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

Stratigraphy of the Mesaverde Group in the Central and Eastern Greater Green River Basin, Wyoming, Colorado, and Utah

By HENRY W. ROEHLER

U. S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1508

A description of Upper Cretaceous rocks deposited along the western margins of the interior seaway in the central Rocky Mountains

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON: 1990

DEPARTMENT OF THE INTERIOR

MANUEL LUJAN, JR., *Secretary*

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, *Director*

Any use of trade, product, or firm names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. Government

Library of Congress Cataloging in Publication Data

Roehler, Henry W.
Stratigraphy of the Mesaverde Group in the central and eastern greater Green River Basin, Wyoming, Colorado, and Utah / by Henry W. Roehler.
p. cm.—(U.S. Geological Survey professional paper ; 1508)
Includes bibliographical references.
Supt.of Docs. no.: I 19.16: 1508
1. Geology—Green River Watershed (Wyo.-Utah) 2. Geology, Stratigraphic—Cretaceous. 3. Mesaverde Group.
I. Title. II. Series.
QE79.R63 1990
557'.29'5—dc20 89-600353
CIP

For sale by the Books and Open-File Reports Section, U.S. Geological Survey, Federal Center, Box 25425, Denver, CO 80225

CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

STRATIGRAPHY OF THE MESAVERDE GROUP IN THE CENTRAL AND EASTERN GREATER GREEN RIVER BASIN, WYOMING, COLORADO, AND UTAH

By HENRY W. ROEHLER

ABSTRACT

This paper establishes a stratigraphic framework for the Mesaverde Group, nearly 5,000 ft thick, in the central and eastern greater Green River basin based on data from measured outcrop sections and drill holes. Stratigraphic correlations are supported by ammonite zonation. No new stratigraphic names are introduced, and no nomenclature problems are discussed. Five long measured sections through the Mesaverde Group are described.

The lower part of the Mesaverde Group, comprising the Rock Springs, Blair, Haystack Mountains, Allen Ridge, and Iles Formations, was deposited during a major eastward regression of the interior Cretaceous seaway of North America during the late Santonian and early Campanian. This regression was followed by regional uplift of the central Rocky Mountain area during the middle Campanian. The regional uplift was accompanied by widespread nondeposition and erosion, which, in turn, were followed by deposition of the Ericson and Pine Ridge Sandstones. The upper part of the Mesaverde Group, comprising the Almond and Williams Fork Formations, was deposited during a major westward transgression of the interior seaway in the early Maestrichtian. The major marine transgressions and regressions of the interior seaway were caused by eustatic changes of sea level, whereas intervening periods of nondeposition and erosion resulted from tectonism in the Sevier orogenic belt west of the study area.

Formations of the Mesaverde Group are composed of sediments deposited in a landward-seaward progression of alluvial-plain, flood-plain, coastal-plain, barrier-plain, tidal-flat, delta-plain, marine-shoreline, and marine-shelf and slope depositional environments. Each of these depositional environments is represented by specific lithofacies, sedimentary structures, and fossils, which are characteristic of depositional settings determined by water salinity, water depth, sedimentary and diagenetic processes, and the nature of sediment source terranes.

The Mesaverde Group was deposited mainly along the western margins of the interior Cretaceous seaway as marine shorelines that trended north to northeast across the study area. Arcuate deltas, which formed at the mouths of major rivers along these shorelines, spread eastward onto shallow marine shelves. Embayed shoreline areas between the deltas were the sites of barrier-island and tidal-flat deposition. Alluvial-plain, flood-plain, and coastal-plain environments were present inland. The marine shorelines were tidally influenced and wave dominated, and shoreline deposits were mostly thick, linear sheets of quartzose sandstone. Deposition was largely controlled by the emergence or submergence of shoreline areas. Stillstands occurred close to local transgressions and regressions, depending on rates of sedimentation and subsidence.

Manuscript approved for publication September 5, 1989.

INTRODUCTION

SCOPE OF INVESTIGATION

This paper indentifies and correlates lithostratigraphic and chronostratigraphic units and maps the paleogeography of the Upper Cretaceous Mesaverde Group in the central and eastern greater Green River basin of Wyoming, Colorado, and Utah. The purpose is to develop a stratigraphic framework for a group of formations in a large area where previous investigations were incomplete and partly inaccurate. The stratigraphic information presented contributes to the understanding of the sedimentary and tectonic evolution of the greater Green River basin and to the origin and distribution of mineral resources.

The paper is entirely stratigraphic in approach. Correlations are based on the physical continuity of lithologic units and are supported by ammonite zonation. Maps and cross sections are constructed to scale. The consistent use of stylized columnar sections, hypothetical depositional models, and cartoons for illustrations has been avoided. No new stratigraphic names are introduced, and no nomenclature problems are discussed.

LOCATION AND ACCESSIBILITY

The area investigated is irregular in shape but occupies more than 11,500 mi^2 of the Rock Springs uplift

FIGURE 1.—Map of the central and eastern greater Green River basin study area, Wyoming, Colorado, and Utah, showing the locations of highways and outcrops of the Mesaverde Group (shaded).

and the adjoining Green River, Great Divide, Washakie, and Sand Wash basins (fig. 1). It comprises the central and eastern parts of what is known as the greater Green River basin, in the area mostly north and east of the point of convergence of the boundaries of Wyoming, Colorado, and Utah. The area is accessible by numerous primary and secondary roads. The major highways that cross the area are U.S. Interstate Highway 80 between Rawlins, Wyo., and Granger, Wyo., and U.S. Highway 40, which passes through Hayden, Craig, and Maybell, Colo. Other paved federal, state, and county roads cross the western and southern parts of the study area (fig. 1). From the paved roads numerous gravel and unimproved roads and trails provide access to outcrops of the Mesaverde Group.

GEOLOGIC AND GEOGRAPHIC SETTING

The study area is an intermontane desert basin that is bounded on the north by the Wind River Range and Granite Mountains, on the east by the Rawlins uplift and

Sierra Madre, and on the south by the Uinta Mountains and Axial basin uplift. An arbitrary western boundary is open to the Green River basin.

The landscape in most of the area is characterized by sandstone escarpments and gravel- or lava-capped mesas that rise above dry drainages, alkali flats, and playa lakes. The southeastern part of the area is more vegetated and consists of sage-covered rolling hills. Altitudes generally range between 6,000 and 9,000 ft. The annual precipitation, mostly as winter snow and spring rain, ranges between 7 and 15 in. (inches) (Root and others, 1973). Annual temperatures usually range between -30°F and +100°F. The major drainage is the Green River on which Flaming Gorge Reservoir is located (fig. 1). Vegetation consists mostly of cedar trees at higher altitudes and patches of sage and other desert bushes and grasses at lower altitudes. Little land is cultivated because of the dry climate and very short growing season, but winter wheat is grown locally in the southeastern part of the study area near Craig, Colo. The chief industries are cattle and sheep ranching, oil and gas production, and trona and coal mining.

The mountain and basin structural framework of the study area was established during the Laramide orogeny at the close of the Cretaceous Period. Excluding the Moxa arch, Lost Soldier anticline, and Rawlins platform (discussed later), there is no evidence of intrabasin tectonism during deposition of the Mesaverde Group. The most prominent structural features are shown on a structure contour map drawn on the top of the Ericson and Pine Ridge Sandstones (fig. 2). Structural relief on the Mesaverde Group is about 25,000 ft. It ranges from about 12,000 ft below sea level near the center of the Washakie basin to more than 13,000 ft above sea level on the crest of the Rock Springs uplift. Thrust faults are present along the flanks of mountains at the margins of the study area, and large high-angle normal faults trend southwest across the eastern flank of the Rock Springs uplift. The study area in the greater Green River basin is divided by anticlinal folds into four closed synclinal subbasins. The largest of these folds, the Rock Springs uplift, trends north-south and separates the Green River basin to the west from the Great Divide, Washakie, and Sand Wash basins to the east. The Wamsutter arch and Cherokee Ridge are minor anticlinal folds that separate the Great Divide basin from the Washakie basin and the Washakie basin from the Sand Wash basin.

METHODOLOGY

Approximately 400 surface sections of the Mesaverde Group were measured with a Jacob's staff and Abney level in the western part of the study area between 1973 and 1985. The sections were measured during the mapping of geologic quadrangles and in conjunction with investigations into the origin, distribution, composition, and resources of coal deposits in the Rock Springs coal field. Twelve additional sections were measured in 1985 and 1986 along outcrops of the Mesaverde Group at the eastern margin of the study area, from near Lamont, Wyo., southward to near Hayden, Colo. (fig. 1). In describing the lithologies in these sections, depositional environments, lithofacies, sedimentary structures, and fossils were identified. Thirty-four of the measured sections are incorporated in illustrations. Five long measured sections through the Mesaverde Group are described in the appendix. Segments of these five sections, that make up parts of eight depositional environments, are illustrated in the text by columnar sections (figs. 11, 15, 16, 18, 19, 23, 25, and 34). Eleven paleogeographic maps (pl. 2) show the areal distribution of the depositional environments and stratigraphic units.

Information on the subsurface stratigraphy between outcrops of the Mesaverde Group is mostly based on interpretations of electric logs from 47 oil and gas drill holes (pl. 1). Data from the 47 drill holes and the above-mentioned measured sections were used to construct 10 cross sections. These cross sections were published previously at the vertical scales of 1 inch equals 200 ft (Roehler, 1983, 1985, 1986, 1987, 1989; Roehler and Hansen, 1989a, 1989b) and 1 inch equals 100 ft (Roehler and Phillips, 1980). Reductions of the 10 cross sections at the vertical scale of 1 inch equals 1,000 ft are on plate 1.

This paper synthesizes geological studies undertaken by the author in the Mesaverde Group over 30 years. The author has borrowed from the geologic literature to obtain some stratigraphic data, but the interpretations and conclusions presented are mostly his. Because of the enormous volume of geologic literature available, no attempt has been made to cite every reference for the Mesaverde Group in the study area.

ACKNOWLEDGMENTS

The Western Interior ammonite zones established by Gill and Cobban (1966a) were used to correlate the stratigraphic units that form the framework of the Mesaverde Group. The ammonite zones were especially helpful in constructing regional cross sections from the western margin of the greater Green River basin near Kemmerer, Wyo. (Smith, 1961) eastward through the study area to the Laramie basin near Rock River, Wyo. (Gill and others, 1970), and from the Powder River basin near Gillette, Wyo. (Gill and Cobban, 1966b) southward through the study area to the vicinity of Kremmling, Colo. (Izett and others, 1971).

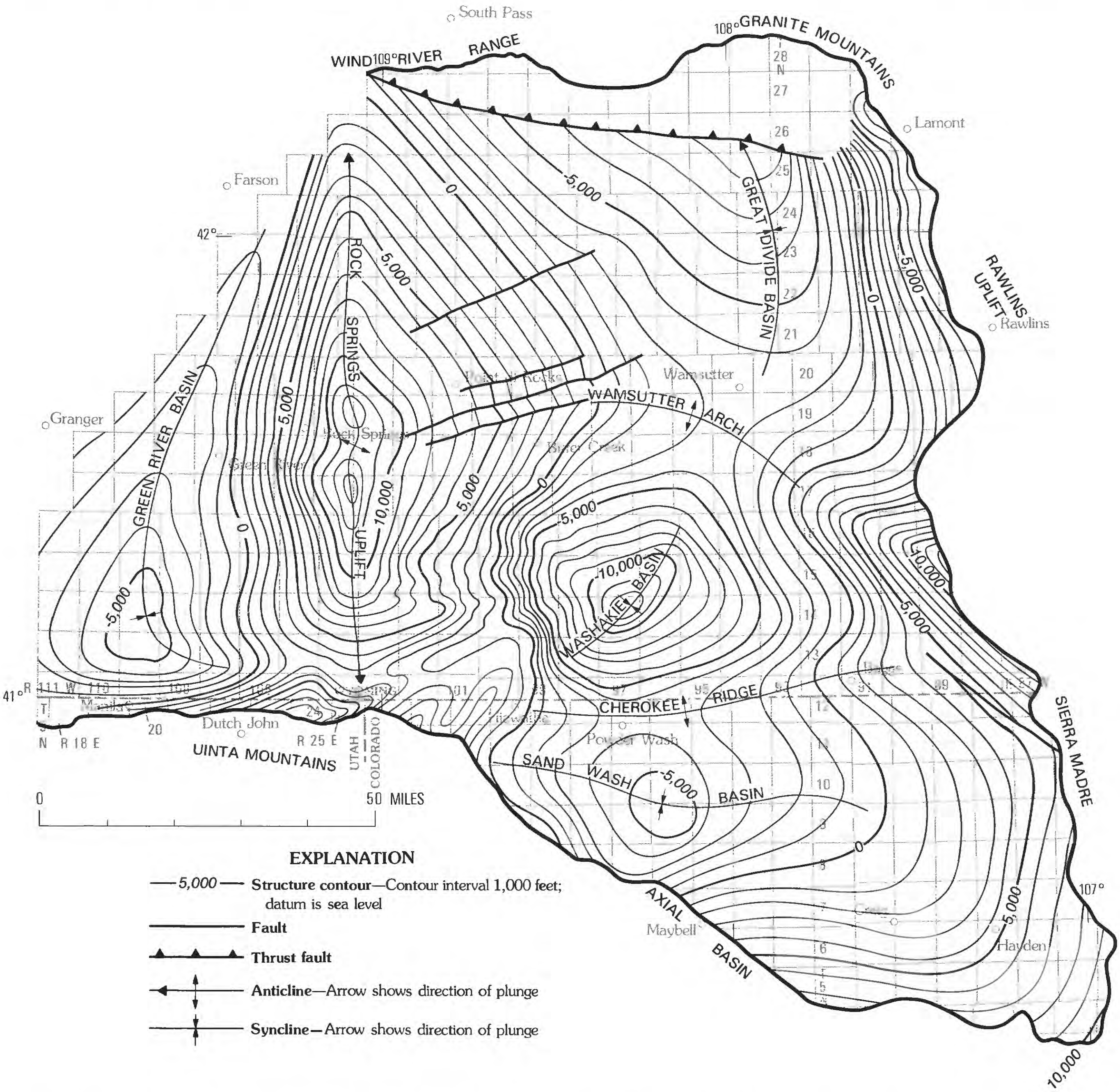


FIGURE 2.—Structure contours drawn on the top of the Ericson and Pine Ridge Sandstones in the central and eastern greater Green River basin, Wyoming, Colorado, and Utah. Contours are approximately located in places where the datum plane is eroded.

The work of Schultz (1909, 1910, 1920), Hancock (1925), Hale (1950, 1961), Konishi (1959), Barlow (1959), Smith (1961, 1965), Gill and others (1970), and Gill (1974) has provided a firm foundation for the stratigraphic framework developed in this paper.

The author was assisted in the field in 1979 by S.T. Phillips and in 1986 by D.E. Hansen. Their contributions to the measured sections that appear in the report are gratefully acknowledged.

STRATIGRAPHY

The Mesaverde Group crops out on the flanks of the Rock Springs uplift, on the northern flank of the Uinta Mountains, on the northern limb of the Axial basin uplift, along the eastern margins of the Great Divide, Washakie, and Sand Wash basins, and in other small, isolated localities (fig. 1). The Mesaverde outcrops commonly weather to prominent barren tan, gray, or

FIGURE 3.—Outcrops of the Mesaverde Group near Minnies Gap in secs. 23 and 24, T. 12 N., R. 107 W. View is toward the east. Glades Ridge (arrow) is capped by the Ericson Sandstone, which is underlain by the Rock Springs Formation. Valley between the ridges is formed by marine shale of the Black Butte Tongue of the Rock Springs Formation.

white sandstone ridges that are separated by deep drab-gray, partly vegetated shale valleys (fig. 3). The weathered outcrops form steeply inclined ravines, ledges, and cliffs. The thickness of the group ranges from less than 2,000 ft to more than 5,000 ft (fig. 4).

The Mesaverde Group is mostly composed of interbedded gray sandstone, gray shale, minor beds of gray siltstone and limestone, and coal. The mineral constituents of the sandstone (in percent) are 46.5–72.0 quartz, 3–10 feldspar, 10.5–28.0 matrix, and 16.5–25.0 rock fragments (Pryor, 1961, p. 38). Most of the sandstone is classified as lithic graywacke. Cementing materials include clay, calcite, and hematite. The sandstone normally contains 3–5 percent heavy-mineral grains. The nonopaque heavy-mineral fraction (in percent) averages 41 zircon, 35 tourmaline, 18 garnet, 3 rutile, and traces of epidote, apatite, and biotite (H.W Roehler, unpub. data). Most coal beds are between 1 and 10 ft thick, but a few are as much as 20 ft thick. The rank is subbituminous to bituminous.

Three relationships are apparent concerning the character and distribution of sedimentary rocks in the Mesaverde Group and its lateral equivalents: (1) clastic rocks become coarser textured from east to west, toward sediment-source areas; (2) carbonaceous rocks are most abundant in paralic environments where the sediments were permanently water saturated; and (3) carbonate rocks were deposited mostly in marine environments.

NOMENCLATURE

The nomenclature of the Mesaverde Group has evolved over the past 80 years to three different sets of names in different geographic areas (fig. 5). These areas are: (1) the central greater Green River basin (measured sections 3 and 17, fig. 5); (2) the northeastern greater Green River basin (measured sections 71 and 57, fig. 5); and (3) the southeastern greater Green River basin (measured section 34, fig. 5). The nomenclature used in each of these areas is discussed below. Measured sections 3, 17, 71, 57, and 34 are described in the appendix.

CENTRAL GREATER GREEN RIVER BASIN

Schultz (1909, 1910) mapped the Rock Springs coal field in the western part of the study area, where he named the Rock Springs and Almond coal groups as members of the Mesaverde Formation. Schultz (1920) named the sandstones and sandy shales underlying the Mesaverde Formation the Blair Formation. The name "Ericson Sandstone" was added by Sears (1926). In the same paper Sears (1926) defined the Blair, Rock Springs, Ericson Sandstone, and Almond as formations of the Mesaverde Group. Hale (1950, p. 52–53) named the Black Butte Tongue of the Rock Springs Formation and the Chimney Rock Tongue of the Blair Formation, and applied the informal term "Rusty zone" to the middle part of the Ericson Sandstone. Smith (1961, 1965) completed the current nomenclature by dividing the upper part of the Rock Springs Formation in the southern Rock Springs uplift into the Brooks, Coulson, McCourt, and Gottsche Tongues, and by naming the Trail and Canyon Creek Members of the Ericson Sandstone.

NORTHEASTERN GREATER GREEN RIVER BASIN

The historical background of the nomenclature of the Mesaverde Group in the northeastern and southeastern parts of the greater Green River basin was discussed at length by Gill and others (1970). In general, the nomenclature consists of Wyoming usage to the northeast and Colorado usage to the southeast. In their report, Gill and others (1970) made several major nomenclature changes in the Wyoming part of the study area. The Mesaverde Formation was elevated to group status and was then divided, in ascending order, into the Haystack Mountains Formation, Allen Ridge Formation, Pine Ridge Sandstone, and Almond Formation. The lower part of Hale's (1961) Mesaverde Formation was divided into the unranked Deep Creek Sandstone and the Hatfield Sandstone Members; the two sandstone units are separated by a 250-ft-thick marine shale and

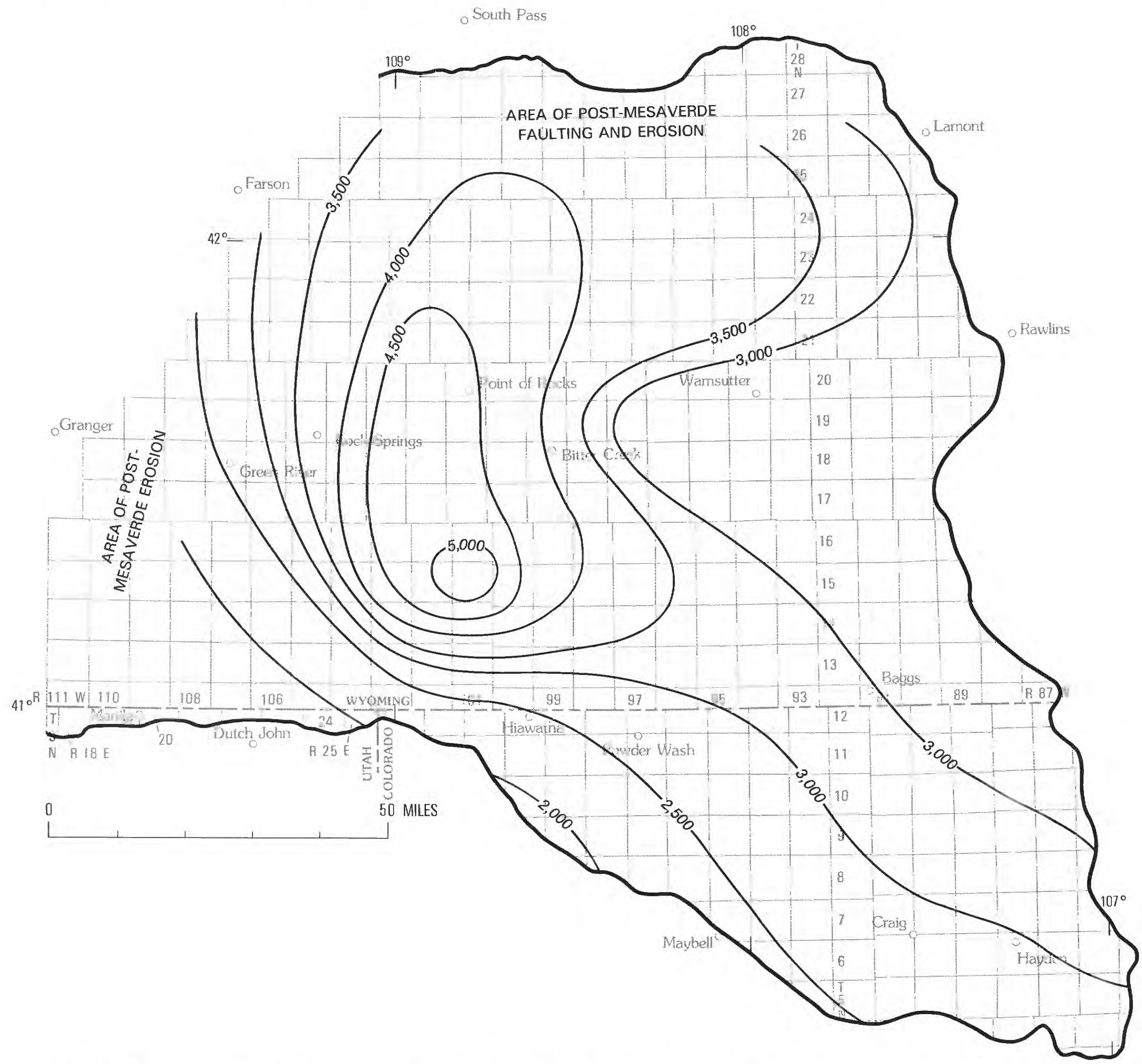
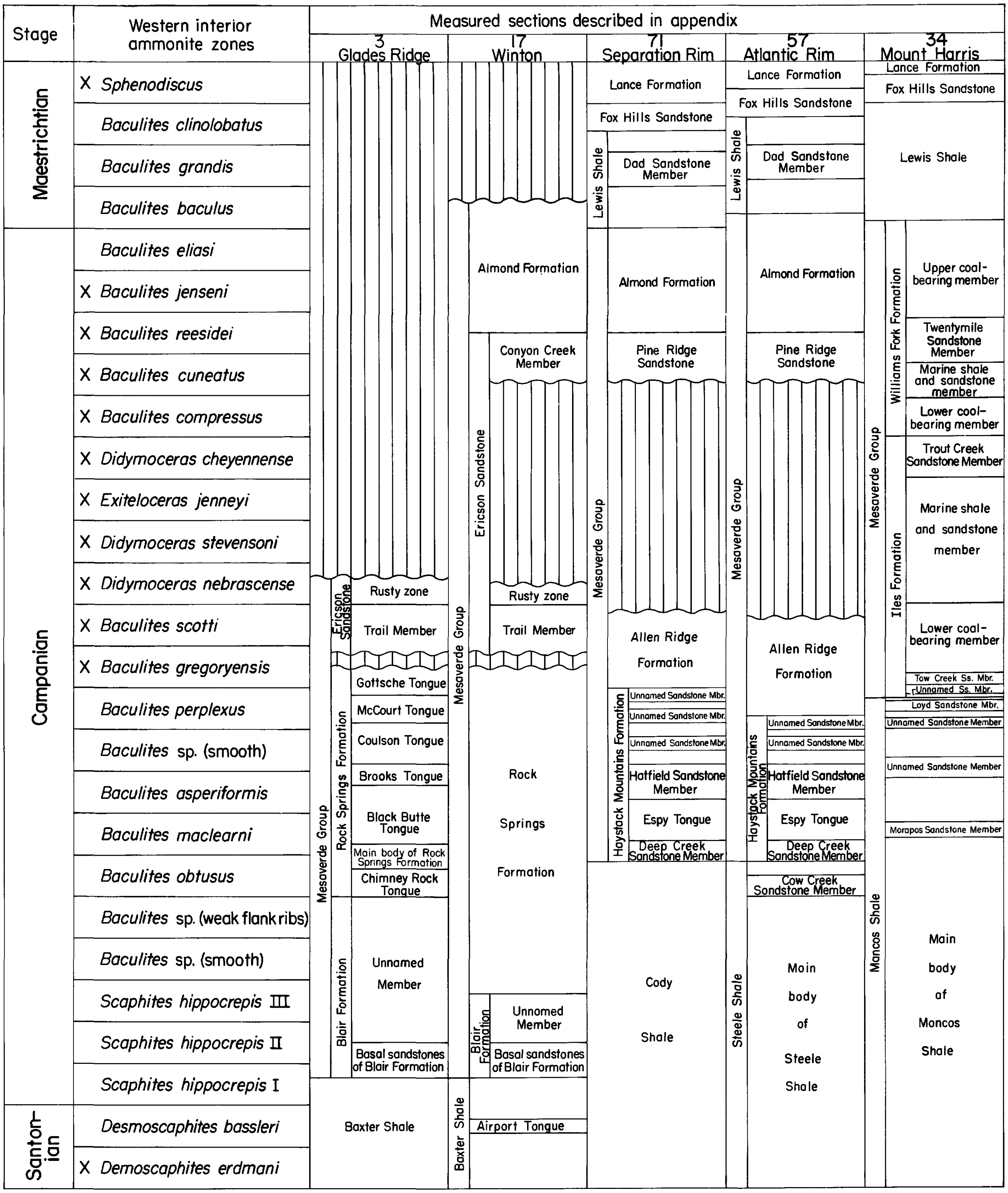


FIGURE 4.—Isopach map of the Mesaverde Group in the central and eastern greater Green River basin. Contour interval 500 ft.

sandstone sequence named the Espy Tongue of the Steele Shale (Hale, 1961, p. 130). A sandstone unit below the Deep Creek was named the Cow Creek Member of the Steel Shale (Hale, 1961, p. 129). The Deep Creek was recognized by Hale (1961, p. 130), in places by Gill and others (1970, p. 20), and by Gill (1974, sheet 2) as the basal unit of the Mesaverde. The uppermost persistent sandstone in the lower part of the Mesaverde Formation was named the Hatfield Sandstone Member (Hale, 1961, p. 130). Gill and others (1970, p. 19–20) included Hale's (1961) Deep Creek Sandstone, Espy Tongue, and Hatfield Sandstone Member, as well as an upper unnamed member, in their Haystack Mountains Formation on the western side of Hatfield dome in Carbon County, Wyo. The author also recognizes the Espy as a member of the Haystack Mountains Formation (fig. 5) rather than a tongue of the Steele Shale.

SOUTHEASTERN GREATER GREEN RIVER BASIN

The Upper Cretaceous stratigraphy at the Yampa coal field near Craig, Colo., was investigated by Fenneman



X Not identified in the study area, but zone is regionally correlatable.

FIGURE 5.—Nomenclature and age of stratigraphic units in the Mesaverde Group and adjacent formations in the central and eastern greater Green River basin. Western Interior ammonite zonation from Gill and Cobban (1966a).

and Gale in 1906, who introduced the name "Mesaverde Formation" into northwestern Colorado. During these investigations, they named the Trout Creek and Twentymile Sandstone Members (Fenneman and Gale, 1906). The Mesaverde Formation was later studied in the Axial basin along the southeastern boundary of the study area by Hancock (1925), who elevated the formation to group status and then divided the group into the Iles and Williams Fork Formations. In the Craig-Hayden area of northwestern Colorado, most of the persistent sandstone tongues in the 800–1,000-ft intertongued interval between the Mancos Shale and Mesaverde Group are included in the Mancos Shale (fig. 5). The Tow Creek Sandstone Member of the Iles Formation was named by Willson (1920). An underlying bed was named the Loyd Sandstone Member of the Mancos Shale by Konishi (1959). The lowest sandstone in the interval was named the Morapos Sandstone Member of the Mancos Shale by Hancock (1925). Other partly lenticular sandstone beds within the intertongued interval remain unnamed.

The contact of the Mancos Shale and Iles Formation was incorrectly placed at the base of the Morapos Sandstone Member of the Mancos Shale by Roehler (1987). The location of the contact was subsequently changed by Roehler and Hansen (1989b) to conform with the base of the Iles Formation as defined by Willson (1920).

REGIONAL STRATIGRAPHIC RELATIONSHIPS

Upper Cretaceous rocks in the study area were mostly deposited across a foreland between the Sevier orogenic belt to the west and the interior Cretaceous seaway of North America to the east (fig. 6). The Mesaverde Group, or its stratigraphic equivalents, is thickest, nearly 7,000 ft, along the Wyoming-Utah State line west of the study area near sediment-source areas. The group thins progressively eastward and wedges out east of the study area in southeast Wyoming.

Rocks described in this report were deposited during two major marine transgressions and regressions that occurred along the western margins of the interior seaway (fig. 7). An early transgression-regression, which includes basal segments of the Mesaverde Group, is separated by a widespread regional unconformity from a later transgression-regression, which includes upper segments of the Mesaverde Group. The early transgression-regression, which lasted about 6 million years, is apparent from the thick deposits of marine Hilliard, Baxter, and Steele Shale, and the later transgression-regression, which lasted about 3 million years, is recorded by the Lewis Shale. The intervening regional unconformity underlies the base of the Pine Ridge Sandstone (equivalent to the Teapot Sandstone Member of the Mesaverde in the Wind River and Powder River basins) and the Canyon Creek Member of the Ericson Sandstone. Although the transgressions-regressions were responses to eustatic sea-level changes in the interior seaway, as discussed by Kauffman (1977), they do not correspond to his Greenhorn, Niobrara, Clagget, and Bearpaw cyclothems.

The early marine transgression-regression began in the Turonian during the deposition of the Frontier Formation (fig. 7). It is synchronous to global sea-level changes that were discussed by Flexer and others (1986). The transgression continued into the Santonian, when the seaway reached its maximum westward extent. The lower part of the Adaville Formation near Kemmerer, Wyo., was deposited in the late Santonian during the early stages of the following regression. As the regression continued eastward across southern Wyoming during the early Campanian, the basal part of the Mesaverde Group, including the Blair and Rock Springs Formations, was deposited near Rock Springs, Wyo. The regression ended near Rock River, Wyo., with the deposition of distal parts of the Allen Ridge Formation. East of Rock River, the Allen Ridge Formation wedges out into the marine Steel Shale(fig. 7).

A tectonic disturbance in the Sevier orogenic belt near the close of the Campanian was accompanied by regional uplift of the foreland across what is now Wyoming and parts of adjacent States (Gill and Cobban, 1966b). The uplifted area was eroded to a peneplain on which the Pine Ridge Sandstone (and equivalent Teapot Sandstone Member) and the Canyon Creek Member of the Ericson Sandstone were deposited (fig. 8). The peneplain in the study area was named the Moxa erosion surface by Roehler (1965). Parallel, northwest-trending pre-Laramide anticlines were truncated by the Moxa erosion surface at the Lost Soldier oil field near Lamont, Wyo. (Zapp and Cobban, 1962), and across the Moxa arch west of Rock Springs, Wyo. (Roehler, 1965). Analysis of the structural patterns and geographical relationships of these folds suggests that the responsible compressional forces emanated from the Sevier orogenic belt near the border of Idaho and Utah. The same compressional forces may be responsible for early fault movements in the thrust belt near the convergence of Wyoming, Utah, and Idaho.

Erosion on the Moxa surface lasted several million years and removed thick intervals of the Mesaverde Group. Strata nearly 1,700 ft thick composing the upper part of the Allen Ridge Formation are missing beneath the Pine Ridge Sandstone at Lamont, Wyo. (fig. 9). The eroded section there is laterally equivalent to the middle and lower parts of the Williams Fork Formation and the Iles Formation down to the level of the Tow Creek Sandstone Member to the south near Hayden, Colo. (fig.

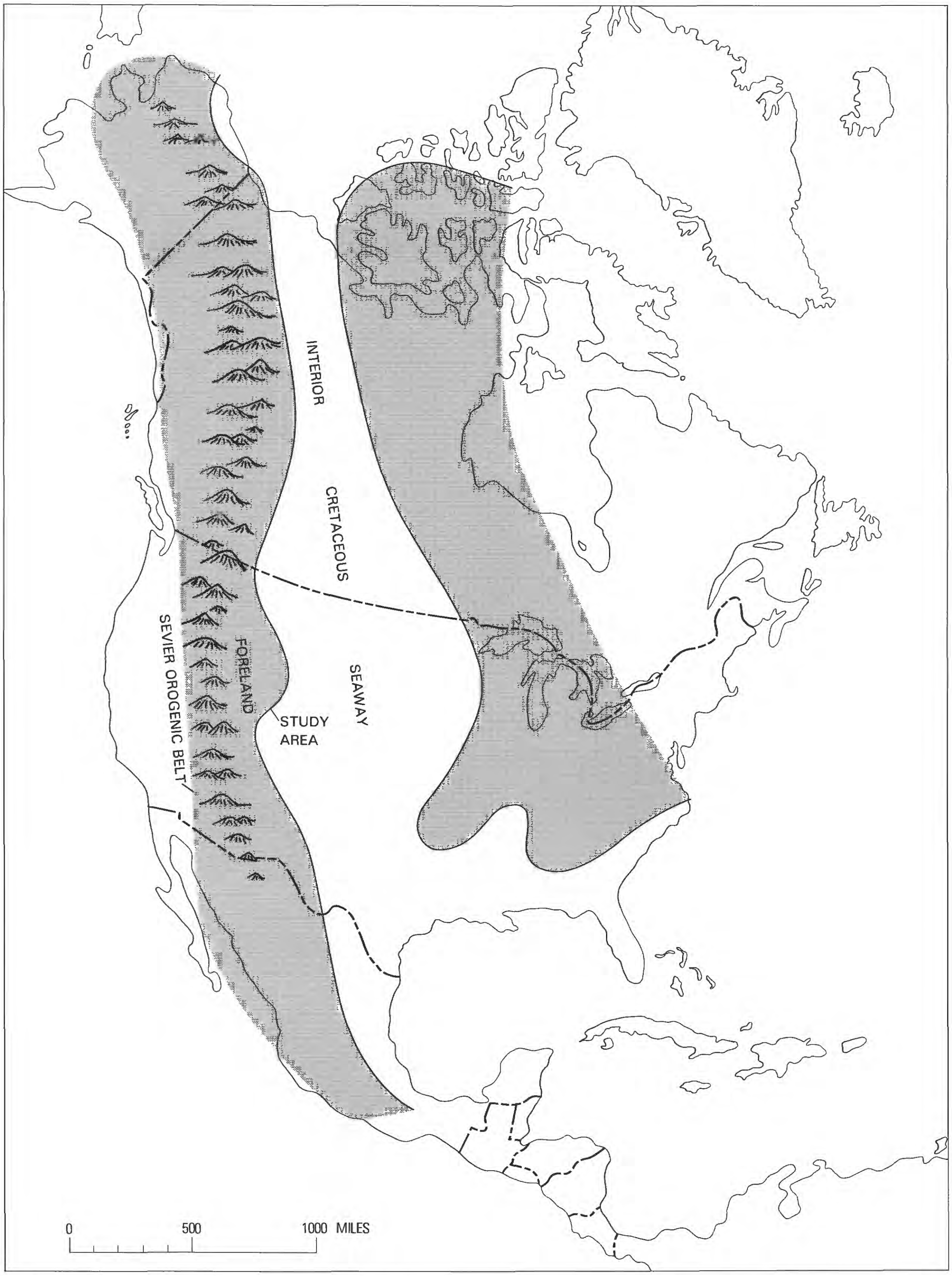


FIGURE 6.—Paleogeographic map of North America during the Campanian showing the location of the study area along the western margins of the interior Cretaceous seaway. Land areas are shaded. Modified from Gill and Cobban, (1966a).

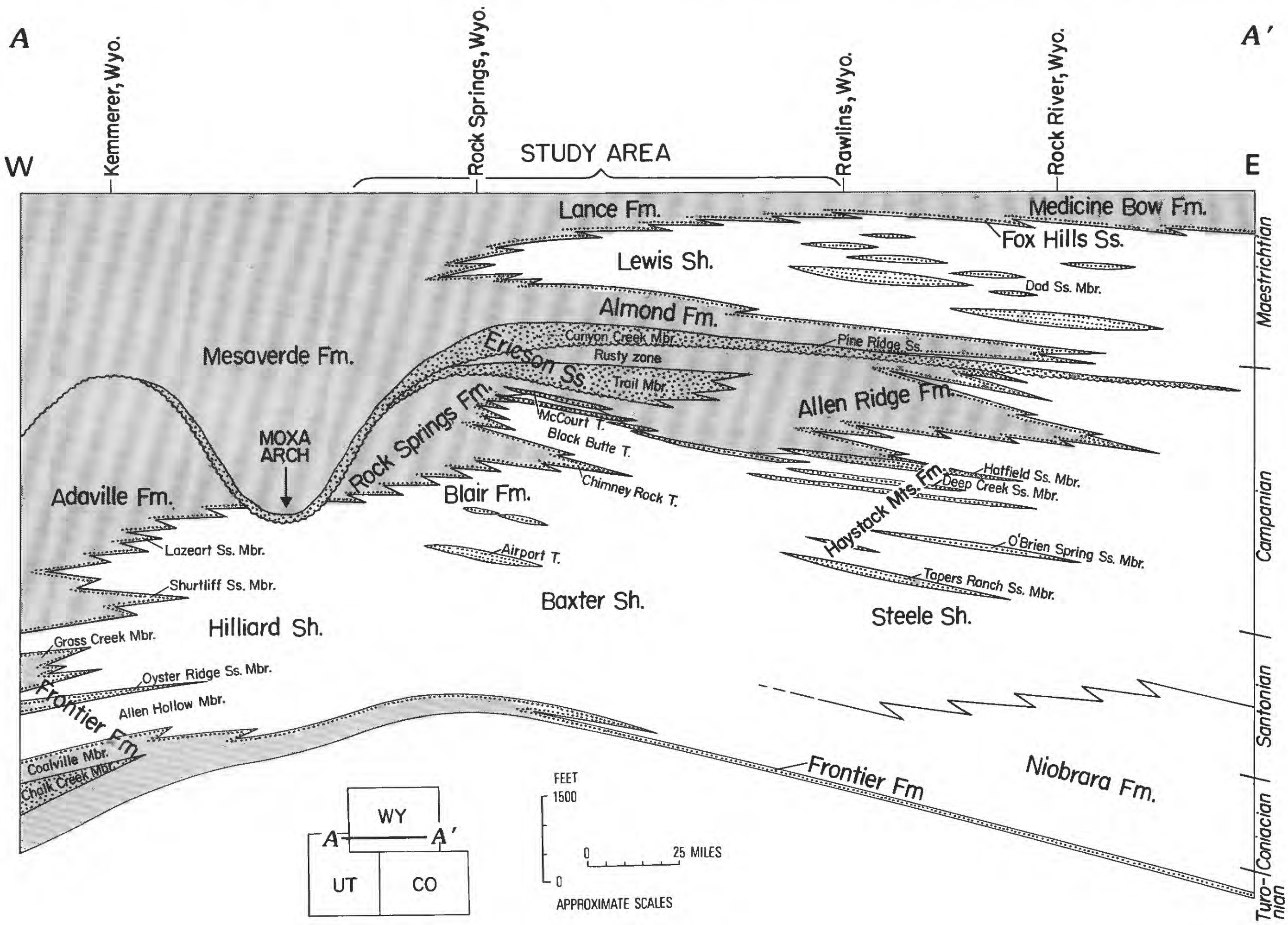


FIGURE 7.—Cross section showing restored Upper Cretaceous rocks across northern Utah and southern Wyoming. Rocks of continental origin are shaded; alluvial-plain and marine-shoreline, shelf, slope, and basin sandstone and siltstone units are shown by dot pattern; marine shale and limestone are unpatterned.

9). The missing section at Lamont, Wyo., includes the zone of *Baculites gregoryensis* at the base and upward through the zone of *Baculites compressus*, a period of about 3 million years (Gill and Cobban, 1966b). Strata nearly 2,500 ft thick making up the Trail Member and Rusty zone of the Ericson Sandstone and all of the Rock Springs Formation, representing a longer erosion period of nearly 7 million years, are missing below the Canyon Creek Member of the Ericson Sandstone across the Moxa arch in southwest Wyoming (fig. 7).

The later marine transgression-regression began in the early Maestrichtian during deposition of the upper part of the Mesaverde Group that includes the Almond and Williams Fork Formations. The transgression progressed westward across southern Wyoming to a short distance west of the city of Rock Springs (fig. 7). The Almond Formation wedges out in the northeastern part of the study area near Lamont, Wyo., where it is replaced to the north mostly by Lewis Shale (fig. 9). The Lewis Shale, which is more than 2,500 ft thick near Hayden, Colo., thins northward to less than 1,000 ft near Lamont, Wyo. The Fox Hills Sandstone, Lance, and Medicine Bow Formations were deposited during the regression that followed. This regression marks the final withdrawal of the interior Cretaceous sea from the study area and from the central Rocky Mountain region.

Late Cretaceous sea-level elevations in the study area are believed to have been remarkably stable, except for the two major marine transgressions and regressions discussed above. The shorelines prograded, but local transgressions, regressions, and stillstands occurred simultaneously and close together (Asquith, 1974, p. 2279). The primary controlling factors were local tectonism and fluctuating rates of sedimentation and subsidence, rather than eustatic changes in sea level. Most 2nd- and 3rd-order transgressions-regressions that

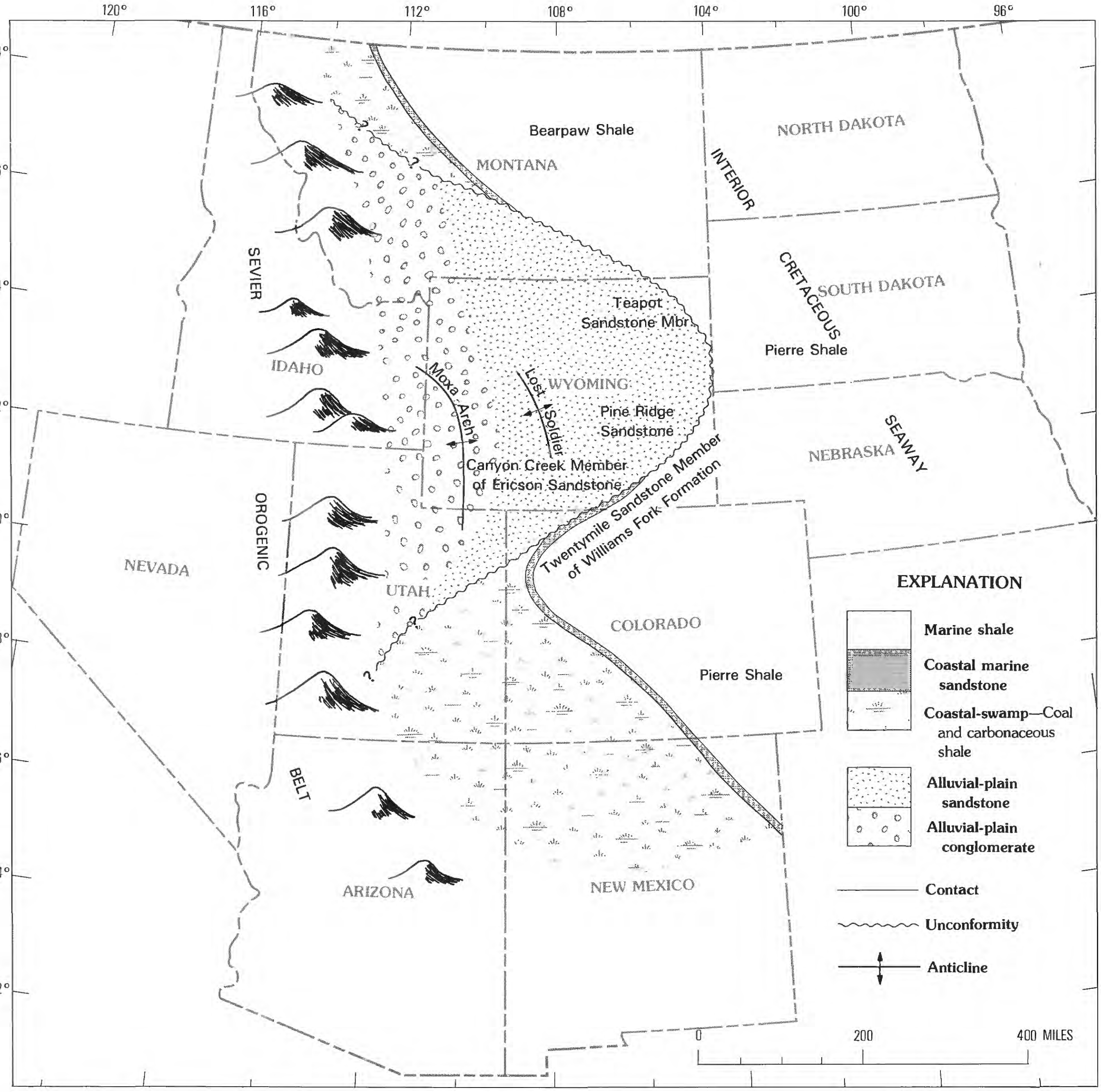


FIGURE 8.—Paleogeographic map of the Rocky Mountain region during deposition of the Canyon Creek Member of the Ericson Sandstone, the Pine Ridge Sandstone, and the Teapot Sandstone Member of the Mesaverde Formation. Zone of *Baculites reesidei*.

are discussed in the literature and attributed to eustatic sea-level changes are local or semiregional changes produced by emerging or submerging coastlines.

DEPOSITIONAL ENVIRONMENTS AND PROCESSES

Average annual temperatures during the Late Cretaceous Epoch in the Western Interior United States probably ranged between 50°F and 85°F (Kauffman, 1977, p. 85). The climate was warm temperate to subtropical with heavy rainfall distributed throughout the year and without frost (Tidwell, 1975, p. 42). The landscape was dominated by palm, cycad, conifer, fern, and a variety of other smaller flora. Altitudes probably never exceeded 1,000 ft across local tectonically active areas, and coastal areas near sea level were extensive.

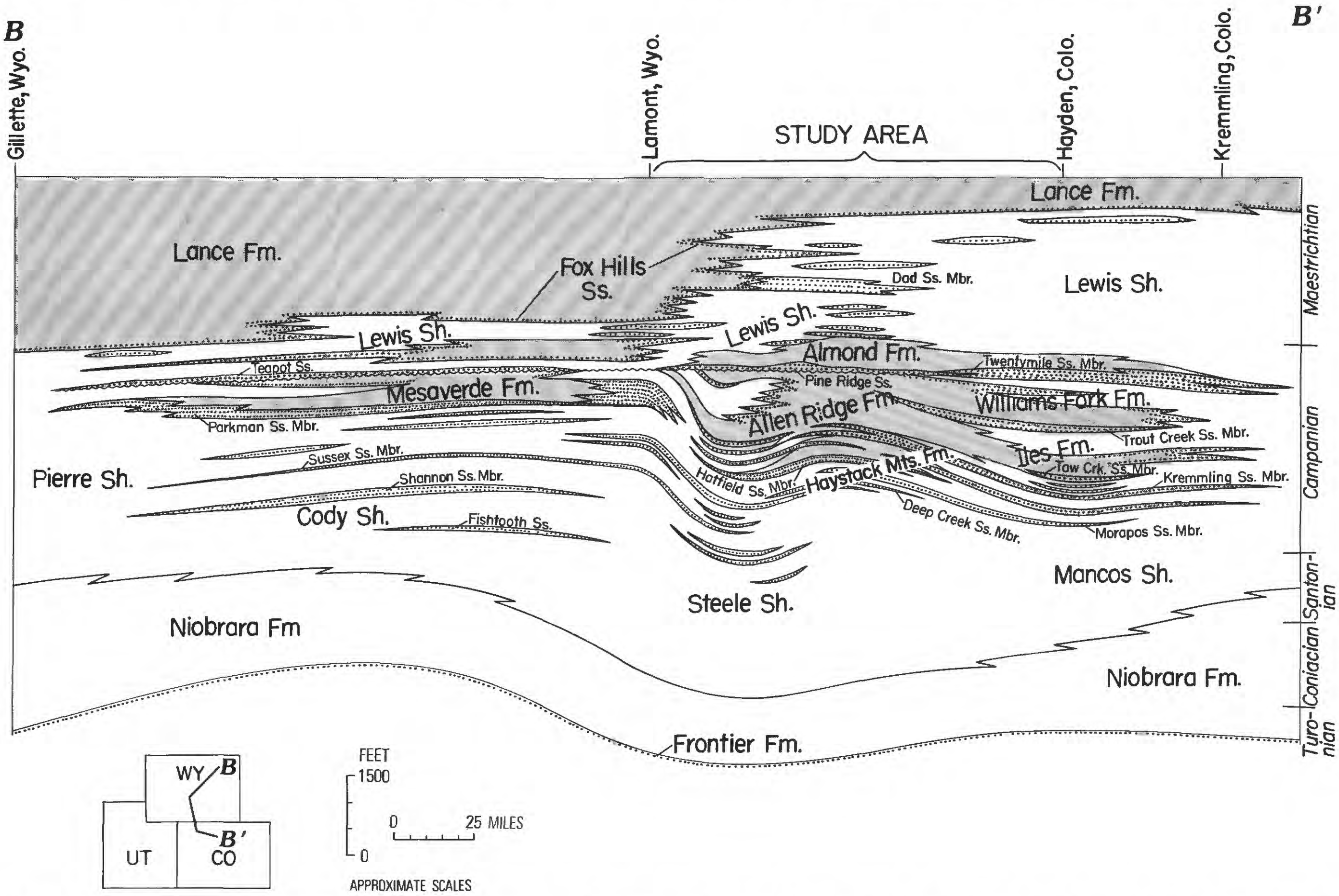


FIGURE 9.—Cross section showing restored Upper Cretaceous rocks across central Wyoming and northwestern Colorado. Rocks of continental origin are shaded; alluvial-plain and marine-shoreline, shelf, slope, and basin sandstone and siltstone units are shown by dot pattern; marine shale and limestone are unpatterned.

Rates of coastal subsidence along the western margins of the interior seaway can be estimated using rock thicknesses, if compaction and other factors are ignored. Near Hayden, Colo., the Mesaverde Group consists of mixed terrestial, shoreline, and marine rocks with no major hiatuses. The thickness of the rocks between the stratigraphic level of *Baculites perplexus* near Hayden (measured section 84, cross section *J–J′*, pl. 1) and the correlated level of *Baculites eliasi* northwest of Rawlins, Wyo. (measured section 72, cross section *I–I′*, pl. 1), is roughly 2,900 ft. The time required for the deposition of these rocks was about 7 million years, according to Kauffman (1977, p. 83). Thus the rate of subsidence averaged about 0.5 inch every 100 years. Finer textured marine rocks in the Steele Shale between the levels of *Baculites* sp. (smooth) and *Baculites asperiformis* northwest of Rawlins, Wyo. (measured section 72, cross section *I–I′*, pl. 1), subsided at a higher rate of about 1.5 inches every 100 years.

Water-circulation patterns in the interior Cretaceous seaway were discussed by Kauffman (1977, p. 92–93), who studied the distribution and mixing of marine faunas in the southern and northern parts of the seaway. He concluded that warm water from a "proto-Gulf Stream" entered the seaway from the south and flowed northward as a near-surface layer. A south-moving, deep-layer counterpart was postulated for the cool water entering the northern opening of the seaway. This circulation pattern would result in vertical counterclockwise water movement (viewed eastward) through the seaway. The author has accumulated evidence that more than 90 percent of the longshore currents were north to south along the coastlines and shelves at the western margin of the seaway in the study area. This evidence is based on hundreds of points of sediment-transport-direction data that have been collected in the field over a period of many years. Although these data alone are not conclusive, they suggest a counterclockwise component of water movement in a horizontal plane through the central part of the seaway. The extreme length of the seaway and its orientation across the northern hemisphere, however, would allow the existence of many circulation patterns that were induced locally by changing meteorological, tidal, and density-current conditions.

The width and angles of seaward slope of the marine shelves along the western margins of the interior seaway are functions of many sedimentologic and tectonic variables. Analyses of lithofacies and estimates of distances from shore vs. water depth in the study area suggest that the slopes ranged between 0.05° and 0.2° and that most were between 10 and 75 mi wide.

Depositional environments are defined as the paleogeographic locales where the physical, chemical, and biological conditions produced favorable habitats for specific plants and animals and where distinct types of sediments were deposited. Depositional environments are important to the stratigraphic framework investigations because they make up the principal lithologic associations (the mappable subdivisions) of the Mesaverde Group. Eight depositional environments were identified and are described in this report: alluvial plain, flood plain, coastal plain, barrier plain, delta plain, tidal flat, marine shoreline, and marine shelf and slope. Strand plains are also present but are included in the barrier-plain depositional environment. The normal landward-seaward progression and intertonguing relationships of the depositional environments are illustrated by a block diagram (fig. 10) and by cross sections (pl. 1). Note that in the cross sections the normal succession of depositional environments shown on figure 10 commonly has an environment missing. For example, the flood-plain environment of the Rusty zone of the Ericson Sandstone shown on cross section *D–D′* (pl. 1) grades laterally seaward into a delta-plain environment with no intervening coastal-plain environment. Similarly, the alluvial-plain environment of the Canyon Creek Member of the Ericson and equivalent Pine Ridge Sandstone shown on several cross sections on plate 1 changes vertically in most places to a coastal-plain environment with no intervening flood-plain environment. The absence of a depositional environment in the succession can generally be attributed to local patterns of sedimentation and(or) erosion.

ALLUVIAL PLAIN

The Trail and Canyon Creek Members of the Ericson Sandstone and the Pine Ridge Sandstone were deposited on alluvial plains (fig. 10). These sandstones are identified in outcrops by their color, texture, and sedimentary structures. The outcrops are massive and weather white or light gray, and commonly show streaks of rust caused by iron staining. Most adjacent Mesaverde Group outcrops weather tan or dark gray. The Canyon Creek Member of the Ericson Sandstone consists of conglomerate less than 50 ft thick composed of rounded pebbles of mostly black chert across parts of the Moxa arch at the western edge of the study area (fig. 7). The conglomerate grades laterally eastward into thick beds of coarse-grained salt-and-pepper sandstone containing thin lenses of black chert pebbles along the western flank of the Rock Springs uplift (fig. 11). Farther east, where the Canyon Creek Member of the Ericson Sandstone changes imperceptibly into the Pine Ridge Sandstone, the conglomerate lenses pinch out, and the sandstones become medium to fine grained and are partly orthoquartzites. The Trail Member of the Ericson Sandstone and the Pine Ridge Sandstone are composed mostly of white quartz, black chert, and dark-colored rock fragments. Some pink and red quartz grains are also present.

The Ericson and Pine Ridge Sandstones were deposited by freshwater streams in a network of channels. Individual beds fine upward and show basal scouring. Planar and trough crossbeds predominate (fig. 12). Shale drape and clay-pebble lag deposits are common locally (fig. 13). The streams appear to have been sluggish and meandering (fig. 14), suggesting that they were sediment choked and braided.

Fossils are extremely rare in the alluvial-plain environment, but dinosaur-bone fragments and leaf impressions were found in the Trail Member in the southern part of the Rock Springs uplift.

FLOOD PLAIN

More than 900 ft of the upper part of the Allen Ridge Formation in the east-central part of the study area and the Rusty zone of the Ericson Sandstone in the western part of the study area are of flood-plain origin (fig. 10). The sediments deposited across the flood plains formed alternating beds of sandstone and shale, associated with rare thin beds of carbonaceous shale (fig. 15). The sandstone beds were deposited either in flood-plain splays or in distributary stream channels. The splay sandstone is tan or light gray, very fine to fine grained, in laterally persistent, parallel or current-rippled laminae and beds less than 5 ft thick. The channel sandstone weathers white, is fine to medium grained, and is trough crossbedded; it contains scattered clay-pebble inclusions in lenticular beds that range from a few feet to 35 ft in thickness. The shale beds are medium gray to medium gray green, or rarely dark gray and carbonaceous. The flood-plain environment differs from most of the other

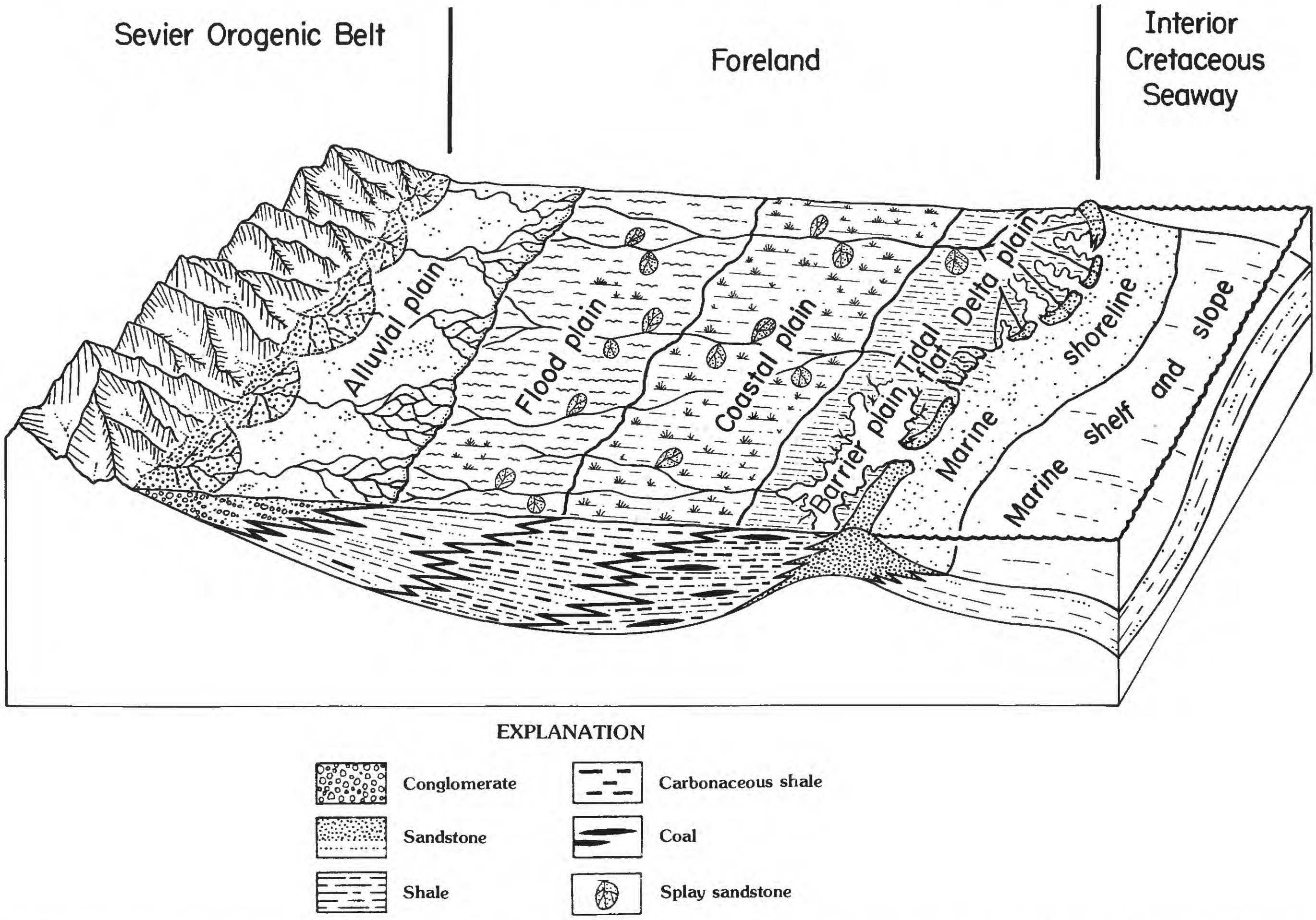


FIGURE 10.—Depositional environments in the Mesaverde Group in the central and eastern greater Green River basin, Wyoming, Colorado, and Utah.

coastal environments by virtue of its freshwater origin and by the general lack of carbonaceous beds.

The composition, thickness, and vertical spacing of beds in the flood-plain environment indicate that deposition occurred across extensive areas of low to moderate topographic relief between alluvial plains to the west and coastal plains to the east (fig. 10). The configurations of the distributary stream courses across the flood plains were mostly straight to slightly sinuous. The stream channels were separated by broad flood basins. Occasional stream flooding produced splays that emanated from breaches (crevasses) in channel banks and fanned outward into the adjacent flood basins. The laminar flow of water across the surface of the splays caused upward coarsening and slow basinward accretion of sediments. Muds were deposited in low topographic areas of the interdistributary flood basins, and ephemeral marshes developed near poorly drained basin centers (fig. 10).

Rocks deposited in the flood-plain environment contain few fossils. Some worm or crustacean burrows, fragments of fossil wood, and leaf impressions are present in splay sandstone. Dinosaur-bone fragments are abundant locally, where they weather from stream-channel sandstone (see bed 136, measured section 57, in appendix).

COASTAL PLAIN

The Gottsche Tongue of the Rock Springs Formation and the lower part of the Almond Formation were deposited in freshwater marshes and swamps that developed on coastal plains seaward of flood plains (fig. 10). Sediments deposited in the coastal-plain environment formed mostly gray carbonaceous shale and thin interbedded gray shale and sandstone, with rare very thin beds of coal (figs. 16–17). The coastal-plain environment differs from paralic depositional

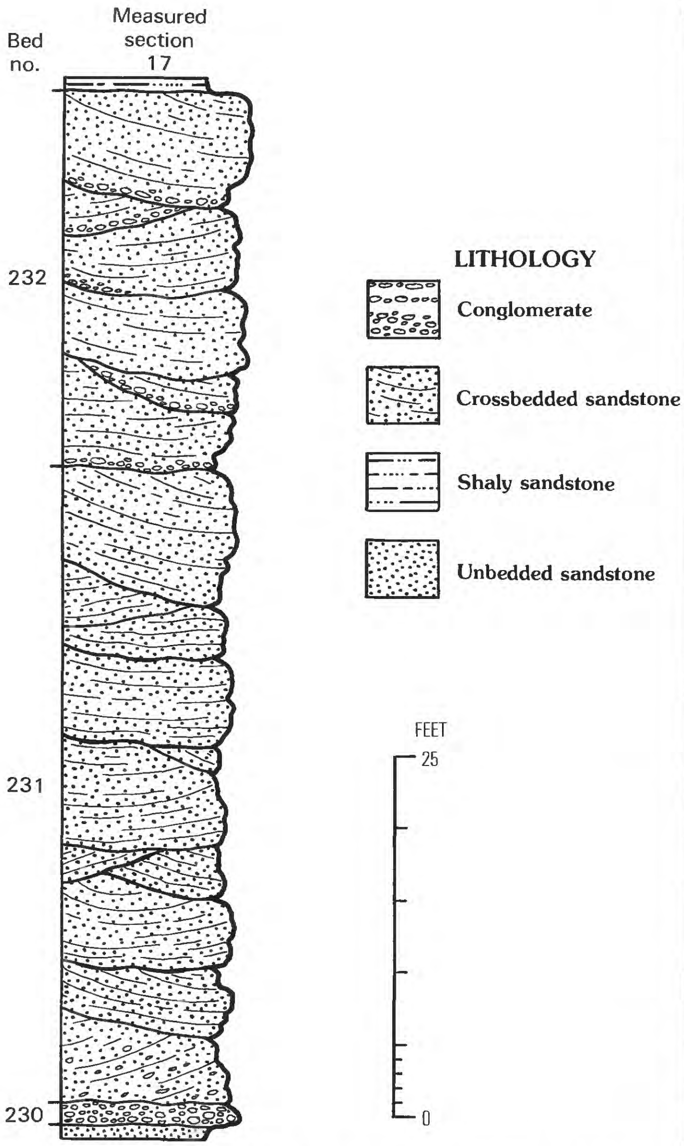


FIGURE 11.—Lithofacies of the alluvial-plain depositional environment in the Canyon Creek Member of the Ericson Sandstone on the western flank of the Rock Springs uplift in SW¼NW¼NW¼ sec. 7, T. 20 N., R. 104 W. Bed lithologies are described under "Section 17" in the appendix.

environments by the absence of lagoon and bay shales, brackish-water fossils, and extensive beds of thick coal.

The lithologies suggest that deposition took place across poorly drained areas where soils were permanently saturated with fresh water. Reedlike vegetation probably dominated a featureless landscape, which was locally interrupted by tree swamps, mud-bottomed ponds, small distributary channels, and numerous splays.

Fossils are rare, but carbonaceous shales contain abundant plant fragments.

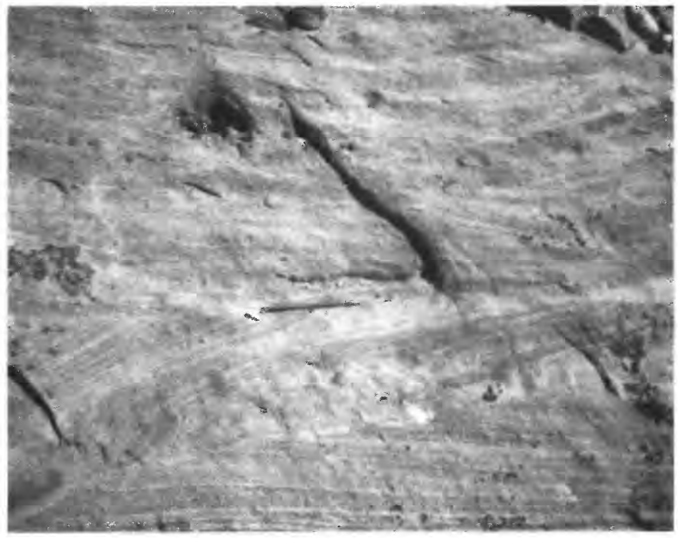


FIGURE 12.—Planar and trough crossbeds in an outcrop of alluvial-plain sandstone in the Trail Member of the Ericson Sandstone on Glades Ridge in SW¼SE¼ sec. 19, T. 12 N., R. 108 W., southwestern Wyoming. Scale is indicated by a pencil near the center of the photograph.

FIGURE 13.—Shale lens and clay-pebble lag in alluvial-plain sandstone of the Canyon Creek Member of the Ericson Sandstone. The exposure is along a pipeline cut in N½ sec. 20, T. 16 N., R. 102 W., on the southeastern flank of the Rock Springs uplift, Wyoming.

BARRIER PLAIN

Sediments making up the upper parts of the Almond and Williams Fork Formations were mostly deposited on barrier plains in tidally influenced areas landward of barrier islands (fig. 10).

The barrier-plain landscape consisted of brackish-water salt marshes and freshwater swamps that were

FIGURE 14.—Accretion beds (arrow) near the base of the Trail Member of the Ericson Sandstone in NW¼NW¼NW¼ sec. 23, T. 17 N., R. 105 W., Wyoming. The beds make up a point bar (about 30 ft thick) on a meander loop of a fluvial channel in an alluvial-plain depositional environment.

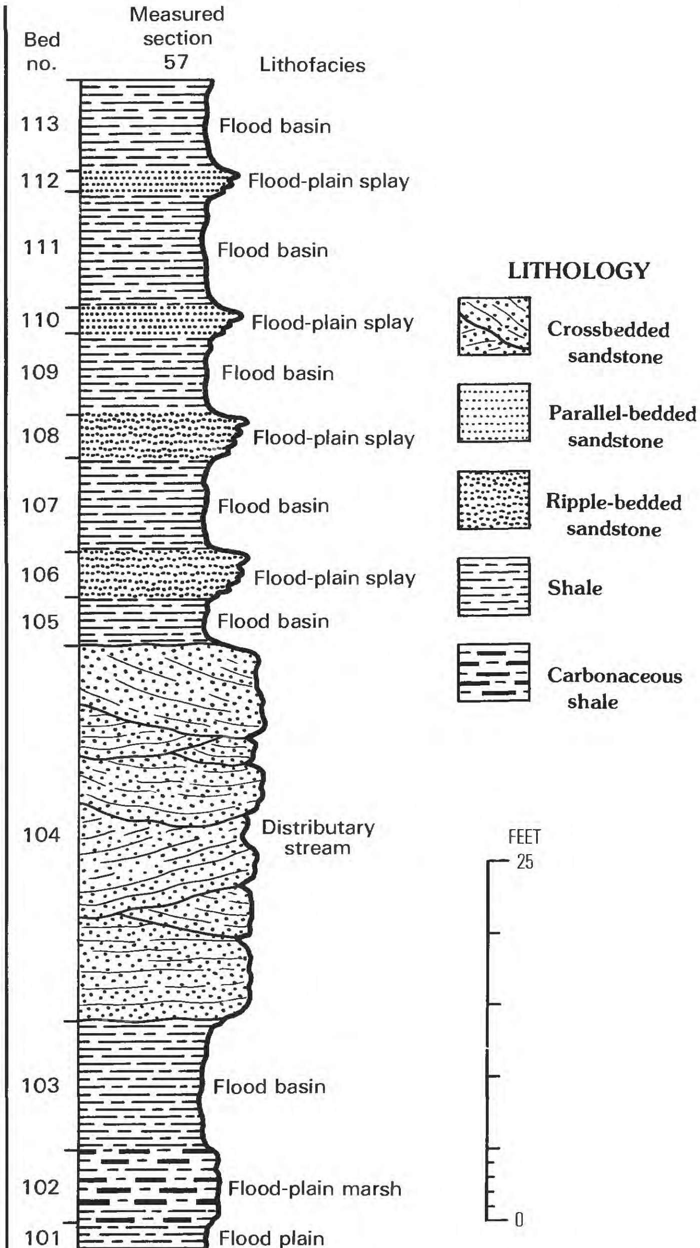


FIGURE 15.—Lithofacies of the flood-plain depositional environment in the Allen Ridge Formation at Atlantic Rim in NE¼NW¼NE¼ sec. 7, T. 19 N., R. 88 W. Bed lithologies are described under "Section 57" in the appendix.

interspersed with open brackish-water mud-bottomed bays and small tidal channels. Splays spread into the adjacent salt marshes and swamps and into nearby bays from widely spaced distributary streams (fig. 10).

Few species of trees are saltwater tolerant, but Cretaceous coals in the barrier-plain environment are composed of more than 50 percent vitrinite (woody material) derived mostly from trees (Roehler, 1988, p. 48). A logical conclusion follows that coal in the environment was deposited as peats in freshwater tree swamps, under reducing conditions where biodegradation did not occur. Marshes on the other hand were the habitat of reedlike herbaceous plants that thrived in both fresh water and salt water. The marshes produced organic debris that accumulated in partly oxidized bottom muds to form carbonaceous shale. Brackish-water fossils, such as oysters, found in bay-fill shales that are interbedded with the carbonaceous shales, are evidence that many of the marshes in the environment were indeed salt marshes.

The sediments deposited in the barrier-plain environment contain abundant mollusks and coquinas (bed 291, fig. 18). Plant megafossils are abundant in carbonaceous shale, and trace fossils, including worm trails, crustacean burrows, and reptile tracks (bed 267, measured section 17, in appendix) are present in some sandstone.

DELTA PLAIN

The Rock Springs, Iles, and Williams Fork Formations and parts of the Allen Ridge Formation were mostly deposited on delta plains (fig. 10). Sediments deposited in the environment formed interbedded carbonaceous shale, shale, sandstone, and coal (fig. 19).

The deltas of the Mesaverde Group were mostly arcuate (narrow and elongated parallel to shorelines) and wave dominated. They were protected along their seaward margins by thick aprons of shoreline sand through which tidal inlets entered open-water interdis-

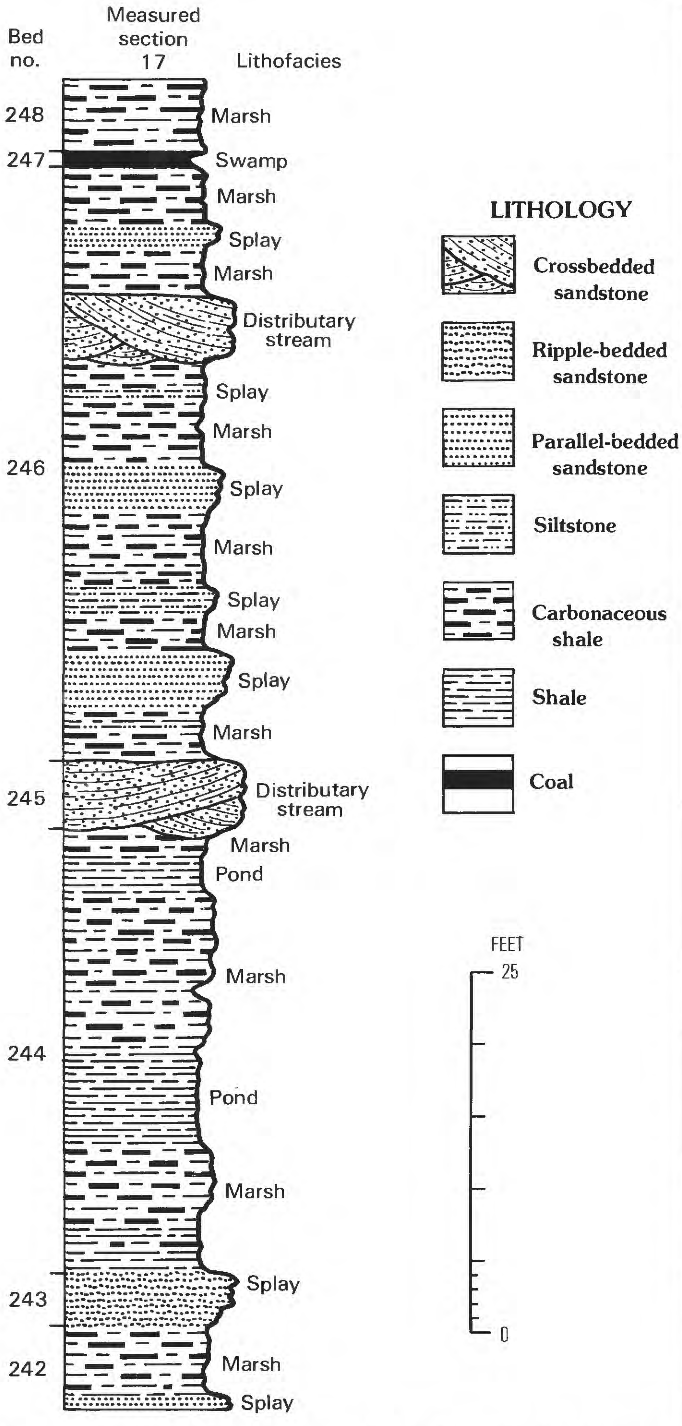


FIGURE 16.—Lithofacies of the coastal-plain depositional environment in the lower part of the Almond Formation on the western flank of the Rock Springs uplift in SE¼NE¼NE¼ sec. 12, T. 20 N., R. 105 W. Bed lithologies are described under "Section 17" in the appendix.

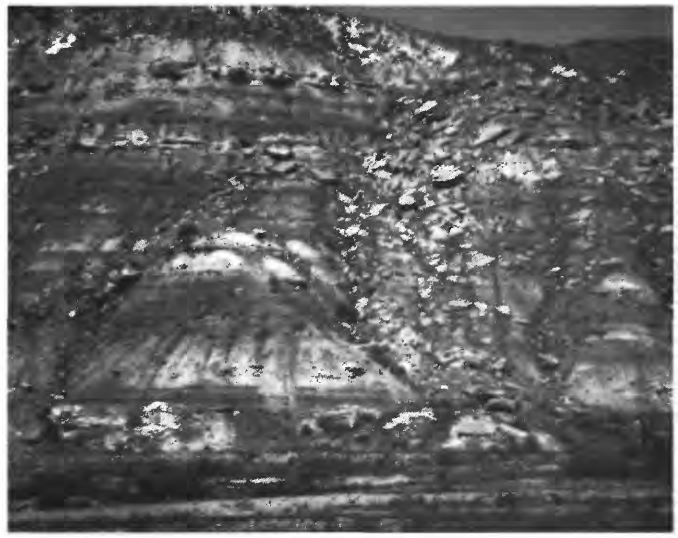


FIGURE 17.—Outcrops of a freshwater coastal-plain depositional environment in the lower part of the Almond Formation on the northern side of Interstate Highway 80 near Point of Rocks, Wyo., in NW¼SW¼ sec. 26, T. 20 N., R. 101 W. Dark bands are carbonaceous shale layers. Thickness of outcrops is about 275 ft.

tributary bays (fig. 20). Salt marshes initially occupied the brackish-water margins and heads of these mud-bottomed bays, but later as the bays filled in and were abandoned, freshwater swamps formed, and thick beds of peat (coal) were deposited (fig. 21).

The lithologies of the delta-plain environment are similar to those of the barrier-plain environment. Sandstone was deposited as distributary channels and splays (fig. 22), coal developed from peat that was deposited in freshwater swamps, carbonaceous shale was deposited as bottom mud in salt marshes, and shale was deposited as bay-fill mud. The barrier-plain and delta-plain depositional environments are primarily distinguished by the geometry of the sandstone bodies deposited along their marine shorelines. The delta plains bulged seaward, whereas barrier plains formed in the embayed coastal areas between deltas. The presence or absence of distributary channels and tidal inlets at the top of sandstone shoreline sequences is not a good criterion for distinguishing delta-front and barrier-island shorelines in the study area.

Fossils are fairly abundant in the delta-plain environment. Trace fossils are common in splay sandstone. Well-preserved plant stems and leaves are present in carbonaceous shale, especially where it underlies and overlies coal beds. Dinosaur-bone fragments and tracks are found locally, mostly in channel and splay sandstone.

TIDAL FLAT

Tidal-flat deposits (mostly of estuarine origin) are present locally in several formations of the Mesaverde

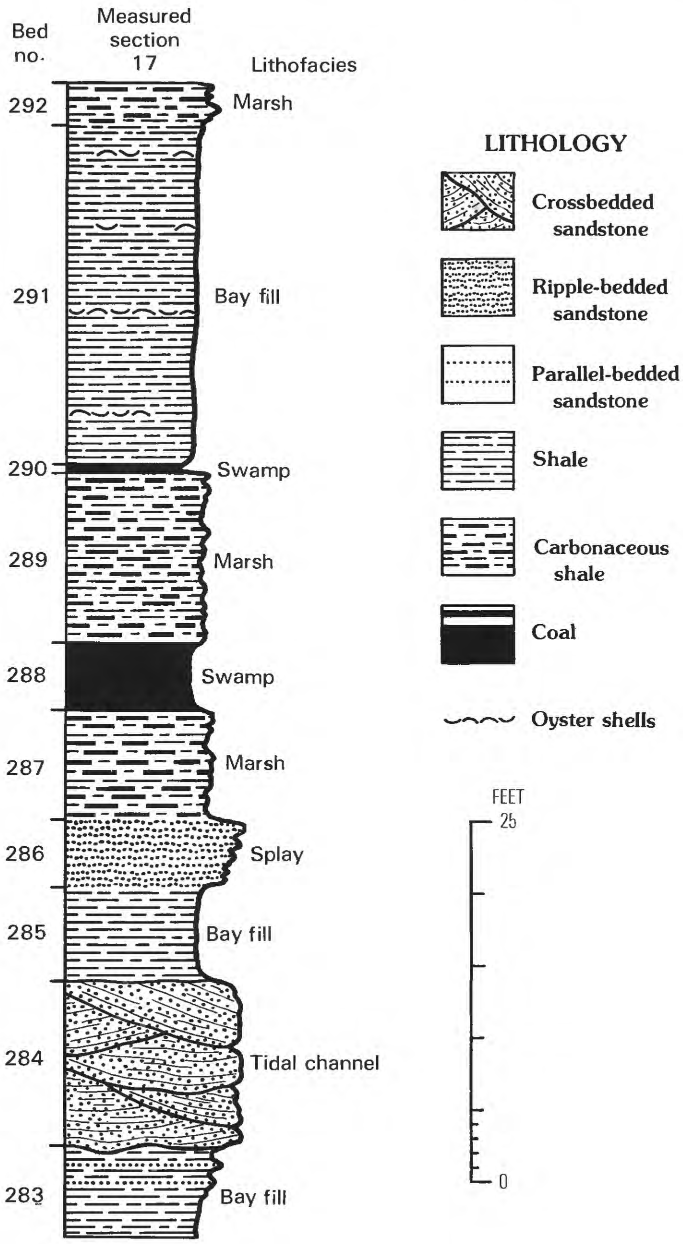


FIGURE 18.—Lithofacies of the barrier-plain depositional environment in the upper part of the Almond Formation on the western flank of the Rock Springs uplift in NW¼NE¼SW¼ sec. 12, T. 20 N., R. 105 W., Wyoming. Bed lithologies are described under "Section 17" in the appendix.

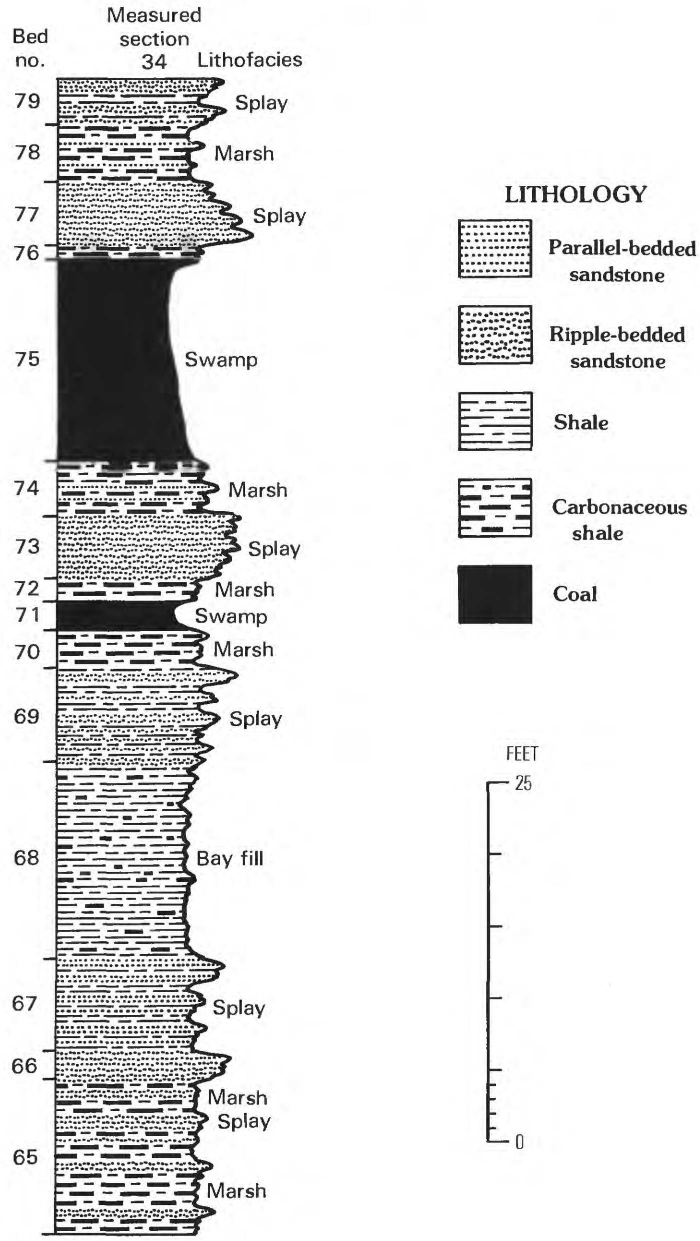


FIGURE 19.—Lithofacies of the delta-plain depositional environment in the Williams Fork Formation near Mount Harris, Colo., in NW¼NE¼SE¼ sec. 15, T. 6 N., R. 87 W. Bed lithologies are described under "Section 34" in the appendix.

Group where they form thin stratigraphic intervals within the delta-plain and barrier-plain depositional environments. They are also recognized as a separate depositional environment because in a few places they compose a continuous stratigraphic interval hundreds of feet thick. Thick parts of the Allen Ridge Formation and nearly all of the Almond Formation in the northeastern part of the study area are of tidal-flat origin.

Thick stratigraphic intervals representing tidal-flat depositional environments formed along embayed marine shorelines that were open to the sea but had no sand beaches to protect them from the destructive forces of tides and waves (fig. 10). In these unprotected areas, which sloped very gently seaward, tides rhythmically flooded and ebbed across barren sand flats and vegetated mud flats, and through small open-water channels and

FIGURE 20.—Flood-ramp sandstone of a flood-tidal delta overlying a thin coal bed in the Rock Springs Formation along the northern side of Interstate Highway 80 in SC sec. 22, T. 20 N., R. 102 W., 20 mi east of Rock Springs, Wyo. Outcrops of the flood-ramp sandstone grade northward from the highway through distal flood-tidal delta sandstone into bay-fill shale.

FIGURE 21.—Outcrop of the Rock Springs Formation deposited in the delta-plain environment in Rock Springs, Wyo., in NW¼NW¼SW¼ sec. 35, T. 19 N., R. 105 W. The faulted outcrop consists of interbedded splay sandstone, coal, and bay-fill shale.

bays. The sediments deposited in this environment (beds 53–60, fig. 23) became interbedded (1) dark-gray carbonaceous shale interlaminated with lenticular white sandstone, (2) white, thin, parallel- to subparallel-bedded, wave- and current-rippled sandstone, and (3) gray shale. The dark-gray carbonaceous shale interlaminated with lenticular white sandstone forms classic flaser bedding (fig. 24). The sand lenses in the flaser bedding were probably deposited across mud flats when tidal currents were active, whereas the mud layers were

FIGURE 22.—Thin interbedded sandstone and carbonaceous shale in one of the splay deposits of the delta-plain depositional environment shown in figure 21, Rock Springs, Wyo. Pick handle is 1.4 ft long.

deposited during intertidal, slack-water periods. The carbonaceous material in the muds indicates the presence of salt-tolerant, presumably reedlike vegetation. The rippled white sandstone was deposited as sand flats that were regularly flooded by tides and periodically washed by waves. The shale is fissile and was deposited as mud on the bottom of channels and bays.

Small crustacean burrows are abundant in some of the sandstone beds in the environment (bed 54, fig. 23). Most of these burrows are vertical to slightly inclined, 0.25 to 0.5 inch wide, as much as 6 inches long, and smooth walled.

MARINE SHORELINE

The marine shoreline deposits of the Mesaverde Group, including delta-front and barrier-island sandstones, are combined in this depositional environment as linear sheets of very fine to medium grained quartzose sandstone. The sandstone sheets are lenticular in cross section and range in thickness from a few feet to more than 75 ft. Outcrops weather to persistent tan and gray scarps. The sands making up these units prograded along wave-dominated shorelines, where they separate marine and nonmarine deposits. Also formed in this environment was shallow-marine shoreface sandstone that extended seaward from beaches, berms, and dunes. The sand bodies deposited during marine regressions and stillstands were commonly much thicker than those deposited during marine transgressions.

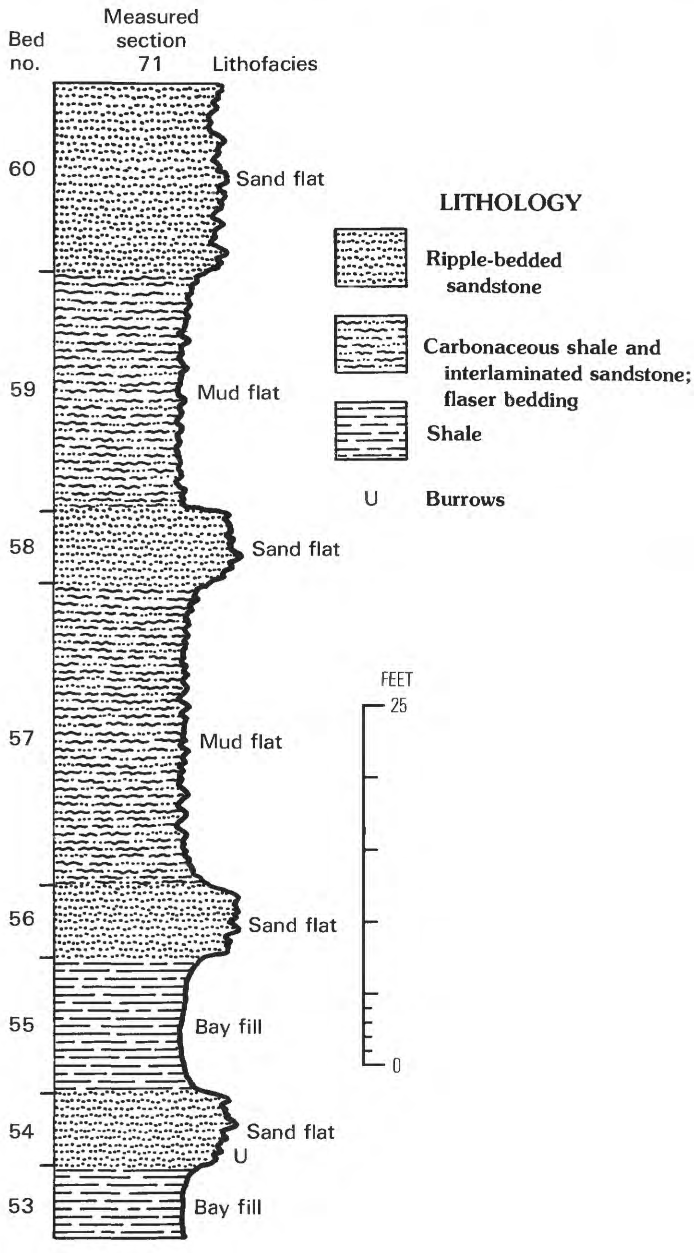


FIGURE 23.—Lithofacies of the tidal-flat depositional environment in the Almond Formation at Separation Rim, Wyo., in NE¼NE¼NW¼ sec. 4, T. 24 N., R. 89 W. Bed lithologies are described under "Section 71" in the appendix.

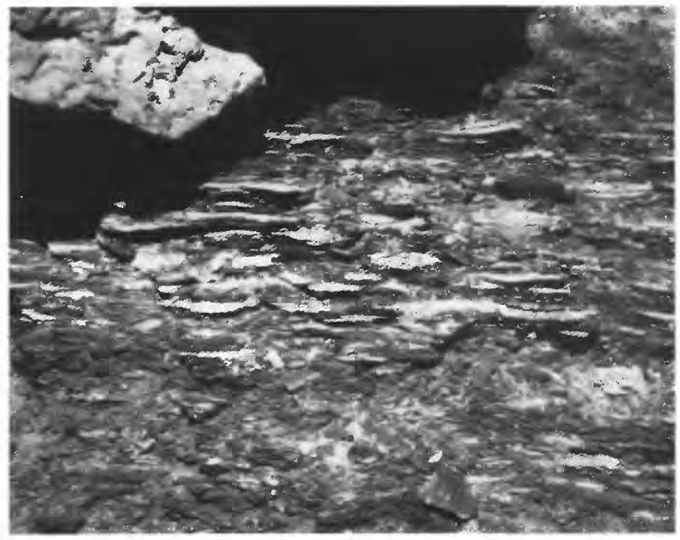


FIGURE 24.—Flaser bedding in tidal-flat deposits in the Allen Ridge Formation in NW¼NE¼NW¼ sec. 4, T. 24 N., R. 89 W., at Separation Rim, Wyo. Pocket knife is 0.27 ft long.

The normal marine shoreline sandstone consists of a monotonously predictable vertical succession of lithofacies. In ascending order they are lower shoreface, middle shoreface, surf (upper shoreface), forebeach (foreshore) (figs. 25–26), berm (beach ridge), and dune. Locally, tidal-channel deposits (fig. 27) and distributary channel deposits (fig. 28) cap these lithofacies; tidal-delta deposits are also present locally (fig. 20). Few berm and dune lithofacies have been preserved because of post-depositional erosion of the topographically elevated parts of abandoned shorelines. Where the berm and dune sandstones were eroded, paleosoils commonly formed on the upper surface of the forebeach (bed 62, fig. 25). Most paleosoils contain roots and are stained gray or black by organic acids (fig. 29).

The lower shoreface lithofacies was deposited at the distal (marineward) edges of the shoreline sandstones, hundreds of yards seaward of beaches, at water depths well below normal wave base (about 75–125 ft). The lithofacies is composed of tan very fine to fine-grained, silty sandstone in very thin parallel beds and laminae (fig. 30). Although the sandstone beds were deposited below normal wave base, small wave ripple marks of undetermined origin are locally present (bed 59, fig. 25). The lithofacies commonly weathers to ledges on steplike slopes.

The middle-shoreface lithofacies is composed of tan fine- to medium-grained sandstone. The sand was deposited in (1) thick and thin parallel beds, (2) thick parallel beds with internal bioturbation, or (3) large-scale low-angle hummocky crossbeds (fig. 31). It was deposited near wave base (about 50 ft) in areas where storm waves periodically churned the sea floor. The lithofacies commonly weathers to massive gold-brown cliffs that are often referred to as "golden walls."

The surf (upper shoreface) lithofacies is composed mostly of medium-grained sandstone that weathers light gray. The color of the sandstone in outcrops contrasts sharply with that of underlying middle-shoreface sandstone that weathers tan. Much of the surf lithofacies

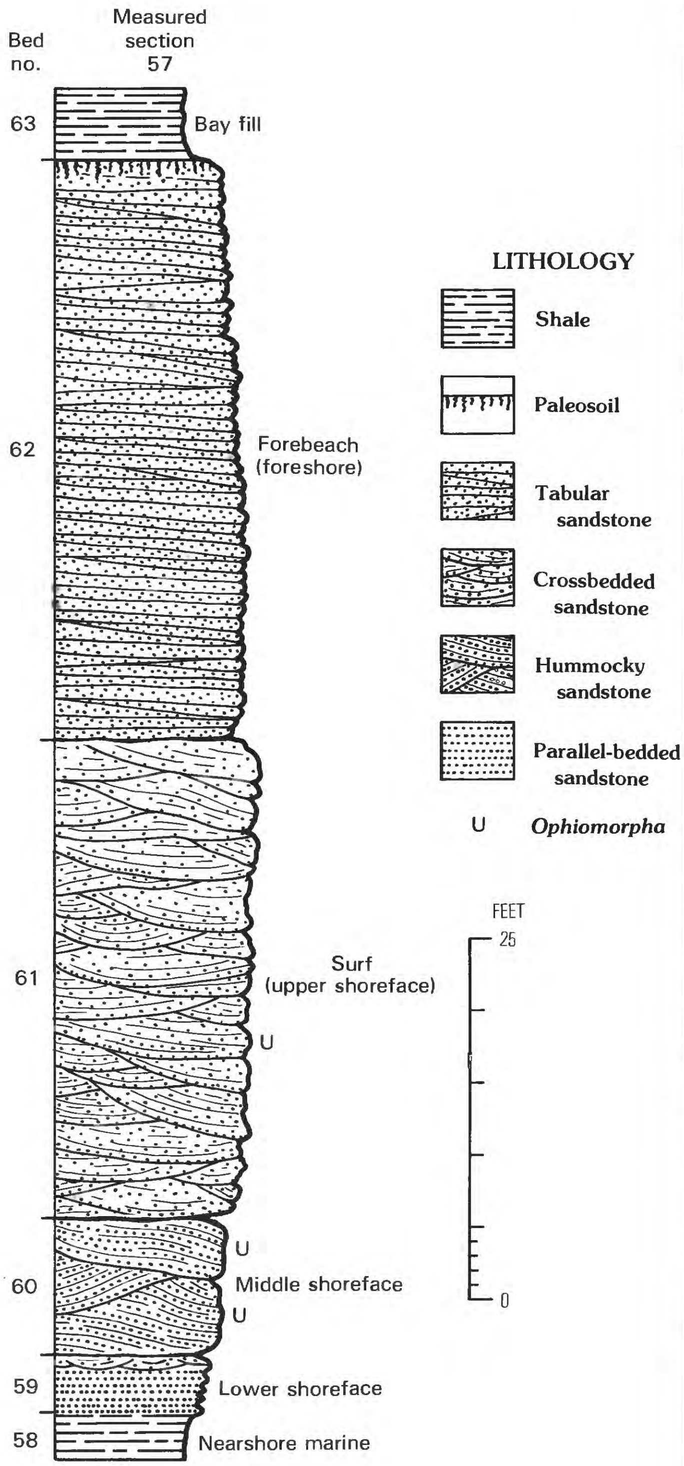


FIGURE 25.—Lithofacies of the marine-shoreline depositional environment in the Allen Ridge Formation at Atlantic Rim, Wyo., in SW¼NE¼SW¼ sec. 18, T. 19 N., R. 88 W. Bed lithologies are described under "Section 57" in the appendix.

is characterized by small-scale trough crossbeds created by breaking waves (bed 61, fig. 25). Locally, the trough crossbeds have been replaced by broadly lenticular, planar crossbeds (fig. 32). The planar crossbeds are the product of either bidirectional longshore currents or tidal currents where they entered the mouths of bays or inlets.

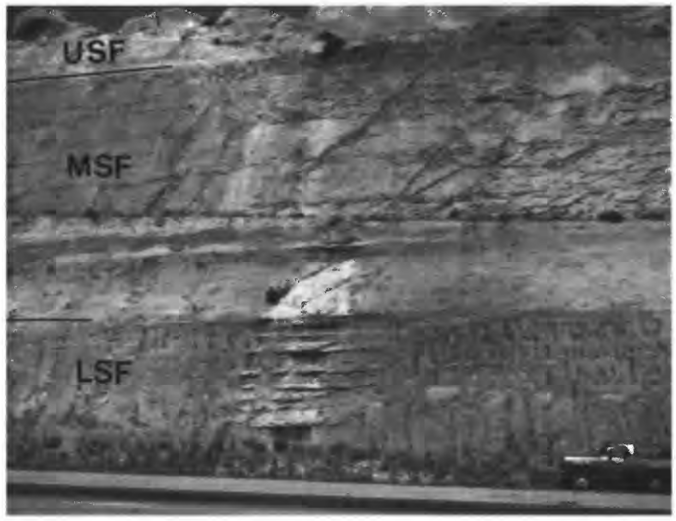


FIGURE 26.—Lower shoreface (LSF), middle shoreface (MSF), and surf (upper shoreface) (USF) sandstone lithofacies in a marine-shoreline depositional environment in the Rock Springs Formation. Exposures are in a road cut along the eastern side of Interstate Highway 80 in SW¼SW¼SE¼ sec. 24, T. 19 N., R. 105 W., in Rock Springs, Wyo.

FIGURE 27.—Tidal-channel deposit (arrow) at the top of a barrier-island sandstone bed in the Almond Formation in NE¼SW¼ sec. 7, T. 21 N., R. 101 W., on the northeastern flank of the Rock Springs uplift, Wyoming. The channel deposit is 175 ft wide and has a maximum thickness of 14 ft. The bedding is flaserlike.

FIGURE 28.—Distributary channel deposit (arrow) resting on a delta-front sandstone bed in the Rock Springs Formation. Outcrops are on the northern side of Interstate Highway 80, 1 mi east of Rock Springs, Wyo., in SE¼NW¼ sec. 29, T. 19 N., R. 104 W. The channel deposit is about 50 ft thick.

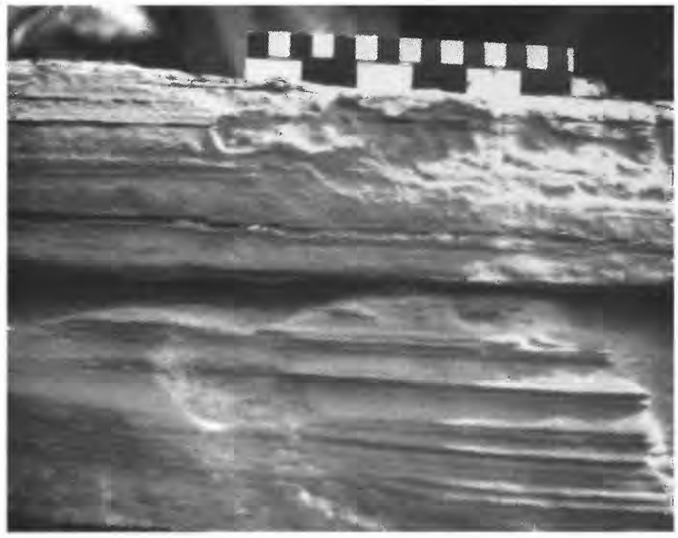


FIGURE 30.—Laminated sandstone in a lower shoreface lithofacies in the Rock Springs Formation in SE¼NE¼ sec. 12, T. 19 N., R. 102 W., Wyoming. Scale is in centimeters (upper) and inches.

FIGURE 29.—Dark-gray, organically stained paleosoil (arrow), containing roots, at the top of a barrier-island sandstone bed in the Almond Formation in NE¼NE½ sec. 3, T. 16 N., R. 102 W., Wyoming. Pick handle is 1.4 ft long.

FIGURE 31.—Large-scale hummocky crossbeds in a middle-shoreface sandstone lithofacies in the Rock Springs Formation in NE¼SW¼ sec. 24, T. 19 N., R. 102 W., Wyoming. Camera-lens cap shows scale.

The forebeach (foreshore) lithofacies is composed of medium-grained sandstone that weathers light gray or white. Its distinctive parallel-to-subparallel tabular bedding (fig. 32; bed 62, fig. 25) is the result of the transverse, laminar flow of water produced by breaking waves as they washed upward from the surf onto subaerial parts of beaches. Beach structures, such as ridge and runnel systems, ebb channels, and so forth, are rarely preserved.

Although dune and berm sandstones are rarely preserved, in a few places lenses of dune sandstone occupy broad depressions along the top of the forebeach lithofacies. The dune sequences have concave-downward crossbedding and polymodal landward-dipping foreset

FIGURE 32.—Planar and trough crossbedded surf (upper shoreface) sandstone lithofacies capped by parallel, tabular forebeach (foreshore) sandstone lithofacies in the Rock Springs Formation in NE¼SW¼ sec. 19, T. 19 N., R. 101 W., on the southeastern flank of the Rock Springs uplift, Wyoming. Arrow shows lithofacies contact.

FIGURE 33.—Dune sandstone unit overlying and welded to forebeach (foreshore) sandstone unit in a barrier island in the Almond Formation in NE¼NE¼ sec. 3, T. 16 N., R. 102 W., on the southeastern flank of the Rock Springs uplift, Wyoming. The person is standing on the dune-forebeach contact, which is marked by a break in slope.

laminae. They are normally welded to the underlying forebeach deposits (fig. 33). Most sand grains are rounded and frosted. Berm sandstone is very rare and has been identified in only two measured sections, the Rock Springs Formation, section 40, pl. 1, and the Almond Formation, section 42, pl. 1, both of which are on the southeastern flank of the Rock Springs uplift. The berm sandstone in these sections forms low mounds consisting of thin, subparallel beds that dipped landward (westward) and seaward (eastward).

MARINE SHELF AND SLOPE

Most of the Blair Formation and parts of the Rock Springs, Allen Ridge, Iles, and Williams Fork Formations were deposited in the marine shelf and slope depositional environment. The rocks in this environment are typically dark-gray shale containing thin interbedded tan very fine grained sandstone and siltstone, and rare thin layers of rounded limy siltstone concretions (fig. 34). The shale was deposited as mud in quiet nearshore water. The sand and silt were deposited as distal lower shoreface or prodelta deposits, as bars formed parallel to shorelines by longshore currents, in submarine channels and overbank deposits, or as sheet deposits that were winnowed from shelf and slope muds by current and wave action. Most of the sandstone occurs in thin parallel beds or parallel laminae (fig. 35). Some small-scale trough crossbeds are present. Channel and bar sandstones are commonly lenticular and have a variety of bedding structures.

CORRELATION AND AGE OF STRATIGRAPHIC UNITS

Deposition of the Mesaverde Group in the study area lasted nearly 13 million years from the early Campanian (about 82 Ma) into the early Maestrichtian (about 69 Ma). The stratigraphic positions of ammonite index fossils used to date the group (fig. 5) are shown by dots on the cross sections on plate 1. The fossil localities are identified by U.S. Geological Survey numbers adjacent to the dots. Lists of additional fossils collected at these localities, as well as their geographical locations, are available from the U.S. Geological Survey, Denver Federal Center, Denver, CO 80225.

Ten cross sections (*A–A′* to *J–J′*, pl. 1) illustrate the stratigraphic relationships of the Mesaverde Group in the study area. The cross sections are constructed to uniform vertical and horizontal scales with a vertical exaggeration of about 50:1. The stratigraphic data shown on the cross sections (pl. 1) are readily available either commercially (for example, geophysical logs) or in the geologic literature. The following discussions of stratigraphic units are in chronological sequence (oldest to youngest). They begin along the western margins of the study area and continue eastward across the study area.

BLAIR FORMATION

The Blair Formation in the western part of the study area is composed of marine rocks that are laterally equivalent to continental rocks in the Rock Springs

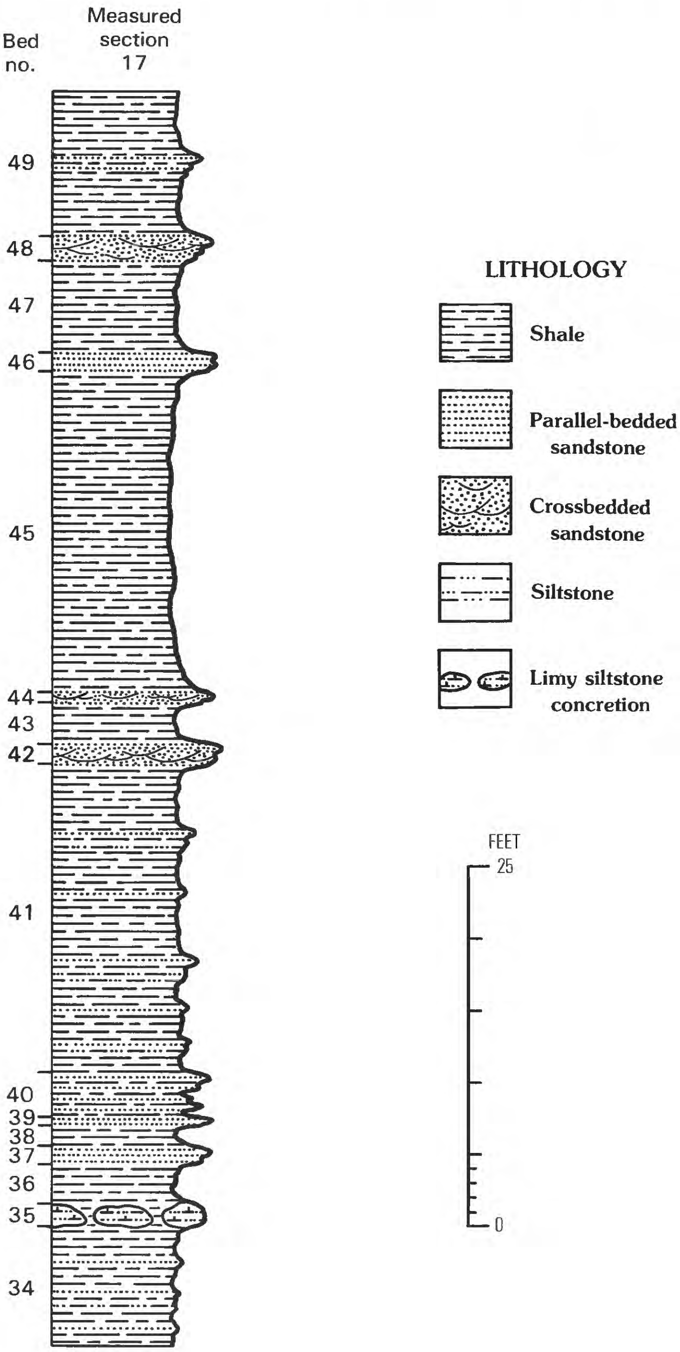


FIGURE 34.—Lithofacies of the marine shelf and slope depositional environment in the Blair Formation on the western flank of the Rock Springs uplift in SW¼SW¼NW¼ sec. 3, T. 20 N., R. 104 W., Wyoming. Bed lithologies are described under "Section 17" in the appendix.

Formation west of the study area (fig. 7). The sandstone, siltstone, and shale beds that compose the Blair Formation grade laterally and imperceptibly eastward from the study area into the Steele and Mancos Shales (cross sections *G–G′*, *H–H′*, pl. 1).

FIGURE 35.—Thin, parallel-bedded shelf sandstone in marine shale in the upper part of the Blair Formation in SE¼SE¼SE¼ sec. 18, T. 19 N., R. 102 W., on the southeastern flank of the Rock Springs uplift, Wyoming.

Sandstone in the basal part of the Blair Formation in the Rock Springs uplift is several hundred feet thick and is informally referred to as the "basal Blair sandstone". The interval consists of 12 intercalated submarine fans (turbidites?) that were deposited on marine slopes as much as 50 mi east (seaward) of the shorelines of the Rock Springs Formation. The fans form lenses 5 to 10 mi wide and from 100 to 250 ft thick. Most become fine grained upwards from a sharp basal contact, but some coarsen upwards. They are mostly composed of alternating parallel-bedded sandstone and shale in couplets, a few inches thick (fig. 36), that are interspersed with widely spaced, thin, broadly lenticular submarine channel sandstone.

The index fossil *Scaphites hippocrepis* is present throughout the Blair Formation and equivalent basal parts of the Rock Springs Formation, indicating that the Blair Formation is early Campanian in age (fossil loc. 24001, cross section *A–A′*; fossil locality D2598, cross section *C–C′*, pl. 1).

ROCK SPRINGS AND HAYSTACK MOUNTAINS FORMATIONS

Rocks of continental origin in the Rock Springs Formation intertongue with and are replaced laterally in a southeastward direction by marine rocks of the Blair Formation and Steele and Mancos Shales (cross sections *C–C′*, *D–D′*, and *H–H′*, pl. 1). The Chimney Rock, Black Butte, Brooks, Coulson, and McCourt Tongues of the Rock Springs Formation are composed of thick and

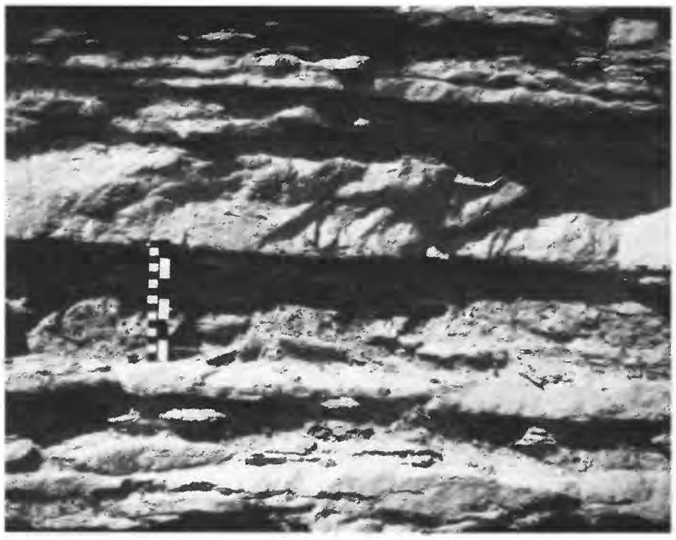


FIGURE 36.—Sandstone and shale beds in a submarine fan near the base of the Blair Formation in a roadcut on Interstate Highway 80 in NW¼SW¼NE¼ sec. 32, T. 20 N., R. 102 W., 18 mi east of Rock Springs, Wyo. Scale is in centimeters (left) and inches.

persistent shoreline sandstone and marine shale in the upper 1,000 ft of the intertongued interval (cross section *E–E'*, pl. 1). The interval between the middle of the Black Butte Tongue and the base of the Gottsche Tongue changes from continental to marine to continental and back to marine deposits from the northern part of the Rock Springs uplift eastward across the study area (cross sections *E–E'* and *G–G'*, pl. 1). In the eastern part of the study area, two marine shoreline sandstone units in this interval make up the Deep Creek and Hatfield Sandstone Members of the Haystack Mountains Formation (cross section *G–G*; pl. 1).

Kiteley (1983, fig. 5) indicated that parts of the Gottsche Tongue of the Rock Springs Formation correlate with the Trout Creek Sandstone Member of the Iles Formation. Kiteley's correlation does not agree with those shown on cross sections *C–C'* and *D–D'*, plate 1 (this report).

Marine equivalents of the Rock Springs Formation in the Steele and Mancos Shales in the east-central part of the study area contain several closely spaced beds of bentonite that are recognizable by low resistivity curves on electric logs of drill holes (cross sections *G–G'* and *J–J'*, pl. 1). The bentonite beds are correlation markers in the zone of *Baculites obtusus*. They are believed to be a southward extension of the Ardmore Bentonite Bed that was identified in northern Wyoming and southern Montana by Gill and Cobban (1973).

Scaphites hippocrepis was collected near the base of the Rock Springs Formation north of Rock Springs, Wyo. (fossil loc. D2221, cross section *C–C'*, pl. 1), *Baculites asperiformis* was collected from the Haystack Mountains Formation on Atlantic Rim (fossil loc. D6361, cross section *G–G*; pl. 1), and *Baculites perplexus* was collected from the Mancos Shale near Hayden, Colo., in stratigraphic equivalents of the upper part of both formations (fossil loc. D6878, cross section *J–J'*, pl. 1). These index fossils indicate that the Rock Springs and Haystack Mountains Formations range in age from early to middle Campanian.

ERICSON AND PINE RIDGE SANDSTONES

The three parts of the Ericson Sandstone, the Rusty zone, Canyon Creek Member, and Trail Member, have variable thicknesses because of intertonguing, intraformational erosion, and nondeposition. The Trail Member is truncated by the Moxa erosion surface west of the Rock Springs uplift (measured sections 10–11, cross section *B–B'*, pl. 1); it thickens eastward, and east of the Rock Springs uplift it intertongues with and is laterally replaced by either the Allen Ridge Formation (cross sections *G–G'* and *H–H'*, pl. 1) or the Iles Formation (cross section *D–D'*, pl. 1). The Rusty zone is also truncated by the Moxa erosion surface west of the Rock Springs uplift. It is 50 to 250 ft thick across the uplift, but east of there it thickens rapidly to several hundred feet and then grades laterally into unnamed parts of the Allen Ridge and Iles Formations (cross sections *D–D'*, *G–G'* and *H–H'*, pl. 1). The Canyon Creek Member and its lateral equivalent, the Pine Ridge Sandstone, rest upon the Moxa erosion surface in most of the study area. Where the Moxa erosion surface dies out in the southeast part of the study area (cross sections *D–D'* and *J–J'*, pl. 1), the Canyon Creek Member and the Pine Ridge Sandstone grade laterally into the Williams Fork Formation. Near Lamont, Wyo., at the northeastern corner of the study area, the Pine Ridge Sandstone is missing by nondeposition across the Lost Soldier anticline (measured sections 67 and 68, cross section *I–I'*, pl. 1).

The Ericson and Pine Ridge Sandstones have not been dated by ammonite index fossils in the study area because the sandstones are continental in origin. However, ammonites collected in marine stratigraphic equivalents by Izett and others (1971) near Kremmling, Colo, southeast of the study area (fig. 9), and by Gill and others (1970) near Rock River, Wyo., east of the study area (fig. 7), indicate that the sandstones occupy the biostratigraphical interval from *Baculites gregoryensis* at the base to *Baculites reesidei* at the top.

ALMOND FORMATION

The Almond Formation intertongues with the Lewis Shale as a result of the second westward marine transgression across the study area (fig. 7). The formation normally ranges in thickness from 300 to 800 ft and is composed of rocks deposited in three successive environments. The earliest environment was a coastal plain characterized by freshwater deposits (fig. 17), the middle environment consisted of brackish-water deposits of barrier-plain origin, and the latest environment was a marine shoreline (mostly barrier island) characterized by saltwater deposits (fig. 33). Rocks deposited in the three depositional environments intertongue with and are replaced by rocks deposited in other environments in the northeastern and southeastern parts of the study area. In the northeastern part of the area rocks of the lower and middle environments are replaced by deposits of tidal-flat origin in the Almond Formation (measured sections 70–73, cross section *I–I′*, pl. 1), and these grade northward into the Lewis Shale (measured sections 67–70, cross section *I–I′*, pl. 1). In most places the marine shoreline sandstones in the upper part of the Almond Formation wedge out into the Lewis Shale. In the southeastern part of the area coastal-plain deposits in the lower part of the Almond Formation grade laterally into delta-plain deposits of the Williams Fork Formation (measured sections 77–83, cross sections *J–J′*, pl. 1).

The Almond Formation is late Campanian and early Maestrichtian in age (Gill and others, 1970). *Baculites baculus* was collected from the top of the formation on the eastern flank of the Rock Springs uplift (fossil loc. D6870, cross section *E–E′*, pl. 1), and *Baculites eliasi* was collected from the Lewis Shale at a stratigraphic position near the middle of the Almond Formation in the northeastern part of the study area (fossil loc. D6326, cross section *I–I′*, pl. 1). The basal part of the formation is undated in the study area, but *Baculites reesidei* was identified in a marine shale tongue near the base of the formation a few miles east of Rawlins, Wyo. (Gill and others, 1970, p. 8). The period of maximum transgression of the Lewis sea (and thickest Almond Formation) probably falls in the zone of *Baculites grandis*.

ALLEN RIDGE AND ILES FORMATIONS

The Allen Ridge and Iles Formations are 1,900 to 2,600 ft thick and compose most of the Mesaverde Group in the eastern part of the study area. The two formations are mostly stratigraphic equivalents. The map boundary separating the two units is arbitrarily placed at the Wyoming-Colorado State line (between measured sections 81 and 82, cross section *J–J′*, pl. 1). The upper parts of the Allen Ridge and Iles Formations were deposited in either flood-plain or delta-plain depositional environments. The lower 800 to 1,200 ft of the Iles Formation consists of marine shoreline deposits that intertongue with marine environments of the underlying Mancos Shale.

The Allen Ridge Formation is unconformably overlain by and progressively truncated below the Pine Ridge Formation northward across the northeastern part of the study area (cross section *I–I′*, pl. 1). Near the northeastern corner of the study area the upper part of the formation grades laterally into tidal-flat and marine shore, shelf, and slope depositional environments (measured sections 67–72, cross section *I–I′*, pl. 1).

The Iles Formation is conformably overlain by the Williams Fork Formation. The upper few hundred feet of the Iles Formation is composed of marine shoreline sandstone (the Trout Creek Sandstone Member) and marine shelf and slope deposits. The formation intertongues with and is rapidly replaced by the Mancos Shale or the equivalent part of the Pierre Shale southeast of the study area (fig. 9).

The base of the Allen Ridge Formation is in the zone of *Baculites obtusus* (fossil loc. D6317, cross section *I–I′*, pl. 1). The Iles Formation remains undated, but Gill and others (1970, p. 9) found *Didymoceras nebrascense* in laterally equivalent rocks in the Hanna basin, 50 mi east of the study area.

WILLIAMS FORK FORMATION

The Williams Fork Formation is 800–1,500 ft thick in the southeastern part of the study area. The formation forms the upper part of the Mesaverde Group and is laterally equivalent to the uppermost part of the Allen Ridge Formation, Canyon Creek Member of the Ericson Sandstone, Pine Ridge Sandstone, and Almond Formation (cross sections *D–D′* and *J–J′*, pl. 1). It is composed of rocks deposited in delta-plain, barrier-plain, and marine shoreline, shelf, and slope depositional environments. The Twentymile Sandstone Member is a persistent stratigraphic marker bed in the upper part of the formation.

The age of the Williams Fork Formation has not been determined in the study area, but Izett and others (1971, p. A3) correlated the base of the formation near Kremmling, Colo., with the zone of *Baculites compressus*. By correlating the top of the Williams Fork Formation with the top of the laterally equivalent Almond Formation along outcrops at the eastern margin of the study area, the top of the Williams Fork Formation appears to be in the zone of *Baculites eliasi*.

PALEOGEOGRAPHY

Eleven maps are used to interpret the paleogeography of the Mesaverde Group in the study area. The maps are lettered and described chronologically from A to K (oldest to youngest) on plate 2 and in the text. The paleogeographic maps were constructed on a cadastral base (townships and ranges) primarily from the data shown on the cross sections (pl. 1), but they also include additional data and observations of the author. The depositional environments identified on the paleogeographic maps (pl. 2) correspond to those shown on the cross sections (pl. 1) with one exception. The delta-plain, barrier-plain, tidal-flat, and coastal-plain depositional environments are combined on the paleogeographic maps because of the small map scale.

The paleogeographic maps portray marine shoreline locations at specific time intervals named for regionally correlatable ammonite zones (fig. 5). Many of the shorelines prograded for long distances and for long periods of time. Consequently, it is rarely possible to precisely locate and correlate specific strandlines within these blanketlike sequences. The overall shoreline configurations are nonetheless believed to be accurately located, even though many of the morphologic details are missing.

MAP A. LOWER PART OF THE ROCK SPRINGS FORMATION, BLAIR FORMATION, AND CODY, STEELE, AND MANCOS SHALES (TIME OF *SCAPHITES HIPPOCREPIS* III)

The lower part of the Rock Springs Formation and the equivalent Blair Formation were the first stratigraphic units of the Mesaverde Group to be deposited in the study area. The lower part of the Rock Springs Formation (pl. 2, map A) was deposited on coastal plains and arcuate deltas and along marine shorelines that strike about N. 45° E. across the Rock Springs uplift area. Marine prodelta and shelf sediments of the Blair Formation were deposited seaward of these shorelines, and the Cody, Steele, and Mancos Shales were deposited in deeper marine water offshore.

The lower part of the Rock Springs Formation and the Blair Formation were deposited during the first regression of the interior Cretaceous seaway (fig. 6). A stillstand occurred during the early Campanian phase of this regression a short distance east of the present-day location of the city of Rock Springs, Wyo. During the stillstand hundreds of feet of shoreline (delta-front) sands were deposited in vertical succession (fig. 37; cross section *E–E′*, pl. 1). The stillstand lasted nearly 5 million years, during which time as many as 15 different shoreline sequences were deposited in the Rock Springs Formation. The stillstand began before the appearance of the Black Butte Tongue and ended with renewed regression during deposition of the McCourt and Gottsche Tongues (cross sections *C–C′*, *E–E′* and *F–F′*, pl. 1).

The width of the area of deposition of the Blair Formation (pl. 2, map A), in the landward-seaward direction, offers a clue as to the width of the marine shelf

FIGURE 37.—Vertically stacked delta-front sandstone beds (1, 2, 3) in the Rock Springs Formation in NW¼NW¼ sec. 2, T. 18 N., R. 102 W., Wyoming. Four additional delta-front sandstones are stacked above those shown in the photograph. Thickness of outcrop is about 250 ft.

at the western edge of the interior seaway during these times. The shelf was probably 12–15 mi wide adjacent to a long, narrow, arcuate delta in the north-central part of the study area. South of this delta the shelf expanded and may have been as much as 30 mi wide.

The marine shorelines of the Rock Springs Formation were affected by tides, as evidenced by flaser bedding, flood-tidal deltas, and tidal channels. The tidal range indicated by the sedimentary structures, size, and geometry of these deposits was 1 to 3 ft.

MAP B. CHIMNEY ROCK TONGUE OF THE ROCK SPRINGS FORMATION AND ADJACENT FORMATIONS (TIME OF *BACULITES OBTUSUS*)

The Chimney Rock Tongue forms an anomalously wide belt of marine shoreline and shelf sandstones across the study area (cross sections *C–C′* and *E–E′*, pl. 1). This large volume of sandstone was probably derived either from erosion following a period of increased tectonism in sediment source areas, or from pronounced changes in coastal drainage patterns whereby more than normal amounts of sand were selectively deposited along the shorelines in the study area.

The shorelines of the Chimney Rock Tongue trended about N. 45° E. in nearly the same direction and location as earlier shorelines of the Rock Springs Formation. A long, narrow, arcuate delta persisted in the north-central part of the study area (pl. 2, map B), and a smaller, arcuate delta appeared a short distance north of the present-day convergence of the boundaries of Wyoming, Utah, and Colorado. A cross-sectional profile of the sandstones along the southern edge of the smaller delta is preserved in east-west-trending outcrops along Glades Ridge west of the three-state boundary (cross section *A–A′*, pl. 1). One of the delta-front sandstones in the Chimney Rock Tongue along Glades Ridge is 200 ft thick, offlaps in an eastward (seaward) direction, and forms a huge accretionary swash bar (Roehler and Phillips, 1980). The bar is believed to have been deposited by strong southwest-directed longshore currents.

Kiteley (1983, p. 291) suggested that the shorelines of the interior seaway at this time trended about N. 45° W. from northwestern Colorado into southwestern Wyoming. Stratigraphic correlations and ammonite zonation in northwestern Colorado and northeastern Utah by Gill and Hail (1975) indicated that the shorelines actually trended about S. 45° W. from the study area into northeastern Utah, as shown on plate 2, map B.

MAP C. MIDDLE PART OF THE ROCK SPRINGS FORMATION, DEEP CREEK SANDSTONE MEMBER OF THE HAYSTACK MOUNTAINS FORMATION, AND ADJACENT FORMATIONS (TIME OF *BACULITES MACLEARNI*)

The two arcuate deltas that had formed earlier during deposition of the Chimney Rock Tongue (pl. 2, map B) enlarged and began to become lobate (pl. 2, map C). The northern of the two deltas developed an extensive marine shelf that projected more than 60 mi southeast (seaward) from the delta front. The name "Rawlins platform" is here applied to this extensive shelf area. The origin of the Rawlins platform is unknown, but its large areal extent and symmetrical shape suggest a structural upwarp of the sea floor. Pryor (1961, p. 40–45) offered persuasive petrographic evidence that the Wind River Mountains were tectonically active in the Late Cretaceous and possibly emergent during the time of Mesaverde deposition. The Rawlins platform trends about N. 45° W. and lies on what could be perceived as a southeastward extension of a middle Campanian uplift of the Wind River Range. Shoaling occurred when the sea floor across the Rawlins platform was elevated to within wave base. The Deep Creek Sandstone Member then accumulated partly from sand and silt winnowed by wave action from sea-floor sediments and partly from sands carried seaward from the shorelines at the delta front. The resulting sand banks created a stable platform for subsequent rapid delta growth to the southeast onto the Rawlins platform (pl. 2, maps C and D). Hale (1961, p. 133) also recognized the shoaling that took place across the Rawlins platform. He believed the shoals were locally emergent, but evidence for such a conclusion was not observed by the author.

MAP D. BLACK BUTTE TONGUE OF THE ROCK SPRINGS FORMATION, HATFIELD SANDSTONE MEMBER OF THE HAYSTACK MOUNTAINS FORMATION, AND ADJACENT FORMATIONS (TIME OF *BACULITES ASPERIFORMIS*)

A large lobate delta, here named the "Rawlins delta," expanded southeastward across the Rawlins platform in the northeastern part of the study area (pl. 2, map D). The delta-front sandstone deposited at the periphery of the Rawlins delta is called the Hatfield Sandstone Member of the Haystack Mountains Formation. The Rawlins delta was about 75 mi long, 50 mi wide, and occupied an area of more than 3,500 mi^2. A delta of this size could have formed only at the mouth of a major river having an extensive drainage basin.

The Black Butte Tongue of the Rock Springs Formation was deposited in an embayment that formed in the central part of the study area between the southeast-trending Rawlins delta and the normal northeast-striking shorelines along which the Rock Springs Formation was deposited. This embayment was named the Black Butte embayment by Hale (1961, p. 133). A small arcuate delta formed near the present-day city of Rock Springs within the Black Butte embayment (pl. 2, map D).

The boundary of the Rock Springs and Haystack Mountains Formations on plate 2, map D (dashed line), is arbitrarily placed at a line defining the eastward wedgeout of the Trail Member of the Ericson Sandstone. At this line the Canyon Creek Member of the Ericson Sandstone becomes the Pine Ridge Sandstone, and the rocks underlying the Pine Ridge Sandstone become the Allen Ridge and Haystack Mountains Formations (cross section *G–G′*, pl. 1). The formation boundary shown for the Black Butte Tongue of the Rock Springs Formation and Steele and Mancos Shales is also arbitrarily placed at the eastward wedgeout of the Trail Member. The use of the term "Mancos Shale," is generally restricted to the Colorado part of the study area.

MAP E. McCOURT SANDSTONE TONGUE OF THE ROCK SPRINGS FORMATION, HAYSTACK MOUNTAINS FORMATION, AND ADJACENT FORMATIONS (TIME OF *BACULITES PERPLEXUS*)

The Rawlins delta retained its large size and shape during deposition of the McCourt Sandstone Tongue, but the delta shifted southwestward to form a new lobe in response to sediment infilling across the Rawlins platform and to strong southwest-directed longshore currents (pl. 2, map E). The old delta lobe was subjected to destructional processes; it subsided and was soon submerged. The new delta lobe prograded southwestward off the flank of the Rawlins platform into the adjacent Black Butte embayment, which was consequently infilled to about one-half of its former size. A small arcuate delta persisted at the head of the Black Butte embayment near the present-day city of Rock Springs.

Shoreline sandstones at the distal edge of the Rawlins delta extended 15–20 mi southward into what is now northwestern Colorado (pl. 2, map E). The marine shelf beyond the delta margin there probably extended another 20–30 mi farther south past the present-day city of Craig. A linear sandstone unit deposited on this part of the shelf was informally called the "Duffy Mountain sandstone" and was used as a model to describe migrating "shelf-bar sandstones" by Boyles and Scott (1982). The "Duffy Mountain sandstone" trends irregularly southwestward for about 40 mi through the Craig area. Boyles and Scott (1982, p. 500) identified back-bar, central-bar, and ramp lithofacies within the bar sequence. Bar migration was apparently toward the southwest.

MAP F. TRAIL MEMBER OF THE ERICSON SANDSTONE, ALLEN RIDGE FORMATION,TOW CREEK SANDSTONE MEMBER OF THE ILES FORMATION, AND ADJACENT FORMATIONS (TIME OF *BACULITES GREGORYENSIS*)

The prolonged marine stillstand that occurred during deposition of the Rock Springs Formation across the Rock Springs uplift area (pl. 2, maps A–E) abruptly ended with uplift of the Moxa arch. Older Mesaverde sediments exposed across the uplifted crest of the arch were rapidly eroded and redeposited east of the arch (pl. 2, map F). The reworked sediments reflect a normal seaward progression of depositional environments beginning at the west with alluvial-plain deposits that make up the Trail Member of the Ericson Sandstone. These grade eastward into flood-plain, delta-plain, and finally marine-shoreline deposits that make up the Allen Ridge and Iles Formations. The Tow Creek Sandstone Member of the Iles Formation was deposited along a marine shoreline near the southeastern corner of the study area. The composition of the Trail Member and its lateral equivalents and the normal seaward progression of their depositional environments suggest a paleolandscape of low sea-level altitudes and low topography.

The Trail Member, contrary to what might be expected, does not appear to have been deposited in a forebasin trough adjacent to the eastern edge of the Moxa arch. The member reaches a thickness of 600 ft or more in local areas, but these areas are believed to be depositional centers related to loading and subsidence rather than to structural depressions. The thickest deposits of the Trail Member are within the topographic depression created by the Black Butte embayment (pl. 2, maps E and F).

The configuration of isopachs of the Trail Member (pl. 2, map F) does not indicate that the Rock Springs uplift (fig. 1) had structural expression during or prior to the deposition of the Trail Member. Miller (1977, p. 127) contended that the Rock Springs area was uplifted following deposition of the Rock Springs Formation and that rocks as much as 1,700 ft thick were eroded prior to deposition of the Trail Member. In the same report Miller (1977, p. 125) correlated the basal sandstone units of the Trail Member in the Rock Springs uplift area with the Hatfield Sandstone Member in the eastern part of the study area. The Hatfield Sandstone Member is believed to be much older than the Trail Member (cross section *G–G′*, pl. 1).

MAP G. RUSTY ZONE OF THE ERICSON SANDSTONE, ALLEN RIDGE FORMATION,AND TROUT CREEK SANDSTONE MEMBER OF THE ILES FORMATION (TIME OF *DIDYMOCERAS NEBRASCENSE*)

The Moxa arch was peneplaned, and erosion diminished across the crest of the arch following deposition of the Trail Member of the Ericson Sandstone. The primary source area for sediments was reestablished in the Sevier orogenic belt. During this period of deposition the Moxa arch probably formed a stable terrace on which no sediments were deposited but across which streams carried sediments to extensive flood plains to the east (pl. 2, map G). On these flood plains, which blanketed most of the study area, the Rusty zone of the Ericson Sandstone and equivalent parts of the Allen Ridge Formation were deposited (pl. 1). A narrow band of delta plains separated the flood plains to the west and marine shorelines to the east. In the southeastern part of the study area (pl. 2, map G), early marine shorelines of the Trout Creek Sandstone Member of the Iles Formation were deposited.

MAP H. CANYON CREEK MEMBER OF THE ERICSON SANDSTONE, PINE RIDGE SANDSTONE, AND TWENTYMILE SANDSTONE MEMBER OF THE WILLIAMS FORK FORMATION (TIME OF *BACULITES REESIDEI*)

The tectonic disturbance that occurred in the Sevier orogenic belt in the late Campanian, as discussed previously, had far-reaching effects on the sedimentation that took place during deposition of the Mesaverde Group in the central Rocky Mountain region. The uplifted foreland across Wyoming and bordering states was soon stripped of the soft sediments making up the older but newly exposed parts of the group. Across this erosion surface were deposited the Canyon Creek Member of the Ericson Sandstone and the Pine Ridge Sandstone (fig. 8).

The Canyon Creek Member and Pine Ridge Sandstone range in thickness from zero to slightly more than 600 ft (pl. 2, map H). The area of thickest deposition was in the south-central part of the study area in approximately the same location as the areas of thick deposition in the Trail Member of the Ericson Sandstone (pl. 2, map F).

The Pine Ridge Sandstone wedges out in the northeastern and southeastern parts of the study area as a result of either nondeposition or facies change. It was not deposited across the Lost Soldier anticline in the northeastern part of the study area (measured section 67, cross section *I–I* ', pl. 1). In the southeastern part of the study area, it wedges out by a facies change of alluvial-plain deposits to marine shoreline deposits making up the Twentymile Sandstone Member of the Williams Fork Formation (measured sections 80–82, cross section *J–J*', pl. 1).

MAP I. ALMOND FORMATION, UPPER PART OF THE WILLIAMS FORK FORMATION,AND LOWERMOST PART OF THE LEWIS SHALE (TIME OF *BACULITES ELIASI*)

The early stages of the second (Maestrichtian) transgression of the interior seaway created a large, elongated embayment across the southeastern part of the study area (pl. 2, map I). This embayment trended northwest from near present-day Baggs, Wyo., to Point of Rocks, Wyo. The embayment was named the "Hallville embayment" by Lewis (1961), who recognized that rocks of marine origin (the Lewis Shale) on the eastern flank of the Rock Springs uplift graded both north and south into rocks of continental origin (the Almond Formation). These relationships are discernible on cross sections *E–E*' and *F–F*'', plate 1.

The Hallville embayment occupied a depression southwest of the rejuvenated Rawlins platform upon which a long, narrow, lobate delta formed. The locations and configurations of the depression and lobate delta correspond to the previous relationships of the Black Butte embayment to the Rawlins delta (compare maps D and I, pl. 2). The major difference between the embayments is that the Hallville embayment was formed by transgressive seas, whereas the Black Butte embayment was formed by regressive seas. The rejuvenated Rawlins platform may reflect a second uplift of the Wind River Mountains during the Late Cretaceous.

The shorelines of the Hallville embayment included extensive chains of barrier islands. The sands composing these barrier islands prograded and rapidly filled the head of the embayment. Outcrops of the barrier sandstone are visible along Interstate Highway 80, 30 mi east of Rock Springs, Wyo.; along Spring Creek, 5 mi north of Maybell, Colo.; and at Bell Rock Dome, 10 mi west of Craig, Colo. Barrier islands were also present at a slightly higher stratigraphic level around the distal margins of the lobate delta resting on the Rawlins platform (pl. 2, map I). Outcrops of the stratigraphically higher barrier sandstone are well exposed along Cow Creek, 25 mi southwest of Rawlins, Wyo. (measured section 75, cross sections *I–I*' and *J–J*', pl. 1). The shorelines facing the open sea along the northeastern edge of the study area consisted of partly barrier islands and partly tidal flats (cross section *I–I*', pl. 1).

The Hallville embayment had a focusing effect on tides. A tidal range of 4 to 8 ft is estimated for the head of the embayment along the eastern flank of the Rock Springs uplift. The barrier islands that formed the shores of the embayment there were drumstick shaped and 5–7 mi long (Roehler, 1988, p. 16). Flood-tidal deltas associated with these barrier islands were as much as 5 mi wide.

MAP J. UPPERMOST PARTS OF THE ALMOND AND WILLIAMS FORK FORMATIONS AND LOWER PART OF THE LEWIS SHALE (TIME OF *BACULITES BACULUS*)

The Hallville embayment expanded to form a broad indentation along the coastline of the interior seaway as the seas transgressed westward (pl. 2, map J). The expansion and opening of the mouth of the embayment took place by the obliteration of the Rawlins platform and its associated delta (compare maps I and J, pl. 2). As the seas transgressed across the delta, it was undoubtedly subjected to the destructional forces produced by tides and waves and was severely eroded. The marine shorelines along which the Almond Formation was being deposited then reestablished a northeastern trend from the central part of the study area northeastward. During this period of deposition, the southwestern shorelines of the expanded Hallville embayment were at stillstand. Evidence of the stillstand is especially noticeable on the eastern flank of the Rock Springs uplift where barrier sandstones marking at least eight shorelines are superposed (cross section *E–E*', pl. 1).

MAP K. ALMOND FORMATION AND THE MIDDLE PART OF THE LEWIS SHALE (TIME OF *BACULITES GRANDIS*)

The second marine transgression of the interior Cretaceous seaway reached its maximum westward extent near the western boundary of the study area (pl. 2, map K). At that time the coastline consisted of a broad, shallow, open-water embayment that covered all of the present-day Rock Springs uplift. New arcuate deltas formed along the northern and southern margins of the embayment, and prodelta sediments began to spread seaward into adjacent shallow shelf waters. The northern delta was named the "Red Desert delta" by Asquith (1970, p. 1210). It expanded southward and covered most of the study area following deposition of the Mesaverde Group. A prodelta sandstone that projected seaward from the basal part of the Red Desert delta formed an early tongue in a cluster of marine sandstone units called the "Dad Sandstone Member" of the Lewis Shale (fig. 9). A smaller arcuate delta developed east of the present-day convergence of the State boundaries of Wyoming, Utah, and Colorado (pl. 2, map K); delta front and prodelta sediments at the margins of this delta prograded to the northeast.

SUMMARY AND CONCLUSIONS

The Mesaverde Group in the central and eastern greater Green River basin was deposited over 13 million years during the Campanian and Maestrichtian Ages of the Late Cretaceous. It was deposited across forelands and along marine shorelines between the Sevier orogenic belt to the west and the interior Cretaceous seaway of North America to the east. Sediment source areas were mostly in mountainous terrain of the Sevier orogenic belt, and large river systems transported the sediments eastward to the interior seaway. The climate was tropical to subtropical.

The Mesaverde Group is composed of a 2,000–5,000-ft-thick wedge of predominantly sandstone, siltstone, shale, and coal of mostly continental origin that intertongues with and is replaced by marine shale to the east. Deposition was controlled by eustacy, tectonism, erosion, and fluctuating rates of sedimentation and subsidence. Eight depositional environments have been identified by their characteristic lithologies, sedimentary structures, fossils, and stratigraphic and paleogeographic positions. They constitute a landward-seaward progression of alluvial plain, flood plains, coastal plains, barrier plains, tidal flats, delta plains, marine shorelines, and marine shelves and slopes.

The paleogeography of the Mesaverde Group reveals a complex depositional history. Most of the sediments composing the group were deposited along the western margins of the interior Cretaceous seaway, where local marine transgressions, regressions, and stillstands occurred in close proximity along submergent, emergent, or stable shorelines. The shorelines were wave dominated and tidally influenced. They were mostly linear sheets of quartzose sand that composed normal shoreface lithofacies. The oldest rocks of the group, the Blair, Rock Springs, Haystack Mountains, Allen Ridge, and Iles Formations, were deposited along shorelines that trended regionally northeastward across the western part of the study area in the zone of the ammonite index fossil *Scaphites hippocrepis* onward in time to the zone of *Baculites gregoryensis* (A–F, fig. 38). These formations prograded southeastward across the area during a major regression of the interior Cretaceous seaway. From the offlapping marine shorelines of this regression, arcuate and lobate deltas spread southeastward onto shallow marine shelves. Barrier islands and tidal flats occupied the embayed shoreline areas between the deltas, while coastal plains, flood plains, and alluvial plains occupied positions inland. During this period the normal Mesaverde deposition was interrupted by local and regional uplifts in the Sevier orogenic belt that elevated coastal areas and accelerated the ongoing marine regression to shorelines located mostly east of the study area. A long period of erosion followed during which the uplifted coastal areas were peneplaned, removing rocks in the zones of *Didymoceras nebrascense* (map G, fig. 38) upward through *Baculites compressus*. Upon this peneplain were deposited coarse clastics making up the Canyon Creek Member of the Ericson Sandstone and Pine Ridge Sandstone. The Almond and Williams Fork Formations, which generally fall within the zones of *Baculites cuneatus* upward to *Baculites baculus* (maps H–J, fig. 38), represent the final stages of Mesaverde deposition during a major westward transgression of the interior Cretaceous seaway across the study area. As these shorelines advanced westward, depositional patterns of delta buildups with intervening embayments were reestablished. The final transgressions of the seaway restored the regional northeast trend of marine shorelines across the western part of the study area.

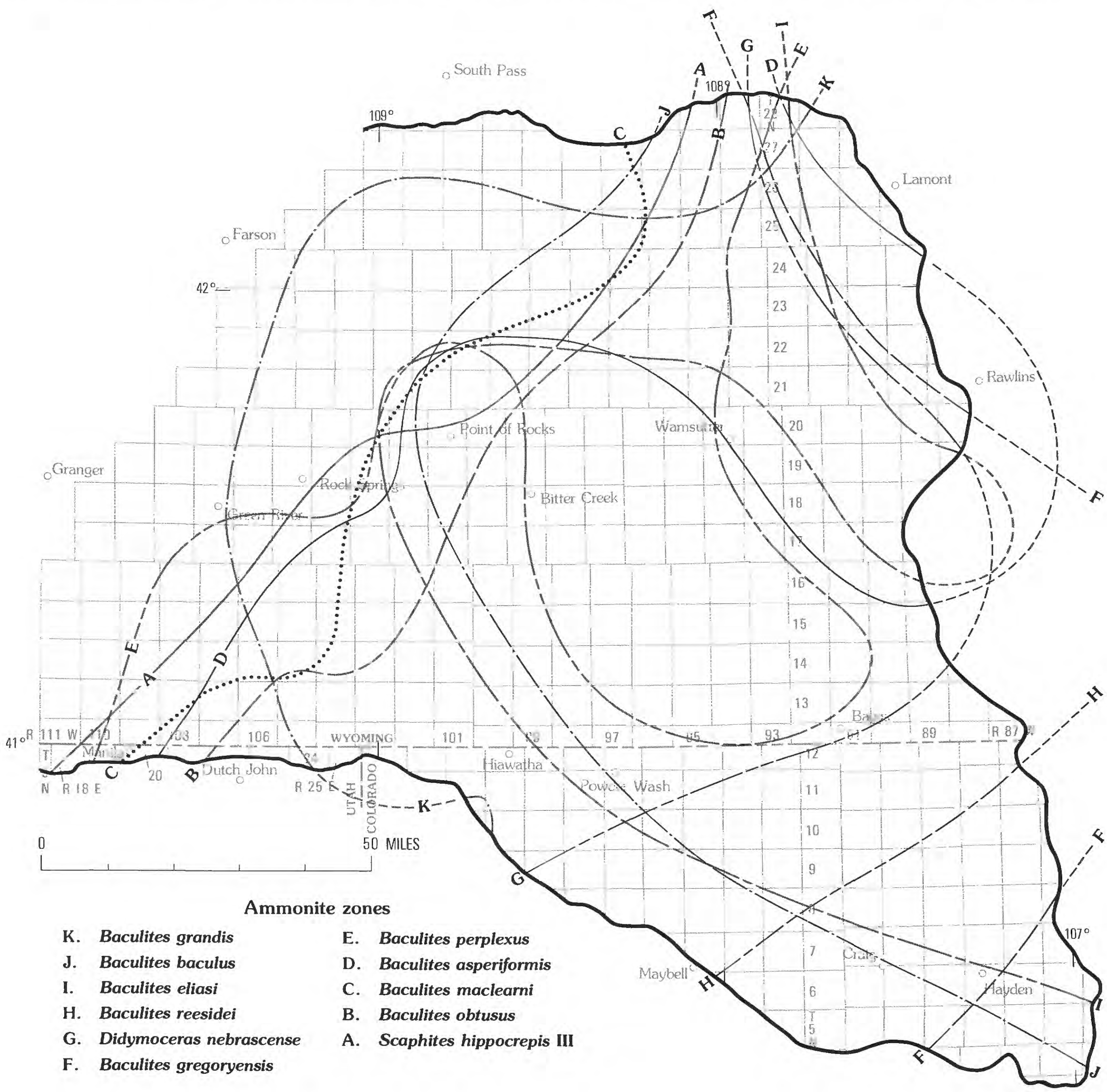


FIGURE 38.—Strandline configurations (A–K) of the Mesaverde Group in the central and eastern greater Green River basin, Wyoming, Colorado, and Utah. Time periods are indicated by ammonite index fossils.

REFERENCES CITED

Asquith, D.O., 1970, Depositional topography and major marine environments, Late Cretaceous, Wyoming: American Association of Petroleum Geologists Bulletin, v. 54, no. 7, p. 1184-1224.

______ 1974, Sedimentary models, cycles, and deltas, Upper Cretaceous, Wyoming: American Association of Petroleum Geologists Bulletin, v. 58, no. 11, p. 2274-2283.

Barlow, J.A., 1959, Cretaceous section, west flank of Rawlins uplift, T. 21 N., R. 88 and 89 W., Carbon County, Wyoming, *in* J.D. Haun and R.J. Weimer, eds., Symposium on Cretaceous rocks of Colorado and adjacent areas: Rocky Mountain Association of Geologists Guidebook, 11th Field Conference, Denver, Colo., p. 110–113.

Boyles, M.J., and Scott, A.J., 1982, A model of migrating shelf-bar sandstone in Upper Mancos shale (Campanian), northwest Colorado: American Association of Petroleum Geologists Bulletin, v. 66, no. 5, p. 491–508.

Fenneman, N.M., and Gale, H.S., 1906, The Yampa coal field, Routt County, Colorado, *with a chapter on* The character and use of the Yampa coals, by M.R. Campbell: U.S. Geological Survey Bulletin 297, 96 p.

Flexer, Akiva, Rosenfeld, Amnon, Lipson-Benitah, Shulamit, and Honigstein, Avraham, 1986, Relative sea level changes during the Cretaceous in Israel: American Association of Petroleum Geologists Bulletin, v. 70, no. 11, p. 1685–1699.

Gill, J.R., 1974, Stratigraphic section of the Mesaverde Group, Lewis Shale, Fox Hills Formation and Medicine Bow Formation, Carbon County, Wyoming: U.S. Geological Survey Open-File Report OF–74–1038, 4 sheets.

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

______ 1966b, Regional unconformity in Late Cretaceous, Wyoming, *in* Geological Survey research 1966: U.S. Geological Survey Professional Paper 550–B, p. B20–B27.

______ 1973, Stratigraphy and geologic history of the Montana Group and equivalent rocks, Montana, Wyoming, and North and South Dakota: U.S. Geological Survey Professional Paper 776, 37 p.

Gill, J.R., and Hail, W.J., Jr., 1975, Stratigraphic sections across Upper Cretaceous Mancos Shale-Mesaverde Group boundary, eastern Utah and western Colorado: U.S. Geological Survey Oil and Gas Investigations Chart OC–68.

Gill, J.R., Merewether, E.A., and Cobban, W.A., 1970, Stratigraphy and nomenclature of some Upper Cretaceous and Lower Tertiary rocks in south-central Wyoming: U.S. Geological Survey Professional Paper 667, 53 p.

Hale, L.A., 1950, Stratigraphy of the Upper Cretaceous Montana Group in the Rock Springs uplift, Sweetwater County, Wyoming, *in* J.W. Harrison, ed., Southwest Wyoming: Wyoming Geological Association Guidebook, 5th Annual Field Conference, Casper, Wyo., p. 49–58.

______ 1961, Late Cretaceous (Montanan) stratigraphy, eastern Washakie basin, Carbon County, Wyoming, *in* G.J. Wiloth, ed., Symposium on Late Cretaceous rocks, Wyoming and adjacent areas: Wyoming Geological Association Guidebook, 16th Annual Field Conference, Casper, Wyo., p. 129–138.

Hancock, E.T., 1925, Geology and coal resources of the Axial and Monument Butte quadrangles, Moffat County, Colorado: U.S. Geological Survey Bulletin 757, 134 p.

Izett, G.A., Cobban, W.A., and Gill, J.R., 1971, The Pierre Shale near Kremmling, Colorado, and its correlation to the east and west: U.S. Geological Survey Professional Paper 684–A, 19 p.

Kauffman, E.G., 1977, Geologic and biological overview, western interior Cretaceous basin, *in* E.G. Kauffman, ed., Cretaceous facies, faunas, and paleoenvironments across the western interior basin, *in* The Mountain Geologist, v. 14, no. 3–4, p. 75–99.

Kiteley, L.W., 1983, Paleogeography and eustatic-tectonic model of Late Campanian (Cretaceous) sedimentation, southwestern Wyoming and northwestern Colorado, *in* M.W. Reynolds and E.D. Dolly, eds., Mesozoic paleogeography of west-central United States: Rocky Mountain Section of Society of Economic Paleontologists and Mineralogists, Paleogeography symposium, Denver, Colo., 1983, v. 2., p. 273–303.

Konishi, Kenji, 1959, Upper Cretaceous surface stratigraphy, Axial Basin and Williams Fork area, Moffat and Routt Counties, Colorado, *in* J.D. Haun and R.J. Weimer, eds., Symposium on Cretaceous rocks of Colorado and adjacent areas: Rocky Mountain Association of Geologists Guidebook, 11th Field Conference, Denver, Colo., p. 67–73.

Lewis, J.L., 1961, The stratigraphy and depositional history of the Almond Formation in the Great Divide Basin, Sweetwater County, Wyoming, *in* G.J. Wiloth, ed., Symposium on Late Cretaceous rocks, Wyoming and adjacent areas: Wyoming Geological Association Guidebook, 16th Annual Field Conference, Casper, Wyo., p. 87–95.

Miller, F.X., 1977, Biostratigraphic correlation of the Mesaverde Group in southwestern Wyoming and northwestern Colorado, *in* H.K. Veal, ed., Exploration frontiers of the central and southern Rockies: Rocky Mountain Association of Geologists Guidebook, Field Conference 1977, p. 117–137.

Pryor, W.A., 1961, Petrology of Mesaverde sandstones in Wyoming, *in* G.J. Wiloth, ed., Symposium on Late Cretaceous rocks, Wyoming and adjacent areas: Wyoming Geological Association Guidebook, 16th Annual Field Conference, Casper, Wyo., p. 34–46.

Roehler, H.W., 1965, Summary of Pre-Laramide Late Cretaceous sedimentation in the Rock Springs uplift area [Wyoming], *in* R.H. DeVoto and R.K. Bitter, eds., Sedimentation of Late Cretaceous and Tertiary outcrops, Rock Springs uplift: Wyoming Geological Association Guidebook, 19th Field Conference, Casper, Wyo., p. 10–12.

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

______ 1985, Electric-log correlations of the Upper Cretaceous Rock Springs and Blair Formations on the east and west flanks of the Rock Springs uplift, Wyoming: U.S. Geological Survey Miscellaneous Field Studies Map MF–1785.

______ 1986, Electric-log correlations of the Upper Cretaceous rocks in the Mesaverde Group, Baxter Shale, and equivalent units across the Great Divide Basin in southwest Wyoming: U.S. Geological Survey Miscellaneous Field Studies Map MF–1828.

______ 1987, Surface-subsurface correlations of the Mesaverde Group and associated Upper Cretaceous Formations, Rock Springs, Wyoming, to Mount Harris, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF–1937.

______ 1989, Surface-subsurface correlations of the Mesaverde Group and associated Upper Cretaceous Formations, Rock Springs to Atlantic Rim, southwest Wyoming: U.S. Geological Survey Miscellaneous Field Studies Map MF–2078.

Roehler, H.W., and Hansen, D.E., 1989a, Depositional environments and correlation of the Cretaceous Mesaverde Group and Associated Formations, Lost Soldier Field to Cow Creek, southwest Wyoming: U.S. Geological Survey Miscellaneous Field Studies Map MF–2076.

______ 1989b, Depositional environments and correlation of the Cretaceous Mesaverde Group and associated formations, Cow Creek in southwest Wyoming to Mount Harris in northwest Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF–2077.

Roehler, H.W., and Phillips, S.T., 1980, Cross section of the Rock Springs and Blair Formations in measured sections in the Flaming Gorge-Minnies Gap-Clay Basin area, Utah and Wyoming: U.S. Geological Survey Miscellaneous Field Studies Map MF–1216.

Root, F.K., Glass, G.B., and Lane, D.W., 1973, Sweetwater County, Wyoming, geologic map, atlas, and summary of economic mineral resources: Wyoming Geological Survey, county resource series no. 2.

Schultz, A.R., 1909, The northern part of the Rock Springs coal field, Sweetwater County, Wyoming: U.S. Geological Survey Bulletin 341, p. 256–282.

______ 1910, The southern part of the Rock Springs coal field, Sweetwater County, Wyoming: U.S. Geological Survey Bulletin 381, p. 214–281.

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

Sears, J.D., 1926, Geology of the Baxter Basin gas field, Sweetwater County, Wyoming: U.S. Geological Survey Bulletin 781, p. 13–27.

Smith, J.H., 1961, A summary of stratigraphy and paleontology, Upper Colorado and Montanan Groups, south-central Wyoming, northeastern Utah, and northwestern Colorado, *in* G.J. Wiloth, ed., Symposium on Late Cretaceous rocks, Wyoming and adjacent areas: Wyoming Geological Association Guidebook, 16th Annual Field Conference, Casper, Wyoming, p. 101–112.

______ 1965, A summary of stratigraphy and paleontology, Upper Colorado and Montanan Groups, south-central Wyoming, northeastern Utah, and northwestern Colorado, *in* R.H. DeVoto and R.K. Bitter, eds., Sedimentation of Late Cretaceous and Tertiary outcrops, Rock Springs uplift: Wyoming Geological Association Guidebook, 19th Field Conference, Casper, Wyo., p. 13–26.

Tidwell, W.D., 1975, Common fossil plants of western North America: Provo, Utah, Brigham Young University Press, 197 p.

Willson, K.M., 1920, Tow Creek anticline (northern part): Colorado Geological Survey Bulletin 23, p. 30–39.

Zapp, A.D., and Cobban, W.A., 1962, Some late Cretaceous strand lines in southern Wyoming, *in* Short papers in geology, hydrology, and topography: U.S. Geological Survey Professional Paper 450–D, Art. 134, p. D52–D55.

APPENDIX

LITHOLOGIC DESCRIPTIONS OF MEASURED SECTIONS

Five measured sections of Mesaverde Group outcrops have been selected as representative of the group in widely separated parts of the study area where different stratigraphic nomenclature is employed. The geographic locations of the sections are shown on the index map on plate 1. The stratigraphic nomenclature, ages, and correlations of units in the measured sections are indicated on figure 5.

Section 3.—*Mesaverde Group and adjacent formations on Glades Ridge, 2 miles east of Flaming Gorge Reservoir*

[Sec. 24, T. 3 N., R. 21 E., Dagget County, Utah, and sec. 20, T. 12 N., R. 107 W., Sweetwater County, Wyo.]

	Thickness (Feet)
Fort Union Formation (part):	
98. Sandstone, gray, fine- to coarse-grained, crossbedded, with some thin lenses of pebble conglomerate composed mostly of black chert	145.0
Unconformity.	
Ericson Sandstone:	
Rusty zone:	
97. Shale, gray; and interbedded sandstone, gray, coarse-grained, abundant white and black grains; in thin, flat beds	28.5
Trail Member:	
96. Sandstone, gray, coarse-grained, abundant white and black grains; some trough crossbeds	58.2
95. Shale, brown, carbonaceous; and interbedded sandstone, gray, fine- to coarse-grained; in beds as much as 0.2 ft thick	3.4
94. Sandstone, gray, coarse-grained, abundant white and black grains; trough crossbedded	19.5
93. Sandstone, gray, coarse-grained, abundant white and black grains; abundant gray clay pebbles; some trough crossbeds	8.6
92. Sandstone, gray, coarse-grained, abundant white and black grains; trough crossbedded; some current ripples	120.0
Total Trail Member	209.7
Total Ericson Sandstone	238.2
Unconformity.	
Rock Springs Formation:	
Gottsche Tongue:	
91. Covered by talus and slope wash	35.0
90. Sandstone, gray, very fine grained, hematitic; no distinct bedding	9.4
89. Shale, gray, brown, partly carbonaceous; and some very thin interbedded sandstone, gray, very fine grained	35.0
88. Shale, very dark brown, very carbonaceous with a few coal laminae	0.5
87. Shale, dark-brown, carbonaceous	10.5

Section 3.–*Mesaverde Group*—Continued

	Thickness (Feet)
Rock Springs Formation—Continued	
Gottsche Tongue—Continued	
86. Sandstone, gray, very fine grained; in thin current-rippled beds	7.0
85. Shale, dark-brown, carbonaceous, silty	2.6
84. Coal	0.2
83. Shale, dark-brown, carbonaceous	2.5
82. Sandstone, gray, very fine grained; in thin current-rippled beds	1.6
81. Shale, gray-brown, silty, soft; and some thin interbedded sandstone, gray, very fine to fine-grained; in thin, tabular, current-rippled beds	23.0
Total Gottsche Tongue	127.3
McCourt Sandstone Tongue:	
80. Sandstone, gray, very fine to fine-grained, poorly sorted, subangular; low-angle, large-scale trough crossbeds and some subparallel, eastward-dipping planar crossbeds	54.0
79. Sandstone, light-gray, very fine grained; in thick, parallel, bioturbated beds	19.7
78. Sandstone, light-gray, very fine grained; in massive, parallel beds with some wave ripples	9.4
77. Shale, gray; and interbedded sandstone, gray, very fine grained; in thin parallel wave-rippled beds; sandstone beds are more abundant at the top	17.8
Total McCourt Sandstone Tongue	100.9
Coulson Shale Tongue:	
76. Shale, gray, fissile, soft	38.0
Brooks Sandstone Tongue:	
75. Sandstone, brown, very fine grained, hematitic; abundant small burrows	1.2
74. Shale, gray, silty	2.5
73. Shale, gray, carbonaceous	4.4
72. Sandstone, brown, very fine grained, hematitic; trough crossbedded	23.0
71. Shale, dark-brown, carbonaceous; and some interbedded siltstone, brown, carbonaceous, current-ripple-bedded	6.3
70. Shale, gray, silty to sandy; and some very thin interbedded sandstone, gray, very fine grained	10.0
69. Sandstone, light-gray, very fine grained, silty at the base	15.8
68. Shale, gray, soft	3.3
67. Sandstone, gray, weathers medium brown, very fine to medium grained, poorly sorted, subangular; in low-angle trough crossbeds	3.1
66. Sandstone, gray, very fine grained; no discernible bedding	8.2
65. Shale, gray; and interbedded sandstone, gray, very fine grained	7.7
64. Sandstone, gray, very fine grained, hematitic; in thin parallel beds	2.7
63. Shale, gray, soft	4.3
62. Coal	0.9
61. Shale, gray, slightly carbonaceous	5.0
60. Sandstone, gray, very fine grained; in large-scale, hummocky trough crossbeds; upper 1.0 ft is a silty paleosoil	13.0

Section 3.—Mesaverde Group—Continued

	Thickness (Feet)
Rock Springs Formation—Continued	
Brooks Sandstone Tongue—Continued	
59. Sandstone, light-gray, very fine grained; in parallel massive beds; the lower 8.0 ft contain some low-angle, eastward-dipping forest laminae	30.0
58. Shale, gray sandy; and thin interbedded sandstone, gray, very fine grained; in thin parallel beds	22.5
57. Sandstone, gray, very fine grained, very hematitic; in parallel beds with some very low angle, small-scale trough crossbeds	1.2
Total Brooks Sandstone Tongue	183.1
Black Butte Tongue:	
56. Shale, gray, soft	363.0
Main body of Rock Springs Formation:	
55. Sandstone, gray, very fine to medium-grained, poorly sorted, subangular, abundant dark and colored grains; in large-scale trough crossbeds	65.0
54. Shale, gray, sandy; and interbedded sandstone, gray, very fine to medium-grained; in trough crossbeds.	2.0
53. Sandstone, gray, very fine to medium-grained, poorly sorted, subangular; in large-scale trough crossbeds; some wood fragments and gray clay pebbles	6.0
52. Shale, gray; and some interlaminated sandstone, gray, very fine grained, silty	1.1
51. Sandstone, gray, very fine grained; in thin, parallel beds	4.0
50. Shale, gray, silty; and very thin interbedded sandstone, gray, very fine grained	12.3
49. Sandstone, tan, very fine grained; in thin parallel beds	12.0
48. Sandstone, light-gray, very fine grained; in large-scale moderately high angle trough crossbeds; some plant impressions	38.0
47. Sandstone, tan, very fine grained; in massive bed	7.0
46. Shale, gray, sandy laminae	9.0
45. Sandstone, very light gray, very fine grained, fairly well sorted, sparse black grains; in very small scale low-angle trough crossbeds	16.4
44. Sandstone, tan, very fine grained, mostly soft, friable, and in loose grains; no discernible bedding; some irregularly shaped, rounded calcareous concretions	102.0
43. Sandstone, gray, very fine grained; and very thin interbedded shale, gray, sandy	10.0
42. Sandstone, tan, very fine to fine-grained; in thin, parallel beds	55.0
41. Shale, dark-gray, carbonaceous	0.9
40. Sandstone, gray, very fine grained; and very thin interbedded siltstone, gray, shaly; in thin, parallel beds	2.3
39. Sandstone, gray, very fine grained; in thin, current-rippled beds	2.1
38. Shale, gray; and interlaminated sandstone, gray, very fine grained; coarsens upward; in thin, current- rippled beds	2.3
37. Shale, gray, fissile, soft	2.8
36. Shale, dark-brown, carbonaceous	3.4

Section 3.—*Mesaverde Group*—Continued

	Thickness (Feet)
Rock Springs Formation—Continued	
Main body of Rock Springs Formation—Continued	
35. Sandstone, gray, very fine grained; and very thin interbedded siltstone, gray, shaly; in thin parallel beds	5.7
34. Siltstone, gray; and interlaminated shale, gray; in thin current-rippled beds	1.2
33. Shale, dark-brown, carbonaceous, silty	4.1
32. Shale, gray, silty	2.0
31. Sandstone, gray, very fine grained; in thin, parallel beds	8.8
30. Shale, black, silty	0.7
29. Sandstone, gray, very fine grained; in thin parallel beds	7.0
28. Shale, gray, very silty	1.5
Total main body of Rock Springs Formation.	384.6
Chimney Rock Tongue:	
27. Sandstone, gray, very fine grained; in thick parallel beds	56.0
26. Sandstone, gray, very fine grained; and very thin interbedded shale, gray, sandy; in thin parallel beds and lenses	4.5
25. Sandstone, gray, very fine grained; in thick parallel massive beds	123.0
24. Shale, gray, sandy in the upper part	12.0
23. Shale, gray, soft	49.6
22. Sandstone, gray, very fine to fine-grained; in low-angle planar crossbeds	17.5
21. Shale, gray, soft	55.0
20. Sandstone, gray, very fine grained, silty; in thin parallel beds	5.0
19. Sandstone, tan, very fine grained; and interbedded shale, gray, soft; in thin parallel beds with some very small scale crossbedding	18.5
18. Shale, gray, soft	46.3
17. Sandstone, light-brown, very fine grained; and interbedded shale, gray; in thin parallel beds with some wave ripples	36.5
16. Shale, gray, soft	285.2
15. Sandstone, light-tan, very fine grained; and interbedded shale, gray; in thin parallel wave-rippled beds; some burrows	6.9
Total Chimney Rock Tongue	716.0
Total Rock Springs Formation	1,912.9
Blair Formation:	
Unnamed member:	
14. Shale, gray	1,100.0
Basal sandstones:	
13. Sandstone, gray, very fine grained; wave-rippled	0.2
12. Shale, gray	24.0
11. Sandstone, tan, very fine grained; in thin parallel beds	10.0
10. Shale, gray	625.0
9. Sandstone, tan, very fine grained; in thin parallel wave-rippled beds	70.0
8. Sandstone, brown, fine-grained; in thin parallel wave-rippled beds; caps ridge	1.5

Section 3.–*Mesaverde Group*–Continued

	Thickness (Feet)
Blair Formation	
Basal sandstones–Continued	
7. Sandstone, gray, very fine grained; in thin parallel wave-rippled beds	13.3
6. Sandstone, gray, very fine grained; in massive bed with wave-rippled upper surface	1.4
5. Sandstone, gray, very fine grained, and interbedded shale, gray; in thin parallel wave-rippled beds	79.2
4. Shale, gray; and interbedded sandstone, gray, very fine grained; in very thin, parallel beds	29.0
3. Shale, gray; and interbedded sandstone, gray, very fine grained; in very thin parallel beds and laminae	51.6
Total basal sandstones of Blair Formation	905.2
Total Blair Formation	2,005.2
Baxter Shale (part):	
2. Shale, gray, sandy	2.7
1. Shale, gray, soft	7.4
Total Baxter Shale measured	10.1

Section 17.–*Mesaverde Group and adjacent formations near abandoned mining town of Winton*

[Sec. 3, 4, 5, and 6, T. 20 N., R. 104 W., and sec. 12, T. 20 N., R. 105 W., Sweetwater County, Wyo.]

	Thickness (Feet)
Fort Union Formation (part):	
294. Sandstone, gray, very fine grained, soft, argillaceous; thin streaks are very hematitic	24.0
293. Sandstone, gray, very fine grained, soft, argillaceous; and interbedded shale, gray, silty, partly carbonaceous	15.0
Total Fort Union Formation measured	39.0
Unconformity.	
Almond Formation:	
292. Shale, dark-brown, carbonaceous, silty, soft	3.0
291. Shale, dark-gray, soft; scattered oyster shells	23.5
290. Coal	0.6
289. Shale, dark-brown, carbonaceous, soft	11.9
288. Coal	4.6
287. Shale, dark-gray, carbonaceous, soft	7.7
286. Sandstone, gray, very fine grained, calcareous, hematitic, firm; in thin parallel current-rippled bed	4.5
285. Shale, dark-gray, soft	6.6
284. Sandstone, gray, very fine grained, calcareous, hard; trough crossbedded	11.5
283. Shale, gray, carbonaceous at base, sandy in upper part	14.0
282. Coal	0.4
281. Shale, dark-brown, carbonaceous, silty	17.4
280. Coal	1.2
279. Shale, dark-gray-brown, carbonaceous, silty	7.7
278. Coal	4.0
277. Shale, dark-gray, carbonaceous, silty	6.2

Section 17.–*Mesaverde Group*–Continued

	Thickness (Feet)
Almond Formation–Continued	
276. Sandstone, gray, very fine grained, calcareous, hard; trough crossbedded	15.5
275. Shale, dark-brown, dark-gray, carbonaceous, soft; and thin interbedded sandstone, gray, very fine grained, argillaceous, soft, hematitic	28.1
274. Coal	1.5
273. Shale, dark-brown, carbonaceous	1.1
272. Sandstone, gray, very fine grained, calcareous, hard; trough crossbedded	6.5
271. Shale, gray, sandy, soft, partly carbonaceous; and interbedded sandstone, gray, very fine grained, calcareous, hard; ripple marked	14.0
270. Shale, gray, sandy, soft	8.0
269. Shale, gray, soft; abundant large oyster shells	1.0
268. Shale, gray, soft	7.1
267. Sandstone, gray, very fine grained, calcareous, hematitic, hard; ripple marked; some plant impressions; unidentified, poorly preserved reptile tracks about 5 inches in diameter	1.8
266. Shale, gray, gray-brown, slightly carbonaceous, soft	8.0
265. Coal	1.8
264. Shale, gray, silty, soft, carbonaceous at top; and some very thin interbedded sandstone, gray, very fine grained, calcareous	20.0
263. Sandstone, gray, very fine grained, calcareous, hematitic, hard; ripple marked	1.5
262. Shale, gray, sandy, soft	9.6
261. Sandstone, gray, very fine grained, calcareous, hematitic; trough crossbedded	4.8
260. Shale, dark-gray, slightly carbonaceous, soft	15.4
259. Coal	7.0
258. Shale, dark-brown, carbonaceous; scattered oyster shells	2.9
257. Sandstone, gray, very fine grained, calcareous, hard; lenticular; ripple marked	8.2
256. Shale, dark-gray, partly carbonaceous, firm	9.3
255. Shale, dark-brown, carbonaceous, soft, silty	0.6
254. Coal	0.4
253. Shale, dark-brown, carbonaceous, silty	0.9
252. Shale, gray, silty, soft	7.5
251. Sandstone, gray, very fine grained, silty, calcareous, hard; trough crossbedded	11.3
250. Shale, gray, gray-brown, partly carbonaceous; and some thin interbedded sandstone, gray, very fine grained, calcareous, hard, hematitic	39.0
249. Coal	5.7
248. Shale, dark-brown, carbonaceous, silty	5.8
247. Coal	1.0
246. Shale, dark-brown, dark-gray, carbonaceous; and some thin interbedded siltstone, gray, limy, hard; and sandstone, gray, very fine grained, calcareous, hard, partly parallel bedded and partly trough crossbedded	41.0
245. Sandstone, gray, very fine grained, calcareous, hematitic; trough crossbedded	4.8
244. Shale, dark-gray, partly carbonaceous, silty	30.8
243. Sandstone, gray, very fine grained, calcareous, hard, hematitic; ripple marked	3.5

Section 17.–*Mesaverde Group*–Continued

	Thickness (Feet)
Almond Formation–Continued	
242. Shale, dark-gray, carbonaceous; and very thin interbedded sandstone, gray, very fine grained, calcareous, hematitic	44.7
241. Shale, dark-gray, soft; and thin interbedded sandstone, gray, very fine grained, calcareous, hematitic	30.0
240. Sandstone, gray, very fine grained, calcareous, hematitic; ripple marked; trough crossbedded	4.3
239. Shale, dark-gray, silty to sandy; and interbedded sandstone, gray, very fine grained, calcareous, hematitic; trough crossbedded	52.0
238. Siltstone, gray, limy, hematitic, hard; part of a concretionary layer	0.5
237. Shale, dark-gray-brown, carbonaceous, very silty	6.5
236. Siltsone, gray-brown, limy, hematitic, hard; part of a concretionary layer	1.1
235. Shale, dark-gray-brown, carbonaceous, silty; and some very thin interbedded sandstone, gray, very fine grained, hematitic, partly carbonaceous	21.5
234. Sandstone, gray, very fine grained, hematitic; lenticular; trough crossbedded	5.5
233. Sandstone, brown, very fine grained, hematitic, carbonaceous, shaly	8.0
Total Almond Formation	623.2
Ericson Sandstone:	
Canyon Creek Member:	
232. Sandstone, medium-gray, very coarse grained, some medium to coarse grained, abundant dark grains; trough crossbedded; some lenses of conglomerate consisting of very small pebbles of subangular gray and black chert and gray siltstone	26.0
231. Sandstone, gray, very fine to coarse-grained, subangular, poorly sorted; trough crossbedded; some gray siltstone pebbles in the lower 6.0 ft	44.0
230. Conglomerate, gray; consists of small subangular pebbles of gray and black chert and gray siltstone in a very coarse grained sandstone matrix	1.3
Total Canyon Creek Member	71.3
Unconformity.	
Rusty zone:	
229. Sandstone, light-gray, fine to very coarse grained, poorly sorted, subangular, white clay cement; irregular rusty hematitic staining along outcrops.	38.5
228. Shale, gray, silty to sandy, and interbedded siltstone, gray	9.5
227. Sandstone, gray, very fine grained, fairly well sorted, partly hematitic; trough crossbedded	22.8
226. Sandstone, gray, very fine grained, hematitic, hard; abundant small flat gray clay pebbles	0.8
225. Shale, gray, brown, soft; and interbedded siltstone, gray, calcareous, firm	5.1
224. Sandstone, gray, very fine grained, very hematitic; weathers rust	0.2
Total Rusty zone	76.9

Section 17.–*Mesaverde Group*–Continued

	Thickness (Feet)
Ericson Sandstone–Continued	
Trail Member:	
223. Sandstone, gray, fine to very coarse grained, angular to subangular, poorly sorted, abundant black, brown, and white grains; trough crossbedded	15.3
222. Sandstone, light-gray, very fine to fine-grained; trough crossbedded	21.0
221. Sandstone, light- to medium-gray, fine- to coarse-grained; trough crossbedded	45.0
220. Sandstone, gray, very fine grained, very hematitic; scattered plant fragments; weathers rust	1.1
219. Sandstone, light-gray, very fine to fine-grained, fairly well sorted, scattered colored grains; trough cross-bedded	72.2
218. Sandstone, light- to medium-gray, mostly very coarse grained, some very fine to medium-grained, abundant dark grains; trough crossbedded	50.0
217. Sandstone, gray, mostly fine- to medium-grained, some colored grains, fairly well sorted; trough crossbedded	41.5
216. Sandstone, gray, very fine grained, hematitic; weathers rust	0.9
215. Sandstone, light-gray, very fine to fine-grained, fairly well sorted, scattered colored grains; trough crossbedded	26.2
214. Sandstone, gray, very fine grained, hematitic; weathers rust	1.2
213. Sandstone, light-gray, very fine to fine-grained, fairly well sorted, scattered red, black, and white grains; convoluted trough crossbedding	48.3
Total Trail Member	322.7
Total Ericson Sandstone	470.9
Unconformity.	
Rock Springs Formation:	
212. Siltstone, gray, very hematitic; weathers dark-brown	0.5
211. Shale, brown, silty to sandy; and some interbedded sandstone, gray, very fine grained, silty, shaly, hard	5.0
210. Sandstone, gray, very fine grained, very hematitic; weathers dark brown	0.8
209. Shale, brown, slightly carbonaceous, very sandy	7.5
208. Sandstone, gray, very fine grained, very hematitic.	2.4
207. Shale, gray, sandy, soft	8.5
206. Sandstone, gray, very fine grained, calcareous, hard; ripple marked	5.0
205. Shale, dark-brown, carbonaceous, silty; and some very thin interbedded sandstone, gray, very fine grained, calcareous, hematitic; thin layers of hematite concretions near the middle and in upper part	53.5
204. Sandstone, gray, very fine grained, trough crossbedded; weathers white	11.5
203. Shale, dark-gray-brown, carbonaceous, silty	1.4
202. Coal	0.4
201. Sandstone, gray, very fine grained, hematitic; and interbedded shale, gray, carbonaceous	19.0

Section 17.–*Mesaverde Group*—Continued

Rock Springs Formation—Continued	*Thickness (Feet)*
200. Shale, dark-brown, carbonaceous	1.6
199. Coal	0.9
198. Shale, dark-brown, carbonaceous	10.0
197. Coal	0.6
196. Shale, dark-brown, carbonaceous; and interbedded sandstone, gray, very fine grained, argillaceous	15.3
195. Siltstone, gray, calcareous, hematitic	1.0
194. Shale, dark-brown, carbonaceous	2.8
193. Coal	3.6
192. Shale, dark-gray, carbonaceous	0.4
191. Sandstone, gray, very fine grained, calcareous; ripple marked	5.2
190. Shale, gray, carbonaceous, silty; and interbedded sandstone, gray, very fine grained, calcareous	6.0
189. Coal	5.7
188. Shale, dark-gray-brown, carbonaceous, soft	15.6
187. Sandstone, gray, very fine grained, calcareous; trough crossbedded	11.0
186. Shale, gray, silty, partly carbonaceous; and interbedded sandstone, gray, very fine grained, calcareous; trough crossbedded	85.0
185. Shale, dark-brown, carbonaceous, silty	1.4
184. Shale, dark-gray-brown, carbonaceous, soft; some very thin beds of siltstone, gray, limy, in lower part	15.0
183. Coal	1.1
182. Shale, dark-brown, carbonaceous, silty	4.6
181. Coal	2.5
180. Shale, dark-brown, carbonaceous	1.9
179. Coal	0.7
178. Shale, dark-brown, carbonaceous, silty	4.8
177. Siltstone, gray, hematitic, calcareous; weathers rust	1.0
176. Shale, dark-brown, carbonaceous, silty	1.5
175. Coal	0.6
174. Shale, dark-brown, carbonaceous	2.1
173. Coal	1.1
172. Shale, dark-brown, carbonaceous	14.3
171. Sandstone, gray, very fine grained, calcareous; trough crossbedded	16.5
170. Shale, gray, carbonaceous, silty	11.0
169. Shale, dark-gray-brown, very carbonaceous with coal laminae	1.1
168. Sandstone, gray, very fine grained, calcareous, and interbedded shale, gray, partly carbonaceous	27.8
167. Shale, dark-gray, carbonaceous, silty	10.7
166. Coal	0.9
165. Shale, dark-gray, carbonaceous, silty; thin laminae of coal near top	5.0
164. Coal	8.5
163. Sandstone, gray, very fine grained, argillaceous; and very thin interbedded shale, gray, sandy, soft, partly carbonaceous	48.0
162. Shale, dark-gray, carbonaceous, silty	1.0
161. Coal	0.5
160. Shale, dark-gray, carbonaceous, silty	5.8
159. Coal	1.0
158. Shale, dark-gray, carbonaceous, silty	5.4
157. Sandstone, gray, very fine grained, calcareous; ripple marked	2.8
156. Shale, gray, carbonaceous, soft	5.2

Section 17.–*Mesaverde Group*—Continued

Rock Springs Formation—Continued	*Thickness (Feet)*
155. Coal	0.8
154. Shale, dark-gray, carbonaceous	3.2
153. Siltstone, gray, limy, hematitic	0.2
152. Shale, gray, sandy, soft	5.2
151. Sandstone, gray, very fine grained, calcareous; and interbedded shale, gray, partly carbonaceous	34.0
150. Coal	11.1
149. Shale, gray, partly carbonaceous; and interbedded sandstone, gray, very fine grained, calcareous, hematitic	97.0
148. Sandstone, gray, very fine grained, calcareous; ripple marked	1.8
147. Shale, gray, partly carbonaceous; and thin interbedded sandstone, gray, very fine grained, calcareous	146.9
146. Coal	7.9
145. Shale, dark-gray, carbonaceous; and interbedded sandstone, gray, very fine grained, hematitic	27.5
144. Coal	1.1
143. Shale, gray, partly carbonaceous; and interbedded sandstone, gray, very fine grained, calcareous	3.6
142. Sandstone, gray, very fine grained, calcareous; trough crossbedded	27.0
141. Shale, dark-gray, carbonaceous	6.4
140. Coal	1.2
139. Shale, dark-gray, carbonaceous, soft	6.3
138. Interval covered by soil and alluvium	48.0
137. Sandstone, gray, very fine grained, calcareous, hematitic; and interbedded shale, gray, soft	20.0
136. Sandstone, gray, very fine grained, calcareous; trough crossbedded	4.8
135. Sandstone, gray, very fine grained, argillaceous, hematitic; and interbedded shale, gray, silty, partly carbonaceous	12.3
134. Coal	1.6
133. Shale, dark-brown, carbonaceous, silty	3.4
132. Coal	0.4
131. Shale, dark-brown, carbonaceous, silty	1.2
130. Shale, gray, soft; and interbedded sandstone, gray, very fine grained, argillaceous	32.0
129. Coal	2.8
128. Shale, dark-brown, carbonaceous, soft	0.4
127. Sandstone, gray, very fine grained, calcareous, silty	4.0
126. Shale, gray, soft; and very thin interbedded sandstone, gray, very fine grained	5.8
125. Coal	2.0
124. Shale, dark-gray, silty, soft; and very thin interbedded sandstone, gray, very fine grained, calcareous, hematitic	22.4
123. Shale, dark-gray, carbonaceous, silty, firm	6.6
122. Coal	2.4
121. Shale, dark-gray, carbonaceous, silty	1.1
120. Sandstone, gray, very fine grained, calcareous; and interbedded shale, gray, partly carbonaceous	30.0
119. Shale, dark-gray, carbonacous	3.2
118. Coal	4.6
117. Shale, dark-gray-brown, carbonaceous, silty	0.8
116. Sandstone, gray, very fine grained, calcareous; trough crossbedded	10.9
115. Shale, dark-gray, slightly carbonaceous, soft	4.0

Section 17.–*Mesaverde Group*—Continued

Rock Springs Formation—Continued	*Thickness (Feet)*
114. Coal	3.1
113. Shale, dark-gray, carbonaceous; and interbedded sandstone, gray, very fine grained, argillaceous; a few laminae of coal	34.1
112. Coal	0.9
111. Shale, dark-gray, carbonaceous; and some interbedded sandstone, gray, very fine grained, calcareous	27.3
110. Coal	4.2
109. Shale, dark-gray, carbonaceous, silty; and interbedded sandstone, gray, very fine grained, calcareous, hard	37.8
108. Shale, gray, soft, partly carbonaceous; and interbedded sandstone, gray, very fine grained, calcareous	28.7
107. Coal	2.7
106. Shale, gray, slightly carbonaceous, silty	8.0
105. Shale, gray, soft; and interbedded sandstone, gray, very fine grained, calcareous, hematitic	15.4
104. Coal	4.0
103. Shale, dark-gray, carbonaceous in the upper part; and interbedded sandstone, gray, very fine grained, calcareous	28.0
102. Shale, dark-gray, carbonaceous, silty	0.3
101. Coal	2.3
100. Shale, dark-gray, dark-brown, carbonaceous; and some very thin interbedded sandstone, gray, very fine grained, calcareous	12.5
99. Coal	1.2
98. Shale, dark-gray, carbonaceous; and some interlaminated siltstone, gray, limy, hard	9.0
97. Coal	0.9
96. Shale, dark-gray, dark-brown, carbonaceous, silty; and very thin interbedded sandstone, gray, very fine grained, hematitic, hard; and siltstone, gray, calcareous, hard	28.4
95. Sandstone, gray, very fine grained, calcareous, hematitic; trough crossbedded	20.0
94. Shale, gray, soft; and interbedded sandstone, gray, very fine grained, calcareous	20.0
93. Shale, dark-gray, carbonaceous, silty	1.7
92. Coal	2.7
91. Shale, brown, carbonaceous, soft	2.8
90. Shale, gray, soft	5.0
89. Coal	3.5
88. Shale, gray, silty; one lamina of siltstone, gray, limy near the middle	4.9
87. Sandstone, gray, very fine grained, calcareous, hematitic	4.0
86. Shale, gray, partly carbonaceous, silty; and some very thin interbedded sandstone, gray, very fine grained, hematitic	17.7
85. Coal	1.8
84. Shale, gray, silty, hard	1.0
83. Sandstone, gray, very fine grained, calcareous, silty; trough crossbedded	3.2
82. Shale, gray, sandy, soft	4.0
81. Shale, dark-gray, carbonaceous, silty	0.8
80. Coal	1.8
79. Shale, gray, brown, carbonaceous	5.7

Section 17.–*Mesaverde Group*—Continued

Rock Springs Formation—Continued	*Thickness (Feet)*
78. Sandstone, gray, very fine grained, calcareous, hematitic; trough crossbedded	15.2
77. Coal	1.7
76. Shale, dark-brown, carbonaceous	0.3
75. Sandstone, gray, very fine grained, argillaceous, soft; and interbedded shale, gray, soft	13.5
74. Sandstone, gray, very fine grained, calcareous	12.2
73. Shale, gray, silty, soft; and thin interbedded sandstone, gray, very fine grained, calcareous	50.0
72. Sandstone, gray, very fine grained, calcareous; ripple marked in upper part	27.5
71. Shale, gray, carbonaceous, sandy	1.3
70. Coal	1.2
69. Shale, brown, carbonaceous, soft	0.1
68. Sandstone, gray, very fine grained, calcareous; trough crossbedded	30.6
67. Shale, dark-brown, carbonaceous, silty	1.3
66. Coal	1.2
65. Shale, dark-gray, carbonaceous at top; and thin interbedded sandstone, gray, very fine grained, calcareous	7.1
64. Shale, dark-gray, carbonaceous, silty	0.9
63. Coal	0.7
62. Shale, dark-gray, carbonaceous, silty; and thin interbedded sandstone, gray, very fine grained, calcareous	16.4
61. Sandstone, gray, very fine grained, calcareous; in large-scale hummocky crossbeds	53.0
60. Shale, gray, sandy, soft	7.9
59. Sandstone, gray, very fine grained, calcareous; some scattered clay pebbles that weather red; trough crossbedded	44.0
58. Sandstone, gray, very fine grained, calcareous, trough crossbedded, and interbedded shale, gray, silty, soft	40.0
Total Rock Springs Formation	1,665.4

Blair Formation:	
Unnamed member:	
57. Shale, gray, silty to sandy, soft; and abundant interlaminated and thin interbedded sandstone, gray, very fine grained, calcareous, hard; and siltstone, gray, calcareous	35.0
56. Siltstone, gray, limy, hard; in layer of large, flattened concretions	1.4
55. Shale, gray, soft; and interlaminated sandstone, gray, very fine grained; and siltstone, gray, calcareous	8.1
54. Sandstone, gray, very fine grained, silty, calcareous, trough crossbedded; and interbedded shale, gray, silty	3.4
53. Shale, gray, silty, soft; and a few interlaminated sandstones, gray, silty; and shale, gray	9.3
52. Sandstone, gray, very fine grained, calcareous; trough crossbedded; abundant worm borings	7.4
51. Shale, gray, soft; and very thin interbedded sandstone, gray, very fine grained	30.0
50. Sandstone, gray, very fine grained, calcareous, massive, abundant small trails on upper surface	10.7

Section 17.—*Mesaverde Group*—Continued

	Thickness (Feet)
Blair Formation–Continued	
Unnamed member—Continued	
49. Shale, gray, silty, soft; and several very thin interbedded sandstones, gray, very fine grained, calcareous	38.5
48. Sandstone, gray, very fine grained, calcareous; trough crossbedded	1.8
47. Shale, gray, silty, soft	6.4
46. Sandstone, gray, very fine grained, calcareous; abundant worm borings	1.3
45. Shale, gray, silty, soft	22.2
44. Sandstone, gray, very fine grained, calcareous; trough crossbedded	0.7
43. Shale, gray, soft	2.9
42. Sandstone, gray, very fine grained, calcareous, hard; trough crossbedded	1.4
41. Shale, gray, silty, soft; and several laminae of sandstone, gray, calcareous, and siltstone, gray, calcareous	21.4
40. Shale, gray, soft; and thin interbedded sandstone, gray, very fine grained	3.0
39. Sandstone, gray, very fine grained, calcareous	0.7
38. Shale, gray, soft	1.4
37. Sandstone, gray, very fine grained, calcareous, hard.	1.3
36. Shale, gray, soft	2.9
35. Siltstone, gray, limy, hard; in layer of large, flattened concretions	1.5
34. Shale, gray, soft; and numerous interlaminated sandstones, gray, very fine grained, calcareous, and siltstones, gray, calcareous	83.0
33. Siltstone, gray, limy, hard	1.0
32. Shale, gray, soft	2.9
31. Siltstone, gray, limy, hard	0.6
30. Shale, gray, soft; and some interlaminated sandstone, gray, very fine grained, calcareous	17.0
29. Sandstone, gray, very fine grained, silty, calcareous; very thin bedded	1.5
28. Shale, gray, silty, soft; and some interlaminated sandstone, gray, very fine grained, calcareous	40.3
27. Sandstone, gray, very fine grained, calcareous, hard, ripple-marked; and interbedded shale, gray, soft.	2.2
26. Shale, gray, silty, soft; and some interlaminated and thin interbedded sandstone, gray, very fine grained, silty, calcareous, and siltstone, gray, limy, platy, hard	87.3
25. Siltstone, gray, limy, platy, hard	1.2
24. Shale, gray, fissile, silty, soft; and some interlaminated and thin interbedded sandstone, gray, very fine grained, calcareous, hard, and siltstone, gray, calcareous	172.5
23. Sandstone, gray, very fine grained, silty, calcareous; ripple marked	0.8
22. Shale, gray, silty, soft; and some interlaminated sandstone, gray, very fine grained, and siltstone, gray, calcareous	45.5
21. Sandstone, gray, very fine grained, calcareous, hard.	7.7
20. Shale, gray, soft	6.5
19. Sandstone, gray, very fine grained, calcareous; and interbedded shale, gray, soft	4.5
18. Shale, gray, soft	7.5
17. Sandstone, gray, very fine grained, calcareous, hard.	0.7
16. Shale, gray, silty, soft	2.5

Section 17.—*Mesaverde Group*—Continued

	Thickness (Feet)
Blair Formation–Continued	
Unnamed member—Continued	
15. Sandstone, gray, very fine grained, calcareous, hard.	0.5
14. Shale, dark-gray, silty, soft; and interlaminated and thin interbedded sandstone, gray, very fine grained, calcareous, hard, and siltstone, gray, calcareous	108.0
13. Shale, gray, silty, soft	12.8
Total unnamed member	819.3
Basal sandstones:	
12. Sandstone, gray, very fine grained, silty, calcareous; and interbedded shale, gray, silty, soft	20.0
11. Shale, gray, silty, soft	4.8
10. Sandstone, gray, very fine grained, silty, calcareous.	1.5
9. Shale, gray, silty, soft	5.8
8. Sandstone, gray, silty, soft	1.5
7. Shale, dark-gray, silty, soft; and some very thin interbedded and interlaminated siltstone, gray, calcareous, hard	101.5
6. Sandstone, gray, very fine grained, silty, calcareous.	3.7
5. Shale, dark-gray, soft; and some interlaminated sandstone, gray, very fine grained, calcareous, and siltstone, gray, calcareous, hard	35.0
4. Sandstone, gray, very fine grained, calcareous, ripple marked; some plant fragments; abundant small, flat gray clay pebbles in lower part	17.3
3. Shale, dark-gray, soft; and some interlaminated and very thin interbedded sandstone, gray, very fine grained, and siltstone, gray, calcareous, hard	265.0
2. Sandstone, gray, very fine grained, calcareous, hard; ripple marked; trough crossbedded	17.7
Total basal sandstones	473.8
Total Blair Formation	1,293.1
Baxter Shale (part):	
1. Shale, dark-gray, soft	35.0

Section 71.—*Mesaverde Group and adjacent formations, measured across Separation Rim*

[Northern parts of secs. 3 and 4, T. 24. N., R. 89 W., Carbon County, Wyo.]

	Thickness (Feet)
Lewis Shale (part):	
137. Shale, gray, soft	215.0
Almond Formation:	
136. Shale, gray, carbonaceous; and several 1–2-ft-thick interbedded sandstones, light-gray, very fine grained; in thin current-rippled beds	34.0
135. Shale, gray, soft	32.2
134. Shale, gray, carbonaceous	5.0
133. Shale, gray, carbonaceous; and numerous 1–2-ft-thick interbedded sandstones, light-gray, very fine grained; in thin wave-rippled beds	23.2
132. Shale, gray, carbonaceous	12.7
131. Sandstone, light-gray, very fine grained; in thin current-rippled beds	5.0

Section 71.—Mesaverde Group—Continued

		Thickness (Feet)
Almond Formation—Continued		
130.	Shale, gray, silty, carbonaceous; becomes very carbonaceous in the upper 4.0 ft	26.5
129.	Sandstone, light-gray, very fine grained; in thin current-rippled beds	4.4
128.	Shale, gray, slightly carbonaceous	12.9
127.	Sandstone, light-gray, very fine grained, poorly sorted, subangular, very sparse black and red grains, in thin current-rippled beds 2–5-ft thick; and interbedded shale, gray, carbonaceous, silty.	79.0
126.	Shale, gray, carbonaceous	7.8
125.	Shale, gray, carbonaceous, silty; and interbedded 2–3-ft-thick sandstone, light-gray, very fine grained, in thin current-rippled beds	35.0
124.	Sandstone, light-gray, very fine grained; in thin current-rippled beds	2.6
123.	Shale, gray, carbonaceous, silty	2.5
122.	Sandstone, light-gray, very fine grained, sparse black and colored grains; in thin current-rippled beds	1.6
121.	Shale, gray, silty, carbonaceous	4.4
	Total Almond Formation	288.8
Pine Ridge Sandstone:		
120.	Sandstone, light-gray, fine- to medium-grained, poorly sorted, subangular, sparse black, red, and gray grains, white clay cement; in large trough crossbeds with some shale drape	87.8
119.	Shale, dark-gray, carbonaceous, silty	2.3
118.	Sandstone, tan, very fine to fine-grained; in thin undulating beds	1.0
117.	Shale, gray, sandy, slightly carbonaceous	4.0
116.	Sandstone, light-gray, very fine grained; indistinct bedding	4.6
115.	Shale, gray, sandy	3.3
114.	Sandstone, gray, weathers rust, very fine to fine-grained, sparse black and red grains; in thin subparallel beds; sharp basal contact; some plant impressions	10.0
	Total Pine Ridge Sandstone	113.0
Unconformity.		
Allen Ridge Formation:		
113.	Shale, gray, soft, some beds slightly carbonaceous; and two 1-ft-thick interbedded sandstone beds, gray, very fine grained	47.0
112.	Shale, dark-gray, carbonaceous	7.7
111.	Shale, gray, soft	10.0
110.	Sandstone, tan, fine- to medium-grained; in large-scale hummocky crossbeds	10.0
109.	Shale, gray, sandy	2.4
108.	Shale, gray, carbonaceous	4.0
107.	Shale, gray, soft	6.0
106.	Sandstone, tan, fine- to medium-grained; in large-scale hummocky crossbeds	42.0
105.	Shale, gray, sandy, soft	3.5
104.	Sandstone, gray, very fine grained; in small-scale trough crossbeds	2.2
103.	Shale, gray, soft	7.8
102.	Shale, gray, carbonaceous; thin bed of sandstone, gray, very fine grained, near middle	3.4

Section 71.—*Mesaverde Group*—Continued

		Thickness (Feet)
Allen Ridge Formation—Continued		
101.	Shale, gray, soft	10.0
100.	Sandstone, tan, very fine grained; in thin, even parallel beds	1.3
99.	Shale, gray, soft, carbonaceous in upper 1.5 ft	5.8
98.	Sandstone, tan, very fine grained; in thin parallel laminae	1.8
97.	Shale, gray, soft	6.4
96.	Shale, dark-gray, carbonaceous	1.2
95.	Shale, gray, silty	3.7
94.	Shale, gray-brown, very slightly carbonaceous	1.2
93.	Sandstone, tan, very fine grained	0.5
92.	Shale, gray, soft	6.0
91.	Sandstone, gray, fine- to medium-grained, poorly sorted, subangular, scattered black and red grains; in small-scale trough crossbeds	9.9
90.	Shale, gray, very sandy	2.5
89.	Sandstone, gray, fine- to medium-grained; in small-scale, moderately high angle trough crossbeds	12.9
88.	Shale, gray, soft	9.7
87.	Sandstone, tan, fine-grained; in parallel, hummocky crossbeds	7.1
86.	Shale, gray, soft	10.1
85.	Sandstone, tan, very fine to fine-grained, poorly sorted, subangular, scattered black and red grains; in small- scale low-angle and planar crossbeds as much as 1.5 ft thick; foreset laminae in the planar crossbeds dip north and south, but mostly south	8.9
84.	Shale, gray, soft; a few laminae of sandstone, gray, very fine grained, in the lower 7.0 ft	22.0
83.	Sandstone, gray, very fine grained; in thin, even, parallel beds	4.5
82.	Shale, gray, soft	7.2
81.	Sandstone, gray, very fine grained; in thin, even, parallel beds	4.1
80.	Shale, gray, soft	29.5
79.	Sandstone, brown, fine-grained; in thin, subparallel wave-rippled beds	4.2
78.	Shale, gray, silty, soft	59.0
77.	Interval covered by Quaternary alluvium. Weathers to nonresistant valley and is probably shale	145.0
76.	Shale, gray, soft; and some interbedded 1–5-ft-thick sandstone, tan, fine-grained, in thin, subparallel wave-rippled beds; sandstone beds are more numerous near the base	205.0
75.	Sandstone, tan, gray, fine- to medium-grained; in thin, subparallel wave-rippled beds	30.0
74.	Shale, gray, soft; and some very thin interbedded sandstones, tan, fine-grained; in thin, subparallel beds	49.4
73.	Sandstone, tan, fine-grained; in mostly thin, subparallel beds	20.0
72.	Shale, gray, soft	10.0
71.	Sandstone, tan, gray, fine-grained; in thin, subparallel beds; partly wave rippled; small-scale trough crossbeds at top	16.0
70.	Shale, gray, soft	31.7
69.	Sandstone, tan, fine-grained; in subparallel, wave-rippled beds	12.3
68.	Shale, gray, soft, some sandy laminae; layer of small hematite concretions near middle	10.0

Section 71.–*Mesaverde Group*—Continued

	Thickness (Feet)
Allen Ridge Formation—Continued	
67. Shale, dark-gray, carbonaceous	5.0
66. Sandstone, tan, fine- to medium-grained; indistinct bedding	28.0
65. Shale, gray, soft	12.0
64. Shale, dark-gray, carbonaceous; and very thin interbedded and interlaminated sandstone, tan, very fine grained	22.0
63. Sandstone, rust-brown, fine-grained; in thin, subparallel current-rippled beds	2.0
62. Shale, gray, soft	7.5
61. Shale, dark-gray, carbonaceous	5.0
60. Sandstone, white, fine-grained, quartzose, sparse dark and red grains; in thin, subparallel wave-rippled and current-rippled beds at the base; becomes subparallel bioturbated beds, about 5.0 ft thick, at the top	41.0
59. Shale, dark-gray, carbonaceous; and some thin, lenticular, interlaminated sandstone, white, very fine grained; flaser bedding	16.5
58. Sandstone, white, fine-grained; in subparallel, current-rippled beds	5.0
57. Shale, dark-gray, carbonaceous; and thin, lenticular, interlaminated sandstone, white, very fine grained; flaser bedding	20.9
56. Sandstone, tan at bottom, white at top, fine- grained; in thin, subparallel, current-rippled beds	5.0
55. Shale, gray, soft	9.4
54. Sandstone, brown, fine-grained; in thin current-rippled beds; abundant burrows	5.0
53. Shale, gray, soft	34.0
52. Sandstone, tan, very fine to fine-grained; in thin, subparallel, current-rippled and wave-rippled beds; abundant burrows	8.0
51. Shale, gray, soft	4.7
50. Shale, black, carbonaceous	3.0
49. Coal, shaly	1.9
48. Sandstone, tan at base, white at top, fine- to medium-grained; in thin, subparallel, current-rippled and wave-rippled beds	10.0
47. Shale, gray, soft, sandy laminae	6.2
46. Sandstone, tan, fine-grained; in thin, subparallel, wave-rippled beds	1.5
45. Shale, dark-gray, carbonaceous; some coal laminae	3.2
44. Sandstone, white, fine- to medium-grained; in thin, subparallel, current-rippled and wave-rippled beds; coarsens upward	7.4
43. Shale, gray, sandy, soft	5.0
42. Sandstone, tan at base, gray at top, fine- to medium-grained; in thin, subparallel, current-rippled and wave-rippled beds; abundant burrows	7.3
41. Shale, gray, soft	11.5
40. Sandstone, tan, brown, fine-grained; in thin subparallel beds	10.6
39. Shale, gray, soft, some sandy laminae	20.1
38. Sandstone, tan, fine- to medium-grained; in thin subparallel beds; abundant burrows	7.4
Total Allen Ridge Formation	1,383.2

Section 71.–*Mesaverde Group*—Continued

	Thickness (Feet)
Haystack Mountains Formation:	
Unnamed sandstone member:	
37. Sandstone, white, fine- to medium-grained, black and white grains; in planar and small-scale trough crossbeds in lower part; upper 9.0 ft are thin, parallel, tabular beds	45.0
36. Sandstone, tan, fine-grained; in thin, parallel beds	20.3
Total unnamed sandstone member	65.3
Unnamed shale member:	
35. Shale, gray, soft; and some interlaminated and thin interbedded sandstone, gray, very fine grained, and siltstone, gray; sandstone and siltstone beds are more numerous at the top	112.7
Unnamed sandstone member:	
34. Sandstone, tan in lower part, white at top, fine- to medium-grained; in thin, parallel beds with some south-dipping foreset laminae	36.5
33. Sandstone, gray, tan, very fine to fine-grained, in thin, parallel beds; and interbedded shale, gray, soft	26.7
Total unnamed sandstone member	63.2
Unnamed shale member:	
32. Shale, gray, soft; and a few interbedded sandstones, gray, very fine grained; in beds as much as 1.5 ft thick with parallel bedding	30.0
31. Shale, gray, soft	50.0
Total unnamed shale member	80.0
Unnamed sandstone member:	
30. Sandstone, gray, fine- to medium-grained, black and white grains; in parallel beds; some beds have north- and south-dipping foreset laminae that form herringbone crossbeds	25.0
29. Sandstone, tan, very fine to medium-grained, in thin, subparallel beds and laminae; and some thin interbedded shale, gray	13.0
28. Shale, gray, soft, some silty and sandy laminae	15.5
27. Sandstone, gray, fine- to medium-grained; in thin, parallel beds as much as 2.0 ft thick; foreset laminae dip north and south	28.0
26. Sandstone, tan, very fine grained, in thin, parallel beds; and interbedded shale, gray, sandy	22.3
Total unnamed sandstone member	103.8
Unnamed shale member:	
25. Shale, gray, soft; and a few very thin beds and laminae of sandstone, gray, very fine grained, and siltstone, gray	106.8
Hatfield Sandstone Member:	
24. Sandstone, tan, brown, very fine grained, hard; caps underlying sandstone bed	16.0
23. Sandstone, tan, brown, very fine grained, in even, parallel laminae and beds as much as 1.5 ft thick, and interbedded shale, gray, soft	108.0
Total Hatfield Sandstone Member	124.0

Section 71.–*Mesaverde Group*—Continued

	Thickness (Feet)
Haystack Mountains Formation—Continued	
Espy Member:	
22. Shale, gray, soft	27.8
21. Shale, gray, soft; and abundant laminae of siltstone, gray	9.7
20. Siltstone, tan; in even, parallel laminae; some *Helminthoidea*	0.7
19. Shale, gray, soft; and sparse laminae of sandstone, gray, very fine grained, and siltstone, gray	384.0
Total Espy Member	422.2
Deep Creek Sandstone Member:	
18. Sandstone, tan, brown, very fine grained; in thin, subparallel beds	12.0
17. Shale, gray, soft; and some laminae of sandstone, gray, very fine grained, and siltstone, gray	42.5
16. Sandstone, tan, brown, very fine grained; in thin, even, parallel beds	83.0
Total Deep Creek Sandstone Member	137.5
Total Haystack Mountains Formation	1,199.5
Cody Shale (part):	
15. Shale, gray, soft; and a few laminae of sandstone, gray, very fine grained, and siltstone, gray	187.5
14. Sandstone, tan, very fine grained; in thin, even, parallel beds as much as a few inches thick	35.4
13. Shale, gray, soft; and some interbedded sandstone, gray, very fine grained, in beds as much as 1 ft thick	55.0
12. Sandstone, tan, very fine grained; in thin, even, parallel beds as much as a few inches thick; coarsens upward	42.7
11. Shale, gray, soft; and some laminae of sandstone, gray, very fine grained, and siltstone, gray	65.0
10. Sandstone, tan, brown, very fine grained; in thin, parallel beds; coarsens upward; abundant very small burrows including *Ophiomorpha*	2.4
9. Shale, gray, soft	4.0
8. Sandstone, tan, very fine grained; in parallel and subparallel, thin, even beds as much as a few inches thick; abundant crawling trails on the upper surface	68.0
7. Shale, gray, soft	168.0
6. Sandstone, tan, very fine grained; in thin, parallel beds as much as a few inches thick; very low angle trough crossbedding in the upper 3.0 ft	35.0
5. Shale, gray, soft	115.0
4. Shale, gray, soft; and thin interbedded sandstone, gray, very fine grained; in thin, parallel laminae; one sandstone bed contains layer of small open-coiled ammonites	26.0
3. Shale, gray, soft	75.5
2. Sandstone, tan, very fine grained; in thin, parallel, planar crossbeds	15.5
1. Shale, gray, soft	85.0
Total Cody Shale measured	980.0

Section 57.—*Mesaverde Group and adjacent formations, measured at Beckman Canyon on Atlantic Rim*

[Secs. 6, 7, 8, and 18, T. 19 N., R. 88 W., and sec. 36, T. 20 N., R. 89 W., Carbon County, Wyo.]

	Thickness (Feet)
Lewis Shale (part):	
227. Shale, gray, soft	15.0
226. Sandstone, gray, very fine grained; in thin, even, parallel beds	11.0
225. Shale, gray, soft	59.0
224. Shale, gray, soft; several 0.5-ft-thick beds of hematitic siltstone, gray, in middle and upper parts	8.0
Total Lewis Shale measured	93.0
Almond Formation:	
223. Shale, dark-gray, carbonaceous	3.0
222. Sandstone, tan, gray, very fine grained, indistinct bedding; and some thin interbedded shale, gray	14.5
221. Shale, gray, soft	6.0
220. Interval covered by talus of clinkered coal and alluvium	103.0
219. Shale, gray	3.0
218. Sandstone, gray, fine-grained; in thin current-rippled beds	4.0
217. Interval covered by talus of clinkered coal	11.1
216. Shale, dark-gray, carbonaceous	2.0
215. Sandstone, gray, fine- to medium-grained; in thick and thin parallel beds	24.0
214. Interval covered by talus on dip slope	22.4
213. Sandstone, light-gray, very fine grained	16.0
212. Shale, gray, slightly carbonaceous, silty	6.0
211. Sandstone, light-gray, very fine to fine-grained, in fairly thick, parallel beds; and some interbedded shale, gray, carbonaceous, silty	85.5
210. Shale, gray, carbonaceous, sparse coal laminae	21.8
209. Shale, gray, soft	27.5
208. Shale, dark-gray, carbonaceous	0.9
207. Shale, gray, soft, sandy	1.8
206. Sandstone, light-gray; indistinct bedding	0.4
205. Shale, gray, soft	22.0
Total Almond Formation	374.9
Pine Ridge Sandstone:	
204. Sandstone, light-gray, fine- to medium-grained, partly crossbedded; and interbedded shale, gray, partly carbonaceous, silty; interval is about 60 percent sandstone	157.5
203. Shale, gray, partly carbonaceous, soft	9.5
202. Sandstone, light-gray, fine-grained; in thin current-rippled beds	4.1
201. Shale, gray, carbonaceous, silty	1.9
200. Coal	1.0
199. Shale, brown, carbonaceous, silty	2.6
198. Sandstone, light-gray, mostly medium-grained, subangular, sparse black and red grains, white clay cement; in subparallel, undulating beds	10.0
Total Pine Ridge Sandstone	186.6

Section 57.–*Mesaverde Group*—Continued

	Thickness (Feet)
Unconformity.	
Allen Ridge Formation:	
197. Shale, dark-gray, carbonaceous, silty	4.0
196. Sandstone, tan, fine-grained; in thin current-rippled laminae	2.6
195. Shale, gray, soft; slightly carbonaceous at base	16.4
194. Sandstone, gray, fine-grained; and thin interbedded shale, gray	7.5
193. Shale, dark-gray, carbonaceous, silty	4.3
192. Sandstone, light-gray, fine-grained; in thin, parallel, trough crossbeds	6.7
191. Shale, gray, soft; and interbedded sandstone, gray, fine-grained; in current-rippled beds as much as 2.5 ft thick	17.1
190. Shale, dark-gray, very carbonaceous, silty	2.8
189. Shale, gray, soft	2.4
188. Sandstone, tan, fine-grained; in current-rippled beds	2.6
187. Shale, gray-brown, carbonaceous, silty	2.8
186. Shale, gray, soft; and two thin interbedded sandstone units, gray, very fine grained; layer of bog-iron concretions 1 ft above base	10.2
185. Sandstone, gray, rust, fine-grained; in thin current-rippled beds	3.9
184. Shale, gray, soft	6.6
183. Sandstone, tan, fine-grained; in thin current-rippled beds; 0.6-ft-thick layer of ironstone concretions at top	6.3
182. Shale, gray, soft	4.5
181. Shale, dark-gray, carbonaceous	0.4
180. Coal	2.7
179. Shale, gray, carbonaceous	1.5
178. Shale, gray; and interbedded sandstone, gray; in thin current-rippled beds	4.5
177. Shale, dark-gray, carbonaceous, silty	3.3
176. Shale, gray, soft, slightly carbonaceous 13 ft above base; and interbedded sandstone, gray, very fine grained, in beds as much as 1 ft thick, current rippled	33.0
175. Sandstone, tan, fine-grained; in thin current-rippled beds	6.1
174. Shale, gray, soft, a few sandy layers	27.4
173. Sandstone, tan, fine- to medium-grained; lenticular; in trough crossbeds	13.2
172. Shale, gray, soft; with thin layer of dolomite concretions 2 ft above base	37.2
171. Sandstone, tan, fine- to medium-grained; lenticular; in trough crossbeds; sharp, scoured base	16.0
170. Shale, gray, soft, some very thin sandy layers	21.0
169. Sandstone, tan, fine- to medium-grained; lenticular; in trough crossbeds	14.5
168. Shale, gray, soft; and some interbedded sandstone, gray, fine-grained, in beds as much as 3 ft thick	43.7
167. Sandstone, gray, fine-grained; in trough crossbeds.	8.0
166. Shale, gray, soft; and interbedded sandstone, gray, fine-grained, in current-rippled beds as much as 1.5 ft thick	25.0
165. Sandstone, tan, fine-grained; in thin, parallel beds.	5.3
164. Shale, gray, soft	2.7
163. Dolomite, tan, hard; consists of a layer of concretions within thin, parallel-bedded sandstone	6.0

Section 57.–*Mesaverde Group*—Continued

	Thickness (Feet)
Allen Ridge Formation—Continued	
162. Shale, gray, soft; and 1.5-ft-thick bed of sandstone, gray, very fine grained, current-rippled, 9 ft above base	26.5
161. Sandstone, tan, fine-grained; in current-rippled beds	5.5
160. Shale, gray, soft; and a 1.5-ft-thick bed of sandstone, gray, very fine grained, near middle	9.0
159. Sandstone, tan, fine-grained; in thin, parallel beds.	6.8
158. Shale, gray, soft, with thin layers of dolomite concretions and sandstone in lower 8 ft	20.0
157. Sandstone, gray, fine-grained; in current-rippled beds	2.1
156. Shale, gray, soft; and three interbedded very thin beds of hematitic siltstone	30.5
155. Sandstone, tan, gray, very fine grained; in thin, current-rippled beds	2.4
154. Shale, gray, soft	7.7
153. Sandstone, gray, fine-grained; in current-rippled beds	1.5
152. Shale, gray, soft	1.2
151. Dolomite, tan, hard; in a layer of rounded concretions that show a vertical fracture pattern.	1.3
150. Shale, gray, soft; two layers of hematitic siltstone near middle	22.8
149. Dolomite, tan, hard; in layer of rounded concretions.	2.6
148. Shale, gray, soft; with thin layer of sandstone, gray, very fine grained, near top	9.0
147. Sandstone, tan, fine- to medium-grained; in thin, parallel beds	10.5
146. Shale, gray, soft	4.2
145. Sandstone, tan, fine-grained; in current-rippled beds and laminae	6.4
144. Shale, gray, soft; with a very thin layer of hematitic siltstone near middle	12.5
143. Sandstone, tan, fine- to medium-grained; in parallel beds	15.0
142. Shale, gray, soft; and a 1.5-ft-thick bed of sandstone, gray, very fine grained, 8 ft above base	19.5
141. Dolomite, tan, hard; in a layer of rounded concretions that has vertical fracture pattern	2.9
140. Shale, gray, soft; and some very thin interbedded sandstone, gray, very fine grained	23.2
139. Shale, dark-gray, carbonaceous	2.0
138. Sandstone, gray, fine- to medium-grained, in trough crossbeds; and interbedded shale, gray, in lower part	20.0
137. Shale, gray, soft	6.4
136. Sandstone, tan, fine- to medium-grained, poorly sorted, subangular, scattered black and colored grains; in trough crossbeds; a few lenses of clay-pebble conglomerate; outcrop debris contains abundant small, disarticulated dinosaur bone fragments	40.5
135. Shale, gray, soft; and two very thin interbedded sandstone beds, gray, very fine grained, in thin, parallel beds	14.5
134. Shale, gray, soft; and thin interbedded sandstone, tan, very fine grained	10.0

Section 57.–*Mesaverde Group*–Continued

Allen Ridge Formation–Continued	Thickness (Feet)
133. Sandstone, tan, fine- to medium-grained; in trough crossbeds; a few lenses of gray clay-pebble conglomerate	14.9
132. Shale, dark-brown, carbonaceous	4.4
131. Shale, gray, soft	14.0
130. Sandstone, tan, fine- to medium-grained; in subparallel beds as much as 1 ft thick; scattered gray clay pebbles	7.6
129. Shale, gray, soft	10.8
128. Sandstone, tan, very fine grained; in thin current-rippled beds	1.9
127. Shale, gray, soft; abundant small dinosaur bone fragments	5.6
126. Sandstone, tan, fine- to medium-grained; in trough crossbeds; some lenses of gray clay-pebble conglomerate	34.0
125. Shale, gray, soft	11.9
124. Sandstone, tan, fine- to medium-grained; in trough crossbeds	23.5
123. Shale, gray, soft; and some very thin interbedded sandstone, gray, very fine grained, in thin, parallel laminae	29.6
122. Sandstone, gray, fine- to medium-grained, poorly sorted, subangular, abundant black and white grains, some colored grains; in trough crossbeds.	21.5
121. Shale, gray, soft	12.2
120. Sandstone, tan, very fine grained; in current-rippled beds	3.8
119. Shale, gray, soft	8.0
118. Sandstone, tan, very fine grained; in thin current-rippled beds	2.9
117. Shale, gray, soft	6.9
116. Sandstone, tan, very fine grained; trough cross-bedded	6.8
115. Shale, gray, soft	8.5
114. Sandstone, tan, fine-grained; trough crossbedded	3.2
113. Shale, gray, soft	6.3
112. Sandstone, gray, fine-grained	1.5
111. Shale, gray, soft	8.0
110. Sandstone, tan, rust, fine-grained; in thin, parallel beds	1.6
109. Shale, gray, soft	5.6
108. Sandstone, tan, fine-grained; in thin current- rippled beds	3.0
107. Shale, gray, soft	6.5
106. Sandstone, tan, fine-grained; in thin current-rippled beds	3.1
105. Shale, gray, soft	3.3
104. Sandstone, light-gray, fine- to medium-grained; in trough crossbeds	26.0
103. Shale, gray, soft	9.0
102. Shale, dark-gray, carbonaceous	5.0
101. Shale, gray, soft, and a few laminae and very thin beds of sandstone, gray, very fine grained	25.4
100. Shale, dark-gray, carbonaceous	1.4
99. Shale, gray, soft	8.3
98. Sandstone, tan, rust, fine-grained; upper surface is weathered and contains roots	1.4
97. Shale, gray, soft, silty	12.4
96. Sandstone, tan, fine-grained; in small-scale trough crossbeds	8.5

Section 57.–*Mesaverde Group*–Continued

Allen Ridge Formation–Continued	Thickness (Feet)
95. Shale, gray, silty	2.6
94. Sandstone, tan, fine-grained; in small-scale trough crossbeds	3.7
93. Shale, dark-brown, carbonaceous, silty	2.5
92. Shale, gray, soft	19.3
91. Sandstone, tan, very fine grained; in small-scale trough crossbeds	4.6
90. Sandstone, tan, fine-grained, silty	1.4
89. Shale, gray, sandy at top	2.6
88. Shale, dark-gray, carbonaceous	1.4
87. Shale, gray, soft	5.0
86. Shale, dark-gray, carbonaceous	7.5
85. Shale, gray, soft	6.5
84. Shale, gray, carbonaceous	2.2
83. Shale, gray, soft	4.2
82. Shale, dark-gray, carbonaceous	3.9
81. Shale, gray, soft	2.9
80. Shale, gray, slightly carbonaceous	2.9
79. Shale, dark-gray, carbonaceous	3.4
78. Shale, gray, soft	3.5
77. Sandstone, tan, fine-grained; in thin current-rippled laminae	9.4
76. Shale, dark-gray, carbonaceous; some coal laminae in top 0.1 ft	6.0
75. Shale, gray, soft	5.1
74. Shale, dark-gray, carbonaceous; a few laminae of coal 5 ft below top; thin bog-iron concretionary zone 1.5 ft above base	15.6
73. Shale, gray, soft	5.8
72. Sandstone, tan at base, light-gray at top; in thick subparallel beds	23.4
71. Shale, gray, soft, silty in top 2 ft	26.0
70. Sandstone, tan, very fine grained, in thin, parallel beds with parallel laminae; and thin interbedded shale, gray, silty	9.9
69. Shale, gray, soft	16.7
68. Sandstone, tan, very fine grained; in thin, parallel laminae	5.5
67. Shale, gray, soft	1.5
66. Sandstone, tan, fine-grained; in thin, parallel laminae	2.2
65. Shale, gray, soft, and a 0.6-ft-thick bed of sandstone, gray, very fine grained, near the middle	13.0
64. Sandstone, tan, fine-grained; in thin, parallel laminae	4.4
63. Shale, gray, soft	9.0
Total Allen Ridge Formation.	1,310.6
Haystack Mountains Formation:	
Unnamed sandstone member:	
62. Sandstone, light-gray, fine- to medium-grained, fairly well sorted; in thin tabular beds; rooted and hematite-stained in upper 1 ft; upper contact is very sharp	40.1
61. Sandstone, light-gray, fine- to medium-grained; in large-scale low-angle trough crossbeds; some *Ophiomorpha*	33.0
60. Sandstone, tan, fine- to medium-grained; in thick, hummocky, bioturbated beds; abundant *Ophiomorpha*	9.7

Section 57.–*Mesaverde Group*—Continued

	Thickness (Feet)
Haystack Mountains Formation—Continued	
Unnamed sandstone member—Continued	
59. Sandstone, tan, very fine grained; in thin, parallel beds and laminae, with some very low angle small-scale trough crossbeds at top	4.0
Total unnamed sandstone member	86.8
Unnamed shale member:	
58. Shale, gray, soft	53.7
Unnamed sandstone member:	
57. Sandstone, gray, tan, fine- to medium-grained; in large-scale low-angle trough crossbeds, and some planar crossbeds with southeast (seaward) dipping fore-set laminae; abundant burrows	45.3
56. Sandstone, tan, very fine to fine-grained; in thin current-rippled laminae	5.6
Total unnamed sandstone member	50.9
Unnamed shale member:	
55. Shale, gray, soft, some carbonaceous layers	43.0
54. Sandstone, light-gray, fine-grained; in thin current-rippled beds; weathered and contains roots in top 1.5 ft	4.1
53. Shale, brown, carbonaceous, very silty in top 2 ft	4.7
52. Shale, gray, soft	2.0
51. Shale, gray, slightly carbonaceous	2.0
50. Sandstone, light-gray, fine-grained; weathered paleosoil containing roots	4.2
49. Shale, gray, soft	5.1
48. Siltstone, brown, carbonaceous; and interbedded shale, brown, silty, carbonaceous	4.5
47. Shale, gray, soft	7.9
46. Sandstone, light-gray, fine-grained; in thin current-rippled beds	7.7
45. Siltstone, gray, brown, carbonaceous	3.9
44. Shale, brown, carbonaceous	3.8
43. Sandstone, gray, very fine grained; in thin current-rippled laminae	1.1
42. Shale, brown, carbonaceous	4.6
41. Coal	0.9
40. Shale, brown, silty, carbonaceous	2.5
39. Sandstone, tan, very fine grained; in thin current-rippled laminae	5.9
38. Shale, gray, soft	18.0
37. Shale, brown, carbonaceous	2.4
36. Sandstone, gray, very fine grained; a weathered paleosoil containing roots	5.4
35. Shale, brown, silty, carbonaceous	2.9
34. Sandstone, gray, very fine grained; in thin, parallel beds	0.8
33. Shale, gray-brown, carbonaceous	13.4
32. Shale, gray, soft	2.0
31. Sandstone, light-gray, medium-grained; in long north- dipping tabular foresets	5.1
30. Shale, gray, soft, silty; some *Crassostrea* shell fragments	7.0
Total unnamed shale member	164.9

Section 57.–*Mesaverde Group*—Continued

	Thickness (Feet)
Haystack Mountains Formation—Continued	
Hatfield Sandstone Member:	
29. Sandstone, light-gray, fine- to medium-grained, fairly well sorted, abundant white and black grains, scattered red grains, subrounded, some muscovite; in small-scale low-angle trough cross-beds in lower and middle parts; upper part is massively bedded; upper 1 ft is hematite stained.	38.0
28. Sandstone, gray, weathers tan, fine- to medium-grained; in parallel, massive, bioturbated beds containing finger-size *Ophiomorpha*; beds are as thick as 6 ft	45.4
27. Sandstone, gray, very fine grained; in very thin parallel laminae with sandy shale partings	15.0
26. Sandstone, gray, very fine grained; in parallel beds as much as 5 ft thick with shaly partings; beds contain mostly very low angle small-scale trough crossbeds	12.5
25. Sandstone, gray, very fine grained; in thin, parallel beds with thin, even laminae; upper 2 ft are distorted and contain flame structures; some shaly partings	5.4
24. Sandstone, gray, very fine to fine-grained, very shaly; in massive bioturbated beds	31.5
23. Sandstone, gray, very fine to fine-grained, fairly well sorted, subangular; in parallel beds as much as 3 ft thick with thicker beds in upper part; some beds have very low angle, undulating, hummocky laminations that in places are slightly cross-bedded	33.0
22. Shale, gray, soft; and thin interbedded and inter-laminated sandstone, gray, very fine grained, in thin, parallel laminae	16.8
Total Hatfield Sandstone Member	197.6
Espy Member:	
21. Shale, gray, soft	173.4
20. Shale, gray, soft, with very thin, silty dolomite concretions in layers near top and bottom	12.3
19. Siltstone, tan, dolomitic	0.5
18. Shale, gray, soft	2.0
17. Sandstone, tan-gray, very fine grained, silty; in parallel bioturbated beds	4.1
16. Shale, gray, soft	17.7
15. Dolomite, gray, silty; forms layer of isolated, flat, podlike concretions	1.4
14. Shale, gray, soft	7.8
13. Dolomite, gray, silty; forms layer of isolated, flat, podlike concretions	0.6
12. Shale, gray, soft	34.3
Total Espy Member	254.1
Deep Creek Sandstone Member:	
11. Sandstone, gray, very fine grained; in thin, even, parallel beds as much as 2 ft thick; beds coarsen and thicken upward	8.5
10. Shale, gray, soft	18.0

Section 57.–*Mesaverde Group*–Continued

	Thickness (Feet)
Haystack Mountains Formation–Continued	
Deep Creek Sandstone Member–Continued	
9. Sandstone, gray, very fine grained; in thin, even, parallel, wave-rippled beds with abundant burrows and trails; and interbedded and interlaminated shale, gray, silty to sandy; beds and laminae are all less than 3 inches thick; coarsens upward	17.5
8. Shale, gray, soft; and some very thin interbedded and interlaminated sandstone, gray, very fine grained; and siltstone, gray, in thin, even, parallel beds	27.2
7. Shale, gray, soft	68.5
6. Sandstone, gray, very fine to fine-grained; in beds as much as 3 ft thick that have southwest-dipping foreset laminae with dips of about 35°	19.1
Total Deep Creek Sandstone Member	158.8
Total Haystack Mountains Formation	966.8
Steele Shale:	
5. Sandstone, tan-gray, very fine grained; in thin, even, parallel beds as much as 2 ft thick with sandy shale partings; abundant worm trails on bedding surfaces	7.0
4. Siltstone, tan-gray; in thin, parallel, subeven beds; abundant small, vertical burrows as much as 0.25 inch in diameter	9.6
3. Shale, gray, soft	88.0
2. Shale, gray, soft; and very thin interbedded and interlaminated sandstone, gray, very fine grained, in parallel beds	2.7
1. Shale, gray, soft	154.0
Total Steele Shale measured	261.3

The section begins at the base of Atlantic Rim. The outcrops below bed 1 are shale with two ridge-forming sandstone beds hundreds of feet below.

Section 34.–*Mesaverde Group and adjacent formations, measured along the north side of U.S. Highway 40 near Mount Harris*

[Secs. 9, 11, 12, 15, and 16, T. 6 N., R. 87 W., Routt County, Colo.]

	Thickness (Feet)
Lewis Shale (part):	
158. Shale, gray, soft	37.0
Williams Fork Formation:	
Upper coal-bearing member:	
157. Shale, dark-gray, carbonaceous	1.5
156. Coal	1.2
155. Shale, dark-gray, carbonaceous	0.8
154. Sandstone, tan, fine-grained	1.3
153. Shale, gray, carbonaceous	4.8
152. Sandstone, tan, fine-grained; in two beds with parallel laminae	3.4
151. Shale, gray, sandy laminae at base; slightly carbonaceous at top	9.9
150. Sandstone, gray, very fine grained; in thin current-rippled laminae	9.2

Section 34.–*Mesaverde Group*–Continued

	Thickness (Feet)
Williams Fork Formation–Continued	
Upper coal-bearing member–Continued	
149. Shale, gray, soft	3.1
148. Sandstone, gray, very fine grained, in thin current-rippled beds that thicken upward to 1.5 ft at top; and thin interbedded shale, gray, sandy	5.7
147. Shale, gray, carbonaceous at top	8.8
146. Sandstone, tan, fine-grained; in thin current-rippled laminae	2.5
145. Shale, gray, soft; two laminae of brown hematitic siltstone	7.4
144. Sandstone, tan, very fine grained; in thin current-rippled laminae	7.3
143. Shale, gray, soft	16.0
142. Sandstone, gray, very fine grained, in thin, current-rippled beds; and some interbedded shale, gray, sandy	9.0
141. Sandstone, tan, very fine to medium-grained; in parallel beds as much as 2 ft thick with gray shale partings	16.5
140. Shale, gray, soft; and some very thin interbedded sandstone, gray, very fine grained	19.3
139. Sandstone, tan, very fine grained, limy; composed mostly of bedded oyster-shell fragments	4.6
138. Sandstone, gray, very fine grained; in thin beds with current-rippled laminae	5.7
137. Shale, gray, soft; and some very thin interbedded sandstone, gray, very fine grained	9.0
136. Sandstone, gray, very fine to fine-grained; in parallel beds with parallel laminae; some northeast-dipping foresets	9.7
135. Shale, gray, sandy	2.7
134. Sandstone, gray, fine- to medium-grained; in large-scale low-angle trough crossbeds; some oyster shells in upper 1 ft	11.9
133. Shale, gray, soft; and thin interbedded sandstone, gray, very fine grained	7.8
132. Sandstone, gray, fine- to medium-grained; weathers to massive outcrop of parallel beds; abundant burrows; some very small scale trough crossbeds in upper 1 ft.	4.5
131. Shale, gray, soft; and interbedded sandstone, gray, very fine grained, in a few very thin parallel beds; top 4 ft consists of sandy laminae	29.0
130. Sandstone, tan, fine-grained; unbedded	2.6
129. Shale, gray, soft	6.8
128. Shale, brown, carbonaceous	0.6
127. Coal	0.5
126. Shale, brown, carbonaceous	0.4
125. Sandstone, gray, very fine grained; in thin current-rippled beds	2.5
124. Shale, gray, soft, silty in top 1.5 ft	3.5
123. Shale, dark-brown, carbonaceous	0.2
122. Coal	0.4
121. Shale, dark-gray-brown, carbonaceous	0.8
120. Shale, gray, soft	1.3
119. Sandstone, gray, very fine to fine-grained; in thin, parallel, current-rippled beds, some with northeast- dipping foresets; beds are as much as 5 ft thick at base and thin upward to less than 1 ft at top; and thin interbedded shale, dark-gray	33.0
118. Shale, gray, carbonaceous	7.8

Section 34.–*Mesaverde Group*–Continued

	Thickness (Feet)
Williams Fork Formation–Continued	
Upper coal-bearing member–Continued	
117. Sandstone, gray, fine- to medium-grained, abundant black and white grains; in bidirectional planar crossbeds as much as 2 ft thick with southwest- and northeast-dipping foresets; lenticular and about 0.25 mi wide	24.5
116. Shale, dark-gray, carbonaceous, and 0.3- and 0.6-ft-thick interbedded sandstone, gray, very fine grained, in parallel beds, near top and bottom	4.3
Total upper coal-bearing member	301.8
Twentymile Sandstone Member:	
115. Sandstone, light-gray, fine- to medium-grained; in thin, parallel beds; convoluted at the top	16.5
114. Sandstone, light-gray, fine- to medium-grained; in small-scale low-angle trough crossbeds; abundant large *Ophiomorpha* in lower part	34.0
113. Sandstone, gray, fine- to medium-grained, abundant black and white grains; in thin, parallel beds with some low-angle, large-scale, hummocky crossbeds; some burrows in upper part	61.0
112. Sandstone, gray, very fine to fine-grained, silty, poorly sorted, abundant dark grains; in thin beds that have low undulations; numerous carbonaceous laminae along bedding planes; extensively burrowed	12.3
111. Sandstone, gray, fine- to medium-grained; weathers to massive bed composed of thin laminae; has scoured base	2.2
110. Sandstone, gray, fine- to medium-grained; weathers to massive bed with large-scale low-angle, hummocky crossbeds	20.3
109. Shale, gray, sandy	0.5
108. Sandstone, gray, fine-grained; in thin, parallel beds with some trough crossbedding in top 0.5 ft	1.6
107. Shale, gray, sandy	0.2
106. Sandstone, gray, fine-grained; in massive, parallel bed composed of parallel laminae	5.9
105. Shale, gray, soft	0.3
104. Sandstone, gray, very fine grained, in thick, parallel beds; and thin interbedded shale near middle and at top	3.8
103. Shale, gray, soft; and interbedded and interlaminated sandstone, gray, very fine grained, in thin, parallel beds	1.7
102. Sandstone, gray, very fine grained; in parallel bed; wave-rippled on upper surface	0.9
Total Twentymile Sandstone Member	161.2
Marine shale and sandstone member underlying Twentymile Sandstone Member:	
101. Shale, gray, soft, silty laminae in upper 10 ft	68.0
100. Covered interval	62.0
99. Sandstone, gray, fine- to medium-grained, abundant black and white grains, poorly sorted, subangular, some red grains; indistinct bedding	54.0
98. Shale, gray, soft	39.0
97. Covered interval	155.0
96. Shale, dark-gray, soft	23.0
Total marine shale and sandstone member	401.0

Section 34.–*Mesaverde Group*–Continued

	Thickness (Feet)
Williams Fork Formation–Continued	
Lower coal-bearing member:	
95. Sandstone, gray, very fine grained; in thin current-rippled beds as much as 0.6 ft thick at base and thinning upward to current-rippled laminae at top	4.1
94. Shale, gray, soft	0.9
93. Sandstone, gray, very fine grained; in thin current-rippled beds at base	1.5
92. Shale, gray, soft	1.2
91. Shale, gray, carbonaceous	0.2
90. Coal	2.6
89. Shale, dark-gray, carbonaceous	1.6
88. Sandstone, gray, very fine grained; in current-rippled laminae	1.6
87. Shale, dark-gray, carbonaceous; very sandy laminae in upper 0.7 ft	2.3
86. Coal	0.7
85. Sandstone, gray, very fine grained; in thin current-rippled beds	2.1
84. Shale, gray, carbonaceous	1.6
83. Sandstone, gray, very fine grained; unbedded	1.3
82. Shale, gray, soft, silty	0.7
81. Sandstone, gray, very fine grained; in thin current-rippled laminae at base; becomes thick bedded at top	9.4
80. Shale, dark-gray, carbonaceous	1.8
79. Sandstone, gray, very fine grained, silty, in thin current-rippled beds as much as 1 ft thick; and very thin interlaminated and interbedded shale, gray	22.5
78. Shale, gray, carbonaceous; and some interlaminated sandstone, gray, very fine grained	4.0
77. Sandstone, gray, very fine grained; in current-rippled beds and laminae; beds thin from 1.5-ft-thick sandstone at base to laminae at top	4.3
76. Shale, dark-gray, carbonaceous, with a few sandy laminae	1.0
75. Coal	13.9
74. Shale, dark-gray, very carbonaceous; and a few interlaminated sandstone beds, gray, very fine grained	3.7
73. Sandstone, gray, very fine grained; in thin current-rippled laminae	4.5
72. Shale, gray, carbonaceous	1.6
71. Coal	1.9
70. Shale, dark-gray, carbonaceous	2.7
69. Sandstone, gray, very fine grained, in thin current-rippled beds as much as 0.5 ft thick; and thin interbedded shale, gray, sandy	6.5
68. Shale, gray, slightly carbonaceous	13.5
67. Sandstone, gray, very fine grained; and interlaminated and thin interbedded shale, gray, sandy	6.5
66. Sandstone, gray, very fine grained; in thin current-rippled beds	1.9
65. Shale, gray, carbonaceous; and thin interbedded sandstone, tan, very fine grained, in current-rippled beds	10.8
64. Interval covered by soil and alluvium	140.0
63. Interval covered by talus	30.0

Section 34.–*Mesaverde Group*—Continued

	Thickness (Feet)
Williams Fork Formation—Continued	
Lower coal-bearing member—Continued	
62. Sandstone, gray, fine- to medium-grained; in trough crossbeds	17.2
61. Interval covered by alluvium	17.7
60. Sandstone, light-gray, fine- to medium-grained, abundant colored grains, subangular; weathers to massive bed	21.3
59. Shale, gray, soft; and some very thin interbedded sandstone, gray, fine-grained, in thin, parallel beds	49.0
Total lower coal-bearing member	809.1
Total Williams Fork Formation	1,272.1
Iles Formation:	
Trout Creek Sandstone Member:	
58. Sandstone, gray, tan, fine- to medium-grained; in thick bioturbated beds	53.0
57. Shale, dark-gray, slightly carbonaceous	3.4
56. Sandstone, tan, fine- to medium-grained, poorly sorted, subangular, abundant colored grains; in planar cross-beds as much as 3 ft thick with pronounced S. 45° W. dips of foreset laminae	21.2
55. Sandstone, tan, fine- to medium grained; bioturbated; weathers with wormy texture	7.3
54. Sandstone, gray, very fine to fine-grained; in thick parallel bioturbated beds; abundant *Ophiomorpha*	36.0
53. Sandstone, gray, very fine grained, silty, in parallel beds as much as 2 ft thick; and interbedded shale, gray, sandy	7.5
Total Trout Creek Sandstone Member	128.4
Marine shale and sandstone member:	
52. Shale, gray, soft	33.3
51. Sandstone, tan, very fine grained, in thin, parallel beds; and some interlaminated shale, gray, soft	5.0
50. Shale, gray, soft	150.0
49. Covered interval; probably shale	140.0
48. Shale, gray, soft	110.0
Total marine shale and sandstone member	438.3
Lower coal-bearing member:	
47. Shale, gray, soft; and some interlaminated siltstone, gray	8.5
46. Sandstone, tan, very fine grained, silty; in thin current-rippled beds	4.9
45. Shale, gray, soft	7.0
44. Sandstone, tan, very fine grained, silty, in thin current-rippled beds and laminae; and some thin interbedded shale, gray, silty	11.6
43. Coal	4.9
42. Shale, gray, carbonaceous	1.6
41. Shale, gray, soft	27.5
40. Shale, gray, soft; and two interbedded 1-ft-thick sandstone beds, gray, very fine grained, in thin current-rippled laminae, in upper 5 ft	11.0
39. Sandstone, tan, very fine grained, silty; in thin current-rippled beds	6.3
38. Shale, brown, carbonaceous	0.5
37. Coal	1.1

Section 34.–*Mesaverde Group*—Continued

	Thickness (Feet)
Iles Formation—Continued	
Lower coal-bearing member—Continued	
36. Shale, gray, soft, slightly carbonaceous; and a 1-ft-thick sandstone bed, gray, very fine grained, current-rippled, near middle	6.7
35. Sandstone, gray, very fine grained, silty; in thin current-rippled beds	5.4
34. Shale, gray, silty	2.7
33. Shale, black, very carbonaceous	0.9
32. Shale, dark-gray, soft; and three interbedded 1-ft-thick sandstone beds, gray, very fine grained	11.9
31. Sandstone, gray, very fine grained; in current-rippled beds	10.8
30. Shale, gray, soft, silty; and two interbedded 5-ft-thick sandstone beds, gray, very fine grained, in lower 20 ft	68.0
29. Shale, gray, soft; and interbedded shale, dark-gray, carbonaceous; and several interbedded sandstone beds, gray, very fine grained, as much as 3 ft thick, composed of current-rippled laminae	102.0
28. Sandstone, tan, very fine grained; trough cross-bedded; scoured base	4.8
27. Shale, gray, silty, some very slightly carbonaceous; and interbedded sandstone, gray, very fine grained; in beds as much as 3 ft thick composed of current- rippled laminae	31.2
26. Sandstone, gray, very fine grained; in thin current-rippled beds	13.0
25. Sandstone, tan, fine- to medium-grained, poorly sorted, subangular; in trough crossbeds as much as 8 ft thick; some shale drape and clay-pebble lag; abundant burrows; scoured base	46.5
Total lower coal-bearing member	388.8
Tow Creek Sandstone Member:	
24. Sandstone, tan, very fine grained; in thin, parallel beds as much as 2 ft thick with parallel laminae; and interbedded shale, gray, sandy; mostly sandstone in upper 20 ft; abundant burrows	129.0
Basal marine shale member:	
23. Shale, gray, sandy	14.3
22. Covered interval	48.0
Total basal marine shale member	62.3
Unnamed basal sandstone member:	
21. Sandstone, gray, tan, fine- to medium-grained; in parallel beds	20.0
Total Iles Formation	1,166.8
Mancos Shale:	
Unnamed tongue (part):	
20. Shale, gray, soft, silty; and thin interbedded and interlaminated sandstone, gray, very fine grained, and siltstone, gray, in parallel beds; interval is mostly shale in middle and sandstone at top	47.5

Section 34.–*Mesaverde Group*—Continued

Mancos Shale—Continued	*Thickness (Feet)*
Loyd Sandstone Member:	
19. Sandstone, gray, very fine grained, fairly well sorted, abundant colored grains; in parallel beds as much as 1.5 ft thick	12.7
Unnamed tongue:	
18. Shale, gray, sandy, soft	21.0
17. Shale, gray, silty, and interbedded sandstone, gray, very fine grained, in numerous thin parallel beds.	105.0
Total unnamed tongue	126.0
Unnamed sandstone member:	
16. Sandstone, gray, fine- to medium-grained, poorly sorted, subangular; in parallel beds at base, small-scale trough crossbeds in middle, and tabular beds at top	54.0
Unnamed tongue:	
15. Shale, gray, sandy, soft	10.0
14. Covered interval, probably shale	65.0
Total unnamed tongue	75.0
Unnamed sandstone member:	
13. Sandstone, tan, very fine grained, in parallel beds that thicken upwards to 2.5 ft thick; and some interbedded shale, gray, very sandy; interval is mostly sandstone in upper part	18.0
Unnamed tongue:	
12. Covered interval, probably shale	40.0
Unnamed sandstone member:	
11. Sandstone, gray, very fine grained, silty; bioturbated; abundant large vertical, smooth-walled burrows; one fragment of a coiled ammonite; some hematized *Inoceramus* shells	3.7

Section 34.–*Mesaverde Group*—Continued

Mancos Shale—Continued	*Thickness (Feet)*
Unnamed sandstone member—Continued	
10. Shale, gray, silty	2.9
9. Sandstone, tan, very fine grained, silty; in subparallel, burrowed beds	1.8
8. Shale, gray, silty; grades upward into siltstone, gray.	3.4
7. Sandstone, gray, very fine grained, silty; in subparallel beds that coarsen upwards	3.5
6. Shale, gray, soft; and some interbedded sandstone, gray, very fine grained, in thin subparallel beds spaced throughout interval	53.0
5. Sandstone, gray, fine- to medium-grained; in small-scale, fairly high-angle trough crossbeds with foresets that have a pronounced S. 88° W. dip component	8.5
4. Sandstone, gray, very fine grained, poorly sorted, subangular; in thick and thin parallel beds; coarsens upward	19.8
Total unnamed sandstone member:	96.6
Unnamed tongue:	
3. Shale, dark-gray, soft; 3-ft-thick sandstone bed, gray, very fine grained, 70 ft above base	208.0
Morapos Sandstone Member:	
2. Sandstone, tan, very fine grained, poorly sorted, subangular; in subparallel beds as much as 2.5 ft thick; many beds contain foreset laminae that dip about S. 80° W.; some beds are bioturbated	26.0
Main body of Mancos Shale:	
1. Shale, gray, silty, soft	43.0
Total Mancos Shale measured	746.8

☆ U.S. GOVERNMENT PRINTING OFFICE: 1990—573-049/26,013 REGION NO. 8