs in parallel beds up to a few feet thick, which locally exhibit trough cross-bedding. These sandstone beds become thinner and interbeds of carbonaceous shale become thicker toward the center and outer (landward) margins of the flood-tidal deltas.

Ebb-tidal deltas are present in barrier shoreline No. 1 below North inlet and in barrier shoreline No. 2 below Jim inlet (pl. 2). The ebb-tidal deltas are lenticular in cross section and as much as 65 ft thick and 4 mi wide. They usually crop out as tan, massive sandstone cliffs. The sandstone is fine to medium grained and occurs in large-scale trough crossbeds, or in bimodal (landward- and seaward-dipping) planar crossbeds. Oyster shells and oyster shell fragments commonly occur as dark-gray-brown lenses in the sandstones.

UNNAMED EBB-TIDAL DELTA IN BARRIER SHORELINE NO. 1

An unnamed ebb-tidal delta crops out in barrier shoreline No. 1 in secs. 8, 9, 14, 15, 16, 17, 22, and 23, T. 21 N., R. 101 W. between measured sections 10 and 29 (pls. 1, 2). The unnamed delta is lenticular in cross section and has a maximum thickness of about 65 ft. It is composed of mostly tan, fine- to medium-grained sandstone containing lenses of oyster shell fragments and a few thin interbeds of gray, sandy shale. *Ophiomorpha* is fairly common. The sandstone beds consist of mostly small scale trough crossbeds, but a few large-scale, seaward-dipping, planar cross-beds are present locally near the base of the delta.

A paleogeographic map of the unnamed ebb-tidal delta area was not prepared, because associated rocks of tidal inlet and flood-tidal delta origins that would provide important details of the delta are missing. It is significant, however, that the unnamed ebb-tidal delta in barrier shoreline No. 1 directly underlies the flood-tidal delta associated with North inlet in barrier shoreline No. 2 (as does the ebb-tidal delta in barrier shoreline No. 2 directly underlie the flood-tidal delta associated with Jim inlet in barrier shoreline No. 3). The superposition of these ebb-tidal and flood-tidal deltas suggests that the barrier islands and inlets that make up barrier shorelines Nos. 1, 2, and 3 remained in essentially the same locations, although laterally offset as a result of offlapping. These relationships, in turn, suggest that the major drainages along the coastal areas west of the barrier islands remained in about the same locations during deposition of the three barrier shorelines.

NORTH INLET

North inlet and its associated flood-tidal delta crop out along the top of the Fox Hills Sandstone between secs. 6 and 25, T. 21 N., R. 101 W., between measured sections 8 and 30 (pls. 1, 2). The rocks composing the inlet and flood-tidal delta intertongue laterally along the outcrops with rocks of bay-fill origin to the north and with rocks of shoreface origin to the south. The inlet consists of a channel about 500 ft wide and 65 ft deep that is filled with soft, gray, partly sandy shale containing a few layers of limy siltstone concretions, and interbedded tan and brown, fine- to medium-grained, trough-crossbedded sandstone containing abundant small trace fossils (worm borings and trails?). The flood-tidal delta associated with North inlet is composed of light-gray, tan, and brown, fine- to medium-grained sandstone in small-scale trough crossbeds and large-scale (landward- and seaward-dipping) planar crossbeds, and some interbedded gray and brown, sandy, partly carbonaceous shale. Lenses of oyster shells and oyster shell fragments, and burrows, including *Ophiomorpha*, are abundant in many of the sandstone beds. The oyster shell lenses weather dark gray brown, exhibit rapid thickness changes from less than 1 to more than 15 ft, and appear to fill depressions scoured into underlying sandstone beds (fig. 22).

FIGURE 22.—Outcrop of ebb-tidal delta sandstone associated with North inlet in the Fox Hills Sandstone in SW¼SW¼ sec. 9, T. 21 N., R. 101 W., near measured section 19 (pl. 2). Lens of dark-colored oyster shells is indicated by arrow.

The paleogeography of the North inlet area is shown in figure 23. Only a small segment of the ebb-tidal delta associated with North inlet is included in the paleogeographic map, but the northwest trend of outcrops of the Fox Hills Sandstone and the northeast facies strike of the barrier shoreline indicate that the ebb-tidal delta that underlies Jim inlet (pl. 2) is also associated with North inlet. This ebb-tidal delta is not connected to North inlet along the outcrops, but the delta and inlet are expected to join in the subsurface a short distance downdip. The ebb-tidal delta in barrier shoreline No. 2 is similar in configuration to the ebb-tidal delta in barrier shoreline No. 1 described previously.

JIM INLET

Jim inlet and its associated flood-tidal delta and accretionary swash bar crop out as part of the white cap at the top of the Fox Hills Sandstone from sec. 25, T. 21 N., R. 101 W., southeastward for more than 7 mi to sec. 29, T. 20 N., R. 100 W., between measured sections 31 and 88 (pls. 1, 2). Jim inlet consists of north and south tidal channels, approximately 2,000 ft and 800 ft wide and 150 ft and 225 ft deep, respectively, that are separated by a mid-channel bar (fig. 24). The tidal channels are filled with dark-gray to gray-brown carbonaceous shale, and interbedded and interlaminated tan to light-gray, fine- to medium-grained sandstone. Flaser bedding is common. Some of the carbonaceous shale and sandstone beds in the

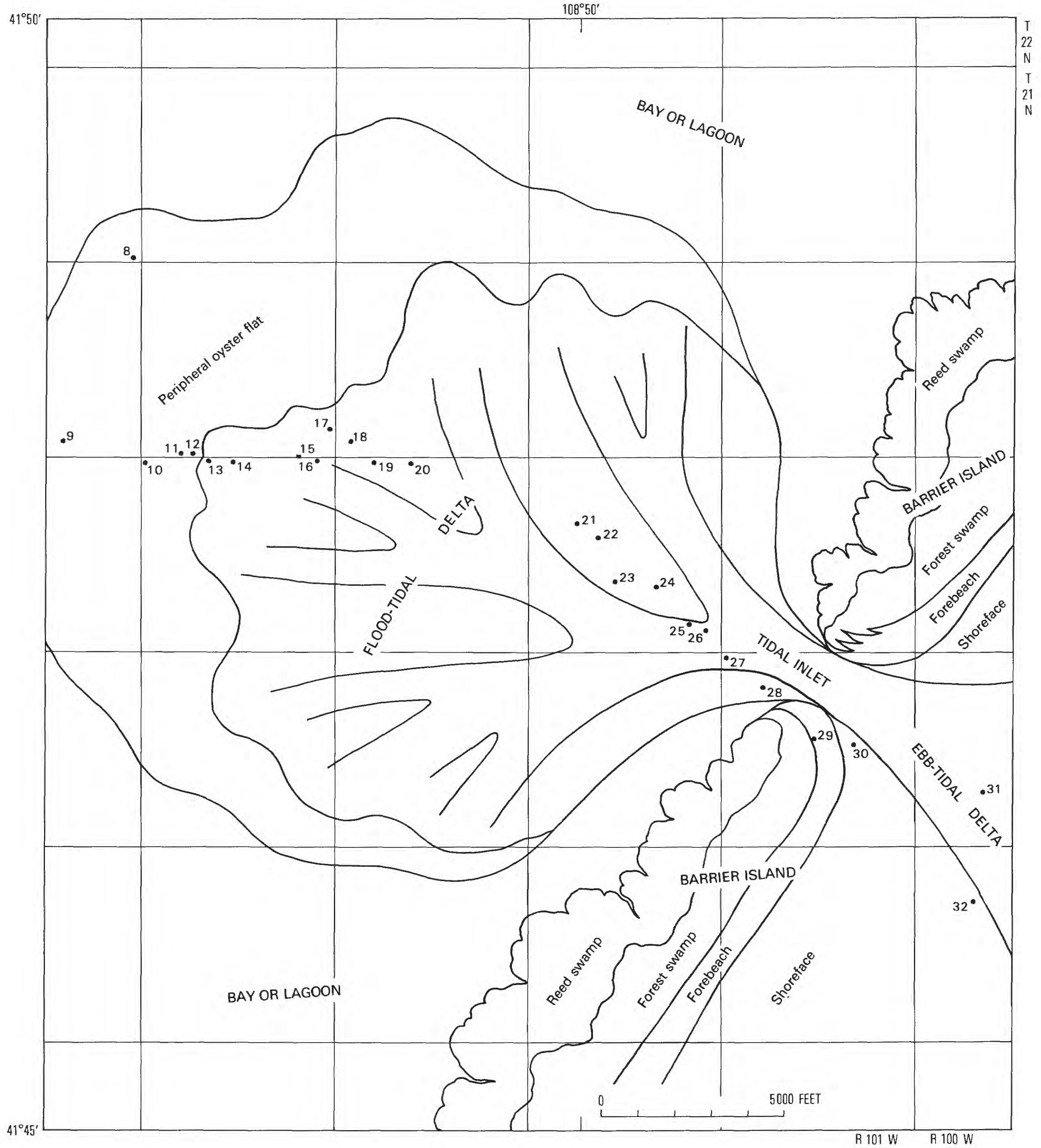


FIGURE 23.—Paleogeographic map of North inlet area of barrier shoreline No. 2 in the Fox Hills Sandstone, east flank of the Rock Springs uplift. Numbered data points indicate locations of measured sections shown on plates 1 and 2.

lower parts of the channels contain disseminated oyster shell fragments. The mid-channel bar consists of mostly light gray to white, fine-grained sandstone in landward- and seaward-dipping, planar crossbeds with wave-rippled, gray, sandy, carbonaceous shale partings, and some very thin interbedded gray to

FIGURE 24.—Contact (dashed line) of 1, mid-channel bar (mostly sandstone), and 2, the north edge of the south tidal channel (carbonaceous shale and sandstone) of Jim inlet, near measured section 65 (pl. 2). Also shown is 3, part of the flood-tidal delta associated with Jim inlet (sandstone). Outcrops shown are about 175 ft thick.

brown, sandy carbonaceous shale. The mid-channel bar also contains abundant disseminated oyster shell fragments.

The flood-tidal delta associated with Jim inlet is lenticular in cross section, as much as 50 ft thick, and nearly 7 mi wide along outcrops. It is composed of mostly tan to gray, fine- to medium-grained sandstone in thin parallel beds, and interbedded gray, carbonaceous shale (fig. 25). These beds are usually current rippled, and flaser bedding is common (fig. 26).

FIGURE 25.—Outcrops near the middle of a flood-tidal delta at Jim inlet in the Fox Hills Sandstone in NE1/4NE1/4NE1/4 sec. 13, T. 20 N., R. 101 W., near measured section 54 (pl. 2). Jacob staff used for scale is 5 ft long.

FIGURE 26.—Flaser bedding in a flood-tidal delta at Jim inlet in the Fox Hills Sandstone in NE1/4NE1/4 sec. 13, T. 20 N., R. 101 W., near measured section 53 (pl. 2). Pencil is 7.2 in. long.

Oyster shell fragments are disseminated through the sandstone and carbonaceous shale beds, and shell coquinas are present in shale matrices as oyster flats at the periphery of the delta (pl. 2; fig. 21).

A paleogeographic map of the Jim inlet area is shown in figure 27. The sections measured along outcrops trend northwest-southeast and transect the inlet area at an angle of about 70° to the north-northeast trend of the adjacent barrier islands of shoreline No. 3.

BLACK BUTTE INLET

Black Butte inlet forms a readily visible gap in the white cap of the Fox Hills Sandstone in sec. 4, T. 18 N., R. 100 W. The inlet is about 900 ft wide, as much as 40 ft deep, and broadly lenticular in cross section. It consists of a large main channel located on the north side of the inlet, which is adjacent to and partly overlain by a small channel located on the south side of the inlet (pl. 2). The lower part of the main channel is filled with gray, fine- to medium-grained sandstone in landward- and seaward-dipping, planar crossbeds of tidal origin (fig. 28). The upper part of the main channel is filled with interbedded gray shale and sandstone on the north side of the channel, and these beds intertongue with gray, planar crossbedded sandstone on the south side of the channel (pl. 2). The contact of the sandstone beds that make up the main channel and the small channel to the south is sharp and easily recognized in outcrops (fig. 29). The two channels are generally separated by a thin bed of gray, slightly carbonaceous shale.

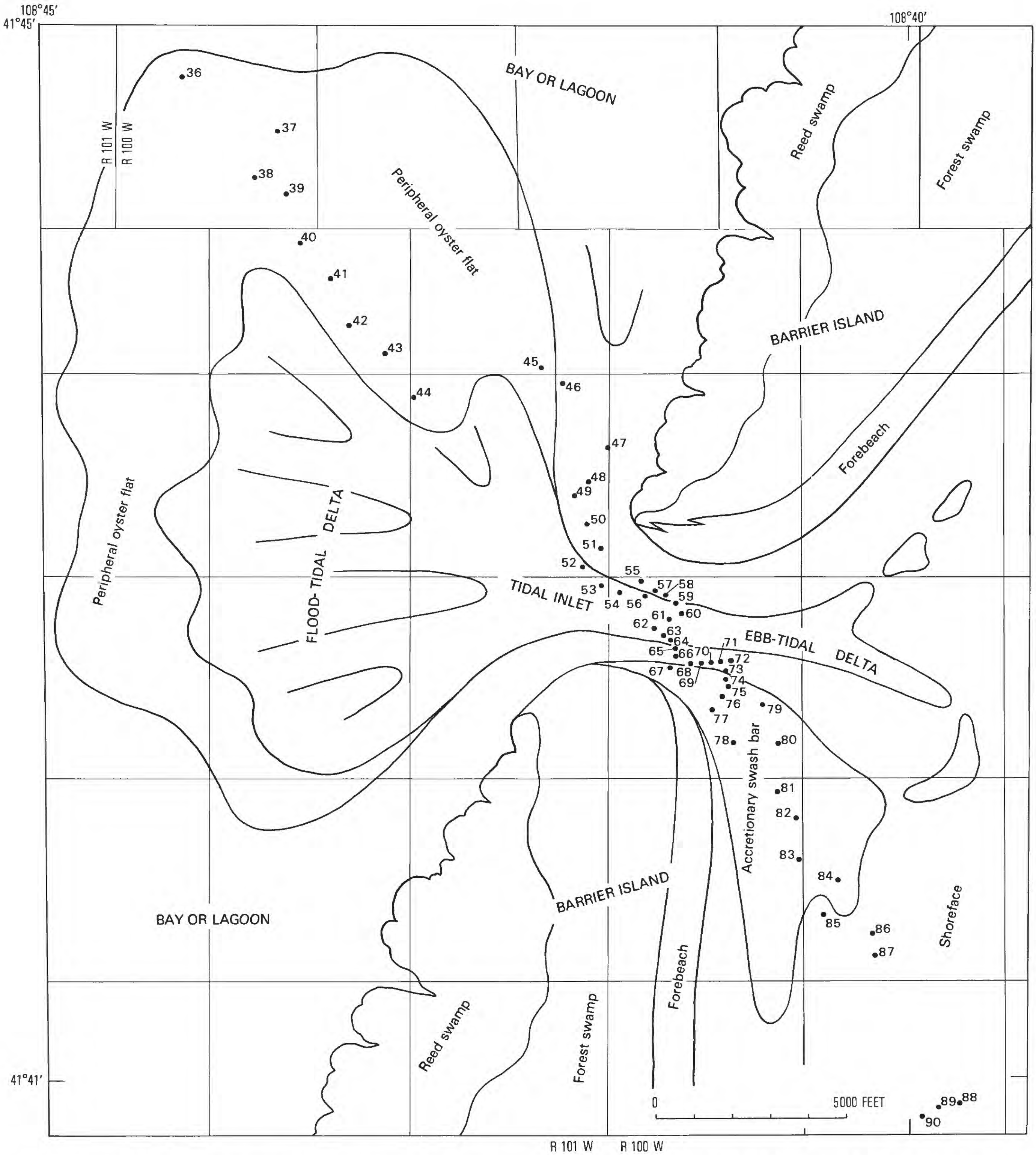


FIGURE 27.—Paleogeographic map of Jim inlet area of barrier shoreline No. 3 in the Fox Hills Sandstone, east flank of the Rock Springs uplift. Numbered data points indicate locations of measured sections shown on plates 1 and 2.

The small channel is composed of mostly soft gray shale, and some thin interbedded dark-gray, carbonaceous shale. Oyster shell fragments are abundant in the upper part. Along the top of the channel, near its south edge, is a thin interbedded sandstone and carbonaceous shale unit that dips northward and

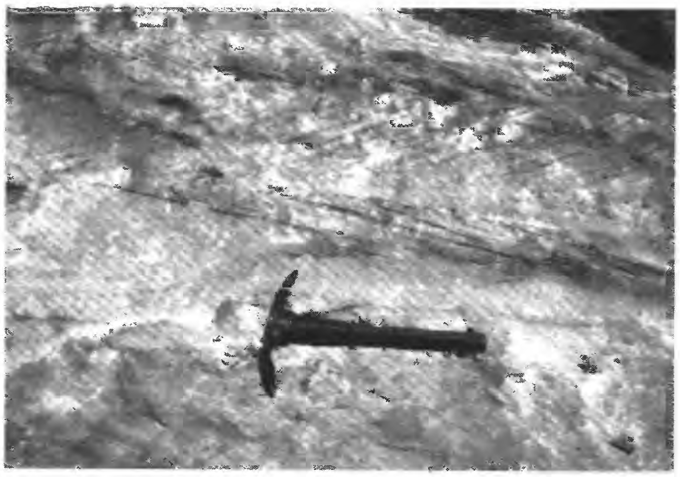


FIGURE 28.—Landward- and seaward-dipping, planar crossbeds in the main channel of Black Butte inlet in the Fox Hills Sandstone in NW1/4SE1/4 sec. 4, T. 18 N., R. 100 W., near measured section 144 (pl. 2). Pick handle is 1.5 ft long.

FIGURE 29.—Contact (dashed line) of 1, small shale-filled channel adjacent to and partly overlying 2, the sandstone-filled main channel at Black Butte inlet, near measured section 146 (pl. 2). Part of 3, underlying middle shoreface sandstone is also visible. Outcrops shown are about 125 ft thick.

accretes toward the center of the small channel. This unit forms a small point bar, which indicates that the course of the river that formed the channel was locally sinuous.

The paleogeography of the Black Butte inlet area is shown in figure 30. The shape and positions of the main and small channels of the inlet suggest that they are parts of a river that flowed seaward between two of the barrier islands along shoreline No. 3 (pl. 2). The main channel was formed by a large tidal river, which was later abandoned, and the south edge of its channel was reoccupied by a smaller river. The bedding structures of the smaller river do not show the effects of tidal currents.

The Hall coal bed that overlies Black Butte inlet is missing downdip of where the inlet is exposed. This fact was revealed in core drilling by the Black Butte Coal Company (Lee Bonjourno, oral commun., 1984). The missing coal bed suggests that the outcrops of Black Butte inlet are located near the mouth of the tidal river that formed the inlet.

SOUTH INLET

South inlet consists of a small, narrow, shale- and sandstone-filled tidal channel located in sec. 1, T. 17 N., R. 101 W., at measured sections 174 and 175 (pl. 2). It is the southernmost tidal inlet in the Fox Hills Sandstone in outcrops along the east flank of the Rock Springs uplift. Associated with the inlet are extensive sandstone beds of flood-tidal origin, as much as 60 ft thick, that crop out from sec. 30, T. 18 N., R. 100 W. southward for more than 4 mi to sec. 22, T. 17 N., R. 101 W. (pls. 1 and 2). The flood-tidal delta sandstones are composed of mostly light gray, fine- to coarse-grained sandstone in large (landward- and seaward-dipping) planar crossbeds in the lower part, which intertongues in the upper part with light-gray, fine-grained sandstone and gray, carbonaceous shale. The upper sandstone and shale part occurs in mostly undulating, current-rippled, subparallel beds; flaser bedding is common. The size, location, and configuration of the inlet in relation to the flood-tidal delta indicate that either the inlet shifted locations southward during late stages of development, or it was very wide and complex and did not consist of a single channel. Of the two possibilities, the latter seems the more plausible.

A paleogeographic map of the South inlet area is shown in figure 31. From available data, it appears that the inlet was located at the mouth of a major, sediment-choked, distributary river. The primary outlet for this river was the tidal channel located in measured sections 174 and 175. The remaining parts of the inlet probably consisted of broad, sandy, tidal flats made up of linear, seaward-trending, swash bars and shallow intervening channels, which near their seaward edge formed an extensive ebb-tidal delta. Remnants of the barrier island shoreline protruded islandlike through the tidal flats at two locations—sec. 30, T. 18 N., R. 100 W., and secs. 2 and 11, T. 17 N., R. 101 W. (fig. 31). South inlet could be classified a sound, but it probably did not have large areas of open water at ebb tide.

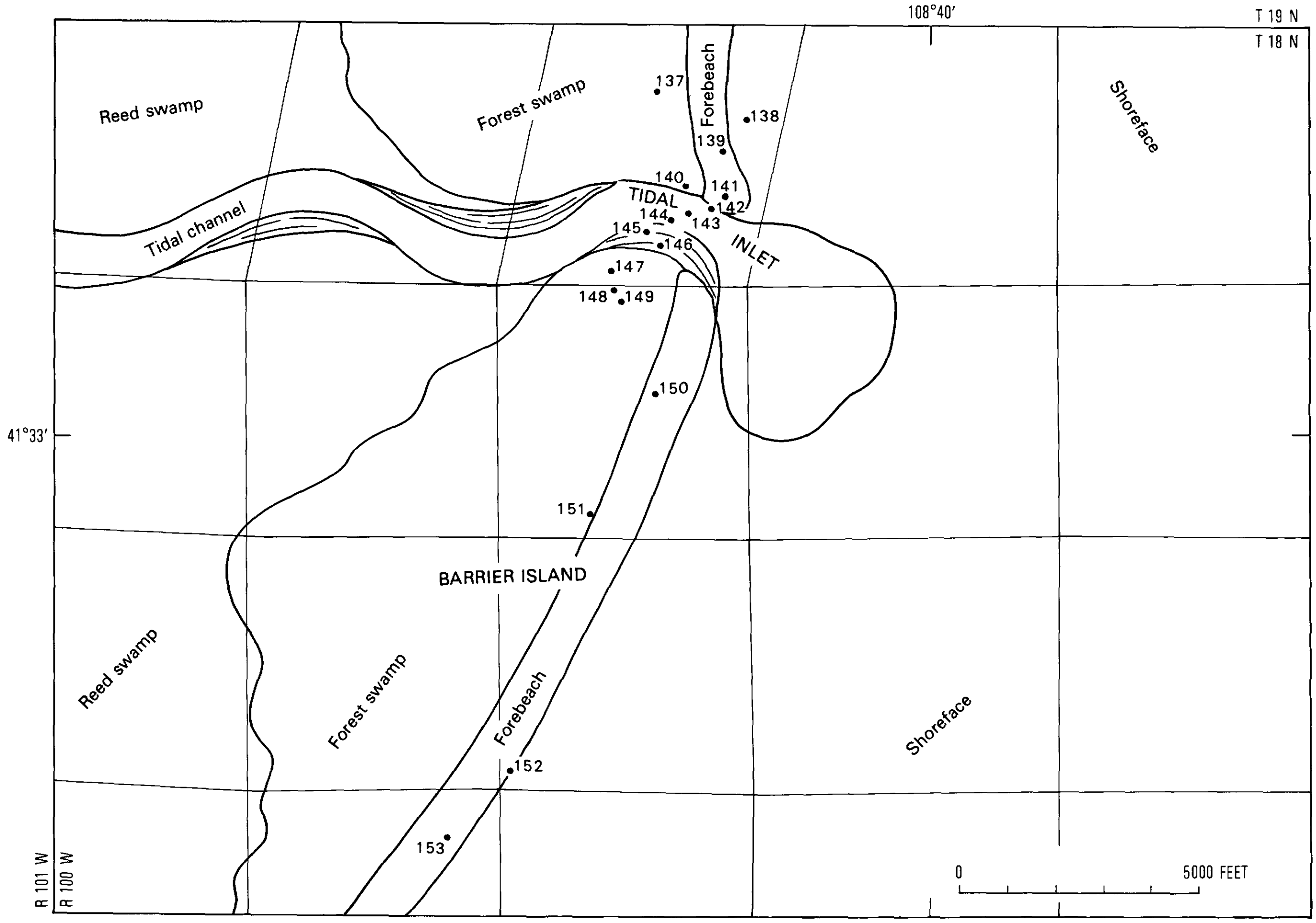


FIGURE 30.—Paleogeographic map of Black Butte inlet area of barrier shoreline No. 3 in the Fox Hills Sandstone, east flank of the Rock Springs uplift. Numbered data points indicate locations of measured sections shown on plates 1 and 2.

SALLEY SOUND

The Fox Hills Sandstone is missing in outcrops across parts of secs. 16 and 21, T. 19 N., R. 100 W., between measured sections 121 and 134, and in sec. 31, T. 19 N., R. 100 W., where measured section 135 is offset by faults (pl. 2). The thick brown, tan, and white middle and upper shoreface sandstones that characterize the Fox Hills outcrops in other places along the east flank of the Rock Springs uplift are replaced by beds of soft gray shale and some thin interbedded tan and gray, very fine to fine-grained sandstone, and tan and gray siltstone (fig. 32). Inspection of these outcrops indicates that these beds were deposited in a sound (Salley sound), which was present between two of the barrier islands in barrier shoreline No. 3 (pl. 2). Salley sound has an overall lenticular configuration in cross section and a lateral extent of slightly more than 2 mi. Shale and sandstone beds, about 50 ft thick, were deposited in the lower part of the sound as bay-fill sediments. Overlying these rocks are sandstone beds that were deposited as a flood-tidal delta, as tidal channels, and as an accretionary swash bar during the abandonment stages of the sound. The flood-tidal delta is separated from underlying rocks of bay-fill origin by a thin split of the Hall coal bed (pl. 2). Large oyster beds are present in the flood-tidal delta and tidal channel sandstones, and their occurrence attests to the presence of brackish water in Salley sound.

A paleogeographic map of the Salley sound area during an early stage of development is shown in figure 33. At that time, the sound had a large accretionary swash bar along its south edge, where it opened into the interior seaway. A linear, submerged channel bar was present near the middle of the sound. Peripheral oyster flats were present in the shallow water at the landward edges of these bars. The small tidal inlet north of Salley sound in sec. 17, T. 19 N., R. 100 W. (fig. 33) is shown to open into a bay landward of

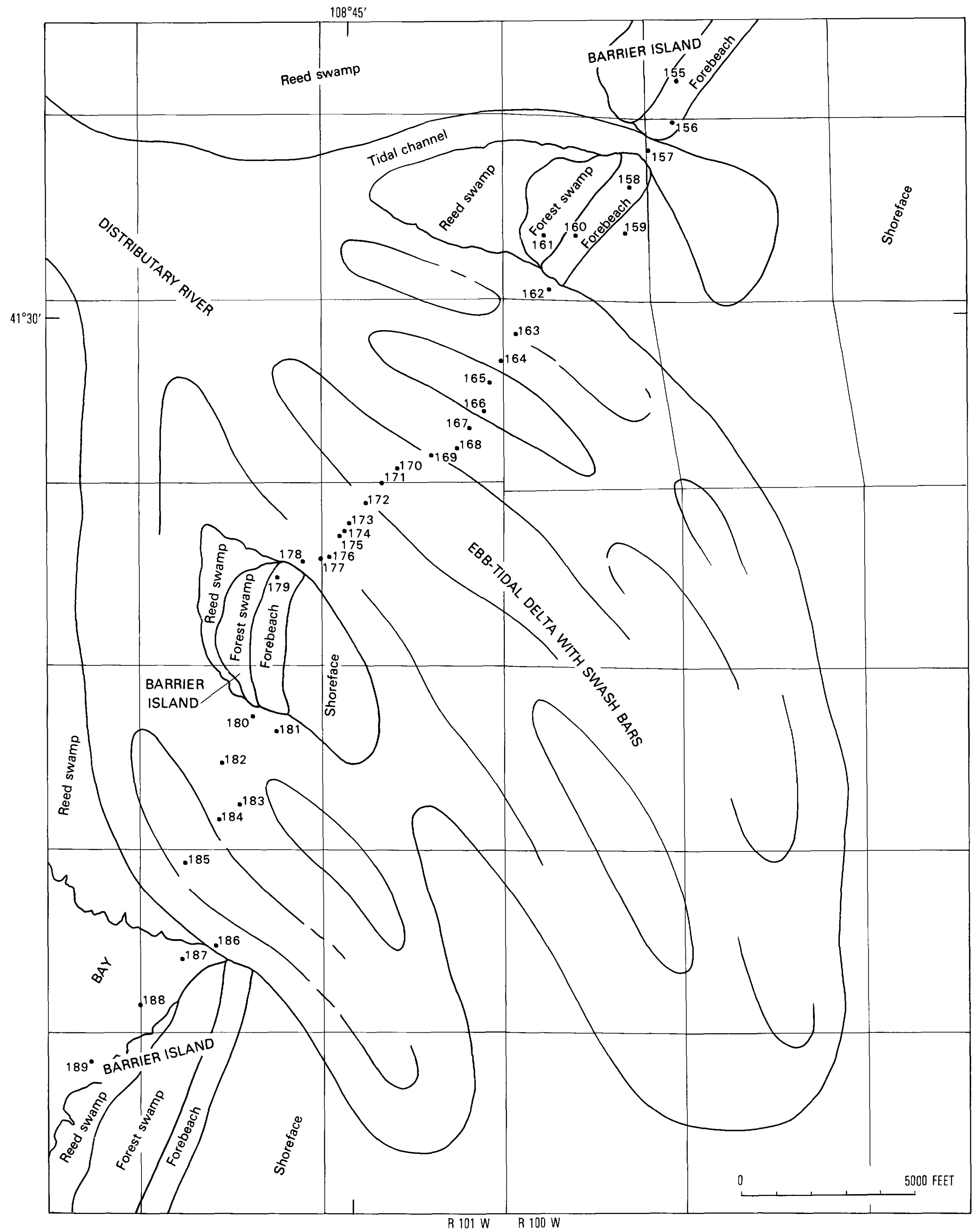


FIGURE 31.—Paleogeographic map of South inlet area of barrier shoreline No. 3 in the Fox Hills Sandstone, east flank of the Rock Springs uplift. Numbered data points indicate locations of measured sections shown on plates 1 and 2.

FIGURE 32.—Outcrops of the Fox Hills Sandstone and Lewis Shale at Salley sound in NE¼NE¼SW¼ sec. 21, T. 19 N., R. 100 W., near measured section 131 (pl. 2). 1, Lewis Shale; 2, lower shoreface sandstone and shale; 3, bay-fill shale and sandstone; 4, flood-tidal delta sandstone. Outcrops shown are about 250 ft thick.

Salley sound; however, there is little evidence to support this interpretation.

ACCRETIONARY SWASH BARS AT JIM INLET AND SALLEY SOUND

The relationship of accretionary swash bars to tidal inlets is illustrated in figure 21. The accretionary swash bar at Jim inlet weathers to a persistent cliff and is part of the white cap on the Fox Hills Sandstone (fig. 34). The beds that form the swash bar crop out for about 2 mi and are as much as 31 ft thick. They are composed of mostly light gray to white, fine- to medium-grained sandstone that occurs in thick, parallel beds that accrete in a southeast direction. The sandstone is commonly bioturbated and some of the beds have very thin, dark-gray, carbonaceous shale interbeds and partings. The upper 0.5 ft of the swash bar is composed of rooted, carbonaceous sandstone where it is in contact with the overlying Hall coal bed (pl. 2). The swash bar at Jim inlet unconformably overlies sandstone and shale beds of flood-tidal delta origin and sandstone beds of upper shoreface (surf zone) origin. A scoured contact of the swash bar sandstone with underlying flood-tidal sandstone and shale is shown in figure 35.

The accretionary swash bar at Salley sound crops out for about 1 mi and has a maximum thickness of about 35 ft. It is composed of light-gray, fine- to medium-grained sandstone with some carbonaceous shale partings. It occurs in thick, subparallel beds. The swash bar was deposited along the south margins of an open water sound, mostly as sand waves as much as 3 ft in height and 60 ft long. These sand waves exhibit sand transport directions ranging from S. 5° E. to S. 30° E.

SHORELINE SUBMERGENCE AND MARINE TRANSGRESSION

The Fox Hills Sandstone and adjacent rocks in the study area were measured and described by Land (1972) and Roehler (this report). Although the same rocks were measured and described in these investigations, we reached different interpretations and conclusions concerning their origin and mode of deposition. Land (1972, p. 62; pl. 2) concluded that the shoreline sequences that comprise the Fox Hills Sandstone offlapped as three distinct sandstone bodies of progressively younger age, which rise stratigraphically in step fashion along the length of the outcrops (fig. 36*A*). He believed that between the offlapping sequences were periods of significant shoreline submergence and marine transgression. My investigations indicate that only barrier shorelines Nos. 1 and 2 offlapped in step fashion and that little evidence exists for pronounced marine transgression in the intervals between shoreline deposition.

Land (1972, pl. 2) identified three different coal beds overlying the Fox Hills Sandstone (fig. 36*A*). My correlations (fig. 36*B*; pl. 2) indicate that Land's three coal beds are actually only two coal beds—the Hall bed and an unidentified coal bed immediately overlying barrier shoreline No. 1. The Hall coal bed contains several splits and partings, but persists along outcrops above the Fox Hills Sandstone across the entire study area. In several places, the Hall coal bed rests directly upon barrier shorelines Nos. 2 and 3. These relationships indicate that the Hall coal bed was diachronous, and that no major interruptions of coal (peat) deposition occurred on the landward side of the barriers as a result of pronounced shoreline subsidence or marine transgression.

I believe that deposition of the Fox Hills Sandstone occurred in three time-transgressive stages that were primarily defined and separated by periods of still-stand, during which time the deposition of coarse clastics (mostly sand) diminished and the shoreline areas underwent minor subsidence. If significant marine transgressions had accompanied these subsidences, their stratigraphic position would be defined by unconformities and transgressive shoreline deposits; none were observed along the outcrops. Also, if major marine transgressions had occurred, one would expect that the forebeach sandstone lithofacies of the three barrier shorelines would overlap each other geographically; no such overlapping was observed along the outcrops. Thus the stratigraphic evidence seems to indicate that the barrier shorelines were stable and that eustatic changes, if they occurred, were minor.

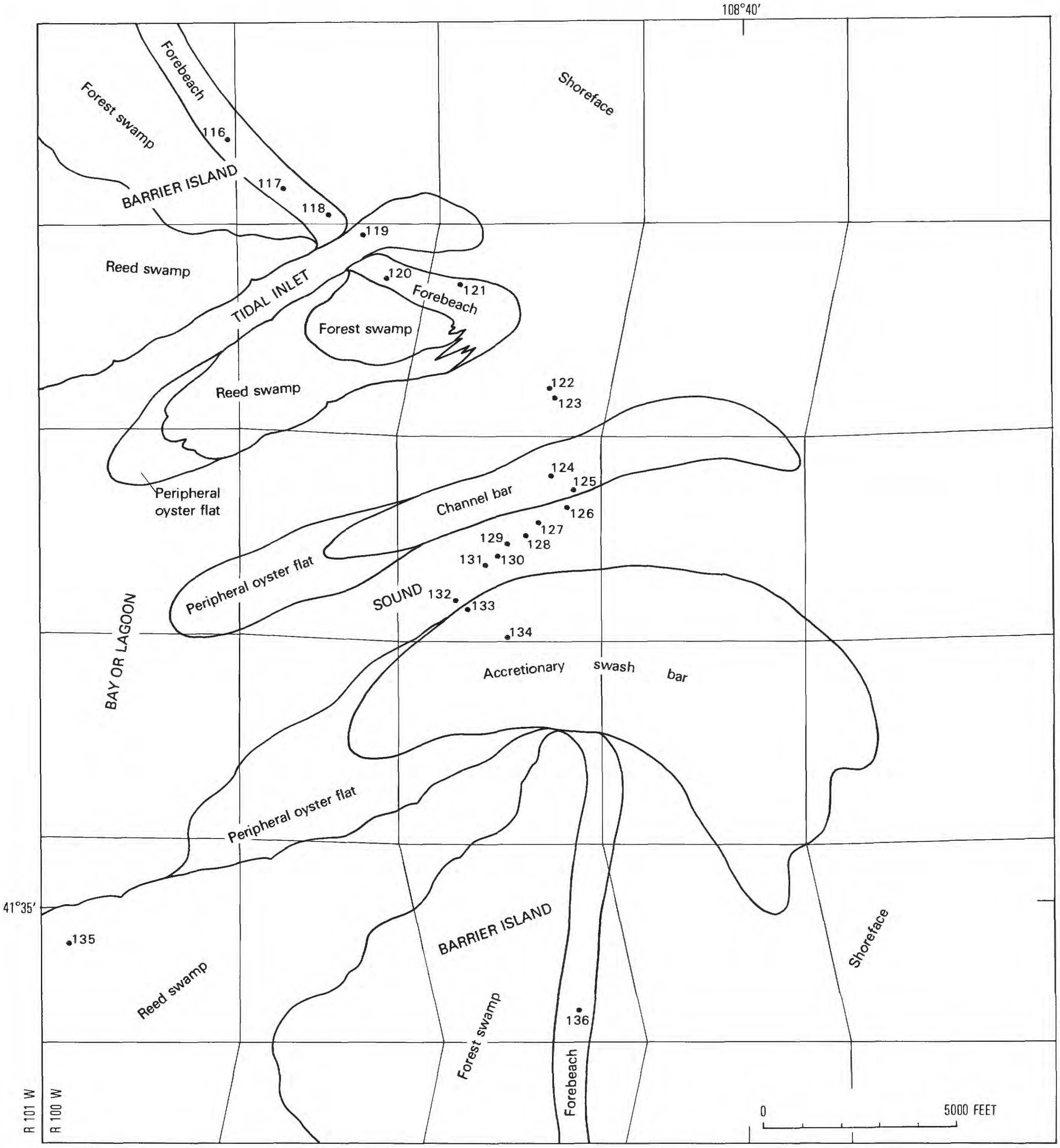


FIGURE 33.—Paleogeographic map of Salley sound area of barrier shoreline No. 3 in the Fox Hills Sandstone, east flank of the Rock Springs uplift. Numbered data points indicate locations of measured sections shown on plates 1 and 2.

BARRIER ISLAND MODELS

A stylized model for barrier shoreline deposition in the Fox Hills Sandstone was prepared by Land (1972), using what is published herein as figure 37*A* as his mature stage of barrier development. Land's model differs from the model prepared by me (fig. 13) in that he interpreted the surf zone and forebeach

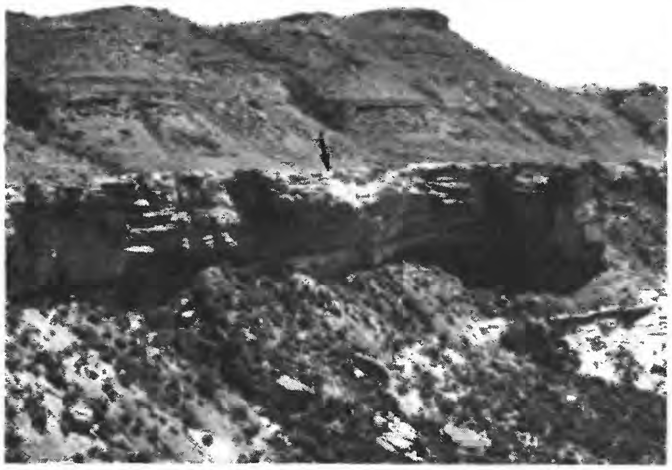


FIGURE 34.—Outcrop of an accretionary swash bar (arrow) at Jim inlet in NW¼SE¼ sec. 18, T. 20 N., R. 100 W., at measured section 74 (pl. 2). The swash bar here is 33 ft thick.

FIGURE 35.—Scour surface (arrow) at the base of an accretionary swash bar at Jim inlet in NW¼SE¼ sec. 18, T. 20 N., R. 100 W., at measured section 76 (pl. 2).

zone of the upper shoreface as "estuary sands." He believed that these estuary sands were deposited in deep inlets that migrated parallel to the shoreline and in this manner eroded and destroyed the record of foreshore and upper shoreface sedimentation. As a result of this interpretation, Land (1972, p. 59–62) placed estuary sandstones everywhere along the top of the Fox Hills Sandstone (fig. 37*A*). Land (1972, pl. 2) also indicated that the estuary sandstones are in unconformable contact with underlying parts of the shoreface lithofacies. My field observations indicate (1) that the primary sedimentary structures and stratigraphic position of Land's estuary sandstones clearly show they are of mostly surf zone and forebeach zone origins; (2) that estuary sandstones when present in the study area are restricted to inlets and lagoons; and (3) that the surf and forebeach zones are everywhere in conformable contact with underlying shoreface lithofacies (pl. 2, this report).

Using Land's (1972) model (fig. 37*A*) as a guide, I have prepared a similar stylized model that reinterprets a mature stage of barrier shoreline development in the Fox Hills Sandstone (fig. 37*B*).

LANCE FORMATION

TYPE OF OUTCROPS

As previously discussed, the Lance Formation overlies and intertongues at its base with the Fox Hills Sandstone; it is unconformably overlain by the Fort Union Formation (fig. 1). The lower 200–400 ft of the Lance Formation crops out in steep, gray and tan, steplike slopes overlying more resistant bench-forming outcrops of the Fox Hills Sandstone (fig. 2). In places, the lower slopes of the Lance Formation are brick red as a result of burned (clinkered) coal and country rock. Above the lower 400 ft of the formation, the outcrops consist of mostly broken terrane formed by barren, resistant, tan sandstone ridges that rise along long dip slopes between sage-covered, drab-gray shale valleys. The drainages that cross the outcrops of the formation are generally dry and mostly trend toward the valley formed by the Lewis Shale.

COMPOSITION AND THICKNESS

The Lance Formation is composed of interbedded tan and gray sandstone and siltstone, gray shale, dark-gray and dark-brown carbonaceous shale, and coal. Dolomite and hematite concretions are common. The formation reaches a maximum exposed thickness of about 1,000 ft near the center of the east flank of the Rock Springs uplift a few miles north of Interstate Highway 80 (Roehler, 1983). The formation continues to thicken in the subsurface off the east flank of the uplift into the adjacent Great Divide and Washakie basins.

PALEONTOLOGY

Freshwater (fig. 38) and brackish-water (fig. 39) mollusks and trace fossils (figs. 40, 41) are abundant

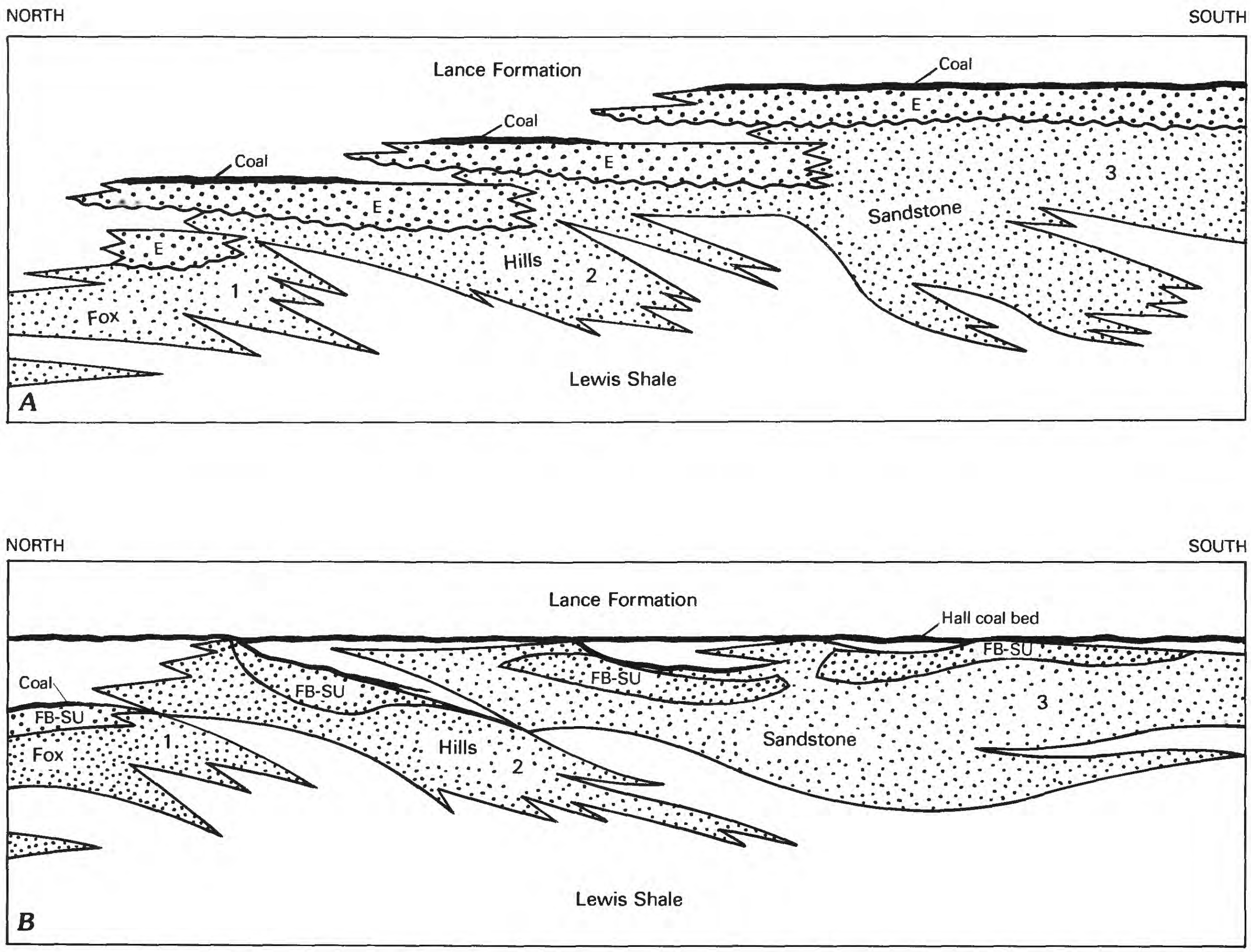


Figure 36.—Simplified cross sections of outcrops of the Fox Hills Sandstone and adjacent formations along east flank of the Rock Springs uplift. The data are from measured sections that show two different interpretations of the stratigraphy. *A*, modified from Land (1972, pl. 2); *B*, Roehler (this report). E, estuary sandstone; FB–SU, forebeach and surf sandstone. 1, 2, 3, barrier shoreline sequences.

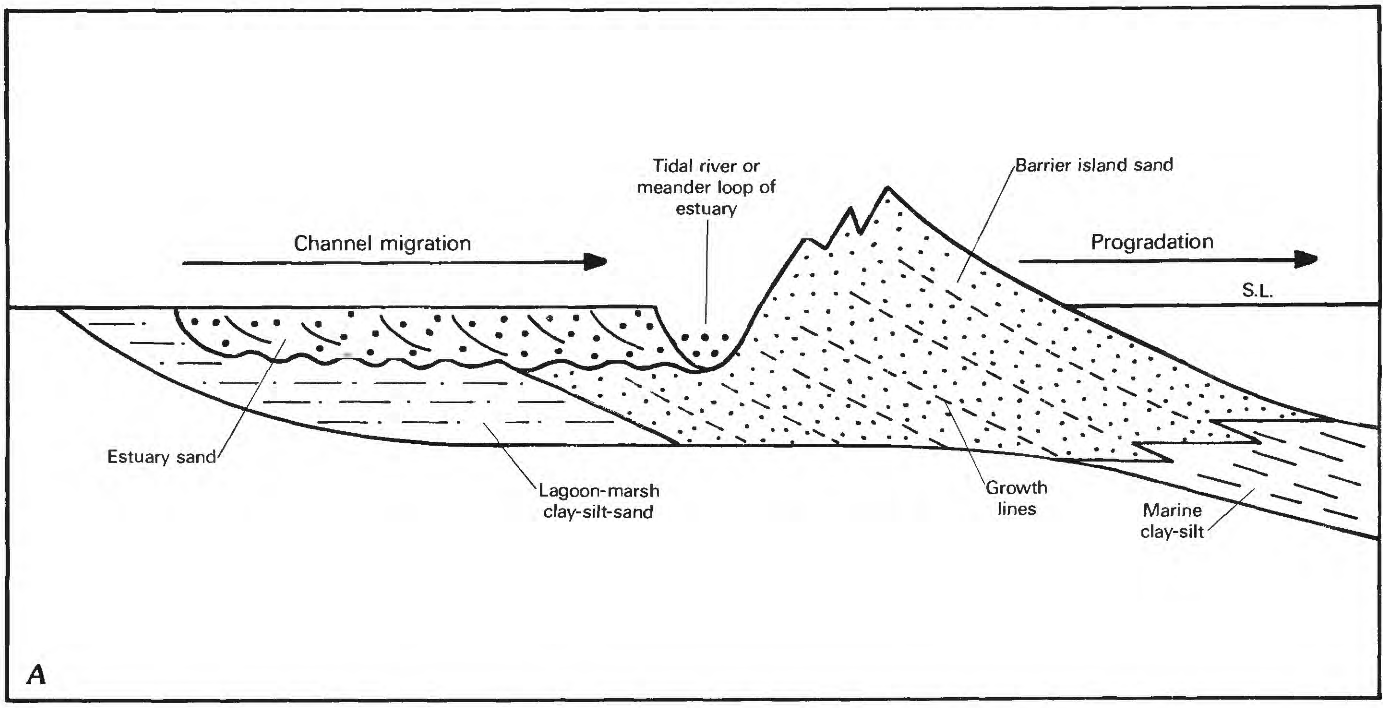
in the Lance Formation. Impressions of palm leaves (fig. 42), wood fragments, and some dinosaur bones and tracks are present locally along outcrops. Ostracodes and charophytes were identified at several horizons in the U.S. Geological Survey corehole BC No. 1. The fossils collected along outcrops (listed by U.S. Geological Survey locality numbers on pl. 2) are identified below. Fossils collected from the BC No. 1 corehole are identified in appendix B.

D9195 NW¼NW¼ sec. 31, T. 18 N., R. 100 W.
Crassostrea sp.
Leptesthes sp.
Unionid
Teredina sp.
Dinosaur bone fragments

D9189 SE¼SE¼NE¼ sec. 2, T. 17 N., R. 101 W.
Leptesthes fracta
Unionid
Tulotomops thompsoni
Campeloma multilineata
Goniobasis sp.

D9188 SW¼SE¼ sec. 11, T. 17 N., R. 101 W.
Crassostrea sp.
Leptesthes fracta
Tulotomops thompsoni

D8889 NE¼ sec. 36, T. 18 N., R. 101 W.
Crassostrea sp.
Leptesthes fracta
Teredina sp.



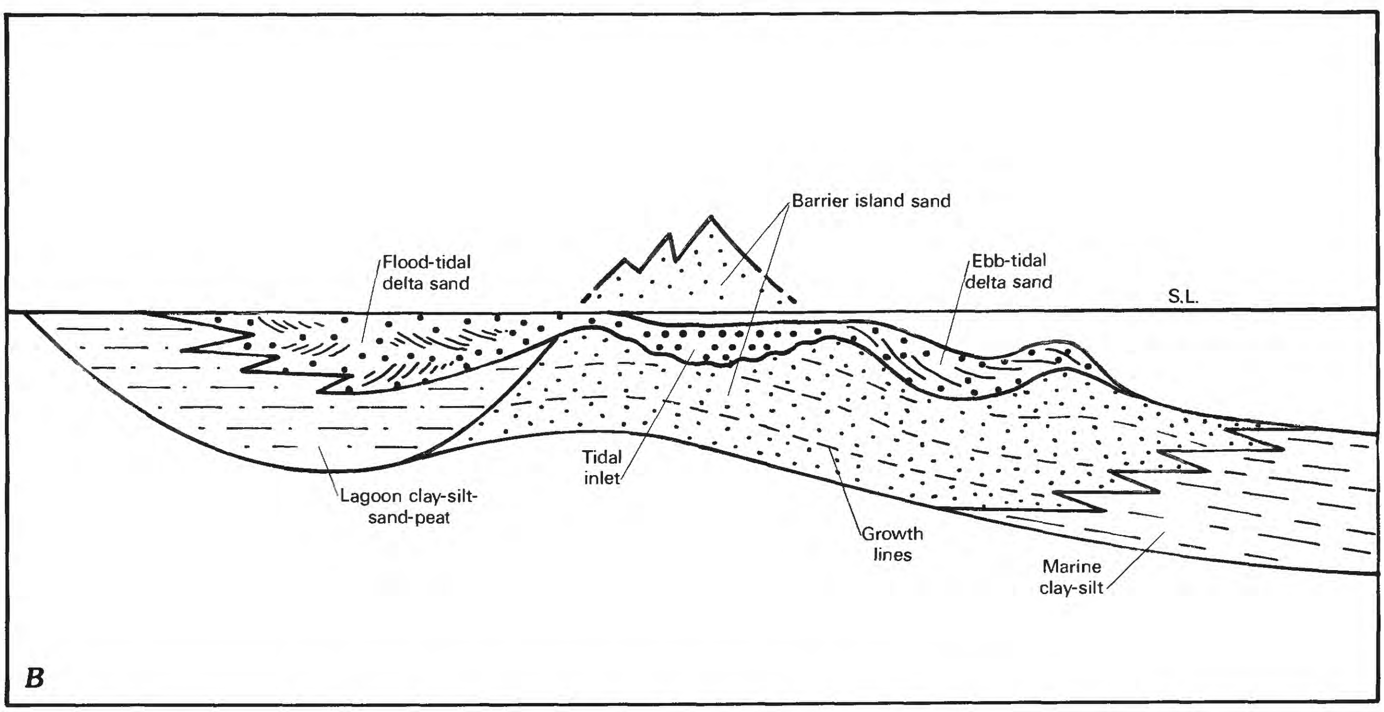


FIGURE 37.—Models for barrier shoreline and associated lagoon and marine depositional environments in the Fox Hills Sandstone, east flank of the Rock Springs uplift. *A*, from Land (1972); *B*, Roehler (this report). S.L., sea level.

D8888 NE¼ sec. 36, T. 18 N., R. 101 W.
Crassostrea sp.
Leptesthes fracta
Teredina sp.

D8887 NE¼ sec. 36, T. 18 N., R. 101 W.
Crassostrea sp.
Leptesthes fracta
Teredina sp.

D8886 SW1/4 sec. 36, T. 18 N., R. 101 W.
Leptesthes fracta
D10211 SE1/4SE1/4 sec. 5, T. 22 N., R. 102 W.
Crassostrea sp.
Leptesthes fracta
Hendersona umbonella
Corbula sp.
D10210 SW1/4NE1/4 sec. 23, T. 22 N., R. 102 W.
Leptesthes fracta
Hendersona cardiniaeformis
D10209 N1/2N1/2SW1/4 sec. 24, T. 21 N., R. 101 W.
Teredina sp.
D10208 NW1/4SW1/4 sec. 24, T. 22 N., R. 102 W.
Leptesthes fracta
Corbula undifera
D10207 SE1/4NW1/4 sec. 36, T. 21 N., R. 102 W.
Corbula sp.
Minute gastropod
D11958 SE1/4SE1/4NE1/4 sec. 32, T. 20 N., R. 100 W.
Anomia gryphorhynchus
Leptesthes fracta
Veloritina sp.
Corbula subtrigonalis
Cassiopella turricula
Tulotomops thompsoni
Melania wyomingensis
D11957 NE1/4SW1/4SE1/4 sec. 29, T. 20 N., R. 100 W.
Leptesthes fracta
Plesielliptio? sp.
D11956 NE1/4NE1/4SE1/4 sec. 29, T. 20 N., R. 100 W.
Crassostrea sp.
Leptesthes fracta
Viviparus plicapressus
Cassiopella turricula
Tulotomops thompsoni
Melania wyomingensis
D6423 SW1/4NW1/4NE1/4 sec. 8, T. 22 N., R. 102 W.
Tellina sp.
Cymbophora? sp.

DEPOSITIONAL ENVIRONMENTS AND LITHOFACIES

Investigations of the Lance Formation are restricted to the lower 400 ft of the formation, which was deposited in bays landward of the barrier islands that formed the Fox Hills Sandstone. The rocks above the lower 400 ft of the formation are mostly of coastal swamp origin (Roehler, 1983). The rocks of bay and coastal swamp origins in the formation are similar in that in both environments they are mostly interbedded sandstone, siltstone, shale, carbonaceous shale, and coal. They are dissimilar in that the rocks of bay origin contain thicker and more numerous beds of coal, thinner and less numerous beds of sandstone, and more fossils.

FIGURE 38.—*Leptesthes* sp. (left) and an unidentified cast and mold of a large Unionid pelecypod (right) in a splay sandstone at locality D11957, 77 ft above the base of the Lance Formation in measured section 92 (pl. 2) in NE1/4SW1/4 sec. 29, T. 20 N., R. 100 W.

FIGURE 39.—Outcrop (arrow) containing *Crassostrea* sp., *Corbula* sp., and *Anomia* sp. in the Lance Formation 10 ft above the top of the Fox Hills Sandstone (lower part of photograph) in measured section 3 (pl. 2) in SE1/4 sec. 9, T. 22 N., R. 102 W. Coal bed in slopes below fossil outcrop is 3.6 ft thick.

FIGURE 40.—*Skolithus* in a splay sandstone 180 ft above base of the Lance Formation in measured section 92 (pl. 2) in NE¼ SW¼ sec. 29, T. 20 N., R. 100 W. Top, top view; bottom, side view.

FIGURE 42.—Ridges and furrows formed by a segment of a palm frond on the surface of sandstone in the Lance Formation in SE¼SW¼ sec. 28, T. 20 N., R. 100 W.

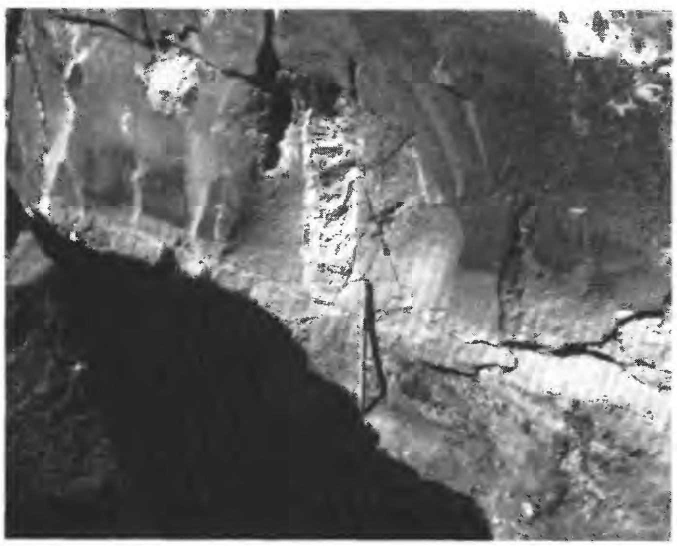


FIGURE 41.—Side view of *Diplocraterion* in a bay-fill sandstone 14 ft above base of the Lance Formation in measured section 13 (pl. 2) in SW¼SE¼SW¼ sec. 8, T. 21 N., R. 101 W.

BAY CYCLES

DEFINITION

The rocks of bay origin in the lower 400 ft of the Lance Formation are composed of sediments of fresh-water and brackish-water origins that were deposited cyclically. The term "bay cycle" is herein applied to this type of sedimentation. A bay cycle is defined as "the alternate freshening and salting of bay waters as a result of coastal emergence and submergence, which caused repetitive changes in the type and distribution of lithologic units and fauna and flora."

ORIGIN

The repetition of lithologic units in the bay cycles occurs in a rhythmic manner, which suggests that the cycles were periodic and climate related. Although supporting data are lacking, the cycles appear to be the result of climate fluctuations brought about by periodic changes in the Earth's orbit and rotation. I believe that they primarily reflect the cycle of the precession of the equinoxes—the noncentric path taken by the polar axis of the Earth as it revolves around the ecliptic pole. Such climate changes would be similar to the climate changes of the Pleistocene glacial-interglacial periods described by Milankovitch (1941). The cycle of the precession of the equinoxes has a period that averages about 21,000 years (Fischer, 1986), and this length of time probably corresponds to the average time required to complete a bay cycle. Fourteen bay cycles are identified in the lower part of the Lance Formation in the U.S. Geological Survey BC No. 1 corehole located in NW¼NW¼NE¼ sec. 4, T. 19 N., R. 100 W. (pl. 3).

The emergent stages of the bay cycles are believed to represent warm and wet climate periods of the precessional cycle and the submergent stages are believed to represent cool and dry climate periods of the precessional cycle. If coastal subsidence in the study area during the Late Cretaceous occurred at a fairly constant rate ranging from about 0.5 to 1.5

inches every 100 years (Roehler, 1990, p. 12), then the emergent stages (the warm and wet periods) were times of increased rates of sedimentation, rapid bay infilling, freshening of the bay waters, and influx of freshwater fauna and flora. The opposite lithologic and biologic relationships would characterize submergent stages of the bay cycle.

If bay cycles reflect the cycle of the precession of the equinoxes, then the total time required to deposit barrier shoreline No. 2 was about 84,000 years. This length of time is indicated by the fact that there are four coal beds (or four bay cycles of 21,000 years each) in the rocks of bay-fill origin overlying barrier shoreline No.1 up to and including the Hall coal bed (measured sections 3–5, pl. 2). The rocks of bay-fill origin in this interval were deposited contemporaneously with barrier shoreline No. 2.

STAGES OF DEVELOPMENT

The freshwater stages of the bay cycles ultimately resulted in the deposition of coal, and the brackish-water stages ultimately resulted in the deposition of bay-fill shale. Spaced between these lithologic units are beds of sandstone and siltstone deposited in interdistributary splays and carbonaceous shale deposited in reed swamps (pl. 3). Sandstones deposited as stream-channel fill are rare in the section, but are present at widely spaced locations. Five stages of development (A to E) of a bay cycle with their corresponding lithologies are illustrated in figure 43: (A) Saline- to brackish-water bay-fill shale that may contain oyster shells, splay sandstones, or concretions; (B) freshwater to brackish-water reed swamp carbonaceous shale; (C) freshwater forest swamp coal: (D) freshwater to brackish-water reed swamp carbonaceous shale; and (E) saline to brackish-water bay-fill shale that may contain oyster shells, splay sandstones, or concretions. Changing salinities of bay waters during these stages are evidenced by beds alternately containing freshwater and brackish-water fossils. The identification of fossils and detailed descriptions of lithologies in the U.S. Geological Survey BC No. 1 corehole appear in appendix B.

The five stages of development of bay cycles are illustrated in plan view by simplified maps in figure 44. Note that views *A* and *E* and views *B* and *D* of figure 44 are similar in appearance, but they represent different periods of submergence and emergence.

Figures 45 and 46 illustrate the development of a bay cycle three dimensionally using block diagrams. The block diagrams show the manner in which the lithologic units that compose the cycles were deposited as mud, carbonaceous mud, and peat. Similar depositional environments and their corresponding sediments are common in bays located behind barrier

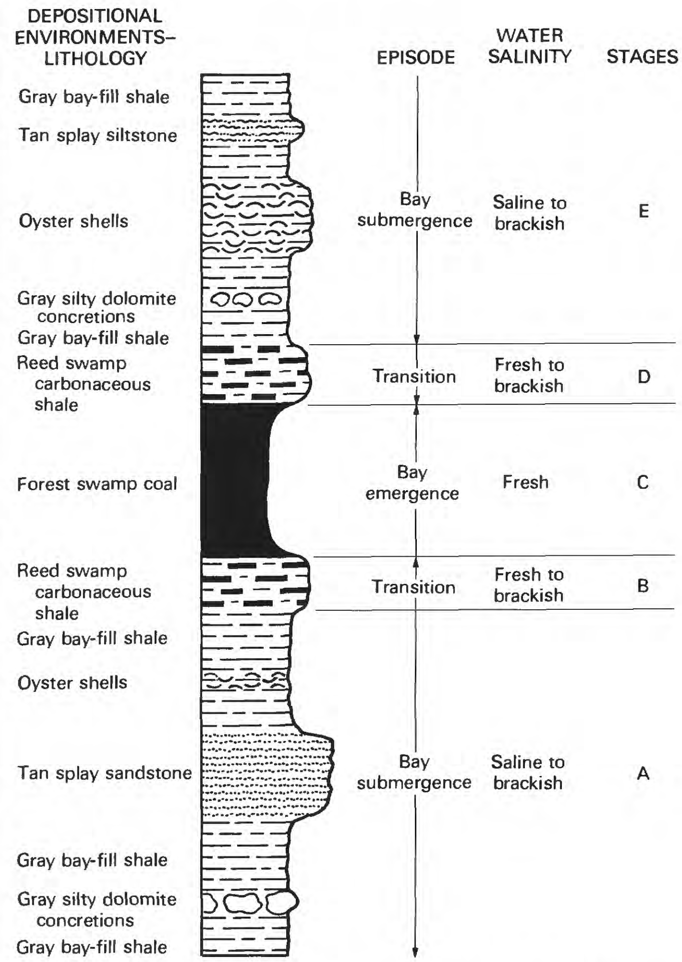


FIGURE 43.—Idealized section illustrating the five stages of development (A to E) of a bay cycle in the lower part of the Lance Formation on the east flank of the Rock Springs uplift.

islands along the southeastern coast of the United States (fig. 47). Compare figures 43 and 46 with figure 47 and the depositional environments and lithologies shown on plate 3.

Bay cycles are readily discernible along outcrops of the lower part of the Lance Formation in the study area. The lithologies of the lower 10 bay cycles in the formation are illustrated in a columnar section (pl. 4) constructed from measured section 104 (pls. 1, 2). Bay cycle No. 7 on plate 4 has been enlarged to illustrate the lithologies, depositional environments, and stages of the cycle. A photograph of outcrops of bay cycle No. 3 in measured section 101 (pls. 1, 2) clearly illustrates the bay cycle lithologic relationships (fig. 48).

CHEMISTRY OF BAY WATERS

The water in the coastal bays during deposition of the lower part of the Lance Formation appears to have undergone chemical changes between the bay margins and the interior parts of the bays. These changes took place as the waters from freshwater

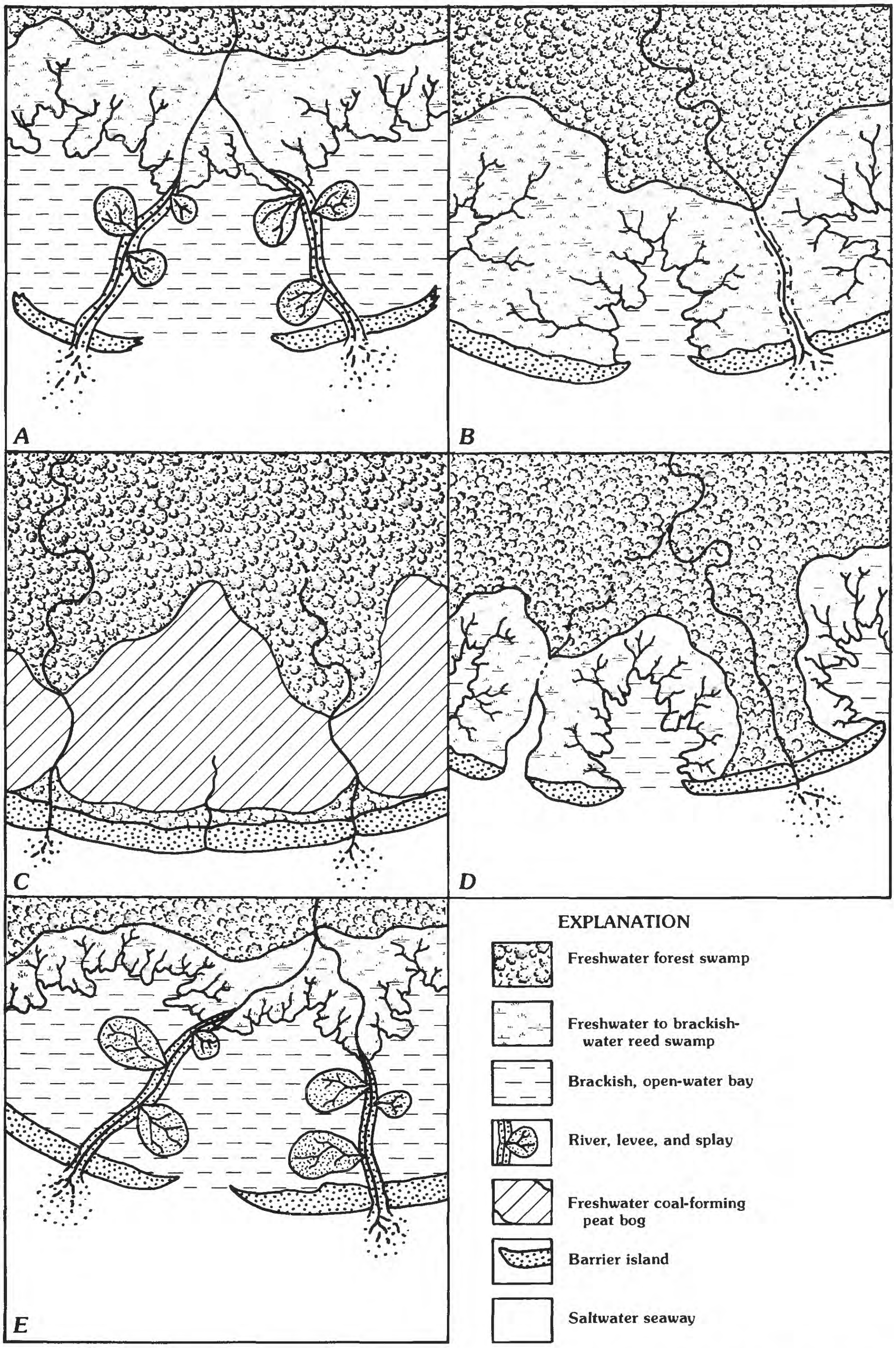


FIGURE 44.—Maps illustrating the stages of development of a bay cycle. *A*, Submergent barrier shoreline landward of which were large, brackish, open-water bays. *B*, Coastal emergence, during which time bay areas were largely filled in by freshwater to brackish-water reed swamps. *C*, Bay was entirely filled in and occupied by freshwater forest peat swamps. *D*, Resubmergence of the bays and reintroduction of freshwater to brackish-water reed swamps. *E*, Submergent barrier shoreline with large brackish, open-water bays.

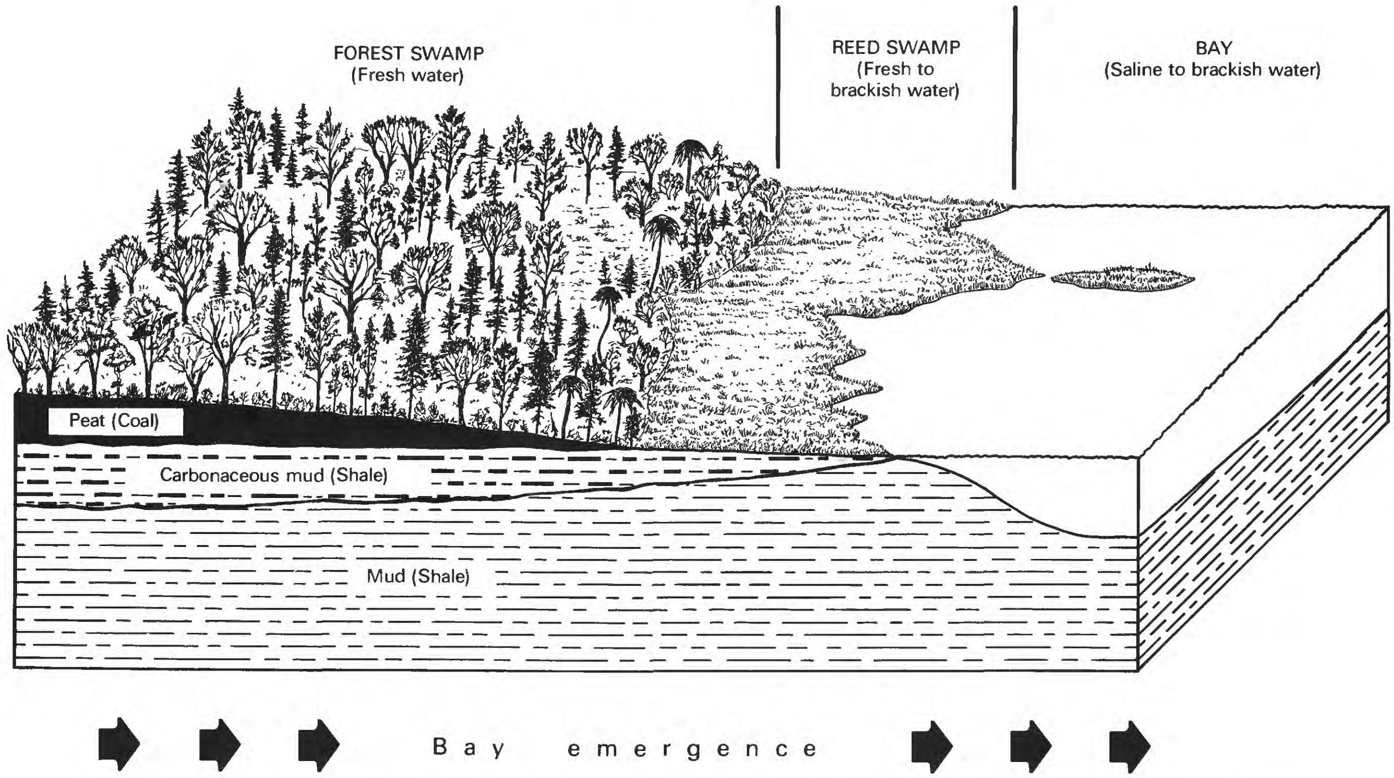


FIGURE 45.—Diagram of a bay cycle during emergence. Arrows indicate the direction of bay shoreline movement.

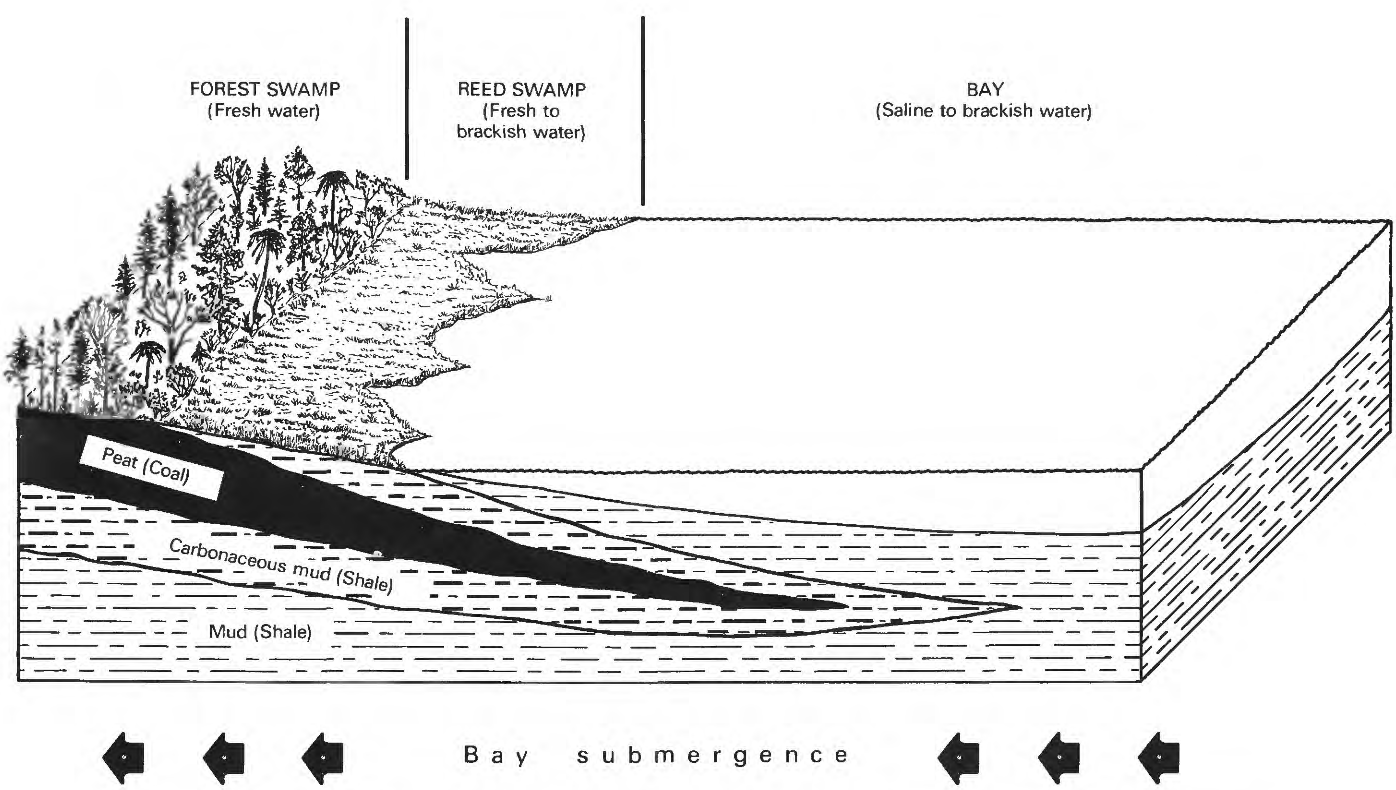


FIGURE 46.—Diagram of a bay cycle during submergence. Arrows indicate the direction of bay shoreline movement.

FIGURE 47.—Vegetation growing along the margins of a brackish-water bay adjacent to Highway 172, Camp LeJeune, North Carolina. 1, Forest swamp; 2, reed swamp.

FIGURE 48.—Lithologic units in bay cycle No. 3 exposed in measured section 101 (pl. 2). 1, bay-fill shale; 2, reed swamp carbonaceous shale; 3, forest swamp coal; 4, reed swamp carbonaceous shale; and 5, bay-fill shale with a layer of oyster shell fragments at the base. Pick handle is 1.5 ft long.

streams entering the bays mixed with the brackish bay waters. The results of this mixing are revealed in the rocks by the composition and lateral distribution of dolomite and hematite concretions. Dolomite concretions commonly overlie the sandstone and siltstone deposited at distal ends of the splays along the former bay margins (fig. 49). Farther into the former bay areas, the splay sandstone and siltstone disappear, but the dolomite concretions remain (fig. 50). Still farther into the former bay areas, the dolomite concretions are overlain by and are eventually replaced by hematite concretions (fig. 51). And, eventually, the hematite concretions thin and wedge out into bay-fill shales (fig. 52). These relationships are illustrated schematically in figure 53. The distribution of the dolomite and hematite concretions is undoubtedly the result of chemical reactions that took place when fresh, carbonate-, iron-, and humate-laden, acidic, negatively charged surface waters entering the bays mixed with brackish, sodium-chloride-laden, positively charged bay waters. During the chemical reactions that followed, calcium carbonate was precipitated first (probably as calcite, later altered to dolomite) and then iron was precipitated (probably as iron carbonate, later altered to hematite).

IMPORTANCE OF BAY CYCLES IN COAL EXPLORATION

The coal beds at 234.3–242.8 ft and 322.5–330.6 ft in the BC No. 1 corehole (pl. 3), each more than 8 ft thick, are minable. The heating values of these coal beds range between 8,500 Btu/lb and 10,400 Btu/lb on an as-received basis (unpublished data). The ash content generally ranges from 3 percent to 6 percent

FIGURE 49.—Lower part of the Lance Formation in SE$^1/_4$ sec. 29, T. 20 N., R. 100 W. 1, dolomite concretion overlying 2, splay sandstone. Pick used for scale is 1.5 ft long.

FIGURE 50.— Lower part of the Lance Formation in SE1/4 sec. 29, T. 20 N., R. 100 W. 1, dolomite concretion in 2, bay-fill shale.

FIGURE 51.—Lower part of the Lance Formation in SE1/4 sec. 29, T. 20 N., R. 100 W. 1, hematite concretion overlying 2, dolomite concretion in 3, bay-fill shale.

and the sulfur content is less than 1 percent. The upper and lower parts of these coal beds have higher ash and sulfur contents and lower heating values than the middle parts of the beds. It appears from these relationships that the quality of the coal of freshwater origin in the lower and upper parts of the coal beds was diminished as a result of contact with overlying and underlying carbonaceous shale beds of brackish-water origin. Whether these changes in coal quality were syngenetic or diagenetic has not been determined.

Bay cycles have been observed by me not only in the Lance Formation on the east flank of the Rock Springs uplift but also in other Cretaceous rocks

FIGURE 52.—Lower part of the Lance Formation in SE1/4 sec. 29, T. 20 N., R. 100 W. 1, hematite concretion in 2, bay-fill shale.

deposited along the western margins of the interior seaway throughout the Rocky Mountains. Bay cycles should play an important role in predicting the geographic and stratigraphic occurrences of coal and in evaluating the quantity and quality of coal resources of the western interior United States.

COMPOSITION, TEXTURE, AND COLOR OF SANDSTONE BEDS IN THE FOX HILLS SANDSTONE AND LOWER PART OF THE LANCE FORMATION

Sandstone beds in the Fox Hills Sandstone and lower part of the Lance Formation are mostly litharenites composed of 40–75 percent quartz, with lesser amounts of chert, feldspar, muscovite, and various rock fragments. They generally contain from 1 to 3 percent heavy minerals consisting of mostly zircon, tourmaline, garnet, and rutile. Cementing materials are hematite, calcite, and an unidentified white clay.

The texture of the sandstones was primarily determined by their depositional environment. Eight sandstone samples were collected for petrographic analysis from outcrops in measured section 52 (pls. 1, 2). The stratigraphic positions of these samples (lettered A to H) are shown in a columnar section (fig. 54). Photomicrographs of the samples are shown in figure 55; letters of the views in figure 55 correspond to letters of the samples in figure 54. Samples shown in views *A* and *B* (fig. 55), from the lower shoreface and lower part of the middle shoreface lithofacies of barrier shoreline No. 2 in the Fox Hills Sandstone (pl. 2), are composed of silt with some intermixed grains of very

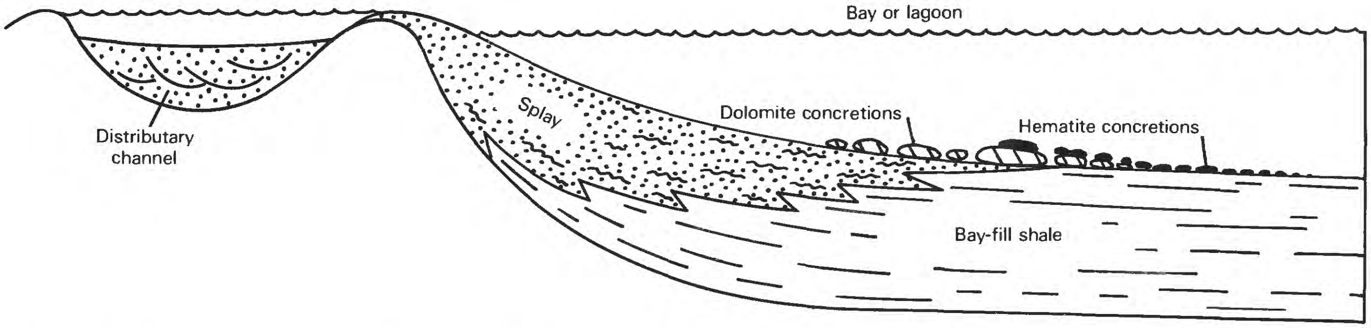


FIGURE 53.—Horizontal distribution of dolomite and hematite concretions in bay deposits of the lower part of the Lance Formation.

fine to fine sand, which is fairly well sorted. These two samples are typical of quiet, deep-water sediments deposited seaward of the barrier shorelines. The size of the sand grains in barrier shoreline No. 2 increases to very fine to medium and the grains are poorly sorted in overlying, nearshore parts of the middle shoreface lithofacies (sample C; fig. 55*C*) and in an ebb-tidal delta (sample D; fig. 55*D*) at the top of the barrier shoreline (pl. 2). The sand grains in sample E, figure 55*E*, are medium to coarse, angular to subrounded, and reflect a terrestrial source of sediments and the high energy associated with tidal currents flowing through Jim inlet (pl. 2). Samples F and G (fig. 55*F*, *G*) are very fine to fine grained, they are poorly sorted, and they characterize splay sandstones deposited in quiet-water bay area in the lower part of the Lance Formation. Sample H (fig. 55*H*) is mostly fine grained and poorly sorted, typical of the sandstone beds deposited in distributary stream channels.

The change in color from brown and tan in the lower and middle shoreface parts of the Fox Hills Sandstone to gray and white in the upper shoreface parts of the Fox Hills Sandstone that forms the "white cap" (fig. 17) was examined by Hickling (1991). Hickling studied the petrology of the Fox Hills Sandstone in four sections that he measured and sampled in T. 20 N., R. 100 W. The sections are located between measured sections 78 and 94 (pls. 1 and 2). Hickling (1991, p. 6) found that the brown and tan sandstone beds of the lower and middle shoreface average 2½ times the matrix of the white-cap sandstone beds and that the matrix of the brown and tan sandstone beds contains large amounts of argillaceous hematite and dolomite that are missing in the white-cap sandstone beds. Hickling (1991, p. 12–13) accounted for these mineralogical differences by the fact that during deposition most clay and matrix-size materials would have been kept in suspension longer and transported farther seaward from shoreline areas into deeper waters of the middle and lower shoreface. Thus the brown and tan colors of the middle and lower shoreface primarily result from the brown pigmentation produced by hematite, which is missing in the gray and white upper shoreface sandstone beds. Hickling (1991, p. 14) discounted the possibility that leaching by organic acids derived from overlying coal beds could have led to the removal or alteration of iron pigments to produce the white-cap sandstone beds. Although they were not studied by Hickling, the brown and tan colors imparted to sandstone beds in the lower part of the Lance Formation are probably also the result of iron (hematite) pigmentation.

CORRELATION OF SURFACE SECTIONS AND DRILL HOLES

Stratigraphic correlations of the Fox Hills Sandstone and overlying and underlying formations of Late Cretaceous age from the east flank of the Rock Springs uplift eastward into the Great Divide and Washakie basins are illustrated on plate 5. The correlations begin at measured sections in the study area, which are correlated into the subsurface with electric logs of oil and gas drill holes.

Correlation *B–B′* (pl. 5) begins at Potash Wash on the northeast flank of the uplift and trends 25 mi northeastward to Red Lake located in the western part of the Great Divide basin (pl. 1). At Potash Wash (No. 1, pl. 5; measured section 23, pl. 2), the Fox Hills Sandstone is composed of barrier shorelines Nos. 1 and 2. These shoreline units correlate northeastward to where they intertongue with and are replaced laterally by coal-bearing rocks of bay origin in the Lance Formation between the Chandler and Simpson Pierson No. 2 dry hole (No. 5, pl. 5) and the Davis Oil Company Olshansky No. 1 dry hole (No. 6, pl. 5). Barrier shoreline No. 1 on correlation diagram *B–B′* is partly underlain by a third, unnumbered barrier shoreline sandstone that is missing in outcrops at Potash Wash but is well developed in the Davis Oil Company Garfield No. 1–Z dry hole (No. 2, pl. 5)

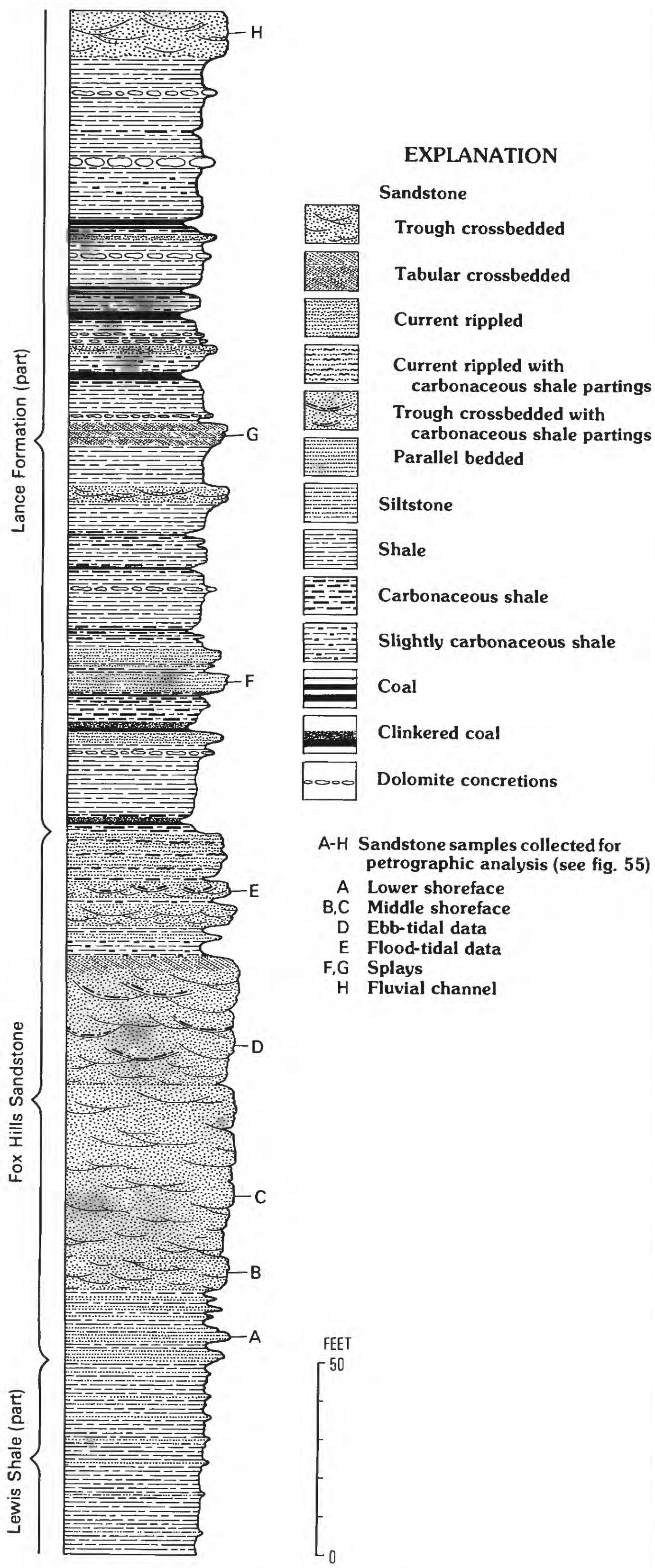


FIGURE 54.—Measured section 52 (pls. 1, 2) showing the stratigraphic position and depositional environments of sandstone samples collected for petrographic analysis. Photomicrographs of the samples are shown in figure 55.

a few miles to the northeast. The unnumbered barrier shoreline is also replaced by the Lance Formation in a northeast direction across the correlation diagram.

Most of the upper part of the Lewis Shale on correlation diagram *B–B′* consists of marine sandstone and siltstone that compose the Red Desert delta. These delta sediments thicken in the subsurface in a northeast direction across the Great Divide basin toward the center of the delta, but thin and wedge out in a southwest direction toward the outcrops on the northeast flank of the Rock Springs uplift. The southwestern wedgeout of the delta sediments occurs between the Davis Oil Company Garfield No. 1–Z dry hole and the measured section at Potash Wash.

The Almond Formation underlies and intertongues with the Lewis Shale on correlation diagram *B–B′*. The Almond Formation consists of barrier shoreline sandstones (stippled) and underlying coal-bearing rocks of bay and coastal swamp origins. The formation conformably overlies thick beds of sandstone of alluvial plain origin that compose the Ericson Sandstone.

Correlation diagram *C–C′* (pl. 1) begins at outcrops near Hallville Station on the Union Pacific Railroad (No. 8, pl. 5; measured section 116, pl. 2) and trends 24 mi northeast to the Utex Exploration Company No. 1 dry hole (No. 14, pl. 5) located in the southeast part of the Great Divide basin. Barrier sandstones of shorelines Nos. 2 and 3 (pl. 2) crop out near Hallville Station. Barrier shoreline No. 2 wedges out in the Lewis Shale a few miles northeast of Hallville Station between the Prenalta Corporation No. 13–4–20–99 gas well (No. 11, pl. 5) and the Mesa Petroleum Company No. 6–1 gas well (No. 12, pl. 5). Barrier shoreline No. 3 (pl. 2) can be correlated from outcrops near Hallville Station across the length of correlation diagram *C–C′*. A third, unnumbered barrier shoreline sandstone of the Fox Hills Sandstone is present above barrier shoreline No. 3 northeast of the Union Pacific Railroad Hallville No. 44–9D gas well (No. 9, pl. 5). This shoreline sandstone intertongues with and is replaced by coal-bearing rocks of bay origin in the Lance Formation southwest of the Union Pacific Railroad No. 41–5 gas well (No. 10, pl. 5).

The Lewis Shale on correlation diagram *C–C′* consists of mostly marine sandstone and siltstone that make up the Red Desert delta. The delta sediments thin and are replaced by marine shale in a southeast direction between Nos. 8 and 14 on correlation diagram *C–C′*.

The Almond Formation on correlation diagram *C–C′* is composed of barrier shoreline sandstones (stippled) that intertongue with the Lewis Shale in its upper part and with coal-bearing rocks of bay and coastal

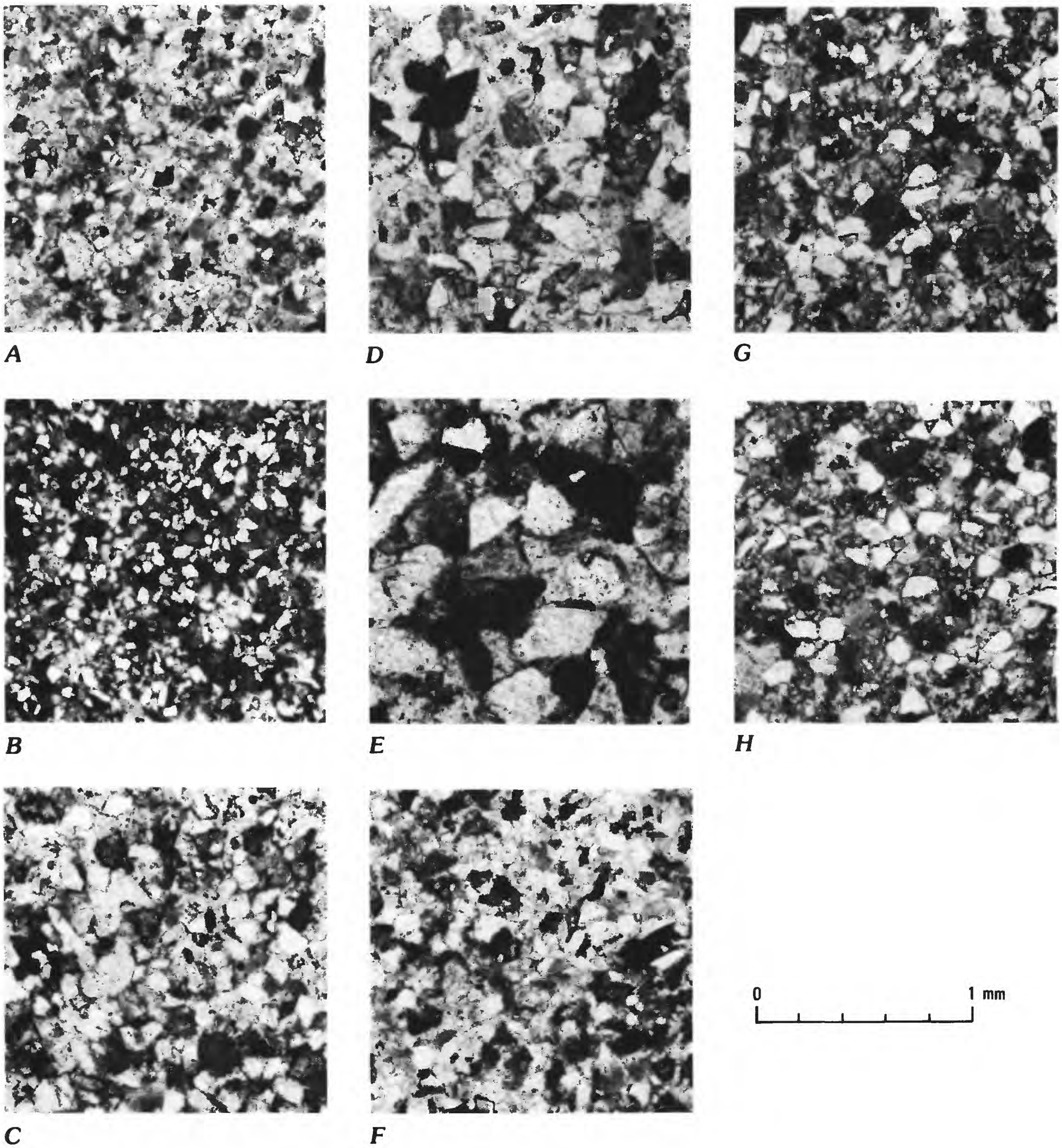


FIGURE 55.—Photomicrographs of sandstone samples collected from the lower part of the Lance Formation and Fox Hills Sandstone. Stratigraphic position and depositional environments of the samples are shown in figure 54.

swamp origins that conformably overlie the Ericson Sandstone in its lower part.

Correlation diagram *D–D′* (pl. 1) extends from outcrops near Black Buttes Station on the Union Pacific Railroad 15 mi eastward to Table Rock field in the northwest part of the Washakie basin. Barrier shorelines Nos. 2 and 3 (pl. 2) of the Fox Hills Sandstone crop out near Black Buttes Station (No. 15, pl. 5;

measured section 149, pl. 2). Barrier shoreline No. 2 is composed of lower shoreface sandstones that thin and wedge out eastward into the Lewis Shale. Barrier shoreline No. 3 consists of thick shoreface sandstones along outcrops near Black Buttes Station that are split into upper and lower parts separated by a thin bed of marine shale. Only thin remnants of barrier shorelines Nos. 2 and 3 remain at Table Rock field (No. 19, pl. 5). A third, unnumbered barrier shoreline sandstone is present above barrier shoreline No. 3 in the Davis Oil Company Champlin–Rock Springs No. 1 dry hole (No. 18, pl. 5), and this barrier shoreline continues from the dry hole eastward to Table Rock field. The unnumbered barrier shoreline sandstone in correlation diagram *D–D′* corresponds to the unnumbered barrier shoreline sandstone on correlation diagram *C–C′*; it is missing in correlation diagram *B–B′*.

The Lewis Shale in correlation diagram *D–D′* is composed of mostly nearshore marine shale with three thin interbedded remnants of Red Desert delta sandstone and siltstone that wedge out in a westward direction across the correlation diagram.

The Almond Formation in correlation diagram *D–D′* thickens from about 290 ft in outcrops near Black Buttes Station (No. 15, pl. 5) to about 375 ft at Table Rock field (No. 19, pl. 5). Near Black Buttes Station the formation is composed of coal-bearing rocks of bay and coastal swamp origins; at Table Rock field two barrier shoreline sandstones (stippled) overlie the rocks of bay and coastal swamp origins. The uppermost of these barrier shoreline sandstones (Nos. 17–19, pl. 5) is the producing interval at Patrick Draw field. Conformably underlying the Almond Formation are sandstones of alluvial plain origin that make up the Ericson Sandstone.

Correlation *E–E′* (pl. 5) extends from outcrops in the Dry Canyon area in secs. 28 and 29, T. 15 N., R. 102 W., near the south end of the Rock Springs uplift, 15 mi southeast to the Grynberg and Associates Trail No. 1–27 dry hole located in sec. 27, T. 14 N., R. 100 W. In outcrops in the Dry Canyon area (No. 20, pl. 5), the Lance Formation, Fox Hills Sandstone, and upper part of the Lewis Shale were removed by erosion along the Laramide unconformity at the Cretaceous-Tertiary boundary. The Laramide unconformity rises stratigraphically, and the underlying Cretaceous rocks thicken toward the southeast across correlation diagram *E–E′*. Where the Fox Hills Sandstone first appears below the unconformity, between the British-American Oil Company Dymond No. 1 dry hole (No. 22, pl. 5) and the General Petroleum Company Salt Wells No. 58–24 dry hole (No. 23, pl. 5), it consists of barrier shoreline No. 3 and an unnamed overlying barrier sandstone. The Red Desert delta in the Lewis Shale does not extend as far south as correlation diagram *E–E′*.

The Almond Formation, which was only about 300 ft thick in outcrops near Black Buttes Station in correlation diagram *D–D′* (No. 15, pl. 5), thickens to nearly 800 ft in the Dry Creek area in correlation diagram *E–E′* (No. 20, pl. 5). The Almond Formation in correlation diagram *E–E′*, as in the other correlations, consists of barrier shoreline sandstones (stippled) and coastal swamp deposits, which conformably overlie the sandstones of alluvial plain origin that make up the Ericson Sandstone.

REGIONAL PALEOGEOGRAPHY OF THE FOX HILLS SANDSTONE IN THE ROCK SPRINGS UPLIFT AREA DURING MAXIMUM MARINE TRANSGRESSION

The embayed western shoreline of the interior seaway during the Maastrichtian Age of the Late Cretaceous, at the time of maximum westward marine transgression of the seaway, is shown in figure 56. The shoreline at that time completely encircled the submerged and featureless Rock Springs uplift area (Roehler, 1990, pl. 2K). A large lobate delta, the Red Desert delta, was present along the northeast, seaward edge of the embayment, and a smaller lobate delta was present at the southeast edge of the embayment near the present-day boundary of Wyoming, Utah, and Colorado (fig. 56). The sediment-laden distributary streams that flowed from these deltas spread marine sandstones in southwest and northeast directions across the shallow mouth of the embayment.

The barrier shorelines of the Fox Hills Sandstone in the study area represent progressive stages of infilling and abandonment of the embayment shown in figure 56. Stratigraphic evidence suggests that the Red Desert delta was abandoned and that the delta area was covered by marine sediments prior to the time of deposition of barrier shorelines Nos. 1–3 in the study area.

PALEOGEOGRAPHY OF BARRIER SHORELINES NOS. 1–3 OF THE FOX HILLS SANDSTONE ON THE EAST FLANK OF THE ROCK SPRINGS UPLIFT

A segment of barrier shoreline No. 1 is preserved in outcrops (measured sections 1–43, pl. 2) on the northeast flank of the Rock Springs uplift and in subsurface rocks east of the uplift (*B–B′*, pl. 5). The shoreline in those areas was arcuate and trended

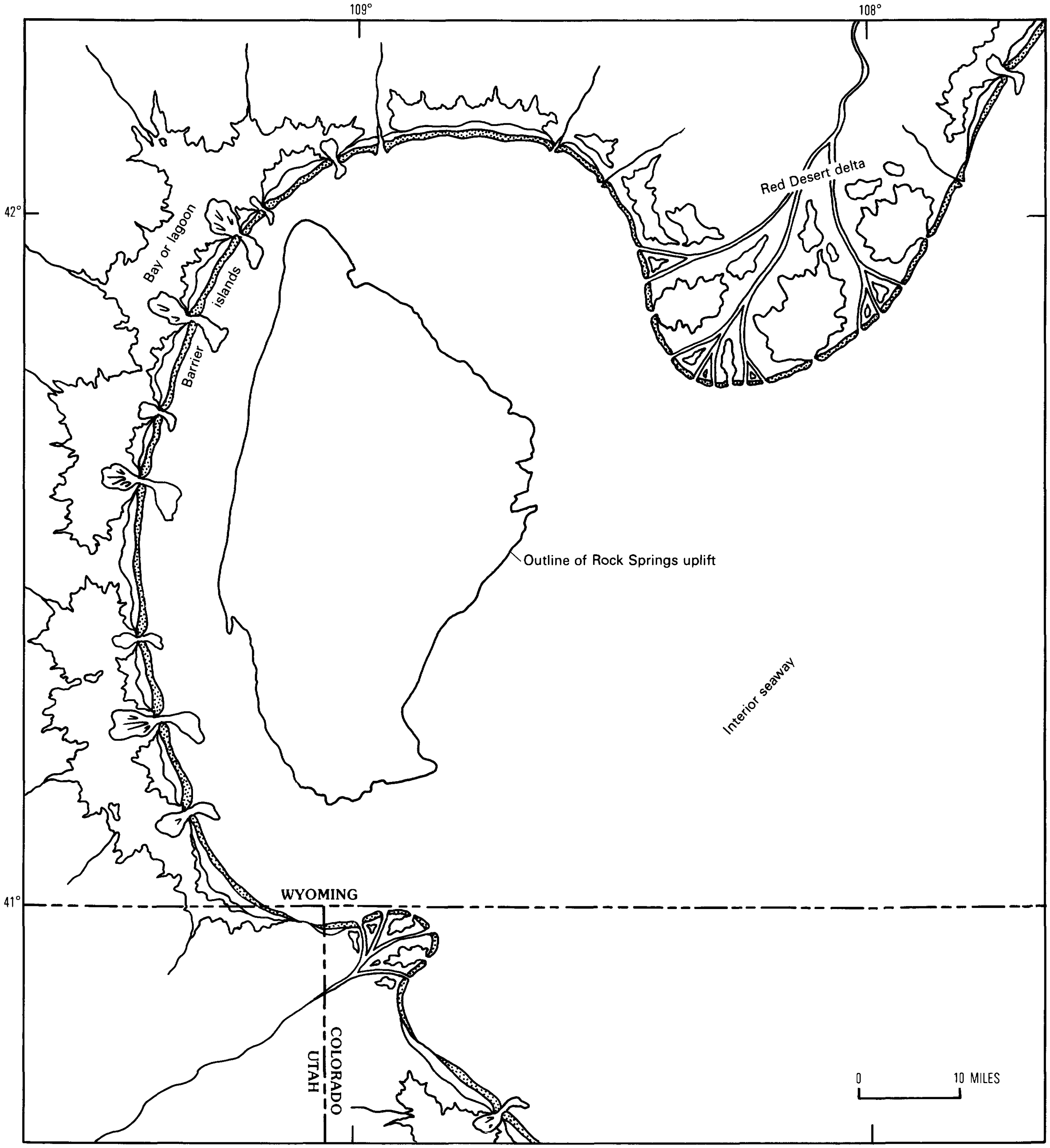


FIGURE 56.—Paleogeographic map of the shoreline of the Fox Hills Sandstone at the time of maximum westward marine transgression of the interior seaway during the Maastrichtian. Rocks of continental origin deposited landward of shoreline are part of the Lance Formation; rocks of marine origin deposited in the interior seaway are part of the Lewis Shale. Shoreline is located from stratigraphic data; inlet locations are hypothetical.

west to southwest (fig. 57). The southwest trend of the shoreline in the study area probably changed to nearly north-south across the central part of the Rock Springs uplift, where the Fox Hills Sandstone has been removed by late Tertiary and Holocene erosion. The Fox Hills Sandstone is also missing in surface and subsurface rocks at the south end of the uplift, because of Late Cretaceous (Laramide) erosion across the axis of the uplift.

Barrier shoreline No. 2 consists of mostly shoreface sandstone and parts of a flood-tidal delta and ebb-tidal delta in outcrops in the study area (pl. 2). The trend of the barrier shoreline is similar to that of barrier shoreline No. 1, but it is offset to the southeast as a result of the regression and infilling of the interior seaway (fig. 58). The trend of barrier shoreline No. 2 in subsurface rocks east of the Rock Springs uplift can be determined by correlating the geophysical logs of drill holes (*B–B′*, *C–C′*, and *D–D′*, pl. 5).

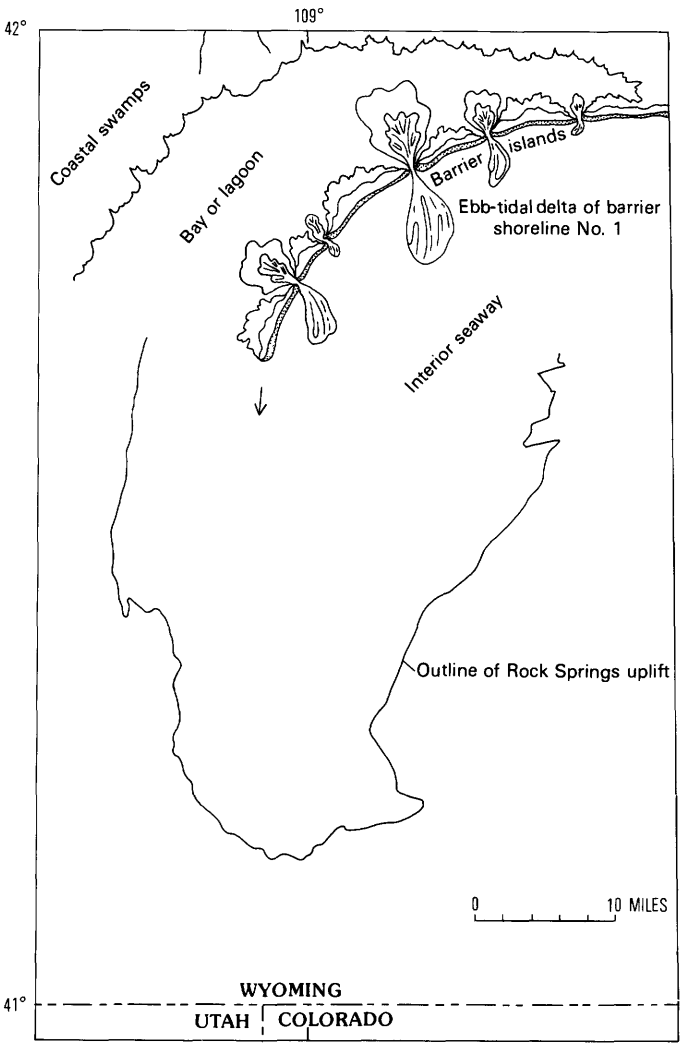


FIGURE 57.—Paleogeographic map of barrier shoreline No. 1 of the Fox Hills Sandstone, east flank of the Rock Springs uplift. The marine shoreline is stippled. The shoreline continued southward across the uplift in the direction of the arrow, where data are missing. Parts of shoreline restoration are hypothetical.

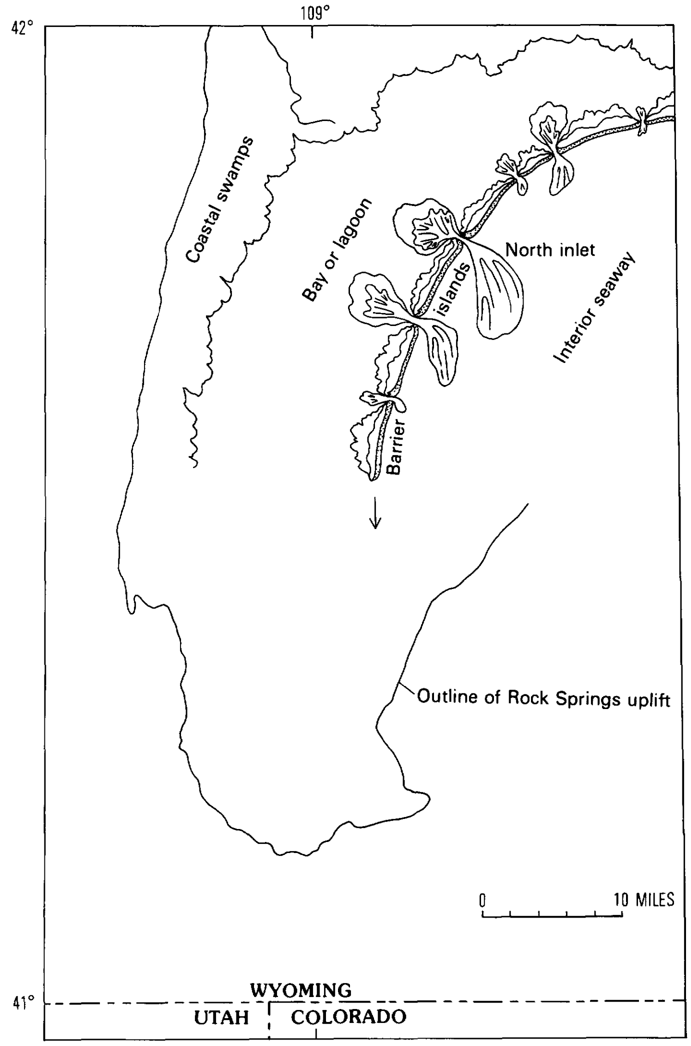


FIGURE 58.—Paleogeographic map of barrier shoreline No. 2 of the Fox Hills Sandstone, east flank of the Rock Springs uplift. The marine shoreline is stippled. The shoreline continued southward in the direction of the arrow, where data are missing. Details of North inlet are shown in figure 23. Parts of shoreline restoration are hypothetical.

A long, linear section of barrier shoreline No. 3 crops out in the study area, because the facies strike of the barrier shoreline closely parallels the trend of outcrops of the Fox Hills Sandstone along the east flank of the Rock Springs uplift. Because of this parallelism, it is possible to reconstruct a large part of the barrier shoreline morphology, including the length and trend of barrier islands and the configuration of bays, inlets, and sounds.

Barrier shoreline No. 3 appears to bulge in an eastward (seaward) direction along the middle part of the east flank of the Rock Springs uplift. This bulge is believed to indicate the presence of a delta of which Salley sound, Black Butte inlet, and South inlet are tidally influenced distributary channels. As the landward parts of barrier shoreline No. 3 in the area have been removed by late Tertiary and Holocene erosion across the uplift, the precise configuration of the delta remains problematical, even though current direction and sedimentary structure data support the interpretation shown in figure 59.

Jim inlet is located at the place where the general north-south trend of barrier shoreline No. 3 swings eastward away from the Rock Springs uplift into the Great Divide basin. Landward of the barrier islands in the vicinity of Jim inlet was a large bay or lagoon in which the Hall coal bed was deposited (fig. 59). The barrier island between Jim inlet and Salley sound trended south-southeast and was about 5 mi long. A small tidal inlet at the south end of this barrier island separated the main part of this island from Salley sound. Salley sound was primarily a mud-bottomed opening between the barrier islands of shoreline No. 3. The barrier island between Salley sound and Black Butte inlet trended nearly north-south and was slightly more than 2 mi long. The barrier island between Black Butte inlet and South inlet trended south-southwest and was about 5 mi long. In subsurface rocks south of South inlet, barrier shoreline No. 3 is missing by erosion, but remnants of the barrier shoreline are present below the unconformity a few miles farther south (*E–E′*, pl. 5).

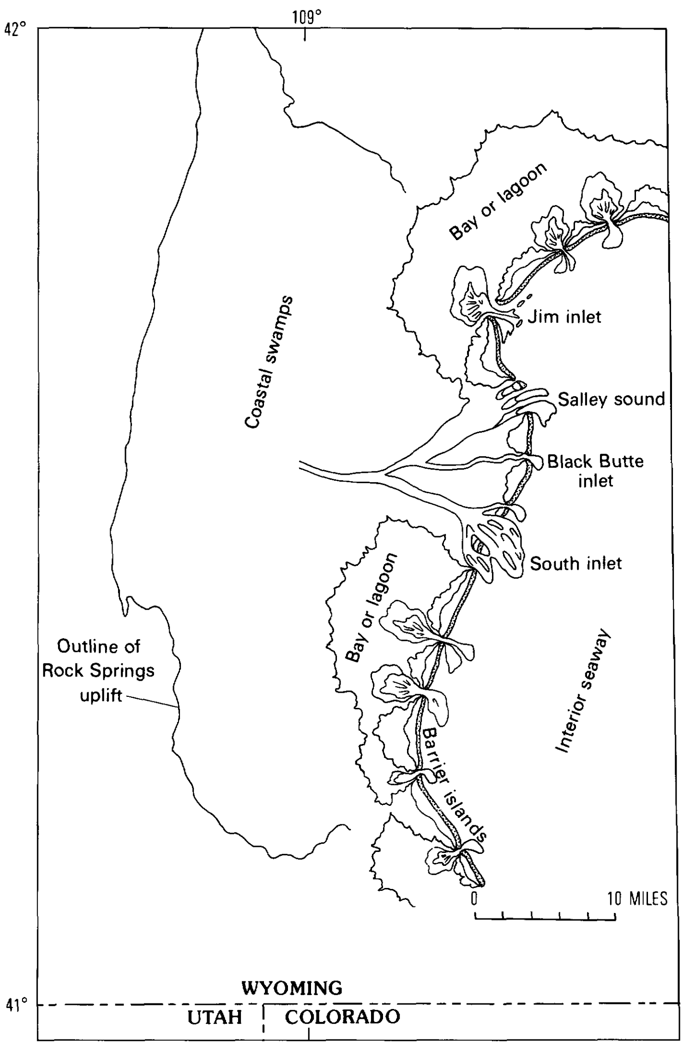


FIGURE 59.—Paleogeographic map of barrier shoreline No. 3 of the Fox Hills Sandstone, east flank of the Rock Springs uplift. The marine shoreline is stippled. Details of Jim inlet, Black Butte inlet, South inlet, and Salley sound are shown in figures 27, 30, 31, and 33. Parts of shoreline restoration are hypothetical.

SUMMARY AND CONCLUSIONS

The Fox Hills Sandstone, Lewis Shale, and Lance Formation were deposited along the western margins of the interior Cretaceous seaway of North America. During the Maastrichtian Age of the Late Cretaceous, the sea retreated from its western shores, including an embayed segment of the shoreline that covered the Rock Springs uplift area. As the sea retreated eastward and evacuated this embayment, progressive offlapping of shoreline sandstones occurred. Three of these offlapping shoreline sandstones crop out in the study area along the east flank of the Rock Springs uplift as the Fox Hills Sandstone. The three shorelines were wave dominated, but were subjected to moderately high tides estimated to range between 4 ft and 10 ft. The tidal range is probably higher than normal for the interior seaway, but it can be explained by the focusing effect that resulted from the convergence of the tidal currents as they approached the head of the embayment that covered the Rock Springs uplift area. The sedimentary structures and configuration of the shoreline sandstones indicate that dominant longshore currents and sediment transport directions were north to south.

Continental rocks of bay or lagoon origin that overlie and intertongue with the three offlapping shorelines of the Fox Hills Sandstone form the basal part of the Lance Formation. Marine rocks that intertongue with and underlie the Fox Hills Sandstone make up the Lewis Shale. The ammonite index fossil *Baculites clinolobatus* was collected from the upper part of the Lewis Shale in the study area, which dates the formations as lower Maastrichtian.

The three offlapping shorelines that form the Fox Hills Sandstone consist of chains of barrier islands. The barrier islands were generally from 3 to 7 mi long and were separated by tidal inlets and a sound. From north to south along the line of outcrops, these coastal features were named: (1) North inlet, (2) Jim inlet, (3) Salley sound, (4) Black Butte inlet, and (5) South inlet. Associated with the inlets and sound were large flood-tidal deltas, ebb-tidal deltas, and accretionary swash bars.

The rocks that compose most of the barrier shorelines of the Fox Hills Sandstone can be divided into ascending sequences of lower, middle, and upper shoreface lithofacies. The lower shoreface lithofacies consists of mostly thin, ridge- and bench-forming, tan, very fine to fine-grained sandstone that occurs in thin, parallel beds. Interbedded with the sandstone are beds of slope-forming, thick to thin, gray, soft shale. The middle shoreface lithofacies consists of mostly cliff- and ledge-forming, tan, very fine to medium-grained sandstone that occurs in thick parallel beds, in large-scale hummocky trough crossbeds, or in massive, bioturbated beds. The upper shoreface lithofacies weathers to a distinct "white cap" along the top of the Fox Hills outcrops. It can be divided into a lower surf zone and an upper forebeach zone. The surf zone consists of mostly light gray, fine- to medium-grained sandstone that occurs in small-scale trough and planar crossbeds. The forebeach zone is similar to the surf zone in color and texture, but it occurs in thin, parallel, tabular beds. The color change of tan sandstone in the lower and middle shoreface lithofacies to white cap sandstone in the upper shoreface lithofacies is attributed to the brown pigmentation imparted by hematite in the tan sandstone, which is missing in the white cap sandstone.

The basal part of the Lance Formation is composed of mostly tan, hematitic, fine-grained sandstone deposited as fluvial channels and splays, which is interbedded with gray shale of bay-fill origin, gray and brown carbonaceous shale of swamp origin, and coal of peat bog origin. The basal part of the formation was deposited rhythmically in bay cycles. Bay cycles are defined as the alternate freshening and salting of bay waters as a result of coastal emergence and submergence, which caused repetitive changes in the type and distribution of lithologic units and fauna and flora. The freshwater stages of bay cycles are characterized by interbedded carbonaceous shale and coal. The saltwater and brackish-water stages are characterized by interbedded shale, sandstone, and siltstone. Fourteen bay cycles were identified in the basal part of the Lance Formation in the study area. The cycles are believed to be related to the 21,000 year cycle of the precession of the equinoxes, which affected rates of coastal sedimentation. The changing water chemistries of the bay waters during the cycles caused the deposition of calcium carbonate in nearshore, freshwater parts of the bays and iron carbonate in deeper, more saline parts of the bays.

Coal beds in the basal part of the Lance Formation are mostly lenticular and range in thickness from less than 1 to about 8 ft. The Hall coal bed that overlies the Fox Hills Sandstone contains numerous splits and partings and is diachronous. The coal beds in the Lance Formation are mostly subbituminous, and many of the thicker beds are minable.

Stratigraphic correlations and paleogeographic reconstructions of the shorelines of the Fox Hills Sandstone suggest that intervals of marine shale that are present between shorelines No. 1 and No. 2 and No. 2 and No. 3 were probably deposited during periods of stillstand and do not reflect major marine transgressions. Barrier shoreline No. 1 had a semicircular configuration, open to the east, with the westernmost parts of the shoreline located near the center of the present-day Rock Springs uplift. Barrier shoreline No. 2 had a similar configuration but was located across the east flank of the Rock Springs uplift area. Barrier shoreline No. 3 was more irregular in shape; its western parts parallel the outcrops of the Fox Hills Sandstone along the east flank of the Rock Springs uplift.

REFERENCES CITED

Asquith, D.O., 1970, Depositional topography and major marine environments, Late Cretaceous, Wyoming: American Association of Petroleum Geologists Bulletin, v. 54, p. 1184–1224.

Bonneville, B.L.E., 1837, A map of the sources of the Colorado and Big Salt Lake, Platte, Yellow-Stone, Muscle-Shell, Missouri, and Salmon and Snake Rivers, branches of the Columbia River, *in* Irving, Washington, The Rocky Mountains, Volume 1: Philadelphia, 1837.

Cope, E.D., 1872, On the existence of dinosauria in the transition beds of Wyoming: American Philosophical Society Proceedings, v. 12, p. 481–483.

Fischer, A.G., 1986, Climate rhythms recorded in strata, *in* Weterill, G.W., ed., Annual review of the earth and planetary sciences, Volume 14: Palo Alto, Calif., Annual Reviews, Inc., p. 351–376.

Fremont, J.C., 1845, Report of the exploring expedition to the Rocky Mountains in the year 1842 and to Oregon and California in the years 1843–44: Senate Document No. 174 and House Document No. 166, 28th Congress, 2nd session, p. 130–132.

Gill, J.R., and Cobban, W.A., 1966, The Red Bird section of the Upper Cretaceous Pierre Shale in Wyoming: U.S. Geological Survey Professional Paper 393–A, 73 p.

Hale, L.A., 1950, Stratigraphy of the Upper Cretaceous Montana Group in the Rock Springs uplift, Sweetwater County, Wyoming: Wyoming Geological Association Guidebook, 5th annual field conference, southwest Wyoming, J.W. Harrison, ed., p. 49–58.

Harms, J.C., MacKenzie, D.B., and McCubbin, D.G., 1965, Depositional environments of the Fox Hills Sandstone near Rock Springs, Wyoming: Wyoming Geological Association Guidebook, 19th annual field conference, sedimentation of late Cretaceous and Tertiary outcrops, Rock Springs uplift, R.H. DeVoto and R.K. Bitter, eds., p. 113–130.

Hayes, M.O., and Kana, T.W., 1976, Terriginous clastic depositional environments: Notes accompanying modern clastic depositional environment field course sponsored by the American Association of Petroleum Geologists, Columbia, South Carolina, May, 1977, 302 p.

Hickling, N.L., 1991, A petrologic study of the Fox Hills Sandstone, Rock Springs uplift, Wyoming: U.S. Geological Survey Bulletin 1919, 15 p.

Land, C.B., Jr., 1972, Stratigraphy of Fox Hills Sandstone and associated formations, Rock Springs uplift and Wamsutter Arch area, Sweetwater County, Wyoming—A shoreline–estuary sandstone model for the late Cretaceous: Colorado School of Mines Quarterly, v. 67, no. 2, 69 p.

Milankovitch, M., 1941, Kanon der Erdbestrahling and seine Anwendung auf das Eiszeitenproblem: Akad. Royale Serbe 133, 633 p.

Rock Springs (Wyoming) Daily Rocket-Miner, 1975, Plant named after frontier giant: 23rd annual progress edition, p. 20E, March 15, 1975.

Roehler, H.W., 1983, Stratigraphy of Upper Cretaceous and lower Tertiary outcrops in the Rock Springs uplift, Wyoming: U.S. Geological Survey Miscellaneous Investigations Map I–1500.

———1988, The Pintail Coal Bed and Barrier Bar G—A model for coal of barrier bar-lagoon origin, Upper Cretaceous Almond Formation, Rock Springs Coal Field, Wyoming: U.S. Geological Survey Professional Paper 1398, 60 p.

———1990, Stratigraphy of the Mesaverde Group in the central and eastern Greater Green River Basin, Wyoming, Colorado, and Utah: U.S. Geological Survey Professional Paper 1508, 52. p.

Root, F.K., Glass, G.B., and Lance, D.W., 1973, Sweetwater County, Wyoming, Geological map atlas and summary of economic mineral resources: Geological Survey of Wyoming, County Resource Series 2, Topography and Climate.

Schultz, A.R., 1920, Oil possibilities in and around Baxter Basin, in the Rock Springs Uplift, Sweetwater County, Wyoming: U.S. Geological Survey Bulletin 702, 107 p.

Weimer, R.J., 1961, Spatial dimensions of Upper Cretaceous sandstones, Rocky Mountain area, *in* Peterson, J.A., and Osmond, J.C., eds., Geometry of sandstone bodies: Tulsa, Okla., American Association of Petroleum Geologists, p. 82–97.

Manuscript approved for publication August 5, 1992
Published in the Central Region, Denver, Colorado
Photocomposition by Marie F. Melone
Graphics by Wayne Hawkins
Edited by Lorna Carter

APPENDIX A.—Lithologic descriptions of measured sections 23, 116, 149, and 3575 of the upper part of the Ericson Sandstone, Almond Formation, Lewis Shale, Fox Hills Sandstone, and lower part of the Lance Formation on the east flank of the Rock Springs uplift. Geographic and stratigraphic locations of the sections are shown on plates 1 and 2, and they are illustrated graphically on plate 5.

Measured section 23 (pls. 1, 2) of the Fox Hills Sandstone and overlying and underlying Upper Cretaceous formations, near Potash Wash, 4.5 mi northwest of the Jim Bridger power plant. Section is illustrated graphically on plate 5.

[Secs. 15, 19, 20, 21, 22, and 30, T. 21 N., R. 101 W.]

	Thickness (Feet)
Lance Formation (part):	
164. Shale, gray, soft	6.0
163. Sandstone, gray, very fine grained, silty, calcareous; current rippled and crossbedded	3.5
162. Shale, gray, soft	6.4
161. Siltstone, gray, dolomitic, hard; concretionary	2.7
160. Shale, gray, soft	4.5
159. Shale, gray, silty to sandy in part	17.4
158. Coal, clean, bright	8.8
157. Shale, dark-gray, carbonaceous, soft, fissile	8.2
156. Sandstone, gray, very fine grained, calcareous, hematitic	1.0
155. Shale, gray, carbonaceous, soft	22.5
154. Sandstone, gray, very fine grained, calcareous; trough crossbedded	2.2
153. Shale, dark-gray, soft	19.0
152. Sandstone, gray, very fine grained, calcareous, slightly hematitic, trough crossbedded, and interbedded shale, dark-gray, fissile, soft	18.0
151. Shale, gray, fissile, soft, partly carbonaceous	27.0
150. Sandstone, gray, very fine grained, soft, at the top and bottom, and shale, gray, sandy, in the middle	11.5
149. Shale, gray, fissile, soft	16.5
148. Sandstone, gray, very fine grained, calcareous, hard; trough crossbedded	10.5
147. Shale, gray, soft	10.9
146. Shale, black, carbonaceous, fissile	0.5
145. Coal, with 1.1 ft thick dark-brown carbonaceous shale parting in the upper part	9.5
144. Shale, dark-gray, dark-brown, carbonaceous at the top, fissile, soft, and very thin interbedded sandstone, gray, very fine grained, hematitic, soft	9.9
143. Sandstone, gray, very fine grained, calcareous; trough crossbedded	15.0
142. Shale, gray, soft	7.8
141. Coal	1.2
140. Shale, dark-gray, dark-brown, carbonaceous, soft	3.3
139. Sandstone, gray, very fine grained, calcareous; trough crossbedded	8.0
138. Shale, gray, silty, fissile	7.8
137. Shale, dark-gray, carbonaceous, fissile, silty	5.0
136. Coal, clean, bright	4.3
135. Shale, dark-gray, carbonaceous, fissile	1.4

	Thickness (Feet)
Measured section 23—Continued	
Lance Formation (part)—Continued	
134. Shale, gray, fissile, soft	4.0
133. Sandstone, gray, very fine grained, slightly calcareous, slightly hematitic	1.8
132. Shale, gray, fissile, soft	11.5
131. Sandstone, gray, very fine grained to fine-grained, silty and limy the upper 1.0 ft; ripple marked with some trough crossbedding	8.0
130. Coal, clean, bright	4.9
129. Bone coal	1.7
128. Shale, dark-gray, carbonaceous, fissile	1.3
Total Lance Formation measured	303.5
Fox Hills Sandstone:	
127. Sandstone, light-gray, very fine grained; hematitic with root impressions the upper 1.0 ft; low-angle trough crossbedded	18.0
126. Sandstone, light-gray, very fine grained; parallel bedded	2.6
125. Sandstone, gray, very fine grained, weathers tan, and some thin interbedded shale, gray, sandy, in the lower part	16.7
124. Shale, gray, silty, soft	6.5
123. Sandstone, gray, fissile, silty in part, soft	4.1
122. Shale, gray, fissile, silty, soft	23.0
121. Sandstone, gray, very fine grained; weathers tan; low-angle trough crossbeds	11.0
120. Sandstone, gray, very fine grained to fine-grained; weathers tan; abundant avalanche slopes	15.0
119. Sandstone, gray, very fine grained to fine-grained; weathers tan; in thick parallel beds	26.0
118. Shale, gray, fissile; becomes silty with some very thin interbedded sandstone, gray, very fine grained, the upper 8.0 ft	24.0
117. Sandstone, gray, very fine grained, calcareous, hard, slightly hematitic; abundant *Ophiomorpha* and small borings and trails	10.0
Total Fox Hills Sandstone	156.9
Lewis Shale:	
116. Shale, dark-gray, fissile, soft	74.5
115. Siltstone, gray, calcareous, hematitic, soft	1.0
114. Shale, gray, fissile, soft	7.0
113. Siltstone, gray, calcareous; weathers to small plates	0.7
112. Shale, dark-gray, fissile, soft	67.5
111. Siltstone, gray, limy, hard	0.9
110. Shale, dark-gray, fissile, soft	44.1
109. Siltstone, gray, dolomitic, hard; a rounded concretion	2.6
108. Shale, dark-gray, fissile, soft	0.5
107. Siltstone, gray, dolomitic, hard; a rounded concretion	2.6
106. Shale, dark-gray, fissile, soft	20.0
105. Siltstone, gray, dolomitic; a rounded concretion	3.0
104. Shale, dark-gray, fissile, soft	22.1
103. Shale, dark-gray, fissile, soft; the top of this interval forms the base of the slope underlying the Fox Hills Sandstone	390.0
Total Lewis Shale	636.5

	Thickness (Feet)
Measured section 23—Continued	
Almond Formation:	
102. Sandstone, gray, very fine grained, calcareous, hematitic; trough crossbedded; some *Ophiomorpha*	3.5
101. Shale, gray, soft; some *Crassostrea* sp. shells in the lower 3.0 ft	13.0
100. Sandstone, gray, very fine grained, soft and loose	10.0
99. Shale, gray, fissile, soft	10.0
98. Coquinal sandstone, gray, very fine grained, limy; composed mostly of *Crassostrea* sp. shell fragments	7.4
97. Sandstone, gray, very fine grained, soft and loose	14.0
96. Sandstone, gray, very fine grained, calcareous, hard, and some interbedded shale, gray, fissile, soft, in the middle	7.5
95. Shale, dark-gray, black, fissile, soft	12.8
94. Sandstone, gray, very fine grained, calcareous; thin lenses of flattened clay pebbles; trough crossbedded; some oyster and gastropod shells	13.0
93. Shale, dark-gray, carbonaceous, fissile, soft; some *Crassostrea* sp. in the upper part	9.5
92. Sandstone, light-gray, very fine grained, argillaceous, soft and loose; weathers white	7.7
91. Shale, gray, fissile, soft	9.0
90. Sandstone, gray, very fine grained, calcareous, hematitic; some oyster shell fragments, becoming more abundant at the top	4.6
89. Shale, gray, carbonaceous, fissile	4.5
88. Coquinal sandstone, gray, very fine grained, limy; composed of mostly oyster shell fragments	8.0
87. Sandstone, gray, very fine grained, soft and loose; weathers white	10.1
86. Sandstone, gray, very fine grained, hematitic; trough crossbedded; weathers brown	9.2
85. Shale, gray, fissile, soft, and some very thin interbedded sandstone, gray, very fine grained, calcareous	13.0
84. Shale, dark-gray, carbonaceous, fissile; very carbonaceous the lower 2.0 ft	8.0
83. Sandstone, gray, very fine grained; upper 1.0 ft is carbonaceous with root impressions	21.5
82. Sandstone, gray, very fine grained, calcareous, hard; trough crossbedded	5.0
81. Sandstone, gray, very fine grained, poorly sorted, subangular, soft and loose; some hematite nodules	49.0
80. Coquinal sandstone, gray, very fine grained, limy, hard; composed of mostly *Crassostrea* sp., small clams and snails; one shark tooth	20.0

U.S. Geological Survey Mesozoic Locality No. D9400:

Crassostrea subtrigonalis
Anomia sp.
Veloritina occidentalis
Veloritina celburni
Leptesthes sp.
bored wood

	Thickness (Feet)
79. Sandstone, light-gray, very fine grained; crossbedded	11.7
78. Sandstone, gray, very fine grained; indistinct crossbedding; abundant	45.2
Measured section 23—Continued	
Almond Formation—Continued	
77. Sandstone, gray, very fine grained, hematitic, soft, and interbedded shale, gray, carbonaceous, fissile	1.5
76. Sandstone, light-gray, very fine grained, silty; some silty carbonaceous laminae, trough crossbedded	4.0
75. Sandstone, gray, very fine grained, hematitic the upper 1.0 ft	13.2
74. Coquinal sandstone, gray, very fine grained, argillaceous; mostly loose fragments of oyster shells	1.5
73. Coquinal sandstone, gray, limy, hard; composed mostly of *Crassostrea* sp. and some small clams	3.1
72. Shale, dark-gray, carbonaceous, fissile, soft	17.5
71. Siltstone, gray, sandy, calcareous, slightly carbonaceous	1.5
70. Shale, gray, partly carbonaceous, fissile, soft	8.3
69. Coal	1.0
68. Sandstone, gray, very fine grained, carbonaceous; root impressions the upper 0.5 ft; tabular bedded	6.9
67. Sandstone, gray, very fine grained, some carbonaceous shale partings; low-angle trough crossbedded	11.5
66. Sandstone, gray, very fine grained, poorly sorted, subangular, slightly calcareous, some carbonaceous shale partings; some herringbone crossbedding	21.4
65. Shale, gray, fissile, silty, carbonaceous; sandy the upper 1.0 ft	7.5
64. Coal	1.6
63. Shale, gray, carbonaceous, fissile	1.7
62. Sandstone, gray, very fine grained, calcareous, hematitic; current ripples	0.3
61. Shale, gray, fissile, soft	3.6
60. Coal	0.9
59. Shale, dark-gray, carbonaceous, fissile	1.3
58. Sandstone, gray, very fine grained, calcareous, hematitic; indistinct bedding	3.2
57. Shale, dark-gray, carbonaceous. soft	10.7
56. Shale, gray, sandy, and interbedded sandstone, gray, very fine grained, calcareous; some oyster shell fragments	5.1
55. Coquinal sandstone, gray, brown at the top, limy, hard; composed of small fragments of *Crassostrea* sp., and *Anomia* sp	1.9
54. Shale, gray, carbonaceous, silty	1.3
53. Coal	1.7
52. Shale, dark-gray, carbonaceous, silty, fissile	0.9
51. Sandstone, gray, very fine grained, argillaceous in the lower part, calcareous at the top, mostly soft	2.8
50. Shale, gray, brown, carbonaceous, silty	8.4
49. Coal, bright, clean	3.5
48. Shale, gray, carbonaceous, fissile	2.3
47. Sandstone, gray, very fine grained, calcareous; current rippled	1.5
46. Shale, gray, silty to sandy, fissile	7.8
45. Shale, dark-gray, carbonaceous, fissile	2.7
44. Sandstone, gray, very fine grained, calcareous, hematitic; wave and current rippled; parallel bedded	2.0

	Thickness (Feet)
Measured section 23—Continued	
Almond Formation—Continued	
43. Shale, dark-gray, fissile, soft, partly carbonaceous	0.7
42. Siltstone, gray, very hematitic, calcareous	0.7
41. Shale, dark-gray, carbonaceous, fissile	1.5
40. Coal	1.8
39. Shale, dark-gray, carbonaceous, fissile	7.3
38. Sandstone, gray, very fine grained, calcareous, ripple-marked, and thin interbedded shale, gray, sandy, soft	5.6
37. Shale, gray, fissile, soft	4.8
36. Sandstone, gray, very fine grained, calcareous, ripple-marked	0.5
35. Shale, dark-gray, carbonaceous at the base, silty at the top	8.1
34. Coal, clean, bright	3.5
33. Shale, dark-gray, carbonaceous, silty	1.5
32. Shale, dark-gray, soft	2.4
31. Sandstone, gray, very fine grained, calcareous, slightly hematitic	0.9
30. Shale, gray, sandy, soft, and some very thin interbedded sandstone, gray, very fine grained, calcareous	9.2
29. Sandstone, gray, very fine grained, calcareous, slightly hematitic; ripple marked	2.2
28. Shale, gray, fissile, soft, and some very thin interbedded sandstone, gray, very fine grained, calcareous, in the upper part	19.0
27. Coal	0.6
26. Shale, dark-gray, carbonaceous, fissile, silty	2.5
25. Coal	1.0
24. Shale, dark-gray, carbonaceous, soft	2.7
23. Coal, with 0.5 ft brown carbonaceous siltstone parting near the middle	4.6
22. Shale, dark-gray, carbonaceous, fissile, soft	7.4
21. Sandstone, gray, very fine grained, calcareous, hematitic	0.9
20. Shale, dark-gray, carbonaceous, fissile, soft	1.7
19. Sandstone, gray, very fine grained, calcareous, hematitic; current rippled	0.9
18. Shale, dark-gray, carbonaceous, fissile, silty	4.5
17. Sandstone, gray, very fine grained, calcareous, hematitic in the lower part	3.2
16. Shale, gray, carbonaceous, silty	5.0
15. Coal, with 0.6 ft of bone coal in the upper part	3.4
14. Shale, dark-gray, carbonaceous, soft	16.5
13. Sandstone, gray, very fine grained, calcareous, hematitic; trough crossbedded; some plant impressions	2.9
12. Shale, dark-gray, carbonaceous, soft	18.0
11. Siltstone, gray, very hematitic, hard	0.6
10. Shale, dark-gray, carbonaceous, soft	10.8
9. Sandstone, gray, very fine grained to medium-grained, calcareous, carbonaceous, hematitic; trough crossbedded; some turtle scutes, garpike scales and tooth fragments the lower 3.0 ft	8.0
8. Shale, dark-gray, carbonaceous, fissile, silty	8.5
7. Sandstone, gray, very fine grained, calcareous, hematitic; weathers rust	1.3
6. Shale, dark-gray, carbonaceous, fissile, silty	8.2
5. Sandstone, gray, very fine grained, silty, calcareous, hematitic	0.4
4. Shale, dark-gray, carbonaceous, fissile, silty	20.8
3. Sandstone, gray, very fine grained, calcareous, slightly hematitic; ripple marked and crossbedded	4.4
2. Shale, dark-gray, carbonaceous, fissile, silty, and some very thin interbedded sandstone, gray, very fine grained; two 0.2 thick beds of coal in the middle and upper parts	35.0
Total Almond Formation	741.7
Ericson Sandstone (part):	
1. Sandstone, gray, very fine grained, poorly sorted, subangular, abundant dark grains; trough crossbedded	25.0

Measured section 116 (pls. 1, 2) of the Fox Hills Sandstone and overlying and underlying Upper Cretaceous formations, 12 mi north of Hallville Station on the Union Pacific Railroad. Section is illustrated graphically on plate 5.

[Secs. 12 and 13, T. 19 N., R. 101 W., and secs. 7 and 8, T. 19 N., R. 100 W.]

	Thickness (Feet)
Lance Formation (part):	
111. Red clinkered coal and country rock	25.0
110. Sandstone, brown, very fine grained; trough crossbedded	18.0
109. Clinkered coal and shale	11.0
108. Coal	1.5
107. Shale, dark-gray, carbonaceous	2.0
106. Sandstone, brown, very fine grained; current rippled	1.8
105. Shale, dark-gray, carbonaceous	9.0
104. Shale, gray, soft	4.9
103. Sandstone, gray, brown, very fine grained, current rippled	2.8
102. Shale, gray, carbonaceous in the lower part	7.2
101. Coal	1.5
100. Shale, dark-gray, carbonaceous	3.0
99. Coal, with 0.5 ft dark-brown carbonaceous shale parting near the middle	7.4
98. Shale, dark-gray, carbonaceous	4.7
Total Lance Formation measured	99.8
Fox Hills Sandstone:	
97. Sandstone, white, very fine grained; small-scale, low-angle trough crossbedding; organic stained and rooted the upper 1.0 ft	25.1
96. Sandstone, tan, very fine grained, soft; indistinct bedding; some burrows	23.0
95. Sandstone, brown, very fine grained, hematitic; low-angle trough crossbedding	4.8
94. Shale, gray, soft, and a few very thin interbedded sandstone, gray, very fine grained	34.8
93. Sandstone, medium-gray, very fine grained; moderately large scale trough crossbedding	8.6
92. Sandstone, brown, very fine grained; small-scale, low-angle trough crossbedding	5.5

	Thickness (Feet)
Measured section 116—Continued	
Fox Hills Sandstone—Continued	
91. Shale, gray, soft, and 0.3 ft thick interbedded sandstone, gray, very fine grained, parallel-bedded, 13.0 ft below the top	38.0
90. Sandstone, gray, very fine grained, soft; massive; current rippled the upper 1.0 ft	29.6
Total Fox Hills Sandstone	169.4
Lewis Shale:	
89. Shale, gray, silty	2.0
88. Sandstone, gray, very fine grained, calcareous; abundant worm borings	1.1
87. Shale, gray, soft	497.0
86. Dolomite, tan; caps ridge	0.2
85. Shale, gray, soft	192.0
84. Dolomite, brown, silty	0.6
83. Shale, black, soft; 0.2 ft thick bentonite bed in the lower part	14.8
82. Dolomite, brown, silty, hard	2.0
81. Shale, gray, soft	8.1
Total Lewis Shale	717.8
Almond Formation:	
80. Sandstone, brown, very fine grained; abundant worm borings; some *Ophiomorpha*	8.5
79. Shale, gray, soft	3.5
78. Sandstone, brown, very fine grained, calcareous, hematitic; abundant worm borings	2.0
77. Shale, gray, soft	5.3
76. Sandstone, brown, very fine grained, and interbedded shale, gray, soft	9.0
75. Shale, gray, soft	25.5
74. Siltstone, gray, dolomitic	2.4
73. Shale, gray, soft	5.8
72. Sandstone, brown, very fine grained, calcareous, slightly hematitic	0.5
71. Shale, gray, soft, and a lamina of sandstone, gray, very fine grained, in the middle	16.5
70. Sandstone, brown, very fine grained, calcareous, hematitic; parallel bedded	0.8
69. Shale, dark-gray	35.5
68. Sandstone, gray, very fine grained to medium-grained, poorly sorted, subangular, abundant dark grains; small-scale, low-angle trough crossbedding	4.5
67. Sandstone, tan, very fine grained; indistinct bedding; some *Ophiomorpha*	21.5
66. Shale, dark-gray, soft	2.9
65. Siltstone, gray; in small, concretionlike pods	1.8
64. Shale, dark-gray, soft	11.0
63. Siltstone, gray; in small rounded, concretionlike pods	1.8
62. Shale, gray, soft	1.3
61. Siltstone, brown, calcareous, hematitic; in thin parallel beds; abundant worm borings	1.1
60. Shale, dark-gray, soft	59.5
59. Siltstone, brown, hematitic	1.0
58. Shale, dark-gray, soft	9.9
57. Sandstone, brown, very fine grained, calcareous, slightly hematitic; small-scale, low-angle trough crossbedding; some *Ophiomorpha*	2.5

	Thickness (Feet)
Measured section 116—Continued	
Almond Formation—Continued	
56. Shale, dark-gray, and thin interbedded sandstone, brown, very fine grained	23.5
55. Sandstone, brown, very fine grained; thin bedded	2.0
54. Shale, dark-gray, soft	9.8
53. Sandstone, gray, brown at the top, very fine grained; indistinct bedding; abundant *Ophiomorpha*	21.0
52. Shale, dark-gray, soft; becomes sandy with a few very thin beds and laminae of sandstone, gray, very fine	28.4
51. Sandstone, gray, very fine grained, silty, calcareous; indistinct bedding	0.7
50. Shale, gray, soft, silty	6.6
49. Sandstone, gray, very fine grained, calcareous; indistinct bedding; abundant worm borings	0.7
48. Shale, dark-gray, carbonaceous the lower 6.0 ft, silty	12.4
47. Shale, gray, silty, soft; abundant *Crassostrea* sp. shell fragments the upper 1.0 ft	2.6
46. Sandstone, gray, very fine grained; current rippled	0.8
45. Coal	2.6
44. Shale, dark-gray, carbonaceous	1.7
43. Sandstone, brown, very fine grained, silty, hematitic; in thin wave- and current-rippled beds	3.0
42. Shale, dark-gray, partly carbonaceous in thin layers	6.5
41. Shale, dark-gray, slightly carbonaceous	0.8
40. Coal	1.4
39. Shale, dark-gray, carbonaceous	0.5
38. Shale, dark-gray, soft	3.0
37. Shale, dark-gray, carbonaceous	1.8
36. Shale, gray, soft, and a thin lamina of sandstone, gray, very fine grained, silty, in the lower part	3.7
35. Shale, dark-gray, carbonaceous	0.3
34. Coal	0.9
33. Shale, dark-gray, carbonaceous, silty	0.5
32. Shale, gray, soft	7.5
31. Sandstone, brown, very fine grained, calcareous, hematitic; current and wave ripple bedded	1.5
30. Shale, dark-gray, soft	4.9
29. Shale, dark-gray, carbonaceous	10.0
28. Shale, dark-gray, soft	6.0
27. Sandstone, brown, very fine grained, calcareous, hematitic, hard; current rippled	2.7
26. Shale, dark-gray, soft	9.0
25. Sandstone, brown, very fine grained, calcareous, hematitic; lenticular; current rippled	2.7
24. Shale, dark-gray, soft	16.7
23. Siltstone, brown, sandy; lenticular; current rippled; abundant worm borings	1.3
22. Shale, dark-gray, carbonaceous, silty; hematitic concretions in the middle and at the top	9.4
21. Sandstone, brown, very fine grained, calcareous, hematitic; lenticular; current rippled	3.3
20. Shale, dark-gray, carbonaceous	3.1
19. Coal	0.7
18. Shale, dark-gray, carbonaceous	7.1
17. Sandstone, brown, very fine grained, calcareous, hematitic; lenticular; current rippled	1.4
16. Shale, dark-gray, carbonaceous	1.6

	Thickness (Feet)
Measured section 116—Continued	
Almond Formation—Continued	
15. Coal	0.5
14. Shale, dark-gray, carbonaceous	2.5
13. Coal	0.8
12. Shale, dark-gray, carbonaceous	5.4
11. Sandstone, brown, very fine grained, silty, calcareous, hematitic; lenticular; current rippled	6.3
10. Shale, dark-gray, carbonaceous	17.9
9. Coal	1.1
8. Shale, dark-gray, carbonaceous	9.7
7. Sandstone, brown, very fine grained, silty, calcareous, hematitic; current rippled	1.5
6. Shale, dark-gray, carbonaceous at the base, and a few laminae of siltstone, brown, hematitic	12.7
5. Sandstone, brown, very fine grained, calcareous, hematitic; lenticular; current rippled	0.9
4. Shale, dark-gray, carbonaceous, soft	3.6
3. Coal	0.7
2. Shale, dark-gray, carbonaceous, and a few very thin interbedded sandstone, gray, brown, very fine grained; partly hematitic; current rippled	67.0
Total Almond Formation	588.8
Ericson Sandstone (part):	
1. Sandstone, light-gray, very fine grained to medium-grained, poorly sorted, abundant dark grains; trough crossbedded	55.0

Measured section 149 (pls. 1, 2) of the Fox Hills Sandstone and overlying and underlying Upper Cretaceous formations near Black Buttes Station on the Union Pacific Railroad. Section is illustrated graphically on plate 5.

[Secs. 3, 4, 5, 6, and 9, T. 16 N., R. 100 W., and sec. 1, T. 18 N., R. 101 W.]

	Thickness (Feet)
Lance Formation (part):	
157. Shale, dark-gray, fissile, carbonaceous, and very thin interbedded sandstone, gray, very fine grained, calcareous, hematitic, and siltstone, gray, hematitic	68.3
156. Coal	1.4
155. Shale, dark-gray, carbonaceous, and sparse very thin interbedded sandstone, gray, very fine grained, calcareous, and siltstone, gray, very hematitic	24.4
154. Sandstone, gray, very fine grained, calcareous, hematitic; trough crossbedded	7.5
153. Shale, gray, carbonaceous, and very thin interbedded sandstone, gray, very fine grained, and siltstone, gray, hematitic; some dolomite concretions about 12 ft below the top	34.0
152. Coal	0.2
151. Shale, dark-gray, carbonaceous, and thin interbedded sandstone, gray, very fine grained, calcareous, hematitic, and siltstone, gray, calcareous, hematitic	45.9
150. Sandstone, gray, very fine grained, calcareous, slightly hematitic; ripple marked	1.7
149. Shale, dark-gray, carbonaceous	3.0
148. Coal	2.8

	Thickness (Feet)
Measured section 149—Continued	
Lance Formation (part)—Continued	
147. Shale, dark-gray, carbonaceous, and very thin interbedded sandstone, gray, very fine grained, hematitic	10.7
146. Sandstone, gray, very fine grained, calcareous, hematitic; ripple marked	1.8
145. Shale, dark-gray, carbonaceous	6.5
144. Coal, clean, bright	8.0
143. Shale, dark-gray, carbonaceous, and thin interbedded sandstone, gray, very fine grained, calcareous, and siltstone, gray, calcareous, hematitic	68.0
142. Sandstone, gray, very fine grained, calcareous, hematitic; trough crossbedded	7.8
141. Shale; dark-gray, slightly carbonaceous	7.5
140. Coal	0.1
139. Siltstone, gray, calcareous	0.4
138. Coal	3.5
137. Shale, dark-gray, carbonaceous, and very thin interbedded sandstone, gray, very fine grained, calcareous, slightly hematitic	33.4
136. Sandstone, gray, very fine grained, calcareous, slightly hematitic; trough crossbedded	39.2
135. Coal	2.6
134. Shale, dark-gray, carbonaceous, silty	12.0
133. Coal	0.4
132. Shale, dark-gray, carbonaceous, silty	5.8
131. Sandstone, gray, very fine grained to fine-grained, calcareous; trough crossbedded; scored base	39.7
130. Shale, dark-gray, carbonaceous	5.0
129. Coal, clean, bright	4.0
128. Shale, dark-gray, carbonaceous	4.0
Total Lance Formation measured	449.6
Fox Hills Sandstone:	
127. Sandstone, gray, very fine grained to fine-grained	31.1
126. Sandstone, gray, very fine grained; in thin parallel beds; weathers to tan cliff	35.0
125. Sandstone, gray, very fine grained, and interlaminated shale, gray, sandy; in thin parallel beds	17.6
124. Sandstone, gray, very fine grained, calcareous, hematitic; some burrows; indistinct bedding; caps dip slope	2.6
123. Sandstone, gray, very fine grained; in parallel beds	14.1
122. Sandstone, gray, very fine grained; trough crossbedded; weathers tan	26.0
121. Shale, dark-gray, sandy, and thin interbedded sandstone, gray, very fine grained, calcareous	12.5
120. Sandstone, gray, very fine grained, calcareous, trough crossbedded; weathers tan	25.8
119. Sandstone, gray, very fine grained; parallel bedding	33.5
Total Fox Hills Sandstone (arbitrary basal contact)	198.2
Lewis Shale:	
118. Shale, dark-gray, fissile, soft, and very thin interbedded and interlaminated sandstone, gray, very fine grained, calcareous; in thin parallel beds; worm borings	47.8

Measured section 149—Continued

Lewis Shale—Continued

	Thickness (Feet)
117. Sandstone, gray, very fine grained; very thin parallel bedded; abundant worm borings	0.5
116. Shale, gray, fissile, soft, and two laminae of sandstone, gray, very fine grained, calcareous	21.5
115. Sandstone, gray, very fine grained, silty; very thin parallel bedded	0.4
114. Shale, gray, fissile, soft, and a few laminae of sandstone, gray, very fine grained, calcareous	58.7
113. Shale, gray, fissile, soft; some small concretions of siltstone, gray, dolomitic, hard	3.6
112. Siltstone, gray, calcareous; thin bedded; abundant worm borings	0.3
111. Shale, gray, fissile, soft	13.5
110. Sandstone, gray, very fine grained, silty, calcareous, hematitic; some small-scale trough crossbeds; weathers brown	0.7
109. Shale, gray, fissile, and a few interlaminated sandstone, gray, very fine grained, in the upper and lower parts	14.3
108. Sandstone, gray, very fine grained, silty, calcareous; some small-scale trough crossbedding; worm borings	1.1
107. Shale, gray, fissile, soft	21.5
106. Sandstone, gray, very fine grained, calcareous; parallel bedded; abundant worm borings	0.4
105. Shale, dark-gray, fissile, soft	536.0
Total Lewis Shale (arbitrary basal contact)	720.3

Almond Formation:

	Thickness (Feet)
104. Siltstone, gray, dolomitic, hard; grades laterally into sandstone, gray, very fine grained	1.9
103. Shale, dark-gray, soft	12.8
102. Sandstone, gray, very fine grained, silty, calcareous; small-scale trough crossbedding	1.7
101. Shale, gray, fissile, soft	6.9
100. Sandstone, gray, very fine grained, silty, calcareous;. abundant worm borings	0.8
99. Shale, dark-gray, soft, and a lamina of siltstone, gray, calcareous, 4.0 ft below the top	11.4
98. Sandstone, gray, very fine grained, calcareous; in thin parallel beds	0.8
97. Shale, dark-gray, fissile, soft	31.7
96. Siltstone, gray, dolomitic, hard, crumbly	0.3
95. Shale, dark-gray, soft	0.9
94. Dolomite, gray, hematitic, silty; some cone-in-cone structure	0.6
93. Shale, gray, fissile, soft	9.1
92. Siltstone, gray, dolomitic, hard; concretionary zone	0.6
91. Shale, gray, soft	6.0
90. Shale, dark-gray, soft; 0.2 ft thick siltstone, gray, calcareous, hematitic, 9.0 ft above the base, and numerous small siltstone concretions, gray, hematitic, the upper 15.0 ft	31.0
89. Siltstone, gray, dolomitic, hard, hematitic, crumbly	0.7
88. Shale, dark-gray, soft, and five 0.2 to 0.3 ft thick interbedded siltstone, gray, calcareous, very hematitic	22.0
87. Siltstone, gray, calcareous, dolomitic, very hematitic	1.7
86. Shale, dark-gray, soft	9.0

Measured section 149—Continued

Almond Formation—Continued

	Thickness (Feet)
85. Shale, dark-gray, sandy, and very thin interbedded sandstone, gray, very fine grained, calcareous, hematitic; some small-scale trough crossbedding; some worm borings and *Ophiomorpha*	9.3
84. Shale, dark-gray, soft	8.1
83. Siltstone, gray, calcareous, very hematitic	0.2
82. Shale, dark-gray, fissile, silty, soft	2.9
81. Sandstone, gray, very fine grained, silty, calcareous, very hematitic; small-scale trough crossbedding; abundant *Ophiomorpha* at the top	3.1
80. Shale, gray, soft	7.1
79. Sandstone, gray, very fine grained, calcareous; small-scale trough crossbedding; worm borings	1.2
78. Shale, dark-gray, fissile, silty	2.8
77. Sandstone, gray, very fine grained, silty, calcareous, hematitic	0.6
76. Shale, gray, soft	7.4
75. Sandstone, gray, very fine grained, calcareous, hematitic; abundant small burrows; bioturbated	0.8
74. Shale, dark-gray, fissile, soft	2.9
73. Sandstone, gray, very fine grained, silty, calcareous, hematitic; some small burrows; bioturbated	0.7
72. Shale, dark-gray, fissile, soft	10.8
71. Siltstone, gray, calcareous, very hematitic; abundant small burrows	0.4
70. Shale, dark-gray, fissile, soft	6.8
69. Siltstone, gray, very fine grained, dolomitic, hard, concretionary, and some interbedded shale, gray, soft	5.0
68. Shale, dark-gray, fissile, soft	14.7
67. Siltstone, gray, calcareous, very hematitic, hard; weathers dark brown	0.4
66. Shale, gray, fissile, soft	1.8
65. Siltstone, gray, hematitic; abundant worm borings	0.3
64. Shale, dark-gray, carbonaceous, sandy at the base	4.2
63. Coal, with dark-gray carbonaceous shale partings	1.4
62. Shale, dark-gray, carbonaceous, partly very carbonaceous	7.5
61. Sandstone, gray, very fine grained, calcareous; trough crossbedded; lenticular	7.0
60. Shale, dark-gray, carbonaceous, silty; thin zone of hematite concretions in the lower part	5.0
59. Sandstone, gray, very fine grained, calcareous, slightly hematitic; small-scale trough crossbedding	2.4
58. Shale, gray, very sandy, soft	3.3
57. Shale, dark-gray, carbonaceous	4.8
56. Sandstone, gray, very fine grained, calcareous, hematitic; current rippled	6.0
55. Shale, dark-gray, silty	10.0
54. Shale, dark-gray, carbonaceous	2.0
53. Coal	1.9
52. Shale, dark-brown, carbonaceous	3.0
51. Sandstone, gray, very fine grained, calcareous, hard; current rippled; weathers brown	1.2
50. Shale, gray, soft	3.3
49. Sandstone, gray, very fine grained, calcareous, hard; current rippled	1.8
48. Shale, dark-gray, carbonaceous at the base	4.7
47. Coal	0.8
46. Shale, dark-brown, carbonaceous	1.3

	Thickness (Feet)
Measured section 149—Continued	
Almond Shale—Continued	
45. Shale, dark-gray, and very thin interbedded sandstone, gray, very fine grained, hematitic	13.5
44. Sandstone, gray, very fine grained, calcareous, hematitic, trough crossbedded	3.0
43. Shale, gray, soft	11.5
42. Siltstone, gray, dolomitic, hard; small concretionary zone	1.1
41. Shale, gray, carbonaceous at the base	1.5
40. Coal	1.0
39. Shale, dark-gray, carbonaceous in part, and very thin interbedded sandstone, gray, very fine grained, calcareous, hematitic	17.0
38. Coal	0.4
37. Shale, dark-gray, partly carbonaceous, and some interbedded sandstone, gray, very fine grained, calcareous, hematitic	18.5
36. Shale, gray, carbonaceous at the base	1.8
35. Coal	0.5
34. Shale, gray, carbonaceous at the top	9.2
33. Sandstone, gray, very fine grained, calcareous, slightly hematitic; a small lenticular fluvial channel trending S. 65° E.	15.5
32. Shale, gray, silty	1.4
31. Siltstone, gray, dolomitic, hard; concretionary zone	1.6
30. Shale, dark-gray, carbonaceous at the base	1.7
29. Coal	1.1
28. Shale, dark-gray, carbonaceous	1.4
27. Sandstone, gray, fine-grained, very calcareous, very hard, slightly hematitic; upper surface has wave ripples, worm borings, and small trails	0.9
26. Shale, gray, silty, and some very thin interbedded sandstone, gray, very fine grained, calcareous, in the upper part	6.6
25. Shale, dark-gray, carbonaceous	4.5
24. Coal with 0.2 ft thick tonstein parting in lower part	5.0
23. Shale, gray, carbonaceous the upper 1.5 ft	5.7
22. Sandstone, gray, very fine grained, calcareous, hematitic; current rippled; lenticular	1.5
21. Coal with gray and brown carbonaceous shale partings	7.7
20. Bone	0.5
19. Shale, dark-gray, carbonaceous	1.3
18. Sandstone, gray, very fine grained, calcareous; trough crossbedded	0.4
17. Shale, dark-gray, carbonaceous, and a very thin bed of siltstone, gray, very hematitic, near the middle	1.9
16. Coal	1.1
15. Shale, gray, carbonaceous; becomes gray-brown at the top	2.6
14. Sandstone, gray, very fine grained, calcareous, slightly hematitic; trough crossbedded	5.2
13. Coal	1.0
12. Shale, dark-gray, carbonaceous	9.0
11. Sandstone, gray, very fine grained, calcareous, hard; trough crossbedded	8.0
10. Coal	0.4
9. Shale, dark-gray, carbonaceous, and some very thin interbedded sandstone, gray, sandy, very hematitic	5.0
8. Siltstone, gray, sandy, very hematitic	5.0
7. Shale, dark-gray, carbonaceous at the base, and some very thin interbedded sandstone, gray, very fine grained	15.0
6. Siltstone, gray, very hematitic	0.7
5. Shale, very dark gray, black, carbonaceous	0.9
4. Coal	0.5
3. Shale, dark-gray, carbonaceous	12.0
Total Almond Formation	531.1
Ericson Sandstone (part):	
2. Sandstone, gray, very fine grained, calcareous, hard, slightly hematitic; trough crossbedded	22.5
1. Shale, dark-gray, carbonaceous, and thin interbedded sandstone, gray, very fine grained, slightly hematitic; trough crossbedded	12.0
Total Ericson Sandstone measured	34.5

Measured section 3575 (pl. 1) of the upper part of the Ericson Sandstone, Almond Formation, Lewis Shale, and lower part of the Fort Union Formation, southeast flank of the Rock Springs uplift. Section is illustrated graphically on plate 5.

[Secs. 28 and 29, T. 15 N., R. 102 W.]

	Thickness (Feet)
Fort Union Formation (part):	
106. Sandstone, gray, very fine grained, soft, hematitic, and interbedded shale, gray, sandy, soft	12.0
105. Shale, gray, sandy, soft	14.0
104. Covered by soil and sand	40.0
103. Sandstone, gray, very fine grained to medium-grained, poorly sorted, subangular, in large, low-angle trough crossbeds, and a few lenses of clay-pebble conglomerate near the base	75.0
102. Shale, dark-gray, carbonaceous, and some laminae of siltstone, gray, in the lower part	4.0
101. Siltstone, light-gray, limy; abundant root impressions	1.3
100. Shale, gray, soft	2.3
99. Sandstone, gray, very fine grained, hematitic; weathers white	1.1
98. Shale, gray, soft	3.2
97. Sandstone, gray, very fine grained, hematitic	3.4
96. Shale, gray, silty, carbonaceous at the top	17.7
95. Sandstone, gray, very fine grained, hematitic	2.5
94. Coal	0.2
93. Shale, gray, carbonaceous at the top	5.9
92. Sandstone, gray, very fine grained, hematitic; very hematitic the top 1.0 ft	8.8
91. Shale, gray, silty, soft, and thin interbedded sandstone, gray, very fine grained, hematitic	23.0
90. Covered by soil and vegetation	45.0
89. Shale, gray, soft	5.0
88. Sandstone, gray, very fine grained to medium-grained, slightly calcareous	13.0
87. Shale, dark-gray, carbonaceous, soft	4.0
86. Coal	4.3
85. Shale, gray, carbonaceous, and very thin interbedded sandstone, gray, very fine grained, calcareous	14.3
84. Sandstone, gray, very fine grained, calcareous, partly hematitic; ripple marked and trough crossbedded	7.7

	Thickness (Feet)
Measured section 3575—Continued	
Fort Union Formation (part)—Continued	
83. Shale, gray, carbonaceous at the base, sandy at the top	5.0
82. Coal	1.9
81. Shale, gray, carbonaceous, soft	2.3
80. Sandstone, gray, very fine grained, calcareous, partly hematitic; ripple marked	1.6
79. Shale, gray, silty, soft	24.0
Total Fort Union Formation measured	342.5
Laramide unconformity.	
Lewis Shale:	
78. Siltstone, gray, limy, hard; a fossil soil	7.9
77. Shale, dark-gray, fissile, soft	236.5
Total Lewis Shale	244.4
Almond Formation:	
76. Sandstone, gray, very fine grained, calcareous, hematitic	39.0
75. Shale, gray, soft	25.0
74. Sandstone, gray, very fine grained, calcareous, hard; trough crossbedded	19.0
73. Shale, gray, soft	21.0
72. Sandstone, gray, very fine grained, calcareous, hard; trough crossbedded	8.0
71. Shale, gray, soft	3.0
70. Sandstone, gray, very fine grained, calcareous; trough crossbedded	4.3
69. Shale, gray, sandy, soft	17.0
68. Sandstone, gray, very fine grained, calcareous, hematitic, hard; trough crossbedded	7.5
67. Shale, dark-gray, fissile, soft	4.6
66. Sandstone, gray, very fine grained, calcareous, hard; crossbedded; weathers brown	3.0
65. Coal	2.5
64. Sandstone, gray, very fine grained to fine-grained, slightly calcareous; some hematite staining; weathers white; trough crossbedded; 3.0 ft of carbonaceous shale near the middle	28.0
63. Shale, gray, sandy, soft	15.0
62. Sandstone, gray, very fine grained, argillaceous, calcareous streaks, and some very thin interbedded shale, dark-gray	5.0
61. Shale, gray, fissile, sandy, soft	5.0
60. Sandstone, gray, very fine grained, calcareous, hematitic; ripple marked	12.7
59. Shale, dark-gray, carbonaceous at the base, sandy at the top	6.7
58. Coal	1.9
57. Sandstone, gray, very fine grained, calcareous, hematitic, and interbedded shale, gray, carbonaceous, soft, in the middle and at the top	11.5
56. Shale, dark-brown, carbonaceous, brittle	0.9
55. Coal, with brown carbonaceous shale partings	4.6
54. Shale, dark-gray, carbonaceous, soft	2.6
53. Sandstone, gray, very fine grained; trough crossbedded in the lower part with carbonaceous shale partings; weathers white	17.0
52. Sandstone, gray, very fine grained, soft, and thin interbedded shale, dark-gray, carbonaceous	7.5
51. Sandstone, gray, very fine grained; abundant oyster shell fragments	2.0

	Thickness (Feet)
Measured section 3575—Continued	
Almond Formation—Continued	
50. Sandstone, gray, very fine grained, soft and loose	4.6
49. Shale, dark-gray, silty, soft	15.0
48. Sandstone, gray, very fine grained, calcareous, hematitic; trough crossbedded	7.0
47. Shale, gray, soft; abundant oyster shell fragments	1.0
46. Coal	2.5
45. Shale, dark-gray, carbonaceous, and interbedded sandstone, gray, very fine grained, calcareous, hematitic	16.7
44. Sandstone, gray, very fine grained, calcareous, hematitic	5.0
43. Shale, dark-gray, carbonaceous, soft	5.3
42. Sandstone, gray, very fine grained, calcareous, hematitic, hard, trough crossbedded	1.3
41. Shale, dark-gray, fissile, soft	11.3
40. Sandstone, gray, very fine grained, calcareous, hematite, and some interbedded shale, dark-gray, carbonaceous	3.5
39. Coal, with brown and gray carbonaceous shale partings	8.4
38. Shale, dark-gray, carbonaceous, soft	10.3
37. Siltstone, gray, dolomitic, hard; exhibits vertical fracture pattern	2.9
36. Sandstone, gray, very fine grained, hematitic, argillaceous, soft	17.0
35. Shale, dark-gray, carbonaceous, soft	8.5
34. Coal	4.3
33. Shale, dark-gray, carbonaceous, and some very thin interbedded sandstone, gray, very fine grained, calcareous, hematitic in the lower part	23.2
32. Sandstone, gray, very fine grained, calcareous, hard; trough crossbedded; scattered plant stem impressions	4.8
31. Coal	0.6
30. Shale, very dark gray, very carbonaceous, soft; weathers to dark-gray band in slopes	11.0
29. Shale, dark-gray, carbonaceous, and thin interbedded sandstone, gray, very fine grained, calcareous, hematitic; trough crossbedded	38.0
28. Sandstone, gray, very fine grained, calcareous, hematitic, hard	1.1
27. Shale, dark-gray, carbonaceous, soft	4.2
26. Coal	1.3
25. Shale, dark-gray, carbonaceous, soft	6.3
24. Sandstone, gray, very fine grained, silty, calcareous, hematitic; ripple marked; scattered plant stem impressions including one fragment of palm leaf	1.9
23. Shale, dark-gray, carbonaceous, and some very thin interbedded sandstone, gray, very fine grained, hematitic, argillaceous	16.2
22. Siltstone, gray, dolomitic, hard; in concretionary pods; exhibits vertical fracture pattern	1.5
21. Shale, dark-gray, carbonaceous, soft, and thin interbedded sandstone, gray, very fine grained, calcareous, hematitic; trough crossbedded	39.2
20. Sandstone, gray, very fine grained, calcareous, hematitic; ripple marked and trough crossbedded	2.9
19. Shale, dark-gray, carbonaceous	8.2
18. Sandstone, gray, very fine grained, calcareous, hematitic; trough crossbedded	1.4

Measured section 3575—Continued

	Thickness (Feet)
Almond Formation—Continued	
17. Shale, dark-gray, partly carbonaceous, and thin interbedded sandstone, gray, very fine grained, hematitic	19.5
16. Shale, dark-gray, carbonaceous, silty in part, soft	15.0
15. Sandstone, gray, very fine grained, calcareous, hematitic, hard; becomes soft and argillaceous the top 5.0 ft	15.0
14. Shale, dark-gray, carbonaceous, and very thin interbedded sandstone, gray, very fine grained, hematitic	30.3
13. Shale, gray, carbonaceous, and very thin interbedded sandstone, gray, very fine grained, hematitic, calcareous; trough crossbedded	16.0
12. Sandstone, gray, very fine grained, calcareous, hematitic; trough crossbedded	1.5
11. Shale, dark-gray, carbonaceous, soft, and a few very thin beds and laminae of siltstone, gray, calcareous, very hematitic	17.5
10. Sandstone, gray, very fine grained, calcareous, hematitic; trough crossbedded	1.3
9. Shale, dark-gray, fissile, soft, and a few very silty interlaminations	13.0
8. Sandstone, gray, very fine grained, calcareous, hematitic; abundant cuspate ripples	13.2
7. Shale, gray, sandy, soft	8.5
6. Sandstone, gray, very fine grained, calcareous, hematitic; abundant cuspate ripples	5.0
5. Shale, dark-gray, mostly carbonaceous, and some very thin interbedded sandstone, gray, very fine grained, calcareous, hematitic; ripple marked	15.6
4. Coal	0.5
3. Shale, dark-gray, partly carbonaceous, soft	23.0
2. Sandstone, gray, very fine grained, slightly hematitic, calcareous, and thin interbedded shale, gray, silty, soft	17.3
Total Almond Formation	788.9
Ericson Formation (part):	
1. Sandstone, gray, very fine grained, slightly calcareous; trough crossbedded; weathers white	90.0

APPENDIX B.—Core description of the U.S. Geological Survey Corehole BC No. 1, on the east flank of the Rock Springs uplift (measured in feet).

U.S. Geological Survey Corehole BC No. 1 (pls. 1, 3)
[NW¼NW¼SE¼ sec. 4, T. 19 N., R. 100 W.]

From	*To*	*Description*
Lance Formation (part):		
0	19.5	No samples.
19.5	19.6	Shale, gray, soft, finely disseminated carbonaceous material. Bay fill.
19.6	20.6	Sandstone, tan, very fine grained, fairly well sorted, slightly hematitic, some muscovite grains, some carbonaceous inclusions and partings, and a few thin laminae of shale, tan-gray, clayey; current ripple bedded. Distal splay.

U.S. Geological Survey Corehole BC No. 1—Continued

From	*To*	*Description*
Lance Formation (part)—Continued		
20.6	21.4	Shale, gray, soft, silty, and interlaminated siltstone, tan, soft; some carbonaceous plant stem impressions; current ripple bedded. Distal splay.
21.4	23.9	Sandstone, tan-gray, very fine grained, slightly carbonaceous, and interlaminated shale, gray, slightly carbonaceous; some carbonaceous inclusions and partings and carbonized plant stems; current ripple bedded. Distal splay.
23.9	31.5	Sandstone, tan, very fine grained, subangular, fairly well sorted, abundant black grains, soft, some muscovite grains; fairly abundant carbonaceous inclusions and plant impressions; current ripple bedded. Splay.
31.5	31.8	Sandstone, tan-gray, very fine grained to fine-grained, poorly sorted, scattered carbonaceous material and plant impressions; some small pyrite nodules; a few small shell fragments. Splay channel.
31.8	32.5	Sandstone, tan, very fine grained, silty, fairly well sorted, some muscovite grains, abundant black grains; carbonaceous laminae with plant impressions and root impression; current ripple bedded. Splay.
32.5	32.7	Shale, gray, carbonaceous; abundant plant debris including roots and deciduous leaf impressions. Reed swamp.
32.7	33.5	Coal. Forest swamp.
33.5	33.8	Shale, very dark gray, clayey, carbonaceous; abundant slickensides. Reed swamp.
33.8	34.0	Coal with cleats filled with gypsum. Forest swamp.
34.0	34.1	Shale, very dark gray, nearly black, carbonaceous, and a few laminae of coal; abundant ribbonlike aquatic plant impressions. Reed swamp and forest swamp.
34.1	36.1	Shale, medium-gray, slightly carbonaceous; sparse scattered plant stem impressions and rootlets.
36.1	36.6	Siltstone, tan-gray, and finely interlaminated shale, gray, carbonaceous; current ripple bedded. Distal splay and bay fill.
36.6	36.8	Sandstone, tan-gray, fine-grained, fairly well sorted, abundant black grains, some red and white grains, sparse muscovite grains; some small carbonaceous inclusions; no distinct bedding. Distal splay.
36.8	37.7	Sandstone, tan-gray, fine-grained, and interlaminated shale, gray, carbonaceous; interval is mostly sandstone in the lower part and fines upward. Splay.
37.7	52.1	Sandstone, gray, fine-grained, fairly well sorted, subangular, abundant black grains, some red grains, carbonaceous with root impressions and wood inclusions; the interval from 42.2-42.4 ft has layers of angular gray shale pebbles up to 0.05 ft in diameter; a few scattered clay pebbles and carbonized wood fragments

U.S. Geological Survey Corehole BC No. 1—Continued

From	*To*	*Description*
Lance Formation (part)—Continued		
		in the lower part; becomes well sorted and fine grained in the lower part; no distinct bedding. Splay channel?
52.1	53.3	Clay pebble conglomerate, gray, flat, rounded clay pebbles up to 0.2 ft long in a matrix of sandstone, tan, fine-grained, subangular, abundant black grains, soft, poorly cemented. Base of splay channel?
53.3	56.5	Shale, dark-gray, very slightly carbonaceous, and very thin interbedded and interlaminated sandstone, tan, very fine grained; current ripple bedded. Bay fill and distal splay.
56.5	60.0	Siltstone, gray, slightly argillaceous, and interlaminated shale, gray, soft, the lower 2.0 ft. Distal splay.
60.0	63.0	Shale, dark-gray, and finely interbedded and interlaminated siltstone, gray; current ripple bedded; abundant smooth-walled, variously oriented burrows from 0.01 to 0.04 ft in diameter; some veinlets filled with gray, fine-grained sandstone. Distal splay.
63.0	64.2	Shale, gray, silty; some smooth-walled burrows; small vertical veinlets filled with gray, fine-grained sandstone. Bay fill.
64.2	67.0	Siltstone, gray, very shaly; becomes mostly shale in the lower part; abundant small white root fillings at the top. Distal splay.
67.0	68.9	Shale, dark gray. Bay fill.
68.9	69.2	Siltstone, gray. Bay fill.
69.2	69.5	Shale, gray, sandy. Bay fill.
69.5	71.0	Sandstone, gray, very fine grained. Splay.
71.0	75.0	Sandstone, gray, very fine grained, and interlaminated shale, gray; abundant small smooth-walled burrows; sparse scattered carbonized plant fragments; current ripple bedded. Distal splay.
75.0	75.9	Shale, gray, scattered carbonaceous material; a few sandstone laminae in the upper part. Bay fill.
75.9	77.1	Sandstone, gray, very fine grained, silty; a few carbonaceous laminae the lower 0.4 ft. Distal splay and reed swamp.
77.1	78.0	Coal. Forest swamp.
78.0	82.7	Shale, dark-gray to black, carbonaceous; abundant aquatic, ribbonlike plant impressions in the upper part. Reed swamp.
82.7	85.1	Siltstone, tan-gray, sandy, and interlaminated shale, dark-gray; scattered, partly pyritic carbonized plant fragments; current ripple bedded. Distal splay.
85.1	85.3	Dolomite, tan, hard; well-preserved thick-stalked aquatic plant impressions; concretionary. Distal splay.
85.3	86.9	Sandstone, gray, very fine grained, and interlaminated shale, gray; disseminated carbonized plant fragments; small, variously oriented, smooth-walled burrows; current ripple bedded. Distal splay.
86.9	87.0	Dolomite, tan, hard; some carbonaceous partings; concretionary. Distal splay.
87.0	87.1	Shale, dark-gray, and interlaminated sandstone, gray, very fine grained. Distal splay.
87.1	87.7	Shale, black, carbonaceous, slightly pyritic; some long, thin plant impressions; scattered fish bones; abundant ostracodes. Reed swamp.
87.7	88.0	Coal. Forest swamp.
88.0	88.2	Shale, black, carbonaceous; plant impressions. Reed swamp.
88.2	88.4	Coal. Forest swamp.
88.4	89.5	Shale, dark-gray to black, carbonaceous. Reed swamp.
89.5	91.6	Shale, dark-gray, and interlaminated sandstone, gray, very fine grained, silty; current ripple bedded. Distal splay.
91.6	92.4	Shale, gray to black, carbonaceous; a few ostracodes and fish scales; abundant root casts. Reed swamp.
92.4	93.6	Shale, gray, and interlaminated sandstone, gray, very fine grained; current ripple bedded. Distal splay.
93.6	94.4	Shale, gray, slightly carbonaceous. Bay fill.
94.4	96.2	Siltstone, gray, argillaceous. Distal splay.
96.2	97.0	Sandstone, gray, very fine grained to fine-grained, fairly well sorted, abundant black grains, some red and white grains; no distinct bedding. Distal splay.
97.0	97.5	Siltstone, medium-gray, very calcareous, very hard. Distal splay.
97.5	98.3	Shale, medium-gray, silty, dolomitic, hard. Bay fill.
98.3	99.1	Siltstone, medium-gray, calcareous, hard; some shaly laminae. Distal splay.
99.1	102.0	Shale, medium-gray, slightly dolomitic, hard. Bay fill.
102.0	104.2	Shale, medium-gray, slightly dolomitic, silty, hard; some mollusks. Bay fill. *Cassiopella* sp. *Viviparus* sp. small unidentified clam small planorbid snail miscellaneous small snails fish scales ostracodes
104.2	106.0	Shale, medium-gray, very silty, slightly carbonaceous; small smooth-walled burrows; some slightly pyritic carbonized plant fragments; a few carbonized seeds? at 105.8 ft. Bay fill.
106.0	106.5	Shale, medium- to dark-gray, very slightly carbonaceous; some shell fragments and fish scales. Bay fill.
106.5	107.4	Shale, medium- to dark-gray, slightly carbonaceous, with tan, silty dolomite nodules; a few slightly pyritic carbonized small plant stems. Bay fill.

U.S. Geological Survey Corehole BC No. 1—Continued

From	*To*	*Description*
Lance Formation (part)—Continued		
107.4	108.7	Shale, very dark gray, slightly silty; scattered very small slightly pyritic carbonized plant fragments. Bay fill.
108.7	111.6	Siltstone, medium-gray; scattered very small vuglike partly calcified and pyritized plant stem impressions.
111.6	112.5	Sandstone, medium-gray, very fine grained to fine-grained, fairly well sorted, abundant black and white grains, slightly carbonaceous.
112.5	124.0	Shale, medium- to dark-gray, slightly pyritic carbonized plant impressions, some small borings filled with sandstone, and very thin interbedded and interlaminated sandstone, gray, very fine grained, and siltstone, gray, slightly carbonaceous; current ripple bedded; leaf impressions at 118.4 ft and 119.0 ft. Distal splay.
124.0	125.0	Shale, dark-gray, silty and sandy laminae; current ripple bedded; scattered shell fragments. Bay fill.
125.0	126.0	Shale, dark-gray; scattered shell fragments. Bay fill. *Viviparus sp.* scattered ostracodes abundant charophytes
126.0	128.0	Shale, gray, very silty; very thin concretionary dolomite layer at 126.7 ft. Bay fill.
128.0	130.3	Coal, banded, bright, shiny. Forest swamp.
130.3	130.5	Shale, dark-gray, carbonaceous; some carbonized plant impressions. Reed swamp.
130.5	130.6	Sandstone, gray, very fine grained. Splay.
130.6	131.1	Shale, gray, silty, carbonaceous. Reed swamp.
131.1	135.0	Sandstone, medium-gray, very fine grained to fine-grained, subangular, fairly well sorted, abundant black and white grains, some red grains, and sparse biotite grains, some finely disseminated carbonaceous material, and a few laminae of shale, dark-gray. Splay.
135.0	137.5	Sandstone, medium-gray, very fine grained to fine-grained, and interlaminated shale, gray; current ripple bedded. Distal splay.
137.5	148.0	Sandstone, medium-gray, fine-grained, abundant black and white grains, some red grains, soft, friable, very calcareous and hard in layers; looks porous. Splay.
148.0	149.5	Sandstone, medium-gray, fine-grained, and some interlaminated shale, dark-gray, carbonaceous. Distal splay.
149.5	153.2	Sandstone, medium-gray, fine-grained, fairly well sorted, abundant black and white grains, some layers very hard and calcareous and some layers soft and friable. Splay.
153.2	155.0	Sandstone, medium-gray, fine-grained, abundant flattened, rounded gray shale pebbles up to 0.3 ft in diameter. Splay.
155.0	156.3	Sandstone, medium-gray, fine-grained, fairly well sorted, soft, friable. Splay.
156.3	157.1	Sandstone, medium-gray, fine-grained, some small gray and tan shale pebbles. Splay.
157.1	162.6	Sandstone, medium-gray, fine-grained, with black carbonaceous shale partings. Distal splay.
162.6	164.0	Shale, medium- to dark-gray, clayey, soft. Bay fill.
164.0	164.8	Coal (log); missing in core. Forest swamp.
164.8	166.2	Shale, medium-gray, very silty, slightly carbonaceous. Reed swamp.
166.2	167.5	Siltstone, medium-gray, slightly carbonaceous, very calcareous in part. Distal splay.
167.5	172.3	Shale, medium-gray, very silty, some carbonized plant fragments and impressions; a few tan dolomite nodules between 169.0 and 170.1 ft. Bay fill.
172.3	174.1	Sandstone, medium-gray, very fine grained to fine-grained, fairly well sorted, abundant black and white grains, some red grains, with numerous carbonaceous shale partings and laminae. Distal splay.
174.1	175.4	Shale, dark-gray, silty, carbonaceous; scattered leaf and stem impressions; some shell fragments; some dark-gray angular shale pebbles at 175.0–175.3 ft. Bay fill. *Viviparus* sp. *Campeloma* sp.
175.4	176.1	Shale, dark-gray; some slightly pyritic carbonized plant material.
176.1	178.5	Siltstone, medium-gray, argillaceous; massive. Distal splay.
178.5	179.9	Shale, medium-gray, silty laminae; some carbonized plant impressions. Bay fill.
179.9	180.2	Shale, dark-gray, carbonaceous. Reed swamp.
180.2	184.9	Shale, medium-gray, silty, with laminae of siltstone; scattered very small, weathered unidentifiable shell fragments at 183.0–184.0 ft; some carbonized plant impressions. Bay fill.
184.9	185.2	Shale, black, very carbonaceous with laminae of coal. Reed swamp.
185.2	185.8	Shale, dark-gray, carbonaceous; abundant burrows filled with medium-gray siltstone. Reed swamp.
185.8	187.2	Siltstone, medium-gray, with gray shale partings; numerous burrows; current ripple bedded. Distal splay.
187.2	189.3	Shale, medium- to dark-gray, a few carbonized plant impressions, including pine needles at 188.0 ft. Bay fill.
189.3	190.4	Siltstone, medium-gray; a few carbonized plant impressions. Bay fill.
190.4	194.0	Shale, medium- to dark-gray; dolomite nodules at 191.5 ft and 192.3 ft; some carbonized plant impressions, including leaf impressions at 193.6 ft. Bay fill.
194.0	194.1	Shale, dark-gray, carbonaceous. Reed swamp.
194.1	194.4	Coal. Forest swamp.

U.S. Geological Survey Corehole BC No. 1—Continued

From	*To*	*Description*
Lance Formation (part)—Continued		
194.4	195.7	Shale, dark-gray to black, carbonaceous. Reed swamp.
195.7	196.9	Shale, gray, soft; some carbonized plant impressions; a few very small, weathered shell fragments. Bay fill.
196.9	197.2	Siltstone, tan, sandy, carbonaceous shale partings; current ripple bedded. Distal splay.
197.2	197.5	Shale, dark-gray, and interlaminated siltstone, medium-gray. Distal splay.
197.5	198.0	Siltstone, medium-gray. Splay.
198.0	198.6	Siltstone, medium-gray, and finely interlaminated shale, medium-gray. Distal splay.
198.6	198.8	Shale, black, carbonaceous. Reed swamp.
198.8	199.1	Coal. Forest swamp.
199.1	199.3	Shale, black, carbonaceous. Reed swamp.
199.3	201.0	Shale, medium- to dark-gray, and interbedded and interlaminated sandstone, medium-gray, very fine grained; some carbonized plant impressions. Distal splay.
201.0	201.3	Shale, black, very carbonaceous. Reed swamp.
201.3	201.6	Shale, dark-gray; some plant impressions. Reed swamp.
201.6	202.3	Siltstone, medium-gray. Distal splay.
202.3	205.0	Shale, gray, slightly silty layers; some carbonized plant impressions. Bay fill.
205.0	212.7	Siltstone, medium-gray, sandy in parts, and interlaminated shale, dark-gray; aquatic plant impressions at 208.0 ft and 210.5 ft; a good leaf impression at 211.0 ft; current ripple bedded. Splay.
212.7	215.0	Siltstone, medium-gray, sandy, with finely interbedded and interlaminated shale, dark-gray, partly carbonaceous; current ripple bedded. Distal splay.
215.0	218.1	Sandstone, medium-gray, very fine grained, and very thin interbedded and interlaminated shale, gray, carbonaceous; thin layers of tan dolomite at 215.5 ft; some carbonized plant impressions. Distal splay.
218.1	218.2	Dolomite, tan, hard; concretionary. Distal splay.
218.2	221.0	Siltstone, gray, shaly, argillaceous. Splay.
221.0	225.5	Sandstone, medium-gray, very fine grained, silty, and interlaminated shale, gray, carbonaceous. Distal splay.
225.5	228.0	Shale, medium- to dark-gray, a few silty layers; some pyritic carbonized plant fragments. Bay fill.
228.0	228.5	Shale, dark-gray; some laminae contain abundant ostracodes; scattered shell fragments. Bay fill.
228.5	231.0	Shale, medium- to dark-gray; some carbonized plant impressions. Bay fill.
231.0	233.1	Sandstone, medium-gray, very fine grained to fine-grained, and interlaminated shale, black, carbonaceous; current ripple bedded. Splay.
233.1	234.0	Shale, black, carbonaceous. Reed swamp.

U.S. Geological Survey Corehole BC No. 1—Continued

From	*To*	*Description*
Lance Formation (part)—Continued		
234.0	235.0	Coal. Forest swamp.
235.0	235.7	(Coal) Sample missing. Forest swamp.
235.7	242.8	Coal (0.1 foot of black carbonaceous shale at 238.4). Forest swamp.
242.8	243.0	Shale, black, carbonaceous. Reed swamp.
243.0	243.7	Shale, medium-gray, silty; abundant carbonized plant impressions. Bay fill.
243.7	244.7	Siltstone, medium-gray; carbonaceous shale partings; current ripple bedded. Distal splay.
244.7	245.8	Shale, medium-gray; some carbonized plant impressions. Bay fill.
245.8	246.4	Shale, black, carbonaceous. Reed swamp.
246.4	246.8	Shale, medium- to dark-gray; some carbonized plant impressions. Reed swamp.
246.8	246.9	Coal. Forest swamp.
246.9	247.3	Siltstone, medium-gray; carbonaceous inclusions. Reed swamp.
247.3	247.7	Shale, dark-gray to black, carbonaceous. Reed swamp.
247.7	247.9	Coal. Forest swamp.
247.9	248.0	Shale, black, carbonaceous. Reed swamp.
248.0	248.6	Shale, medium-gray; some carbonized, pyritic plant impressions. Reed swamp.
248.6	248.7	Shale, black, carbonaceous. Reed swamp.
248.7	249.1	Shale, medium-gray; some carbonized, pyritic plant impressions. Bay fill.
249.1	249.4	Shale, black, carbonaceous. Reed swamp.
249.4	250.0	Sandstone, medium-gray, very fine grained to fine-grained, calcareous, hard; abundant small crystals and clusters of pyrite throughout. Splay.
250.0	250.7	Sandstone, medium- to dark-gray, very fine grained to fine-grained, very calcareous, very hard. Splay.
250.7	252.2	Sandstone, medium-gray, very fine grained to fine-grained, and some interlaminated shale, dark-gray, carbonaceous; current ripple bedded. Distal splay.
252.2	254.1	Shale, dark-gray, and finely interlaminated siltstone, medium-gray; current rippled. Distal splay.
254.1	256.4	Shale, medium- to dark-gray; abundant shell fragments, becoming more fossiliferous downward. Bay fill. *Brachidontes* sp. *Corbula* sp. *Viviparus* sp. small planorbid snail ostracodes
256.4	256.5	Dolomite, brown, hard concretionary; abundant plant impressions, including a small pine branch with needles; some pine seeds? Bay fill.
256.5	257.9	Shale, dark-gray; abundant mollusk shells. Bay fill. *Corbula* sp. *Leptesthes* *Viviparus* sp. small planorbid snail

U.S. Geological Survey Corehole BC No. 1—Continued

From	*To*	*Description*
Lance Formation (part)—Continued		
257.9	258.0	Dolomite, tan-gray, hard; concretionary. Bay fill.
258.0	259.0	Shale, dark-gray; abundant mollusk shells. Bay fill. *Leptesthes* sp. *Viviparus* sp. *Cassiopella* sp. ostracodes
259.0	259.5	Shale, medium- to dark-gray, very silty, dolomitic; a few shell fragments in the upper 0.3 ft. Bay fill.
259.5	261.5	Shale, medium-gray, silty, and interlaminated siltstone, medium-gray. Distal splay.
261.5	261.8	Sandstone, medium-gray, very fine grained, and some interlaminated shale, dark-gray. Distal splay.
261.8	263.9	Shale, dark-gray, silty, and interlaminated siltstone, tan-gray. Distal splay.
263.9	266.5	Sandstone, medium-gray, fine-grained, fairly well sorted, subangular, abundant black and some red grains, soft, friable, looks porous, and some interlaminated shale, dark-gray, carbonaceous. Splay.
266.5	267.7	Shale, medium- to dark-gray, and finely interbedded and interlaminated siltstone, medium-gray; abundant borings. Distal splay.
267.7	268.0	Shale, medium-gray; scattered mollusk shells. Bay fill. *Viviparus* sp. *Cassiopella* sp. fingernail clam ostracodes
268.0	268.5	Shale, dark-gray; very abundant mollusk shells. Bay fill. *Viviparus* sp. *Leptesthes* fingernail clam calcareous worm tubes
268.5	269.0	Shale, black, carbonaceous. Reed swamp.
269.0	270.2	Coal. Forest swamp.
270.2	270.6	Shale, black, carbonaceous. Reed swamp.
270.6	273.2	Coal. Forest swamp.
273.2	273.3	Shale, black, carbonaceous. Reed swamp.
273.3	274.7	Shale, dark-gray; abundant carbonized plant impressions. Bay fill.
274.7	277.2	Sandstone, medium-gray, very fine grained, silty, and interlaminated shale, gray, slightly carbonaceous. Splay.
277.2	282.0	Shale, dark-gray, some carbonized plant impressions, and interlaminated and very thin interbedded sandstone, medium-gray, very fine grained; current ripple bedded. Distal splay.
282.0	283.7	Sandstone, light-gray, fine-grained, abundant black and white grains, dirty, some carbonaceous inclusions; current ripple bedded; sharply defined base. Distal splay.

U.S. Geological Survey Corehole BC No. 1—Continued

From	*To*	*Description*
Lance Formation (part)—Continued		
283.7	284.5	Sandstone, medium-gray, very fine grained to fine-grained, and interlaminated shale, dark-gray, carbonaceous; current ripple bedded. Splay and distal splay.
284.5	288.5	Shale, dark-gray, a few silty laminae in the upper 0.5 ft; abundant mollusk shells. Bay fill. *Corbula* sp. *Brachidontes* sp. *Leptesthes* sp. *Viviparus* sp. fish scales ostracodes calcareous worm tubes
288.5	288.8	Shale, black, carbonaceous; abundant well-preserved *Brachidontes* sp. Reed swamp.
288.8	289.8	Coal. Forest swamp.
289.8	292.7	Shale, black, carbonaceous; a few carbonized plant impressions; one well-preserved seed at 292.7 ft; a few fish scales. Reed swamp.
292.7	294.3	Shale, black to dark-gray, carbonaceous; a few mollusk shells. Bay fill. *Corbula* sp. *Campeloma* sp. *Cassiopella* sp. fish scales
294.3	294.4	Dolomite, tan, hard, nodular. Bay fill.
294.4	295.2	Shale, medium- to dark-gray; scattered shell fragments. Bay fill.
295.2	300.8	Sandstone, medium-gray, very fine grained to fine-grained, fairly well sorted, abundant black grains, and some interlaminated shale, dark-gray, carbonaceous. Splay.
300.8	301.8	Sandstone, medium-gray, fine-grained, and interlaminated shale, black, carbonaceous. Splay.
301.8	309.0	Sandstone, medium-gray, very fine grained to fine-grained, and some interlaminated shale, dark-gray, slightly carbonaceous. Splay.
309.0	309.6	Dolomite, tan, gray, hard, silty in part; concretionary. Bay fill.
309.6	309.9	Shale, gray, slightly dolomitic; some shell fragments. Bay fill.
309.9	310.0	Dolomite, tan, hard. Bay fill.
310.0	311.0	Shale, medium- to dark-gray; scattered carbonized plant impressions; some shell fragments. Bay fill.
311.0	313.9	Shale, medium- to dark-gray, clayey; some carbonized plant fragments. Bay fill.
313.9	314.5	Shale, black, carbonaceous. Reed swamp.
314.5	316.3	Coal. Forest swamp.
316.3	318.2	Shale, black, carbonaceous. Reed swamp.
318.2	319.3	Coal. Forest swamp.
319.3	321.5	Shale, black to dark-gray, carbonaceous. Reed swamp.
321.5	322.0	Coal. Forest swamp.
322.0	322.5	Shale, black, carbonaceous. Reed swamp.

U.S. Geological Survey Corehole BC No. 1—Continued

From	*To*	*Description*
Lance Formation (part)—Continued		
322.5	330.6	Coal. Forest swamp.
330.6	331.0	Shale, black, carbonaceous. Reed swamp.
331.0	331.2	Coal. Forest swamp.
331.2	331.5	Shale, black to dark-gray, carbonaceous. Reed swamp.
331.5	334.7	Siltstone, medium-gray, and interlaminated shale, medium-gray, partly carbonaceous; some plant impressions. Distal splay.
334.7	335.7	Dolomite, tan, medium-gray, very hard, shaly; concretionary. Distal splay.
335.7	337.0	Shale, medium-gray; a few shell fragments. Bay fill. *Brachidontes* sp. *Corbula* sp. fingernail clam small planorbid snail ostracodes
337.0	338.6	Shale, dark-gray, slightly carbonaceous in the lower part; mollusk shells. Bay fill. *Brachidontes* sp. *Corbula* sp. small planorbid snail small pecten
338.6	344.2	Shale, medium- to dark-gray, and interlaminated siltstone, medium-gray, sandy; mollusk shells. Distal splay. *Brachidontes* sp. *Leptesthes* *Corbula* sp. *Anomia* sp.
344.2	346.5	Shale, medium-gray, silty; mollusk shells. Bay fill. *Corbula* sp. *Leptesthes* sp. *Brachidontes* sp.
346.5	348.2	Shale, dark-gray; abundant mollusks. Bay fill. *Brachidontes* sp. *Anomia* sp. *Leptesthes* sp. fingernail clams small planorbid snail ostracodes
348.2	349.6	Shale, black, carbonaceous; some plant impressions; mollusk shells. Reed swamp. *Corbula* sp. large turreted snail
349.6	350.8	Shale, medium- to dark-gray; disseminated carbonaceous material; mollusks. Bay fill. unidentified snails and clams ostracodes fish scales fingernail clam
350.8	352.0	Sandstone, medium-gray, very fine grained to fine-grained, calcareous, hard; some carbonaceous debris. Splay.
352.0	353.6	Siltstone, medium-gray, and interlaminated shale, medium-gray; some carbonaceous debris; abundant borings. Distal splay.
353.6	353.9	Sandstone, medium-gray, very fine grained, calcareous, and some interlaminated shale, medium-gray. Distal splay.
353.9	354.2	Shale, medium- to dark-gray, and interlaminated sandstone, medium-gray. Distal splay.
354.2	354.7	Sandstone, medium-gray, very fine grained to fine-grained; some plant debris. Distal splay.
354.7	355.2	Sandstone, medium-gray, very fine grained to fine-grained, and interlaminated shale, dark-gray; mollusk shells. Distal splay. *Corbula* sp. *Brachidontes* sp. *Anomia* sp. pecten ostracodes
355.2	356.0	Shale, dark-gray to black, carbonaceous; mollusk shells. Reed swamp. *Brachidontes* sp. pecten *Anomia* sp. ostracodes
356.0	358.6	Coal. Forest swamp.
358.6	359.9	Shale, black, carbonaceous. Reed swamp.
359.9	361.7	Shale, medium- to dark-gray, slightly carbonaceous. Bay fill.
361.7	362.6	Sandstone, medium-gray, very fine grained, and interlaminated shale, dark-gray. Distal splay.
362.6	363.3	Sandstone, medium-gray, fine-grained. Splay.
363.3	363.6	Sandstone, medium-gray, fine-grained, and interlaminated shale, dark-gray. Splay.
363.6	364.1	Sandstone, medium-gray, fine-grained. Splay.
364.1	365.0	Siltstone, medium-gray, sandy in part, and interlaminated shale, dark-gray. Distal splay.
365.0	366.0	Siltstone, medium-gray, and interlaminated shale, dark-gray; a few *Corbula* sp. Distal splay.
366.0	367.0	Shale, dark-gray to black carbonaceous; mollusks. *Corbula* sp. *Crassostrea* sp. ostracodes
367.0	368.7	Coal. Forest swamp.
368.7	370.0	Shale, black, carbonaceous. Reed swamp.
370.0	370.3	Coal. Forest swamp.
370.3	371.4	Shale, black, carbonaceous. Reed swamp.
371.4	371.6	Coal. Forest swamp.
371.6	372.4	Shale, black, carbonaceous. Reed swamp.
372.4	372.9	Coal. Forest swamp.
372.9	375.4	Sandstone, medium-gray, fine-grained, argillaceous; some carbonaceous debris; root casts. Splay.

U.S. Geological Survey Corehole BC No. 1—Continued

From	*To*	*Description*
Lance Formation (part)—Continued		
375.4	378.3	Sandstone, medium-gray, very fine grained to fine-grained, and some interlaminated shale, dark-gray; current ripple bedded. Splay.
378.3	380.7	Shale, medium-gray, silty, a few sandy laminae; some very small carbonized plant fragments; some burrows; sparse very small shell fragments. Bay fill.
380.7	381.0	Siltstone, light-gray, and interlaminated shale, black, carbonaceous. Distal splay.
381.0	381.2	Shale, black, carbonaceous; mollusk shells. Reed swamp. *Crassostrea* sp. small clams
381.2	381.3	Coal. Forest swamp.
381.3	382.3	Shale, black, carbonaceous. Reed swamp.
382.3	383.0	Shale, medium- to dark-gray; and interlaminated sandstone, medium-gray, very fine grained; mollusk shells. Distal splay. *Corbula* sp. *Leptesthes* sp.
383.0	385.7	Shale, medium- to dark-gray, and interlaminated sandstone, medium-gray, very fine grained; mollusk shells. Distal splay. *Corbula* sp. *Leptesthes* sp.
385.7	388.0	Shale, black; abundant mollusk shells. Bay fill. *Crassostrea* sp. *Corbula* sp. pecten *Brachidontes* sp. small planorbid snail ostracodes
388.0	388.6	Shale, medium-gray, soft. Bay fill.
388.6	389.3	Sandstone, medium-gray, very fine grained to fine-grained, and some interlaminated shale, gray; abundant burrows. Distal splay.
389.3	389.9	Sandstone, medium-gray, very fine grained, and interlaminated shale, gray. Distal splay.
389.9	390.4	Shale, medium-gray, silty; sparse scattered shell fragments. Bay fill.
390.4	392.7	Shale, medium-gray, and interlaminated siltstone, medium-gray; scattered *Crassostrea* sp. and *Anomia* sp. Distal splay.
392.7	393.5	Shale, black, carbonaceous; abundant *Corbula* sp. and some *Crassostrea* sp. Bay fill.
393.5	393.7	Sandstone, medium-gray, fine grained; abundant shell fragments. Splay.
393.7	394.0	Shale, black, silty, very carbonaceous. Reed swamp.
394.0	397.0	Coal. Forest swamp.

U.S. Geological Survey Corehole BC No. 1—Continued

From	*To*	*Description*
Fox Hills Sandstone (part):		
397.0	397.1	Sandstone, dark-gray, fine-grained, fairly well sorted, very carbonaceous; organically stained.
397.1	398.4	Sandstone, medium-gray, fine-grained, fairly well sorted, subangular, very porous, soft, friable; abundant colored grains; abundant carbonized root impressions. Shoreface.
398.4	407.5	Sandstone, light- to medium-gray, fine- to medium-grained, soft, friable, porous; abundant colored grains. Shoreface.

APPENDIX C.—Lithologic description of measured section 104 of the upper part of the Lewis Shale, Fox Hills Sandstone, and lower part of the Lance Formation, east flank of the Rock Springs uplift.

Measured section 104 (pls. 1, 2) of the Fox Hills Sandstone and overlying Lance Formation (part) and underlying Lewis Shale (part), 4 mi southeast of Point of Rocks, Wyoming. Section is illustrated graphically on plate 4.

[Secs. 32 and 33, T. 20 N., R. 100 W.]

	Thickness (feet)
Lance Formation (part):	
95. Sandstone, gray, very fine grained, calcareous, trough-crossbedded, and some interbedded shale, gray, the lower 7.0 ft	9.0
94. Shale, gray, soft	3.4
93. Siltstone, gray, hematitic, dolomitic; concretionary zone	0.8
92. Shale, gray, soft	3.2
91. Sandstone, gray, very fine grained, trough-crossbedded	17.0
90. Shale, gray, soft	7.9
89. Shale, brown, carbonaceous	1.8
88. Shale, gray, soft	8.0
87. Dolomite, gray, hard; concretionary zone	1.6
86. Shale, gray, and a few 0.2 to 0.4 ft thick interbedded sandstone, gray, very fine grained, and siltstone, gray, very hematitic	14.7
85. Shale, gray, slightly carbonaceous	0.5
84. Shale, gray, soft, and 0.4 ft thick silty, hematitic concretionary zone near the middle	2.8
83. Shale, brown, carbonaceous	0.5
82. Shale, gray, soft, and a 0.5 ft thick hematitic siltstone concretionary zone near the middle	6.5
81. Coal (freshwater stage of bay cycle No. 10)	3.1
80. Shale, brown, carbonaceous	0.2
79. Shale, gray, soft	4.0
78. Shale, gray, soft, and several 0.2 to 0.5 ft thick layers of gray, hematitic siltstone concretions	5.1
77. Shale, gray, soft	3.5
76. Coal, with brown carbonaceous shale partings near the middle (freshwater stage of bay cycle No. 9)	5.5
75. Shale, brown, carbonaceous	0.2
74. Shale, gray, soft	3.0
73. Siltstone, gray, very hematitic	0.3

Measured section 104—Continued

Lance Formation (part)—Continued

	Thickness (feet)
72. Shale, gray, soft	0.4
71. Shale, brown, carbonaceous	0.4
70. Shale, gray, soft	1.3
69. Sandstone, gray, very fine grained, silty; current rippled	0.6
68. Shale, gray, soft	1.8
67. Shale, dark-gray-brown, carbonaceous	1.3
66. Shale, gray, soft	2.5
65. Sandstone, gray, very fine grained; current and wave rippled; weathers dark brown	3.0
64. Shale, gray, soft	12.3
63. Shale, brown, fissile, carbonaceous	0.4
62. Coal	1.6
61. Shale, brown, carbonaceous	0.3
60. Shale, gray, soft	8.4
59. Shale, brown, carbonaceous	0.3
58. Coal	1.8
57. Shale, gray, silty to sandy, slightly carbonaceous	2.4
56. Coal	0.6
55. Shale, brown, carbonaceous	0.9
54. Coal (freshwater stage of bay cycle No. 8)	2.8
53. Shale, brown, carbonaceous	1.3
52. Coal	0.2
51. Shale, brown, carbonaceous	6.5
50. Shale, gray, soft	2.4
49. Sandstone, gray, very fine grained, calcareous; current and wave rippled; small, poorly preserved dinosaur tracks on the upper surface	4.0
48. Shale, gray, soft	10.0
47. Shale, dark-gray-brown, carbonaceous	1.1
46. Coal (freshwater stage of bay cycle No. 7)	3.9
45. Shale, brown, carbonaceous	0.7
44. Shale, gray, soft	2.8
43. Dolomite, gray, hard; concretionary zone	0.6
42. Shale, gray, soft	5.9
41. Sandstone, gray, very fine grained, silty; current rippled	0.6
40. Shale, gray, soft	7.7
39. Shale, brown, carbonaceous	0.4
38. Coal (freshwater stage of bay cycle No. 6)	6.1
37. Shale, brown, carbonaceous	3.0
36. Shale, gray, soft	24.0
35. Dolomite, gray; concretionary zone	1.5
34. Siltstone, gray, sandy; current rippled	0.7
33. Shale, gray, soft	3.4
32. Shale, brown, carbonaceous	0.8
31. Coal (freshwater stage of bay cycle No. 5)	6.5
30. Shale, brown, carbonaceous	1.3
29. Shale, dark-gray, soft; abundant oyster shells the upper 3.0 ft	14.3
28. Shale, brown, carbonaceous (interval of bay cycle No. 4)	10.0
27. Shale, gray, soft	3.1
26. Siltstone, gray, sandy; current rippled	1.6
25. Shale, gray, soft	2.5
24. Shale, brown, carbonaceous	2.4
23. Coal (freshwater stage of bay cycle No. 3)	3.9
22. Shale, brown, carbonaceous	1.2
21. Shale, gray, soft	1.3

Measured section 104—Continued

Lance Formation (part)—Continued

	Thickness (feet)
20. Sandstone, gray, very fine grained, silty; current rippled	4.6
19. Shale, gray, fissile, and some interbedded siltstone, gray, upper 1.0 ft	2.9
18. Shale, brown, carbonaceous	0.6
17. Coal (freshwater stage of bay cycle No. 2)	4.3
16. Shale, brown, carbonaceous, silty	3.0
15. Shale, gray, fissile, silty the upper 0.5 ft	3.7
14. Shale, gray, carbonaceous	0.8
13. Coal (freshwater stage of bay cycle No. 1)	3.2
Total Lance Formation measured	317.5

Fox Hills Sandstone:

	Thickness (feet)
12. Sandstone, gray, very fine grained; large-scale, low-angle trough crossbeds; numerous burrows; bioturbated; weathers to massive gray cliff. Surf zone of upper shoreface	43.5
11. Sandstone, gray, very fine grained, calcareous, slightly hematitic; some low-angle trough cross-beds; bioturbated with abundant *Ophiomorpha* the top 3.0 ft; weathers medium brown. Middle shoreface	8.0
10. Sandstone, gray, very fine grained, soft, and two 0.5 ft thick interbedded shale, gray, sandy; weathers tan. Middle shoreface	16.0
9. Shale, gray, and some 0.5 to 1.0 ft thick interbedded sandstone, gray, very fine grained, soft; becomes increasingly sandy near the top. Lower shoreface and nearshore marine	16.0
8. Sandstone, gray, very fine grained; small-scale low-angle trough crossbeds; abundant burrows the top 1.0 ft; weathers tan. Middle shoreface	10.8
7. Sandstone, gray, very fine grained; small-scale, low-angle trough crossbeds; weathers tan in the lower part and dark brown the upper 2.0 ft. Middle shoreface	11.0
6. Shale, gray, and a few 0.5 to 1.0 ft thick inter-bedded sandstone, gray, very fine grained, soft; weathers tan. Lower shoreface and nearshore marine	43.5
5. Sandstone, gray, very fine grained; large-scale, low-angle trough crossbeds; abundant burrows; weathers tan. Middle shoreface	8.6
4. Sandstone, gray, very fine grained, argillaceous; in thin parallel beds separated by laminae of shale, gray, sandy; burrowed near the top; weathers tan. Lower shoreface	12.2
3. Shale, gray, and thin interbedded sandstone, gray, very fine grained, argillaceous. Lower shoreface	18.4
2. Sandstone, gray, very fine grained, calcareous; in thin parallel beds; some wave ripples. Lower shoreface	1.0
Total Fox Hills Sandstone	189.0

Lewis Shale (part):

	Thickness (feet)
1. Shale, gray, soft. Nearshore marine	28.5

☆ U.S. GOVERNMENT PRINTING OFFICE: 1993—774-049 / 66058 REGION NO.8