Depositional Controls on the Late Campanian Sego Sandstone and Implications for Associated Coal-Forming Environments in the Uinta and Piceance Basins

U.S. GEOLOGICAL SURVEY BULLETIN 1787–F

Chapter F

Depositional Controls on the Late Campanian Sego Sandstone and Implications for Associated Coal-Forming Environments in the Uinta and Piceance Basins

By KAREN J. FRANCZYK

A multidisciplinary approach to research studies of
sedimentary rocks and their constituents and
the evolution of sedimentary basins, both ancient and modern

U.S. GEOLOGICAL SURVEY BULLETIN 1787

EVOLUTION OF SEDIMENTARY BASINS—UINTA AND PICEANCE BASINS

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

UNITED STATES GOVERNMENT PRINTING OFFICE: 1989

For sale by the
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U.S. Geological Survey
Federal Center, Box 25425
Denver, CO 80225

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Library of Congress Cataloging-in-Publication Data

Franczyk, Karen J.
Depositional controls on the Late Campanian Sego sandstone and implications for associated coal-forming environments in the Uinta and Piceance basins.

(Evolution of sedimentary basins—Uinta and Piceance basins ; ch. F) (U.S. Geological Survey bulletin ; 1787–F)
Bibliography: p.
Supt. of Docs. no.: I 19.3:1787–F
1. Sandstone—Uinta Basin (Utah and Colo.)
2. Sandstone—Colorado—Piceance Creek Watershed. 3. Geology, Stratigraphic—Cretaceous. 4. Coal—Geology—Uinta Basin (Utah and Colo.) 5. Coal—Geology—Colorado—Piceance Creek Watershed. I. Title. II. Series. III. Series: U.S. Geological Survey bulletin ; 1787–F.
QE75.B9 no. 1787–F 557.3 s [552'.5] 88–600287
[QE471.15.S25]

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CONVERSION FACTORS FOR SOME SI METRIC AND U.S. UNITS OF MEASURE

To convert from	To	Multiply by
Feet (ft)	Meters (m)	0.3048
Miles (mi)	Kilometers (km)	1.609
Pounds (lb)	Kilograms (kg)	0.4536
Degrees Fahrenheit (°F)	Degrees Celsius (°C)	Temp °C = (temp °F-32)/1.8

Depositional Controls on the Late Campanian Sego Sandstone and Implications for Associated Coal-Forming Environments in the Uinta and Piceance Basins

By Karen J. Franczyk

Abstract

In the Uinta and Piceance basins of eastern Utah and western Colorado, the late Campanian Sego Sandstone is a regionally extensive regressive unit composed of as many as six stacked sequences of backbarrier and shoreface deposits. The regression probably occurred during a gradual eustatic rise; however, tectonic events, primarily in the Sevier thrust belt, controlled sediment supply, which in turn controlled the style of progradation including both local and more regional episodes of regression and transgression. The shoreface sequences were deposited along a microtidal barrier-island coastline, and the backbarrier sequences accumulated in tidal flats, deltas, and channels and in washovers, marshes, swamps, lagoons, and bays. In general, only thin, discontinuous peat beds formed because of frequent shifting of environments and inundation of the lower coastal plain during numerous periods of shoreline retreat. The alternating episodes of shoreline advance and retreat produced the stacked shoreface sequences and caused a thick accumulation of tidal deposits near the landward limit of the Sego. A comparison of detailed measured sections and geophysical well-log profiles through the Sego allows subsurface identification of both depositional cycles and lateral facies changes.

INTRODUCTION

The late Campanian Sego Sandstone extends throughout northeastern Utah and northwestern Colorado and was deposited during the last regression of the Cretaceous sea from Utah. It represents the first major marine depositional event completely away from the previously rapidly subsiding foredeep that existed near the eastern margin of the Sevier thrust belt. During deposition of the upper part of the lower Campanian Blackhawk Formation and the upper Campanian Castlegate Sandstone, the center of subsidence shifted away from the thrust belt margin toward the less rapidly subsiding part of the foreland basin to the east. The regional geometry and distribution, internal sedimentologic structure, and geophysical log response of the Sego Sandstone and the characteristics of its associated coal deposits distinguish the Sego from other coastal marine deposits of the area. Preliminary regional and local examination of the Sego and associated units was conducted to interpret depositional environments and events and to identify depositional controls such as subsidence rate, areas of maximum subsidence, sediment supply, tectonic activity, and eustatic fluctuations. The results of these studies will help us better understand the evolution of the foreland basin during the Late Cretaceous in the present-day area of the Uinta and Piceance basins and will help explain and predict regional facies changes.

Acknowledgments.—Melisa Fry, Janet Pitman, and Doug Owen ably assisted in field studies. Ron Johnson, Curt Huffman, and Bill Cashion provided helpful criticism, advice, and discussion. This study was conducted as part of the U.S. Geological Survey Evolution of Sedimentary Basins program.

METHODS

Four detailed sections of the Sego Sandstone and parts of the overlying Neslen Formation were measured

Publication approved by the Director, U.S. Geological Survey, June 17, 1988.

along the Book Cliffs in Utah (fig. 1), and additional outcrop information and two measured sections (one each in Utah and Colorado) were obtained from published and unpublished data. Outcrop studies focused on identification of depositional sequences by evaluating lithologic, textural, and sedimentary properties. Outcrop interpretations were then used to model the depositional environments and to identify the progression of depositional events, both of which provide a key to interpreting well-log subsurface data, predicting lateral facies changes, and identifying depositional controls. A subsurface cross section was constructed, the line of which (fig. 1) parallels outcrops of Sego Sandstone from west of the Green River in Utah eastward into Colorado north of Grand Junction.

PREVIOUS WORK

Both Fisher (1936) and Erdmann (1934) extensively studied the coal fields along the Book Cliffs in Utah and Colorado and defined and correlated much of the Upper Cretaceous stratigraphy; however, they used different nomenclature in each State for the Cretaceous section above the Sego Sandstone (fig. 2). Fisher (1936) first used the name Sego Sandstone to describe the first marine cliff-forming sandstone above the Castlegate Sandstone at the abandoned coal-mining settlement of Sego. The Sego Sandstone was originally a member of the Price River Formation and was later raised to formation status by Fisher and others (1960). It can be traced from west of the Green River in the Beckwith Plateau along the Book Cliffs into Colorado. For convenience, Fisher and others (1960) chose the Green River as nomenclatural dividing line: west of the Green River, Cretaceous rocks above the Castlegate are assigned to the Price River Formation; east of the Green River, they are assigned to the Buck Tongue of the Mancos Shale, the Sego Sandstone, and the Neslen, Farrer, and Tuscher Formations. Fouch and others (1983) expanded the Castlegate Sandstone to include the Bluecastle Tongue of the Castlegate Sandstone: a unit Fisher and others (1960) had named the Bluecastle Sandstone Member of the Price River Formation and the Bluecastle sandstone member of the Neslen Formation, respectively, west and east of the Green River. Wherever they are present, the Buck Tongue, Sego Sandstone, and Neslen Formation lie between the basal part of the Castlegate Sandstone and the Bluecastle Tongue. The Bluecastle Tongue pinches out as a mappable unit between the Tusher and Sego Canyon areas (fig. 1), and the Castlegate pinches out into the Mancos near the State line; as a result, the Buck Tongue of the Mancos Shale is not applied in Colorado. Erdmann (1934) carried the name Sego Sandstone into Colorado, but above the Sego he applied the names Mount Garfield and Hunter Canyon Formations of the Mesaverde Group. He correlated the Neslen and the lower part of the Farrer Formation with the Mount Garfield Formation, and the upper part of the Farrer and the Tuscher Formations with the Hunter Canyon Formation.

In Utah, the Sego Sandstone generally is a single sandstone unit that has an average thickness of 175 ft (Fisher, 1936), a gradational contact with the underlying Buck Tongue of the Mancos Shale, and a conformable but locally sharp contact with the overlying Neslen Formation. Fisher defined the Neslen as the coal-bearing sequence of shale and sandstone above the Sego. The average thickness of the Neslen is 350 ft, but its thickness varies because its contact with the overlying Farrer Formation is gradational and is placed where the greenish shales and abundant fluvial sandstones typical of the Farrer replace the more carbonaceous lithologies of the Neslen. Fisher identified and named four coal zones in the Neslen Formation, traced them across Utah, and correlated them with coal zones in the Book Cliffs of Colorado. Our sections measured through the Neslen do not show these four coal zones occurring everywhere in this unit. Young (1955) later recorrelated coal zones between Utah and Colorado.

East of the Colorado-Utah State line, the Sego is split into an upper and lower sandstone by the Anchor Mine Tongue of Mancos Shale (Erdmann, 1934). Erdmann's correlations show the seaward pinchout of the lower sandstone and upper sandstone into the Mancos Shale as being in the northwest corner of T. 10 S., R. 99 W., and near sec. 28, T. 12 S., R. 97 W., respectively. According to Erdmann, the Anchor Mine Tongue undergoes facies transitions from marine to continental and back to marine from east to west. Near the eastern pinchout of the lower Sego Sandstone, the lithology of the Anchor Mine is typical of that of the Mancos. To the west, toward Hunter Canyon (sec. 7, T. 9 S., R. 100 W.), the Anchor Mine thins and contains coastal-plain deposits of coal, carbonaceous shale, and channel-fill sandstone. Farther to the west, it thickens again and has a lithology typical of the Mancos, and, as it merges into the main body of the Sego, it gradually becomes sandier.

Subsequent recorrelations of the Sego Sandstone and the Anchor Mine Tongue from Utah to Colorado (Young, 1955; Gill and Hail, 1975) show that, in western Colorado, Erdmann (1934) miscorrelated a marine sandstone in the Mount Garfield Formation with the upper Sego Sandstone. Young stated that the coal-bearing sequence placed in the Anchor Mine Tongue by Erdmann lies above the upper Sego Sandstone, and thus the Anchor Mine Tongue is entirely of marine origin. Gill and Hail's cross section along the Book Cliffs from eastern Utah to western Colorado shows the lower Sego Sandstone pinching out into the Mancos between their

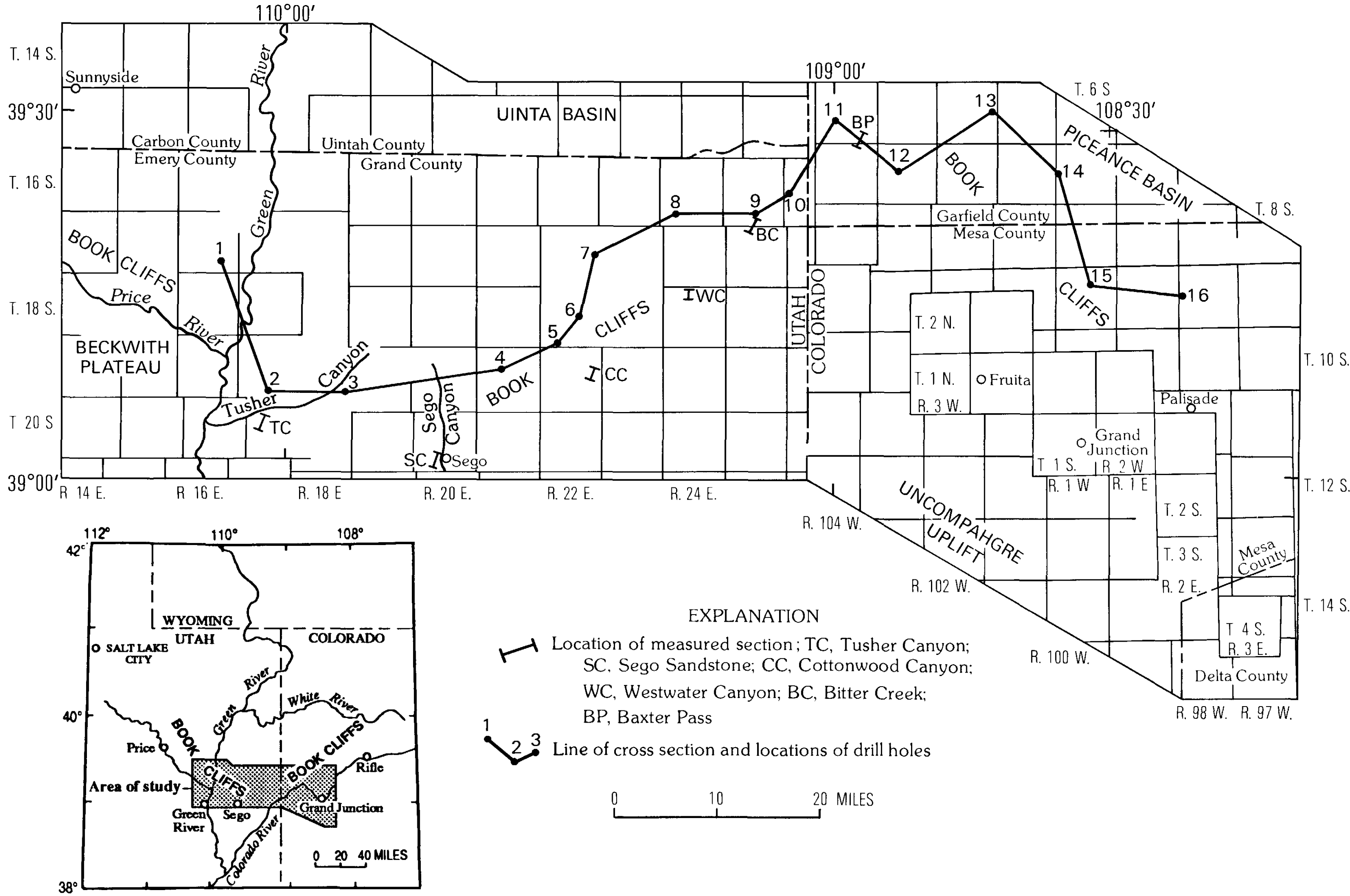

Figure 1. Location of measured sections, drill holes, and line of cross section, eastern Utah and western Colorado. Cross section shown on plate 1, measured sections on plate 2.

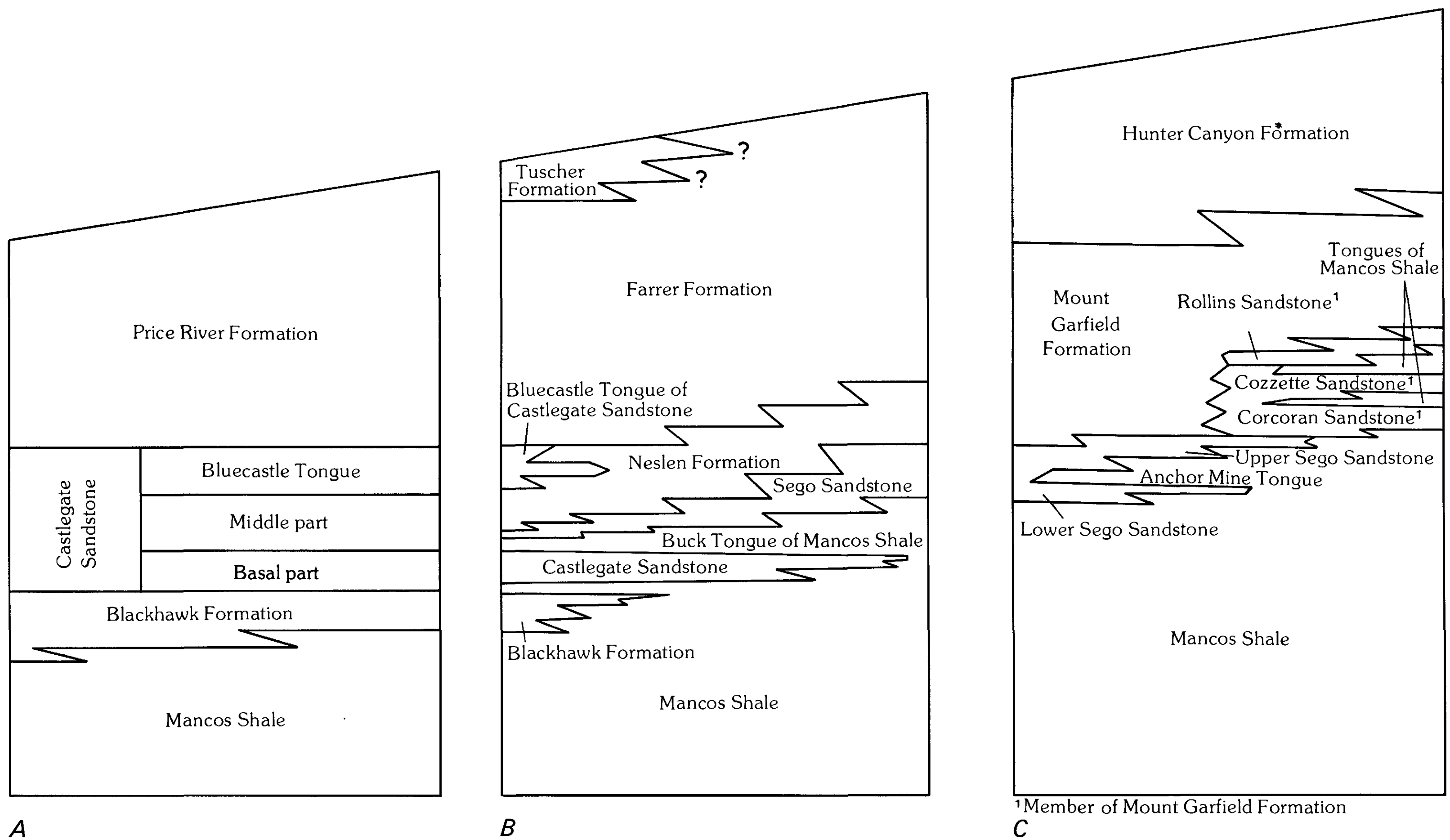

Figure 2. Schematic diagrams showing stratigraphic nomenclature and correlations of Upper Cretaceous rocks from west to east along the Book Cliffs. No scales implied. *A*, Beckwith Plateau area west of Green River. *B*, Eastern Utah from Green River to Utah-Colorado State line. *C*, Western Colorado from State line to Grand Junction area.

Dry Gulch (sec. 30, T. 8 S., R. 101 W.) and Hunter Canyon (sec. 5, T. 9 S., R. 100 W.) sections and the upper Sego Sandstone pinching out between their Grasso (sec. 2, T. 10 S., R. 100 W.) and Farmers mines (sec. 3, T. 11 S., R. 98 W.) sections. Both pinchouts are much farther west than Erdmann placed them.

The Mount Garfield Formation overlying the Sego in Colorado is depositionally and lithologically more complex than the Neslen Formation. Erdmann (1934) divided the Mount Garfield into two parts: a lower part, or "coal measures," 305–666 ft thick, and an upper part, or "barren measures," 405–665 ft thick. The lower part contains coal, carbonaceous shale, and siltstone, but the dominant lithology is marine sandstone and lesser amounts of fluvial sandstone. Erdmann applied the name Rollins Sandstone Member of the Mount Garfield Formation to the uppermost marine sandstone in the coal measures but did not name the numerous, thinner marine sandstone units that he identified below the Rollins.

Young (1955) extended the name Price River Formation east of the Green River and into Colorado where it replaced both the Mount Garfield and the Hunter Canyon Formations. He divided the lower part of the Price River Formation in Colorado into three members, each consisting of coastal-marine sandstone and associated coastal-plain deposits and separated from each other by thin tongues of Mancos Shale. His members are, in ascending order, the Corcoran, Cozzette, and Cameo. The Corcoran and Cozzette terminology is used extensively in this area. Because use of the name Mount Garfield in Colorado has precedence over use of the name Price River, the Corcoran and Cozzette are assigned as members of the Mount Garfield in this report. Young's Cameo Member of the Price River is recognized as the Rollins Sandstone Member of the Mount Garfield Formation in the western Book Cliffs area of Colorado and as the Rollins Sandstone Member of the Mesaverde Formation in the eastern Book Cliffs area of Colorado. The term Cameo is not used. Gill and Hail's (1975) cross section shows Young's Corcoran and Cozzette Members as composed of numerous, stacked coastal-marine sandstone units. The maximum thickness of the Corcoran is about 120 ft; its westernmost extent is about 2 mi west of Hunter Canyon, and its eastern pinchout into the Mancos Shale is about 6.5 mi east of Watson Creek (sec. 25, T. 11 S., R. 98 W.). The maximum thickness of the Cozzette is about 220 ft; its western limit is about 1 mi west of Dry Gulch (sec. 30, T. 8 S., R. 101 W.), and it is still present at the eastern limit of Gill and Hail's cross section (T. 13 S., R. 93 W.). The westernmost extent of the Rollins Sandstone Member is about 3 mi west of Hunter Canyon, and The Rollins is present at the east end of Gill and Hail's cross section.

The upper part of the Mount Garfield Formation differs from the lower part in that it has less carbonaceous shale, very rare coal beds, and no coastal-marine sandstone. The contact between the Mount Garfield Formation and the overlying Hunter Canyon Formation is similar to that between the Neslen and Farrer Formations; it is gradational and arbitrary, placed where fluvial sandstones become more numerous, coarse grained, grayer, and massive (Erdmann, 1934).

The Sego Sandstone and overlying coastal-marine sandstones in the Book Cliffs are late Campanian in age and become younger to the east. Fossils from the *Baculites scotti* faunal zone were reported by Gill and Hail (1975) from the Anchor Mine Tongue in westernmost Utah and from the base of the upper Sego Sandstone at Hunter Canyon. The ammonite *Didymoceras nebrascense* was found at the top of the Corcoran at Watson Creek (sec. 25, T. 11 S., R. 98 W.) and *Didymoceras stevensoni* was found in the Cozzette at sec. 15, T. 13 S., R. 95 W. (Gill and Hail, 1975). Cobban (1973) placed the Rollins Sandstone Member in western Colorado in the *Didymoceras cheyennense* faunal zone.

SEGO SANDSTONE

Physical Characteristics and Inferred Depositional Environments

The basal contact of the Sego Sandstone with the Mancos Shale is gradational; toward the top of the Mancos, interbedded siltstone and very fine grained sandstone become increasingly abundant, and, on the outcrop, the base of the first thick continuous sandstone is selected as the base of the Sego. The contact between the Sego and the overlying Neslen or Mount Garfield Formation generally is sharp but conformable and is placed at the top of the thick, generally cliff forming sandstone. In the Green River area, the top of the Sego is difficult to determine because only a thin part of the sandstone unit weathers as a resistant ledge; about 130 ft of sandstone with only minor siltstone interbeds occurs as a slope-forming interval above the resistant ledge. Because the well-log response of this sandstone interval is similar to that of the more typical cliff-forming sections, the entire interval is considered Sego even though its slope-forming nature makes it difficult to identify.

The base of the Sego rises stratigraphically from west to east, as illustrated by thickening of the underlying Buck Tongue of the Mancos Shale from 140 ft near Green River to 380 ft near the Colorado-Utah State line (pl. 1). The Sego gradually thickens from about 130 ft near Green River to about 280 ft near the State line but locally thickens and thins. Wherever the Anchor Mine Tongue is well developed, both the upper and lower Sego thin rapidly to the east.

Internally, the Sego is composed of stacked depositional sequences that are identified by lithology, grain-size trends, systematic progressions of sedimentary structures, and assemblages of fossils and trace fossils. These sequences are about 10–90 ft thick and are shown on the measured sections in plate 2. Two basic types of sequences were identified: thicker, coarsening-upward sequences that are dominant in most sections of the Sego and thinner, locally fining upward sequences, separated by interbedded organic-rich mudstone and siltstone, that commonly compose the slope-forming, upper part of the Sego in the western part of the study area.

Coarsening-Upward Sequences

In the Sego Sandstone, coarsening-upward sequences are more prevalent than fining-upward sequences. Coarsening-upward sequences can be subdivided into three depositional units: a basal unit of interbedded, laminated to thin-bedded, very fine grained sandstone and siltstone that grades upward into a fine-grained sandstone that can be divided into a lower and upper unit. A complete sequence can be 60–90 ft thick, but thinner, incomplete sequences are common.

In the interbedded sandstone-siltstone basal unit, sedimentary structures in the siltstone beds often are difficult to discern because of weathering characteristics or obliteration by bioturbation or intense burrowing. The sandstone beds have slightly to intensely scoured bases that are overlain by hummocky cross-stratified sandstone (fig. 3) or sandstone containing horizontal laminations or low-angle trough(?) cross-stratification overlain by wave-generated ripple cross-laminations that are locally burrowed. A thin structureless bed is rarely present above the scour base.

The sandstone overlying the interbedded unit can be divided, based on sedimentary structures, into a lower unit 10–40 ft thick and an upper unit 10–30 ft thick. Beds in the lower unit are very fine to fine-grained sandstone that contain local laminations of siltstone. They are thin to medium bedded and locally scoured at the base and contain dominantly very low to low-angle trough(?) cross-stratification and less abundant ripple and horizontal to low-angle planar laminations and hummocky cross-stratification. The tops of these beds commonly are burrowed to bioturbated (fig. 4); straight, simple, horizontal and vertical burrows and *Ophiomorpha* burrows are present. Beds in the upper unit are fine- to medium-grained sandstone that contain locally abundant concentrations of siltstone and mudstone rip-

Figure 3. Stacked hummocky cross-stratified beds, each of which has scour base (arrows), in the lower part of a depositional sequence within the Sego Sandstone. Occurrence of beds within transition and lower shoreface zones suggests that storm waves periodically reworked sediment surface. Hammer shown for scale.

up clasts. They are medium to thick bedded and dominantly medium-angle trough cross-stratified (fig. 5) except for the upper 5 ft or less, which may contain low-angle parallel laminations. Trace fossils are rare; *Ophiomorpha* and *Chondrites* occur in the uppermost beds. Wherever the upper unit is overlain by coal or carbonaceous shale, root casts are just below the top of the unit.

The thickest basal interbedded sandstone and siltstone unit occurs where the Buck Tongue grades into the Sego. The occurrence of this interbedded unit above the sandstone units signals the beginning of another depositional sequence. Individual sequences are more difficult to differentiate wherever the interbedded unit is absent below the sandstone units; the sequences must be distinguished by changes in grain size, sedimentary structures, and trace fossil assemblages.

These sequences in the Sego were deposited in a nearshore coastal-marine environment. The vertical progression of lithologies and sedimentary structures in each sequence suggest deposition in progressively shallower water environments: the transition zone between the shoreface and the deeper shelf, the lower shoreface, the upper shoreface, and the foreshore. These environments are identified on the measured sections shown in plate 2.

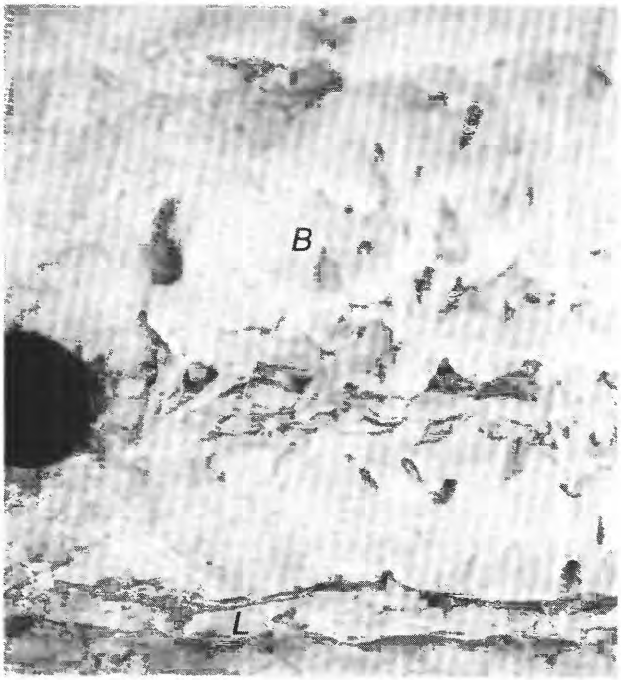

Figure 4. Alternating burrowed (*B*) and laminated (*L*) bedding within lower part of sandstone sequence in the Sego Sandstone indicates alternating periods of deposition and quiescence. Lens cap shown for scale.

Figure 5. Medium to thick sets of medium-angle trough cross-stratified beds (*tr*) in the upper part of a sandstone sequence in the Sego Sandstone. Cross beds indicate deposition in shallower water within zone affected by daily wave base. Hammer shown for scale.

The interbedded sandstone and siltstone unit at the base of a sequence was deposited in the transition zone below daily effective wave base but within the influence of storm-wave base. Hummocky cross-stratification within this interval suggests that periodic storm waves reworked the ocean bottom in this zone (Harms and others, 1975). Sandstone beds containing the vertical sequence of horizontal laminations, low-angle trough(?) cross-stratification, and ripples are similar to modern storm-generated sand deposits described by Nelson (1982) and ancient storm-generated deposits in the Blackhawk Formation described by Balsley (1982). Although storms strongly controlled deposition in the transition zone, the burrowed to bioturbated silt and mud beds were deposited from suspension during periods of calm between storms.

As the shoreline prograded, lower shoreface sand was deposited over the interbedded sand and silt. The lower shoreface marks the zone in which sediment is affected by both fair-weather and storm waves, and siltstone deposition is rare. Both the grain-size increase to fine-grained sand and the presence of low-angle trough(?) cross-stratification and local hummocky stratification indicate higher energy conditions, but the locally abundant burrowed beds indicate occasional periods of quiescence. The abrupt upward change to medium- to high-angle trough cross-stratification, a virtual absence of burrows, and a local increase in grain size suggest prograding of the shallow, high-energy upper shoreface zone over the lower shoreface zone. Clay rip-up clasts locally present in this interval probably were derived from storm-reworked tidal deposits and may indicate proximity to a tidal inlet. Similar occurrences of shale rip-up clasts within tidally influenced shoreface deposits have been noted by Driese and others (1986). Low-angle, seaward-sloping, parallel-laminated sand was deposited in the foreshore above the upper shoreface. Such deposits generally are less than 5 ft thick but often are not well preserved or apparent in many of the Sego sections studied. Root casts in foreshore deposits overlain by carbonaceous shale and areas of locally abundant trace fossils or bioturbation of the foreshore deposits indicate contemporaneous and postdepositional sediment reworking.

The stacked coastal-marine sequences characteristic of much of the Sego (pl. 2) indicate frequent but minor changes in relative sea level resulting from variations in subsidence rates, sediment supply, or small eustatic fluctuations. The thinness and local absence of deeper water transition-zone deposits at the base of each successive shoreface deposit suggest transgressions of a limited extent except for the Anchor Mine transgression. These conditions led to vertical stacking of coastal sand bodies rather than regional progradation of an individual shoreface deposit.

Fining-Upward Sequences

The less prevalent, thinner, locally fining-upward sequences common in the upper part of the Sego Sandstone in the western part of the study area have highly variable bedding characteristics, lithologies, and depositional environments. These sequences are above the uppermost shoreface and foreshore deposit and generally are 10–15 ft thick but may be as thick as 20–30 ft. Although slight but significant differences exist between the individual sequences, the sequences generally are composed of fine-grained sandstone that may grade upward to very fine grained sandstone and siltstone, mudstone, or carbonaceous shale before being overlain by another sandstone sequence. Disseminated organic material, plant fragments, and coaly pods are abundant and are either concentrated along bedding planes or scattered throughout the beds.

These sequences are difficult to define and describe because of their variable character, but they can be divided into two basic types. The first type is as thick as 30 ft and very thin to thin bedded; it is characterized by current- and less commonly wave-ripple cross-laminations (fig. 6) that show 90°-180° variations in transport direction in succeeding beds. Orange-yellow siltstone rip-up clasts are abundant along many of the bedding surfaces. Planar-laminated bedding and wavy and flaser bedding are also locally present (fig. 7). The second type of sequence is medium to thick bedded, contains low- to medium-angle trough cross-stratification that grades upward to ripple cross-stratification, and frequently contains zones of intense burrowing or bioturbation. Trace fossils have been identified in both types and consist of *Ophiomorpha*, *Arenicolites*, and *Skolithos*. Oyster shells are concentrated locally within and at the top of the rippled sandstone sequences in the Tusher Canyon measured section (pl. 2).

Deposition of these sequences occurred primarily behind microtidal barrier-island coastlines. The absence of both delta-plain deposits and distributary-channel deposits scoured into shoreface deposits precludes the existence of a fluvial-dominated or wave-dominated deltaic shoreline. Detailed work along the outcrop and in the subsurface may locate small deltaic areas, but, as yet, none have been identified along the outcrop section of the Sego. Tidal deposits are also associated with the Sego Sandstone much farther to the northeast along the White River (Noe, 1983). The high percentage of sand in these sequences indicates an abundant sediment supply transported by longshore currents from deltaic centers

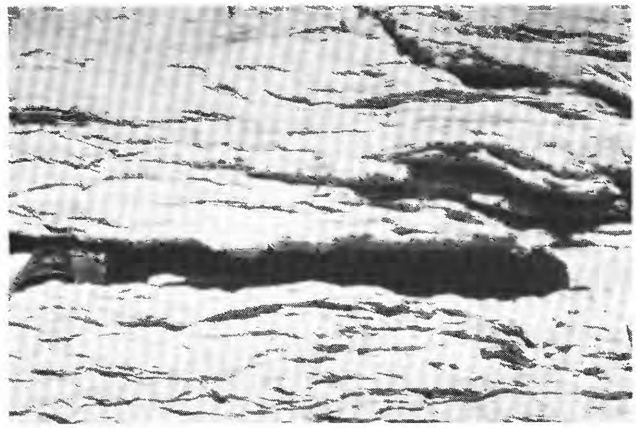

Figure 6. Thin- to very thin bedded, ripple-stratified sequences common in backbarrier deposits in the upper part of the Sego Sandstone, western part of study area. This type of bedding is absent in shoreface sandstone sequence in the Sego Sandstone. Top of hammer shown for scale, left side of photograph.

that probably existed northeast of the study area. A smaller sediment supply was brought into the coastal plain by local, short-headed rivers.

These backbarrier sequences in the upper part of the Sego merge into each other both laterally and vertically. Lateral tracing of these units between closely spaced sections is necessary to define their extent and better characterize this depositional system, but, by using the present data, the following depositional environments and associated deposits can be broadly outlined. Tidal inlets are rare in microtidal barrier-island settings, and none were identified in the measured sections. Adjacent to the Bitter Creek section, a tidal-inlet deposit comprises a scoured base with a lag of shell fragments and woody material overlain by trough and planar cross-stratified, medium-grained sandstone (fig. 8). In addition, large-scale lateral accretion surfaces locally observed along cliff faces in the upper parts of shoreface deposits may have developed during the lateral migration of tidal inlets.

The thick sequences of thin- to very thin bedded, current- and wave-ripple cross-laminated, and parallel-laminated sandstone (fig. 7) were probably deposited primarily along the margins of flood-tidal deltas. Because of the relatively low tidal energy along these coastlines, extensive flood-tidal deltas form landward of the tidal inlet (Hayes and Kana, 1976). The flood-tidal delta deposits laterally grade into and are overlain by lagoonal silt and mud. The sandstone sequences characterized by medium- to low-angle trough cross-stratification that grades upward into wave- and current-ripple laminations were deposited behind the shoreline as washovers, lagoon-margin deltas, or extensive bay fills. Their strati-

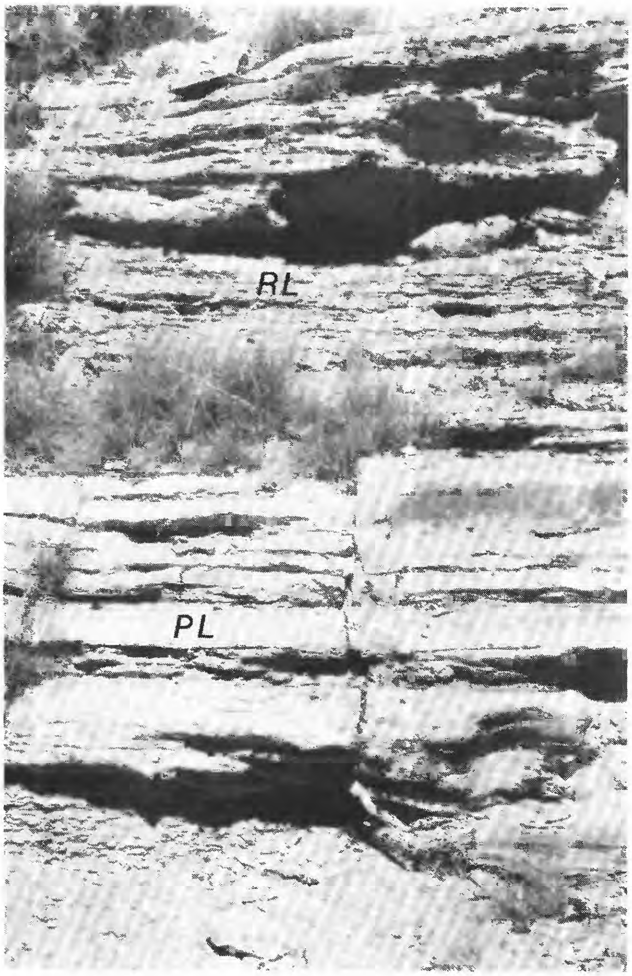

Figure 7. Parallel (*PL*)- and ripple (*RL*)-laminated sandstone sequence characteristic of sandstone sequences in the upper part of the Sego Sandstone, western part of study area. Current-generated and less common wave-generated ripple-laminated bedding are dominant within these tidally influenced backbarrier deposits; parallel-laminated beds are thinner, less abundant, and interbedded with ripple-laminated sequences. Resistant ledge in lower part of photograph about 2 ft thick.

Figure 8. Scour base (dashed line) of a tidal-inlet deposit located about 1 mi southwest of Bitter Creek section. Wood and shell fragments are concentrated immediately above scour base. These tidal-inlet deposits are not frequently observed in outcrop. Pencil (5 in. long) shown for scale. Location of Bitter Creek section shown on figure 1.

graphic position and the depositional origins of underlying, overlying, and laterally equivalent beds determine their particular origins.

Although tidal flats are not extensively developed in microtidal settings, they are present on the back side of barriers. In the Sego backshore deposits, some of the thin-bedded, ripple-laminated, wavy- and flaser-bedded sandstones that contain abundant small oxidized clay and siltstone rip-up clasts along bedding planes resemble tidal-flat deposits. At the measured section locations, these deposits do not grade vertically from intertidal to supratidal but instead are overlain by lagoonal deposits that prograded over the tidal-flat deposits. More detailed work is needed on this facies to document its regional extent and to differentiate it from the deposits of flood-tidal delta margins, which locally have similar characteristics.

The backbarrier sandstone deposits are interbedded with units of siltstone, mudstone, and silty sandstone, 2–5 ft thick, that were deposited in quiet-water lagoons behind the barrier islands. These deposits generally are horizontal or wavy laminated and locally ripple laminated; they contain abundant organic matter and coaly pods and locally coarsen upward into *Ophiomorpha*-burrowed to bioturbated sandstone. The thinness of the lagoonal deposits and their coarsening-upward nature suggest that in this area lagoons were rapidly infilled with clastic sediments and were not stable features for any length of time.

The sandy backbarrier deposits are thickest in the west and thin progressively eastward to an area in which the shoreface sandstones are almost immediately overlain by fine-grained coastal-plain sequences. The lack of development of extensive thick sandy backbarrier deposits in these areas probably reflects a change in the rate of both sediment supply and coastline progradation.

Comparison of Measured Sections with Well Logs

The best-available gamma-ray, spontaneous potential, and resistivity well logs located as near the outcrop as possible were used to construct a subsurface stratigraphic cross section (pl. 1) and to compare depositional sequences interpreted at the measured sections to the well-log signatures. This cross section extends from west of the landward depositional pinchout of the Sego Sandstone in Utah to slightly east of the seaward pinchout of the upper Sego Sandstone in western Colorado and shows the eastward stratigraphic rise of the Sego. Above the Sego in western Colorado, the Corcoran and Cozzette Members of the Price River Formation (Young, 1955) are identified as members of the Mount Garfield Formation because these names are regionally applied. The top of the Castlegate Sandstone is the datum in Utah (Johnson, 1986), except for the westernmost wells in which a distinctive resistivity "kick" in the Mancos Shale is used for correlation. If the Anchor Mine Tongue is present, the top of the lower Sego is the datum; in areas where the lower Sego pinches out, the datum is the top of the Cozzette.

The locations of the seaward pinchouts of the upper and lower Sego and the landward pinchouts of the Corcoran, Cozzette, and the Rollins Sandstone Members shown on plate 1 agree well with those on the surface cross section of Gill and Hail (1975). One difference is the landward extent of the Anchor Mine Tongue of the Mancos Shale. The Anchor Mine Tongue first appears in the subsurface in westernmost Colorado (pl. 1) and is not discernable in Utah in either well logs or in the measured section at Bitter Creek (pl. 2). Gill and Hail's surface cross section shows extensions of the Anchor Mine Tongue in eastern Utah; these beds are probably equivalent to the transition zone deposits identified in the Bitter Creek surface section.

The Tusher Canyon and Bitter Creek measured sections are compared to nearby well logs in plate 2. The wells and measured sections are either approximately along or not far from the northeast-southwest paleodepositional strike of the Sego shoreline (Warner, 1964; Gill and Cobban, 1969), but, because the measured sections are a few miles from the nearest well and some lithofacies changes may have occurred, the outcrop sections and well logs do not match exactly. The overall thickness and distribution of depositional sequences in the Sego agree well, however, between outcrop and well sections. When the sections were matched for best fit, a measuring error of about 60 ft was indicated in the Buck Tongue at the Bitter Creek section.

Well-log responses through the Mancos Shale below and east of the pinchout of the Sego Sandstone indicate numerous coarsening-upward sequences that may include beds as coarse grained as sandstone. Many of these sequences can be correlated over long distances in the subsurface, and either they may represent the distal ends of shoreface-attached sandstone bodies or they may be nonshoreface-attached shelf sandstones such as those described by Rice and Gautier (1983) from other sequences of Campanian Age in the Western Interior of the United States.

As the Mancos Shale grades upward into the Sego through the basal transition zone deposits, gamma-ray, spontaneous potential, and resistivity well logs show the beginnings of inverted bell-shaped curves that characterize the transition from marine shale to sandstone as the abundance and thickness of sandstone beds gradually increase. These curves are only well developed for the basal transition zone to shoreface sequence. Curves for the overlying stacked sequences are blocky and have sharp or slightly gradational lower contacts because interbedded sandstone and siltstone deposits of the transition zone are thin to absent. These blocky curves are typical of those produced by stacked barrier-island and strand-plain sequences deposited during periods of coastal progradation or aggradation (Galloway, 1986; Tyler and Ambrose, 1986). Without nearby outcrop control or numerous, closely spaced well logs, subenvironments within the Sego barrier-island system are difficult to distinguish from a single well log. For example, although tidal-inlet deposits have blocky spontaneous potential and gamma-ray curves similar to those of the stacked shoreface deposits, curves for inlet deposits should indicate a very sharp, abrupt lower contact. These deposits have been identified along the outcrop and are probably present in some subsurface sections.

Within a single shoreface sequence, log responses show numerous deflections that indicate either thin beds of finer grained lithologies, such as siltstone or mudstone, or concentrations of siltstone rip-up clasts. These deflections are not as extreme as those that separate shoreface sequences from overlying transition zone sequences. The number of stacked depositional sequences can be reasonably well estimated from the log signature, but, as discussed below, a sequence of sandy backbarrier deposits can be mistaken for a single shoreface sequence or may be included with the underlying shoreface sequence and interpreted as a single, exceptionally thick deposit. West of the Anchor Mine Tongue pinchout, the Sego Sandstone usually has at least two stacked shoreface sequences and locally may have as many as six. Wherever the Anchor Mine Tongue is developed, the upper and lower Sego rarely each contain more than two stacked shoreface sequences.

Correlation of the Tusher Canyon section to the nearest well log (pl. 2) shows that stacked, sandy flood-tidal-delta, tidal-flat, and washover deposits, all of which contain only thin interbeds of lagoonal mudstone and siltstone, produce blocky curves having minor deflections. These backbarrier deposits are difficult to distinguish from the shoreface deposits without outcrop or core control. High-resistivity "kicks" within a blocky log interval may be a reliable indicator of organic-rich marsh deposits interbedded with sandier backbarrier deposits. The log character of the upper part of the highest shoreface sequence in the Sego in many of the wells studied is very similar to that of tidal deposits in the vicinity of Tusher Canyon. Widespread preservation of tidal deposits above the youngest shoreface sequence is expected because no subsequent transgressions occurred that would erode them. A cross section of well logs aligned parallel with depositional strike should show lateral lithofacies changes from sandy tidal deposits to lagoonal mud and silt deposits. Such lateral lithofacies changes could explain thickness variations in the Sego between well logs at sec. 32, T. 18 S., R. 22 E., and sec. 15, T. 18 S., R. 22 E. (pl. 1) that lie along depositional strike.

Detailed measured sections of the Sego and overlying units through the Rollins Sandstone Member are not available for the eastern part of the study area where the Anchor Mine Tongue divides the Sego, but well-log signatures in this area can be compared with those through the Sego to the west to infer depositional events. The lower sandstone of the Sego thins to the east and shows at most two incomplete inverted bell-shaped curves instead of blocky curves. The upper shoreface and foreshore never extended far into Colorado during progradational events prior to the Anchor Mine transgression. The upper sandstone of the Sego shows a similar eastward change in well-log curves as the seaward limit of backshore, foreshore, and shoreface deposition is reached during each progradational pulse. Reconnaissance studies of the upper sandstone of the Sego and lower part of the overlying Mount Garfield Formation in the Douglas Pass area reveal that possible tidal deposits are rare and that the coastal plain may have formed behind a strandline.

Stratigraphic boundaries between the Sego, the Corcoran, and the Cozzette were arbitrarily selected in areas where the units are not separated by thick marine shale sequences. The combined Corcoran, Cozzette, and Rollins interval locally is as thick as 500 ft (pl. 1) and, near its western limit, is composed of interbedded marginal-marine sandstone units, less than 20 to 100 ft thick, and fine-grained, carbonaceous coastal-plain deposits (Young, 1955; Warner, 1964; Gill and Hail, 1975). Farther east, tongues of marine shale separate the Corcoran, Cozzette, and Rollins sequences. Well-log curves for the marginal-marine sandstone units west of the landward pinchout of the marine shale tongues show a sharp or slightly gradational basal contact with underlying siltstone or shale and a sharp, abrupt upper contact with overlying shale, siltstone, or coal. The similarity of these curves to those in the upper part of the Sego suggest that the sandstone units formed in upper and possibly lower shoreface environments and as bay fills, tidal deltas, washovers, and tidal flats, inlets and channels. In the western part of the Piceance basin, near Rifle, Colo., Johnson (1988) reported lagoonal, marsh, tidal-flat, and tidal-channel deposits in the combined Corcoran-Cozzette sequence. The thicknesses of the intertonguing marginal-marine and coastal-plain sequences above the Anchor Mine Tongue indicate that landward limits of the numerous transgressions associated with Corcoran, Cozzette, and Rollins deposition were in a restricted area for a relatively long time.

COAL-FORMING ENVIRONMENTS ASSOCIATED WITH DEPOSITION OF THE SEGO SANDSTONE

Depositional environments inferred from measured sections through the Sego Sandstone and the Neslen and Mount Garfield Formations provide a broad understanding of the processes that controlled coal-forming environments. Many recent studies on Cretaceous coal-forming environments (for example, Flores and Erpenbeck, 1981; Ryer, 1981; Balsley, 1982; Flores and others, 1984; Kamola and Howard, 1985) indicate that the type of coastline and associated backshore environment are important in controlling the thickness, lateral extent, and distribution of coal beds. The type of coastline is in turn controlled by wave and tidal energies and changes in relative sea level, rates of subsidence, and rates of sediment supply.

Unlike the Ferron Sandstone Member of the Mancos Shale and the Blackhawk Formation in the Wasatch Plateau and western Book Cliffs, coastal-plain sequences deposited contemporaneous with the Sego do not contain numerous, extensive, economical coal beds. The distribution and depositional environments of coal in the Neslen Formation and in the Mount Garfield where it overlies the upper sandstone of the Sego will be briefly discussed, but coal zones associated with the Corcoran, Cozzette, and Rollins are too extensive and complex to be discussed in this report. Studies of the Book Cliffs in Utah and Colorado by Fisher (1936) and Erdmann (1934) provide detailed measured sections through coal zones, information on coal quality, and production data. Fisher and Erdmann named the coal zones in the Neslen and Mount Garfield Formations and correlated these zones throughout the Book Cliffs. Young (1955) subsequently revised some correlations, but most of the original names and correlations are still in use. Coal beds in the Neslen and the lowest part of the Mount Garfield generally are thin and discontinuous and contain abundant splits of carbonaceous shale or siltstone. Fisher (1936) did not extend any coal zones in the Neslen farther west than T. 20 S., R. 19 E., and, east of Nash Wash (T. 20 S., R. 21 E.), coal beds in the Neslen are poorly developed. West of the Hunter Canyon area, the

Anchor coal zone in the Mount Garfield Formation is above the upper Sego sandstone.

In all of the measured sections and most of the well logs, thin beds of coal and carbonaceous shale containing coaly lenses that correspond to the Palisade coal zone (Fisher, 1936) and the Anchor coal zone (Young, 1955) are directly above to as much as 50 ft above the Sego. These coal beds formed on a coastal plain in both brackish and freshwater environments. The stratigraphically lower coal beds formed in short-lived marshes behind the barrier islands and are thin, discontinuous, and interbedded with tidal-flat and flood-tidal delta sequences (fig. 9). Frequent inundation of these marshes by clastic material deposited during storms and extreme tides prohibited development of thick, clean, extensive peat deposits. Coal beds in the upper part of this interval are locally thicker and probably formed at the landward edges of lagoons and bays in more extensive marshes that prograded seaward as the lagoons and bays infilled. Farther landward, peat accumulated in poorly drained swamps on the floodplain, but thin, discontinuous coal beds within lower-alluvial-plain deposits indicate that the duration of peat-forming environments was limited by shifting channels and formation of crevasse splays. These backshore peat-forming environments are similar to those behind Cretaceous barrier-island coastlines in New Mexico and Utah described by Flores and Erpenbeck (1981) and Flores and others (1984). The Neslen and Mount Garfield coal beds are much thinner and less extensive, however, than those that formed in similar environments in the Star Point Sandstone and Blackhawk Formation on the Wasatch Plateau (Flores and others, 1984). During the Sego regression, equilibrium conditions between subsidence and sediment supply probably were not maintained long enough to preserve marshes and swamps for extended time periods. Peat-forming environments behind the Sego coastline contrast strongly with extensive marshes that developed on stable platforms formed by prograding wave-dominated strandlines, such as documented by Balsley (1982) for the Blackhawk Formation in the western Book Cliffs.

The best-developed coal beds in the Neslen are in the Ballard and Chesterfield coal zones (Fisher, 1936) in the Thompson and Sego Canyon areas, where coal was extensively mined in the 1920's and 1930's. The Ballard coal zone is just below the Thompson Canyon Sandstone Bed (Fisher, 1936), which is 100-140 ft above the top of the Sego, and the Chesterfield zone is just above the bed. Although the Thompson Canyon Sandstone Bed was mapped by Fisher from T. 20 S., R. 19 E., to T. 19 S., R. 23 E., it was definitively identified in this study only at the Sego Canyon measured section (pl. 2).

The Thompson Canyon Sandstone Bed is extensively burrowed to bioturbated (*Ophiomorpha* burrows occur locally) and contains low-angle trough cross-stratification and ripple laminations near the top. Its tabular geometry, lateral extent, and sedimentary structures indicate deposition in a brackish-water environment, probably as an extensive bay fill. Stratigraphically, the Thompson Canyon Sandstone Bed appears to correlate with the upper part of the Sego below the Anchor Mine Tongue of the Mancos Shale (pl. 1). The marine transgression associated with deposition of the Anchor Mine may have flooded a large area of the coastal plain and resulted in formation of estuaries and bays. The Ballard coal below the Thompson Canyon Sandstone Bed is interbedded with mudstones of lacustrine and possibly lagoonal origin. Extensive marshes interspersed among these environments indicate the initial decrease in gradient on the coastal plain that precedes marine inundation. Deposition of the Thompson Canyon and the overlying coastal-plain sequences

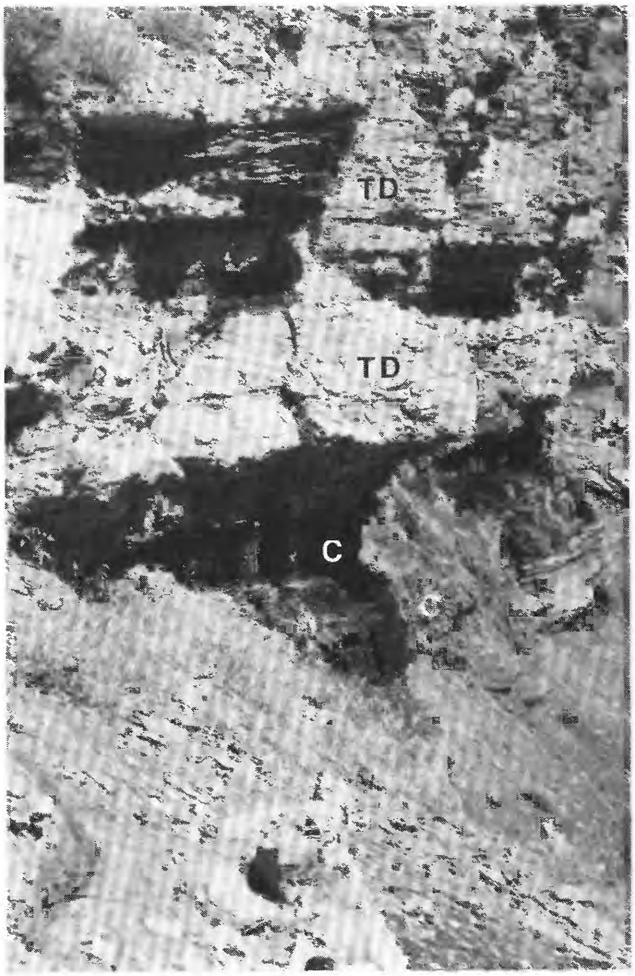

Figure 9. Coal (C) and carbonaceous shale (Cs) interbedded with sandy tidal deposits (TD) in the lowest part of the Neslen Formation. Coal interbedded with tidal deposits typically is thin and laterally discontinuous and contains laminations of clastic material. Coal layer under sandstone ledge about 1.5 ft thick.

that contain the Chesterfield coal indicates infilling of bays and lagoons and resumption of coastal progradation during deposition of the upper Sego sandstone. The coal beds in the Chesterfield zone are associated primarily with freshwater coastal-plain deposits. The swamps in this environment were frequently flooded with clastic material, infilled by crevasse splays, and scoured by migrating channels. Locally extensive peat deposits accumulated and were preserved, but the resulting coals generally are thin and discontinuous.

Deposition of the Neslen Formation near the Utah-Colorado State line was influenced by continual shoreline fluctuations that resulted in deposition of the upper Sego, Corcoran, Cozzette, and Rollins in western Colorado. Stacked, coarsening-upward lagoonal sequences in the Bitter Creek area (fig. 1) contain abundant carbonaceous shale and local coaly pods, but no well-developed coal beds formed behind the continually migrating coastline. The first well-developed coal in this area is about 200 ft above the Sego and is associated with fluvial-channel, crevasse-splay, and flood-plain deposits (pl. 2). This coal probably corresponds to Fisher's (1936) fourth unnamed coal zone in the Neslen that he correlated to Erdmann's (1934) Carbonera coal zone in the Mount Garfield Formation in western Colorado.

REGIONAL CONTROLS ON DEPOSITION OF THE SEGO SANDSTONE

The primary control on the geometry and distribution of coastal-marine sand bodies and their associated coal-forming environments is the type of coastline, such as microtidal or mesotidal barrier island, fluvial- or wave-dominated delta, or wave-dominated strand line. Regional forces also influence the configuration of these deposits. Source-area tectonism affects basin subsidence patterns and controls rates of sediment supply. Relative changes in the balance of subsidence and sedimentation rates play a major role in determining progradational style. Eustatic sea-level fluctuations have the most regional affect on shoreline movement and base-level changes but are often difficult to separate from local tectonic and depositional events that result in relative sea-level changes. On a local scale, subtle structural features such as small-scale movement along basement faults or incipient activity of structural elements also can influence facies distribution.

Correlation of the Sego Sandstone and associated continental sequences with units closer to the thrust belt indicates deposition during part of a major episode of tectonism in the Sevier orogenic belt. Fouch and others (1983) related deposition of the Castlegate Sandstone to tectonism possibly coincident with movement on thrust sheets. The Sego Sandstone and Neslen Formation in the western part of the study area probably are temporally equivalent to the middle part of the Castlegate Sandstone, as identified by Lawton (1983) and Pfaff (1985) in Price River Canyon (T. 12 S., R. 9 E.). The thick, medium- to coarse-grained sandstone in the lower part of the Castlegate reflects the first pulse of tectonic activity. Both the decrease in sandstone abundance and change in fluvial depositional style that characterize the middle part of the Castlegate probably indicate a waning of orogenic activity before a second pulse of tectonic activity that provided coarse-grained sediment for the Bluecastle Tongue of the Castlegate Sandstone (Pfaff and Chan, 1985). No well-constrained age data are available for the Bluecastle Tongue. Fouch and others (1983) used available drill-hole and outcrop data to postulate that the Bluecastle was deposited during the *Didymoceras stevensoni* faunal zone and thus temporally equivalent to the Cozzette. New outcrop and subsurface data from this study suggest that the Bluecastle corresponds to the upper part of the Sego and possibly the upper Sego sandstone above the Anchor Mine Tongue (pl. 1) and thus was deposited during the *Baculites scotti* faunal zone. Deposition of part of the Sego, therefore, occurred during a period of relatively high sediment influx from the thrust belt.

After deposition of the Bluecastle, the thrust belt no longer was the sole sediment source for this part of the foreland basin. Lawton (1983) postulated that after Bluecastle deposition source areas to the south and southwest of the northern Utah thrust belt contributed significant amounts of sediment to eastern Utah. In eastern Utah and western Colorado, specific sedimentation events after deposition of the Sego cannot be solely correlated with documented periods of thrusting.

The numerous stacked shoreface sequences within the Sego indicate the coastline position fluctuated frequently but, except for the Anchor Mine transgression, never over an extensive area. These minor fluctuations probably resulted from autocyclic processes governing the formation and abandonment of deltaic centers that supplied sediment to the Sego coastline. Although the Sego contains stacked depositional sequences, its gradual stratigraphic rise to the east reflects a relative sea-level rise. This depositional pattern could have been produced by a sediment supply that slightly exceeded the subsidence rate, and, depending on the relation of subsidence rate to sea level, absolute sea level may have been rising, falling, or stable (Vail and others, 1977). The Anchor Mine transgression can be explained by changes in the rates of sediment supply from the source area. Waning tectonic activity at the end of Bluecastle deposition may have sufficiently decreased sediment supply such that the rate of subsidence began to exceed sediment influx, a change that resulted in a more extensive transgression. A subsequent increase in sediment supply associated with new source areas south and west of the thrust belt produced regressions associated with the marginal-marine units overlying the Anchor Mine Tongue.

Vail and others (1977), Pitman (1978), and many others have documented worldwide sea-level changes during the Cretaceous. Eustatic changes are best documented on continental margins and are difficult to document in shallower interior seaways because local tectonic effects complicate regional assessment. In an analysis of regional transgressions, regressions and unconformities in the foreland basin, Weimer (1983) postulated eustatic drops at 80 Ma and 73 Ma and an intervening gradual eustatic rise. The 80-Ma event preceded deposition of the Castlegate Sandstone, which Fouch and others (1983) estimated began about 79 Ma. Based on studies of scouring of the top of the Blackhawk Formation in the vicinity of the Green River, J. Von Wagoner (oral commun., 1985) believed that a eustatic drop preceded deposition of the Castlegate Sandstone and that the Castlegate was deposited during the ensuing rise. In this scenario, deposition of the regionally widespread Buck Tongue and the Sego may indicate an increase and decrease, respectively, in the rate of sea-level rise. The eustatic drop at 73 Ma (Weimer, 1983) would have occurred in western Colorado after deposition of the Rollins Sandstone Member, which Cobban (1973) placed in the *Didymoceras cheyennense* faunal zone at about 73.5 Ma. The Anchor Mine transgression is probably much more localized than the Buck Tongue transgression and thus may reflect changes in subsidence and sedimentation rates rather than eustatic changes.

Pitman (1978) believed that in the Late Cretaceous sea level dropped slowly between 85 and 65 Ma and that during this period transgressions and regressions resulted from changes in the rate of sea-level fall. Transgressions and regressions in the Buck Tongue and the Sego can be explained by using this model; however, in order to produce the relative rise in sea level indicated by the Sego progradational sequence, the rate of subsidence would have had to be greater than the rate of eustatic fall. Lateral and vertical facies distributions can help distinguish between variable rates of eustatic fall and episodes of eustatic fall and rise. If a eustatic fall and rise of sufficient magnitude occurs, then a period of fluvial incisement followed by flooding of parts of the paleovalley should result. A correct interpretation of eustatic events requires accurate interpretation of the nature of the unconformity at the base of the Castlegate. There are no apparent unconformities or erosion surfaces in the Sego and correlative Neslen sequence that would indicate fluvial incisement resulting from a major eustatic fall. The effects of thrusting also complicate evaluation of eustatic changes. As previously mentioned, changes in sediment supply rates resulting from pulses in tectonic activity during thrusting could also explain the Sego transgressive-regressive patterns.

On a regional scale, subsidence in the foreland basin resulted from crustal loading by thrust plates and sedimentation (Jordan, 1981), but local structures may have caused slight but significant changes in subsidence rates that affected facies distributions. Lawton (1983) documented uplift on Laramide structures in east-central Utah beginning in the late Campanian, and earlier workers (Ritzma, 1955; Tweto, 1975; Gries, 1983) suggested that incipient movement along the Douglas Creek arch in western Colorado occurred at the same time during foreland basin deposition. Isopach maps of various Cretaceous and Tertiary intervals (Johnson and Finn, 1986) indicate movement on the arch began sometime after deposition of the Castlegate Sandstone, about 77.5 Ma, but do not indicate if movement occurred contemporaneously with Mount Garfield or Hunter Canyon deposition. The arch developed asymmetrically during uplift. During the latest Cretaceous, a pronounced eastern flank and a broad, extensive western bulge developed, but a pronounced western flank did not develop until the Paleocene.

Although there is no firm evidence that foreland basin deposition was influenced by the arch, numerous lithologic and depositional facies changes occur near the arch. During deposition of the Corcoran, Cozzette, and Rollins, the sea regressed far into and out of the Piceance basin along northeast-trending shorelines. Although orientations of the regressive shorelines and the arch are not similar, the maximum landward limits of transgressions that occurred between upper and lower Sego, Corcoran, Cozzette, and Rollins regressions follow northerly trends more parallel with the arch (Johnson, 1988) and do not extend west of it. Just east of the flank of the arch, a stacked section of interbedded marine and coastal-plain deposits 500 ft thick indicates that the landward limit of coastal retreat was restricted to a fairly narrow belt. Along the northern part of the arch, however, this stacking is less pronounced (R.C. Johnson, oral commun., 1986). These facies distributions may be the only indicators of minor, incipient activity along the eastern flank of the Douglas Creek arch. Because the eastern flank developed early in the structural history of the arch, the area may have been more susceptible to the earliest phase of Laramide east-west compression, which could have resulted in almost imperceptible changes in subsidence. Although very slight structural movement can influence depositional patterns (Weimer, 1983), documenting such control usually is difficult. Any structural control on the extent of marine transgressions in western Colorado is purely speculative but cannot be entirely discounted.

SUMMARY

In the southern Uinta and Piceance basins, the late Campanian Sego Sandstone was deposited primarily along a microtidal barrier-island coastline. West of the Anchor Mine Tongue, the main body of the Sego is composed of stacked shoreface depositional sequences that indicate numerous minor fluctuations in the shoreline probably produced by variable rates of sediment influx. These fluctuations caused thick buildups of sandy, tidal-influenced backbarrier deposits in the vicinity of the Green River. Marshes and swamps formed on the coastal plain behind the Sego shoreline, but high sediment input and rapid shifting of backbarrier environments caused these coal-forming environments to be short lived; only thin, discontinuous coal beds are observed.

The stacked shoreface and backbarrier deposits in the Sego produce characteristic blocky well-log curves from which the number of depositional cycles can be determined. In many well logs, however, a thick sequence of sandy backbarrier deposits can easily be misinterpreted to be part of an unusually thick shoreface deposit. As a result of the orientation of the Book Cliffs, strike-parallel lithofacies changes commonly cannot be traced along the surface, but lateral lithofacies changes interpreted to represent the transition from sandy backbarrier to quiet-water lagoonal environments are apparent in subsurface cross sections.

Deposition of the Sego Sandstone was probably contemporaneous with part of a major thrusting episode in the Sevier orogenic belt. The basal part of the Castlegate Sandstone was deposited during the first major pulse of sediment influx, and the Buck Tongue of the Mancos Shale and the Sego Sandstone apparently were deposited during the subsequent decrease in sediment influx and during the second clastic influx associated with Bluecastle deposition. A decrease in sediment supply from the thrust belt after deposition of the Bluecastle and the upper part of the main body of the Sego may have triggered the Anchor Mine transgression. Later activity in the southern thrust belt and in areas outside the thrust belt provided sediment for the regressions that followed the Anchor Mine transgression. Thick, stacked marginal-marine deposits and rapid facies changes from nonmarine to marine occur in the vicinity of the eastern flank of the Douglas Creek arch, but no firm evidence exists to suggest that any structural controls influenced depositional patterns and limited the landward extent of shoreline movement that preceded deposition of the Corcoran, Cozzette, and Rollins.

If a major drop in sea level occurred immediately before Castlegate deposition, then the Buck Tongue of the Mancos Shale and the Sego would have been deposited during the subsequent rise. Major sea-level changes apparently did not occur during Sego deposition. During most of Sego deposition, sediment supply slightly exceeded either sea-level rise or subsidence to produce the regionally progradational but internally stacked sequence of coastal and shoreface deposits. This pattern continued through deposition of the Cozzette. The regionally extensive, single-cycle regressive deposits characteristic of the Rollins indicate a change in progradational style. Either an increase in sediment supply, a stabilization or drop in sea level, or a decrease in rate of subsidence resulted in a more rapidly prograding shoreline.

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U.S. GOVERNMENT PRINTING OFFICE: 1989—673-047/86,051 REGION NO. 8